CHESAPEAKE BAY PROGRAM
NUTRIENT REDUCTION STRATEGY REEVALUATION

REPORT # 8:

FINANCIAL COST EFFECTIVENESS OF POINT AND NONPOINT SOURCE NUTRIENT REDUCTION TECHNOLOGIES IN THE CHESAPEAKE BAY BASIN

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December, 1992

ICPRB Report 92-4

INTERSTATE COMMISSION ON THE POTOMAC RIVER BASIN

This publication has been prepared by the Interstate Commission on the Potomac River Basin. Funds for this publication are provided by the United States Government, the U. S. Environmental Protection Agency, and the signatory bodies to the Interstate Commission on the Potomac River Basin: Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia. The opinions expressed are those of the authors and should not be construed as representing the opinions or policies of the United States or any of its agencies, the several states, or the Commissioners of the Interstate Commission on the Potomac River Basin.

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ACKNOWLEDGEMENTS

The author would like to thank all the members of the Nutrient Reduction Task Force of the Chesapeake Bay Program Nonpoint Source Subcommittee, for their assistance in data acquisition and review of portions of the Nonpoint Source Section of this report. Thanks are also due to Professor John Cumberland of the University of Maryland for his review and valuable comments on the draft report.

The author would like to extend his most sincere gratitude to the many agencies and groups who provided information and technical reviews of this report:

- The Chesapeake Bay Program 1991 Reevaluation Workgroup.
- The Maryland Department of the Environment.
- The Maryland Department of Agriculture.
- The Pennsylvania Department of Environmental Resources: Bureau of Soil and Water Conservation.
- The Pennsylvania Department of Environmental Resources: Bureau of Water Quality Management.
- The Virginia Department of Conservation and Recreation: Division of Soil and Water Conservation.
- The Virginia State Water Control Board.
- The District of Columbia Department of Consumer and Regulatory Affairs.
- The District of Columbia Department of Public Works: Water and Sewer Utility Administration.
- The United States Department of Agriculture: Soil Conservation Service.
- The United States Environmental Protection Agency: Chesapeake Bay Program Office.
- Computer Sciences Corporation.

The author would like also to thank the staff of the Interstate Commission on the Potomac River Basin (ICPRB) for reviewing and providing valuable comments and suggestions to the final draft of this report. Special thanks are also extended to Alan Blasenstein of ICPRB for his help in analyzing the Watershed Model output files and the Soil Conservation Plans.

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EXECUTIVE SUMMARY

Purpose:

This report is one of a series of reports prepared for the Chesapeake Bay Program Reevaluation of the Nutrient Reduction Strategy. This report provides information on the financial cost effectiveness and nutrient removal effectiveness of point and nonpoint source technologies in the Chesapeake Bay Basin. The report evaluates financial costs of different nutrient reduction technologies in a uniform way and expresses the costs on an equivalent annual basis, so that relative comparisons can be made among nutrient removal options.

Use of the cost information provided by this report with the Chesapeake Bay Watershed Model will allow relative cost comparisons of nutrient reduction scenarios to determine cost effective strategies for point and nonpoint source nutrient reduction. Unit costs and nutrient reduction efficiencies presented in this report can also be used in optimization models to identify cost effective nutrient reduction strategies.

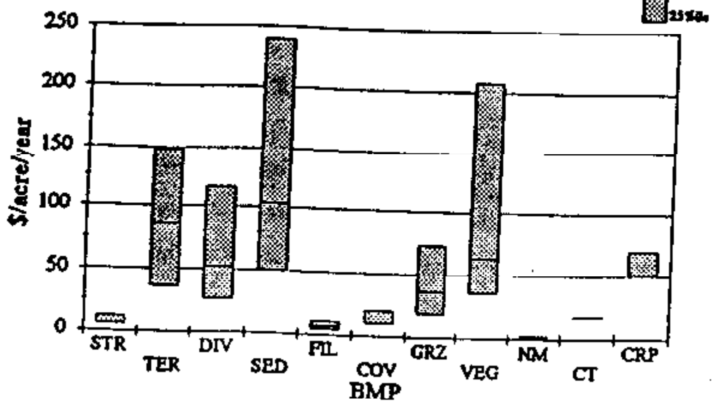
The report cannot be used to calculate the absolute cost of implementation of nutrient removal programs. Those costs will depend on factors such as local/state/federal government cost-share programs, schedule of implementation etc., in addition to site-specific conditions. Site-specific considerations can significantly affect costs and the application of nutrient removal technologies. Potential economic benefits of nutrient reduction controls also are not evaluated but may need to be considered.

Process and Approach:

Nonpoint Source Costs - The report focuses on the financial cost effectiveness of agricultural Best Management Practices (BMPs). Cost and BMP longevity information have been obtained from the Chesapeake Bay Program BMP tracking database, BMP longevity studies (Rosenthal and Urban, 1990), and the states' BMP unit cost data. Information also is presented for urban BMPs. Capital, technical assistance, and operation and maintenance (O&M) costs are expressed on an equivalent annual basis for comparisons. Nonpoint source BMP unit costs (in equivalent annual dollars per acre) are shown in Figure 1.

Figure 1. Nonpoint Source BMP Unit Cost Ranges

(a) Cropland and Pasture BMP Costs
Equivalent Annual Costs

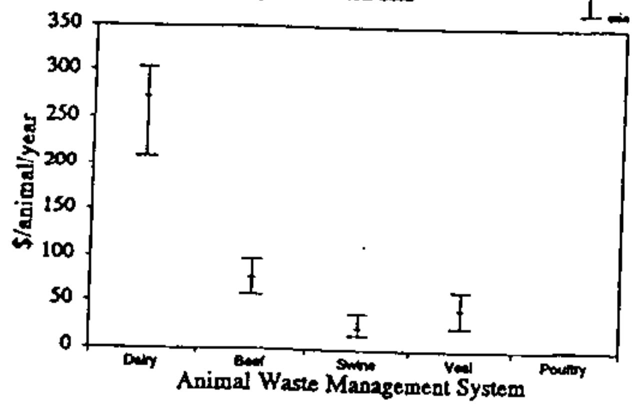


STR = Strip-cropping
TER = Terraces
DIV = Diversions
SED = Sediment Retention and Water Control Structures
FIL = Filter Strips
COV = Cover Crops
GRZ = Grazing Land Protection
VEG = Permanent Vegetation on Critical Areas
NM = Nutrient Management
CT = Conservation Tillage
CRP = Conservation Reserve Program

Grassed Waterway Annual Unit Cost Range: $0.39 - $1.50 per linear foot.

Unit costs obtained from the Chesapeake Bay Program BMP Tracking data base and states' unit cost data. Equivalent annual costs includes construction, planning, technical assistance, and O&M costs. Cost for CT and CRP are government incentive costs.

(b) Animal Waste Systems
Equivalent Annual Costs

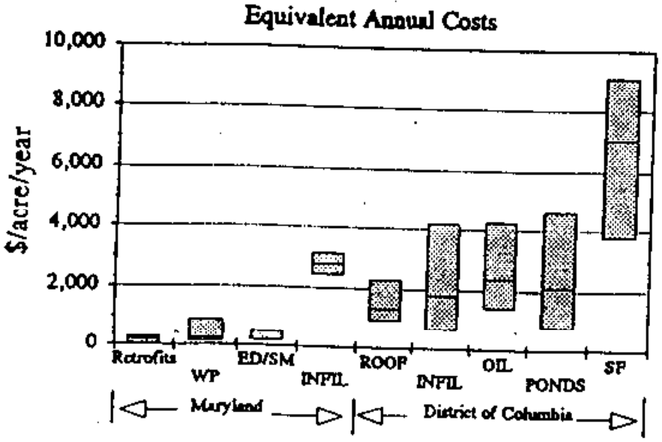


Unit cost ranges obtained from examples of animal waste management systems developed by Pennsylvania (Ritter, 1990).

Equivalent annual costs including capital, labor and energy costs for collection, storage, transport, and utilization of manure.

Animal waste system costs (CBPO tracking database):
Interquartile range = $1.99/ton - $3.88/ton
Median = $2.81/ton
(ton = ton of manure treated)

(c) Urban BMP Costs
Equivalent Annual Costs



Retrofits = Dry Pond-> Extended Detention/Wet Pond
Wet Pond-> Extended Detention
WP = Wet Ponds
ED/SM = Extended Detention/Shallow Marsh
INFIL = Infiltration Trenches
ROOF = Rooftop Detention
OIL = Oil Grit Chambers
PONDS = Ponds
SF = Sand Filters

Equivalent annual costs including construction and O&M costs

Point Source Costs - The focus is on the financial cost effectiveness of upgrading municipal wastewater treatment plants (WWTPs) for nutrient removal. Based on earlier U.S. Environmental Protection Agency (EPA) studies (Hazen and Sawyer Engineers and J. M. Smith and Associates, 1988), planning level cost equations have been developed for retrofitting WWTPs for two sets of effluent levels (TN*=8.0 mg/l,TP*=2.0 mg/l; and TN=3.0 mg/l,TP=0.5 mg/l) on a seasonal and annual basis. Capital and O&M costs are expressed in equivalent annual dollars. Unit cost data ($/mgd/year) from these equations are depicted in Figure 2. Figure 3 shows retrofit planning level unit cost ranges from planning level studies prepared for Maryland (Beavin Co., Camp Dresser and McKee Inc., and Metcalf & Eddy Inc., 1989), Virginia (CH2M-HILL, 1989) and the District of Columbia (Greeley and Hansen, 1989; and McName, Porter, and Seeley Engineers/Architects, 1990).

Nutrient Removal - Watershed Model runs will determine nutrient removals for BMP implementation scenarios. Nutrient removal for each scenario is the difference between the loads generated by that scenario and the "Base Case" model run. Relative cost comparisons of scenarios will be made by comparing the product of unit costs (e.g. Figures 1-3) and acres put under BMPs, plus cumulative costs to retrofit WWTPs for each scenario.

Cost Effectiveness - Cost effectiveness is defined as the ratio of the cost per pound of pollutant removed per year. It may be expressed in several ways depending on the scale of analysis. For instance, cost effectiveness can be expressed for individual nutrient reduction controls, or combination of controls ("Resource Management Systems"), or basin-wide management scenarios.

Findings and Conclusions:

Based on the cost effectiveness information presented in this report, and other aspects related to the implementability of point and nonpoint source nutrient reduction controls, the following conclusions are presented for the nonpoint and point source nutrient reduction controls examined in this study:

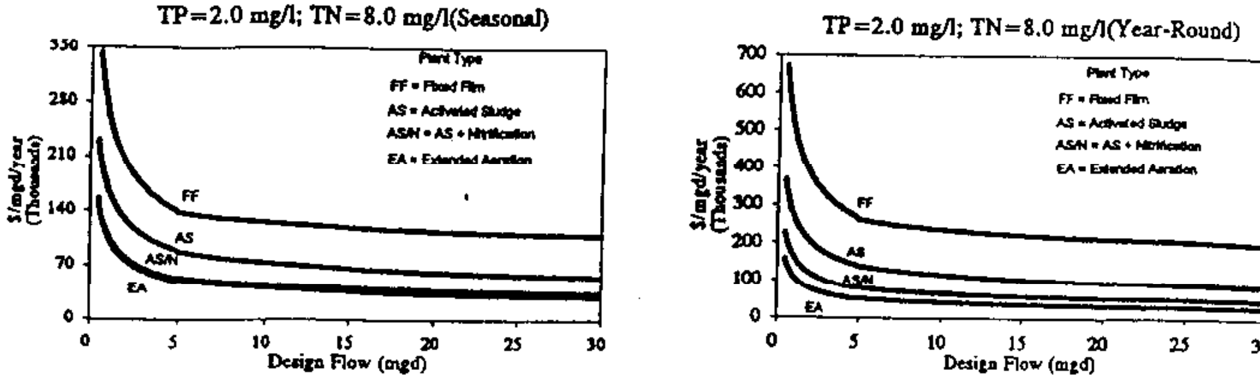
Nonpoint Sources

- BMP cost effectiveness should not be judged only on individual BMP nutrient reduction performance, but rather on combinations of BMPs or "Resource Management Systems" that together more effectively reduce the pollutant loads.

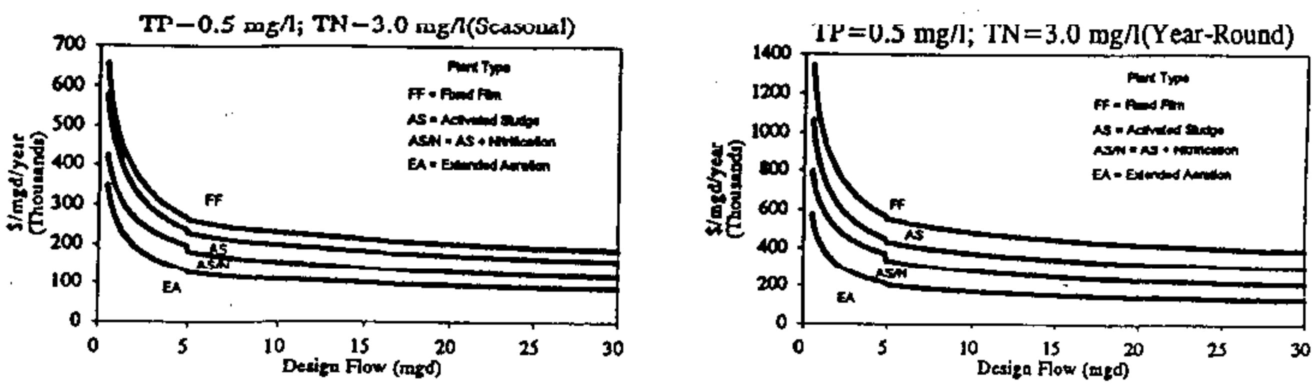
* TN = Total Nitrogen
TP = Total Phosphorus

Figure 2. Biological Nutrient Removal (BNR) Planning Level Retrofit Unit Costs for Municipal Wastewater Treatment Plants *

(a) High Level Nutrient Discharge



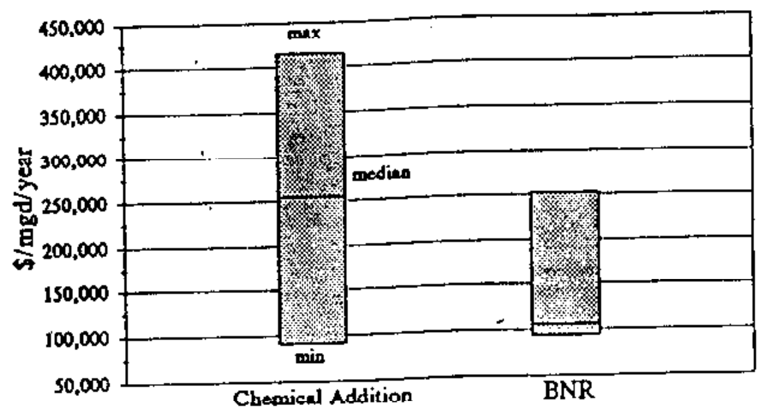
(b) Low Level Nutrient Discharge



* Adapted from: Hazen and Sawyer Engineers and J.M Smith and Associates (1988).

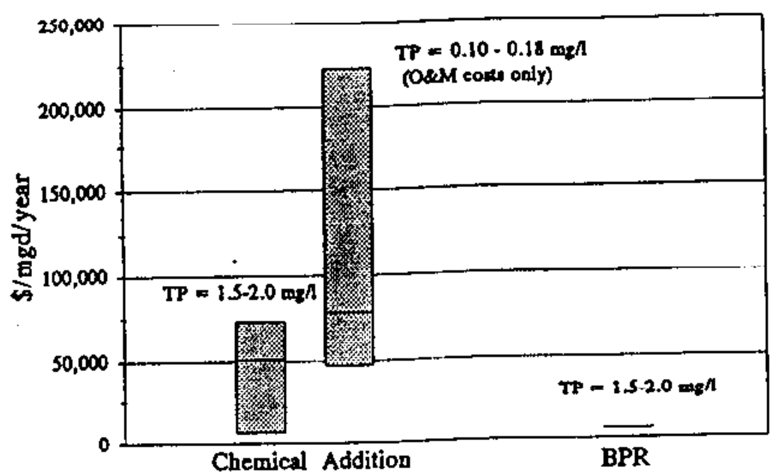
Figure 3. Planning Level Retrofit Unit Cost Ranges (States' Nutrient Removal Studies)

(a) Nitrogen Removal
TN = 7.0-8.0 mg/l (Annual Average)



BNR = Biological Nitrogen Removal

(b) Phosphorus Removal
TP= 0.1-2.0 mg/l (Annual Average)



BPR = Biological Phosphorus Removal

- In-field BMPs that reduce runoff and sediment, such as terraces and conservation tillage, can increase infiltration, thus increasing the potential of pollutant leaching into the groundwater. Conservation tillage may increase the concentration of pollutants in the soil surface. Therefore, any reductions achieved through surface runoff and sediment reductions may be offset by the increase in pollutant concentrations and the potential leaching of pollutants into the groundwater (Heatwole, et al., 1991). However, with nutrient management (i.e. proper fertilizer application rates, timing, and methods) nutrient losses to both surface waters and groundwater can be reduced. This accounts for the favorable cost effectiveness ratios for nutrient management.

- Results of the watershed model show nutrient management to be the most cost effective (Figure 4-a). Also, from field-scale research studies, nutrient management in combination with in-field BMPs such as strip-cropping, conservation tillage, and winter cover crops (where appropriate) have been found cost effective management alternatives for nutrient reduction.

- Winter cover crops have been found very effective in removing excess nitrates during the non-growing season after the main crop harvest. Excess nitrates accumulated in the soil may be significant after dry periods during the growing season.

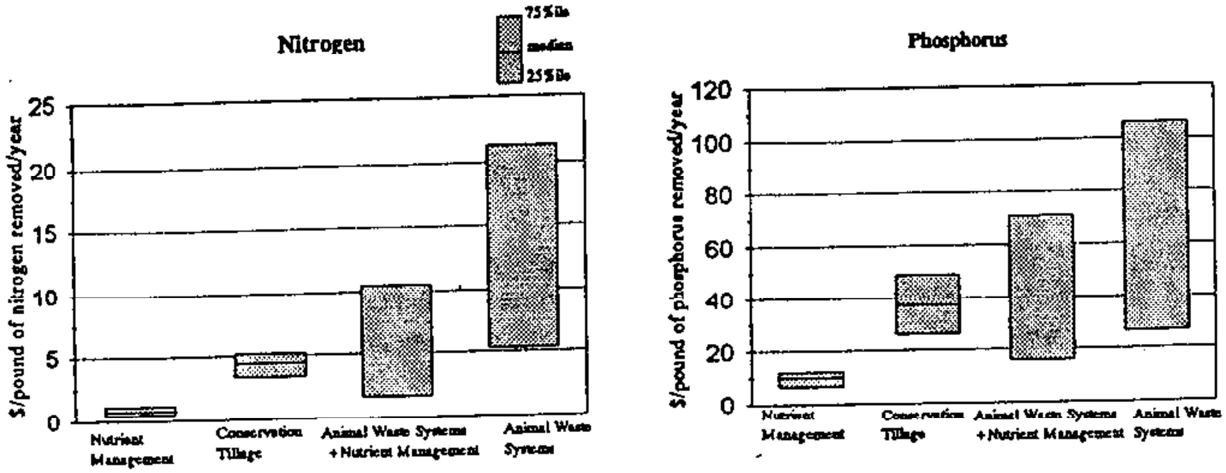
- Edge-of-field BMPs that reduce pollutant delivery into streams may be required for cases where nutrient loads are high due to increased runoff concentrations and sediment loads in large fields with long slope lengths. Some of these BMPs are structural BMPs such as erosion or water control structures, or non-structural BMPs such as filter strips, riparian zones, etc. However, structural BMPs are often expensive (see Figure 1-a), and despite the cost-share money available, implementation of these can result in a negative net field income (Hamlett and Epp, 1991). Also, despite the benefits of some of these structural BMPs in decreasing the sediment loads delivered into the streams, they should be accompanied by an in-field BMP to protect against severe soil losses that can have detrimental effects on the long term productivity of the fields.

- Conversion of highly erodible land (HEL) to permanent vegetation has been shown to be cost effective since it can considerably reduce sediment, runoff, and nutrient loads.

Figure 4. Financial Cost Effectiveness Ratios for Point and Nonpoint Source Nutrient Removal Technologies

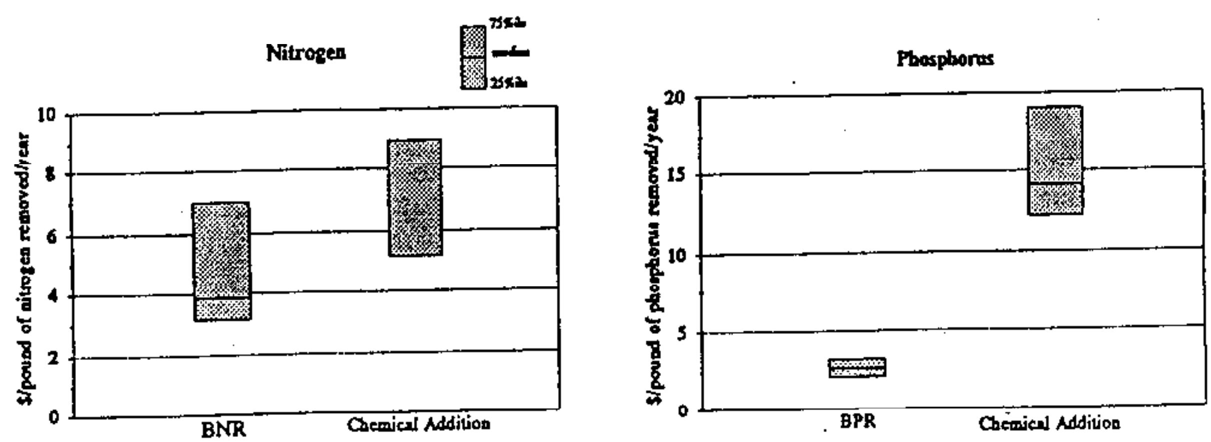
(Interquartile Ranges)

(a) Nonpoint Sources



Cost effectiveness is calculated as the ratio of the total annualized BMP cost divided by the pounds of nitrogen or phosphorus removed per year. Interquartile ranges reflect different nutrient removals within the Chesapeake Bay Basin. Nutrient Removals are at the edge-of-stream (Chesapeake Bay Watershed Model).

(b) Point Sources



Cost effectiveness ratios for nitrogen are calculated as the total annualized cost for nitrogen removal divided by the pounds of nitrogen removed per year. Similarly, cost effectiveness ratios for phosphorus are calculated as the total annualized cost for phosphorus removal divided by the pounds of phosphorus removed per year. Nutrient removals are calculated at the "end-of-pipe." The information shown in these figures came from the states' nutrient removal retrofit studies for municipal WWTPs and some existing retrofits in Maryland.

- Animal waste has been identified as a significant contributor of nutrient loads. Animal waste management systems should be considered important components of "Resource Management Systems." Proper design of animal waste facilities, including collection, storage, and transport, together with waste utilization will make these facilities cost effective (Figures 4-a). Figure 1-b shows that animal waste management systems including collection, storage, transport and labor costs, can be expensive. Nevertheless, experiences from the Rural Clean Water Program (U.S. EPA, 1990) projects show that there also are simple cost effective measures such as keeping animals away from the streams, controlling animal waste runoff, and protecting riparian areas.

- For urban BMPs, wide ranges of cost effectiveness ratios have been reported in the literature. Mostly, these ratios are higher than those shown in Figure 4, suggesting that they are the least cost effective controls for nutrient removal. However, urban BMPs have other important functions, such as aesthetics, water quantity control, and removal of petroleum hydrocarbons and heavy metals.

Point Sources

- Biological Phosphorus Removal (BPR) can be a cost effective alternative for phosphorus removal (Figure 4-b). It has potential for cost savings in chemical use and sludge handling. However, site-specific economic evaluations as well as the reliability of this technology for each plant should be carefully investigated. Also, it is important to point out that plants implementing BPR technologies may need chemical phosphorus removal facilities as a backup for permit compliance or when the effluent requirements are below 1.0 mg/l.

- Biological Nitrogen Removal has been found cost effective. Full-scale retrofits of WWTPs have supported this finding. However, planning level studies show, for certain facilities, that chemical addition (methanol) also can be cost effective. Therefore, the selection of chemical addition vs. Biological Nitrogen Removal without the use of chemicals would depend on site specific constraints.

- Seasonal nitrogen removal appears more cost effective than annual removal. Costs can significantly increase for annual removal (see Figure 2) because at lower temperatures biological activity is reduced. Therefore, longer wastewater retention times are needed requiring larger reactor tank sizes, thereby increasing costs. In addition, selection of the months for seasonal nitrogen removal and the permit compliance period can have a significant impact on the retrofit designs and therefore the costs associated with meeting the required effluent limitations.

- Regulatory measures such as the phosphate detergent ban have proven to be cost effective. Due to lower influent phosphorus levels to WWTPs, the chemical use required to meet the effluent level limitations and the amount of sludge created will decrease. Reduction in sludge and chemical use for phosphorus removal can significantly decrease the O&M costs in a WWTP. Another example of a regulatory measure being suggested is the adoption of permitting approaches such as the "bubble concept" (Virginia Retrofit Study) where the combined nutrient discharge of a group of plants are also regulated within a tributary, basin, etc. This approach would allow flexibility in the implementation of the most cost effective nutrient removal alternatives to a subset of plants within the "bubble". Nevertheless, individual permit limitations would still be required according to a careful examination of the quality of the receiving waters.

1. INTRODUCTION

The purpose of this report is to provide information on the financial cost and nutrient removal effectiveness of point and nonpoint source nutrient removal technologies in the Chesapeake Bay basin. This information can be used by the states to evaluate the cost and effectiveness of a mix of point and nonpoint source nutrient reduction controls. Financial costs developed in this report can be used with the watershed model to evaluate the cost and effectiveness of nutrient reduction management scenarios. Unit cost and nutrient reduction efficiencies presented in this report can also be used in optimization models to identify cost effective nutrient reduction strategies.

This report cannot provide the most cost effective nutrient reduction alternative for a particular farm, wastewater treatment plant (WWTP) or watershed. Other economic considerations, the site specific applicability of technologies, the quality of receiving waters, etc., may be important issues for the states to consider in their selection of nutrient reduction alternatives.

For nonpoint sources, the report focuses on the financial cost and nutrient removal effectiveness of agricultural Best Management Practices (BMPs). For point sources, the focus is on the financial cost and effectiveness of upgrading municipal WWTPs for nutrient removal. In the Chesapeake Bay the contribution of nutrient loads from agriculture is large (about 40% of the nitrogen and 50% of the phosphorus of the total nutrient load into the Bay). On the other hand, urban nonpoint source nutrient loads contribute about 8% for phosphorus and 9% for nitrogen. Forest loads comprise about 19% of the nitrogen and 3% of the phosphorus entering the Bay (Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation Report #1, 1992). Total point sources are approximately 23% of the nitrogen and 34% of the phosphorus loads. Approximately 90% of the point source nutrients come from municipal WWTPs (Chesapeake Bay Program, 1988).

This report compiles information from various recent sources. The Chesapeake Bay Program Scientific and Technical Advisory Committee report (STAC, 1987) describes the available point and nonpoint source nutrient reduction technologies. A recent description of point source nutrient removal technologies and their effectiveness was presented in the Chesapeake Bay Program Reevaluation of the Nutrient Reduction Strategy Report #7 (VWCB-1991). Effectiveness of nonpoint source nutrient reduction technologies is evaluated with the Chesapeake Bay Watershed Model which uses the EPA HSPF (Hydrologic Simulation Program - Fortran) computer program. Also, background information on agricultural BMP efficiencies was summarized in two reports (Casman, 1990 and Camacho, 1990) by the Interstate Commission on the Potomac River Basin (ICPRB).

This report is divided into two major sections: Nonpoint Source Nutrient Reduction Technologies, and Point Source Nutrient Reduction Technologies. The nonpoint source section summarizes BMP financial costs for the Chesapeake Bay Basin (Figures 1.1 and 1.2). A synthesis of the nonpoint source nutrient reduction efficiencies is presented. Also, the cost and effectiveness of some states' small watershed demonstration projects are summarized.

The second major section summarizes the cost of point source nutrient removal technologies. This section is subdivided into three parts: 1) States' nutrient removal retrofit studies, which summarize the estimated costs of retrofitting several selected municipal WWTPs for nutrient removal; 2) Planning level estimates for retrofitting municipal WWTPs based on the Hazen and Sawyer Engineers and J.M. Smith and Associates (1988) report prepared for EPA. Retrofit cost equations are provided for the two sets of retrofit effluent levels: TN = 8.0 mg/l, TP = 2.0 mg/l; and TN = 3.0 mg/l, and TP = 0.5 mg/l. Also, retrofit cost equations are given for these effluent limitations on a seasonal or annual basis (year-round); and 3) Cost and effectiveness of some of Maryland's nutrient removal WWTPs in operation are presented.

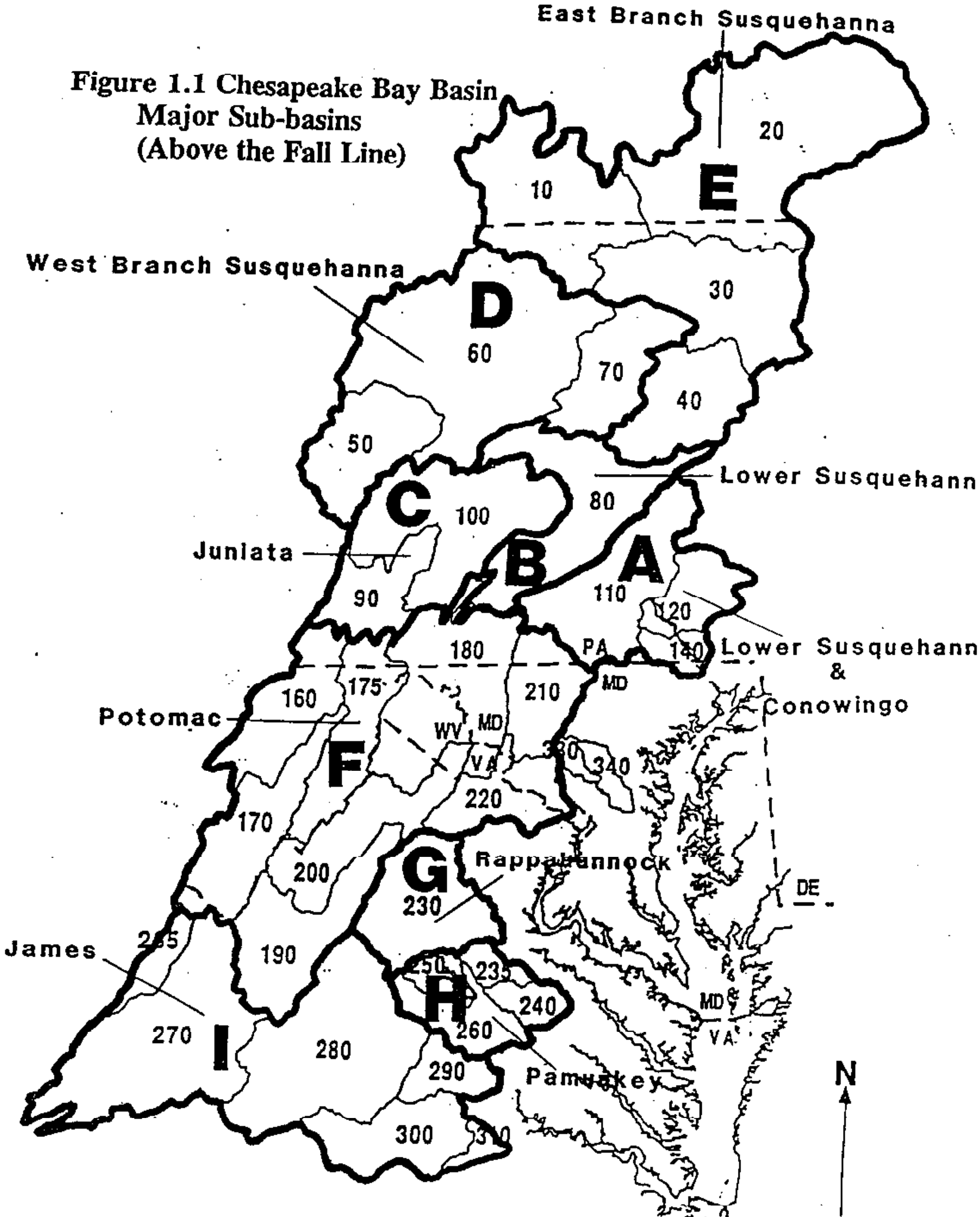
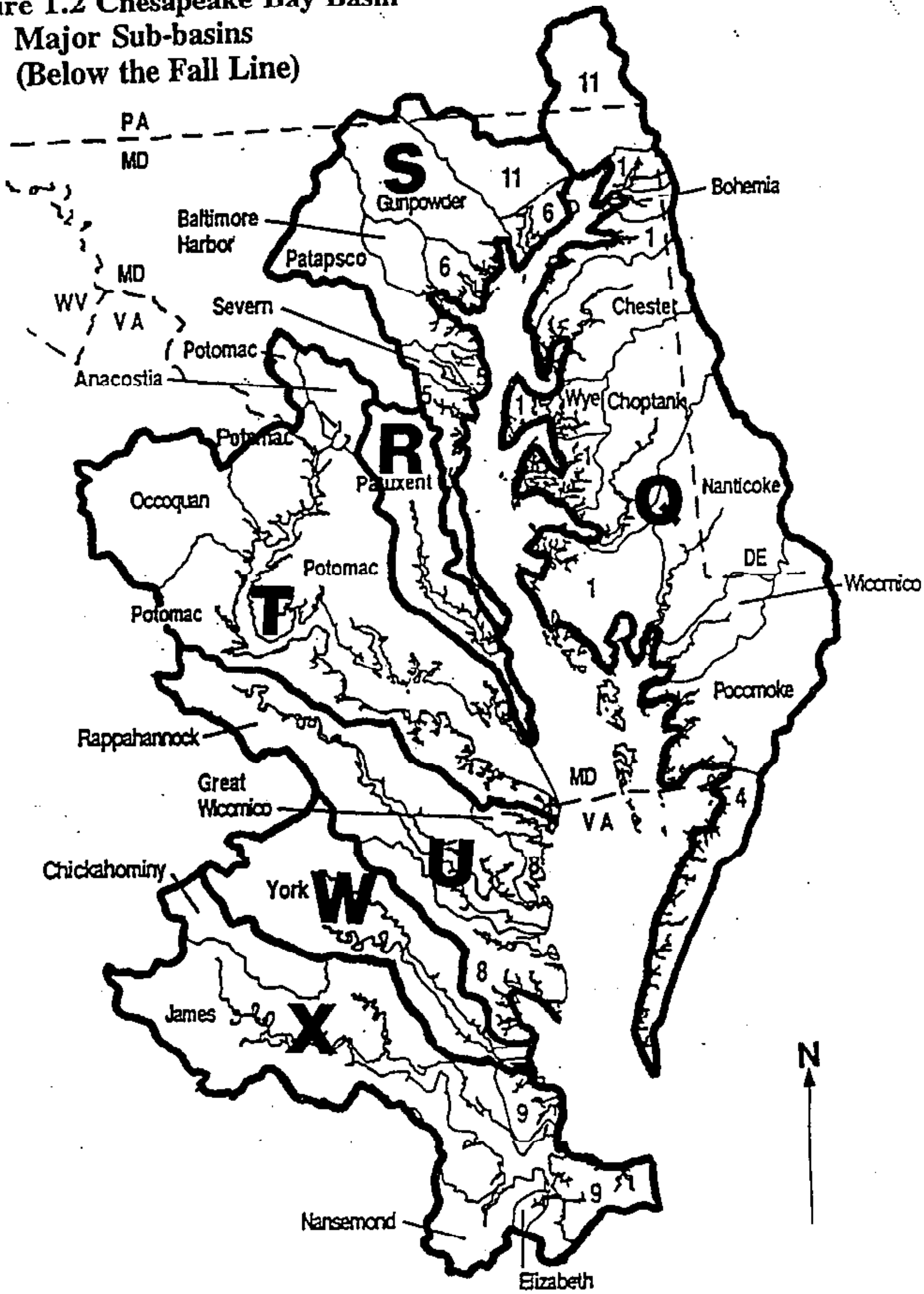


Figure 1.1 Chesapeake Bay Basin
Major Sub-basins
(Above the Fall Line)

Figure 1.2 Chesapeake Bay Basin Major Sub-basins (Below the Fall Line)



2. NONPOINT SOURCE NUTRIENT REDUCTION TECHNOLOGIES

This section summarizes the nutrient reduction effectiveness and financial costs of nonpoint source Best Management Practices (BMPs) in the Chesapeake Bay basin. Summary and description of nonpoint source BMPs can be found in: "Available Technology for the Control of Nutrient Pollution in the Chesapeake Bay Watershed" (STAC, 1987). Nutrient loading and BMP nutrient reduction efficiencies are obtained from the Chesapeake Bay Watershed Model and previous studies on BMP efficiencies. Sources for the development of the financial costs included the Chesapeake Bay agricultural cost-share program tracking database, the National Rural Clean Water Program (RCWP) projects, and states' BMP unit cost data including planning and technical assistance costs.

2.1 Chesapeake Bay Basin Nutrient Loading Factors

The edge-of-stream nutrient loading factors (pounds of nitrogen or phosphorus per acre per year) for each land use category and segment were obtained from the Chesapeake Bay Watershed Model Base Case Scenario (CBPO, 1992). Tables A-1 to A-4 (Appendix A) summarizes the loading factors for all the Chesapeake Bay Watershed segments shown in Figure 1.1 and 1.2. Figures 2.1 and 2.2 depict the ranges of nutrient loading factors for each land use category calculated from the tables of Appendix A. Animal waste loading factors are in pounds per manure acre (one manure acre represents a density of 150 animals).

Table A-5 shows the transport factors for each segment from the Chesapeake Bay Watershed Model Base Case Scenario. Transport factors are used to determine the amount of the edge-of-stream nutrient load that reaches the fall line.

2.2 Chesapeake Bay Basin Agricultural BMPs

Table 2.1 shows a summary of the agricultural BMPs in the Chesapeake Bay basin for Maryland, Pennsylvania and Virginia. The BMP classification and cross reference codes were developed by the Nutrient Reduction Task Force (NRTF) of the Nonpoint Source Subcommittee of the Chesapeake Bay Program. Similarly, Table 2.2 shows a classification of these BMPs by the groups selected by the NRTF for use in the Chesapeake Bay watershed model. For modeling purposes, the Nutrient Management (NM) and Farm Plan BMPs (FP) were defined by the NRTF as follows:

Figure 2.1 Edge-of-Stream Nitrogen Loading Factors by Land Use Category Chesapeake Bay Watershed Model Base Case Scenario

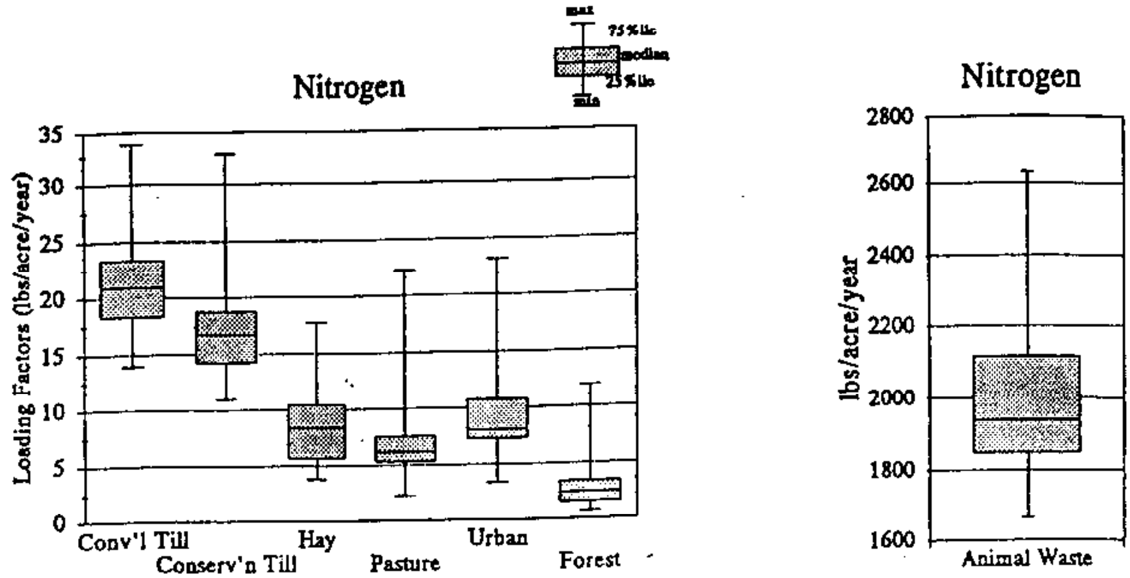


Figure 2.2 Edge-of-Stream Phosphorus Loading Factors by Land Use Category Chesapeake Bay Watershed Model Base Case Scenario

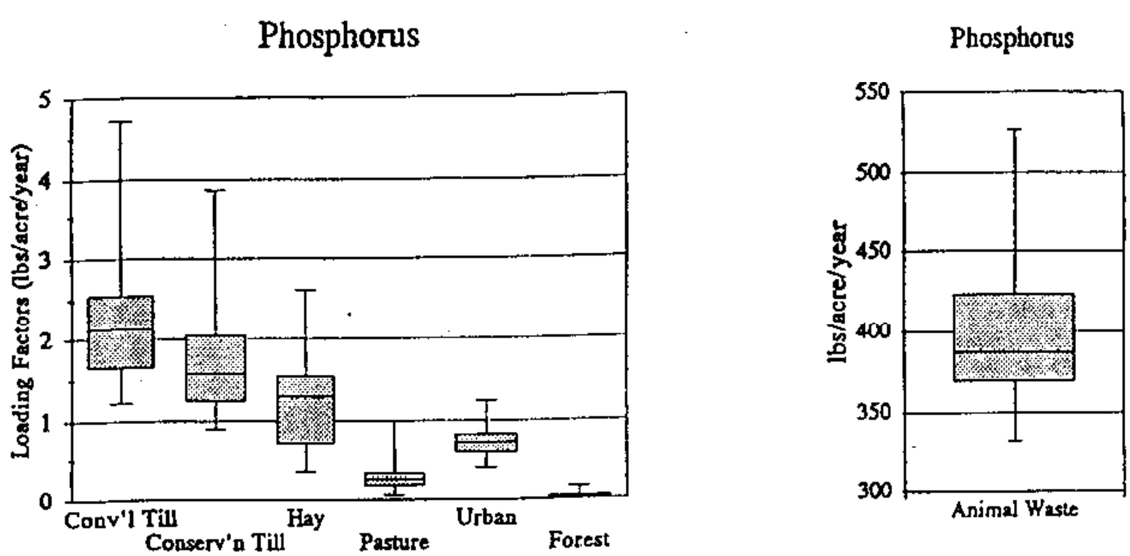


Table 2.1 State Agricultural BMP Cross Reference

BMP	Maryland Code	Pennsylvania Code	Virginia Code
Cropland Protection			
In Field:			
Strip-cropping	SL-3	BMP-3	SL-3
Buffer Strip-cropping			SL-3B
Terrace System	SL-4	BMP-4	SL-4
Sod Waterways	WP-3	BMP-7	WP-3
Protective Cover for Specialty Crops	SL-8	BMP-8	SL-8
No-till Cropland	SL-15	BMP-9	SL-15
Legume Cover Crop			WQ-4
Contour Farming	SL-13		
Minimum-till Cropland	SL-14	BMP-9	
Field Wind Breaks	SL-7		
Edge of Field:			
Diversions	SL-5	BMP-5	SL-5
Sediment Retention, Erosion, or Water Control Structures	WP-1 WC-1	BMP-12	WP-1
Grass Filter Strips	SL-11		WQ-1 WQ-2
Water Control Structures			WQ-5
Woodland Buffer Filter Area			FR-3
Pasture/Grazing Land Protection			
No-till Pasture and Hayland			SL-1
Grazing land Protection	SCS382	BMP-6	SL-6
Intensive Rotational Grazing Systems			WQ-3
Spring Development, Trough/Tank.	SL-6		
Stream Protection			
Stream Bank Protection	WP-2	BMP-10	WP-2
Vegetative Stabilization of Marsh Fringe Areas			SE-1
Nutrient Management (NM)			
Small Grain Cover Crop for NM			SL-8B
Animal Waste Control Structure	WP-4	BMP-2	WP-4
Soil and Manure Analysis	SCS680	BMP-13	NMP
Transport of Excess Manure		BMP-14	NMP
Fertilizer Management	SCS680	BMP-15	NMP
Nutrient Management	NM	BMP-16	NMP
Land Conversion			
Permanent Vegetative Cover of Critical Areas	SL-11	BMP-1 BMP-11	SL-11
Reforestation of Erodible Crop and Pastureland	SL-11		FR-1
Conservation Reserve Program	CRP	CRP	CRP
Forest Land Protection			
Woodland Erosion Stabilization			FR-4

Table 2.2 State BMPs Within Pervious Land Segments (PLS). Watershed Model (Phase II)			
BMP	Maryland	Pennsylvania	Virginia
1-Conventional Tillage			
2-Conservation Tillage			
No-till Cropland	SL-15	BMP-9	SL-15
Minimum-till Cropland	SL-14	BMP-9	
3-Conventional Tillage with NM			
Fertilizer Management	SCS680	BMP-15	NMP
Nutrient Management Plans	SCS680	BMP-16	NMP
Soil and Manure Analysis	SCS680	BMP-13	NMP
Small Grain Cover Crop for NM			SL-8B
Legume Cover Crop			WQ-4
4-Conservation Tillage with NM			
Fertilizer Management	SCS680	BMP-15	NMP
Nutrient Management Plans	SCS680	BMP-16	NMP
No-till Cropland	SL-15	BMP-9	SL-15
Minimum-till Cropland	SL-14	BMP-9	
Soil and Manure Analysis	SCS680	BMP-13	NMP
Small Grain Cover Crop for NM			SL-8B
Legume Cover Crop			WQ-4
5-Conventional Tillage with NM and FP			
6-Conservation Tillage with NM and FP			
PLS 3 or 4 BMPs, plus:			
Strip-cropping	SL-3	BMP-3	SL-3
Buffer Strip-cropping			SL-3B
Contour Farming	SL-13		
Terrace Systems	SL-4	BMP-4	SL-4
Sod Waterways	WP-3	BMP-7	WP-3
Diversions	SL-5	BMP-5	SL-5
Sediment Retention, Erosion,	WP-1		
or Water Control Structures	WC-1	BMP-12	WP-1
Water Control Structure			WQ-5
Grass Filter Strips	SL-11		WQ-1
Protective Cover for Specialty Crops	SL-8	BMP-8	SL-8
Field Wind Breaks	SL-7		WQ-2
7-Hayland with NM	same as in PLS 3-4		
8-Hayland with NM and FP	same as in PLSs 5 and6		
9-Pasture		BMP-1	
Permanent Veg. Cover on Critical Areas	SL-11	BMP-11	SL-11
Conservation Reserve Program	CRP	CRP	CRP
10-Forest			
Woodland Buffer Filter Area			FR-3
Reforestation of Erodible Crop&Pastureland	SL-11		FR-1
Conservation Reserve Program	CRP	CRP	CRP
11-Manure Acres			
Animal Waste Control Structure	WP-4	BMP-2	WP-4
Transport of Excess Manure		BMP-14	NMP

NM = Nutrient Management

FP = Farm Plan

CRP = Conservation Reserve Program

Nutrient Management - A management practice that provides recommendations on optimum nutrient application rates, nutrient application times, and nutrient application methods based on soil and manure analysis results and expected crop yields.

Farm Plan - For the purposes of the Chesapeake Bay Watershed Model, a resource management system for a farm consisting of soil conservation erosion controls for cropland. These controls may include: contour farming, strip-cropping, terraces, cover crops, grassed waterways, filter strips, diversions, and sediment retention, erosion, or water control structures. The "Farm Plan" does not include conservation tillage and nutrient management which are covered in other Chesapeake Bay Watershed Model BMP categories.

2.3 Nutrient Reduction Effectiveness of Agricultural BMPs

This section provides a summary of the edge-of-field nutrient reduction effectiveness of agricultural BMPs compiled by Camacho (1990) from research studies. In addition, nutrient reduction efficiencies at the edge-of-stream for BMPs modeled by the Chesapeake Bay Watershed Model are summarized. The edge-of-field nutrient reduction efficiencies have been presented to provide modelers with some background information on the expected edge-of-field nutrient reduction efficiencies of the BMP groups simulated by the model. Some of this information has been used for modeling certain BMP scenarios. Ultimately, evaluation of basin-wide agricultural BMP nutrient reductions is performed by simulation of different BMP scenarios with the Chesapeake Bay Watershed Model.

2.3.1 Edge-of-Field BMP Effectiveness Reported in Research Studies

Edge-of-field BMP nutrient reduction efficiencies based on small watershed research studies, field plots, and CREAMS modeling were reported by Camacho (1990). The efficiencies were calculated as: *Efficiency(%) = [1 - post-BMP/pre-BMP]x100* where *pre-BMP* is the nutrient load before BMP installation or base case and *post-BMP* is the nutrient load after BMP installation. Although over 150 sets of efficiencies were reported from over 30 research studies, this was insufficient to accurately characterize BMP nutrient reduction efficiencies in both groundwater and surface waters for some regions in the Chesapeake Bay basin. Nevertheless, the study provided valuable information to modelers on the expected edge-of-field BMP nutrient reduction efficiencies and the expected nutrient reduction capabilities of the BMP groups were confirmed.

Some of the important factors to be considered when examining the BMP nutrient reduction efficiencies from this study are:

- Many studies focused on short term efficiencies from single rainfall events. Therefore, extrapolation of these efficiencies to annual or long term efficiencies is questionable due to annual hydrologic, crop, and farm activity changes within a year.

- Many studies were carried out in small field plots using artificial rainfall. Use of artificial rainfall in small field plots may not represent actual field conditions.

- Sampling techniques may be different for each study which make comparisons between studies difficult.

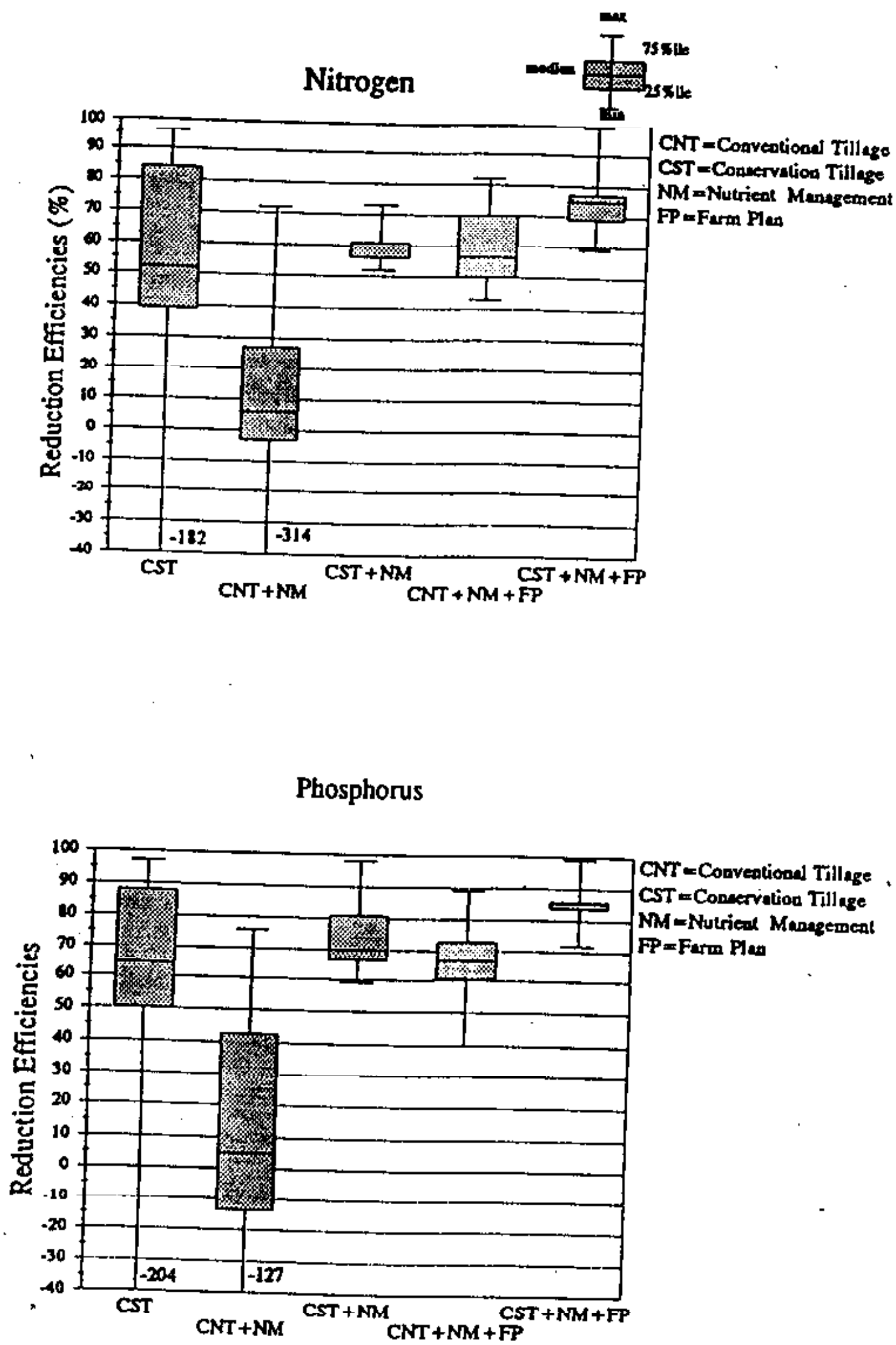
- Studies analyzing BMP nutrient reduction efficiencies from a combination of BMPs are usually the result of mathematical modeling. Unless the models are properly calibrated, efficiencies derived can only be considered at best to be educated guesses.

- In general there was a lack of research studies analyzing both surface and groundwater nutrient changes.

With the acknowledgement of the limitations described above, Figure 2.3 shows ranges of literature values for nutrient reduction efficiencies in surface water runoff for selected groups of BMPs. Again, the nutrient reduction efficiencies were derived from a variety of research studies and the efficiencies are at the edge-of-field (Camacho, 1990). Figure 2.3 shows that nutrient management, when accompanied by soil conservation BMPs such as conservation tillage or any other erosion control BMP under the "farm plan" category, is effective in reducing nutrient loss to surface water.

Figure 2.4 gives interquartile ranges of nutrient, runoff and soil loss reduction efficiencies in surface and groundwater for no-tillage. From this figure, it can be concluded that reduction in soil loss is effective in reducing phosphorus as the transport of sediment-bound phosphorus decreases. Reduction in runoff results in a reduction in the transport of dissolved nutrient in surface waters. However, leaching of nitrates reduces the efficiencies in groundwater as shown by the interquartile range of -9% to 18% for total nitrogen in groundwater. Also, conservation tillage may increase the concentration of nutrients in the soil surface (and therefore

Figure 2.3 Edge-of-Field Nutrient Reduction Efficiencies in Surface Water for Agricultural BMPs (Literature Values)



in surface runoff), offsetting any reductions achieved by the reduction in runoff volume. For instance, Heatwole et al. (1991) reported from Erbach (1982), that the concentration of phosphorus in a no-till corn-soybean rotation was 67% higher than in a conventional tillage field.

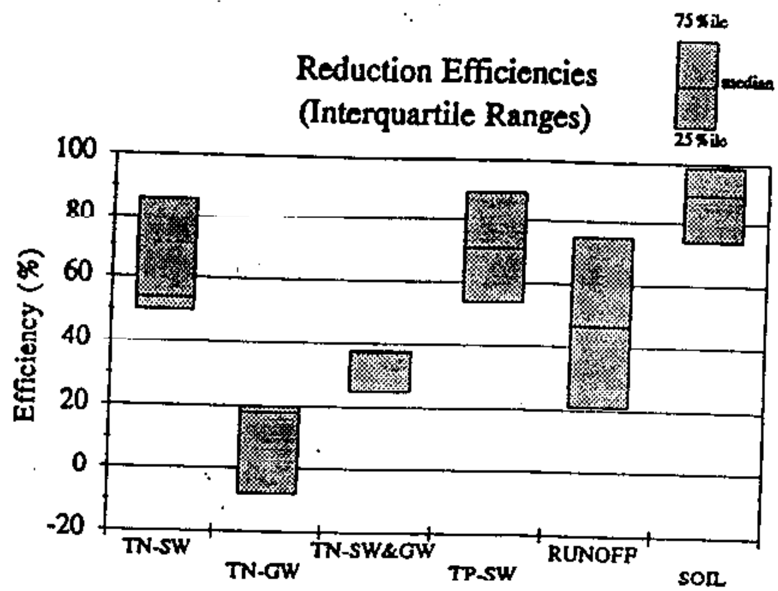
From the literature review on BMP efficiencies (Camacho, 1990), it was concluded that adding soil erosion control BMPs to conventional tillage with or without nutrient management can reduce the amount of nutrient loss to surface water. However, although there is a net improvement in the nutrient reductions efficiencies in surface water, the efficiency for nitrogen in groundwater decreased by an average of 10 percentage points when adding these practices. This decrease in surface water may be due to the increase in the leaching of nitrates into the groundwater. It was also shown that adding soil conservation erosion controls BMPs (such as: terraces, contouring, waterways, etc.) slightly increases the nutrient reduction efficiency. This is mainly because conservation tillage with nutrient management has already accounted for most of the nutrient reduction. However, this conclusion does not diminish the importance of erosion control BMPs. For instance, a large field with long slopes may require an erosion control BMP, in addition to conservation tillage and nutrient management, if there is a severe erosion problem. In such cases, other erosion control BMPs may be necessary and can significantly improve the efficiencies above those obtained only with conservation tillage and nutrient management.

Figure 2.5 shows the additional nutrient reductions above no-till with nutrient management when adding soil conservation erosion control BMPs. The additional reductions in nutrient loads are expressed as a percentage of the conventional tillage load. These reductions were summarized by Camacho (1990) from CREAMS modeling in four major subbasins in Pennsylvania by Shirmohammadi and Shoemaker (1988) and field plot simulations in Virginia reported by Ross et al. (1990). BMPs analyzed included contour tillage, strip-cropping, diversions, grassed waterways and filter strips. From this figure, it is observed that the addition of these BMPs can slightly increase the nutrient load reductions.

2.3.2 Basin-Scale Agricultural BMP Effectiveness

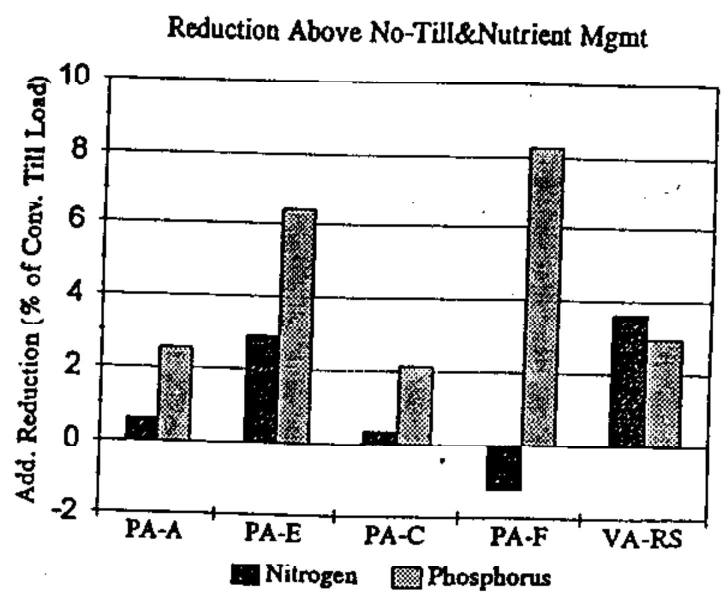
This section describes the nutrient reduction effectiveness for agricultural BMPs obtained by the Chesapeake Bay Watershed Model. Results of the watershed model are summarized for the conservation tillage and nutrient management BMPs. Nutrient reduction efficiencies are calculated at the edge of stream for each of the watershed model segments of the Chesapeake Bay Watershed (Figure 1.1 and 1.2).

Figure 2.4 No-till Reduction Efficiencies*



TN= Total Nitrogen
TP= Total Phosphorus
SOIL= Soil Loss Reduction
SW= Surface water
GW= Groundwater

Figure 2.5 Additional Nutrient Reductions from Soil Conservation Erosion Control BMPs



PA-A to F Creams Model Runs in Pennsylvania (Shirmohammadi & Shoemaker, 1988)
VA-RS= Virginia Rainfall Simulator Studies (Ross et al., 1990)

* Source: Agricultural BMP Nutrient Reduction Efficiencies:
Chesapeake Bay Watershed Model BMPs (Camacho, 1990)

2.3.2.1 Conservation Tillage

Table B-1 (Appendix B) shows a list of the nutrient reduction efficiencies for conservation tillage from the Chesapeake Bay Watershed Model. Figure 2.6 depicts the ranges of nutrient reduction efficiencies from Table B-1. From this figure, it is observed that the ranges for nitrogen and phosphorus are similar but the median for phosphorus is higher (about 25%) than nitrogen (about 20%). Nitrogen reduction efficiencies ranged from about 2% to 32% with interquartile values of 17% to 23%. It is noted that edge-of-field efficiencies from research studies for no-till shown in Figure 2.4 are close to the high end of this range.

In general, conservation tillage has been found to be an attractive BMP for farmers, with many studies reporting net increases in farm income (Epp and Hamlett, 1990). Conservation tillage has been found in most cases to be cost effective because it can reduce production costs as well as increase the soils long-term productivity and yield (Heatwole, et al. 1991). On the other hand, other edge-of-field structural erosion control BMPs (such as sediment ponds) with higher costs, usually reduce the farm income despite the availability of high cost-share rates (Epp and Hamlett, 1991). Moreover, although these structural BMPs can significantly reduce the sediment delivered to streams, they do not stop erosion from the fields. This must be controlled by an in-field erosion control BMP.

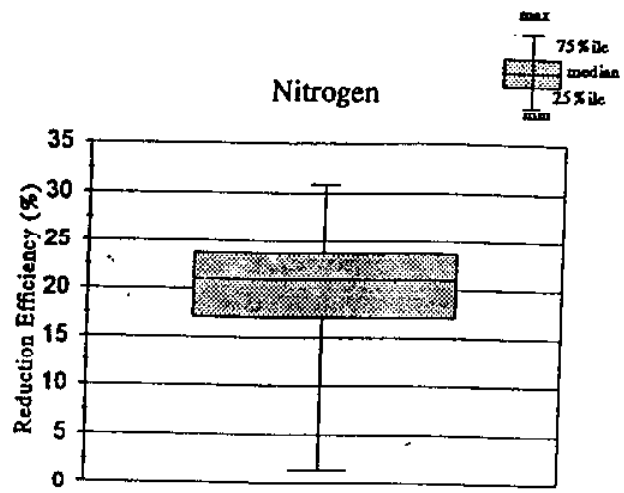
2.3.2.2 Nutrient Management

Table B-2 (Appendix B) shows the nutrient reduction efficiencies for the nutrient management scenario simulated by the Watershed Model. Figure 2.7 shows the ranges of nutrient reduction efficiencies from this table. The ranges shown in Figure 2.7 reflect the regional impacts on different nutrient applications rates and changes throughout the basin.

2.3.3 Summary

Agricultural BMP nutrient reduction efficiencies from the literature, as well as nutrient reduction efficiencies for conservation tillage and nutrient management modeled by the Chesapeake Bay Watershed Model, have been summarized. Edge-of-field efficiencies shown in Section 2.3.1 should be used with caution. Limitations on the use of these numbers has been summarized earlier, and again it is important to note that the efficiencies were obtained from a variety of field and modeling research studies in different physiographic regions under different BMP installation conditions. BMP efficiencies for a particular physiographic region, crop, soil,

Figure 2.6 Conservation Tillage Edge-of-Stream Nutrient Reduction Efficiencies Chesapeake Bay Watershed Model



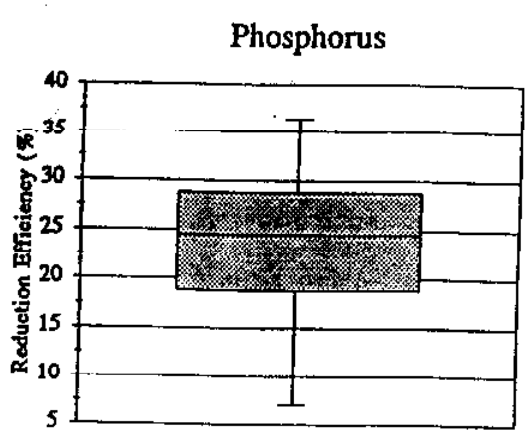
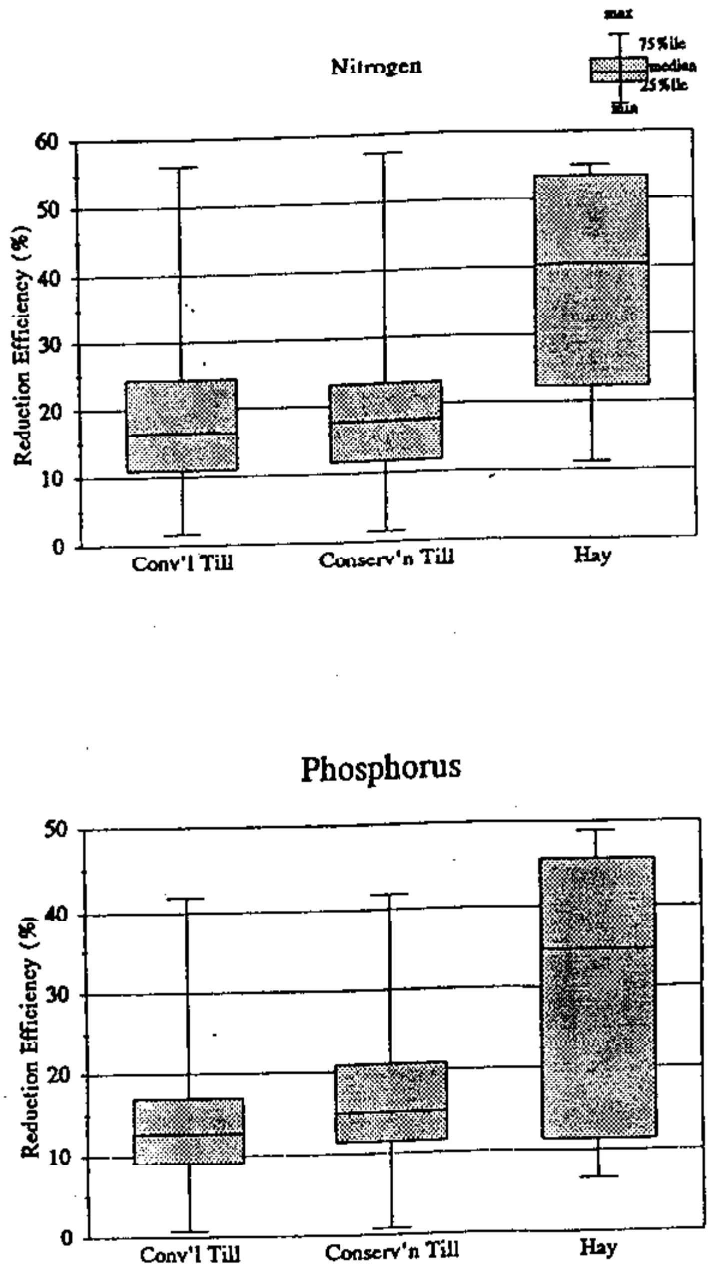


Figure 2.7 Nutrient Management Edge-of-Stream Reduction Efficiencies Watershed Model Nutrient Management Scenario



fertilizer application, and period of simulation should be examined from each particular study summarized by Camacho (1990). Although it is very difficult to generalize the efficiencies shown in the last sections for all regions in the Chesapeake Bay basin, there are some conclusions that can be drawn from these efficiencies which agree with most of the findings of current studies on BMP effectiveness:

- Nutrient management together with soil conservation erosion control BMPs are effective in reducing the total nutrient loads from the field for both surface waters and groundwater.

- Erosion control BMPs reducing both runoff and sediment leaving the field reduce the transport of sediment-bound pollutants. In particular, where transport of sediment attached phosphorus is the main path for the phosphorus losses, significant phosphorus reductions can be achieved.

- Although erosion control BMPs reduce both the runoff and the transport of sediment-bound pollutants, they can increase infiltration, causing a potential increase in the transport of soluble nutrients into groundwater. In particular, nitrate losses can increase, offsetting the nitrogen reduction achieved through erosion control BMPs that reduce surface runoff. This is one of the reasons that nutrient management should be couple with erosion control BMPs.

2.4 Financial Costs of Agricultural BMPs

This section summarizes the financial costs for agricultural BMPs. In Table 2.5, total BMP financial costs are expressed in equivalent annual dollars per acre benefitted ($/acre/year). Total costs include planning, technical assistance and operation and maintenance (O&M) costs.

The costs do not include potential cost savings to the farmer or other economic benefits. Therefore, besides the financial costs there are other factors that need to be considered to allow proper selection of BMPs. Such factors may include changes in farm income, suitability of different BMPs for a particular physiographic region, cost-share rates, and other site-specific constraints.

2.4.1 Financial Base Costs for BMPs

Financial base costs for BMPs were obtained from the total cost-share costs compiled by the Chesapeake Bay Program (CBPO) BMP tracking database. Costs in the tracking system do not include planning, technical assistance and operation and maintenance (O&M) costs which are discussed in the following sections. From these data, the cost, acres benefitted, and the erosion reduced in tons per year were obtained for each BMP. This information was also supplemented with the states' BMP cost tables. Table 2.3 shows the interquartile BMP unit base cost ranges for Agricultural BMPs in the Chesapeake Bay Basin.

2.4.2 Planning and Technical Assistance Costs

Besides the BMP installation base cost, planning and technical assistance (PT) costs should be considered for the full implementation of a BMP in the farm. Total BMP installation costs are obtained by the following relationship:

Total BMP Installation Cost ($/acre) = BMP Base Cost x (PT-Factor)

where:

BMP Base Cost = BMP base cost from Table 2.3.
PT-Factor = Escalation factor to account for planning and technical assistance costs.

The escalation factors were derived from the states' planning and technical assistance cost rates, and other sources of information such as 1989 BMP implementation cost tables from the Rural Clean Water Program (RCWP) projects (see Appendix C). Table 2.4 shows the escalation factors for each BMP and the adjusted BMP unit cost including planning and technical assistance costs.

Table 2.3 Financial Base Cost Ranges of Agricultural BMPs in the Chesapeake Bay Basin[1]					
BMP Type	# of BMPs	BMP Life (years)	BMP Base Cost ($/acre)		
			25%ile	median	75%ile
Strip-cropping	393	5	15	30	30
Terraces	64	10	136	326	564
Diversions	88	10	107	214	477
Sediment Retention and Water Control Structures	165	20	256	523	1209
Grassed Filter Strips	213	5	14.60	23.80	35.30
Cover Crops	366	1	10	10	20
Grazing Land protection	274	1	49	95.30	194
Permanent Vegetative Cover on Critical Areas	239	5	134	240	778
Nutrient Management[2]	-	3	6		
Conservation Tillage[3]	2,004	1	15		
Conservation Reserve Program[3] (CRP)	5,881	10	52-71/year[4]		
Animal Waste Systems[5]	572	10	9/ton	12.80/ton	17.60/ton
Grassed Waterways[6]	-	10	1.50-5.90/lf		

1. Interquartile unit cost ranges obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and States' unit cost data. Dashes under the # of BMPs analyzed column indicates that the costs where derived from the states' unit cost data information.
2. Nutrient Management Plan Cost.
3. Government incentive costs which do not reflect actual practice costs.
4. Average annual rental rate for MD, PA, and VA (USDA-CRP, 1990). Does not include costs of BMPs.
5. Units for animal waste are given as $/Ton of manure treated.
6. Unit cost range per linear foot of waterway.

2.4.3 Operation and Maintenance Costs

There is little information on the O&M costs mainly because they are not cost-shared. Also, these costs may vary for different practices and local conditions. Sometimes the O&M activities may not include major costs but mainly depend on farmer diligence (Rosenthal and Urban, 1990). Nevertheless, O&M annual costs expressed as a percentage of BMP base cost have been reported by the Soil Conservation Service (North Carolina State University, 1982). Table 2.5 shows these percentages and the total BMP costs including the O&M cost for several BMPs.

2.4.4 Total Annual BMP Financial Unit Costs

The total annual BMP unit costs are calculated by annualizing the total BMP installation costs and adding the O&M costs as shown by the following expression:

$$\textit{Total annual BMP cost} = \textit{Annual Total BMP Installation Cost} + \textit{(O\&M)factor} \times \textit{BMP Base Cost}$$

where:

Annual Total BMP Installation Cost = Annualized Cost for the BMP life period
(O&M)factor = Operation and Maintenance Cost factor (Table 2.5)

2.4.5 Animal Waste Systems Financial Costs

The annualized animal waste management cost per ton of manure treated is given in Table 2.5. These costs reported to the Chesapeake Bay Program tracking system are the combination of the costs of many different systems to control animal wastes. These include management systems for dairy, beef, swine, poultry, etc. Besides the tracking system information, some costs in this section were estimated based on examples given by a manual prepared for the Pennsylvania Department of Environmental Resources, Bureau of Soil and Water (Ritter, 1990). This manual is a guide to aid in the economic evaluation of manure management plans for farmers. Costs of alternative manure management systems for dairy, beef, swine, veal and poultry operations were presented in this manual. Detailed cost tables, cost estimation assumptions, and advantages and disadvantages of the different systems can be found in the manual.

Table 2.4 Financial Unit Costs Ranges of Agricultural BMPs in the Chesapeake Bay Basin[1] (Base plus Technical Assistance Costs)				
BMP Type	Escalation Factor (Planning and Technical Assistance costs)	Total BMP Installation Cost ($/acre)		
		25%ile	median	75%ile
Strip-cropping	1.43	21.40	42.80	42.80
Terraces	1.31	178	427	739
Diversions	1.19	127	255	567
Sediment Retention and Water Control Structures	1.25	321	655	1515
Grassed Filter Strips	1.012	14.80	24.00	35.70
Cover Crops	-	10	10	20
Grazing Land protection	1.25	61.40	119	243
Permanent Vegetative Cover on Critical Areas	1.10	147	263	856
Nutrient Management[2]	-	6		
Conservation Tillage[3]	1.156	17.30		
Conservation Reserve Program[3] (CRP)	-	52-71/year[4]		
Animal Waste Systems[5]	1.17	10.50/ton	14.90/ton	20.60/ton
Grassed Waterways[6]	1.25	1.90-7.40/lf		

1. Interquartile unit cost ranges obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and States' unit cost data.
2. Nutrient Management Plan Cost.
3. Government incentive costs which do not reflect actual practice costs.
4. Average annual rental rate for MD, PA and VA (USDA-CRP, 1990). Does not include BMP costs.
5. Units for animal waste are given as $/Ton of manure treated.
6. Unit cost range per linear foot of waterway.

Table 2.5 Total Annual Costs Ranges of Agricultural BMPs in the Chesapeake Bay Basin[1] (Base plus Technical Assistance plus O&M costs)				
BMP Type	Annual O&M Cost Factor[2] (% of BMP Base Costs)	Total Annual BMP Cost[3] EAC ($/acre/year)		
		25%ile	median	75%ile
Strip-cropping	1.0	5.80	11.60	11.60
Terraces	5.0	35.70	85.80	148
Diversions	5.0	26.10	52.20	116.20
Sediment Retention and Water Control Structures	3.0	50.50	103	238
Grassed Filter Strips	5.0	4.30	7.10	10.50
Cover Crops	-	10	10	20
Grazing Land protection	5.0	18.60	36.30	73.80
Permanent Vegetative Cover on Critical Areas	3.0	38.90	69.50	225.70
Nutrient Management[4]	-	2.40		
Conservation Tillage[5]	-	17.30		
Conservation Reserve Program[5] (CRP)	-	52-71[6]		
Animal Waste Systems[7]	10.0	2/ton	2.80/ton	3.90/ton
Grassed Waterways[8]	5.0	0.39-1.50/lf		

1. Original interquartile BMP installation costs ranges obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and States' unit cost data.
2. Annual operation and maintenance cost. Source: North Carolina State University (1982). Annual O&M costs are determined multiplying these percentages by the BMP base costs on Table 2.3.
3. Total annual BMP costs. Costs include planning, technical assistance and O&M costs. EAC= Equivalent annual costs in dollars per acre benefitted. Interest rate = 10%, practice life from Table 2.3
4. Does not include potential cost savings to the farmer.
5. Government incentive costs which do not reflect actual practice costs.
6. Average annual rental rate for MD, PA and VA (USDA-CRP, 1990). Does not include BMP costs.
7. Units for animal waste are given as $/Ton of manure treated.
8. Unit cost range per linear foot of waterway.

The tables in Appendix D show typical annual costs of different alternatives for manure management of dairy, beef, swine, veal, and poultry operations. Table 2.6 shows maximum, minimum and median costs from these examples. Also, included are the annual costs per ton of manure treated. The animal waste systems shown in the examples in Appendix D represent a small subset of possible combinations of different collection, storage and application systems on a farm. The Ritter (1990) manual provides individual costs for different components of collection, storage and utilization of animal waste operations of different sizes. Also, guidelines for selecting alternatives were provided in the manual. Therefore, the examples given in Appendix D are only for illustrative purposes. It is likely that costs of animal waste systems may vary significantly depending on site-specific conditions. The annual costs per ton of manure treated shown in Table 2.6 are much higher than the ones shown in Table 2.5 from the BMP tracking system ($2.81/ton). The main reason for this difference is that costs under the BMP tracking system include other animal waste BMPs such as fencing, filter strips, runoff control etc. which have lower costs than total systems including collection, storage, and utilization. In addition, annual labor and energy costs are not considered in the BMP tracking data costs.

Table 2.6 Statistics of Examples of Animal Waste System Costs[1]

Animal Waste System	Minimum		Median		Maximum	
	($/Animal)	($/Ton)	($/Animal)	($/Ton)	($/Animal)	($/Ton)
Dairy	209.63	18.30	272.39	23.70	303.93	26.50
Beef	57.19	6.80	77.27	9.20	97.34	11.60
Swine	15.06	6.34	22.83	9.60	38.01	16.00
Veal	24.28	14.30	43.24	25.40	62.2	36.60
Poultry	0.44	2.00	0.51	2.90	0.64	11.40

1. Statistics from the examples of animal wastes shown in Appendix D. Assumptions for the calculation of the tonnage of manure treated are described in the footnotes of the tables in Appendix D. Annualized costs. Interest rate = 10%.

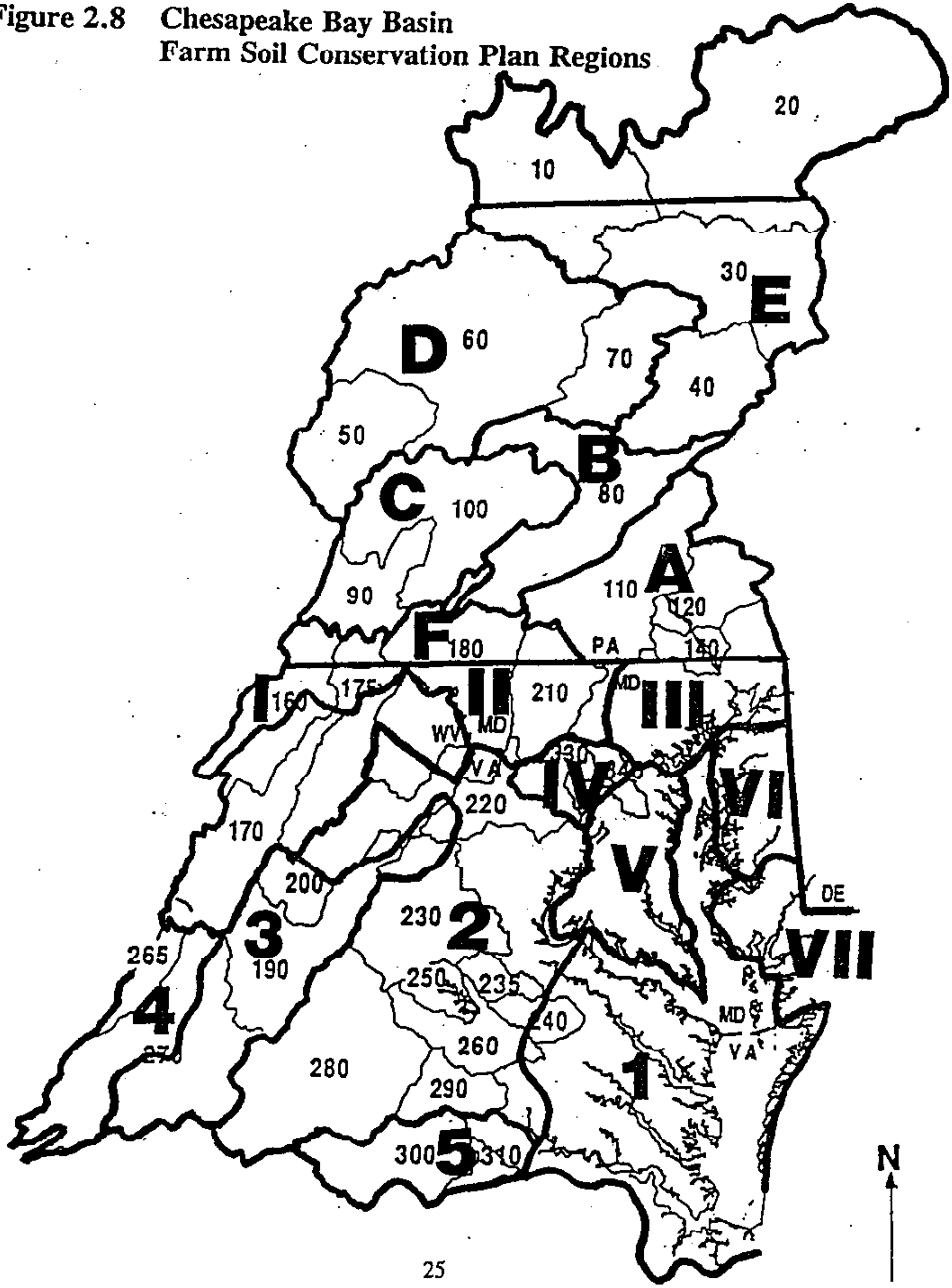
2.4.6 Combined Unit Costs of Erosion Control BMPs from Soil Conservation Plans

The costs of soil conservation erosion controls BMPs are evaluated for combinations of BMPs within a farm from selected soil conservation plans. A soil conservation plan representing a "typical" farm was selected by the states for each region shown in Figure 2.8. The BMP annual unit cost ranges from Table 2.5 are applied to the BMPs of each soil conservation plan. Interquartile unit cost ranges (annual BMP costs per acre of cropland or pasture) for each typical farm in each region are shown in Table 2.7. Detailed BMP descriptions for the farms in each region and the tons of soil saved after BMP implementation are shown in the Tables E-1 to E-3 (Appendix E).

Table 2.7 Annual Unit Cost of Erosion Control BMPs from Typical Chesapeake Bay Basin Soil Conservation Plans

State	Farm	Annual Costs per Acre		
	Location	25%ile	Median	75%ile
Maryland	I	14.94	19.88	19.88
	II	31.57	41.06	46.56
	III	74.76	96.08	122.41
	IV	37.85	49.73	52.58
	V	39.76	55.03	70.03
	VI	42.84	56.23	69.38
	VII		27.54 -67.88	
Pennsylvania	A+B	23.93	35.08	48.95
	D+E	16.45	24.24	31.30
	C+F	20.18	27.25	38.79
Virginia	1	29.52	34.06	38.58
	2+4	18.64	36.27	73.78
	3	21.46	33.42	40.87
	5	20.85	25.88	30.83

Figure 2.8 Chesapeake Bay Basin
Farm Soil Conservation Plan Regions



2.4.7 Summary

Figure 2.9 shows the total annual BMP unit cost ranges from Table 2.5, and the interquartile cost ranges for BMPs within each farm in the Chesapeake Bay watershed from Table 2.7. Figure 2.9 shows wide cost ranges for terraces, diversions, sediment retention structures, grassed waterways, and permanent vegetation on critical areas. Therefore, wide ranges of cost for some farms are due to the use of structural practices with a wide range in the unit cost. In conclusion, from Figure 2.9 and the tables in Appendix E, it is observed that the combined cost of BMPs for a farm can significantly vary depending on the type, amount and density of BMPs within the farm. For instance, the costs for the farm on region MD:III are higher than all the other farms. Examining Table E-1 for this region, it is observed that the farm selected contains BMPs with wide unit cost ranges over a relatively small area resulting in a wide and high unit cost range.

2.5 Cost and Effectiveness of Small Watershed Demonstration Projects

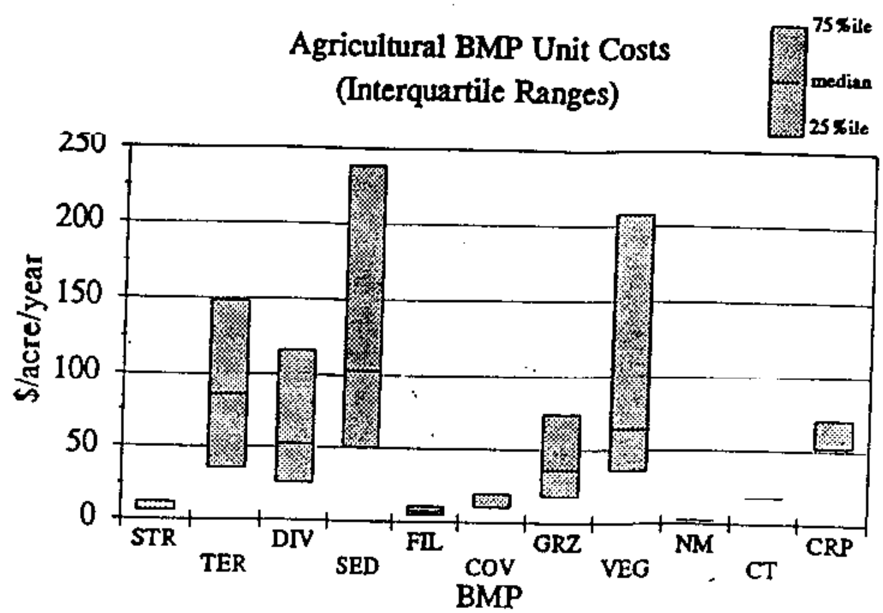
The states have been conducting small watershed studies for the assessment of the effectiveness of BMPs. Among these studies, the Conestoga Headwaters, Double Pipe Creek, and the Nasemond-Chuckatuck RCWP projects are reported for Pennsylvania, Maryland and Virginia respectively. The Owl Run and Nomini Creek demonstration projects provide similar data in Virginia. In this section, the Conestoga Headwaters and Owl Run projects are summarized, where information on both cost and BMP nutrient reduction effectiveness has been reported.

2.5.1 Conestoga Headwaters

The Conestoga Headwaters RCWP project started in the early 1980s with the main objective of reducing the water pollution from agricultural sources. Another objective of the project was to investigate the effects of agricultural BMPs on groundwater pollution abatement (Pennsylvania-RCWP, 1989).

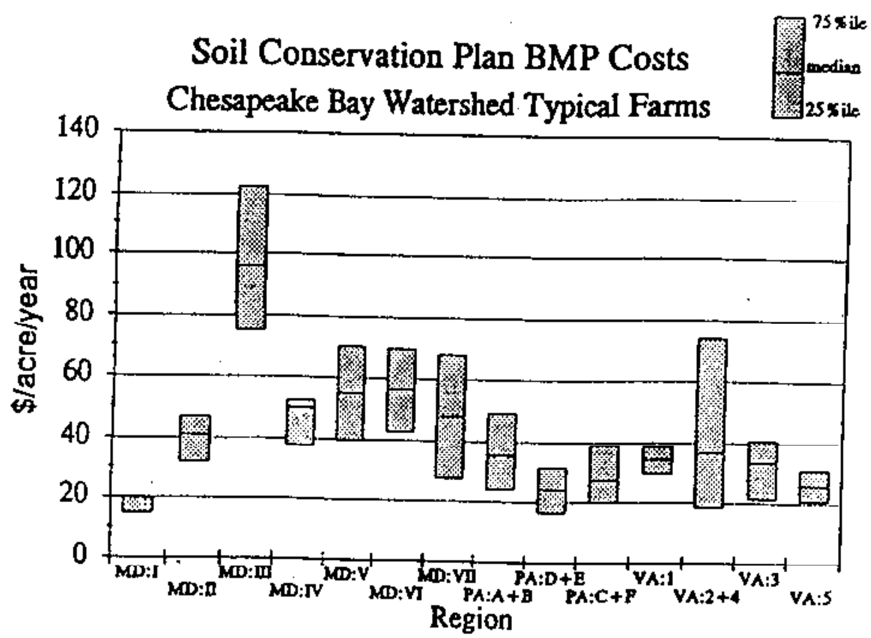
Nutrient management for both manure and commercial fertilizer has been identified as one of the most important factors in improving the water quality. Nutrient management plans are expected to eliminate approximately 2/3 of the excess nitrogen and phosphorus. The entire area of the Conestoga Headwaters is approximately 120,320 acres. Water quality monitoring has been conducted in this area with detailed monitoring of a small watershed and more intensive

Figure 2.9 Agricultural BMP Unit Costs and Soil Conservation Plan BMP Costs for Typical Farms within the Chesapeake Bay Watershed



STR = Strip-cropping
TER = Terraces
DIV = Diversions
SED = Sediment Retention and Water Control Structures
FIL = Filter Strips
COV = Cover Crops
GRZ = Grazing Land Protection
VEG = Permanent Vegetation on Critical Areas
NM = Nutrient Management
CT = Conservation Tillage
CRP = Conservation Reserve Program

Grassed Waterway Annual Unit Cost Range : $0.39 - $1.50 per linear feet.
Unit costs obtained from the Chesapeake Bay Program BMP Tracking data base and states' unit cost data.
Equivalent annual costs includes construction, planning, technical assistance, and O&M costs.
Cost for CT, CRP and REF are government incentive costs.



monitoring on two small fields of 23 and 48 acres, respectively. It was found that the effectiveness of nutrient management was dependent on the reduction of nutrient application rates (Pennsylvania-RCWP, 1991).

From one of the field sites, it was found that terraces were effective in reducing the amount of sediment loss, but ineffective in reducing the nutrient loads in both surface and groundwater. Simultaneous implementation of terracing and nutrient management was recommended, due to the potential increase in nitrate concentrations in the groundwater after terracing.

For the Conestoga area, it was found that areas underlain by carbonate rock discharge most of their water as groundwater and base flow. Therefore, these areas are highly susceptible to agricultural nonpoint source pollution (Pennsylvania-RCWP, 1992).

Total soil loss reductions during the entire project period were 110,000 tons. Nitrogen reductions were about 1.3 million pounds and phosphorus reductions were about 0.57 million pounds. The nutrient reductions were estimated using the CREAMS model results of nutrient reductions by BMP for 1984. These reductions were then applied to the entire project period. Table C-1 in Appendix C summarizes the BMP costs including planning, technical assistance and water quality development plan costs for 1989.

2.5.2 Owl Run

The Owl Run watershed is located in Faquier County VA within the Piedmont physiographic region. It has an area of approximately 2,800 acres. Land use in this watershed is described as follows:

Corn:	723 acres (300 acres no-till)
Hay:	573 acres
Pasture:	500 acres (active)
	190 acres (idled)
Woodland:	575 acres
Developed:	250 acres

The soils in the watershed are predominantly of the Penn-Croton-Buck Soil association whose physical characteristics are highly variable. These soils are not in general of the productivity expected of soils for dairy operations. The soils on the Penn series have a low "T" (soil loss tolerance) of 1 ton/acre/year at which productivity can be affected by erosion. In the Owl Run watershed, 75% of the soils have "T" values between 1 and 2. This low "T" value can have negative impacts on the application of animal wastes which are recommended to be applied to soils eroding less than "T" (VA-DSWC, 1991).

BMP implementation in Owl Run has focused on animal waste management facilities. Estimated installation costs of these facilities are summarized as follows:

Site	Herd Size	BMP	Installation Cost
Dairy A	475 cows	earthen pit 2 reception pits and pumps	$65,000
Dairy B	65 cows	earthen pit & concrete pushing ramp	$10,000
Dairy C	175 cows	concrete upright gravity load & unload	$45,000
Dairy D	145-165 cows	concrete upright, pump load	$40,000

Some of these structures may seem expensive. However, due to the soil characteristics and site specific conditions, the facilities shown above are necessary. Also, it has been reported that animal waste management at the Owl Run watershed may also indirectly contribute to soil erosion control. The main reason for this indirect benefit is that, without storage facilities, the current practice is to leave some fields without any vegetation for winter application of manures. It was reported that these fields may erode at an average of four times the acceptable soil loss tolerance (T). In addition, manure applied to frozen ground is available for increased transport by runoff and snow melt which has a negative impact on the water quality of the receiving waters.

Besides the animal waste facilities, there are also other BMPs installed in the basin which include:

Animal waste storage facilities:	6 units
Strip-cropping:	78 acres
Waterways (16 units):	16 acres
Watering troughs (6 units):	350 acres rotational grazing
Fencing (4,000 ft.):	350 acres rotational grazing
Filter Strips	13 acres
Cropland converted to grass	99 acres
Diversion (400 ft.):	5 acres
Conservation tillage	315 acres

The total estimated cost of BMP implementation at Owl Run watershed is $267,000, with costs due to planning, technical assistance, and administration around $100,000.

The post-BMP monitoring to assess the effectiveness of BMP implementation has recently begun and results from this monitoring are expected in the future. Hession, et al. (1989) used the AGNPS water quality model to simulate expected nutrient reductions due to the implementation of BMPs. Since, AGNPS is designed to simulate single rainfall events, input parameters reflecting average annual conditions were selected, and storm events ranging from 1 to 6 inches were simulated. The model was validated with observed data showing results within ranges of observed average conditions. Expected nutrient reductions from the above BMPs and 50% fertilizer application reduction averaged 42% for the storm events simulated.

2.6 Financial Cost Effectiveness of Agricultural BMPs

The previous sections summarized the unit costs of different agricultural best management practices and their nutrient reduction effectiveness. In this section, cost effectiveness ratios are provided for these BMPs. The cost effectiveness ratio for BMPs can be generally defined as the ratio of the cost to the pounds or tons of pollutant removed. For instance, if the cost effectiveness is evaluated solely on the ability of BMPs to remove nitrogen or phosphorus, the cost effectiveness ratio for a BMP may be defined as the ratio of the equivalent annual cost (EAC) to the pounds of nitrogen or phosphorus removed per year. On the other hand, for soil conservation erosion controls BMPs, a cost effectiveness ratio could also be defined as the equivalent annual cost (EAC) divided by the tons of soil saved. Cost effectiveness can be evaluated for individual BMPs or for combinations of BMPs ("Resource Management Systems") in a farm. For large watersheds, cost effectiveness of combinations of pollutant removal technologies ("Pollutant Reduction Strategies") can be evaluated using the total costs of BMPs for the watershed and the nutrient, soil loss reductions, and other benefits achieved at the edge of the stream or at the outlet of the watershed.

2.6.1 Cost Effectiveness Ratios for Soil Conservation Erosion Control BMPs

In this section, cost effectiveness of soil conservation erosion control BMPs are analyzed. The cost effectiveness for these BMPs is calculated as the ratio of the cost to the tons of soil saved.

Table 2.8 shows the cost effectiveness ratios for these BMPs. Again, original costs and tons of soil saved were obtained from the Chesapeake Bay BMP tracking system (CBPO, 1990). For CRP the tons of soil saved were obtained from "The Conservation Reserve Program" (USDA, 1990). Figure 2.10 depicts the interquartile cost effectiveness ratios for the soil conservation erosion controls BMPs shown in Table 2.8. This figure shows that, in general, structural practices such as grassed waterways, water and sediment control structures and diversions show a wide range of cost effectiveness ratios.

To track progress on nutrient reductions associated with sediment reduction by individual BMPs, soil nutrient content factors (1.1 pounds of phosphorus and 5.4 pounds of nitrogen per ton of soil, Chesapeake Bay Program, 1988) have traditionally been used Therefore, cost effectiveness ratios such as the ones shown in table 2.8 have been converted to annual costs per pound of nitrogen or phosphorus removed. However, this method has some limitations due to 1-) the potential wide range of nutrient content factors associated with different soil types and farm practices, and 2-) the lack of consideration of soluble nutrient forms. Moreover, if this approach is used, it is also important to properly account for the transport of soil between the edge-of-field and the receiving waters (delivery ratio concept) so reductions in nutrients are not overestimated. These limitations are further explained as follows:

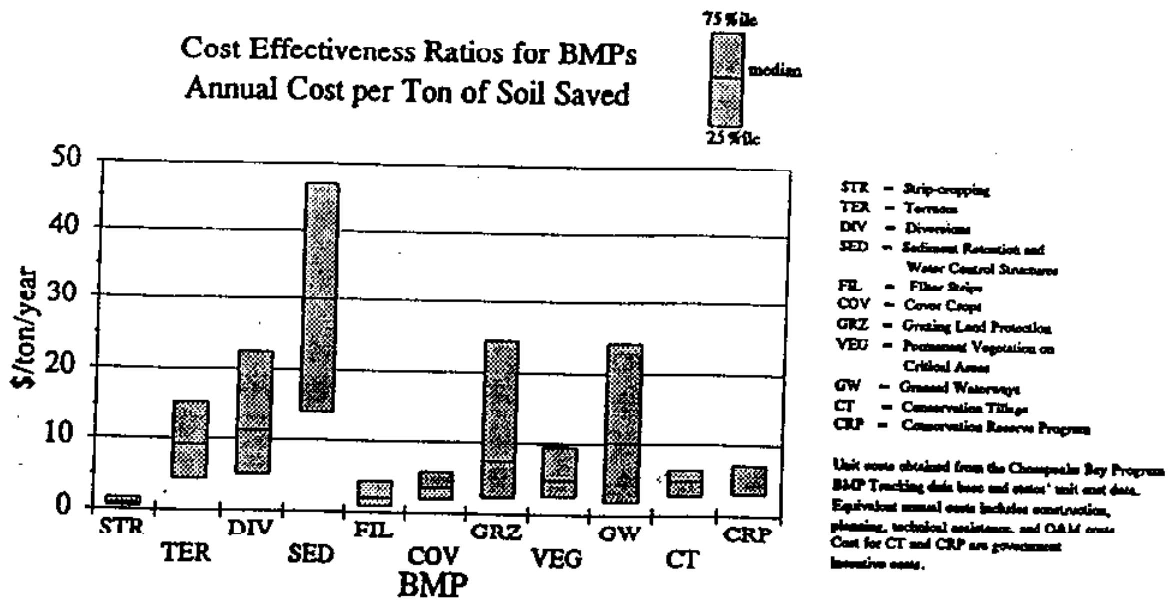
1-) Soil nutrient content factors may be affected by many factors such as the amount and type of fertilizer application, method, time, tillage treatment, soil characteristics etc. (McIsaac, et al. 1991; R.E Wright and Associates, 1990). Therefore, it is expected that these nutrient content factors may vary through the Chesapeake Bay Basin.

Table 2.8 Total Annual Costs Ranges per Ton of Soil Saved for Agricultural BMPs in the Chesapeake Bay Basin[1]

BMP Type	# of BMPs Analyzed	Total Annual Cost per Ton of Soil Saved[2] EAC ($/ton/year)		
		25%ile	median	75%ile
Strip-cropping	393	0.50	0.90	1.70
Terraces	64	4.40	9.30	15.40
Diversions	88	5.10	11.20	22.50
Sediment Retention and Water Control Structures	415	14.20	29.90	46.90
Grassed Filter Strips	213	0.90	2	4.40
Cover Crops	366	1.90	3.60	5.80
Grazing Land protection	274	2.30	7.40	24.50
Permanent Vegetative Cover on Critical Areas	239	2.50	4.80	9.50
Grassed Waterways	261	1.80	10.20	24.30
Conservation Tillage[3]	2,004	2.70	4.80	6.40
Conservation Reserve Program[4] (CRP)	5,881	3.10-7.10		

1. Original interquartile BMP installation cost ranges obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and states' unit cost data.
2. Costs include planning, technical assistance and O&M costs. EAC= Equivalent annual costs in dollars per ton of soil reduced. Interest rate = 10%, practice life from Table 2.3
3. Government incentive costs which do not reflect actual practice costs.
4. Average annual rental rate for MD, PA and VA (USDA-CRP, 1990). Does not include BMP costs.

Figure 2.10 Cost Effectiveness Ratios for Soil Conservation Erosion Control BMPs



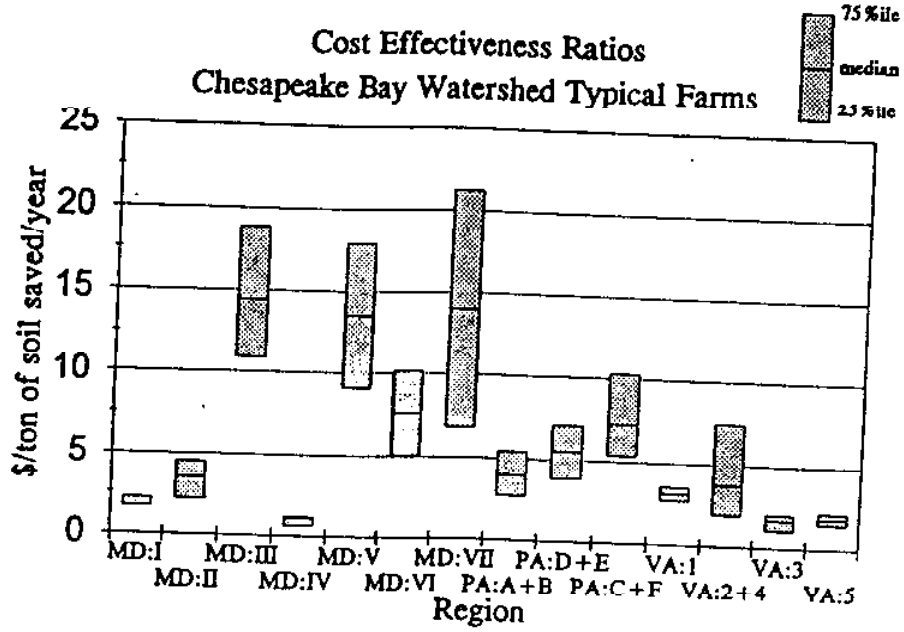
2-) Using soil nutrient content factors to estimate nutrient reductions does not account for soluble nutrient forms. Although reducing the amount of soil loss reduces transport of sediment-bound nutrients in surface waters, for some BMPs, the reduction in runoff is accompanied by an increase in water infiltration. Therefore, the transport of nitrates in subsurface flows may increase and it would not be accounted for in the cost effectiveness ratio. Nevertheless, in many cases for surface water, most of the nutrient losses are associated with sediment loss (Laflen and Tabatabai, 1984), with phosphorus losses better correlated to sediment loss than nitrogen.

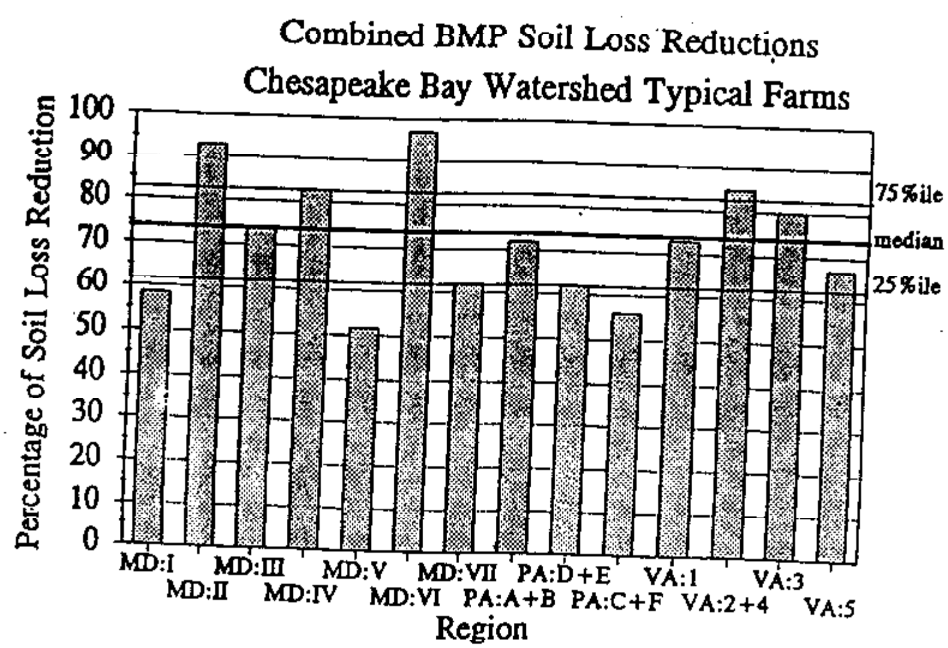
2.6.2 Cost Effectiveness Ratios for Erosion Control BMPs from Soil Conservation Plans of Typical Farms

In this section, the cost effectiveness ratios of soil conservation erosion controls BMPs are evaluated using typical soil conservation plans for farms within the different Chesapeake Bay physiographic regions shown in Figure 2.8. The BMPs for the farms in each region and the tons of soil saved after BMP implementation are tabulated in Tables E-1 to E-3 (Appendix E). These tables show typical BMPs for farms in each region and the expected soil loss reductions after full implementation of BMPs.

Figure 2.11 shows the soil loss reductions (in percentage) after full implementation of BMPs and the cost effectiveness ratio ranges for each farm. The cost effectiveness ratios shown in Figure 2.11 are calculated as the equivalent annual cost of all the BMPs installed within a farm divided by the tons of soil saved. Therefore, BMP unit costs from Table 2.5 were applied to the typical farms selected for each region, and the total soil saved was obtained from SCS estimates of expected soil loss reductions after full implementation of BMPs. The first figure shows cost effectiveness ratios ranging from $2/ton to $20/ton with some farms showing wide interquartile ranges. The wide range in the cost effectiveness ratios shows the potentially wide range of costs and associated soil loss reductions of BMPs throughout the Chesapeake Bay Watershed. Nevertheless, it is noted that cost effectiveness ratios for individual BMPs shown in Tables E-1 to E-3 are within the interquartile ranges of ratios determined from the BMP tracking system (Table 2.8 and Figure 2.10). Also, the second plot of Figure 2.11 shows the total soil loss reductions in percentage for each region. A median soil loss reduction of about 73% with interquartile range between 63 and 83 is calculated for all the regions.

Figure 2.11 Cost Effectiveness Ratios and Combined BMP Soil Loss Reductions for Typical Farms within the Chesapeake Bay Watershed (Interquartile Ranges)





2.6.3 Cost Effectiveness Ratios for BMPs Simulated by the Chesapeake Bay Watershed Model

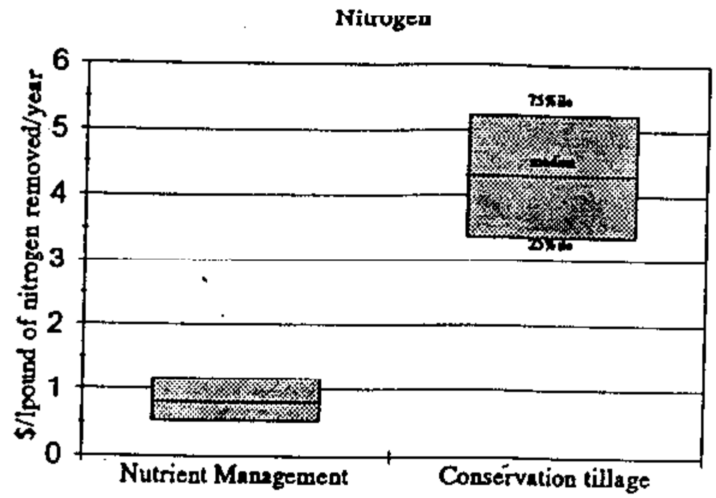
In this section, cost effectiveness ratios calculated using basin edge-of-stream nutrient removals from the Chesapeake Bay Watershed Model are provided. Cost effectiveness ratios are calculated for conservation tillage, nutrient management and animal waste systems.

Nutrient management and conservation tillage cost effectiveness ratios were calculated using the unit cost for nutrient management and conservation tillage (Table 2.5) and the edge-of-stream nutrient reductions from the Watershed Model. Figure 2.12 shows the interquartile ranges of cost effectiveness ratios for these two BMPs. From this figure it is observed that, for nitrogen and phosphorus, nutrient management has lower cost effectiveness ratios than conservation tillage. Although nutrient management has a positive water quality benefit, there is still much uncertainty over the quantitative effect and water quality response time of the receiving waters after its implementation. Nevertheless, a combination of nutrient management with appropriate soil erosion control BMPs in the complete planning of a farm can be cost effective and should have, in the long-term, a positive water quality benefit.

For animal waste systems, two sets of costs are used: 1-) interquartile cost ranges from the CBPO BMP tracking system as shown in Table 2.5 and 2-) median costs from examples of animal waste systems developed by Pennsylvania (Table 2.6 Ritter, 1990). The latter has the advantage that the use of the unit costs ($/animal) would better reflect the relative costs among basins according to their animal type distributions (i.e dairy, beef, swine etc.).

The nutrient reduction effectiveness of animal waste systems was obtained by conversion of 75% of the manure acres to pasture (Watershed Model: Limit of Technology Scenario). The representation of the costs for animal waste systems that achieve this reduction will depend on site-specific conditions and therefore, cost effectiveness ratio ranges are provided for both cost sources. Figure 2.13 shows the interquartile ranges for animal waste systems using the two sets of costs. Cost effectiveness ratios are calculated for animal waste systems alone and for animal waste systems and nutrient management combined. This combination is important when evaluating a total "Resource Management System" for a farm where both animal waste systems and nutrient management are important components of this system.

Figure 2.12 Financial Cost Effectiveness Ratios for Nutrient Management and Conservation Tillage (interquartile ranges)



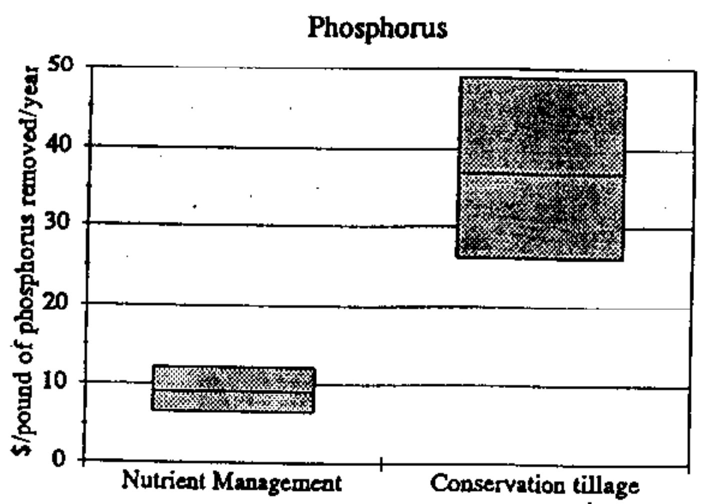
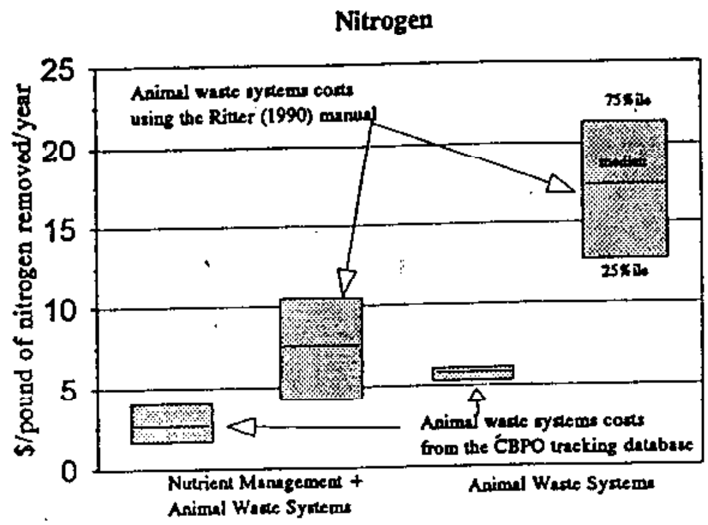
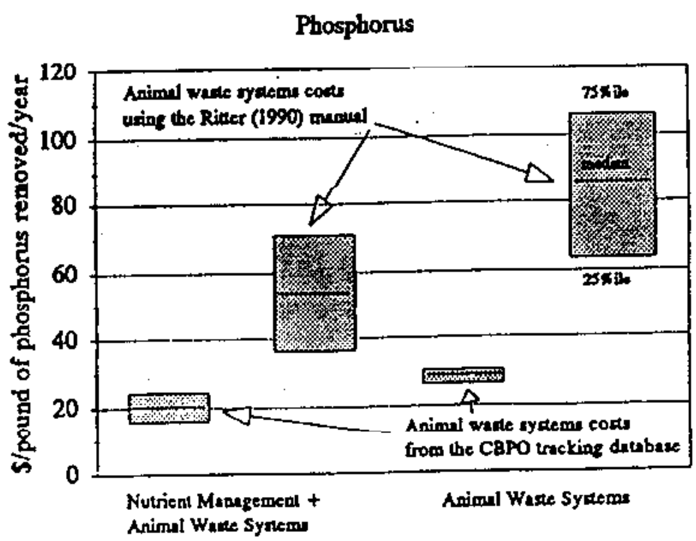


Figure 2.13 Financial Cost Effectiveness Ratios for Animal Waste Systems (interquartile ranges)





2.7 Chesapeake Bay Basin Urban Best Management Practices

This section briefly describes the costs and nutrient reduction efficiencies of urban BMPs. There is limited information compiled on urban BMP costs and nutrient reduction efficiencies within the Chesapeake Bay basin. Cost information provided in this section has been compiled from the District of Columbia and Maryland. It is very difficult to generalize urban BMP costs and nutrient reduction efficiencies of urban BMPs due to site specific conditions. For instance, urban BMP costs can significantly vary among locations (inner-urban or suburban) due to real estate values. Costs are also different between retrofits and new facilities. Moreover, maintenance costs, which are directly correlated to the long term pollutant removal efficiency of BMPs can be highly variable depending on the type of BMP and urban landuse draining into the facility. Finally, it is important to note that urban BMPs offer multiple benefits besides nutrient removal such as stormwater management (water quantity control), detention of sediment, heavy metals and petroleum hydrocarbons. Therefore, cost effectiveness of these BMPs should not be judged only on their potential for nutrient removal.

A recent report by the Metropolitan Washington Council of Governments (Schueler et al., 1992) summarizes the characteristics of eleven urban BMP types or "options". Table 2.9 lists these BMPs along with their longevity. Detailed information on the characteristics of each of these BMPs is found in the MWCOG report.

2.7.1 Nutrient Removal Effectiveness of Urban BMPs

Since the beginning of the 1980s there have been studies for the assessment of the pollutant removal effectiveness of urban BMPs. However, these studies have reported wide ranges of pollutant removal for these BMPs. The wide range of pollutant removal efficiencies may be attributed to the different physical characteristics for each site as well as sampling techniques to determine removal efficiencies. For instance, Schwartz and Velinsky (1992) point out that sampling techniques to determine BMP pollutant removal efficiencies need to be carefully defined since they determine the type of removal efficiency obtained (i.e. event-based, base flow, seasonal, annual or long term). In addition, they noted the potential differences between long-term average annual removal efficiencies and short term seasonal or event-based calculations of removal efficiencies. For instance, a study on the Mays Chapel Wetlands Pond in Baltimore County (Baltimore City, 1989) has shown phosphorus removal efficiencies around 40% for storm events but about 16% when both storm events and baseflow are considered.

Table 2.9 Longevity of Urban BMPs[1]	
BMP Options	Longevity[2]
Extended Detention Ponds	20+ years, but frequent clogging and short detention common
Wet Ponds	20+ years
Stormwater Wetlands	20+ years
Multiple Pond Systems	20+ years
Infiltration Trenches	50% failure rate within five years
Infiltration Basins	60-100% failure within five years
Porous Pavement	75% failure within five years
Sand Filters	20+ years
Grassed Swales	20+ years
Filter Strips	Unknown, but may be limited
Water Quality Inlets	20+ years

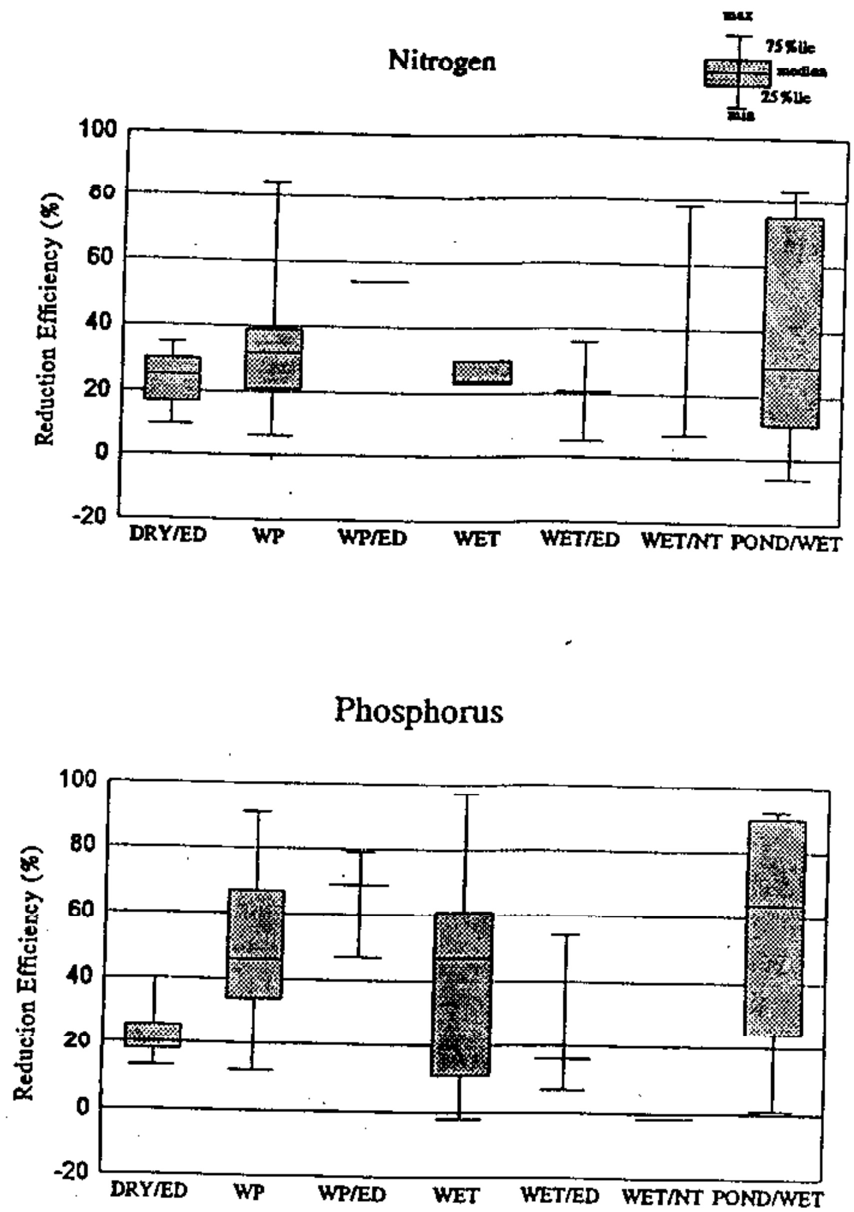
1. Source: Schueler et. al (1992).
2. Based on current designs and maintenance practices.

Table F-1 (Appendix F) shows summary statistics of nutrient reduction efficiencies reported by Schueler et al. 1992. This table shows a wide range of removal efficiencies for each BMP type. Therefore, this information should be used with caution. Original sources of each study should be carefully examined for the methodologies used to determine the efficiencies. Figure 2.14 summarizes the nutrient reduction efficiency statistics shown in Table F-1.

2.7.2 Costs of Urban BMPs

Urban BMP costs are summarized from available cost data on retrofits and new facilities completed or planned within Maryland and the District of Columbia. For initial cost estimates of urban BMPs, planning level cost equations are available from Weingand et al. (1986) which are also summarized by Schueler (1987).

Figure 2.14 Nutrient Reduction Effectiveness of Urban BMPs *



DRY/ED= Dry extended detention ponds
WP= Wet Ponds
WP/ED= Wet ponds/extended detention
WET= Stormwater wetlands
WET/ED= Extended detention wetlands
WET/NT= Natural wetlands
POND/WET Pond wetlands Systems

* Nutrient reduction statistics calculated from "A Current Assessment of Urban Best Management Practices", (Schueler et. al, 1992)

2.7.2.1 Cost of Urban BMPs (District of Columbia)

Table F-2 shows ranges of BMP costs for the District of Columbia. Cost information provided in this table was obtained from the District of Columbia BMP tracking database. This table shows that the type of BMPs used in the District of Columbia generally serves areas smaller than two acres. Only ponds benefit areas greater than 2 acres.

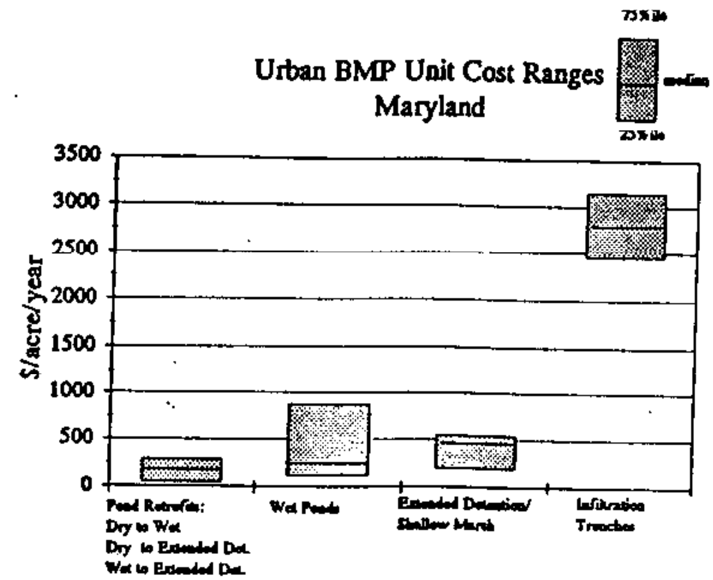
2.7.2.2 Cost of Urban BMPs (Maryland)

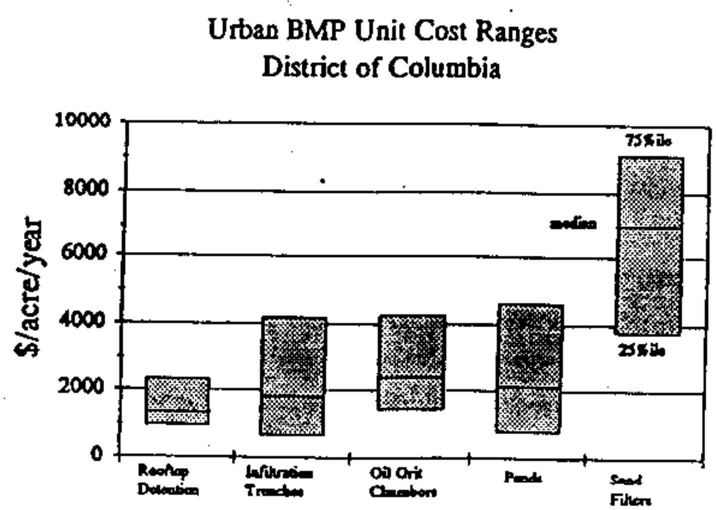
Table F-3 shows ranges of total costs, acres benefitted, and unit cost ranges for urban BMP types compiled from Maryland. Unit cost statistics are given for four BMP categories: 1-) new extended detention ponds with shallow marsh 2-) new wet ponds, 3-) retrofit of dry ponds to wet ponds , and 4-) infiltration structures. In contrast to the BMPs summarized for the District of Columbia, the type of urban BMPs in Maryland serve larger areas (up to 800 acres in some cases). This is mainly due to the availability of land in suburban areas compared to inner-urban areas. Land availability in suburban areas allows the construction or retrofit of regional facilities using BMPs that can benefit larger areas at a lower unit cost.

2.7.2.3 Summary

Figure 2.15 depicts the unit cost ranges for Maryland and the District of Columbia. This figure shows that sand filters and infiltration structures have the highest unit costs. However, it is important to point out that these structures may be the only alternative for on-site treatment at smaller sites where other BMPs such as ponds may not be cost effective. It is also noted that ponds within the District of Columbia show higher unit costs than in Maryland. As pointed out before, most of the BMPs analyzed for Maryland are located in suburban areas where BMPs serving larger drainage areas can be more cost effective.

Figure 2.15 Financial Unit Costs for Urban BMPs (Interquartile Ranges)





3. POINT SOURCE NUTRIENT REMOVAL TECHNOLOGIES

This section summarizes the nutrient removal retrofit studies conducted by Maryland, Virginia, and the District of Columbia that include biological nutrient removal technologies (BNR). Planning level retrofit cost estimates for municipal WWTPs are developed for two sets of effluent levels: TN = 8.0 mg/l, TP = 2.0 mg/l; and TN = 3.0 mg/l, and TP = 0.5 mg/l. Retrofit cost equations are provided for these effluent levels for both seasonal and annual (year-round) nutrient removal. Also, cost and effectiveness of selected existing nutrient removal WWTPs in Maryland are summarized.

3.1 Chesapeake Bay Nutrient Removal Technologies for Municipal WWTPs

A summary of technologies for point source nutrient removal controls is found in "Available Technologies for Control of Nutrient Pollution in the Chesapeake Bay Watershed" (STAC, 1987) and Report #7 of the Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation (VWCB, 1991). Chapter III (Background to BNR) of the Maryland Nutrient Removal Study prepared by the Beavin Co., Camp Dresser & McKee and Metcalf & Eddy (1989) also reviews nutrient reduction technologies in WWTPs.

The effectiveness, advantages and disadvantages of the different technologies were described in the 1991 Reevaluation Report #7 (VWCB, 1991). Among these, Biological Nutrient Removal (BNR) has increasingly become a good candidate for nutrient removal. The Chesapeake Bay jurisdictions have focused their efforts on studying the feasibility of this relatively new technology to upgrade existing WWTPs or to build new BNR facilities in the future. In this section, point source nutrient reduction technologies are briefly enumerated following the format presented in Chapter III of the Maryland Nutrient Removal Study. Wastewater nutrient removal processes within a WWTP can involve a combination of physical, biological and chemical processes. However, for nutrient removal, these processes may be classified into two major categories as described in the Maryland Nutrient Removal Retrofit Study:

- Biological nutrient removal processes
- Non-Biological nutrient removal processes

3.1.1 Biological Nutrient Removal Processes

Biological nitrogen removal can be classified into nitrification processes and biological denitrification processes. Nitrification is the first step in a biological nitrogen removal process where ammonia and organic nitrogen are converted to nitrate. This process occurs under aerobic conditions. Processes listed under this category in the Maryland Nutrient Removal Study are:

Nitrification Processes

- Separate stage aeration reactors
- Combined carbon oxidation/nitrification reactor
- Attached growth processes
  - Trickling filters
  - Rotating biological contactors
  - Biological activated filters (BAF)
  - Suspended fixed growth media
  - Combined attached growth/suspended growth

Within these categories, many of the conventional secondary aerobic processes are found. In the Chesapeake Bay basin, secondary treatment plant total nitrogen (TN) effluent levels can vary between 15 and 25 mg/l depending on the plant type.

Denitrification Processes

In the biological denitrification process, nitrates are converted into nitrogen gas under anoxic conditions with dissolved oxygen concentration less than 0.5 mg/l. Processes listed under this category in the Maryland Nutrient Removal Study are:

- Post-aeration anoxic reactors
- Separate sludge, post aeration anoxic reactors
- Anoxic/aerobic process (Modified Ludzack-Ettinger Process)

- Attached growth processes
  - Rotating biological contactors (RBCs)
  - Fluidized beds
  - Stationary media
    - Deep bed denitrification filters

- Upflow, fluidized bed reactors
- Suspended, fixed growth media

Combined Biological Nitrogen and Phosphorus Removal (BNR) Processes

For both nitrogen and phosphorus removal combined, the following processes are listed:

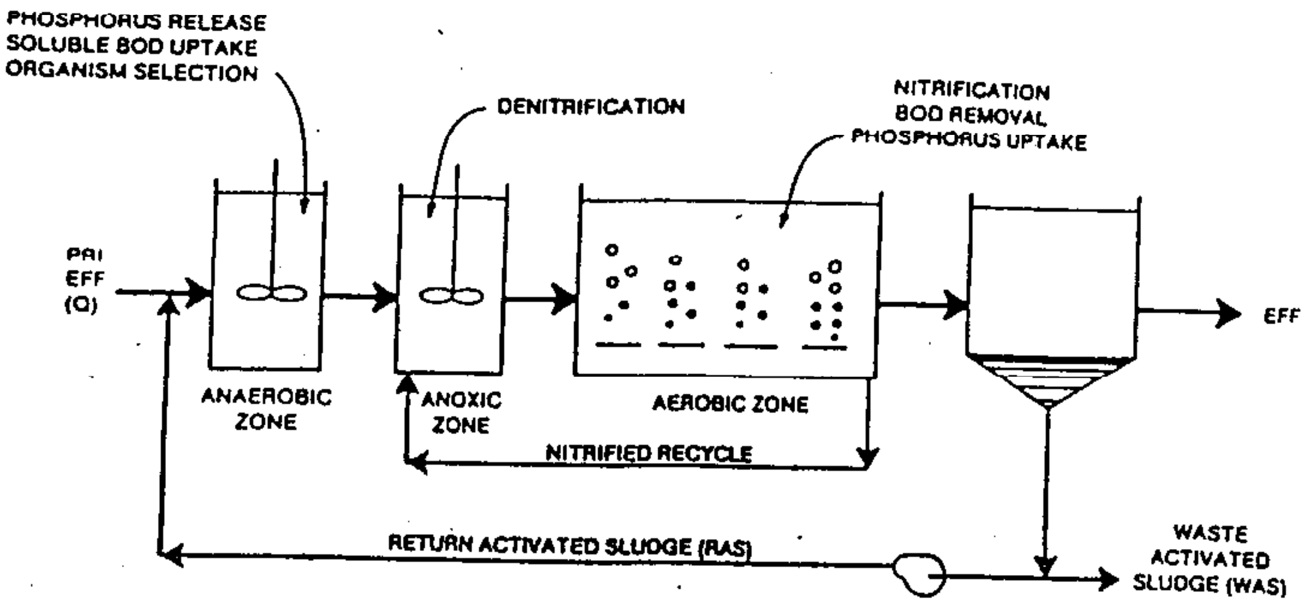
- A/O™ and A²O™
- Bardenpho™ and modified Bardenpho™ processes
- Lagoon systems (Biolac™)
- Operationally-modified activated sludge process
- Oxidation ditches
- Phostrip™
- Sequencing batch reactors (SBRs)
- University of Capetown (UCT) process
- Virginia Initiative Plant (VIP)

Removal of both nitrogen and phosphorus using biological processes has increasingly become an attractive alternative due to its cost effectiveness. For some of these processes the wastewater passes through a system of anaerobic, anoxic and aerobic compartments as shown in the simplified diagram shown in Figure 3.1 (Freudberg and Lugbill, 1990). There are different variations of this concept that are shown in Figure 3.2 for the A/O, A²O™, Bardenpho™ and the VIP (Virginia Initiative Process) process (Morales, et al., 1988). Design, removal efficiencies, and costs can vary for each of these processes (VWCB, 1990).

Other Biological Nutrient Removal Processes

Other biological nutrient removal processes may include land application of wastewaters by overland flow, rapid infiltration basins over permeable soils, and slow-rate application methods such as irrigation, and ponds and wetlands.

Figure 3.1
Generic BNR Process Schematic



(Source: Freudberg and Lugbill, 1990)

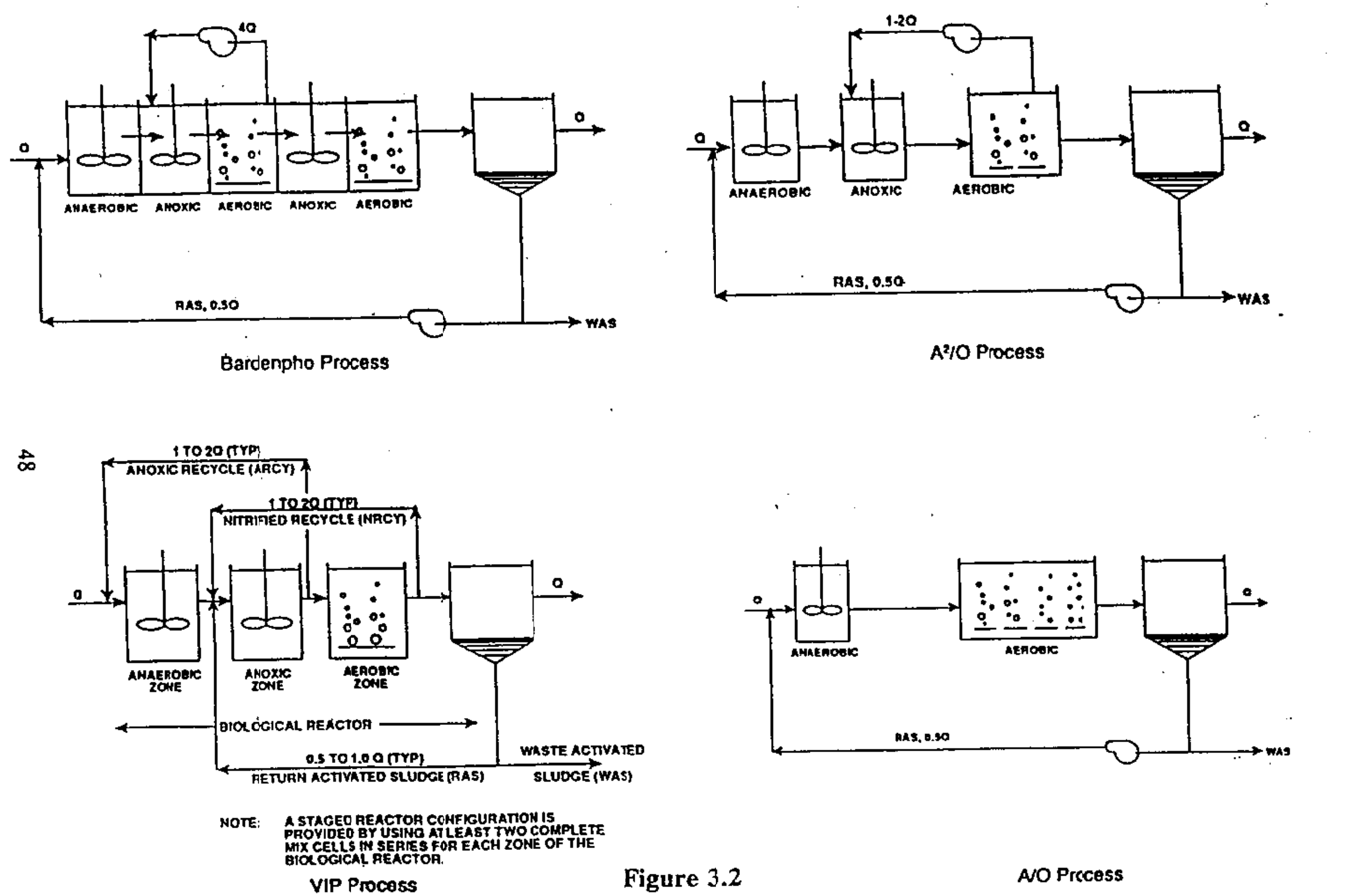


Figure 3.2
BNR Processes

(Source: Morales et al., 1988)

3.1.2 Non-Biological Nutrient Removal Processes

In the Maryland Nutrient Removal Study the following physical and chemical methods for nutrient removal were listed:

- Breakpoint chlorination
- Chemical addition for phosphorus removal
- Ion exchange
- Electrodialysis
- Reverse osmosis
- Electrochemical treatment
- Chemical denitrification
- Distillation
- Air stripping

Of all these treatments, chemical addition for phosphorus removal has been most commonly used within the Chesapeake Bay basin. For total phosphorus (TP), typical effluent concentrations are between 2.5 mg/l and 8.0 mg/l without any chemical removal facilities. Effluent levels achieved by secondary WWTPs without chemical removal depend on the plant's wastewater influent characteristics. For instance, in phosphate ban areas, TP effluent levels of 2.5 mg/l may be achieved without chemical addition with influent levels ranging from approximately 4.0 mg/l to 6.0 mg/l.

3.1.3 Summary of Point Sources in The Chesapeake Bay Basin

A computerized database of the Chesapeake Bay point sources can be found in the Chesapeake Bay Program Point Source Atlas (Chesapeake Bay Program, 1988). This database contains information on 1,345 municipal and 4,651 industrial point source discharges. From the point source atlas, municipal point source discharges account for 94% of the total phosphorus load and 88% of the total nitrogen point source load. Also, municipal WWTPs with design capacities greater than or equal to 0.5 mgd accounted for nearly 97% of the flow, with about 97% of the total nitrogen load and 93% of the total phosphorus load. Therefore, the analysis of this report focuses on municipal wastewater treatment plants with design discharges greater than or equâl to 0.5 mgd (large municipal WWTPs).

Appendix G summarizes the major Chesapeake Bay Basin Municipal WWTPs by major basins. In these tables, the flows and effluent concentrations reflect the most recent average annual nutrient effluent and flow data that could be compiled through 1990. Design capacity flow information includes expected expansion of WWTPs before the year 2000. This information was only obtained for 51 out of 265 WWTPs. However, the combined flow for these WWTPs account for nearly 70% of the total design flow capacity of large (design flows greater than 0.5 mgd) municipal WWTPs in the Chesapeake Bay region (about 1,500 mgd). Data for these expansions came mainly from the retrofit studies conducted by the states and the District of Columbia.

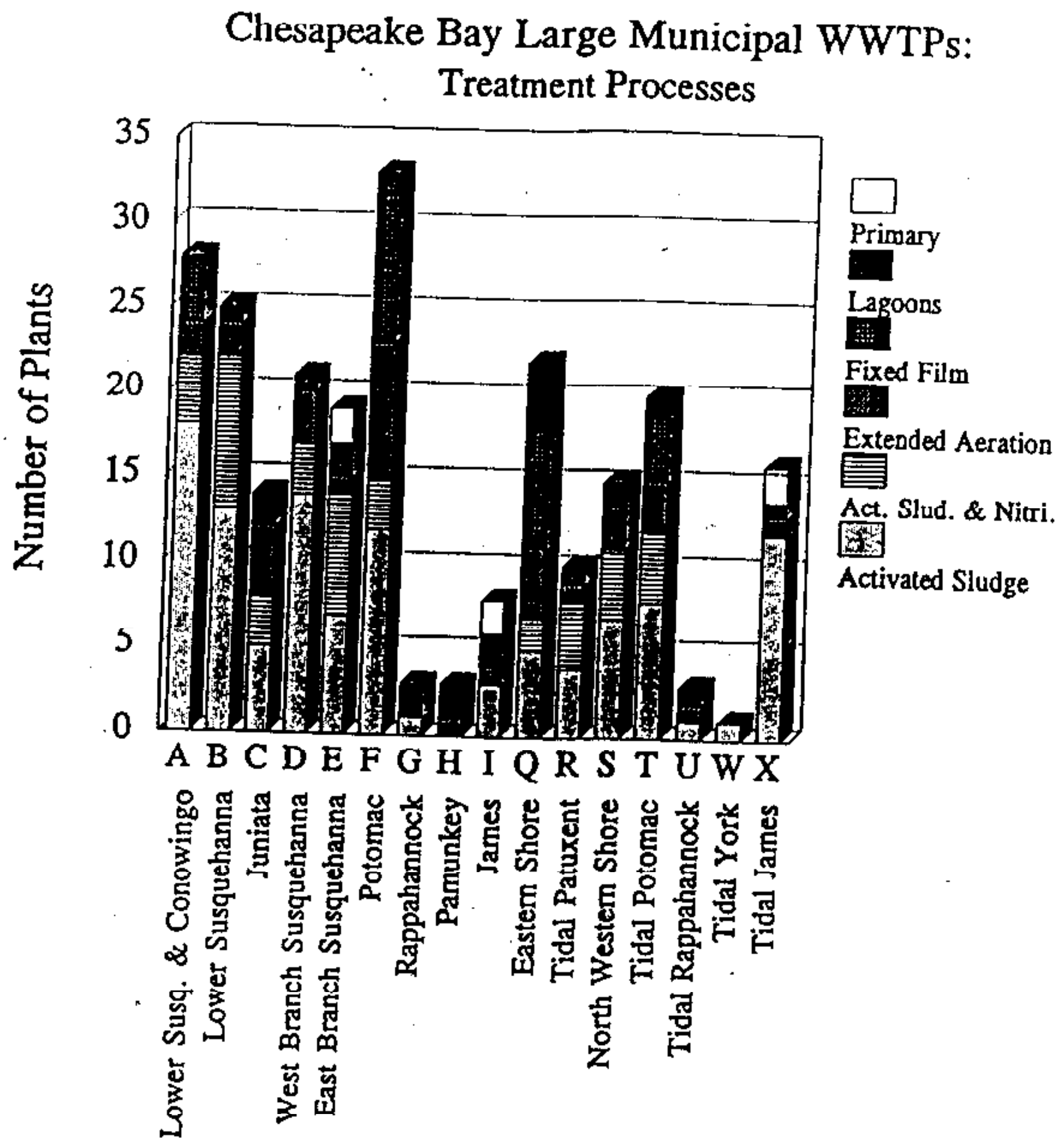
Figure 3.3 shows the distribution of WWTPs by basin and treatment process. This figure shows that activated sludge processes followed by fixed film processes are the most common treatment types within the basin. Although this figure shows a significant number of plants (about 50%) in the Susquehanna River basin (A through E), Figure 3.4 shows that the combined flow of these plants is relatively small (about 20%). Large WWTP flows are in the Potomac (F and T), James (X and I) and West Chesapeake Bay basin (S), accounting for approximately 73% of the total municipal point source flow (large WWTPs) into the Chesapeake Bay basin.

Average annual effluent concentrations for total nitrogen and phosphorus are depicted in Figure 3.5. The nutrient effluent concentrations by basin have been weighted by each WWTP average annual flow. The tables in Appendix G show the flow-weighted average annual effluent concentrations for each treatment process and basin. Overall, total effluent concentrations varied between 12 and 22 mg/l for nitrogen and between 0.14 mg/l and 6.7 mg/l for phosphorus. The average flow-weighted concentration for the entire Chesapeake Bay basin was 17 mg/l and 2.1 mg/l for nitrogen and phosphorus, respectively.

3.2 Nutrient Removal Effectiveness of Municipal WWTPs Technologies

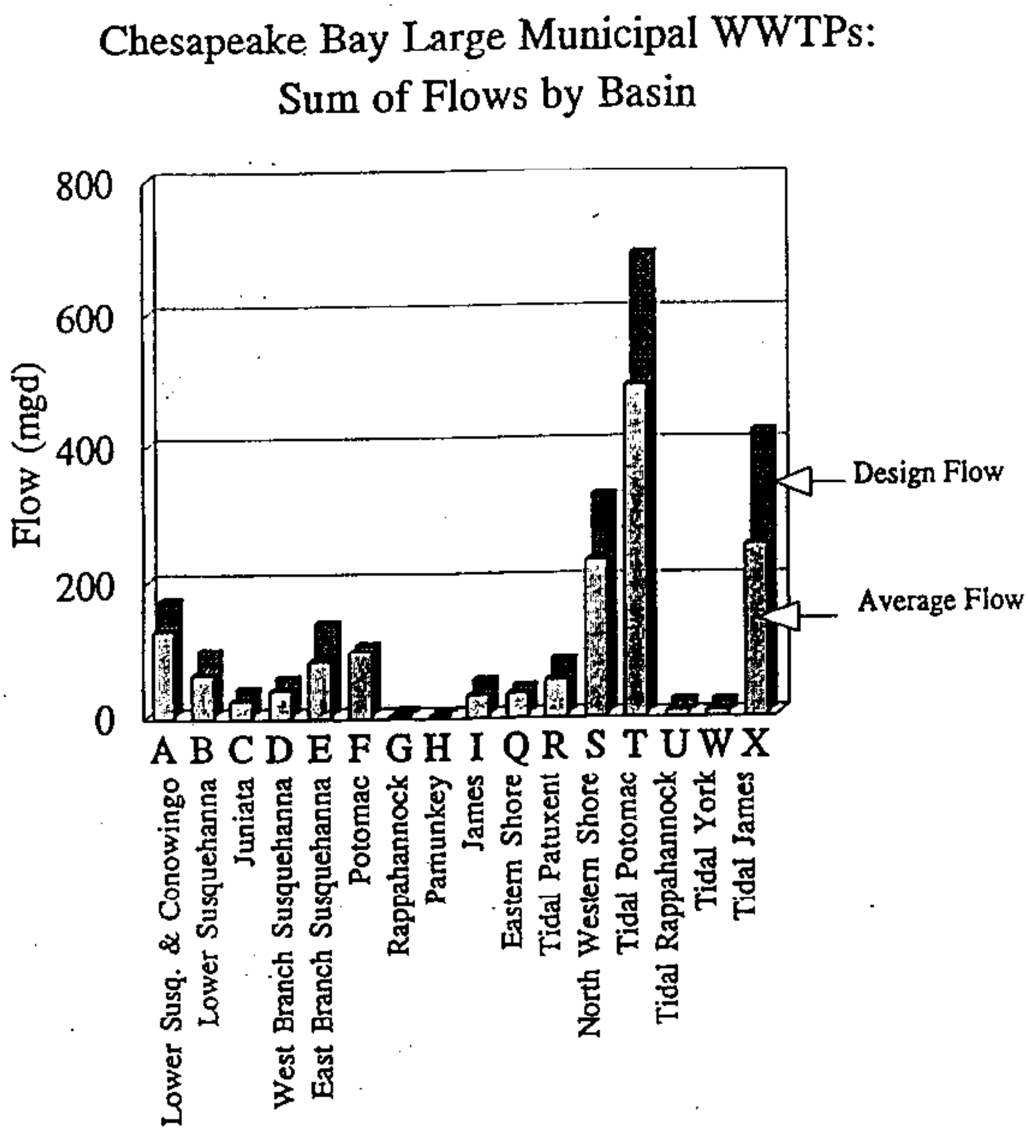
Effectiveness of point sources was summarized in the Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation Report #7 (VWCB, 1991). Table 3.1 summarizes the effectiveness of the different point source nutrient reduction controls for both nitrogen and phosphorus, and Table 3.2 provides a qualitative assessment of BNR point source technologies (VWCB, 1991). Report 7 also highlighted the significance of the expected effluent levels based on average annual performance when compared to the monthly effluent permit limits. It was found that plants with monthly effluent limits showed average annual performance effluent levels better than the ones specified in the monthly permit limit. Table 3.3 summarizes the expected effluent levels for both monthly limits and expected average annual performance (VWCB, 1991).

Figure 3.3



Chesapeake Bay Large Municipal WWTPs:
Treatment Processes
Number of Plants
35
30
25
20
15
10
5
0
A B C D E F G H I Q R S T U W X
Lower Susq. & Conowingo
Lower Susquehanna
Juniata
West Branch Susquehanna
East Branch Susquehanna
Potomac
Rappahannock
Pamunkey
James
Eastern Shore
Tidal Patuxent
North Western Shore
Tidal Potomac
Tidal Rappahannock
Tidal York
Tidal James
Primary
Lagoons
Fixed Film
Extended Aeration
Act. Slud. & Nitri.
Activated Sludge

Figure 3.4



Chesapeake Bay Large Municipal WWTPs:
Sum of Flows by Basin
800
600
400
200
0
Flow (mgd)
Design Flow
Average Flow
A B C D E F G H I Q R S T U W X
Lower Susq. & Conowingo
Lower Susquehanna
Juniata
West Branch Susquehanna
East Branch Susquehanna
Potomac
Rappahannock
Pamunkey
James
Eastern Shore
Tidal Patuxent
North Western Shore
Tidal Potomac
Tidal Rappahannock
Tidal York
Tidal James

Figure 3.5 Chesapeake Bay Large Municipal WWTPs Flow-Weighted Annual Effluent Concentrations

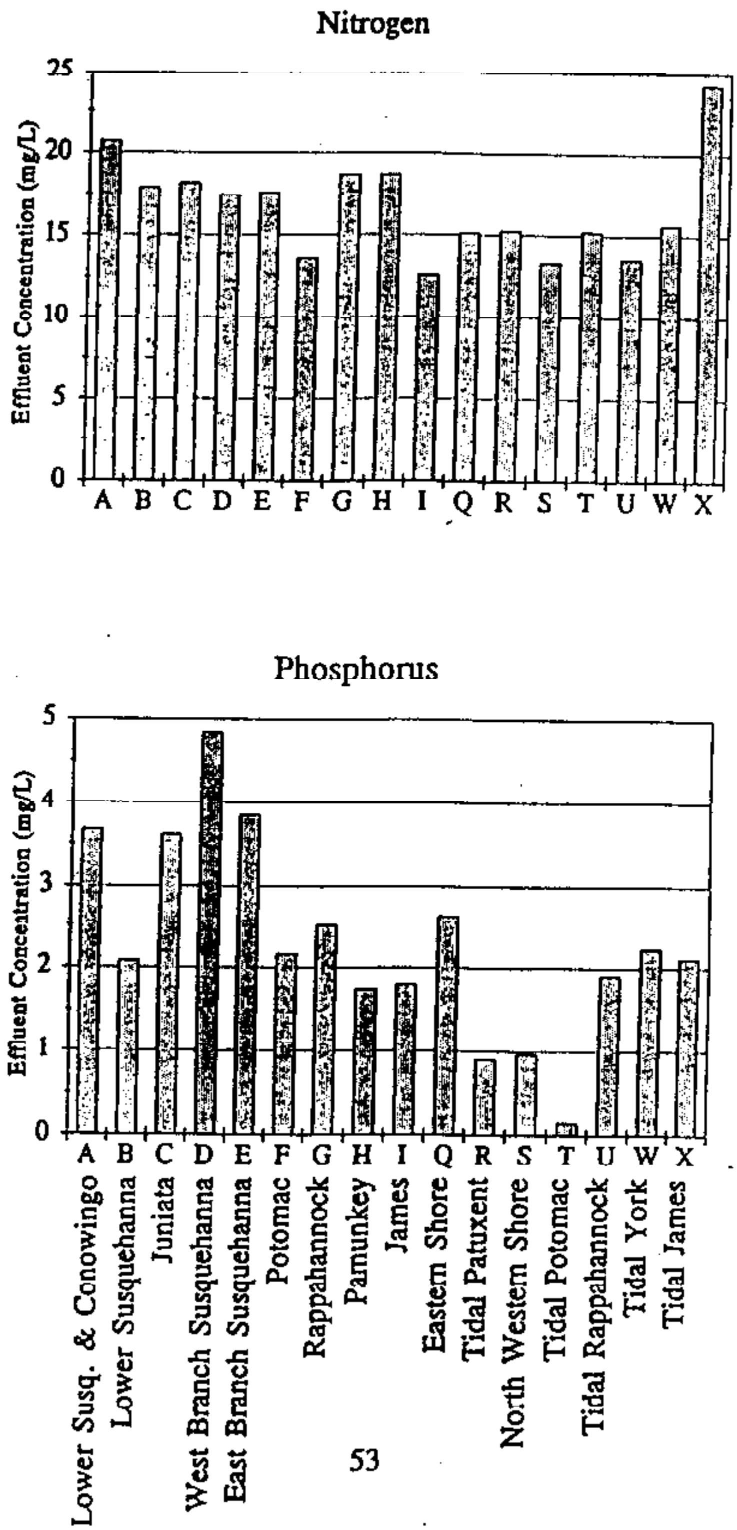


Table 3.1 Effectiveness of Point Source Nutrient Removal Technologies	
Technology	**Effluent Nutrient Levels[1]**
Chemical Addition (pre and simultaneous precipitation)	TP = 1.0 to 2.0 mg/l
Chemical addition (post-precipitation)	TP < 0.2 mg/l TP < 0.1 mg/l using lime treatment
Biological Phosphorus Removal	TP = 2.0 mg/l or less if standby chemical addition is available to ensure permit compliance
Separate Stage Biological Nitrification/Denitrification	TN = 3.0 mg/l
Breakpoint Chlorination	NH_3-N = 1.0 mg/l; TN level depends upon whether nitrification occurred prior to chlorine addition and the amount of organic-nitrogen that is unaffected by the process.
Ion Exchange	TN = 2.0 mg/l depending upon the composition of the wastewater.
Ammonia Stripping	NH_3-N = 1.0 mg/l can be achieved in combination with breakpoint chlorination.
Biological Nitrogen Removal	TN = 3.0 - 12.0 mg/l

1. Adapted from the Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation Report #7 (VWCB, 1991)

Table 3.2 Comparison of BNR Process Characteristics[2]				
Process Name	Nutrient Removal Capability		Operational Flexibility	New Plant Costs
	Phosphorus	Nitrogen		
Bardenpho	Low	High	Low	High
A^2/O	Medium	Medium	Low	Low
UCT	Medium	Medium	Medium	Medium
VIP	Medium	Medium	Medium	Low
A/O	Medium	Low	Low	Low

2. Source: Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation Report #7 (VWCB, 1991)

3.3 Retrofit Cost Studies

In response to the Chesapeake Bay Agreement and to the commitment of the signatories of the Agreement to reduce by 40% the 1985 nutrient loads into the Bay by the year 2000, the District of Columbia, Maryland, and Virginia have conducted nutrient removal retrofit studies of selected municipal WWTPs. This section briefly summarizes the states' studies for retrofitting WWTPs with biological nutrient removal (BNR) and other technologies prepared by Greeley and Hansen (1989) and McNamee, Porter & Seeley (1990) for the District of Columbia; Beavin Co., Camp Dresser & McKee Inc., and Metcalf & Eddy Inc. (1989) for Maryland; and CH2M HILL (1989) for Virginia.

3.3.1 Blue Plains

In this section the studies performed by Greeley and Hansen (1989) and McNamee, Porter & Seeley (1990) for retrofitting Blue Plains for nutrient removal are briefly summarized.

3.3.1.1 Greeley and Hansen Study

The Greeley and Hansen (1989) report was prepared for the District of Columbia Department of Public Works to update an earlier report (Greeley and Hansen, 1984) with the most recent information on the feasibility of implementing nitrogen removal at Blue Plains. This study evaluated the feasibility of retrofitting Blue Plains using deep bed filter denitrification. Ten alternatives were evaluated in the study and procedures for the selection of alternatives were outlined.

Table 3.4 shows a summary of the alternatives evaluated in this study for cost effectiveness comparison. The alternatives were developed to achieve a total nitrogen annual average effluent level of 7.52 mg/l. This effluent level was determined using a 40% reduction of the 1985 nitrogen loads with the plant operating at the year 2000 average flow of 370 mgd. From this table, alternatives 2C and 5C appear to be cost effective. This is attributed to the seasonal nitrogen removal approach (TN=5.75 mg/l in 5 summer months, and TN=8.78 mg/l in 7 winter months), and the use of biological phosphorus removal (BPR) for alternative 5C. However, the selection of the alternatives may be subjected to the appropriateness of the seasonal removal concept for the Chesapeake Bay program goals, the performance of BPR 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).

Table 3.3 Expected Effluent Levels:Monthly Limit vs Annual Average Performance		
Alternative	Effluent Level (mg/l)	
	Monthly Limit	Annual Average
PHOSPHORUS		
1. Standard P Removal Chemical Addition (simultaneous precipitation or BPR)	2.00	1.50
2. Advanced P Removal (chemical addition post precipitation)	0.50	0.37
3. Limit of Technology (chemical addition/post-precipitation with filters)	0.10	0.075
NITROGEN		
1. Optimized N Removal (for plants with existing nitrification capability)	14-20	10-14
2. BNR minimum (3-stage BNR with small units)	14	10
3. BNR standard (3-stage BNR)	12	8
4. BNR (enhanced) (3-stage BNR with larger units)	10	7
5. BNR (advanced) (5-stage Bardenpho process)	5	3

Source: Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation Report #7 (VWCB, 1991)

Table 3.4 Blue Plains Nutrient Removal Retrofit Costs.[1] Effluent Levels: TN = 7.52 mg/l (annual average), TP = 0.18 mg/l (current NPDES limit).[2]

Alternative	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [3] (ETC)	Equivalent Annual Costs [3] (EAC)	EAC/Flow[4] ($/mgd/yr.)
2A [5]	Two-stage biological-chemical system, anoxic reactor, reaeration preceding anoxic reactor and 8 additional deep bed filters.	$191,745,243	$9,577,373	$273,282,819	$32,099,697	$86,756
2B [5]	Same as alternative 2A with larger anoxic zone (no new filters).	$194,276,735	$8,128,424	$263,478,589	$30,948,096	$83,644
2C [6]	Same as alternative 2A with seasonal effluent quality (no new filters).	$169,866,733	$7,087,558	$230,207,113	$27,040,041	$73,081
3 [5]	Deep bed filter denitrification following nitrification (24 new filters).	$179,540,242	$12,638,505	$287,138,960	$33,727,235	$91,155
5A [5]	Same as alternative 2A with the addition of biological phosphorus removal (BPR) in the secondary system (10 new filters).	$192,823,068	$6,648,239	$249,423,271	$29,297,164	$79,182
5B [5]	Same as 2B and 2C with addition of BPR (no new filters)	$194,251,886	$5,316,173	$239,511,460	$28,132,926	$76,035
5C [6]		$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.
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 = 11°C.
6. Design operating temperature = 23°C (5 months in the summer), 15°C (7 months in the winter).

3.3.1.2 McNamee, Porter & Seeley Study

The McNamee, Porter & Seeley (1990) report summarized the results of a feasibility study for retrofitting Blue Plains with biological nutrient removal technologies. The study recommended the use of biological phosphorus removal (BPR) using the A/O process. Implementation of this process in the secondary reactors at 75% of the maximum monthly flow was found to be a feasible alternative. The cost of performing this retrofit was estimated at $1.6 million. This cost does not include license fee costs for the A/O process which can reach a maximum of $500,000 for any user in the United States. Expected total phosphorus effluent levels from pilot studies in the secondary reactors were estimated at 1.3 mg/l. Potential annual savings by using BPR at Blue Plains were estimated between $0.7 and $1.18 million from elimination of the addition of iron salts in the secondary reactors and the cost reduction of sludge handling. The unit cost of phosphorus removal for this retrofit in $/mgd/year is: EAC/flow = 508 and the ETC/flow = 4,324. Therefore, the low cost of this alternative would probably lead to a full scale demonstration of BPR at Blue Plains.

Five alternatives were evaluated for nitrogen removal. The selected alternative was addition of methanol at the fourth pass in the existing nitrification reactors. Capital costs of performing the retrofit were estimated at $12.9 million. Annual chemical costs were estimated at $1.6 million per year; however, no increase in O&M (if any) was provided. Retrofit modifications for nitrogen removal were designed to meet an effluent level of TN = 7.5 mg/l to comply with the 40% reduction in total nitrogen. Results from pilot tests on the selected alternatives showed performance levels below the effluent limit of 7.5 mg/l (McNamee, Porter & Seeley, 1990). Using the capital and O&M costs, the unit costs for nitrogen removal for this retrofit are: EAC/flow = 8,420 ($/mgd/year) and the ETC/flow = 71,680. Although no other O&M costs were reported in this study, the unit costs are substantially lower than the ones presented in previous studies for Blue Plains.

The study also recommended performing a full scale demonstration project in one of the secondary reactors (West No. 1) to assess the annual performance and reliability of the BPR technology. It was recommended that half of the nitrification reactors be converted for nitrogen removal. The total cost and tests of the full scale demonstration studies are estimated at $1.6 million.

3.3.2 Maryland Biological Nutrient Removal Study

The report prepared for the Maryland Department of the Environment by Beavin Co., Camp Dresser and McKee Inc., and Metcalf & Eddy Inc.(1989), analyzed the capability and cost effectiveness of retrofitting Maryland's municipal WWTPs to biologically remove nitrogen and phosphorus (BNR).

Table 3.5 shows the 24 WWTPs evaluated in this study along with the "conceptual level cost estimates" to perform the retrofit for the recommended technologies. Alternatives were evaluated for each plant for the proposed effluent levels of TN = 8 mg/l on a seasonal basis without the use of chemicals, and for the smallest total phosphorus (TP) level of 2.0 mg/l or the National Pollution Discharge Elimination System (NPDES) permit limit for the plant.

3.3.3 Virginia Retrofit Study

The CH2M HILL (1989) report prepared for the Virginia Water Control Board (VWCB) evaluated the cost of implementing four scenarios for nutrient removal in 26 WWTPs. The four scenarios were: 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; and Alternative 4: alternative 1 plus year-round nitrogen removal to 10 mg/l total nitrogen. The nutrient effluent limits for the preceding alternatives are average monthly limits.

Table 3.6 summarizes the total costs for all the 26 WWTPs for each alternative. The "costs opinions" shown are "order-of-magnitude" which are expected to be accurate within +50 percent and -30 percent (CH2M HILL, 1989). Costs do not include license fees for proprietary treatment processes. The study reported that these costs were approximately $11.9 and $11.3 million (in 1989 dollars) for alternatives 3 and 4 respectively.

Tables 3.7 and 3.8 summarize for each plant the retrofit "cost opinions" for alternative 3 and alternative 4 respectively. Based on the estimated year 2000 average daily flow of 522 mgd (76% of total design capacity), the VWCB estimated that annual average TN = 7.0 mg/l would have to be achieved to comply with the Chesapeake Bay Agreement goals. This average annual performance may be obtained with a 9.7 mg/l maximum monthly limit. Therefore, alternatives 3 and 4 were set at TN = 10 mg/l maximum monthly limit. The year-round TN = 10 mg/l is expected to meet an average annual performance effluent level of TN = 7 mg/l.

Table 3.5 Maryland WWTPs Nutrient Removal Retrofit Costs.[1] Effluent Levels: TN=8.0 mg/l (seasonal), TP= Smallest of 2.0 mg/l or NPDES Limit

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M 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	A²/O™	$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	A²/O™ & CPR [3]	$368,835	$24,183	$574,717	$67,506	$35,529
BROADWATER	2.0	A²/O™ & 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

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 operati maintenance and repair (OMR) indexes for O&M costs.
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. Cost reflect design temperature of 12.5°C.
5. Plant is already removing phosphorus below 2.0 mg/l.

Table 3.5 Maryland WWTPs Nutrient Removal Retrofit Costs.[1] Effluent Levels: TN=8.0 mg/l (seasonal), TP= Smallest of 2.0 mg/l or NPDES Limit

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flow ($/mgd/yr.)
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.
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. Cost reflect design temperature of 12.5°C.
5. Plant is already removing phosphorus below 2.0 mg/l.

Table 3.6 Virginia WWTPs Nutrient Removal Retrofit Costs.[1]

Alternatives	Capital Costs	Annual O&M 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 to 10 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 = costs 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 capital costs plus annual O&M costs.
   Interest rate = 10%, project life = 20 years.

Table 3.7 Virginia WWTPs Nutrient Removal Retrofit Costs.[1] Alternative 3: Effluent Levels: TN = 10 mg/l (Seasonal), TP = Permit Limit (2.0 mg/l or less)

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flow ($/mgd/yr.)
QUANTICO [8]	2.0	Denitrifying Fluid Bed Reactor [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 [4]	$7,209,391	$629,759	$12,570,884	$1,476,571	$246,095
MASSAPONAX	6.0	Nitr./Denitr. Two Anoxic Zones [4]	$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 [4]	$3,011,023	$266,010	$5,275,718	$619,684	$61,968
HRSD-YORK RIVER	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 [4]	$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 RIVER	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

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).
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 = 0.18mg/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.

Table 3.7 Virginia WWTPs Nutrient Removal Retrofit Costs.[1] Alternative 3: Effluent Levels: TN=10 mg/l (Seasonal), TP=Permit Limit (2.0 mg/l or less)

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flo ($/mgd/yr
H. L. MOONEY [8]	24.0	Nitr./Denitr. Two Anoxic Zones [3]	$7,498,260	$2,548,256	$29,193,003	$3,428,999	$142,87
HRSD-CHES./ELIZ.	24.0	Nitr./Denitr. Two Anoxic Zones [5]	$47,596,580	$763,772	$54,098,998	$6,354,448	$264,76
HRSD-BOAT HARBOR	25.0	Nitr. Trick. Filt. & Denitr. Filt. [5]	$58,165,488	$2,178,462	$76,711,962	$9,010,558	$360,42
PROCTORS CREEK	27.0	Nitr./Denitr. Two Anoxic Zones [4]	$10,872,169	$1,079,155	$20,059,622	$2,356,196	$87,26
HRSD-NANSEMOND	30.0	Nitr./Denitr. Two Anoxic Zones [5]	$28,200,202	$1,626,289	$42,045,720	$4,938,675	$164,62
ARLINGTON [8]	40.0	Nitr./Denitr. Two Anoxic Zones [3]	$35,870,139	$5,459,254	$82,347,845	$9,672,547	$241,81
HRSD-VIP	40.0	Nitr./Denitr. Two Anoxic Zones [6]	$31,481,591	$2,237,911	$50,534,190	$5,935,727	$148,39
HENRICO	45.0	Nitr. Trick. Filt. & Denitr. Filt. [7]	$59,143,119	$2,657,079	$81,764,328	$9,604,007	$213,42
HOPEWELL [10]	50.0	Nitr. Trick. Filt. & Denitr. Filt.	$73,522,838	$6,841,701	$131,770,091	$15,477,665	$309,55
ALEXANDRIA [8]	54.0	Nitr./Denitr. Two Anoxic Zones [3]	$73,336,769	$7,048,261	$133,342,592	$15,662,371	$290,04
UOSA [8]	54.0	Nitr./Denitr. Two Anoxic Zones [4]	$17,846,147	$12,969,003	$128,258,577	$15,065,204	$278,98
RICHMOND [9]	70.0	Nitr./Denitr. Two Anoxic Zones [6]	$40,786,054	$99,754	$41,635,314	$4,890,468	$69,86
LOWER POTOMAC [8]	72.0	Nitr./Denitr. Two Anoxic Zones [3]	$61,090,159	$9,117,901	$138,715,990	$16,293,528	$226,29
	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 percent to -30 percent (CH2M Hill).
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 filtraion.
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=0.18mg/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.

Table 3.8 Virginia WWTPs Nutrient Removal Retrofit Costs.[1] Alternative 4: Effluent Levels: TN = 10 mg/l (monthly average limit), TP = Permit Limit (0.10-2.0 mg/l)

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flow ($/mgd/yr.)
QUANTICO [8]	2.0	Denitrifying Fluid Bed Reactor [3]	$1,590,322	$291,201	$4,069,476	$477,999	$239,000
FORT EUSTIS	3.0	Nitr. Trick. Filt. & Denitr. Filt. [5]	$6,175,219	$301,277	$8,740,157	$1,026,616	$342,205
FREDERICKSBURG	4.5	Nitr./Denitr. Two Aroxic Zones [5]	$2,811,591	$438,312	$6,543,189	$768,561	$170,791
AQUIA [8]	6.0	Nitr./Denitr. Two Aroxic Zones [3]	$3,724,458	$1,496,307	$16,463,364	$1,933,781	$322,297
FMC	6.0	Nitr./Denitr. Two Aroxic Zones [6]	$12,564,263	$654,949	$18,140,216	$2,130,743	$355,124
MASSAPONAX	6.0	Nitr./Denitr. Two Aroxic Zones [6]	$16,221,901	$669,056	$21,917,951	$2,574,474	$429,079
LITTLE FALLS RUN [8]	8.0	Nitr./Denitr. Two Aroxic Zones [5]	$310,457	$405,061	$3,758,969	$441,527	$55,191
FALLING CREEK	10.0	Nitr./Denitr. Two Aroxic Zones [6]	$4,125,380	$303,292	$6,707,474	$787,857	$78,786
HRSD-YORK RIVER	15.0	Nitr./Denitr. Two Aroxic Zones [6]	$11,342,995	$900,807	$19,012,074	$2,233,151	$148,877
PETERSBURG	15.0	Nitr./Denitr. Two Aroxic Zones [5]	$6,860,898	$1,067,063	$15,945,411	$1,872,942	$124,863
HRSD-ARMY BASE	18.0	Nitr. Trick. Filt. & Denitr. Filt. [5]	$29,751,460	$1,754,256	$44,686,434	$5,248,852	$291,603

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).
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 filtraion.
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=0.18mg/l or 0.1mg/l). 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.

Table 3.8 Virginia WWTPs Nutrient Removal Retrofit Costs.[1] Alternative 4: Effluent Levels: TN=10 mg/l (monthly average limit), TP=Permit Limit (0.10-2.0 mg/l)

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flo ($/mgd/y
HRSD-JAMES RIVER	20.0	Nitr./Denitr. Two Anoxic Zones [5]	$13,452,459	$720,444	$19,586,006	$2,300,565	$115,0
HRSD-WILLIAMSBURG	22.5	Nitr./Denitr. Two Anoxic Zones [5]	$20,058,412	$2,704,437	$43,082,805	$5,060,490	$224,9
H. L. MOONEY [8]	24.0	Nitr./Denitr. Two Anoxic Zones [3]	$11,393,367	$2,557,325	$33,165,315	$3,895,585	$162,3
HRSD-CHES./ELIZ.	24.0	Nitr./Denitr. Two Anoxic Zones [5]	$64,044,642	$939,096	$72,039,699	$8,461,756	$352,5
HRSD-BOAT HARBOR	25.0	Nitr. Trick. Filt. & Denitr. Filt. [5]	$80,239,815	$2,516,013	$101,660,049	$11,940,951	$477,6
PROCTORS CREEK	27.0	Nitr./Denitr. Two Anoxic Zones [6]	$14,973,905	$1,294,784	$25,997,133	$3,053,613	$113,0
HRSD-NANSEMOND	30.0	Nitr./Denitr. Two Anoxic Zones [5]	$37,830,543	$1,812,698	$53,263,063	$6,256,259	$208,5
ARLINGTON [8]	40.0	Nitr./Denitr. Two Anoxic Zones (Denitr. on Carbon Columns) [3]	$45,521,040	$6,620,025	$101,881,048	$11,966,910	$299,1
HRSD-VIP	40.0	Nitr./Denitr. Two Anoxic Zones [6]	$46,921,181	$3,296,914	$74,989,666	$8,808,258	$220,2
HENRICO	45.0	Nitr. Trick. Filt. & Denitr. Filt. [7]	$73,253,501	$3,680,815	$104,590,351	$12,285,143	$273,0

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).
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=0.18mg/l or 0.1mg/l). 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.

Table 3.8 Virginia WWTPs Nutrient Removal Retrofit Costs.[1] Alternative 4: Effluent Levels: TN=10 mg/l (monthly average limit), TP=Permit Limit (0.10-2.0 mg/l)

WWTP	Design Flow (mgd)	Technology	Capital Costs	Annual O&M Costs	Equivalent Total Costs [2] (ETC)	Equivalent Annual Costs [2] (EAC)	EAC/Flow ($/mgd/yr.)
HOPEWELL [10]	50.0	Nitr. Trick. Filt. & Denitr. Filt.	$73,522,838	$11,703,439	$173,160,812	$20,339,404	$406,788
ALEXANDRIA [8]	54.0	Nitr./Denitr. Two Anoxic Zones [3]	$130,903,958	$7,694,142	$196,408,528	$23,070,072	$427,224
UOSA [8]	54.0	Nitr./Denitr. Two Anoxic Zones [4]	$24,900,310	$13,047,596	$135,981,854	$15,972,378	$295,785
RICHMOND [9]	70.0	Nitr./Denitr. Two Anoxic Zones [6]	$53,920,860	$182,378	$55,473,548	$6,515,902	$93,084
LOWER POTOMAC [8]	72.0	Nitr./Denitr. Two Anoxic Zones [3]	$68,083,669	$9,196,495	$146,378,615	$17,193,577	$238,800
	691.0		$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).
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=0.18mg/l or 0.1mg/l). 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.

3.3.4 Summary

Despite possible operational problems for BNR technologies, particularly when both nitrogen and phosphorus are biologically removed, BNR offers the potential advantage of low operation and maintenance (O&M) costs. Due to the limited data on the performance of a full scale retrofit in the Chesapeake Bay basin, there is still much uncertainty over the precise nutrient effluent levels that a particular BNR retrofit can achieve. Nutrient removal performance of a BNR retrofit is likely to come from pilot or full scale demonstration studies for each plant or after the retrofit is completed and nutrient effluent levels have been determined from annual operation data at each site. Also, most cost estimates reported are likely to change as the selection of alternatives is narrowed and the preliminary retrofit designs are refined. Also, it is important to point out that the required effluent levels for each plant or group of plants in a tributary will likely be determined according to receiving water quality.

Equivalent annual costs per mgd retrofitted (EAC/Flow) also are shown in the tables for all WWTPs. These ratios give a rough idea of the relative cost differences between the different WWTPs and studies summarized. However, it is important to point out that comparisons of costs between these studies should be done with caution. Retrofit design approaches as well as proposed effluent levels are different. Each retrofit is unique with cost estimates strongly dependent on each site's characteristics. Retrofit design assumptions and expected effluent levels are likely to be different for each WWTP. Nevertheless, the costs for the proposed effluent levels reported by these studies give an insight into the expected costs and effectiveness of retrofitting WWTPs for nutrient removal in the Chesapeake Bay basin.

3.4 Planning Level Retrofit Cost Estimates

Planning level cost curves were derived from the Hazen and Sawyer Engineers and J. M. Smith and Associates (1988) report which provides Biological Nutrient Removal (BNR) planning level retrofit cost estimates for four types of secondary treatment plants: extended aeration, activated sludge, activated sludge with nitrification and fixed film (trickling filter or rotating biological contactors). Retrofit WWTP plant diagrams for these secondary plants are shown in Appendix H. Hazen and Sawyer Engineers and J.M. Smith and Associates provided retrofit costs for five plant design flow sizes: 0.5, 1.0, 5.0, 10.0 and 30 mgd. The costs were provided for two long-term average nutrient effluent levels:

High Level Nutrient Discharge (HLND) : TP = 2.0 mg/l and TN = 8.0 mg/l (seasonal)

Low Level Nutrient Discharge (LLND) : TP = 0.5 mg/l and TN = 3.0 mg/l (seasonal)

3.4.1 Retrofit Assumptions

Detailed assumptions on the cost and retrofit process selection are described in the Hazen and Sawyer Engineers and J. M. Smith and Associates (1988) report. For the HLND target the A²/O™ BNR process (Figure 3.1) was used as the retrofit alternative. This process was judged capable of meeting the TN effluent level with supplemental alum feed to meet the TP effluent level. For the LLND target, the Bardenpho BNR process (Figure 3.1) with two separate stages of denitrification was used to meet the TN effluent level. The LLND target level for TP was judged to be achieved with alum addition facilities and effluent filtration. Addition of alum facilities at all plants will meet both TP effluent levels on an average long term basis.

3.4.2 Retrofit Cost Modifications

The Hazen and Sawyer Engineers and J. M. Smith and Assoc. (1988) report provided cost curves for the two effluent levels for warm weather plant operation (design temp = 20°C; seasonal TN removal). Also, the retrofit cost curves are based on chemical cost with an influent level of TP = 9.0 mg/l, which only applies to states that have not implemented a phosphate detergent ban (Delaware, New York, and West Virginia). However, the report provided information on chemical costs for influent levels of 6.5 mg/l, which approximate the total phosphorus influent level of WWTPs in states with phosphate bans. Information on escalating the capital cost for a design temperature of 10°C (i.e. year-round removal) also was provided. No incremental cost ratios were given for O&M costs. However, most of the incremental costs for the 10°C design are due to the increase in wastewater retention times (i.e. tank size). The only O&M costs that may increase are the power costs (personal communication with J. M. Smith and Associates). This further adjustment may have slight effects in the overall O&M costs and therefore no attempt is made here to modify these costs.

In this report, cost curves are updated and modified for the two sets of effluent levels for both seasonal and year-round TN removal and for application of these costs in states with and without phosphate bans. Today, all Chesapeake Bay signatories have a phosphate ban in place, and therefore, cost equations for non-phosphate ban areas may be applied only for those WWTPs in Delaware, New York and West Virginia. Then, four sets of equations are presented for the two sets of effluent levels:

- Seasonal TN removal with phosphorus removal costs in phosphate ban areas;
- Seasonal TN removal with phosphorus removal costs in non-phosphate ban areas;
- Year-round TN removal with phosphorus removal costs in phosphate ban areas; and
- Year-round TN removal with phosphorus removal costs in non-phosphate ban areas.

In order to update the original cost curves to obtain these four sets, the following steps were followed:

1) Original cost estimates were updated to 1990 dollars. Appropriate ENR indexes were used to escalate construction costs. EPA operation, maintenance, and repair (OMR) indexes were used to escalate O&M and labor costs. Different indexes for labor, chemical, power, and maintenance were used to reflect adequate changes of these parameters. Land prices were adjusted using the consumer price index. After the first quarter of 1990, OMR indexes were not produced by EPA due to fiscal constraints.

2) The chemical costs for phosphate ban areas are modified based on a total phosphorus (TP) influent level of 6.5 mg/l, which are also provided in the Hazen and Sawyer Engineers and J. M. Smith and Associates (1988) report. This influent level contrasts with the chemical costs given by the original cost curves that were developed based on an influent level of TP = 9.0 mg/l. The 6.5 mg/l influent level better reflects the implementation of the phosphate ban although some states may have influent levels that are slightly below this level.

3) The Hazen and Sawyer Engineers and J. M. Smith and Associates (1988) report provided factors used to adjust the capital costs for a design temperature of 10°C (i.e. year-round TN removal).

4) To ease the planning level cost estimation, equations were developed from the estimated costs for each type of retrofit and design flow. The equations were obtained using nonlinear regression for two discharge ranges: 0.5 to 5.0 mgd and 5.0 to 30 mgd. Appendix I shows the coefficients and exponents of these equations for the four sets specified above.

These coefficients and exponents are given for two sets of equations for capital and O&M costs expressed as:

$$Capital = a(Flow)^{b}$$

$$O\&M = c(Flow)^{d}$$

where:

Capital = Capital costs,
O&M = Operation and maintenance costs,
Flow = Design flow in million gallons per day (mgd), and
a,b,c,d = Regression coefficients and exponents

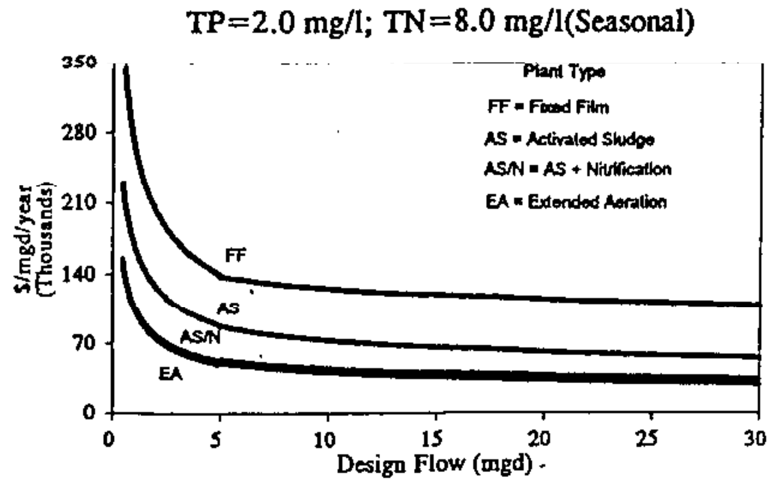
The cost equations applicable to phosphate ban areas are plotted for the two effluent levels (Figures 3.6 and 3.7). For the two effluent levels, these figures show that the unit cost significantly increases as the plant design flow decreases below 5 mgd. Within each retrofit type, the unit costs do not vary much for design flows greater than 5 mgd. Also for the two effluent levels, the retrofit costs are highest for fixed film plants (trickling filters, rotating biological contactors) followed by activated sludge, activated sludge with nitrification and extended aeration processes.

It is also important to point out that royalty fees are not included in these equations. These costs should be evaluated on a case by case basis because they are subject to negotiations. The Hazen and Sawyer Engineers and J. M. Smith & Associates report gives the following information on license fees:

- Air products royalty fee for the A^2O process: Fee = $1,000/lb day of phosphorus removed.

- Royalty fee for the Bardenpho process: Fee = $60,000 x $Q^{0.75}$

Figure 3.6 Planning Level BNR Retrofit Unit Cost Curves
High Level Nutrient Discharge



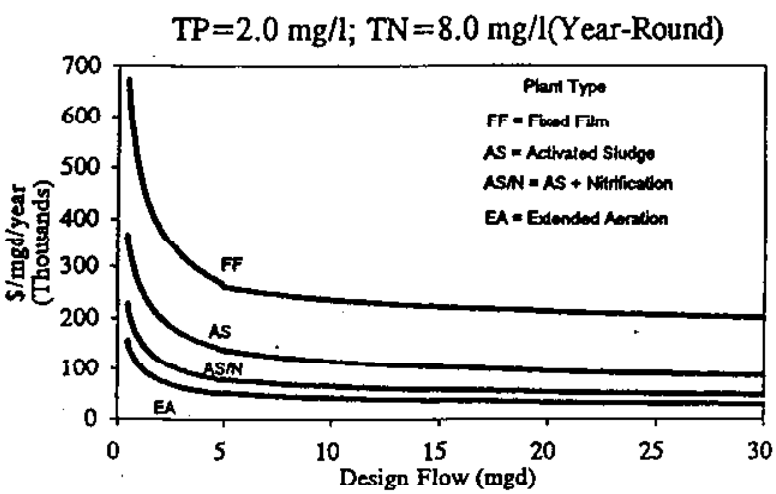
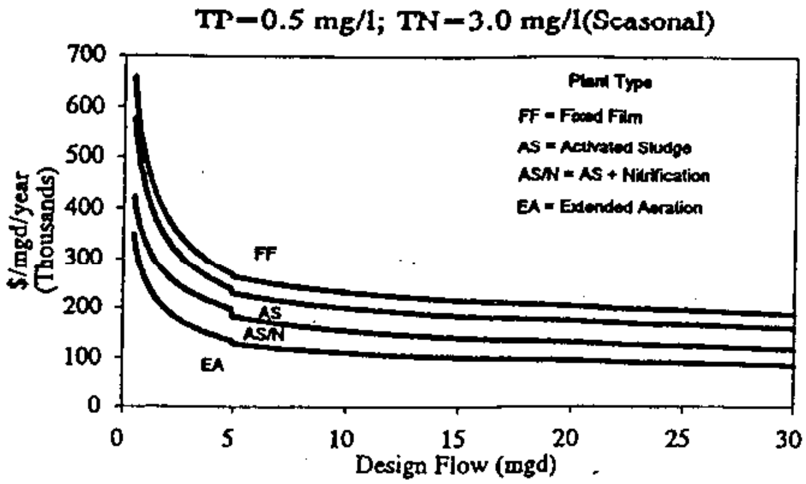
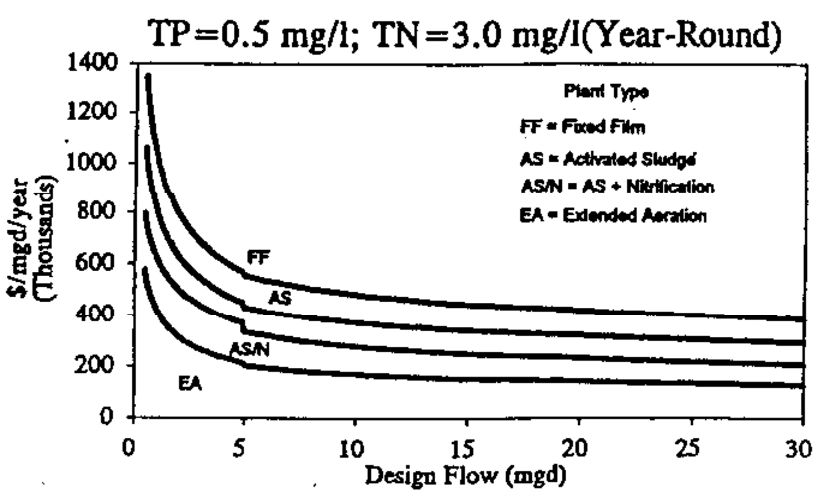


Figure 3.7 Planning Level BNR Retrofit Unit Cost Curves
Low Level Nutrient Discharge





3.4.3 Application of Planning Level Retrofit Cost Equations

Planning level cost estimates were applied to the municipal WWTPs in the Chesapeake Bay basin listed in Appendix G. The cost equations were applied only for those plants that are not removing nitrogen and phosphorus to the specified effluent levels (HLND : TN = 8.0 mg/l, and TP = 2.0 mg/l and for LLND : TN = 3.0 mg/l and TP = 2.0 mg/l) with design flows between 0.5 and 30 mgd. The cost equations for phosphate ban areas were used for WWTPs in Maryland, Pennsylvania, and Virginia. These planning level cost estimates should be used with caution. Again, actual retrofit costs may vary from the planning level ones as WWTPs deviate from the general plant configurations shown in the diagrams of Appendix H. Cost equations were developed for these plant configurations with the assumptions described in detail in the Hazen and Sawyer Engineers and J. M. Smith & Associates (1988) report. Also, it is very likely that some of these plants may not be able to be retrofitted to BNR due to specific site constraints or plant type configurations. Therefore, the cost estimates from the planning level equations should be used only as an initial rough estimate. In this report, these estimates are used for relative cost comparisons between basins, effluent levels (low and high), and seasonal versus year-round nutrient removal.

Figures 3.8 and 3.9 show the EAC/mgd ratio by basin for retrofitting existing WWTPs for the two effluent levels for both year-round removal and seasonal removal. For the year-round retrofit cost (Figure 3.8) and the high level nutrient discharge (HLND), the average annual cost per mgd was about $150,000; for the low level nutrient discharge (LLND) the average annual cost was about $450,000. For seasonal nitrogen removal, retrofit costs averaged about $95,000 per mgd for the HLND and about $235,000 per mgd for the LLND.

3.4.4 Comparison of Planning Level Cost Estimates Using Cost Equations with States' Cost Studies

It is very difficult, if not impossible, to perform accurate comparisons between the costs derived from the planning level cost equations and those from the states' retrofit studies. The main reason for this difficulty is that assumptions, effluent levels, site constraints, and sometimes selection of technologies are different. However, the comparison is made here just to have an idea of the how the planning level retrofit cost estimates from the Hazen and Sawyer Engineers and J. M. Smith and Associates report differ from the states' studies. Figure 3.10 shows the relative unit cost (EAC/mgd) difference for selected WWTPs from the states' retrofit studies. The WWTPs selected from the Maryland (9 plants) and Virginia (11 plants) retrofit studies are those BNR retrofits that meet the TP = 2.0 mg/l, and the TN = 8.0 mg/l long term average

Figure 3.8

Planning Level Retrofit Costs
Year-Round Nitrogen Removal

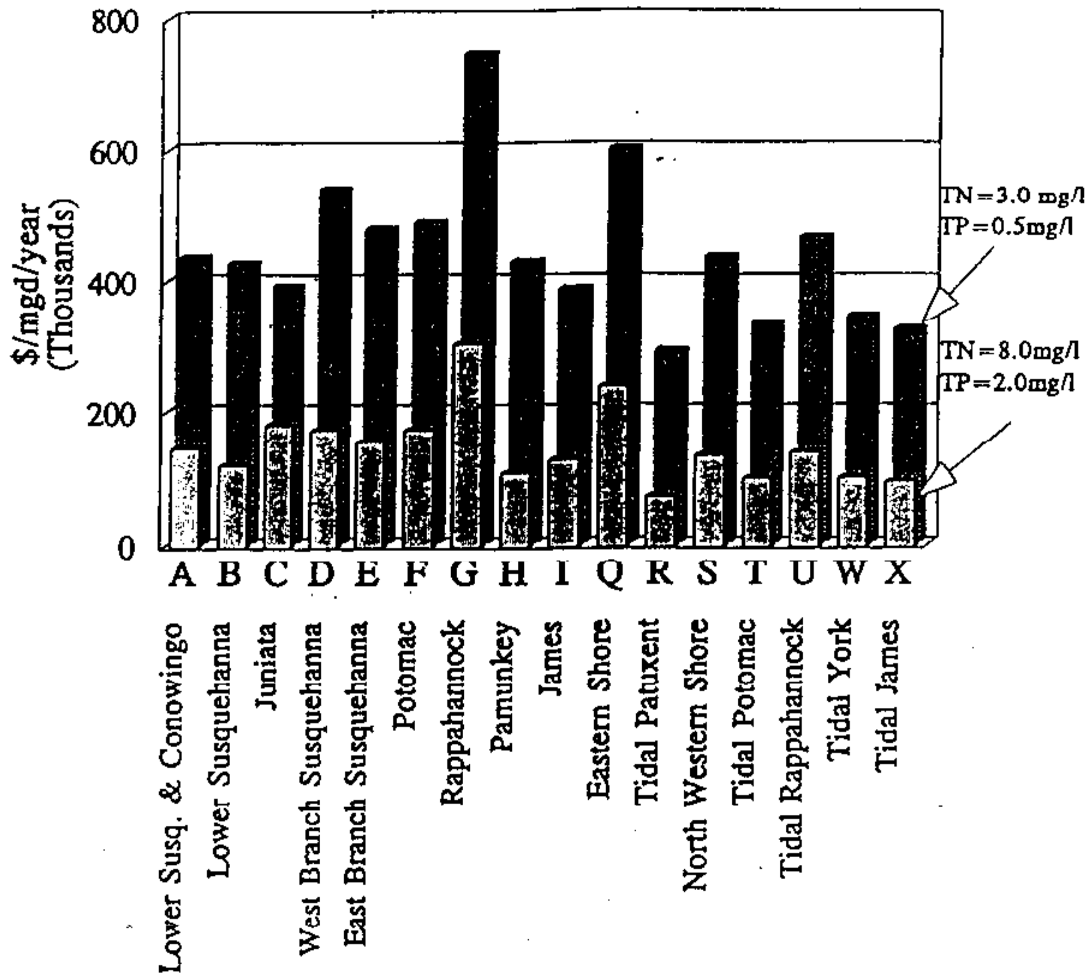
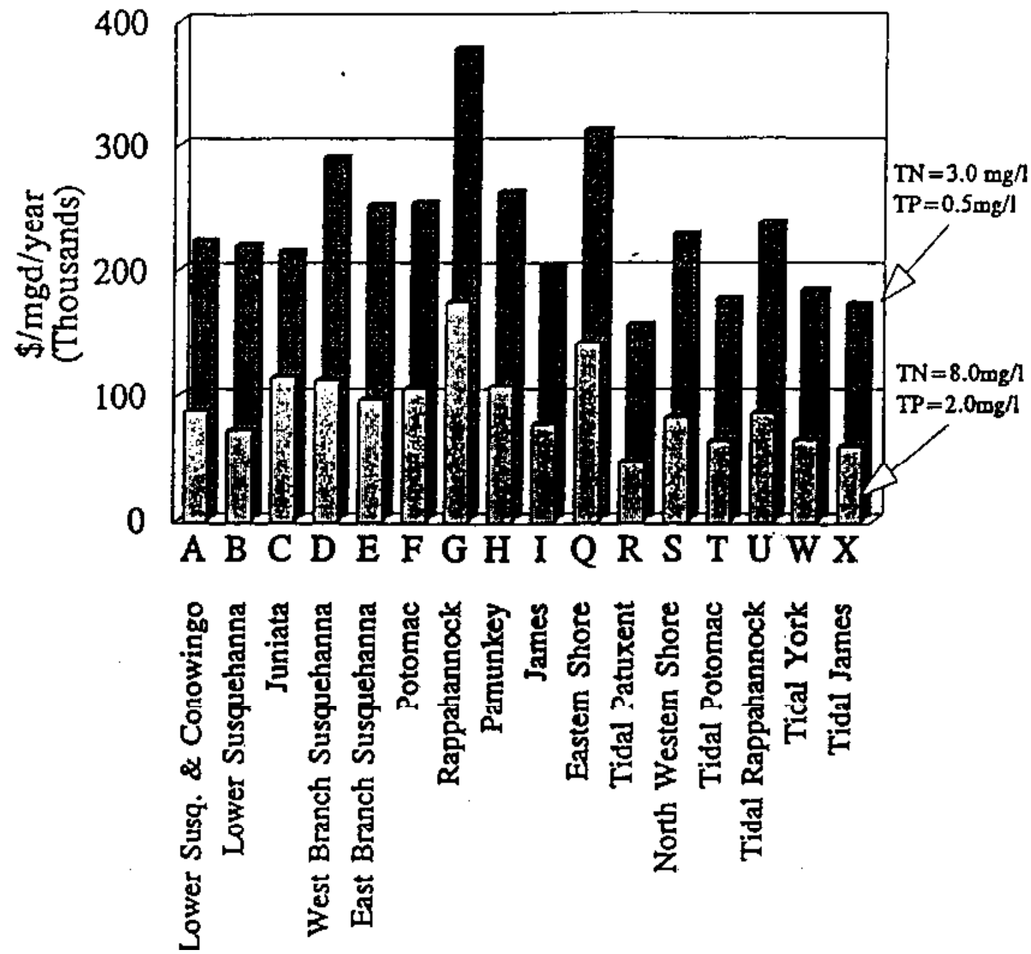


Figure 3.9

Planning Level Retrofit Costs:
Seasonal Nitrogen Removal



limit for Maryland, and TN = 10 mg/l seasonal monthly limit (Alternative 3, CH2M-HILL study). The TN = 10 mg/l monthly effluent limitation is expected to result in a seasonal average of TN = 7.0 mg/l. Therefore, the selected plants' effluent levels are somewhat comparable to the planning level cost curves for the high level nutrient discharge (HLND: TN=8.0 mg/l, TP = 2.0 mg/l) with seasonal nitrogen removal.

Figure 3.10 shows that in general the planning level cost estimates are lower than the cost estimates from the states' retrofit studies with an overall average relative difference of -53%.

3.5 Cost and Effectiveness of Existing Nutrient Removal WWTPs

This section summarizes the cost and effectiveness of some of the recently completed WWTP retrofits with nutrient removal. Although only a few plants are reported, the costs and effluent performance levels provide valuable information for comparisons with existing retrofit cost estimates derived from site specific studies or planning level estimates.

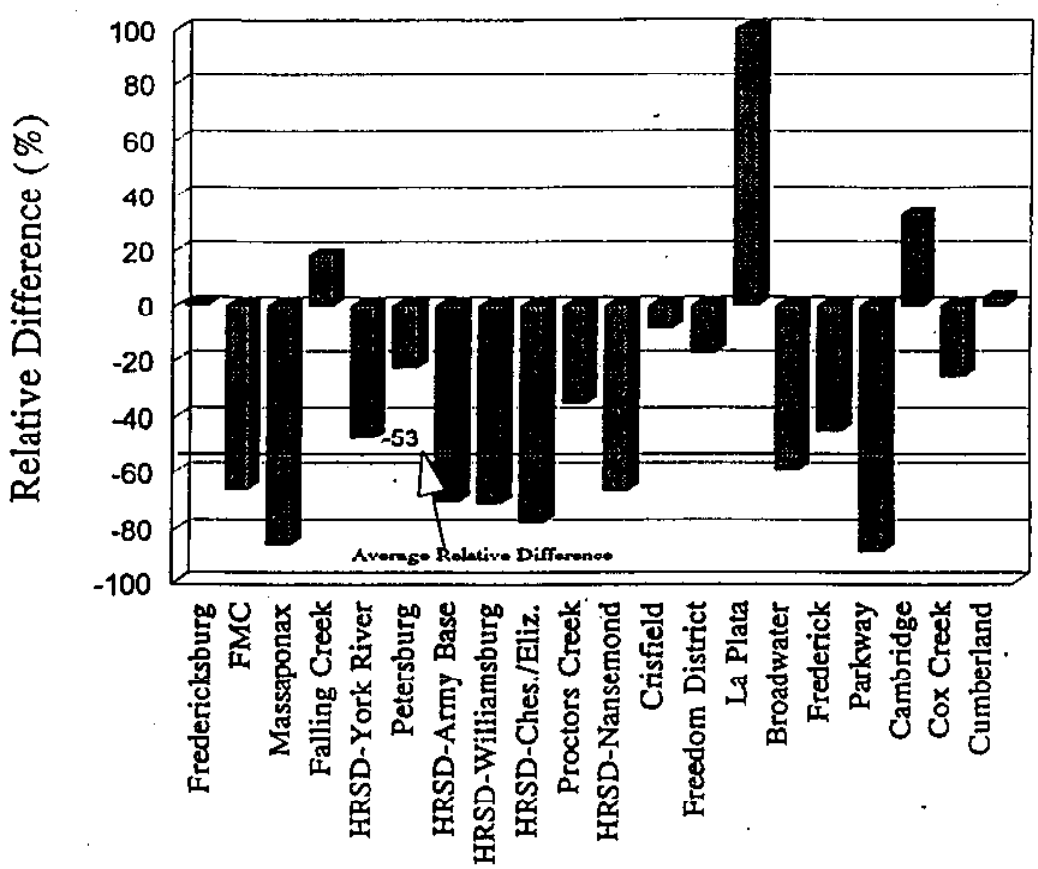
3.5.1 Bowie WWTP (VT2-BNR)

The Bowie plant is located on the Patuxent river. This plant was initially designed as an oxidation ditch. The plant has been retrofitted to biologically remove nitrogen and phosphorus. Anaerobic, anoxic and aerobic zones were created in the oxidation ditches for operation in the VT2 mode (adaptation of the UCT process). In this mode of operation, the oxidation ditches are operated in series with the return activated sludge (RAS) recycled to the head of the first anoxic tank.

Initially, ferrous sulfate and polymer were added for phosphorus removal and caustic soda was added to supplement the influent alkalinity. Chemical phosphorus removal was discontinued after the retrofits, and since then, average effluent levels for total phosphorus have been reported to be around 0.6 mg/l. Also, phosphorus effluent levels are expected to reach 0.3 mg/l (Sen, et al., 1990). These phosphorus levels are achieved without effluent filtration, which could further reduce them by 80%.

According to Sen et al., 1990, the volume in the oxidation ditches is adequate to comply with the effluent permit limitations of TN = 6.0 mg/l and TP = 1.0 mg/l. Total nitrogen annual

Figure 3.10
BNR Retrofit Cost Estimates Difference
Cost Eqs. vs. States' Cost Estimates



effluent levels at the Bowie plant have fluctuated between 5 and 7 mg/l between 1990 and 1992, and the total phosphorus effluent level averaged about TP = 0.7 mg/l.

The total cost of the Bowie retrofit was around $400,000 for a 2.5 mgd design flow. Although the facility was rated at 3.0 mgd, Sen et al. (1990) pointed out that the available air supply clarifier and solids handling would need to be upgraded for flows over 2.5 mgd. Increases in O&M costs by $13,000 annually were given in the Beavin Co., Camp Dresser & McKee,and Metcalf & Eddy report (1988). However, Sen et al. (1990) reported potential net savings of $57,000 per year by implementing the BNR retrofit. Assuming no increase at all in the O&M costs, an equivalent annual cost per mgd of approximately $19,000 is obtained. This unit cost is significantly lower than other unit costs reported in the cost tables from the states' studies.

3.5.2. Patuxent WWTP (BNR)

The Patuxent plant was built to replace an existing plant. It is an oxidation ditch where nitrogen is biologically removed and chemical addition is used for phosphorus removal. The design flow of the plant is 6.0 mgd and currently the plant is operating at an annual average flow of 3.6 mgd. The cost of building this facility was $24 million, and current O&M costs are around $2 million, where $0.6 million of these costs are sludge handling and $29,000 are chemical addition costs.

The Patuxent plant is operating very well. The permit limit for total nitrogen is 10 mg/l seasonally and for total phosphorus 1.0 mg/l. Annual average performance for total nitrogen is around 8 mg/l with performance levels as low as 5.0 mg/l during the warmer season. The plant also has been averaging an annual total phosphorus effluent level of 0.5 mg/l.

3.5.3. Western Branch WWTP (Denitrification Filters)

The Western Branch has been retrofitted to remove nitrogen using denitrification filters. Current phosphorus removal at this plant will continue in order to comply with an effluent level of TP = 1.0 mg/l. The retrofit with denitrification filters is expected to comply with a seasonal (April to October) effluent level of TN = 3.0 mg/l. For other months, total nitrogen effluent levels are expected to be between 13 mg/l and 15 mg/l.

Nitrogen removal retrofit costs for this facility were $19.5 million in capital costs, and $1.05 million in O&M costs. Therefore, an EAC/mgd ratio of $111,348 is obtained. With the 30 mgd design flow capacity, an effluent level of TN = 3.0 mg/l between April and October, and an assumed effluent level of TN = 14 mg/l the rest of the year, the annualized cost per pound of nitrogen removed is calculated at $6.7.

3.5.4 VIP (Virginia Initiative Plant)

The Hampton Roads Sanitation District HRSD-Lamberts Point WWTP (now named the VIP) has been retrofitted with the VIP process (Figure 3.2). Earlier pilot studies were performed to test for annual removal of phosphorus and seasonal nitrogen removal. Results from the pilot study showed that the VIP is capable of achieving low effluents for phosphorus (soluble P effluent of 1.6mg/l) and total nitrogen effluent levels about 8.0 mg/l (Sedlak, 1991). Performance data for 1992 shows that the plant can achieve total nitrogen effluent levels between 7 and 8 mg/l on a seasonal basis.

3.6 Financial Cost Effectiveness Ratios for Municipal WWTPs

This section attempts to provide an estimate of the cost per pound of nitrogen or phosphorus removed. Nitrogen and phosphorus cost effectiveness ratios are calculated for chemical addition and biological nutrient removal processes. The distinction between biological and chemical addition treatment is made for retrofits that place emphasis on either of these nutrient removal processes, recognizing that physical, chemical and biological processes may be found in all types of WWTPs.

Cost information using the states' retrofit cost studies, and actual facility cost data are used to provide an overall idea of these cost effectiveness ratios. Use of all this information will help identify a "ballpark" cost of removing a pound of nitrogen or phosphorus for a variety of effluent levels and technologies. However, caution should be exercised when making comparisons among the calculated cost effectiveness ratios using the aforementioned data. Assumptions for estimating retrofit costs for nutrient removal are different. Assumptions from the different data sources used to obtain these cost effectiveness ratios should be carefully examined. Some important issues that affect the calculation of these ratios are summarized as follows:

- Different cost estimation assumptions have a significant impact on the unit cost estimates. Actual retrofit costs may vary significantly from the planning or site specific states' studies. For instance, retrofit "costs opinions" for Virginia WWTPs are "order-of-magnitude", which are expected to be accurate within +50% to -30%.

- Post-retrofit effluent levels are assumed values of expected average annual performance of these retrofits. Actual annual performance levels after the retrofits are completed will determine the true annual nutrient load removed in each particular plant.

- For some cases, rough apportioning of the total retrofit costs are made for each nutrient. The apportioning approach would significantly impact the cost effectiveness ratio.

3.6.1 Cost Effectiveness Ratios for Nitrogen Removal

In this section, examples from the states' retrofit studies are used to estimate ranges of nitrogen removal cost effectiveness ratios. Figure 3.11 shows a summary of the cost effectiveness ranges for nitrogen removal presented in this section.

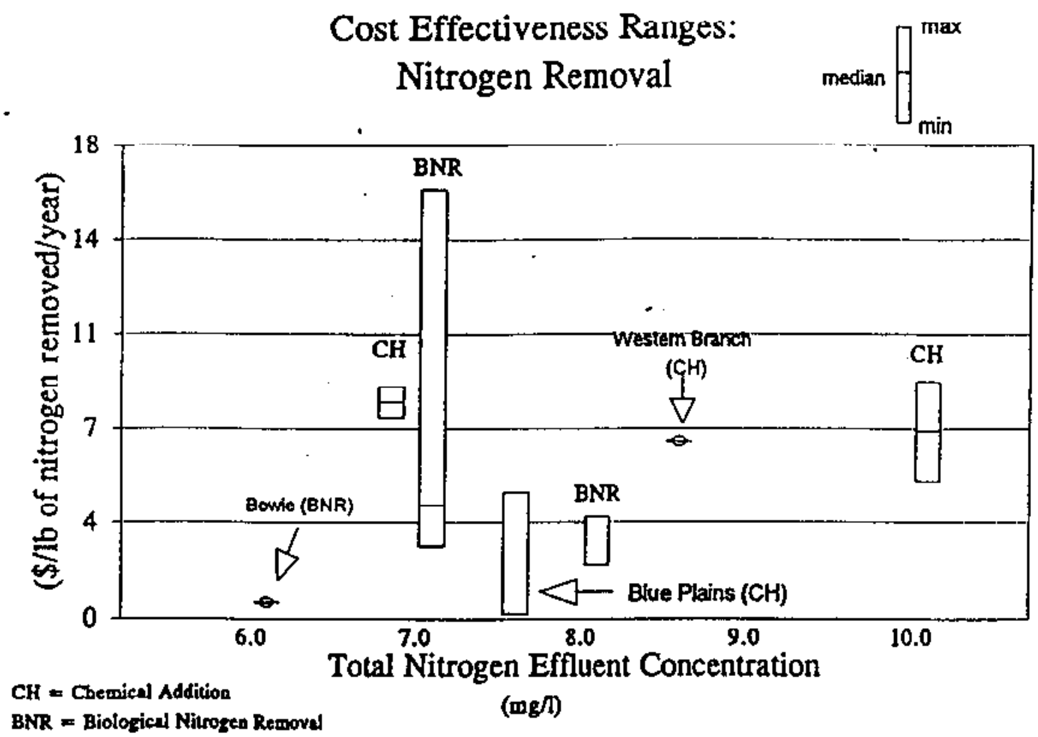
3.6.1.1 Cost Effectiveness Ratios: Chemical Addition

Table 3.9 shows the cost effectiveness ratios for nitrogen removal for selected WWTPS. The following assumptions were made to obtain these cost effectiveness ratios.

- WWTPs using chemical addition (methanol) in the process of removing nitrogen were selected from the Virginia retrofit study. Phosphorus removal costs (alternative 1) were subtracted from alternative 4 to obtain an estimate of the cost of removing nitrogen only. Post retrofit annual average effluent concentration is assumed to be 7.0 mg/l.

- For the two Maryland WWTPs, incremental costs were provided for the removal of nitrogen using the existing phosphorus removal facilities. Retrofit costs were estimated to achieve an effluent level of 8.0 mg/l on a seasonal basis. Therefore, an annual performance level of TN = 10 mg/l is assumed. This estimate assumes that the plant provides some nitrification in the cold months and that performance levels in the warmer months of the summer can reach effluent levels below 8.0 mg/l.

Figure 3.11 Financial Cost Effectiveness Ratios for Nitrogen Removal



The cost effectiveness ratio is defined as the total annualized nitrogen retrofit cost divided by the pounds of nitrogen removed per year. Nutrients removed are at the "end-of-pipe". The information in this figure came from the states' nutrient removal retrofit studies for municipal WWTPs, and some existing retrofits in Maryland.

• For Blue Plains in D.C., the costs were provided for nitrogen removal only. A $4.8 cost effectiveness ratio (annual dollars per pound of nitrogen removed) was obtained for Blue Plains using chemical addition for nitrogen removal. This low cost may be in part due to the size of the plant (design flow = 370 mgd).

Table 3.9 shows a range of $7.6 to $10.2 per pound of nitrogen removed for retrofit designs to achieve an average annual performance level of TN = 7.0 mg/l. For an effluent level of TN = 10 mg/l the cost per pound of nitrogen removed was between $5.6 and $9.0 which are similar to the Virginia retrofits for the effluent level of TN = 7.0 mg/l.

3.6.1.2 Cost Effectiveness Ratios: Biological Removal

It is very difficult to separate the costs associated with the removal of each nutrient in a BNR system. Biological processes for some BNR systems are not independent for phosphorus or nitrogen removal, making it difficult if not impossible for some cases to apportion the total retrofit costs to each nutrient. However, data for some WWTPs in Virginia and Maryland presented cost information in a format that allows making some inferences about the costs of only removing nitrogen. The selected plants and assumptions are presented as follows:

• The Virginia plants selected for this analysis were those that are removing phosphorus by chemical addition and meeting the current phosphorus effluent limits. Chemical phosphorus removal was chosen as the technology capable of reliably meeting the monthly phosphorus effluent limits. The same O&M costs of removing phosphorus were presented in their alternative 1 (phosphorus removal to permit limit) and alternative 4 (alternative 1 + year-round nitrogen removal to TN = 10 mg/l). Therefore the current O&M costs, which also are included in alternative 4, are subtracted from the total costs in alternative 4 to get some idea of the biological nitrogen removal cost. Some of these O&M phosphorus removal costs are presented later in this section.

• The Maryland plants selected for this analysis were those plants with BNR retrofit costs provided using existing chemical removal facilities. The retrofits used here were those mainly targeted for nitrogen removal by using an anoxic zone followed by an aerobic zone. For the selected Maryland plants the costs were provided for a design temperature of 12.5°C; therefore, the nitrogen effluent level of 8.0 mg/l is assumed to be met on a year-round basis.

Table 3.9 Examples of Nitrogen Removal Cost Effectiveness Ratios: Chemical Addition

WWTP	Technology	Design Flow (mgd)	Pre-Retrofit TN (mg/l)	Post-Retrofit TN (mg/l)	TN Removed[1] (lbs/Year)	EAC/mgd[2] ($/mgd/yr.)	Cost Effectiveness Ratio[3] ($/lb-N/Yr.)
QUANTICO (VA)	Denitrifying Fluid Bed Reactor	2.0	13.0	7.0[5]	36,529	160,406	8.80
KENT NARROWS (MD)	RBC Nitr.,Fluid Bed Denitr.	2.0	21.1	10.0[4]	67,615	305,976	9.00
FORT EUSTIS (VA)	Nitr. Trick. Filt. & Denitr. Filt.	3.0	18.9	7.0[5]	108,857	296,584	8.20
ABERDEEN WWTP (MD)	Denitrification Filters & Meth.	4.0	15.9	10.0[4]	72,910	96,063	5.20
HRSD-BOAT HARBOR (VA)	Nitr. Trick. Filt. & Denitr. Filt.	25.0	20.4	7.0[5]	1,019,012	414,442	10.20
HENRICO (VA)	Nitr. Trick. Filt. & Denitr. Filt.	45.0	18.0	7.0[5]	1,506,830	254,452	7.60
BLUE PLAINS (DC)	Nitrification-Denitrification. Methanol added to the 4th pass in the Nitrification reactor	370.0	13.7	7.5	6,994,429	1,809	0.20[6]
BLUE PLAINS (DC)	Deep bed filter denitrification following nitrification (24 new filters)	370.0	13.7	7.5	6,994,429	91,155 56,997[7]	4.80 3.00[8]

1 Pounds of nitrogen removed per year at design flow.
2 EAC= Equivalent annual cost: amortized capital costs plus annual O&M costs.
3 Cost Effectiveness ratio = Annual EAC divided by pounds of N removed.
4 Plant designed to meet TN=8.0mg/l (seasonal). TN=10mg/l assumed as annual performance.
5 Annual performance effluent level.
6 Does not include O&M costs.
7 EAC cost with capital cost only.
8 Include only capital costs.

Table 3.10 shows examples of the cost effectiveness ratios for biological nitrogen removal technologies. For the Virginia plants, a range of cost effectiveness ratios between $2.70 and $16.30 with a median of $4.35 was obtained for an annual performance effluent level of 7.0 mg/l. Only two plants in Maryland are shown on these tables with cost effectiveness ratios of $2.0 and $3.8. Therefore, despite the limited information, it seems that biological nitrogen removal can be more cost effective than chemical addition (methanol). The retrofit cost effectiveness ratio of the Arlington plant is high ($16.30) due to the low existing effluent level of TN = 12.1 mg/l. Also, from the retrofit cost data obtained from the states' studies, no correlation was found between the retrofit unit cost ($/mgd/year) of a plant and its size for a particular technology. This reaffirms an earlier statement that retrofit costs are highly dependent on the particular site specific conditions at each WWTP.

3.6.2 Phosphorus Removal Cost Effectiveness Ratios

This section summarizes the retrofit cost effectiveness ratios for phosphorus removal retrofits of WWTPs. Both biological phosphorus removal (BPR) and chemical phosphorus removal are considered. Chemical phosphorus removal cost data includes EPA estimates, site specific cost estimates, and existing O&M phosphorus removal costs for some plants. Biological phosphorus removal include cost estimates for retrofitting the Blue Plains WWTP and the HRSD-VIP plant. Figure 3.12 shows a synthesis of the cost effectiveness ratio ranges derived in this section.

3.6.2.1 Cost Effectiveness Ratios: Chemical Addition

Chemical phosphorus removal has been a technology practiced in many WWTPs for quite some time. Cost and effectiveness of this technology has been documented (EPA, 1987). Tables 3.11 and 3.12 show the capital and O&M costs of retrofitting municipal WWTPs for chemical phosphorus removal given by EPA (1987). However, costs of handling increased sludge, pH instrumentation controls, chemical storage and effluent filtration that require site-specific evaluation are not included in these costs. The cost estimates are applicable to all WWTPs except lagoons. The application of these cost data for retrofitting WWTPs with design flows less than 10 mgd gives the cost effectiveness ranges shown in Table 3.13. Again, it is assumed that the pre-retrofit phosphorus effluent level (within phosphate ban areas) for conventional secondary treatment plants is TP = 3.0 mg/l.

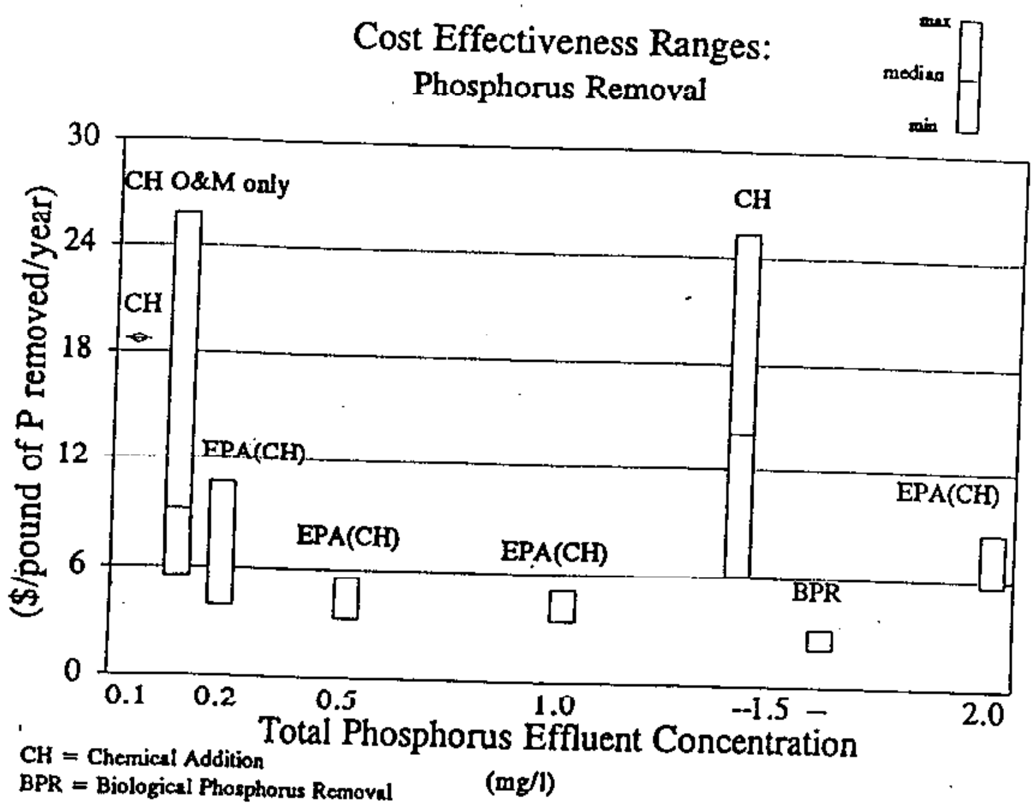
Chemical phosphorus removal costs also were documented for alternative 1 of the Virginia retrofit study (CH2M-HILL, 1988). Table 3.14 lists the cost effectiveness ratios of a selected number of plants in the CH2M-HILL study. As shown in Table 3.14 the cost effectiveness ratios can vary between $6.10 per pound of phosphorus removed to $25.00. These costs are

Table 3.10 Examples of Nitrogen Removal Cost Effectiveness Ratios: Biological Removal

WWTP	Technology	Design Flow (mgd)	Pre-Retrofit TN (mg/l)	Post-Retrofit TN (mg/l)	TN Removed[1] (lbs/Year)	EAC/mgd[2] ($/mgd/yr.)	Cost Effectiveness Ratio[3] ($/lb-N/Yr.)
AQUIA (VA)	Nitr./Denitr. Two Anoxic Zones	6.0	10.6	7.0	64,839	99,782	9.20
BROADNECK[4] (MD)	Anoxic/Aerobic Zones	6.0	24.0	8.0	292,128	96,977	2.00
H. L. MOONEY (VA)	Nitr./Denitr. Two Anoxic Zones	24.0	20.5	7.0	988,480	112,607	2.70
ARLINGTON (VA)	Nitr./Denitr. Two Anoxic Zones (Carbon Column.)	40.0	12.1	7.0	618,561	251,865	16.30
UOSA (VA)	Nitr./Denitr. Two Anoxic Zones	54.0	19.1	7.0	1,984,083	131,096	3.60
RICHMOND (VA)	Nitr./Denitr. Two Anoxic Zones	70.0	13.3	7.0	1,350,972	93,084	4.80
LOWER POTOMAC (VA)	Nitr./Denitr. Two Anoxic Zones	72.0	21.7	7.0	3,215,300	175,390	3.90
PATAPSCO[4] (MD)	Anoxic/Aerobic	87.5	16.2	8.0	2,183,356	95,973	3.80

1 Pounds of nitrogen removed per year at design flow.
2 EAC= Equivalent annual cost: amortized capital costs plus annual O&M costs.
3 Cost Effectiveness ratio = Annual EAC divided by pounds of N removed.
4 Plant designed at 12.5°C. TN=8 mg/l assumed as annual performance.

Figure 3.12 Financial Cost Effectiveness Ratios for Phosphorus Removal



The cost effectiveness ratio is defined as the total annualized phosphorus retrofit cost divided by the pounds of phosphorus removed per year. Nutrients removed are at the "end-of-pipe". The information in this figure came from the Virginia nutrient removal retrofit study for municipal WWTPs, and the EPA. The EPA cost data do not include the costs of sludge handling facilities, additional clarification capacity, and pH control.

higher than the costs given in Table 3.13. The main reason for this is that the high cost of sludge handling, and pH control costs that were included in the CH2M-HILL report can significantly increase the cost effectiveness ratios. Sludge handling costs may represent about 30% to 40% of the total O&M costs.

The CH2M-HILL report also presented some of the existing phosphorus removal costs for WWTPs already removing phosphorus. These plants have total phosphorus performance levels below 0.18 mg/l. Table 3.15 shows some examples of the O&M cost effectiveness ratios. To obtain these ratios, it is assumed that each plant can achieve an effluent level of 3.0 mg/l without chemical removal. Therefore, pounds of phosphorus removed are calculated based on a hypothetical pre-retrofit effluent level of 3.0 mg/l.

3.6.2.2 Cost Effectiveness Ratios: Biological Removal

The are only two studies for which retrofit costs for Biological Phosphorus Removal (BPR) were reported. The HRSD-VIP plant in Virginia, and the new feasibility study for implementation of BNR at the Blue Plains WWTP in the District of Columbia. Table 3.16 shows that retrofitting WWTPs with biological phosphorus removal can be relatively inexpensive. However, there are still questions about the reliability of BPR in meeting a specific effluent level in the long term. For instance, at Blue Plains a full scale demonstration study has been suggested to evaluate the performance of this technology. Nevertheless, if this technology is proven reliable for a particular plant with cost effectiveness ratios about $2 to $3, it seems to be a promising cost effective technology for phosphorus removal. Moreover, sludge handling costs are expected to decrease by using BPR as shown in the Bowie WWTP. Nevertheless, it has been concluded that chemical phosphorus removal facilities may still be needed for permit compliance (backup), or when effluent limitations are below 1.0 mg/l.

Table 3.11 Annual Chemical Phosphorus Removal O&M Retrofit Costs[1]		
Effluent TP Level (mg/l)	TP Influent Level	
	6.0-10.0 mg/l	3.0-6.0 mg/l
	Annual Cost Ranges ($/mgd/Year)	
2.0	25,009-30,893	15,447-19,125
1.0	30,198-38,249	18,389-23,538
0.5	37,513-52,225	22,802-32,365
0.2	50,386-128,723	30,526-79,808

1. Adapted from EPA (1987). Original costs have been escalated to 1990 dollars. Incremental phosphorus removal costs do not include the costs of sludge handling facilities.

Table 3.12 Chemical System Capital Costs[1]					
TP Influent Level	Plant Size (mgd)	Total Phosphorus Effluent Level (mg/l)			
		2.0	1.0	0.5	0.2
6-10 mg/l	<0.1	36,554	36,554	36,554	44,079
	0.1-1	58,056	58,056	58,056	93,534
	>1-5	139,764	139,764	155,890	198,895
	>5-10	182,768	182,768	182,768	215,021
3-6 mg/l	<0.1	36,554	36,554	36,554	44,079
	0.1-1	58,056	58,056	58,056	84,933
	>1-5	123,637	123,637	129,013	198,895
	>5-10	172,017	172,017	182,768	215,021

1. Source EPA (1987). Original costs have been escalated to 1990 dollars. Incremental capital costs are for chemical storage, feed, and piping systems. Cost do not include capital costs for pH equipment, sludge handling facilities or effluent filtration (EPA, 1987).

Table 3.13 Chemical Phosphorus Removal Cost Effectiveness Ratios[1]		
Effluent TP Level (mg/l)	TP Influent Level	
	6.0-10.0 mg/l	3.0-6.0 mg/l
	Cost Ranges per Pound of Phosphorus Removed[2] ($/lb-P/Year)	
2.0	8.90-12.80	5.70-8.70
1.0	5.30-7.60	3.40-5.10
0.5	5.20-8.10	3.30-5.30
0.2	6.20-16.50	3.90-10.70

1. Incremental phosphorus removal costs do not include the costs of additional sludge handling facilities, additional clarification capacity, and pH control.
   Cost effectiveness ranges were estimated by selecting the minimum and maximum annualized cost per pound of phosphorus removed for WWTPs with flows between 1 and 10 mgd.
2. Pounds of phosphorus removed based on a pre-retrofit TP effluent level of 3.0 mg/l.
   Ranges are for WWTPs with design flows smaller than 10 mgd.

Table 3.14 Examples of Phosphorus Removal Cost Effectiveness Ratios: Chemical Addition

WWTP	Technology	Design Flow (mgd)	Pre-Retrofit TP (mg/l)	Post-Retrofit TP (mg/l)	TP Removed[1] (lbs/Year)	EAC/mgd[2] ($/mgd/yr.)	Cost Effectiveness Ratio[3] ($/lb-P/Yr.)
FORT EUSTIS (VA)	Metal Salt Additior, pH Adjustment	3.0	2.47	1.5	8,855	45,622	15.50
FMC (VA)	Metal Salt Addition, pH Adjustment	6.0	2.5	1.5	18,258	58,205	19.10
MASSAPONAX (VA)	Metal Salt Addition, pH Adjustment	6.0	2.5	1.5	18,258	41,272	13.60
PETERSBURG (VA)	Metal Salt Addition, pH Adjustment	15.0	2.16	1.5	30,126	51,167	25.50
HRSD-ARMY BASE (VA)	Metal Salt Addition, pH Adjustment	18.0	2.47	1.5	53,131	6,445	14.50
HRSD-JAMES RIVER (VA)	Metal Salt Addition, pH Adjustment	20.0	2.45	1.5	57,817	73,041	25.30
HRSD-CHESA/ELIZA (VA)	Metal Salt Addition, pH Adjustment	24.0	3.08	1.5	115,391	63,216	13.10
HRSD-BOAT HARBOR (VA)	Metal Salt Addition, pH Adjustment	25.0	2.97	1.5	111,830	63,196	14.10
PROCTORS CREEK (VA)	Metal Salt Addition, pH Adjustment	27.0	2.38	1.5	72,302	31,320	11.70
HRSD-NANSEMOND (VA)	Metal Salt Addition, pH Adjustment	30.0	3.54	1.5	186,232	75,690	12.20
HENRICO (VA)	Low Lime Treatment, pH Adjustment	45.0	2.5	1.5	136,935	18,552	6.10

1 Pounds of phosphorus removed per year at design flow.
2 EAC= Equivalent annual cost: amorized capital costs plus annual O&M costs.
3 Cost Effectiveness ratio = Annual EAC divided by pounds of P removed.
4 TP=1.5 mg/l assumed as annual performance.

Table 3.15 Examples of Actual Phosphorus Removal O&M Cost Effectiveness Ratios: Chemical Addition

WWTP	Tehnology	Design Flow (mgd)	TP Effluent Limit (mg/l)	TP Removed[1] (lbs/Year)	Annual TP Removal Costs per mgd[2] ($/mgd/yr.)	Cost Effectiveness Ratio[3] ($/lb-P/Yr.)
QUANTICO	Multi-point Metal Salt Addition with Effluent Filtration and pH Adjustment	2.0	0.18	17,169	78,594	9.20
AQUIA	Multi-point Metal Salt Addition with Effluent Filtration and pH Adjustment	6.0	0.18	51,506	222,515	25.90
H. L. MOONEY	Multi-point Metal Salt Addition with Effluent Filtraion and pH Adjustment	24.0	0.18	206,025	49,709	5.80
ARLINGTON	Multi-point Metal Salt Addition with Effluent Filtraion and pH Adjustment	40.0	0.18	343,374	47,307	5.50
UOSA	High Lime Treatment with Two-stage Recarbonation and Effluent Filtration	54.0	0.10	476,706	164,689	18.70
ALEXANDRIA	Multi-point Metal Salt Addition with Effluent Filtration and pH Adjustment	54.0	0.18	463,556	80,870	9.40
LOWER POTOMAC	Multi-point Metal Salt Addition with Effluent Filtration and pH Adjustment	72.0	0.18	618,074	63,410	7.40

1 Pounds of phosphorus removed per year at design flow. An effluent level of TP = 3.0 mg/l is assumed if there were not any chemical removal at the plant.

2 Existing annual TP chemical removal costs.

3 Cost Effectiveness ratio = Annual TP removal O&M costs divided by pounds of P removed.

Table 3.16 Examples of Phosphorus Removal Cost Effectiveness Ratios: Biological Removal

WWTP	Technology	Design Flow (mgd)	Pre-Retrofit TP (mg/l)	Post-Retrofit TP (mg/l)	TP Removed[1] (lbs/Year)	EAC/mgd[2] ($/mgd/yr.)	Cost Effectiveness Ratio[3] ($/lb-P/Yr.)
HRSD-VIP (VA)	Biological Nutrient Removal Metal Salt Supplement with pH Adjustment (back-up)	40.0	2.5	1.5	121,720	6,540	2.10
BLUE PLAINS (Secondary Reactors)	A/O (BPR)	90.0	3.1[4]	1.3[5]	492,967	5,477[6]	3.20

1 Pounds of phosphorus removed per year at design flow.
2 EAC= Equivalent annual cost: amortized capital costs plus annual O&M costs.
3 Cost Effectiveness Ratio = Annual EAC divided by pounds of P removed.
4. TP influent level into the west secodary reactor.
5. Assumed post-retrofit TP effluent level from pilot study.
6. Annual costs does not include O&M costs, and A/O process license fee which has a maximum of $500,000. However, total annual savings on chemical cost are estimated as $1,178,678.

4. SUMMARY AND USE OF COST EFFECTIVENESS RATIOS FOR POINT AND NONPOINT SOURCE NUTRIENT REDUCTION TECHNOLOGIES

This section presents a synthesis of the cost effectiveness ratios calculated in this report. The previous sections highlighted some assumptions and limitations when using the available data for the estimate of the cost effectiveness ratios. Cost effectiveness ratios are calculated in order to put nutrient removal technologies on an equal base for comparison. Therefore, use of these ratios for other cost purposes should be done with caution, taking into account the assumptions and source of information used to derive them. Some general issues that need to be taken into account when using this information are as follows:

- Sources of costs for point and nonpoint source nutrient reduction controls are many. In this report, cost information on agricultural and urban nonpoint sources in general reflect costs of already installed BMPs. For point source retrofits of WWTPs, most of the costs are initial estimates from states' studies for retrofitting WWTPs with relatively new BNR technologies. Use of BNR planning level cost equations for retrofitting WWTPs should be done with caution since they were derived assuming generic plant configurations and wastewater characteristics. As pointed out before, site specific conditions such as plant layout and wastewater characteristics are important for the estimate of retrofit costs for nutrient removal.

- BMP nutrient removal efficiencies vary. Factors such as the diffuse nature of nonpoint sources, meteorology, and site-specific conditions such as soils, slopes, crop practices, farmer diligence, etc. make BMP nutrient removal effectiveness highly variable. Estimates of basin-scale nutrient reductions associated with the implementation of BMPs have come from the results of the Chesapeake Bay Watershed Model supplemented by research studies from field scale models, field plot studies, small watershed demonstration projects and conceptual models.

- In conclusion, use of the point and nonpoint source nutrient reduction cost effectiveness ratios summarized below for any purpose other than gross comparison would require a careful examination of the assumptions of each estimate.

4.1 Nonpoint Sources

For nonpoint sources, cost effectiveness ranges are shown for agricultural BMPs (Figure 4.1). The cost effectiveness ratios are defined as the total BMP cost divided by the pounds of nitrogen or phosphorus removed. Therefore, the BMP costs were not apportioned to each nutrient. The costs are joint costs of removing both nutrients. Some BMPs may emphasize the removal of either nitrogen or phosphorus for which the total BMP cost is mainly associated with the removal of that nutrient. Alternatively, there are BMPs that provide multiple benefits besides nutrient removal such as removal of sediment, heavy metals, etc. For these BMPs, the total cost is the joint cost for of providing all the benefits.

Urban nonpoint source cost effectiveness ratios are not shown in Figure 4.1. However, the results presented by Freudberg and Lugbill (1990) in an adaptation of the work on urban BMP cost effectiveness by the Metropolitan Washington Council of Governments (Wiegand et al. 1986) showed cost effectiveness ratios to be highly variable. Nitrogen cost effectiveness ratios for ponds and infiltration systems varied between $1 and $128 per pound of nitrogen removed. Similarly, phosphorus cost effectiveness ratios ranged from $7 to $886 per pound of phosphorus removed. In this study, cost effectiveness ratios of urban BMPs (dry and wet ponds, and infiltration trenches and basins, and porous pavement) were given for three drainage areas (1 ,10, and 25 acres) for land uses described as: single family residential, townhouse residential and commercial shopping center. Phosphorus removal cost effectiveness ratios for wet ponds varied between $54/lb-P/year for a 25 acre shopping center to $367/lb-P/year for a 10 acre single family residential area. Nitrogen removal cost effectiveness ratios for wet ponds varied between $14/lb-N/year for a 25 acre shopping center to $94/lb-N/year for a 10 acre single family residential area. Cost effectiveness ratios were higher for infiltration trenches and porous pavement, and lower for dry ponds.

Recently, an evaluation of BMPs in the Occoquan watershed by the Northern Virginia Planning District Commission (1990), reported cost effectiveness ranges for phosphorus removal within the range of the ones reported by Freudberg and Lugbill. Without on-site controls, cost effectiveness ratios of approximately $140/lb-P/year and $165/lb-P/year were reported for regional coverage (percent of drainage area under BMP) of 25% and 50% respectively. With on-site controls, cost effectiveness ratios of approximately $260/lb-P/year and $325/lb-P/year were reported for regional coverage of 25% and 50% respectively.

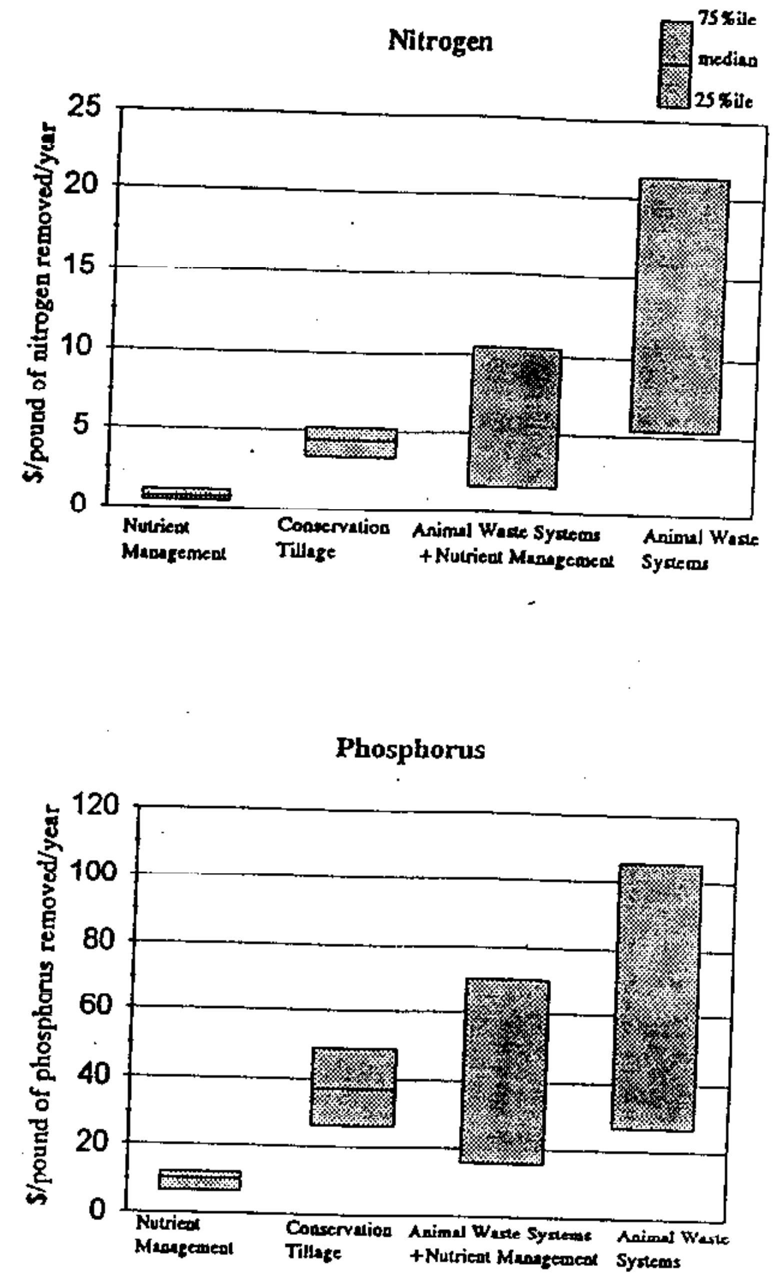
In conclusion, although urban BMP cost effectiveness ratios appear to be high, it should be kept in mind that some of these controls also are providing stormwater management control, removal of other pollutants such as sediment and heavy metals, and sometimes recreational amenities. Furthermore, irrespective of relative cost effectiveness compared to agricultural BMPs or point source controls, urban BMPs will play a major role in pollutant load control from the increased development in the Chesapeake Bay region over the next years.

4.2 Point Sources

Interquartile cost effectiveness ranges from the states' retrofit studies, as well as from some of the nutrient removal WWTPs in operation are shown in Figure 4.2. Information used to calculate the cost effectiveness ratios for retrofitting municipal WWTPs allowed the separation of the cost of removing each nutrient independently.

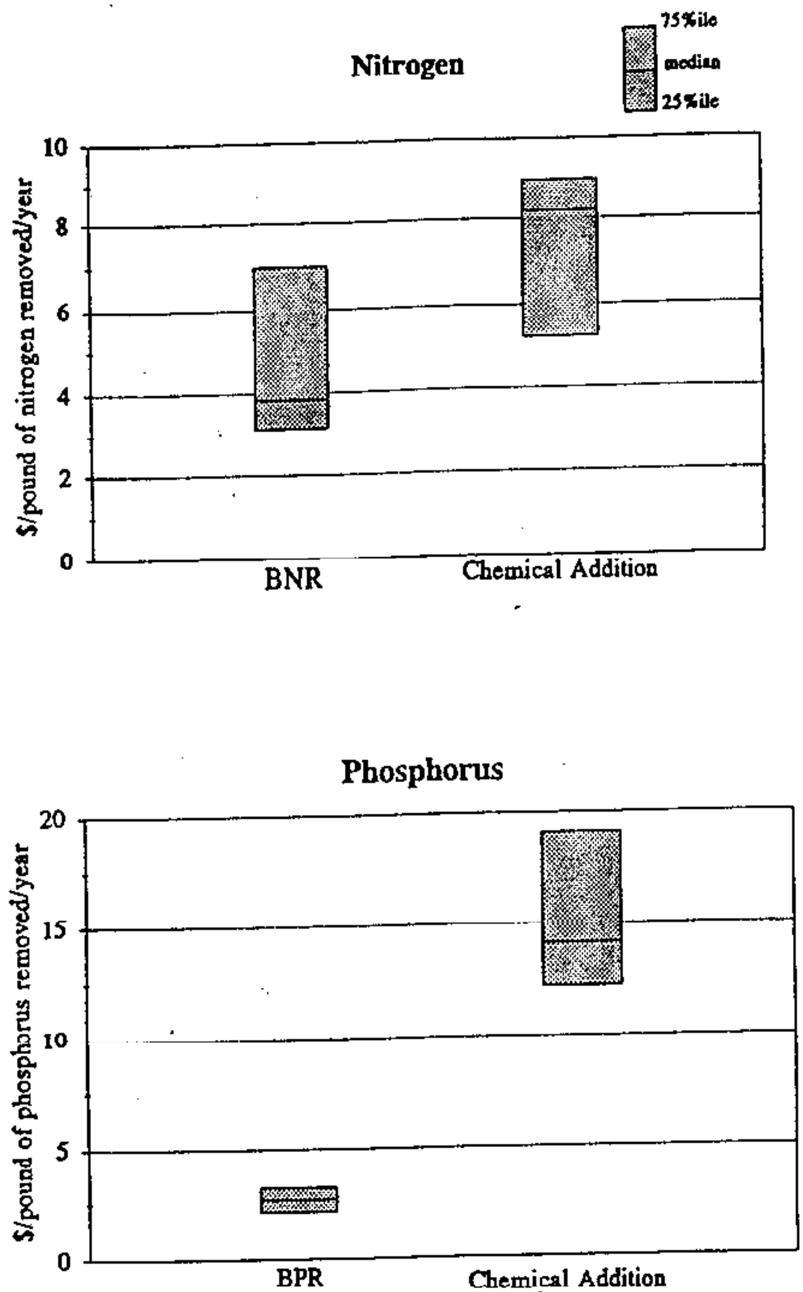
Figure 4.2 shows that biological nitrogen removal can be cost effective compared to chemical addition (methanol) for nitrogen removal. However, the ranges show that for nitrogen removal, some chemical addition cost effectiveness ratios may be comparable to the ones for BNR. For instance, from the recent retrofit study at the Blue Plains WWTP (MacNamee, Porter and Seeley, 1990), it can be concluded that methanol addition at this plant can be cost effective if the proposed retrofit works as assumed. Based on the limited data on biological phosphorus removal (BPR), it appears that the biological removal of phosphorus can be cost effective compared to chemical addition. If BPR is proven operationally reliable for a given plant, additional cost savings in the use of chemicals and sludge handling may be achieved.

Figure 4.1 Financial Cost Effectiveness Ratios for Nonpoint Sources (Interquartile Ranges)



Cost effectiveness ratios are calculated as the ratio of the total annualized BMP cost divided by the pounds of nitrogen or phosphorus removed per year. Interquartile ranges reflects different nutrient removals within the Chesapeake Bay Basin. Nutrient Removals are based on the Chesapeake Bay Watershed model.

Figure 4.2 Financial Cost Effectiveness Ratios for Point Sources (Interquartile Ranges)



Cost effectiveness ratios for nitrogen are calculated as the total annualized cost for nitrogen removal divided by the pounds of nitrogen removed per year. Similarly, cost effectiveness ratios for phosphorus are calculated as the total annualized cost for phosphorus removal divided by pounds of phosphorus removed per year. Nutrient removals are calculated at the "end-of-pipe". The information shown in these figures came from the states' nutrient removal retrofit studies for municipal WWTPs and some existing retrofits in Maryland as summarized in the Tables of Chapter 3.

5. SUMMARY AND CONCLUSIONS

This report provides information on the cost and effectiveness of point and nonpoint source nutrient reduction controls applicable to the Chesapeake Bay drainage area. This report may be used as a resource document, along with other information provided by the 1991 Reevaluation and the Chesapeake Bay jurisdictions, to determine the best mix of point and nonpoint source controls to achieve tributary nutrient reduction targets. The report also may be used for costing different nutrient reduction scenarios in the Watershed Model. Nonpoint source BMP unit costs (in dollars per acre) given in this report can be used in conjunction with the watershed model to determine the cost and nutrient reductions associated with a given test scenario. For point sources, unit cost information (in dollars per mgd) from the states' retrofit studies can be used for upgrades of WWTPs. The planning level cost equations developed in this report may be used as a first rough estimate, where appropriate, for facilities where no site-specific cost estimates have been developed. These estimates may help in the evaluation of different BNR options at those facilities. Costs of both point and nonpoint source nutrient reduction controls together with the nutrient reductions obtained with the Watershed Model, can be used with optimization tools to identify cost effective nutrient reduction strategies for a watershed.

There still is much to be learned about the cost effectiveness of nutrient controls. For instance, the performance and reliability of BNR processes, the effectiveness of agricultural and urban BMPs, and the water quality responses from implementation of these controls are examples of issues that are expected to be understood better in the future. Nevertheless, this report provides an insight into the cost effectiveness of existing nutrient technologies as well as estimates of the cost effectiveness of some of the relatively new emerging technologies for nutrient removal. Also, it is important to point out that there are other technologies for nutrient removal which were not discussed in this report. Some of these technologies include: subsurface wastewater infiltration systems including "septic tanks," slow rate, rapid infiltration and overland flow land treatment systems, and other natural systems. Information on the characteristics and performance of these systems can be found in "Natural Systems for Wastewater Treatment" (WPCF, 1990).

Evaluation of the most cost effective mix of point and nonpoint source nutrient reduction controls for a particular region also would require careful examination of other issues in addition to the financial cost and the nutrient removal effectiveness. For instance, impact of the adoption of BMPs on farms' net income and the productivity of the land may play important roles in the selection of alternatives to achieve a predetermined water quality goal. The quality of the receiving waters also may influence allocation of resources for nutrient reduction controls. These issues require site specific analysis and extrapolation to other sites is generally difficult.

Based on the cost effectiveness information presented in this report, and other aspects related to the implementability of point and nonpoint source nutrient reduction controls, the following conclusions are presented for the nonpoint and point source nutrient reduction controls examined:

Nonpoint Sources

Recently, Heatwole et al. (1991), pointed out that the mechanisms of BMPs in reducing pollutants such as nutrients can be grouped into three processes: 1) reducing the volume of the carrier which is mainly water and sediment, 2) reducing the concentration of the pollutants, and 3) reducing the delivery of the nutrients from the fields to the receiving waters. A combination of BMPs ("Resource Management Systems") can achieve nutrient reductions in these three processes. Within the framework of these processes and with the financial cost effectiveness information presented in this report, the following is concluded:

- BMP cost effectiveness should not be judged only on individual BMP nutrient reduction performance, but rather on combinations of BMPs or "Resource Management Systems" that achieve a desired water quality goal, by reducing pollutant loads with the three processes described above. The assessment of the nutrient reduction effectiveness of resource management systems has been performed by monitoring in small watershed demonstration projects, as well as by using small watershed and field-scale water quality models.

- In-field BMPs such as conservation tillage and strip-cropping are examples of cost effective BMPs that reduce both runoff and sediment. A recent study by Epp (1991) showed that adoption of these BMPs resulted in a positive net field income with or without cost-share in two out of three counties analyzed.

- In-field BMPs that reduce the carrier mass (runoff and sediment) such as terraces and conservation tillage can increase infiltration, thus increasing the potential of pollutant leaching into the groundwater. Conservation tillage may increase the concentration of pollutants in the soil surface (McIsaac, et al., 1991; Heatwole, et al., 1991; Staver et al., 1988; Laflen and Tabatabai, 1984). Therefore, any reductions achieved through surface runoff and sediment reductions may be offset by the increase in pollutant concentrations and the potential leaching of pollutants into the groundwater. However, with nutrient management (i.e. proper fertilizer application rates, timing, and methods) nutrient losses to both surface waters and groundwater can be reduced. This accounts for the favorable cost effectiveness of nutrient management.

- Results of the Watershed Model show nutrient management to be the most cost effective BMP (Figure 4.1). Also, from field-scale research studies, nutrient management in combination with in-field BMPs such as strip-cropping, conservation tillage and winter cover crops (where appropriate) have been found cost effective management alternatives for nutrient reduction.

- Winter cover crops have been found very effective in removing excess nitrates during the non-growing season after the main crop harvest. Excess nitrates accumulated in the soil may be significant after dry periods during the growing season.

- Edge-of-field BMPs that reduce pollutant delivery into streams may be required for cases where nutrient loads are high due to increased runoff concentrations and sediment loads in large fields with long slope lengths. Some of these BMPs are structural BMPs such as erosion or water control structures, or non-structural BMPs such as filter strips, riparian zones etc. However, structural BMPs are often expensive (see Figure 1-a), and despite the cost-share money available, implementation of these BMPs can result in a negative net field income (Hamlett and Epp, 1991). Also, despite the benefits of some of these structural BMPs in decreasing the sediment loads delivered into the streams, they should be accompanied by an in-field BMP to protect against severe soil losses that can have detrimental effects on the long term productivity of the fields.

- Conversion of highly erodible land (HEL) to permanent vegetation has been shown to be cost effective since it can considerably reduce sediment, runoff, and nutrient loads.

- Animal waste has been identified as a significant contributor of nutrient loads. Animal waste management systems should be considered important components of "Resource Management Systems." Proper design of animal waste facilities, including collection, storage, and transport, together with waste utilization will make these facilities effective. It was shown that animal waste management systems including all of the above controls, can be expensive. Nevertheless, experiences from the Rural Clean Water Program (U.S.

EPA, 1990) projects show that simple cost effective measures such as keeping animals away from the streams, controlling animal waste runoff, and protecting riparian areas can be effective components of animal waste systems.

- Studies on urban BMPs have shown wide ranges of cost effectiveness ratios. However, it should be pointed out that some urban BMPs can have multiple functions, which were not addressed in this report, such as aesthetics, water quantity control, and removal of sediment, petroleum hydrocarbons and heavy metals.

Point Sources

As mentioned before, there is still much to be learned about the reliability of the new emerging nutrient reduction technologies for municipal WWTPs. Effluent performance levels, operational experiences, and costs are important elements to be considered in a cost effectiveness analysis using these nutrient reduction technologies. With the data available today, and the relatively few full scale operational BNR technologies, the following conclusions are presented:

- Biological Phosphorus Removal (BPR) can be a cost effective alternative for phosphorus removal (Figure 4-b). It has potential for cost savings in chemical use and sludge handling. However, site-specific economic evaluations as well as the reliability of this technology for each plant should be carefully investigated to show its cost effectiveness. The Bowie plant in Maryland showed significant cost savings by using BPR, and its annual effluent performance levels prove that this technology can be cost effective. Similarly, the feasibility study found retrofitting Blue Plains with BPR to be cost effective. Also, it is important to point out that plants that implement BPR technologies may need chemical phosphorus removal facilities as a backup for permit compliance or when the effluent requirements are below 1.0 mg/l.

- Biological Nitrogen Removal has been found cost effective. Full-scale retrofits of WWTPs have supported this finding. However, planning level studies show, for certain facilities, that chemical addition (methanol) also can be cost effective. Therefore, the selection of chemical addition vs. Biological Nitrogen Removal without the use of chemicals would depend on site specific constraints.

- Seasonal nitrogen removal appears more cost effective than annual removal. Costs can significantly increase for annual removal (see Figure 2) because at lower temperatures biological activity is reduced. Therefore, longer wastewater retention times are needed requiring larger reactor tank sizes, thereby increasing costs. In addition, selection of the months for seasonal nitrogen removal and the permit compliance period can have a significant impact on the retrofit designs and therefore the costs associated with meeting the required effluent limitations.

- Regulatory measures such as the phosphate detergent ban have proven to be cost effective. Due to lower influent phosphorus levels to WWTPs, the chemical use required to meet the effluent level limitations and the amount of sludge created will decrease. Reduction in sludge and chemical use for phosphorus removal can significantly decrease the O&M costs in a WWTP. Another example of a regulatory measure being suggested is the adoption of permitting approaches such as the "bubble concept" (Virginia Retrofit Study) where the combined nutrient discharge of a group of plants are also regulated within a tributary, basin, etc. This approach would allow flexibility in the implementation of the most cost effective nutrient removal alternatives to a subset of plants within the "bubble". Nevertheless, individual permit limitations would still be required according to a careful examination of the quality of the receiving waters.

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GLOSSARY: NONPOINT SOURCES

Conservation Tillage - "Any tillage or planting system that leaves at least 30% of the soil surface covered with crop residue after planting". Or it may be simply defined as any tillage system involving less soil disturbance than conventional tillage. Examples are: no-till, ridge tillage, mulch tillage, strip tillage etc.

Conventional Tillage - Complete inversion of the soil incorporating all residues with a moldboard plow or any practice with less than 30% residue.

Contour Farming - Farming along the contour on slopes generally less than 8%.

Diversion[1] - A channel with a supporting ridge on the lower side constructed across or at the bottom of the slope for the purpose of intercepting surface runoff.

Filter Strips - Vegetated filter strips are areas of close-growing grasses or other vegetation placed down gradient from pollutant areas to filter pollutants carried by runoff.

Grassed Waterways - A natural or artificial channel covered with flow resistance grasses used to conduct water and protect against the formation of rills or gullies.

No-till - Planting of crops in a small slot leaving the residue from the previous crop undisturbed.

Nutrient Management[2] - A management practice which provides recommendations on optimum nutrient application rates, nutrient application times, and nutrient application methods based on soil and manure analysis results and expected crop yields.

Ponds and Reservoirs[1] - Ponds and reservoirs are bodies of water created by constructing a dam or embankment across a water course or by excavating a pit or dugout. Ponds constructed by the first of these methods are referred to herein after as "Embankments Ponds" and those constructed by the latter methods as "Excavated Ponds". Ponds resulting from both excavation and embankment are classified as Embankment Ponds where the depth of water impounded against the embankment at emergency.

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1 Virginia Erosion and Sediment Control Handbook (VA-DSWC, 1992)

2 Nutrient Reduction Task Force (Chesapeake Bay Program Nonpoint Source Subcommittee)

Farm Plan[3] - For the purposes of the Chesapeake Bay watershed model, a resource management system for a farm consisting of soil conservation erosion controls for cropland. These controls may include: contour farming, strip-cropping, terraces, cover crops, grassed waterways, filter strips, diversions, and sediment retention, erosion, or water control structures. The "Farm Plan" does not include conservation tillage and nutrient management which are covered in other Chesapeake Bay Watershed Model BMP categories.

Strip-cropping - Alternating close grown crops such alfalfa with row crops in strips. The strips can be also grown following the contour (contour strip-cropping).

Terraces[4] - An earth embankment, or a ridge and channel, constructed across the slope at a suitable location to intercept surface runoff water. It may be constructed with an acceptable grade to an outlet or with a level channel ridge.

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[3] Nutrient Reduction Task Force (Chesapeake Bay Program Nonpoint Source Subcommittee)

[4] Virginia Erosion and Sediment Control Handbook. (VA-DSWC, 1992)

Activated Sludge - A biological process for wastewaters. The settled wastewater is mixed with the activated sludge in an aerated tank. Settled sludge is removed or returned to aeration tank as needed.

A/O™ - A biological nutrient removal process consisting of a two-stage single sludge system. This process is generally used for phosphorus removal and includes an aerobic tank preceded by an anaerobic tank.

A^2/O™ - A biological nutrient removal system similar to the A/O with an anoxic tank preceding the aerobic tank. Both nitrogen and phosphorus are removed. The A/O as well as the A^2/O processes were patented by Air Products and Chemicals, Inc. in the 1970s.

Aerobic - In the presence of oxygen

Air Stripping - A wastewater treatment process primarily used to remove ammonia. The Ph of the wastewater is increased with lime and passed through a stripping column where ammonia is volatilized. Also, phosphates are precipitated with the addition of lime.

Anaerobic[1] - (1) A condition in which no free oxygen is available. (2) Requiring, or not destroyed by, the absence of air or free oxygen.

Anoxic - In the absence of oxygen but with the presence of nitrates (Beavin Co., Camp Dresser & McKee, and Metcalf & Eddy, 1989).

Bardenpho™ - A single sludge wastewater treatment process with two anoxic zones followed by an aerobic zone. In the five-stage Bardenpho, an anaerobic zone (fermentation zone) precedes the first anoxic zone. The return activated sludge (RAS) is returned to the fist anoxic zone in the 5-stage Bardenpho and to the anaerobic zone in the 5-stage Bardenpho. The 4-stage process is generally used to remove nitrogen. Bardenpho is an acronym for BAR = due to Dr. James Barnard of South Africa who developed the system; DEN = denitrification; and PHO = phosphorus removal.

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1 Glossary: Water and Wastewater Control Engineering. 3rd Edition. Published by: American Public Health Association, American Society of Civil Engineers, American Water Works Association, and Water Pollution Control Federation.

Breakpoint Chlorination - A treatment process used to remove ammonia by oxidizing it into nitrogen gas.

Complete Mix - An activated sludge process with the highest load of BOD per unit volume in the aeration tank.

Contact Stabilization - An activated sludge process where return activated sludge (RAS) is aerated before it enters the aeration tank.

Deep Bed Denitrification Filters - A wastewater treatment process where methanol or another organic substrate is added to the filter media at a typical depth of 6 feet.

Extended Aeration - An activated sludge process which exposes the wastewater to long periods of aeration (greater that 24 hours).

Fixed Film - see Trickling Filter or Rotating Biological Contactor

Fluidized Bed Reactors - A wastewater treatment process where the wastewater is usually fed at the bottom of the filter expanding the filter media. Organic substrate is usually required for denitrification.

Ion Exchange - A non-biological wastewater treatment process primarily used for ammonia removal. The process involve exchange of ions between the wastewater and a ion exchange resin.

Oxidation Ditch - An extended aeration activated sludge process which uses a horizontal rotor to provide mechanical aeration in a closed loop channel.

Plug Flow[1] - Flow in which fluid particles are discharged from a tank or pipe in the same order in which they entered it. The particles retain their discrete identities and remain in the tank for a time equal to the theoretical detention time.

Pure Oxygen- An activated sludge process which uses oxygen instead of air for aeration.

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[1] Glossary: Water and Wastewater Control Engineering. 3rd Edition. Published by: American Public Health Association, American Society of Civil Engineers, American Water Works Association, and Water Pollution Control Federation.

Rotating Biological Contactor - A wastewater treatment process where the wastewater is passed trough a series of rotating chambers with plastic media where biological film is formed. The blade rotates around a horizontal shaft. The rotating chambers are approximately 40% submerged in the wastewater.

Sequencing Batch Reactors - A wastewater treatment process where biological reactions and clarification occur in one tank or in a multiple series of alternating tanks.

Step Aeration - An activated sludge process where wastewater is introduced at different points in the aeration tank.

Trickling Filter - A wastewater treatment process where the wastewater is sprayed on a filter of crushed rocks, plastic media etc. The wastewater is biologically treated under aerobic conditions where aerobic microorganisms assimilate and oxidize the wastewater. Low rate trickling filter is usually 5 to 10 feet deep, and the high rate trickling filter is 3 to 6 feet deep.

UCT™ - A wastewater treatment process developed at the University of Capetown similar to the Bardenpho process except that the return activated sludge is directed to the first anoxic tank to enhance phosphorus removal.

APPENDIX A

Edge-of-Stream Nutrient Loading Factors, Land Use Acreage, and Transport Factors*
Chesapeake Bay Watershed Model

* Source: Obtained from the Watershed Model Base Case Scenario Output Files (CBPO, 1992)

Table A-1 Nitrogen Loading Factors: Conventional Tillage, Conservation Tillage and Hayland
Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Nitrogen in lbs/acre

Segment	Conventional Tillage Acres	Conventional Tillage LF	Conservation Tillage Acres	Conservation Tillage LF	Hayland Acres	Hayland LF
10	100,723	20.1	10,869	16.7	226,565	10.8
20	160,951	19.0	10,943	16.7	401,085	11.0
30	78,620	18.8	14,797	18.0	240,216	12.1
40	126,240	21.6	54,651	17.7	63,556	11.0
50	37,257	33.2	9,509	32.7	54,900	17.7
60	66,122	31.1	43,988	29.1	134,578	17.1
70	62,800	25.9	44,435	24.3	62,979	15.3
80	144,248	24.9	133,753	21.2	149,693	7.9
90	24,395	23.4	29,316	20.0	71,198	8.8
100	91,758	21.4	62,717	18.1	148,417	7.6
110	173,581	31.7	200,603	24.0	152,836	11.2
120	104,846	23.4	85,976	19.4	70,578	7.7
140	27,034	20.2	37,578	15.8	20,404	7.5
160	17,350	24.6	11,180	17.2	57,926	6.1
170	7,080	23.4	2,998	18.7	37,911	11.1
175	13,174	24.5	11,118	18.5	41,362	10.1
180	84,971	23.1	168,939	19.3	199,500	5.3
190	21,425	33.9	49,723	28.2	116,083	8.5
200	22,470	28.3	32,018	22.2	88,901	7.3
210	38,588	23.2	127,498	18.9	97,542	6.0
220	8,121	17.6	69,422	13.5	71,578	5.4
230	25,054	15.2	37,390	11.0	121,214	10.3
235	7,131	20.5	5,094	16.0	8,852	9.4
240	4,081	17.3	18,703	13.3	2,816	7.4
250	9,007	25.8	5,830	20.5	14,837	10.1
260	17,381	22.0	28,427	16.7	28,076	9.3
265	335	22.3	738	17.9	10,845	8.9
270	8,075	31.9	37,671	24.2	162,192	11.6
280	25,308	23.0	29,341	17.8	147,753	10.4
290	11,562	23.3	14,252	17.4	21,120	8.4
300	33,120	24.2	37,019	18.4	52,912	8.4
310	8,054	23.0	2,600	18.2	217	7.7
330	2,225	17.4	10,233	14.5	4,845	5.2
340	4,956	18.5	8,806	14.5	5,352	4.8
ANACOSTIA	4,486	22.8	5,712	16.8	3,966	10.4
BALT_HARBOR	2,193	15.4	3,558	12.1	1,718	6.3
BOHEMIA	2,891	18.0	5,875	13.9	1,924	4.4
CHESTER	26,375	17.5	115,199	14.2	7,451	5.4
CHICKAHOMINY	5,661	20.2	13,915	15.4	3,729	9.1
CHOPTANK	80,022	17.6	103,255	13.9	6,059	5.0
COASTAL_1	58,234	17.9	131,680	13.2	8,949	4.0
COASTAL_11	40,061	16.3	68,763	14.3	41,278	5.0
COASTAL_4	35,242	16.5	23,897	12.6	297	5.1
COASTAL_5	4,553	17.2	5,191	12.4	3,353	5.7
COASTAL_6	3,883	14.0	9,975	11.4	5,048	5.1
COASTAL_8	37,840	18.6	11,244	15.3	2,045	10.0
COASTAL_9	5,854	17.4	20,614	13.7	213	9.5
ELIZABETH	1,187	21.1	1,433	15.0	3	11.4

Table A-1 Nitrogen Loading Factors: Conventional Tillage, Conservation Tillage and Hayland

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Nitrogen in lbs/acre

	Conventional Tillage		Conservation Tillage		Hayland	
Segment	Acres	LF	Acres	LF	Acres	LF
GREAT_WICOMICO	8,774	21.3	3,167	17.3	133	9.7
GUNPOWDER	14,662	15.4	26,048	12.2	13,068	6.7
JAMES	43,813	18.6	45,912	15.4	5,829	9.5
NANSEMOND	15,119	23.9	19,434	19.7	349	10.9
NANTICOKE	74,878	25.0	137,165	22.3	7,919	4.7
OCCOQUAN	4,508	21.4	23,599	15.8	41,292	11.1
PATAPSCO	20,211	16.1	36,968	11.6	21,148	5.2
PATUXENT	26,009	19.0	12,075	13.2	9,760	7.6
POCOMOKE	40,847	24.8	79,758	21.2	2,839	3.8
POTOMAC	93,729	20.5	56,477	14.4	28,398	8.1
RAPPAHANNOCK	90,525	20.9	38,466	17.0	7,942	10.7
SEVERN	377	18.7	897	14.1	630	5.9
WICOMICO	23,068	20.5	12,012	17.8	752	4.8
WYE	10,255	18.3	19,856	14.6	1,028	4.9
YORK	44,936	18.5	44,700	15.3	8,220	11.0

Table A-2 Nitrogen Loading Factors: Pasture, Animal Waste, Forest and Urban

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Nitrogen in lbs/acre

Segment	Pasture		Animal Waste		Forest		Urban	
	Acres	LF	Acres	LF	Acres	LF	Acres	LF
10	159,325	4.14	614	1858.2	984.938	2.72	199,187	8.04
20	300,413	7.13	1,716	2203.7	1,844,310	5.92	420,461	10.98
30	145,469	7.37	668	2234.5	875,001	5.49	105,210	11.78
40	29,624	7.85	149	2514.5	570,931	6.50	96,136	12.47
50	73,066	5.43	94	2633.5	679,540	3.45	56,731	10.49
60	139,180	6.88	402	2286.9	2,254,498	5.04	78,824	12.13
70	31,756	6.17	193	2191.5	610,012	4.74	32,814	11.87
80	76,049	13.22	614	2110.4	802,377	11.34	134,620	16.56
90	50,173	8.03	211	2193.9	394,793	7.89	16,180	12.41
100	87,849	7.63	607	1962.9	1,076,335	7.47	74,940	12.33
110	127,594	11.23	792	1932.7	416,256	6.48	146,910	15.16
120	58,097	22.27	806	2014.3	80,692	12.00	73,096	23.18
140	24,304	15.47	160	1899.7	52,115	8.63	26,872	15.77
160	108,588	9.35	145	2099.4	614,346	3.91	48,740	9.97
170	148,161	9.90	108	1936.1	726,540	3.95	22,927	10.76
175	105,876	7.67	128	1788.8	584,313	3.21	46,443	8.82
180	220,191	7.09	925	1778.8	722,664	3.80	198,101	8.55
190	211,836	6.84	522	2025.7	594,668	3.71	40,625	8.90
200	200,709	5.82	412	1695.5	503,065	2.74	50,154	7.90
210	79,147	8.55	540	2059.0	189,716	3.98	83,164	9.67
220	105,951	7.62	186	1881.9	209,156	3.19	146,032	7.76
230	224,145	3.29	391	2181.5	577,312	1.02	38,857	6.86
235	7,370	3.06	21	2136.2	123,800	0.79	11,106	3.56
240	2,337	2.88	9	2136.2	176,769	0.81	9,702	3.43
250	22,253	3.45	50	2136.2	146,892	1.57	11,153	3.42
260	24,010	3.11	71	2136.2	335,375	0.84	37,553	4.34
265	19,176	4.65	13	1884.6	189,339	1.04	2,350	6.30
270	233,212	6.71	316	2185.4	1,364,448	1.24	58,967	8.17
280	269,838	5.82	331	2332.1	1.356.569	1.49	74,187	7.32
290	32,646	4.54	57	2118.3	222,413	1.15	21,071	6.24
300	80,932	3.87	137	2118.3	525,824	1.00	33,036	6.50
310	4,191	3.87	8	2118.3	71,259	1.01	11,673	5.97
330	8,477	3.87	23	1893.0	25,606	1.49	30,668	7.09
340	10,534	3.24	26	1893.0	45,387	1.59	53,586	9.34
ANACOSTIA	3,532	6.37	11	1847.2	33,308	2.52	52,442	8.28
BALT_HARBOR	3,540	6.13	10	1858.9	14,612	2.46	26,055	8.29
BOHEMIA	1,867	5.90	12	1663.3	13,354	2.34	11,089	7.31
CHESTER	5,493	5.84	72	1663.3	77,240	2.50	30,044	7.25
CHICKAHOMINY	4,013	7.72	11	2007.7	96,481	2.83	32,942	12.78
CHOPTANK	5,884	5.71	49	1663.3	135,173	2.42	40,276	7.51
COASTAL_1	9,108	5.34	71	1663.3	249,573	2.36	50,373	6.48
COASTAL_11	49,235	6.52	321	1858.9	164,399	2.50	107,100	8.24
COASTAL_4	2,658	6.71	2	1687.3	123,651	2.64	6,204	7.47
COASTAL_5	3,147	5.79	2	1687.3	62,007	2.53	42,370	7.80
COASTAL_6	7,632	6.36	5	1847.2	38,912	2.53	33,815	8.09
COASTAL_8	7,143	2.77	28	1858.9	197,054	1.26	25,137	6.61
COASTAL_9	1,361	8.44	7	2055.8	54,841	3.01	44,327	15.20
ELIZABETH	112	8.34	0	2007.7	6,276	3.04	3,431	13.72

Table A-2 Nitrogen Loading Factors: Pasture, Animal Waste, Forest and Urban

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Nitrogen in lbs/acre

Segment	Pasture		Animal Waste		Forest		Urban	
	Acres	LF	Acres	LF	Acres	LF	Acres	LF
GREAT_WICOMICO	990	2.59	1	2055.8	23,861	1.27	2,023	4.67
GUNPOWDER	22,795	6.69	72	1858.9	88,338	2.58	126,398	9.65
JAMES	18,257	8.27	30	2007.7	525,519	2.90	105,949	13.31
NANSEMOND	3,860	8.28	5	2007.7	73,812	2.97	16,444	13.15
NANTICOKE	4,579	6.42	37	1663.3	239,890	2.46	46,993	7.27
OCCOQUAN	50,331	6.21	97	1847.2	150,755	2.54	55,594	7.33
PATAPSCO	29,197	6.15	110	1858.9	88,664	2.45	80,015	7.93
PATUXENT	7,105	6.28	15	1847.2	163,992	2.54	128,881	7.87
POCOMOKE	5,601	6.35	22	1663.3	326,226	2.47	23,929	7.42
POTOMAC	38,337	5.83	65	1847.2	628,468	2.51	297,355	7.46
RAPPAHANNOCK	17,024	2.67	86	2055.8	422,678	1.27	31,801	4.98
SEVERN	673	5.57	2	1847.2	12,270	2.42	14,288	7.25
WICOMICO	1,249	6.17	4	1663.3	81,851	2.33	18,478	7.29
WYE	1,164	5.53	10	1663.3	15,138	2.39	8,274	6.77
YORK	12,615	2.33	44	2055.8	401,542	1.12	59,765	8.92

Table A-3 Phosphorus Loading Factors: Conventional Tillage, Conservation Tillage and Hay
Chesapeake Bay Watershed Model Base Case Scenario
Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Phosphorus in lbs/acre

Segment	Conventional Tillage Acres	Conventional Tillage LF	Conservation Tillage Acres	Conservation Tillage LF	Hayland Acres	Hayland LF
10	100,723	1.7	10,869	1.4	226,565	1.3
20	160,951	1.8	10,943	1.5	401,085	1.2
30	78,620	1.7	14,797	1.5	240,216	1.4
40	126,240	2.3	54,651	1.7	63,556	1.9
50	37,257	2.2	9,509	1.9	54,900	1.5
60	66,122	2.2	43,988	1.9	134,578	1.3
70	62,800	2.4	44,435	1.9	62,979	1.8
80	144,248	2.7	133,753	2.2	149,693	1.7
90	24,395	2.7	29,316	2.3	71,198	1.4
100	91,758	2.3	62,717	2.0	148,417	1.0
110	173,581	4.4	200,603	3.1	152,836	1.7
120	104,846	2.9	85,976	2.3	70,578	1.3
140	27,034	2.9	37,578	2.3	20,404	1.7
160	17,350	2.1	11,180	1.8	57,926	2.6
170	7,080	2.5	2,998	2.1	37,911	2.5
175	13,174	2.4	11,118	2.1	41,362	2.4
180	84,971	2.4	168,939	2.2	199,500	1.8
190	21,425	4.7	49,723	3.9	116,083	1.6
200	22,470	3.5	32,018	2.8	88,901	1.4
210	38,588	2.6	127,498	2.2	97,542	1.3
220	8,121	2.2	69,422	1.7	71,578	1.3
230	25,054	1.6	37,390	1.1	121,214	0.8
235	7,131	2.7	5,094	2.1	8,852	1.9
240	4,081	1.9	18,703	1.5	2,816	1.3
250	9,007	3.2	5,830	2.3	14,837	1.7
260	17,381	3.0	28,427	2.1	28,076	1.6
265	335	2.1	738	1.6	10,845	1.5
270	8,075	3.5	37,671	2.5	162,192	2.1
280	25,308	2.7	29,341	2.0	147,753	2.0
290	11,562	2.4	14,252	1.7	21,120	1.4
300	33,120	3.1	37,019	2.2	52,912	1.7
310	8,054	2.5	2,600	1.9	217	1.5
330	2,225	2.0	10,233	1.5	4,845	0.7
340	4,956	2.4	8,806	1.6	5,352	0.7
ANACOSTIA	4,486	3.5	5,712	2.3	3,966	1.4
BALT_HARBOR	2,193	1.6	3,558	1.1	1,718	0.7
BOHEMIA	2,891	1.3	5,875	1.0	1,924	0.4
CHESTER	26,375	1.3	115,199	1.0	7,451	0.5
CHICKAHOMINY	5,661	1.4	13,915	1.1	3,729	0.7
CHOPTANK	80,022	1.2	103,255	0.9	6,059	0.4
COASTAL_1	58,234	1.4	131,680	1.0	8,949	0.5
COASTAL_11	40,061	1.7	68,763	1.3	41,278	0.7
COASTAL_4	35,242	1.2	23,897	0.9	297	0.7
COASTAL_5	4,553	2.1	5,191	1.4	3,353	0.7
COASTAL_6	3,883	1.6	9,975	1.1	5,048	0.6
COASTAL_8	37,840	1.6	11,244	1.2	2,045	1.0
COASTAL_9	5,854	1.5	20,614	1.1	213	0.8
ELIZABETH	1,187	2.2	1,433	1.5	3	1.1

Table A-3 Phosphorus Loading Factors: Conventional Tillage, Conservation Tillage and Hay

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Phosphorus in lbs/acre

	Conventional Tillage		Conservation Tillage		Hayland	
Segment	Acres	LF	Acres	LF	Acres	LF
GREAT_WICOMICO	8,774	2.0	3,167	1.6	133	1.3
GUNPOWDER	14,662	1.6	26,048	1.1	13,068	0.8
JAMES	43,813	1.4	45,912	1.1	5,829	0.7
NANSEMOND	15,119	2.0	19,434	1.5	349	1.1
NANTICOKE	74,878	1.7	137,165	1.4	7,919	0.4
OCCOQUAN	4,508	2.1	23,599	1.4	41,292	1.3
PATAPSCO	20,211	1.5	36,968	0.9	21,148	0.6
PATUXENT	26,009	2.9	12,075	1.8	9,760	1.0
POCOMOKE	40,847	2.0	79,758	1.7	2,839	0.3
POTOMAC	93,729	1.8	56,477	1.3	28,398	0.7
RAPPAHANNOCK	90,525	1.9	38,466	1.5	7,942	1.4
SEVERN	377	2.3	897	1.5	630	0.7
WICOMICO	23,068	1.7	12,012	1.4	752	0.5
WYE	10,255	1.4	19,856	1.0	1,028	0.4
YORK	44,936	1.3	44,700	1.0	8,220	0.8

Table A-4 Phosphorus Loading Factors: Pasture, Animal Waste, Forest and Urban

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Phosphorus in lbs/acre

Segment	Pasture		Animal Waste		Forest		Urban	
	Acres	LF	Acres	LF	Acres	LF	Acres	LF
10	159,325	0.168	614	371.6	984,938	0.045	199,187	0.73
20	300,413	0.196	1,716	440.7	1,844,310	0.048	420,461	0.65
30	145,469	0.215	668	446.9	875,001	0.057	105,210	0.88
40	29,624	0.287	149	502.9	570,931	0.071	96,136	1.24
50	73,066	0.173	94	526.7	679,540	0.061	56,731	0.82
60	139,180	0.252	402	457.4	2,254,498	0.058	78,824	0.85
70	31,756	0.165	193	438.3	610,012	0.064	32,814	0.90
80	76,049	0.172	614	422.1	802,377	0.051	134,620	0.84
90	50,173	0.073	211	438.8	394,793	0.046	16,180	0.72
100	87,849	0.057	607	392.6	1,076,335	0.037	74,940	0.68
110	127,594	0.500	792	386.5	416,256	0.055	146,910	1.21
120	58,097	0.206	806	402.9	80,692	0.033	73,096	0.75
140	24,304	0.264	160	379.9	52,115	0.036	26,872	0.77
160	108,588	0.401	145	419.9	614,346	0.045	48,740	0.92
170	148,161	0.235	108	387.2	726,540	0.045	22,927	0.82
175	105,876	0.201	128	357.8	584,313	0.021	46,443	0.83
180	220,191	0.305	925	355.8	722,664	0.043	198,101	0.78
190	211,836	0.351	522	405.1	594,668	0.125	40,625	0.85
200	200,709	0.302	412	339.1	503,065	0.060	50,154	0.75
210	79,147	0.396	540	411.8	189,716	0.050	83,164	0.83
220	105,951	0.534	186	376.4	209,156	0.073	146,032	0.73
230	224,145	0.193	391	436.3	577,312	0.025	38,857	0.72
235	7,370	0.334	21	427.2	123,800	0.040	11,106	0.54
240	2,337	0.300	9	427.2	176,769	0.039	9,702	0.50
250	22,253	0.373	50	427.2	146,892	0.159	11,153	0.49
260	24,010	0.325	71	427.2	335,375	0.045	37,553	0.63
265	19,176	0.661	13	376.9	189,339	0.046	2,350	0.82
270	233,212	1.000	316	437.1	1,364,448	0.052	58,967	1.21
280	269,838	0.907	331	466.4	1,356,569	0.094	74,187	1.04
290	32,646	0.672	57	423.7	222,413	0.054	21,071	0.79
300	80,932	0.357	137	423.7	525,824	0.048	33,036	0.86
310	4,191	0.357	8	423.7	71,259	0.048	11,673	0.72
330	8,477	0.169	23	378.6	25,606	0.028	30,668	0.60
340	10,534	0.102	26	378.6	45,387	0.037	53,586	0.85
ANACOSTIA	3,532	0.289	11	369.4	33,308	0.030	52,442	0.67
BALT_HARBOR	3,540	0.151	10	371.8	14,612	0.024	26,055	0.63
BOHEMIA	1,867	0.207	12	332.7	13,354	0.028	11,089	0.57
CHESTER	5,493	0.186	72	332.7	77,240	0.044	30,044	0.52
CHICKAHOMINY	4,013	0.356	11	401.5	96,481	0.048	32,942	0.88
CHOPTANK	5,884	0.173	49	332.7	135,173	0.016	40,276	0.54
COASTAL_1	9,108	0.270	71	332.7	249,573	0.036	50,373	0.58
COASTAL_11	49,235	0.162	321	371.8	164,399	0.019	107,100	0.65
COASTAL_4	2,658	0.315	2	337.5	123,651	0.029	6,204	0.63
COASTAL_5	3,147	0.157	2	337.5	62,007	0.022	42,370	0.40
COASTAL_6	7,632	0.167	5	369.4	38,912	0.024	33,815	0.97
COASTAL_8	7,143	0.089	28	371.8	197,054	0.021	25,137	0.73
COASTAL_9	1,361	0.375	7	411.2	54,841	0.044	44,327	0.61
ELIZABETH	112	0.316	0	401.5	6,276	0.035	3,431	0.74

Table A-4 Phosphorus Loading Factors: Pasture, Animal Waste, Forest and Urban

Chesapeake Bay Watershed Model Base Case Scenario

Land Use Acreage and Edge-of-Stream Loading Factors (LF) for Phosphorus in lbs/acre

Segment	Pasture		Animal Waste		Forest		Urban	
	Acres	LF	Acres	LF	Acres	LF	Acres	LF
GREAT_WICOMICO	990	0.103	1	411.2	23,861	0.022	2,023	0.42
GUNPOWDER	22,795	0.182	72	371.8	88,338	0.029	126,398	0.79
JAMES	18,257	0.357	30	401.5	525,519	0.035	105,949	0.80
NANSEMOND	3,860	0.319	5	401.5	73,812	0.037	16,444	0.77
NANTICOKE	4,579	0.263	37	332.7	239,890	0.017	46,993	0.52
OCCOQUAN	50,331	0.310	97	369.4	150,755	0.042	55,594	0.63
PATAPSCO	29,197	0.145	110	371.8	88,664	0.021	80,015	0.58
PATUXENT	7,105	0.222	15	369.4	163,992	0.024	128,881	0.60
POCOMOKE	5,601	0.288	22	332.7	326,226	0.023	23,929	0.56
POTOMAC	38,337	0.221	65	369.4	628,468	0.030	297,355	0.59
RAPPAHANNOCK	17,024	0.110	86	411.2	422,678	0.020	31,801	0.49
SEVERN	673	0.133	2	369.4	12,270	0.015	14,288	0.49
WICOMICO	1,249	0.253	4	332.7	81,851	0.015	18,478	0.54
WYE	1,164	0.197	10	332.7	15,138	0.023	8,274	0.53
YORK	12,615	0.156	44	411.2	401,542	0.031	59,765	1.06

Table A-5 **Transport Factors For Nitrogen and Phosphorus Chesapeake Bay Watershed Model Base Case Scenario (Above the Fall Line Segments)**

Segment	Nitrogen	Phosphorus
10	0.72111	0.18793
20	0.52402	0.16957
30	0.65916	0.28833
40	0.75120	0.39342
50	0.73893	0.24691
60	0.68700	0.31675
70	0.77200	0.39344
80	0.83058	0.47410
90	0.34657	0.13695
100	0.76931	0.37998
110	0.86792	0.58113
120	0.89819	0.64535
140	0.94614	0.81778
160	0.69145	0.65920
170	0.71690	0.97926
175	0.77578	0.77271
180	0.80419	0.79696
190	0.69010	0.81116
200	0.83798	0.80452
210	0.80958	0.74528
220	0.91303	0.91048
230	0.91117	0.86967
235	0.49755	0.60021
240	0.49755	0.60021
250	0.56307	0.59120
260	0.56307	0.59120
265	0.69392	0.84488
270	0.69392	0.84488
280	0.69392	0.84488
290	0.69392	0.84488
300	0.47277	0.56359
310	0.47277	0.56359
330	0.67852	0.60804

APPENDIX B

Nutrient Reduction Efficiencies for Conservation Tillage and Nutrient Management*
Chesapeake Bay Watershed Model

* Source: Obtained from the Watershed Model Base Case and Nutrient Management Scenario Output Files (CBPO, 1992)

Table B-1 Conservation Tillage Nutrient Reduction Efficiencies
Chesapeake Bay Watershed Model

Segment	Nitrogen Efficiency %	Phosphorus Efficiency %
10	16.9	17.3
20	11.9	17.0
30	4.4	7.0
40	17.9	26.8
50	1.5	12.8
60	6.3	14.9
70	6.1	19.4
80	15.0	17.9
90	14.5	14.6
100	15.4	16.4
110	24.3	29.0
120	17.1	20.7
140	21.6	18.9
160	30.0	15.5
170	19.9	17.2
175	24.4	13.4
180	16.6	8.9
190	16.7	18.2
200	21.3	19.8
210	18.7	17.3
220	22.9	21.3
230	27.4	33.8
235	21.8	22.5
240	23.0	20.9
250	20.8	27.1
260	24.0	30.7
265	19.5	24.3
270	24.1	29.5
280	22.5	26.1
290	25.1	29.4
300	23.7	28.8
310	21.1	26.0
330	17.0	24.6
340	21.8	31.7
ANACOSTIA	26.4	35.4
BALT_HARBOR	21.5	32.5
BOHEMIA	22.7	27.3
CHESTER	19.1	27.8
CHICKAHOMINY	23.6	23.4
CHOPTANK	21.1	25.5
COASTAL_1	26.1	24.3
COASTAL_11	12.6	26.9
COASTAL_4	23.8	28.0
COASTAL_5	27.4	36.4
COASTAL_6	18.5	28.8
COASTAL_8	17.8	23.6
COASTAL_9	21.5	27.6
ELIZABETH	28.9	32.2
GREAT_WICOMICO	18.6	20.0

Table B-1 Conservation Tillage Nutrient Reduction Efficiencies
Chesapeake Bay Watershed Model

Segment	Nitrogen Efficiency %	Phosphorus Efficiency %
GUNPOWDER	21.0	32.5
JAMES	17.3	24.9
NANSEMOND	17.9	26.8
NANTICOKE	11.0	15.5
OCCOQUAN	25.9	32.3
PATAPSCO	28.0	35.7
PATUXENT	30.9	36.5
POCOMOKE	14.3	17.7
POTOMAC	29.8	30.4
RAPPAHANNOCK	18.6	21.6
SEVERN	24.5	34.6
WICOMICO	13.5	20.3
WYE	20.2	25.8
YORK	17:2	21.2

Table B-2 Nutrient Management Reduction Efficiencies
Chesapeake Bay Watershed Model Nutrient Management Scenario

Segment	NITROGEN Conv'l Till %	NITROGEN Conser'n Till %	NITROGEN Hayland %	PHOSPHORUS Conv'l Til %	PHOSPHORUS Conser'n %	PHOSPHORUS Hayland %
10	8.8	11.7	16.0	3.6	6.3	19.6
20	6.3	9.3	11.2	3.8	6.5	11.4
30	16.0	19.4	28.5	4.0	7.6	34.5
40	21.0	22.8	40.6	8.0	9.5	45.6
50	18.6	19.7	55.2	14.6	17.4	48.9
60	21.3	21.8	54.0	15.3	18.7	45.7
70	18.2	17.6	53.0	7.7	9.3	45.2
80	5.0	5.6		12.7	16.3	
90	6.9	6.7		30.1	33.7	
100	10.8	10.7		31.1	35.0	
110	3.9	5.4		4.0	6.1	
120	10.9	11.5		9.5	10.4	7.7
140	8.3	9.7		7.6	10.1	6.5
160	17.0	17.6		13.4	18.4	
170	8.2	9.1		5.8	7.2	
175	13.4	13.8		9.1	11.9	
180	37.8	39.9		28.7	37.3	
190	36.0	39.9		31.8	37.3	
200	40.7	43.0		37.2	41.7	
210	40.6	41.5		35.7	39.9	
220	27.5	29.7		21.9	27.1	
230	8.2	9.3		7.3	9.1	
235	13.7	13.9		9.8	12.4	
240	13.7	13.8		19.5	26.3	
250	14.3	16.1		8.9	11.4	
260	14.3	16.2		8.2	10.6	
265	16.1	17.5		13.6	16.3	
270	14.5	16.8		10.8	14.2	
280	11.2	12.1		10.6	12.3	
290	10.4	11.6		9.1	11.9	
300	10.6	12.4		10.4	14.2	
310	12.0	13.6		13.4	17.6	
330	39.2	40.9		22.7	23.1	
340	33.2	36.1		14.9	16.2	
ANACOSTIA	19.6	20.5		13.2	14.4	
BALT_HARBOR	33.8	34.8		14.0	14.1	
BOHEMIA	17.6	17.8		8.9	11.0	
CHESTER	19.1	19.7		8.6	10.2	
CHICKAHOMINY	10.7	10.6		16.8	19.0	
CHOPTANK	20.4	20.7		11.5	12.9	
COASTAL_1	20.0	20.1		12.1	15.3	
COASTAL_11	56.1	57.3		41.7	39.8	
COASTAL_4	16.6	17.1		20.5	25.8	
COASTAL_5	27.2	29.5		9.8	11.5	
COASTAL_6	46.5	47.4		26.1	25.2	
COASTAL_8	10.8	11.1		14.2	16.7	
COASTAL_9	2.7	2.7		3.1	3.9	
ELIZABETH	1.6	1.5		0.7	0.8	
GREAT_WICOMICO	12.3	12.6		17.0	21.7	

Table B-2 Nutrient Management Reduction Efficiencies
Chesapeake Bay Watershed Model Nutrient Management Scenario

Segment	NITROGEN Conv'l Till %	NITROGEN Conser'n Till %	NITROGEN Hayland %	PHOSPHORUS Conv'l Til %	PHOSPHORUS Conser'n %	PHOSPHORUS Hayland %
GUNPOWDER	35.5	36.4		16.2	16.4	
JAMES	7.4	8.2		11.5	15.0	
NANSEMOND	4.0	4.2		13.9	19.0	
NANTICOKE	19.6	19.7		15.7	16.9	
OCCOQUAN	18.6	18.2		10.5	11.7	
PATAPSCO	36.7	35.1		19.6	15.5	
PATUXENT	21.8	23.1		9.7	10.6	
POCOMOKE	27.1	27.6		24.4	26.6	
POTOMAC	24.3	23.0		12.3	14.3	
RAPPAHANNOCK	12.8	13.1		16.6	20.8	
SEVERN	28.0	30.7		10.8	12.5	
WICOMICO	26.5	27.2		22.5	24.4	
WYE	21.1	21.8		11.7	14.1	
YORK	13.0	13.4		19.2	23.9	

APPENDIX C

Rural Clean Water Program Cost Tables

Conestoga Headwaters (Pennsylvania)
Double Pipe Creek (Maryland)
Highland Silver Lake (Illinois)
Prairie Rose Lake (Iowa)
Garvin Brook (Minnesota)
Long Pine Creek (Nebraska)
Tillamook Bay (Oregon)

BMP-1: Permanent Vegetative Cover
BMP-2: Animal Waste Management Systems
BMP-3: Stripcropping and Contour Farming Systems
BMP-4: Terrace System
BMP-5: Diversion System
BMP-6: Grazing Land Protection System
BMP-7: Waterway System
BMP-8: Cropland Protective System
BMP-9: Conservation Tillage Systems
BMP-10: Stream Protection System
BMP-11: Permanent Vegetative Cover on Critical Areas
BMP-12: Sediment Retention, Erosion, or Water Control Structures
BMP-13: Soil and Manure Analysis
BMP-14: Management of Excess Manure
BMP-15: Fertilizer Management
BMP-16: Pesticide Management

Table C-1

RCWP-4

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS

Project: CONESTOGA HEADWATERS - LANCASTER | State: PENNSYLVANIA | 1989

Item	Unit	No. of units	Installation cost per unit	Total cost (thousands)	C/S level	RCWP	Farmer	Other	Hours per unit	Total hours	SCS Hours	SCS Cost	FS Hours	FS Cost	CES Hours	CES Cost	Other Hours	Other Cost
1. RCWP Plan of Work and Annual Review	Hours	300																
2. Water Quality Plans a. Development	Farms	300							30	9000	9000	135,000						
b. Revisions	WQ Plans	100							5	400	400	6,000						
c. Annual Status Review	WQ Plans	1000							4	4000	4000	60,000						
3. CODE: a. BMP-1	Ac.	200	120.00	24	50	12,000	12,000											
b. BMP-2	No.	30	20,000.00	600	50	300,000	300,000											
c. BMP-3	Ac.	2200	10.00	22	50	11,000	11,000		60	10126	10126	151,890			420	5,250		
d. BMP-4	Mi.	90	8,448.00	760	75	570,000	190,000		.33	726	726	10,900						
e. BMP-5	Mi.	9	5,280.00	48	75	36,000	12,000		117.2	18564	18564	278,460						
f. BMP-6	No.	30	1,000.00	30	50	15,000	15,000		73.3	2217	2217	33,255						
g. BMP-7	Mi.	26	9,240.00	259	75	194,250	64,750		20	600	600	9,000						
h. BMP-8	Ac.	2500	20.00	50	50	25,000	25,000		53.6	4038	4038	60,570						
i. BMP-9*	Ac.	12000	10.00	1200	0	0	12,000		1									
j. BMP-10	No.	10	2,000.00	20	50	10,000	10,000		1						600	7,340		
k. BMP-11	Ac.	64	125.00	8	50	4,000	4,000		20	1200	1200	18,000						
l. BMP-12	No.	10	4,000.00	40000	50	20,000	20,000		2	160	160	2,400						
m. BMP-14	Ac.	30	100.00	3	75	2,250	750		40	1200	1200	18,000						
n. BMP-15 A	Ac.	3600	10.00	36	50	18,000	18,000		8	240			240	3,600				
o. BMP-16	Ac.	3600	5.00	18	0	0	18,000		.1	360	360	540			380	4,730		
p. BMP-13 Dee	Ac.	20000	17.00	342	0				.17	600	-				600	7,500		
q. BMP. MISC.						1,277									14,560	342,000		
r. BMP.	* 40 Ac. X 300 = 12,000									CES	OTS and Monitoring Projects					96,150		
s. BMP.	** BMP 15 B, Nutrient Management = RCWP Contract and Non-contract farms FY 1986–1990 - Two full time people - RCWP funds transferred to E.S.																	
t. BMP.																		
Project Totals						1,200,777	712,500				+	784,013 20,400 Monitoring	240	3,600	16,560	461,150		-

(Source: Pennsylvania-RCWP, 1989)

Table C-2

RCWP-4 RCWP Estimated Best Management Costs

RCWP-4 (6-14-80)

RCWP ESTIMATED BMP COSTS

PROJECT: DOUBLE PIPE CREEK

STATE: MARYLAND

Item	Unit	Amount	Installation Cost per Unit	Total Cost (Thousands)	C/S Level	BMP Cost Shares: RCWP	BMP Cost Shares: Farmer	BMP Cost Shares: Other	Hour Factor	Total Hours	Technical Assistance: SCS Hours	SCS Cost	FS Hours	FS Cost	SEA Hours	SEA Cost	Other Hours	Other Cost
1. RCWP Plan of Work and Annual Review	Hours	PEOPLE 2							30	60	60	1150						
2. Water Quality Plans a. Development	Farms	135							40	5400	5400	103464						
b. Revisions	WQ Plans	60							15	900	900	17244						
c. Annual Status Review	WQ Plans	675							5.25	3514	3544	67903						
3. CODE: a. BMP. 1	AC	167	120.00	20	60	12024	8016		.09	15	15	287						
b. BMP. 2	NO	84	26000.00	2184	15	1638000	546000		100.0	8400	8400	160944						
c. BMP. 3	AC	3588	20.00	72	75	53820	17940		.51	1830	1830	35063						
d. BMP. 5	FT	15300	2.25	34	75	25819	8606		.095	1454	1454	27859						
e. BMP. 6	NO	111	2500.00	280	75	210000	67500		28.5	3164	3164	60622						
f. BMP. 6	NO	6	11667.00	70	50	29168	40834		65.4	392	392	7511						
g. BMP. 7	FT	311203	5.93	1867	75	1400540	466847		.08	25192	25192	482679						
h. BMP. 8	AC	29	25.00	73	50	363	362		.10	3	3	57						
i. BMP. 9	AC	-	18.00	0	0	-	-		-	-	-							
j. BMP. 10	NO	17	3458.00	59	75	44090	14696		24.3	413	413	7913						
k. BMP. 11	AC	25	325.00	8	50	4063	4062		1.0	25	25	479						
l. BMP. 12	NO	12	3500.00	42	75	31500	10500		60.0	720	720	13795						
m. BMP. 15	AC	7680	1.00	23	75	17250	5750		.6	6000	-	-			6000	23360		
n. BMP. 15	AC	3750	1.00	11	75	8250	2750		1.56	5850	-	-			5850	21026		
o. BMP. 16	AC	7500	6.00	135	75	101250	33750		.5	3750	-	-			3750	58350		
p. BMP.																		
q. BMP. ***Planning w/landowners who did not sign Contract (30)									.40	1200	1200	22992						
r. BMP.																		
s. BMP.																		
t. BMP.																		
Project Totals				4878		3576137	1227613			68312	52712	1009962			15600	242736		

(Source: Maryland-RCWP, 1989)

Table C-3

RCWP-4 (10-3-80)

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS

Project: Highland Silver Lake, Madison County — 11-17-86

State: Illinois

Item	Unit	No. of Units	Installation Cost per Unit	Total Cost (Thousands)	C/S Level	BMP Cost Share: RCWP	BMP Cost Share: Farmer	BMP Cost Share: Other	Hour Factor	Total Hours	Technical Assistance: SCS Hours	SCS Cost	FS Hours	FS Cost	SEA Hours	SEA Cost	Other Hours	Other Cost
1. RCWP Plan of Work and Annual Review	Hours									2049	1888	27,477	161	1,939				
2. Water Quality Plans a. Development	Farms	101							125	9500	7846	114,190					1654	13,645
b. Revisions	WQ Plans	300							20	6000	5235	76,188					765	6,311
c. Annual Status Review	WQ Plans	375							4	1500	989	14,394					511	4,216
3. CODE: a. BMP. 1	AC	650	145.00	94.25	75	70,688	23,563		0.50	325	255	3,710					70	577
b. BMP. 2	NO	15	20,000	300	75	225,000	75,000		187.7	2816.3	1826	26,575			416.3	5,000	574	4,735
c. BMP. 4	FT	2,500	3.04	159.6	75	119,724	39,908		.027	1400	786	11,438			83	1,000	531	4,381
d. BMP. 5	FT	0,000	3.04	91.2	75	68,400	22,800		.075	752	585	8,514			83	1,000	86	693
e. BMP. 7	FT	00000	1.40	140	75	105,000	35,000		.017	1658	1280	18,627			83	1,000	295	2,433
f. BMP. 8	AC	300	10.00	3	75	2,250	750		.20	60	19	277					41	33
g. BMP. 9	AC	8000	50.59	404.75	75	303,563	101,187		.694	5550	3539	51,509			1248	15,000	763	6,29
h. BMP. 10	FT	45000	1.00	45	75	33,750	11,250		.024	1065	887	12,909					178	1,46
i. BMP. 11	AC	100	300.00	30	75	22,500	7,500		6.32	632	508	7,392					124	1,02
j. BMP. 12	NO	225	2200.00	495	75	371,250	123,750		14.5	3261	2830	41,186					431	3,55
k. BMP. 14	AC	37.5	53.33	2	75	1,500	500		2.13	80			80	963				
l. BMP. 15	AC	0,000	5.00	50	75	37,500	12,500		2808	2808					2808	33,750		
m. BMP.																		
n. BMP.																		
o. BMP.																		
p. BMP.																		
q. BMP.																		
r. BMP.																		
s. BMP.																		
t. BMP.																		
Project Totals				1,814.8		1,361,125	453,708			39456.3	28473	414,382	241	2,902	4721.3	56,750	6,021	49,

(Source: Illinois-RCWP, 1986)

Table C-4

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service
RCWP ESTIMATED BMP COSTS

Project: Prairie Rose Lake, Shelby ty
State: Iowa

Item	Unit	No. of Units	Installation Cost per Unit	Total Cost (Thousands)	C/S Level	RCWP	Farmer	Other	Hour Factor	Total Hours	SCS Hours	SCS Cost	[illegible] Hours	[illegible] Cost	[illegible] Hours	[illegible] Cost	Other Hours	Other Cost
1. RCWP Plan of Work and Annual Review	Hours																	
2. Water Quality Plans a. Development	Farms	37							20	740	740	7,680						
b. Revisions	WQ Plans	57							3.6	205	205	2,127						
c. Annual Status Review	W.Q Plans	222							2	441	444	4,608						
3. CODE: a. BMP. 1	Ac.	111	30	3,330		2,497	833		4	444	444	4,608						
b. BMP. 2	No.	6	4,000	24,000		18,000	6,000		60	360	360	3,736						
c. BMP. 4	Mile	75	5,280	396,000		297,000	99,000		70	5,250	5,250	54,488						
d. BMP. 5	Ft.	2,000	.90	1,800		1,350	450		.013	26	26	270						
e. BMP. 7	Ac.	20	3,375	67,500		50,625	16,875		8	160	160	1,660						
f. BMP. 9	Ac.	2,100	20	42,000		31,500	10,500		0.15	315	315	3,269						
g. BMP. 11	Ac.	10	30	300		210	90											
h. BMP. 12	No.	6	10,000	60,000		45,000	15,000											
i. BMP. 15	Ac.	3,170				0	0		0.72	2,281					2,281	24,347		
j. BMP. 16	Ac.	3,170				0	0		0.72	2,281					2,281	24,347		
k. BMP.																		
l. BMP.																		
m. BMP.																		
n. BMP.																		
o. BMP.																		
p. BMP.																		
q. BMP.																		
r. BMP.																		
s. BMP.																		
t. BMP.																		
Project Totals				594,930		446,182	148,748		--	12,306	7,944	82,446			4,562	48,694		

(Source: Iowa-RCWP, 1989)

Table C-5

RCWP-1 (Minn.) U.S. DEPARTMENT OF AGRICULTURE — Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS

Project: Garvin Brook RCWP 1989 — State: Minnesota

Item	Unit	No. of units	Installation cost per unit	Total cost (thousands)	C/S level	ACP	Farmer	Other	Hours per unit	Total hours	@ 21.00 Hours	@ 21.00 Cost	@ 12.00 Hours	@ 12.00 Cost	@ 12.00 Hours	@ 12.00 Cost	Other 12.00 Hours	Other 12.00 Cost
1. RCWP Plan of Work and Annual Review	Hours	1							-	1750.0	1312.0	27,552.0	175.0	2100.0	263.0	3156.0	-	-
2. Water Quality Plans a. Development	Farms	81							50.0	4050.0	2926.0	61,446.0	314.0	3768.0	810.0	972.0	-	-
b. Revisions	WQ Plans	196							15.0	2940.0	1972.0	41,432.0	120.0	1440.0	848.0	10,174.0	-	-
c. Annual Status Review	WQ Plans	585							9.0	5265.0	3612.0	75,847.0	483.0	5796.0	1170.0	14,040.0	-	-
3. CODE a. BMP 1	AC	455.0	233.0	106.0	75%	79,511.3	26,503.7	-	0.75	341.3	316.3	6,642.3	-	-	-	-	25.0	300.0
b. BMP 2	NO	14	60,000.0	840.0	75%	630,000.0	108,000.0	102,000.0	250	3500.0	2676.0	56,196.0	-	-	-	-	824.0	9868.0
c. BMP 3	AC	546.0	14.75	8.1	75%	6,040.1	2,013.4	-	0.20	109.2	75.8	1,591.8	-	-	-	-	33.4	400.8
d. BMP 4	FT	14,850	2.25	33.4	75%	25,059.4	8,353.1	-	.03	445.5	428.0	8,988.0	-	-	-	-	17.5	210.0
e. BMP 5	FT	2020.0	1.43	2.9	75%	2,166.5	722.1	-	.01	20.2	17.3	363.3	-	-	-	-	2.9	34.8
f. BMP 6	NO	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
g. BMP 7	AC	16.8	1505.87	25.3	75%	18,974.0	6,324.6	-	13.35	224.3	189.5	3,979.5	-	-	-	-	34.8	417.6
h. BMP 9	AC	4465.0	13.4	59.8	75%	44,873.3	14,957.7	-	0.60	2679.0	2428.8	51,004.8	-	-	-	-	250.2	3002.4
i. BMP 10	FT	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
j. BMP 11	NO	16	7529.0	120.5	75%	90,348.0	30,116.0	-	12.0	192.0	132.7	2,786.7	-	-	-	-	59.3	711.6
k. BMP 12	NO	5	13,676.0	68.4	75%	51,285.0	17,095.0	-	92.0	460.0	460.0	9,660.0	-	-	-	-	-	-
l. BMP 14	AC	1.9	200.0	0.4	75%	285.0	95.0	-	0.60	1.1	-	-	1.1	13.2	-	-	-	-
m. BMP 15	AC	6454.0	20.0	129.1	75%	96,810.0	45,580.0	-	0.20	1290.8	35.6	747.0	-	-	1255.2	15,062.4	-	-
n. BMP 16	AC	6758.0	-	-	-	-	-	-	0.02	135.2	13.0	273.0	-	-	122.2	1,466.4	-	-
o. BMP 17	FT	3000.0	1.67	5.0	75%	3,757.5	1,252.5	-	0.01	30.0	-	-	30.0	360.0	-	-	-	-
p. BMP 18	AC	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
q. BMP																		
r. BMP																		
s. BMP																		
t. BMP																		
Project Totals 24 C				1398.9		1,049,110.1	261,013.1	102,000.0		23,433.6	16,595.0	348,509.4	1123.1	13,477.2	4468.4	53,618.8	1247.1	14,965.2

(Source: Minnesota-RCWP, 1989)

Table C-6

U. S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS — Revised 11/87

PROJECT: Long Pine Creek Rural Clean Water Program — STATE: Nebraska

Item	Unit	No. of Units	Installation Cost per Unit	Total Cost (Thousands)	C/S Level	ACP	Farmer	Other	Hour Factor	Total Hours	SCS Hours	SCS Cost	ES Hours	ES Cost	SCA Hours	SCA Cost	Other (NRD) Hours	Other (NRD) Cost
Plan of Work / Annual Review	Hours	15							320	4800	4185	50,220	15	180	600	7200		
Water Quality Plan Development	Farms	85							151	12,835	11,135	133,620	30	360	1670	20,040		
Revisions	WQ Plans	340							16	5440	5305	63,660	10	120	125	1500		
Annual Status Review	WQ Plans	850							8	6800	5990	71,880	10	120	800	9600		
BMP 1	AC	3390	7.96	27.0	.75	20,250	6750	0	.1	339	339	4068						
BMP 2	NO	4	2550.00	10.2	75	7650	2550	0	240.0	960	960	11,520						
BMP 5	NI	4	15,250.00	61.0	75	45,750	15,250	0	100.0	400	400	4800						
BMP 6	AC	3390	34.81	118.0	75	88,500	29,500	0	.5	1695	1695	20,340						
BMP 7	NI	1	16,300.00	16.3	75	12,225	4075	0	30.0	30	30	360						
BMP 8	AC	10,433	0	0	.0	0	0	0	.025	261	261	3132						
BMP 9	AC	306	13.40	4.1	75	3075	1025	0	.4	122	61	732			61	732		
BMP 10	NI	4	17,775.00	71.1	75	51,200	10,400	1500*	200.0	800	800	9600						
BMP 11	AC	92	142.39	13.1	75	9825	3275	0	2.0	184	184	2208						
BMP 12	NO	101	979.21	98.9	75	74,175	24,725	0	50.0	5050	5050	60,600					886	10,622
BMP 13	NO	42	14,264.29	599.1	75	449,325	149,775	0	60.0	2520	2220	26,640			300	3600		
BMP 14	AC	53	384.91	20.4	75	15,300	5100	0	8.0	424	115	1380	309	3708				
BMP 15	AC	7250	4.00	29.0	75	21,750	7250	0	1.3	9425	425	5100			9000	108,000		
BMP 16	AC	7375	4.00	29.5	75	22,125	7375	0	1.3	9588	588	7056			9000	108,000		
BMP																		
BMP 13-A.L.[illegible]	NO	1	255,591.00	254.6	75	186,993	35,492	33,106**	350.0	350	350	4200					572	20,155
BMP																		
BMP								*Game and	Parks									
BMP								** NRD and	NWCP									
BMP																		
Totals				1352.3		1,309,143	302,542	34,606		62,023	40,093	481,116	374	4488	21,556	258,672	1558	30,777

(Source: Nebraska-RCWP, 1989)

Table C-7

RCWP-4 (11-7-80)

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS — Updated to Reflect Total Project Estimates

PROJECT: TILLAMOOK BAY DRAINAGE BASIN RCWP#18 — STATE: OREGON

Item	Unit	No. of Units	Installation Cost per Unit	Total Cost (Thousands)	C/S Level	BMP Cost Shares: RCWP	BMP Cost Shares: Farmer	BMP Cost Shares: Other	Hour Factor	Total Hours	SCS Hours	SCS Cost	FS Hours	FS Cost	SEA Hours	SEA Cost	Other Hours	Other Cost
1. RCWP Plan of Work and Annual Review	Hours	10																
2. Water Quality Plans a. Development	Farms	*110							69	690	400	5020			24	368	255	1133
b. Revisions	WQ Plans	40							77	8470	3380	42250			311	4356	4779	76850
c. Annual Status Review	WQ Plans	935							20	800	400	9270			340	4760	53	250
3. CORE: a. BMP. 1			PERMANENT VEGETATIVE COVER						3	2865	2865	35810						
b. BMP. 1-a	Ac.	704	55	38.7	N/C	0	38700	0	0.10	70	3	60						
c. BMP. 1-b	Ac.	450	238	107.1	75	5355	101745	0	0.14	63	5	60			67	1620		
d. BMP. 2			ANIMAL WASTE MANAGEMENT SYSTEMS												58	1120		
e. BMP. 2-a-1 (Dry)	No.	100	23278	2327.2	75	1612380	609886	104724	106	10400	9176	205345						
f. BMP. 2-a-1 (Liquid)	No.	105	22554	2368.2	75	1375899	793796	198475	141.25	14830	11725	246975					424	12920
g. BMP. 2-a(2a)	Ft.	52000	2.05	106.6	75	61654	26450	18295	0.007	365	280	3440					3105	64620
h. BMP. 2-a(2b)	Ft.²	490500	3.34	1640.1	75	1119230	440308	10734	0.007	3433	3300	71875					85	1050
i. BMP. 2-a(3)	Ft.	21290	4.00	85.2	75	63870	21290	0	0.02	425	425	8340					53	1080
j. BMP. 2-b	No.	1	63000	63.0	75	47250	15750	0	306	306	300	3750						
k. BMP. 2-d-1	Ft.	0													6	84		
l. BMP. 2-d-2	Ft.	11980	7.07	84.7	75	52950	21180	10570	0.025	300	250	4720						
m. BMP. 2-e	Ft.	45	4.03	0.18	75	136	45	0	3.0	15	15	285					53	930
n. BMP. 2-f	No.	58	309	17.9	75	12978	4483	460	2.5	145	140	2890						
o. BMP. 2-g	Ac.	1462	612	894.7	75	83540	223685	587520	1.0	1462	132	3460					5	100
p. BMP. 2-h	Ft.	4000	1.50	6.0	75	1175	1500	3325	0.02	170	20	505					1280	24335
q. BMP. 2-i	No.	101	1000	101.0	N/C	0	101000	0	0.89	90	0	0					104	2520
r. BMP. 6			GRAZING LAND PROTECTION SYSTEMS												90	1232		
s. BMP. 6-a	Ft.	8350	0.45	3.7	75	1925	920	825	0.003	25	17	315						
t. BMP. 6-b	No.	20	460	9.2	75	5795	2300	1105	2.5	50	30	560					8	14[illegible]
Project Totals																	20	77[illegible]

*INCREASE IN PLANS DUE TO RECONSTITUTION OF UNITS - NOT REVISIONS

(Source: Oregon-RCWP, 1989)

RCWP-4
(1-2-86)

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

RCWP ESTIMATED BMP COSTS

Updated to Reflect
Total Project Estimates

PROJECT: TILLAMOOK BAY DRAINAGE BASIN RCWP 11

STATE: OREGON

ITEM	UNIT a	NO. OF UNITS b	INSTALLATION COST PER UNIT c	TOTAL COST (Thousands) d	C/S LEVEL e	RCWP f (BMP Cost Shares)	FARMER g (BMP Cost Shares)	OTHER h (BMP Cost Shares)	HOUR FACTOR i	TOTAL HOURS j	SCS HOURS k	SCS COST l	FS HOURS m	FS COST n	SEA HOURS o	SEA COST p	OTHER HOURS q	OTHER COST r
1. RCWP Plan of Work and Annual Review	Hours																	
2. Water Quality Plans a. Development	Farms																	
b. Revisions	WQ Plans																	
c. Annual Status Review	WQ Plans																	
3. CODE: a. BMP. 6c	No.	6	5000	30.0	75	22500	7500	0	15.0	90	90	1820						
b. BMP. 10			STEAM PROTECTION															
c. BMP. 10-b	Ft.	15515	0.85	13.2	75	4000	3300	5890	0.007	109	44	870					65	12
d. BMP. 11			PERMANENT VEGETATIVE COVER ON CRITICAL AREAS															
e. BMP. 11-a	Ac.	0																
f. BMP. 12			SEDIMENT RETENTION, EROSION OR CONTROL STRUCTURES															
g. BMP. 12-a	No.	6	4500	27.0	75	1425	8700	16875	30.0	180	30	610					150	31
h. BMP. 15			FERTILIZER MANAGEMENT															
i. BMP. 15-a	Ac.	8805	7	61.7	N/C	0	61162	0	0.97	8540	1980	41770			3445	47377	3115	15
j. BMP.																		
k. BMP.																		
l. BMP.																		
m. BMP.																		
n. BMP.																		
o. BMP.																		
p. BMP.																		
q. BMP.																		
r. BMP.																		
s. BMP.																		
t. BMP.																		
Project Totals				7993.38		4540278	2484304	968198		33843	35737	690000			4341	60315	13765	2096

(Source: Oregon-RCWP, 1989)

APPENDIX D

Examples of Animal Waste System Costs*

* Animal waste management system examples reported in this appendix were obtained from: "Manual for Economic and Pollution Evaluation of Livestock Manure Management Systems" by William F. Ritter (1990). Production and nutrient content of animal wastes were obtained from "Assessment of Field Manure Nutrient Management with regards to Surface & Groundwater Quality" by R.E. Wright Associates, Inc.(1990)

Table D-1 Examples of Evaluation of Alternatives for Dairy Manure Management Systems

System			Annual Cost[1] ($/Cow)	Annual Cost[2] ($/Ton)
Collection	Storage	Transport and Utilization		
Tractor scrape	Earthen basin storage	Surface application	217	18.90
Tractor scrape	Concrete tank storage	Surface application	268	23.40
Tractor scrape	Steel tank storage	Surface application	288	25.10
Tractor scrape	Earthen basin storage	Injection	234	20.30
Tractor scrape	Concrete tank storage	Injection	284	24.80
Tractor scrape	Steel tark storage	Injection	304	26.50
Mechanical scraper	Earthen basin	Surface application	210	18.30
Mechanical scraper	Concrete storage tank	Surface application	261	22.70
Mechanical scraper	Steel storage tank	Surface application	279	24.30
Mechanical scraper	Earthen basin storage	Injection	226	19.70
Mechanical scraper	Concrete storage tank	Injection	277	24.10
Mechanical scraper	Steel storage tank	Injection	296	25.80

1. Source: Ritter (1990). Costs in 1989 dollars include: capital, labor, and energy costs based on 100 milking cows. Manure handled as a slurry and storage capacity of 114,000 ft^3 was planned. Interest rate = 10%.
2. Cost per ton of manure treated. Based on an animal size of 1,000 lbs with 82 lbs of manure per 1000 lbs of animal live weight produced daily (R.E. Wright and Assoc. Inc., 1990). Assume animals are confined during 280 equivalent days per year.

Table D-2 Examples of Evaluation of Alternatives for Beef Manure Management Systems

System			Annual Cost[1] ($/Head)	Annual Cost[2] ($/Ton)
Collection	Storage	Transport and Utilization		
Tractor scrape without bedding, gravity transfer	Earthen basin concrete-lined storage	Slurry spreader with surface application	57.10	6.80
Tractor scrape without bedding, gravity transfer	Earthen basin concrete-lined storage	Slurry spreader with subsurface injection	67.50	8.00
Mechanical spreader with slotted floors, gravity transfer	Earthen basin concrete-lined storage	Slurry spreader with surface application	75.00	8.90
Mechanical scraper with slotted floors, gravity transfer	Earthen basin concrete-lined storage	Slurry spreader with subsurface injection	85.30	10.20
Tractor scrape without bedding, gravity transfer	Concrete tank below ground storage	Slurry spreader with surface application	69.20	8.20
Tractor scraper without bedding, gravity transfer	Concrete tank below ground storage	Slurry spreader with surface application	79.50	9.50
Mechanical scraper with slotted floors, gravity transfer	Concrete tank below ground storage	Slurry spreader with surface application	87.00	10.40
Mechanical scraper with slotted floors, gravity transfer	Concrete tank below ground storage	Slurry spreader with surface application	97.30	11.60

1. Source: Ritter (1990). Costs in 1989 dollars include: capital, labor, and energy costs based on 200-head beef feedlot. Manure handled as a slurry and storage capacity of 50,000 ft^3 was planned. Interest rate = 10%.
2. Cost per ton of manure treated. Based on an animal size of 1,000 lbs with 60 lbs of manure per 1000 lbs animal live weight produced daily (R.E. Wright and Assoc., Inc., 1990). Assume animals are confined for 280 equivalent days per year.

Table D-3 Examples of Evaluation of Alternatives for Swine Manure Management Systems

System			Annual Cost[1] ($/Hog)	Annual Cost[2] ($/Ton)
Collection	Storage	Transport and Utilization		
Flushing under slotted floors, gravity transfer	Aerated lagoon	Irrigation	15.10	6.40
Mechanical scraper, gravity transfer	Earthen storage basin	Slurry spreader with injection	25.60	10.80
Mechanical spreader with pump transfer	Above ground steel tank	Slurry spreader with injection	38.00	16.00
Slotted floors	Pit storage under the slotted floors	Slurry spreader with subsurface injection	22.40	9.40
Flushing under slotted floors, gravity transfer	Earthen basin	Slurry spreader with subsurface injection	22.80	9.60

1. Source: Ritter (1990). Costs in 1989 dollars include: capital, labor, and energy costs based on 500-finishing hogs. Anaerobic lagoon with capacity of 20,000 ft^3 was planned. Interest rate = 10%.
2. Cost per ton of manure treated. Based on an animal size of 200 lbs with 65 lbs of manure per 1000 lbs of animal live weight produced daily (R.E. Wright and Assoc., Inc., 1990). Assume animals are confined year-round.

Table D-4 Examples of Evaluation of Alternatives for Veals Manure Management Systems

System			Annual Cost[1] ($/Head)	Annual Cost[2] ($/Ton)
Collection	Storage	Transport and Utilization		
Gravity transfer with transfer pipe	Earthen basin with recompacted liner	Irrigation	24.30	14.30
Gravity transfer with transfer pipe	Earthen storage basin	Slurry spreader with surface application	38.80	22.80
Pump transfer	Above ground concrete storage tank	Irrigation	47.70	28.00
Pump transfer	Above ground storage tank	Irrigation	62.20	36.60

1. Source: Ritter (1990). Costs in 1989 dollars include: capital, labor, and energy costs based on 300 veal calves. Storage capacity of 40,000 ft^3 was planned. Interest rate = 10%.
2. Cost per ton of manure treated. Based on an animal size of 300 lbs with 63 lbs of manure per 1000 lbs of animal live weight produced daily (R.E. Wright and Assoc. Inc., 1990). Assume animals storage facilities are used for 300 veals for 180 days per year.

Table D-5 Examples of Evaluation of Alternatives for Poultry Manure Management Systems

System			Annual Cost[1] ($/Bird)	Annual Cost[2] ($/Ton)
Collection	Storage	Transport and Utilization		
Shallow pit with tractor scrape (solid manure)	Storage shed	Land aplication by incorporation	0.44	2.00
Shalow pit with mechanical scraper (solid manure)	Storage shed	Land application by incorporation	0.64	2.90
Flushing with gravity transfer (liquid manure)	Earthen basin	Irrigation	0.51	11.50

1. Source: Ritter (1990). Costs in 1989 dollars include: capital, labor, and energy costs based on 50,000 flock laying hens. Storage capacity of 275,000 ft^3 was planned for the last alternative. Interest rate = 10%.
2. Cost per ton of manure treated. Based on an animal size of 4 lbs with 300 lbs per 1000 lb animal live weight of liquid manure produced daily, and 61 lbs for solid manure (R.E. Wright and Assoc. Inc. 1990). Assume animals storage facilities are used for the 50,000 hens year-round.

Table D-6 Production and Nutrient Content of Animal Wastes[1]

Animal	Animal Size (lb)	Manure Production per 1000 lb live weight (lbs/day)	Dry Matter %	Approximate Total Nutrients (lb/ton)		
				N	P_2O_5	K_2O
Dairy	150-1,500	82	13	10	4	8
Beef	400-1,400	60	12	11	7	10
Veal	100-350	63	1.6	8	2	11
Pigs	35-200	65	9	14	11	11
Sheep	100	40	25	23	8	20
Horse	1,000	45	20	12	5	9
Poultry (liquid)[2]	4[3]	300	5	10	7	3
Poultry (Fresh)[2]	4[3]	61	25	30	20	10

1. Adapted from R.E. Wright and Assoc. Inc. (1990). Original source: DER "Field Application of Manure" Supplement to Manure Management for Environmental Protection. Data are for manures as voided.
2. Storage losses already deducted.
3. Assumed value.

APPENDIX E

Soil Conservation Farm Plans*

* Source: Obtained from Maryland, Pennsylvania and Virginia (MDA, PADER, and VA-DSWC, 1991)

Table E-1 Maryland Soil Conservation Farm Plans[1]

Farm Location	Cropland (acres)	BMP Type	area (acres)	length (ft)	Soil Saved Tons/yr	% Reduc'n Soil Losses	Annual Costs per Ton of Soil Saved			Annual Cost per Acre Cropland		
							25%ile	Median	75%ile	25%ile	Median	75%ile
I	55.2	Cons. Crop System	57.4									
		Contour-Strip-cropping	9.6									
		Strip-cropping	37.4									
		Farm Total			519	58.4	1.63	2.16	2.16	14.94	19.88	19.88
II	200	Cons. Tillage	174									
		Strip-cropping	49									
		Cover crop	174									
		Contour Farming	85									
		Grassed Waterways		2000								
		Farm Total			1043	93.3	2.11	3.43	4.48	31.57	41.06	46.56
III	70.0	Cons Till+Residue Mgmt	67									
		Grassed Waterways		2500								
		Diversions		4700								
		Filter Strip		2100								
		Critical Area Planting	3									
		Farm Total	70		417	73.8	10.89	14.46	18.88	74.76	96.08	122.41
IV	209	Cons. Tillage	209									
		Contour-Strip-cropping	209									
		Grassed Waterway		700								
		Filter Strip		2000								
		Farm Total			2858	82.9	0.60	1.04	1.17	37.85	49.73	52.58
V	44	Cons. Tillage	22									
		Grassed Waterways		1200								
		Diversions		300								
		Sediment Control Pond										
		Farm Total			151	51.7	9.07	13.52	17.89	39.76	55.03	70.03

Table E-1 Maryland Soil Conservation Farm Plans[1]

Farm Location	Cropland (acres)	BMP Type	area (acres)	length (ft)	Soil Saved Tons/yr	% Reduc'n Soil Losses	Annual Costs per Ton of Soil Saved			Annual Cost per Acre Cropland		
							25%ile	Median	75%ile	25%ile	Median	75%ile
VI	115	Cons. Tillage Veg. Filter Strip +Grassed Waterways+Ponds(2)	115	1200 2750								
		Farm Total			590	97.2	4.97	7.58	10.14	42.84	56.23	69.38
VII (Wicomico)	13.5	Cons. Crop + Cons. Till + Cover	13.6		55	63.7		6.81			27.54	
VII (Somerset)	18.5	Cons Crop+Cons Till+ Crop Res+Pond	18.5		59	60.4		21.21			67.88	

1. Original Source: Maryland Department of Agricultre.

Table E-2 Pennsylvania Soil Conservation Farm Plans[1]

Farm Location	Cropland (acres)	BMP Type	area (acres)	length (ft)	Soil Saved Tons/yr	% Reduc'n Soil Losses	Annual Costs per Ton of Soil Saved			Annual Costs per Acre Cropland		
							25%ile	Median	75%ile	25%ile	Median	75%ile
A+B	81	Stripcropping	11		90		0.71	1.42	1.42			
		Terraces	8	750	81		3.52	8.47	14.67			
		Diversions	5	250	15		8.71	17.40	38.92			
		Grassed Waterway	8	550	39		5.50	13.40	21.15			
		Cropland Protection	3		14			2.14				
		Other BMPs[2]	70		490			1.43				
		Farm Total			729	72	2.66	3.90	5.44	23.93	35.08	48.95
D+E	93	Stripcropping	21		155		0.79	1.57	1.57			
		Terraces	2	150	18		3.97	9.53	16.50			
		Diversions	1	50	3		8.71	17.40	38.92			
		Grassed Waterways	3.5	850	60		5.53	13.46	21.25			
		Cropland Protection	6		27			2.23				
		Other BMPs[2]	53		146			3.63				
		Farm Total			409	62	3.74	5.51	7.12	16.45	24.24	31.30
C+F	100	Stripcropping	1		8		0.73	1.45	1.45			
		Terrace	6	600	72		2.97	7.15	12.38			
		Diversion	10	500	30		8.71	17.40	38.92			
		Grassed Waterway	16	250	18		5.42	13.19	20.83			
		Other BMPs[2]	83		249			3.33				
		Farm Total			377	56	5.35	7.23	10.29	20.18	27.25	38.79

1. Original Source: Pennsylvania Department of Environmental Resources: Bureau of Soil and Water Conservation.
2. Other BMPs are non cost-shared practices including cropland protective cover, conservation tillage, contour farming and contour strip-cropping, and some conversions to hay. Soil loss was assumed at 2T (T= allowable soil loss) before the implementation of these BMPs. Expected soil loss after implementation of these BMPs is assumed at T.

Table E-3 Virginia Soil Conservation Farm Plans[2]

Farm Location	Cropland/ Pasture (acres)	BMP Type	area (acres)	length (ft)	Soil Saved Tons/yr	% Red'n Soil Losses	Annual Costs per Ton of Soil Saved			Annual Cost per Acre Cropland/Pasture		
							25%ile	Median	75%ile	25%ile	Median	75%ile
1	143.6	Convert to Hay	6.3		96	97						
		Cons. Till+Rot'n	137.3		1480	71	16.19	2.54	62.26			
		Waterways		1100	27	100		39.43				
		Filter Strips	13.0									
		Farm Total			1603	73	2.64	3.05	3.46	29.52	34.06	38.58
3	201.2	Cons. Tillage	49.5		190	55		4.53				
		Strip-crop+Rot'n	151.7		3906.3	81	0.61	0.84	0.84			
		Waterways		2725	54	100	19.68	47.94	75.69			
		Farm Total			4150	80	1.04	1.62	1.98	21.46	33.42	40.87
5	55.6	Cons. Tillage	55.6		781	67						
		Waterway	55.6	500	17	100	11.47	27.94	44.12			
		Contour Farming										
		Farm Total			797.92	67	1.45	1.80	2.15	20.85	25.88	30.83
2+4	86.2	Rot. Grazing	86.2		854	85	1.88	3.66	7.44	18.64	36.27	73.78

1. Original Source: Virginia Department of Conservation and Recreation: Division of Soil and Water Conservation.
1= Cash Grain; 2= Beef Cattle; 3=Dairy; 4=Beef/Sheep; 5= Tobacco/Grain.

APPENDIX F

Nutrient Removal Efficiencies and Cost for Urban BMPs

Table F-1 Nutrient Removal Efficiencies of Urban BMPs[1]					
BMP	#	Range	Drainage Area (acres)	Total Nitrogen (%)	Total Phosphorus (%)
Dry Pond/ Extended Deten.(ED)	7	min 25%ile median 75%ile max	11 17 28 34 88	10 17 25 30 35	13 18 20 26 40
Wet Ponds	25	min 25%ile median 75%ile max	.8 27 58 348 4,872	6 21 32 39 85	12 34 46 67 91
Wet Ponds/ED	3	min median max	395 860 2139	54	47 69 79
Stormwater Wetalnds	12	min 25%ile median 75%ile max	6 42 462 1,207 2,340	23 23 24 30 30	-2 11 47 61 97
Wetlands/ED	4	min median max	40 255 1070	5 21 36	7 16 54
Natural Wetlands	1		55.4	-1.6	7.0
Pond/Wetalands Systems	7	min 25%ile median 75%ile max	18 42 389 2230 23393	-6 11 29 75 83	1 24 64 90 92

1. Nutrient removal ranges calculated from pollutant removal tables in the report: "A Current Assessment of Urban Best Management Practices" (Schueler et. al, 1992)

Table F-2 Unit Costs of Urban BMPs in the District of Columbia[1]				
BMP	#	Range	Acres Benefitted	Unit Costs ($/acre/year)
Sand Filters	68	minimum	0.14	344
		25%ile	0.46	3,787
		median	0.60	7,036
		75%ile	1.17	9,101
		maximum	12.17	29,903
Infiltration Trenches	5	minimum	0.16	478
		25%ile	0.20	670
		median	0.46	1,820
		75%ile	0.50	4,186
		maximum	0.70	5,233
Rooftop Detention	50	minimum	0.13	335
		25%ile	0.29	957
		median	0.66	1,340
		75%ile	1.00	2,310
		maximum	2.00	7,281
Oil Grit Chamber	33	minimum	0.12	797
		25%ile	0.30	1,444
		median	0.59	2,392
		75%ile	1.20	4,257
		maximum	5.00	16,746
Ponds	8	minimum	0.69	262
		25%ile	3.08	790
		median	7.87	2,125
		75%ile	20.25	4,615
		maximum	32.00	12,134

1. Unit cost ranges calculated from the report: "Chesapeake Bay Implementation Grant Quarterly Progress Report." District of Columbia Department of Consumer and Regulatory Affairs (DCRA, 1992).

Table F-3 Unit Costs of Urban BMPs in Maryland[1]				
BMP	#	Range	Acres Benefitted	Unit Costs ($/acre/year)
Extended Detention/ Shallow Marsh	13	minimum 25%ile median 75%ile maximum	23 32 58 230 326	38 195 465 545 1,589
Wet Ponds	6	minimum 25%ile median 75%ile maximum	17 51 117 242 267	102 116 250 870 1,152
Retrofits Dry-Extended Detention Dry-Wet Pond Wet Pond-Extended detention	12	minimum 25%ile median 75%ile maximum	18 40 190 440 1168	9 49 179 289 698
Infiltarion Trenches	2	minimum median maximum	3 12 21	2,456 2,803 3,150

1. Unit cost ranges calculated from cost tables in the Maryland Department of Environment report: "A Survey and Analysis of Stormwater Management Cost-Share Projects" (Majedi and Comstock, 1992).

APPENDIX G

Chesapeake Bay Basin Large Municipal Wastewater Treatment Plants*

Basin A	=	Lower Susquehanna & Conowingo
Basin B	=	Lower Susquehanna
Basin C	=	Juniata
Basin D	=	West Branch Susquehanna
Basin E	=	East Branch Susquehanna
Basin F	=	Potomac
Basin G	=	Rappahannock
Basin H	=	Pamunkey
Basin I	=	James
Basin Q	=	Eastern Shore
Basin R	=	Tidal Patuxent
Basin S	=	North Western Shore
Basin T	=	Tidal Potomac
Basin U	=	Tidal Rappahannock
Basin W	=	Tidal York
Basin X	=	Tidal James

* Data shown in this appendix were obtained from the Chesapeake Bay Program Point Source Atlas supplemented with more recent data from the states. Flows and nutrient effluent concentrations reflect the most recent average annual data compiled through 1990. Design capacity flow information, for 51 out 265 WWTPs, includes expected expansion of these WWTPs before the year 2000.

TABLE G-1. BASIN A: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
NY	22730	OWEGO (T) WATE	SUSQUEHANNA	TIOGA	0.50	0.39	21.80	6.50	
NY	25712	PAINTED POST (	SUSQUEHANNA	STEUBEN	0.50	0.29	18.63	6.50	FF
NY	20672	HAMILTON (V) W	SUSQUEHANNA	MADISON	0.50	0.42	29.29	6.50	AS/
NY	22906	ERWIN (T) STP	SUSQUEHANNA	STEUBEN	0.52	0.27	18.76	6.50	AS/
NY	23591	COOPERSTOWN SE	SUSQUEHANNA	OTSEGO	0.52	0.43	18.95	6.50	
NY	31089	WAVERLY (V) WW	SUSQUEHANNA	TIOGA	0.60	0.61	27.70	6.50	AS/
NY	29262	OWEGO (V) STP	SUSQUEHANNA	TIOGA	0.62	0.69	15.42	6.50	
NY	21431	BATH (V) WWTP	SUSQUEHANNA	STEUBEN	1.00	0.77	16.97	6.50	AS/
NY	35742	MILTON STREET	SUSQUEHANNA	CHEMUNG	1.00	5.00	28.21	6.50	
NY	22357	ALFRED (V) SEW	SUSQUEHANNA	ALLEGANY	1.00	0.34	20.98	6.50	
NY	29271	SIDNEY (V) WWT	SUSQUEHANNA	DELAWARE	1.70	0.60	16.54	6.50	AS/
NY	25798	OWEGO WATER PO	SUSQUEHANNA	TIOGA	2.00	0.63	15.83	6.50	AS/
NY	25721	CORNING (C) WA	SUSQUEHANNA	STEUBEN	2.13	0.96	19.77	6.50	
NY	21423	NORWICH WASTE	SUSQUEHANNA	CHENANGO	2.20	2.60	30.04	6.50	AS/
NY	23647	HORNELL (C) WA	SUSQUEHANNA	STEUBEN	4.00	1.89	15.74	6.50	AS/
NY	31151	ONEONTA (C) WW	SUSQUEHANNA	OTSEGO	4.00	2.62	16.88	6.50	
NY	36986	CHEMUNG COUNTY	SUSQUEHANNA	CHEMUNG	4.80	4.90	19.68	6.50	
NY	27669	ENDICOTT (V) W	SUSQUEHANNA	BROOME	7.67	6.80	21.06	6.50	
NY	27561	CORTLAND (C) W	SUSQUEHANNA	CORTLAND	10.00	4.86	17.38	6.50	AS/N
NY	24414	BINGHAMTON-JOH	SUSQUEHANNA	BROOME	18.25	27.70	25.97	6.50	AS/
PA	21717	MARIETTA DONEG	SUSQUEHANNA	LANCASTER	0.60	0.33	17.00	5.63	AS/CS
PA	20923	NEW OXFORD MUN	SUSQUEHANNA	ADAMS	0.83	0.61	17.00	2.55	AS/N
PA	26620	MILLERSVILLE B	SUSQUEHANNA	LANCASTER	1.00	0.64	17.00	5.63	AS/CS
PA	21890	NEW HOLLAND BO	SUSQUEHANNA	LANCASTER	1.18	0.65	19.20	1.32	TF
PA	43257	NEW FREEDOM WT	SUSQUEHANNA	YORK	1.35	0.96	17.00	5.63	AS/CS
PA	21067	MOUNT JOY SEWA	SUSQUEHANNA	LANCASTER	1.53	0.76	19.20	1.47	AS/N&TF
PA	26123	COLUMBIA WASTE	SUSQUEHANNA	LANCASTER	2.00	0.86	17.00	0.35	AS/CS
PA	20893	MANHEIM BOROUG	SUSQUEHANNA	LANCASTER	2.16	0.59	19.20	1.90	TF/
PA	27405	EPHRATA BOROUG	SUSQUEHANNA	LANCASTER	3.00	3.42	19.20	1.68	AS/N&TF
PA	23108	ELIZABETHTOWN	SUSQUEHANNA	LANCASTER	3.00	1.57	17.00	0.68	TF/
PA	20320	LITITZ SEWAGE	SUSQUEHANNA	LANCASTER	3.50	2.01	19.20	1.48	AS/N
PA	20826	DOVER TOWNSHIP	SUSQUEHANNA	YORK	3.50	2.86	19.20	0.37	AS/OD
PA	26875	HANOVER STP, B	SUSQUEHANNA	YORK	3.65	3.37	19.20	1.40	AS/OD
PA	37150	PENN TOWNSHIP	SUSQUEHANNA	YORK	5.75	1.51	19.20	0.83	AS/N
PA	42269	LANCASTER AREA	SUSQUEHANNA	LANCASTER	10.00	7.68	17.00	0.58	AS/CS
PA	26808	SPRINGETTSBURG	SUSQUEHANNA	YORK	15.00	8.63	19.20	0.72	AS/CM
PA	26263	YORK SEWAGE WA	SUSQUEHANNA	YORK	18.00	13.83	17.00	1.35	AS/CS
PA	26743	LANCASTER SEW	SUSQUEHANNA	LANCASTER	29.70	19.14	19.20	0.77	AS/CS
					169.25	132.19			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR= Sequencing Batch Reactors
P= Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-2. BASIN B: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
NY	20672	HAMILTON (V) W	SUSQUEHANNA	MADISON	0.50	0.42	29.29	6.50	AS/
PA	23183	MT. HOLLY SPRI	SUSQUEHANNA	CUMBERLAND	0.60	0.22	20.9	0.81	AS/OD
PA	20915	PINE GROVE BOR	SUSQUEHANNA	SCHUYLKILL	0.60	0.49	14.3	0.60	AS/N
PA	21806	ANNVILLE TOWNS	SUSQUEHANNA	LEBANON	0.75	0.45	20.9	1.38	AS/N
PA	44113	S MIDDLETON TW	SUSQUEHANNA	CUMBERLAND	0.75	0.27	24.56	0.98	AS/N
PA	24384	CARLISLE SUBUR	SUSQUEHANNA	CUMBERLAND	0.90	0.53	20.9	2.00	AS/N
PA	24040	HIGHSPIRE STP	SUSQUEHANNA	DAUPHIN	0.90	1.03	17.2	1.56	AS/CS
PA	22535	MILLERSBURG BO	SUSQUEHANNA	DAUPHIN	0.90	0.43	14.58	8.00	AS/PF
PA	26654	NEW CUMBERLAND	SUSQUEHANNA	CUMBERLAND	1.25	0.55	24.68	1.82	AS/CS
PA	23558	ASHLAND MUNICI	SUSQUEHANNA	SCHUYLKILL	1.30	0.86	13.76	2.08	AS/EA
PA	21075	MYERSTOWN BORO	SUSQUEHANNA	LEBANON	1.40	0.61	20.9	0.58	AS/N
PA	24287	PALMYRA BOROUG	SUSQUEHANNA	LEBANON	1.42	0.70	28.04	2.90	AS/PF
PA	28746	HAMPDEN TOWNSH	SUSQUEHANNA	CUMBERLAND	1.76	1.32	12.67	2.04	AS/PF
PA	70386	SHENANDOAH MUN	SUSQUEHANNA	SCHUYLKILL	2.00	1.32	13.28	3.34	AS/CM
PA	20885	MECHANICSBURG	SUSQUEHANNA	CUMBERLAND	2.08	0.91	26.2	1.22	TF/
PA	26441	LEMOYNE BOROUG	SUSQUEHANNA	CUMBERLAND	2.09	1.48	25.12	2.00	AS/PF
PA	20664	MIDDLETOWN WAS	SUSQUEHANNA	DAUPHIN	2.20	1.04	24.56	1.20	AS/PF
PA	80314	HAMPDEN TOWNSH	SUSQUEHANNA	CUMBERLAND	2.50	1.98	14.41	2.00	AS/CS
PA	30643	SHIPPENSBURG B	SUSQUEHANNA	FRANKLIN	2.75	1.73	24.56	1.00	
PA	10582	SELINSGROVE BO	SUSQUEHANNA	SNYDER	2.80	1.50	20.90	8.00	AS/PF
PA	38415	EAST PENNSBORO	SUSQUEHANNA	CUMBERLAND	3.70	2.42	25.56	1.46	AS/N
PA	26484	DERRY TOWNSHIP	SUSQUEHANNA	DAUPHIN	5.00	3.19	13.71	1.30	AS&FILT C
PA	27189	LOWER ALLEN TO	SUSQUEHANNA	CUMBERLAND	5.95	3.25	9.45	1.95	AS/N
PA	26735	SWATARA TOWNSH	SUSQUEHANNA	DAUPHIN	6.30	3.25	23.17	7.50	AS/CS
PA	27316	LEBANON CITY A	SUSQUEHANNA	LEBANON	6.60	5.46	24.23	1.40	AS/N
PA	26077	CARLISLE BOROU	SUSQUEHANNA	CUMBERLAND	8.50	3.45	15.25	0.85	AS/N
PA	27197	HARRISBURG SEW	SUSQUEHANNA	DAUPHIN	30.90	24.24	15.59	1.51	AS/PF
					96.4	63.1			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P= Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-3. BASIN C: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
PA	28347	MARTINSBURG SE	SUSQUEHANNA	BLAIR	0.5	0.62	17	4.88	AS/EA
PA	32557	LOGAN TWP.(GRE	SUSQUEHANNA	BLAIR	0.6	0.44	17	4.88	AS/CS
PA	28240	BELLWOOD BOROU	SUSQUEHANNA	BLAIR	0.6	0.26	17	6	TF
PA	28088	BROWN TWP MUN	SUSQUEHANNA	MIFFLIN	0.6	0.22	17	6	EA
PA	23264	TWIN BOROUGHS	SUSQUEHANNA	JUNIATA	0.6	0.20	17	6	AS/CS
PA	20214	MOUNT UNION BO	SUSQUEHANNA	HUNTINGDON	0.63	0.40	17	6	EA
PA	22209	BEDFORD BOROUG	SUSQUEHANNA	BEDFORD	1.2	0.78	19.2	1.1	AS/PF
PA	23493	HOLLIDAYSBURG	SUSQUEHANNA	BLAIR	1.33	1.61	10.37	6	AS/N
PA	43273	HOLLIDAYSBURG	SUSQUEHANNA	BLAIR	2	1.20	19.2	6	AS/N
PA	26280	LEWISTOWN, BOR	SUSQUEHANNA	MIFFLIN	2.4	1.69	17	6	EA
PA	26191	HUNTINGDON, BO	SUSQUEHANNA	HUNTINGDON	3.75	1.81	17	4.65	TF/
PA	27014	ALTOONA CITY A	SUSQUEHANNA	BLAIR	5.5	4.97	19.2	3.75	AS/
PA	27022	ALTOONA CITY A	SUSQUEHANNA	BLAIR	6.5	6.67	19.2	3.75	AS/PF
PA	26727	TYRONE BOROUGH	SUSQUEHANNA	BLAIR	9	5.00	19.2	0.38	AS/N
					35.21	25.9			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P= Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-4. BASIN D: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
PA	23736	TRI BORO MUNIC	SUSQUEHANNA	SUSQUEHANNA	0.5	0.37	17	1.88	EA
PA	24759	CURWENSVILLE M	SUSQUEHANNA	CLEARFIELD	0.5	0.60	17	7.13	AS/EA
PA	20699	MONTGOMERY BOR	SUSQUEHANNA	LYCOMING	0.6	0.44	17	6	AS/PF
PA	24325	MUNCY BOROUGH	SUSQUEHANNA	LYCOMING	0.7	1.18	17	4.88	TF
PA	28665	JERSEY SHORE,	SUSQUEHANNA	LYCOMING	0.8	0.65	17	6	AS/PF
PA	43893	WESTERN CLINTO	SUSQUEHANNA	CLINTON	0.9	0.40	17	6	AS/PF
PA	28461	MIFFLINBURG BO	SUSQUEHANNA	UNION	0.9	0.73	17	6	SBR
PA	21814	MANSFIELD BORO	SUSQUEHANNA	TIOGA	1	0.53	17	6	AS/N
PA	27553	PINE CREEK MA-	SUSQUEHANNA	CLINTON	1.3	1.13	17	4.88	AS/CS
PA	37966	MOSHANNON VALL	SUSQUEHANNA	CENTRE	1.5	1.55	17	6	AS/CS
PA	24406	MT CARMEL MUN	SUSQUEHANNA	NORTHUMBERLA	1.5	1.04	17	4.88	AS/CS
PA	21687	WELLSBORO MUN	SUSQUEHANNA	TIOGA	2.3	1.08	19.2	7.13	AS/
PA	20486	BELLEFONTE BOR	SUSQUEHANNA	CENTRE	2.4	1.87	19.2	1.1	AS/CS
PA	44661	LEWISBURG AREA	SUSQUEHANNA	UNION	2.42	1.03	17	6	AS/
PA	20273	MILTON MUN AUT	SUSQUEHANNA	NORTHUMBERLA	2.6	1.89	17	6	AS/EA
PA	25933	LOCK HAVEN CIT	SUSQUEHANNA	CLINTON	3.75	2.52	18.5	6	AS/
PA	28681	KELLY TWP MUN	SUSQUEHANNA	UNION	3.75	2.25	17	6	AS/PF
PA	26999	PENNSYLVANIA S	SUSQUEHANNA	CENTRE	3.84	3.05	17	1.13	AS/N
PA	26239	UNIVERSITY ARE	SUSQUEHANNA	CENTRE	3.84	3.20	19.2	0.14	AS/N&
PA	26310	CLEARFIELD MUN	SUSQUEHANNA	CLEARFIELD	4.5	3.56	17	6	AS/PF
PA	27049	WILLIAMSPORT S	SUSQUEHANNA	LYCOMING	4.5	2.67	17	6	AS/PF
PA	27057	WILLIAMSPORT S	SUSQUEHANNA	LYCOMING	7.15	8.31	17	6	AS/PF
					51.25	40.05			

D-FLOW = Design Flow in mgd
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mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
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FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM. = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-5. BASIN E: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
PA	46388	ST. JOHNS SEWE	SUSQUEHANNA	LUZERNE	0.6	0.12	17	2.51	AS/N
PA	27081	LACKAWANNA RIV	SUSQUEHANNA	LACKAWANNA	0.7	0.40	17	2.01	AS/EA
PA	27073	LACKAWANNA RIV	SUSQUEHANNA	LACKAWANNA	1	0.57	17	2.28	AS/N
PA	34576	TOWANDA MUN AU	SUSQUEHANNA	BRADFORD	1	0.82	17	6	AS/PF
PA	45985	MOUNTAINTOP AR	SUSQUEHANNA	LUZERNE	1.83	2.29	19.2	2.18	AS/N
PA	43681	SAYRE	SUSQUEHANNA	BRADFORD	1.94	0.82	17	7.13	P
PA	26221	DALLAS AREA MU	SUSQUEHANNA	LUZERNE	2.2	2.09	19.2	2.44	AS/CS
PA	28576	CLARKS SUMMIT-	SUSQUEHANNA	LACKAWANNA	2.5	2.77	19.2	4.46	AS/CS
PA	27065	LACKAWANNA RIV	SUSQUEHANNA	LACKAWANNA	3	3.38	17	2.57	AS/N
PA	23531	DANVILLE MUN A	SUSQUEHANNA	MONTOUR	3.22	2.60	17	6	AS/CS
PA	26557	SUNBURY CITY M	SUSQUEHANNA	NORTHUMBERLA	3.5	3.00	17	6	AS/PF
PA	23248	BERWICK MUN AU	SUSQUEHANNA	COLUMBIA	3.65	2.28	17	7.13	P
PA	27171	BLOOMSBURG MUN	SUSQUEHANNA	COLUMBIA	4.29	2.59	17	6	AS/CS
PA	26361	LOWER LACKAWAN	SUSQUEHANNA	LUZERNE	6	3.52	17	1.35	AS/N
PA	27090	LACKAWANNA RIV	SUSQUEHANNA	LACKAWANNA	7	5.34	17	3.12	AS/N
PA	27324	SHAMOKIN-COAL	SUSQUEHANNA	NORTHUMBERLA	7	3.04	17	4.88	TF
PA	26921	GREATER HAZELT	SUSQUEHANNA	LUZERNE	8.9	7.80	17	3.21	AS/PF
PA	26492	SCRANTON SEWER	SUSQUEHANNA	LACKAWANNA	28	14.68	19.2	3.21	AS/N
PA	26107	WYOMING VALLEY	SUSQUEHANNA	LUZERNE	50	24.21	17	4.07	TF/
					136.33	82.32			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
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AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR= Sequencing Batch Reactors
P= Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE F-6. BASIN F: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
MD	60071	GEORGE'S CREEK	POTOMAC	ALLEGANY	0.6	0.6	14.1	1.9	AS/OD
MD	23001	POOLESVILLE	POTOMAC	MONTGOMER	0.6	0.77	18.7	2.5	SBR
MD	20672	TANEYTOWN CITY	POTOMAC	CARROLL	0.66	0.92	9.75	2.1	AS/
MD	20958	BRUNSWICK SEWA	POTOMAC	FREDERICK	0.7	0.435	19.42	1.94	AS/
MD	20257	EMMITSBURG	POTOMAC	FREDERICK	0.75	0.64	18.79	1.7	TF
MD	20982	WASH.SUB.SAN.C	POTOMAC	MONTGOMERY	0.75	0.633	19.86	2.6	AS/N
MD	21121	THURMONT WASTE	POTOMAC	FREDERICK	1	0.92	14.57	3.29	AS/OD
MD	20214	WCSC SUBDIV 1-	POTOMAC	WASHINGTON	1.6	1.373	22.43	3.48	TF
MD	27405	MD CORRECTION	POTOMAC	WASHINGTON	1.63	0.805	12.2	1.38	TF
MD	21822	FREDERICK CO M	POTOMAC	FREDERICK	2	0.68	20.5	4.4	AS/
MD	20877	US ARMY FORT D	POTOMAC	FREDERICK	2	1.07	1.62	1.2	TF
MD	21831	WESTMINSTER WA	POTOMAC	CARROLL	3	3.72	13.67	2.5	AS/N
MD	21491	SENECA CREEK	POTOMAC	MONTGOMERY	5	4.71	9.06	1.3	AS/EA
MD	21610	FREDERICK CITY	POTOMAC	FREDERICK	7	8.34	19.04	3.84	AS/
MD	21776	HAGERSTOWN STP	POTOMAC	WASHINGTON	8	9.68	13.89	1.98	AS/PO
MD	21598	CUMBERLAND,CIT	POTOMAC	ALLEGANY	15	14.32	18	1.15	AS/N
PA	80225	WASHINGTON TOW	POTOMAC	FRANKLIN	1	0.75	19.2	4.88	AS/
PA	21563	GETTYSBURG MUN	POTOMAC	ADAMS	1.41	1.61	19.2	0.36	AS/OD
PA	20621	WAYNESBORO BOR	POTOMAC	FRANKLIN	1.87	0.97	17	6	AS/PF
PA	26051	CHAMBERSBURG B	POTOMAC	FRANKLIN	5.2	3.59	19.2	5.57	TF
VA	31780	FCSA: ABRAMS C	POTOMAC	WINCHESTER C	0.5	0.00	0	0	AS/EA
VA	22802	PURCELLVILLE S	POTOMAC	LOUDOUN	0.5	0.33	18.7	2.5	AS&TF
VA	66877	STUARTS DRAFT	POTOMAC	AUGUSTA	0.7	0.78	18.7	2.5	AS/OD
VA	64637	VERONA	POTOMAC	AUGUSTA	0.8	0.6	18.7	2.5	RBC
VA	62642	LURAY STP	POTOMAC	PAGE	0.8	0.97	18.7	2.5	AS/EA
VA	20311	STRASBURG STP	POTOMAC	SHENANDOAH	0.81	0.46	18.7	2.5	AS/OD
VA	62812	FRONT ROYAL ST	POTOMAC	WARREN	2	1.94	18.7	2.5	AS/CM
VA	25291	FISHERSVILLE S	POTOMAC	AUGUSTA	2	0.81	18.7	2.5	AS/CM
VA	21377	LEESBURG STP	POTOMAC	LOUDOUN	2.5	2.02	18.7	2.5	TF/HR
VA	25151	WAYNESBORO STP	POTOMAC	AUGUSTA	4	2.90	18.7	2.5	TF/HR
VA	25135	WINCHESTER STP	POTOMAC	FREDERICK	4	0	0	0	TF/HR
VA	64793	STAUNTON STP	POTOMAC	STAUNTON CIT	4.5	2.40	18.7	2.5	TF/HR
VA	65552	FWSA OPEQUON S	POTOMAC	FREDERICK	5	18.70	2.5	0	AS/CM
VA	60640	HARRISONBURG/R	POTOMAC	ROCKINGHAM	8	7.50	18.7	2.5	AS/CM
WV	20699	ROMNEY, CITY O	POTOMAC	HAMPSHIRE	0.5	0.50	17.12	6.50	AS/
WV	22349	CHARLES TOWN S	POTOMAC	JEFFERSON	0.8	0.53	20.90	6.50	AS/
WV	24392	KEYSER, CITY O	POTOMAC	MINERAL	1.1	0.71	16.95	6.50	
WV	23167	MARTINSBURG, C	POTOMAC	BERKELEY	5	3.00	14.77	6.50	FF
					103.28	100.776			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-7. BASIN G: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLO (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	21385	ORANGE STP	RAPPAHANNOCK	ORANGE	0.75	0.67	18.7	2.5	TF/SR
VA	21172	WARRENTON STP	RAPPAHANNOCK	FAUQUIER	1	1.19	18.7	2.5	TF&RBC
VA	61590	CULPEPER STP	RAPPAHANNOCK	CULPEPER	3	1.63	18.7	2.5	AS/CM
					4.75	3.49			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-8. BASIN H: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	21105	GORDONSVILLE	YORK	ORANGE	0.67	0.62	18.7	2.5	LA
VA	29521	DOSWELL STP	YORK	HANOVER	1	1.65	18.7	1.01	AS/EA
VA	24899	ASHLAND STP	YORK	HANOVER	2	0.96	18.7	2.5	LA
					3.67	3.23			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P= Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-9. BASIN I: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	21351	FARMVILLE BRID	JAMES	PRINCE EDWAR	1.05	0.60	18.7	2.5	LA
VA	22772	CLIFTON FORGE	JAMES	CLIFTON FORG	2	1.47	18.7	2.5	TF/HR
VA	20567	LEXINGTON STP	JAMES	ROCKBRIDGE	2	1.01	18.7	2.5	AS/CM
VA	20991	BUENA VISTA ST	JAMES	BUENA VISTA	2.25	1.89	18.7	2.5	RBC
VA	25542	COVINGTON STP	JAMES	COVINGTON CI	3	1.70	18.7	2.5	P
VA	25518	MOORES CREEK S	JAMES	CHARLOTTESVI	15	10.21	9.25	1.63	AS/CM
VA	24970	LYNCHBURG STP	JAMES	LYNCHBURG CI	22	14.65	12.14	1.6	AS/CM
					47.3	31.53			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-10. BASIN Q: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
DE	20249	BRIDGEVILLE ST	E SHORE	SUSSEX	0.5	0.80	20.70	7.00	AS/EA
DE	20257	GEORGETOWN TOW	E SHORE	SUSSEX	0.5	0.36	18.50	1.44	AS/EA
DE	20125	LAUREL STP	E SHORE	SUSSEX	0.75	0.31	20.70	7.20	
DE	20265	SEAFORD WASTE	E SHORE	SUSSEX	0.92	0.72	15.83	6.00	AS/
MD	23604	TALBOT CO. SAN	E SHORE	TALBOT	0.5	0.23	18.00	3.00	RBC
MD	52000	FRUITLAND, CIT	E SHORE	WICOMICO	0.5	0.43	18.00	3.00	TF
MD	22764	SNOW HILL WATE	E SHORE	WORCESTER	0.5	0.56	18	3	RBC
MD	20532	DELMAR WWTP	E SHORE	WICOMICO	0.65	0.83	10.56	0.44	AS/
MD	22641	MEADOWVIEW UTI	E SHORE	CECIL	0.7	0.16	18.00	3.00	AS/EA
MD	20249	FEDERALSBURG S	E SHORE	CAROLINE	0.74	0.37	15.70	3.05	AS/
MD	20010	CHESTERTOWN UT	E SHORE	KENT	0.9	0.76	9.3	2.30	LA
MD	20869	BAINBRIDGE	E SHORE	CECIL	1	0.18	18.00	3.00	TF
MD	22730	HURLOCK, TOWN	E SHORE	DORCHESTER	1.1	0.97	18	3	LA
MD	22551	POCOMOKE CITY	E SHORE	WORCESTER	1.2	1.47	18	3	LA
MD	20001	CRISFIELD SEWA	E SHORE	SOMERSET	1.2	0.80	19.05	1.83	AS/N
MD	20656	PRINCESS ANNE	E SHORE	SOMERSET	1.26	0.87	18	0.17	AS/N
MD	20613	TOWN COMMISSIO	E SHORE	CECIL	1.65	0.70	5.6	0.44	RBC
MD	23485	KENT NARROWS	E SHORE	QUEEN ANNES	2	0.98	19.9	3.93	RBC
MD	20273	EASTON WASTE S	E SHORE	TALBOT	2	7.50	6.87	1.94	LA
MD	52027	NORTHEAST STP	E SHORE	CECIL	2	0.51	16.20	0.33	AS/EA
MD	20681	ELKTON SEWAGE	E SHORE	CECIL	2.7	1.48	20.96	1.64	AS/
MD	21571	SALISBURY CITY	E SHORE	WICOMICO	6.8	5.22	18	3	TF
MD	21636	CAMBRIDGE COMM	E SHORE	DORCHESTER	8.1	7.90	18	3	AS/
					38.17	34.1013			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-11. BASIN R: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
MD	20281	CHESAPEAKE BEA	PATUXENT	CALVERT	0.5	0.42	18.00	3.60	AS/
MD	23132	MARYLAND CITY	PATUXENT	ANNE ARUNDEL	0.75	0.80	14.25	2.6	AS/
MD	23957	MD CORRECTIONA	PATUXENT	HOWARD	1.23	1.00	12.2	1.38	AS/
MD	21628	BOWIE CITY STP	PATUXENT	PRINCE GEORG	3.3	2.11	5.7	0.35	AS/OD
MD	21717	USA HQ, FORT M	PATUXENT	ANNE ARUNDEL	4.5	3.72	14.37	0.05	AS/N
MD	21679	PINE HILL RUN	W CHESAP	SAINT MARYS	4.5	3.62	23.04	4.08	TF
MD	21652	PATUXENT-ANNE	PATUXENT	ANNE ARUNDEL	6	3.79	7.85	0.5	AS/
MD	21725	PARKWAY	PATUXENT	PRINCE GEORG	7.5	6.76	19.5	0.6	AS/N
MD	55174	LITTLE PATUXEN	PATUXENT	HOWARD	19.4	16.10	14.81	0.5	AS/N
MD	21741	WESTERN BRANCH	PATUXENT	PRINCE GEORG	30	14.59	15.6	0.9	AS/N
					77.68	52.9			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-12. BASIN S: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
MD	22535	JOPPATOWNE STP	W CHESAP	HARFORD	0.75	0.82	15.40	3.5	AS/N
MD	22446	HAMPSTEAD	W CHESAP	CARROLL	0.9	0.40	18.00	0.56	AS/
MD	23523	US NAVAL ACADE	W CHESAP	ANNE ARUNDEL	1	0.50	18.00	0.5	TF
MD	61794	MAYO WWTP	W CHESAP	ANNE ARUNDEL	1	0.05	5.98	1.47	SF
MD	21512	MES-FREEDOM	W CHESAP	CARROLL	1.8	1.88	7.75	4.43	AS/
MD	21750	HAVRE DE GRACE	W CHESAP	HARFORD	1.9	1.94	18.03	0.86	TF
MD	24350	BROADWATER SEW	W CHESAP	ANNE ARUNDEL	2	1.24	27.90	0.74	AS/N
MD	21237	ABERDEEN PROVI	W CHESAP	HARFORD	3	1.23	20.53	0.4	TF
MD	21229	ABERDEEN PROVI	W CHESAP	HARFORD	3	1.10	7.47	0.6	TF
MD	21563	ABERDEEN, TOWN	W CHESAP	HARFORD	4	1.97	15.95	0.05	AS/N
MD	21644	AA COUNTY BROA	W CHESAP	ANNE ARUNDEL	6	5.13	16.3	2.4	AS/
MD	56545	SOD RUN	W CHESAP	HARFORD	10	9.57	25.96	0.7	AS/
MD	21814	ANNAPOLIS STP,	W CHESAP	ANNE ARUNDEL	10	8.46	9.75	1.28	AS/N
MD	21661	ANNE ARUNDEL C	W CHESAP	ANNE ARUNDEL	15	12.70	14.79	0.99	AS/
MD	21601	PATAPSCO	W CHESAP	BALTIMORE CI	87.5	62.57	12.7	1	AS/
MD	21555	BACKRIVER	W CHESAP	BALTIMORE CI	175	123.00	12.5	0.84	AS/
					322.85	232.557			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-13. BASIN T: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
DC	21199	BLUE PLAINS	POTOMAC	DC	370	316.3	13.73	0.11	AS/N
MD	20885	NAVORD/INDIAN	POTOMAC	CHARLES	0.5	0.334	18	1.55	AS/
MD	20052	INDIAN HEAD, T	POTOMAC	CHARLES	0.5	0.64	17.59	2.63	AS/
MD	22781	UTILITIES INC.	POTOMAC	P.GEORGES	0.6	0.259	12.9	1.34	AS/EA
MD	20842	US DEPARTMENT	POTOMAC	P.GEORGES	0.6	1.31	4.5	2.12	TF
MD	24767	LEONARDTOWN SE	POTOMAC	SAINT MARYS	0.68	0.318	14.31	1.09	LA
MD	20524	TOWN OF LA PLA	POTOMAC	CHARLES	1.9	0.75	18	0.74	AS/EA
MD	21865	CHARLES CNTY S	POTOMAC	CHARLES	15	6.79	11.58	1.76	AS/
MD	21539	PISCATAWAY	POTOMAC	PRINCE GEORG	30	20.12	13.15	0.1	AS/N
VA	26409	COLONIAL BEACH	POTOMAC	WESTMORELAND	0.8	0.75	18.70	2.50	TF/HR
VA	28363	QUANTICO/MAINS	POTOMAC	PRINCE WILLI	2	1.55	18.7	0.26	AS&TF
VA	24678	DALE CITY STP	POTOMAC	PRINCE WILLI	2	1.72	18.66	0.09	AS/CS
VA	24724	DALE CITY STP	POTOMAC	PRINCE WILLI	4	2.02	11.84	0.11	AS/CS
VA	60968	AQUIA STP	POTOMAC	STAFFORD	6	2.33	9.7	0.16	AS/N
VA	25372	L. HUNTING CRE	POTOMAC	FAIRFAX	6.6	4.63	21.41	0.09	TF/HR
VA	25101	PWCSA MOONEY S	POTOMAC	PRINCE WILLI	24	10.58	19.36	0.11	AS/N
VA	25143	ARLINGTON STP	POTOMAC	ARLINGTON CI	40	28.12	10.63	0.06	AS/EA
VA	25160	ALEXANDRIA STP	POTOMAC	ALEXANDRIA C	54	42.99	24.15	0.05	RBC
VA	24988	UPPER OCCOQUAN	POTOMAC	PRINCE WILLI	54	16.32	21.48	0.04	AS/CM
VA	25364	LOWER POTOMAC	POTOMAC	FAIRFAX	72	35.15	13.65	0.12	AS/SA
					685.18	492.98			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-14. BASIN U: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	28096	CLAIRBONE RUN	RAPPAHANNOCK	STAFFORD	1.5	0.88	18.7	2.5	AS/CS
VA	25127	FREDERICKSBURG	RAPPAHANNOCK	FREDERICKSBU	4.5	1.68	21.47	2.5	TF/HR
VA	25658	MASSAPONAX STP	RAPPAHANNOCK	FREDERICKSBU	6	2.34	19.17	1.5	AS/EA
VA	68110	SPOTSYLVANIA C	RAPPAHANNOCK	SPOTSYLVANIA	6	2.78	8.43	2.5	AS/CM
VA	76392	LITTLE FALLS	RAPPAHANNOCK	STAFFORD	8		18.7	2.5	AS/OD
					26	7.68			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-15. BASIN W: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	64238	HRSD-YORK RIVE	YORK	YORK	15.0	8.14	15.64	2.23	AS/PF
					15.0	8.14			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

TABLE G-16. BASIN X: LARGE MUNICIPAL WASTE WATER TREATMENT PLANTS

STATE	NPDES	FACILITY NAME	BASIN	COUNTY	D-FLOW (mgd)	FLOW (mgd)	TN (mg/l)	TP (mg/l)	TYPE
VA	23809	SMITHFIELD CAR	JAMES	ISLE OF WIGH	0.5	0.54	18.7	2.5	AS/OD
VA	25216	FT. EUSTIS STP	JAMES	NEWPORT NEWS	3	1.67	18.92	2.48	TF
VA	24996	FALLING CREEK	JAMES	CHESTERFIELD	10	9.96	10.4	1.58	AS/CM
VA	25003	PORTSMOUTH STP	JAMES	PORTSMOUTH C	15	12.12	20.76	3.99	P
VA	25437	PETERSBURG STP	JAMES	PETERSBURG C	15	10.37	15.52	2.5	AS/CM
VA	25208	HRSD - ARMY BA	JAMES	NORFOLK CITY	18	12.09	14.17	3.02	AS/PO
VA	25241	HRSD - JAMES R	JAMES	NORFOLK CITY	20	12.59	20.54	2.55	AS/PF
VA	25267	HRSD - WILLIAM	JAMES	NORFOLK CITY	22.5	9.44	15.76	2.06	AS/PF
VA	25275	HRSD - CHESAPE	E SHORE	NORFOLK CITY	24	18.13	20.86	3.08	AS/PF
VA	25283	HRSD - BOAT HA	JAMES	NORFOLK CITY	25	17.14	20.39	2.92	AS/PO
VA	60194	PROCTORS CREEK	JAMES	CHESTERFIELD	27	8	12.63	1.67	AS/CM
VA	64459	HRSD - NANSEMO	JAMES	VIRGINIA BEA	30	9.67	24.8	3.54	AS/PF
VA	25259	HRSD - VIP STP	JAMES	NORFOLK CITY	40	22.00	18	1.5	BNR
VA	63690	HENRICO STP	JAMES	HENRICO	45	21.78	18.7	2.5	AS/PO
VA	66630	HOPEWELL STP	JAMES	HOPEWELL CIT	50	33.07	70.64	1.79	AS/PO
VA	63177	RICHMOND STP	JAMES	RICHMOND CIT	70	55.5	14.93	0.95	AS/SA
					415	254.07			

D-FLOW = Design Flow in mgd
FLOW = Annual Average Flow in mgd
mgd = Millions Gallons per Day
TN = Annual Average Total Nitrogen Conc.
TP = Annual Average Total Phosphorus Conc.
NPDES = National Pollution Discharge Elimination Number

AS/ = Activated Sludge
AS/N = Activated Sludge with Nitrification
FF = Fixed Film (TF or RBC)
TF = Trickling Filter
RBC = Rotating Biological Contactors
SBR = Sequencing Batch Reactors
P = Primary
LA = Lagoon

EA = Extended Aeration
CM = Complete Mix
CS = Contact Stabilization
OD = Oxidation Ditch
PF = Plug Flow
PO = Pure Oxygen
SA = Step Aeration
HR = High Rate
LR = Low Rate

APPENDIX H

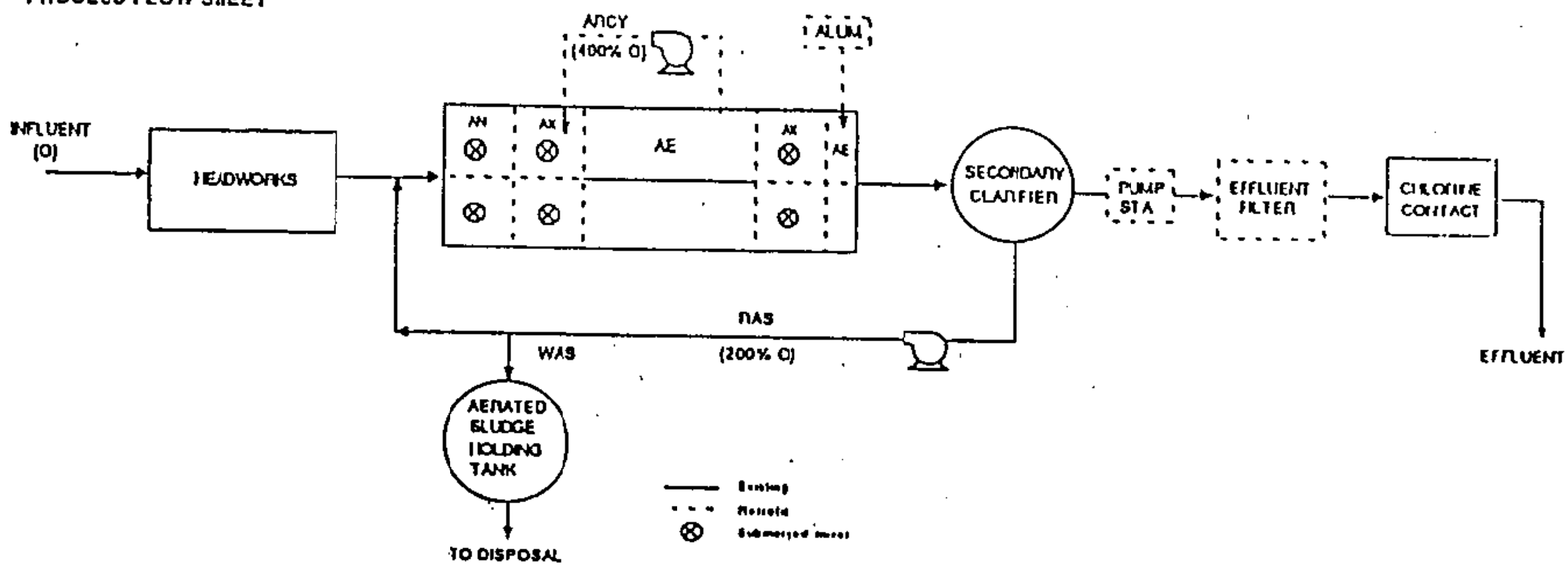
Planning Level Retrofit Configurations*

* Retrofit configurations shown in this appendix were obtained from: "Assessment of Cost and Effectiveness of Biological Dual Nutrient Removal Technologies in the Chesapeake Bay Drainage Basin" by Hazen and Sawyer and J.M. Smith and Associates (1988).

RETROFIT PLANT IN CBDB

PLANT TYPE: EXTENDED AERATION

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (LOW)

TN = 3 mg/l

TP = 0.5 mg/l

Existing Plant

- Aeration tank @ 20 hours detention time
- Clarifier @ 600 gpd/sq ft
- Existing RAS @ 200% Q (no standby)

Retrofit Plant

- Install baffles in existing tanks and submerged mixers
- Add gravity filters @ 3 gpm/sq ft ADF and alum feed system
- Add pump station 400% capacity ARCY

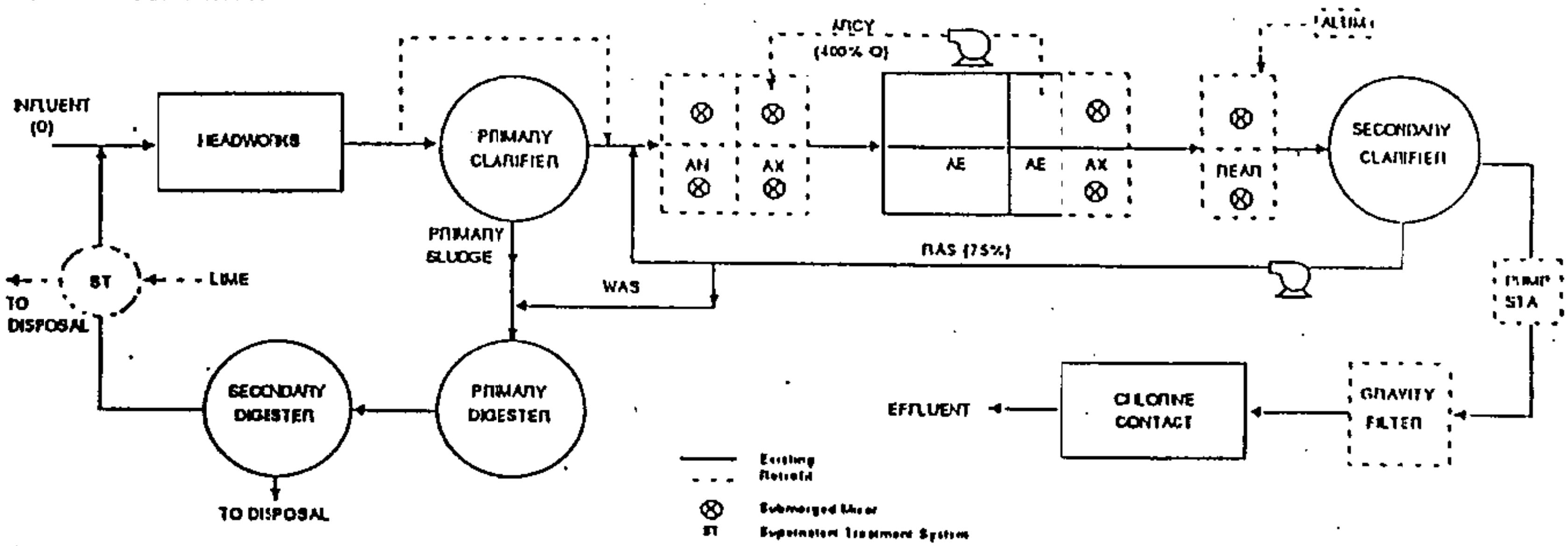
Figure H-1 Low Level Nutrient Discharge (Extended Aeration)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: CONVENTIONAL ACTIVATED SLUDGE

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (LOW)

TN - 3 mg/l
TP - 0.5 mg/l

Existing Plant

- Aeration - 6 hrs HRT
- Clarifier @ 600 gpd/sq ft
- Existing RAS @ 75% Q

Retrofit Plant

- 5 stage process (18.5 hrs HRT)
- Add new Anaerobic, 1st stage anoxic, 2nd anoxic and reaeration.Expand aeration
- Add effluent filters 3 gpm/sq ft @ ADF and alum
- Add internal recycle pump @ 400% Q
- Add full flow pump station 20' TDH
- Add supernatant treatment system
- Add additional blower capacity
- Add submerged mixer
- Add 25% Q RAS pumps

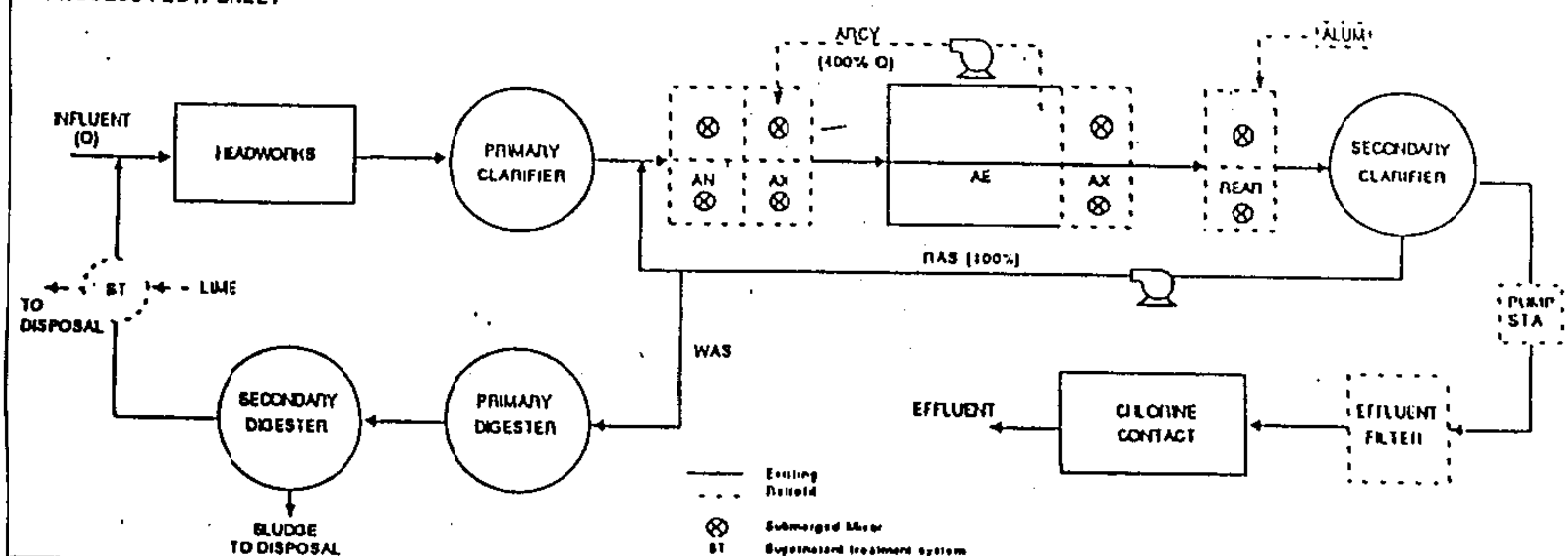
Figure H-2 Low Level Nutrient Discharge (Activated Sludge)

urce: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: ACTIVATED SLUDGE WITH NITRIFICATION

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (LOW)

TN - 3 mg/l
TP - 0.5 mg/l

Existing plant

- Aeration tank @ 10 hour detention time
- Clarifier @ 400 gpd/sq ft
- Existing RAS @ 100 Q

Retrofit Plant

- Add anaerobic (2 hrs), 1st anoxic (3 hrs), 2nd anoxic (3hrs) and reaeration tanks (1/2 hr)
- Add 400% capacity ARCY pump
- Provide additional 100% Q RAS pumps
- Install alum feed system and effluent gravity filters (5 gpm/sq ft at ADF)
- Add pump station
- Add submerged mixer
- Add supernatant treatment system

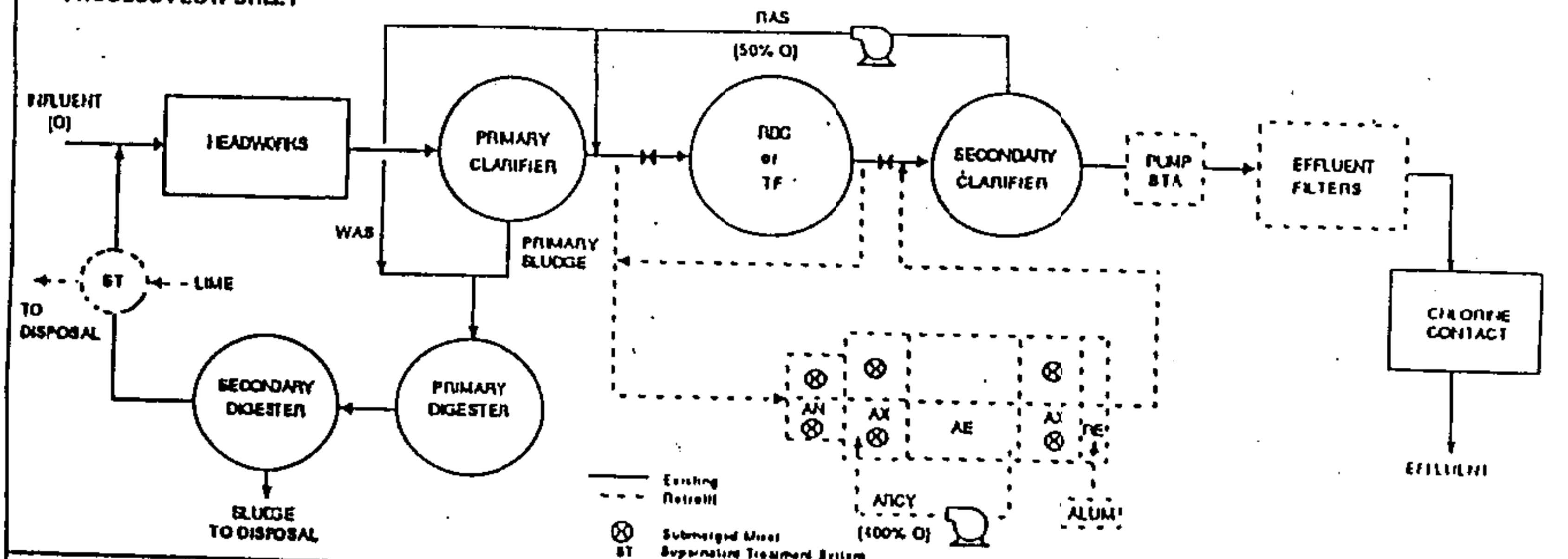
Figure H-3 Low Level Nutrient Discharge (Activated Sludge with Nitrification)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: FIXED FILM PROCESS

PROCESS FLOW SHEET



DESIGN CRITERIA
EFFLUENT LIMITS: (LOW)

TN = 3 mg/l
TP = 0.5 mg/l

Existing Plant

- Rotating Biological Contactor (RBC) or Trickling Filter (TF)
- Clarifier capacity @ 600% gpd/sq ft
- Existing equivalent RAS 50% Q

Retrofit Plant

- Install new 5-stage process tanks
- Add 400% Q internal recycle pumps
- Install effluent gravity filters 3 gpm/sq ft (ARF), and alum feed system
- Bypass existing TF or RBC or use as biological roughing
- Add pump station
- Add supernatant treatment system
- Add submerged mixer
- Add new blower
- Add new RAS, ARCY pump and blower bldg.
- Add 50% Q RAS pump

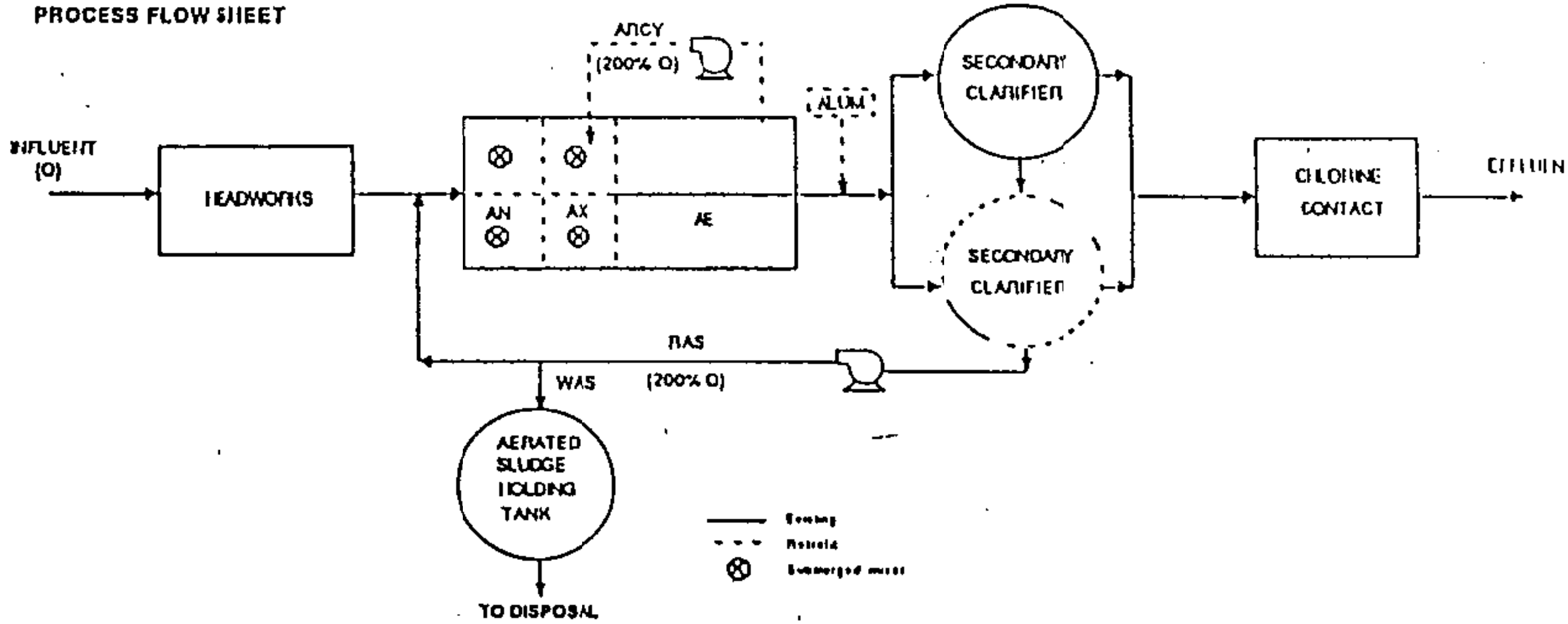
Figure H-4 Low Level Nutrient Discharge (Fixed Film)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: EXTENDED AERATION

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (HIGH)

TN = 8 mg/l

TP = 2 mg/l

Existing Plant

- Aeration tank @ 20 hours detention time
- Clarifier @ 600 gpd/sq ft
- Existing RAS @ 200% Q (no standby)

Retrofit Plant

- Install baffles in existing tanks and submerged mixers
- Add internal recycle pump at 200% Q
- Add standby alum system
- Construct 50% more clarification capacity (400 gpd/sq ft)

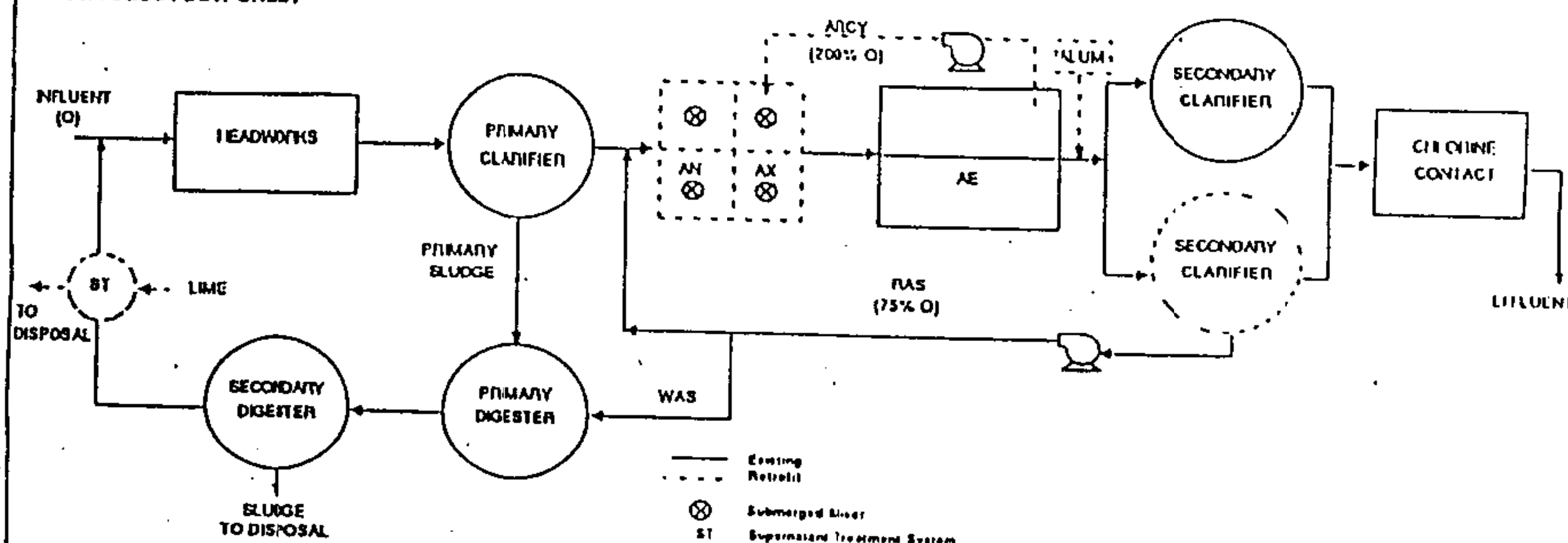
Figure H-5 High Level Nutrient Discharge (Extended Aeration)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: CONVENTIONAL ACTIVATED SLUDGE

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (HIGH)

TN = 8 mg/l
TP = 2 mg/l

Existing Plant

- Aeration tank @ 6 hour detention time
- Clarifier @ 600 gpd/sq ft
- Existing RAS @ 75% Q

Retrofit Plant

- Add Anaerobic (1 hr) and Anoxic (1 hr) tanks
- Add internal recycle at 200% Q
- Add standby alum system
- Construct 50% more clarification capacity (400 gpd/sq ft)
- Add supernatant treatment system
- Add additional blower capacity
- Add submerged mixer

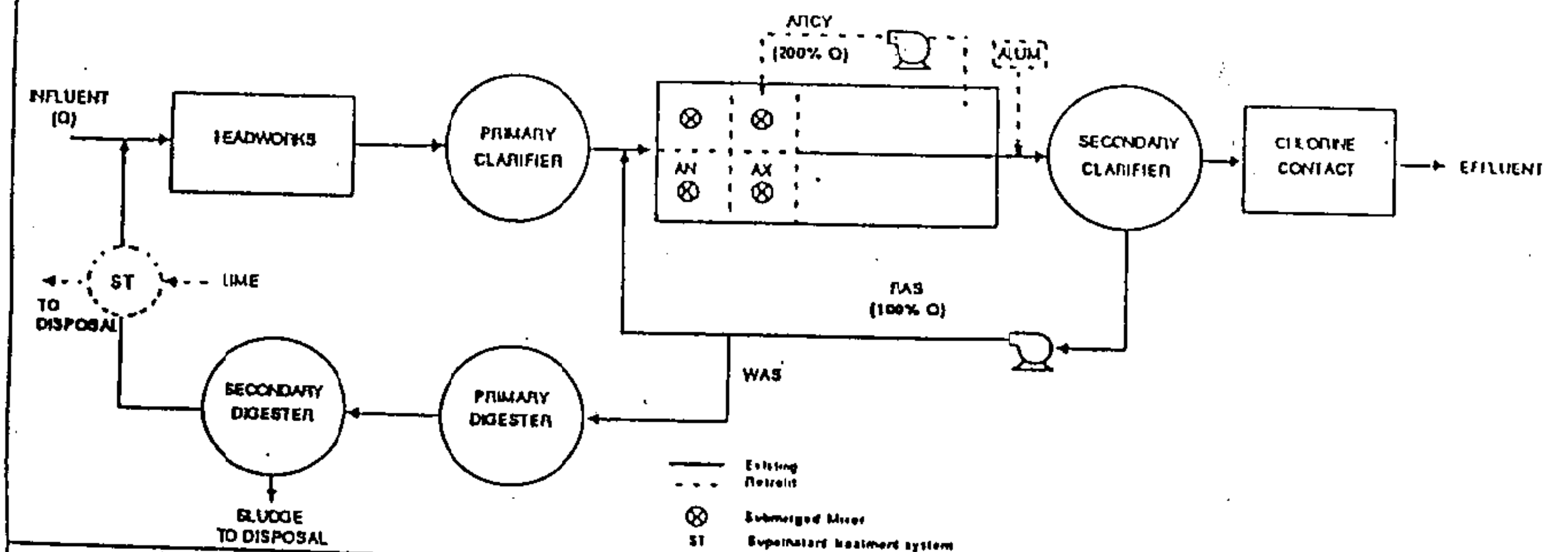
Figure H–6 High Level Nutrient Discharge (Activated Sludge)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: ACTIVATED SLUDGE WITH NITRIFICATION

PROCESS FLOW SHEET



DESIGN CRITERIA

EFFLUENT LIMITS: (HIGH)

TN = 8 mg/l
TP = 2 mg/l

Existing Plant

- Aeration tank @ 10 hour detention time
- Clarifier @ 400 gpd/sq ft
- Existing RAS @ 100% Q

Retrofit Plant

- Install baffles in existing tank
- Install submerged mixers in AN/AX zones
- Add internal recycle at 200% Q
- Install alum feed system as back-up
- Add supernatant treatment system

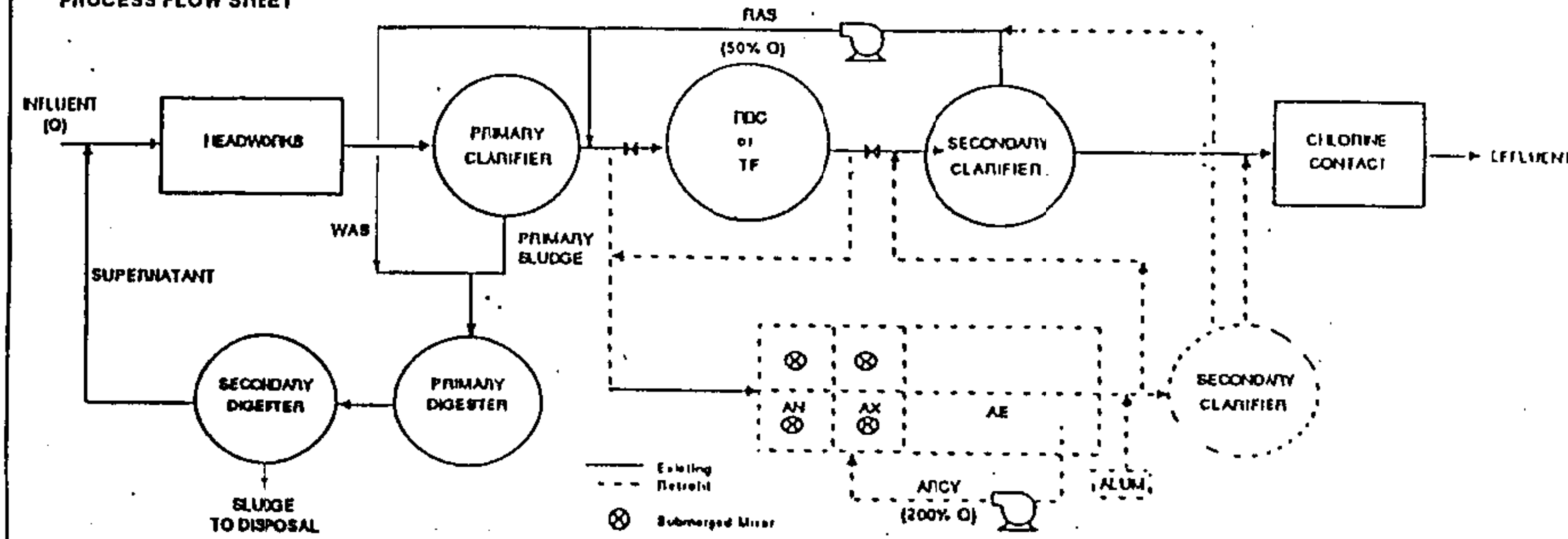
Figure H-7 High Level Nutrient Discharge (Activated Sludge with Nitrification)

(Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

RETROFIT PLANT IN CBDB

PLANT TYPE: FIXED FILM PROCESS

PROCESS FLOW SHEET



DESIGN CRITERIA
EFFLUENT LIMITS: (HIGH)

TN = 8 mg/l
TP = 2 mg/l

Existing Plant

- Rotating Biological Contractor (RBC) or Trickling Filter (TF)
- Clarifier @ 600% gpd/sq ft
- Existing equivalent RAS 50% Q

Retrofit Plant

- Install new 3-stage process tanks and aeration system
- Add 200% Q internal recycle pumps
- Install 50% more clarifiers (400 gpd/sqft)
- Bypass existing TF or RBC or use as biological roughing

Figure **H-8** High Level Nutrient Discharge (Fixed Film)

Source: Hazen and Sawyer and J.M. Smith and Associates, 1988)

APPENDIX I

Planning Level Retrofit Cost Equations*

* Retrofit cost equations were developed based on cost tables from the Hazen and Sawyer and J.M. Smith and Associates report (1988). Costs from these tables were modified according to the assumptions described in Section 3.4.2.

Table I-1 Planning Level Retrofit Cost Equations[1]: Seasonal TN Removal (Phosphate Ban Areas)

$$Capital = a(Flow)^b$$

$$O\&M = c(Flow)^d$$

Plant Type	Design Flow Range (mgd)	High Level Nutrient Discharge TP = 2.0 mg/l TN = 8.0 mg/l				Low Level Nutrient Discharge TP = 0.5 mg/l TN = 3.0 mg/l			
		Capital		O&M		Capital		O&M	
		a	b	c	d	a	b	c	d
Extended Aeration	0.5 - 5.0	614,207	0.475	37,058	0.541	1,408,539	0.550	94,994	0.649
	5.0 - 30.0	461,461	0.669	30,941	0.696	1,098,160	0.670	61,658	0.899
Activated Sludge	0.5 - 5.0	852,255	0.560	72,899	0.622	2,163,027	0.640	187,999	0.578
	5.0 - 30.0	658,674	0.720	57,154	0.758	1,656,464	0.780	125,301	0.812
Activated Sludge with Nitrification	0.5 - 5.0	644,876	0.510	35,475	0.592	1,885,670	0.610	113,815	0.670
	5.0 - 30.0	524,224	0.659	22,828	0.866	1,565,680	0.710	90,377	0.816
Fixed Film	0.5 - 5.0	,328,948	0.620	119,815	0.521	2,699,363	0.640	183,985	0.556
	5.0 - 30.0	911,733	0.840	65,451	0.897	2,071,261	0.790	117,863	0.833

1. Nonlinear regression results showed and R^2 above 0.99 for all the equations.

Table I-2. Planning Level Retrofit Cost Equations[1]: Seasonal TN Removal (Non-Phosphate Ban Areas)

$$Capital = a(Flow)^b$$

$$O\&M = c(Flow)^d$$

Plant Type	Design Flow Range (mgd)	High Level Nutrient Discharge TP = 2.0 mg/l TN = 8.0 mg/l				Low Level Nutrient Discharge TP = 0.5 mg/l TN = 3.0 mg/l			
		Capital		O&M		Capital		O&M	
		a	b	c	d	a	b	c	d
Extended Aeration	0.5 - 5.0	614,207	0.475	37,984	0.551	1,408,539	0.550	98,654	0.660
	5.0 - 30.0	461,461	0.669	31,329	0.712	1,098,160	0.670	64,623	0.905
Activated Sludge	0.5 - 5.0	852,255	0.560	73,782	0.627	2,163,027	0.640	191,730	0.586
	5.0 - 30.0	658,674	0.720	57,710	0.764	1,656,464	0.780	127,730	0.819
Activated Sludge with Nitrification	0.5 - 5.0	644,876	0.510	36,393	0.602	1,885,670	0.610	117,470	0.678
	5.0 - 30.0	524,224	0.659	23,535	0.876	1,565,680	0.710	93,409	0.825
Fixed Film	0.5 - 5.0	1,328,948	0.620	120,757	0.525	2,699,363	0.640	187,761	0.565
	5.0 - 30.0	911,733	0.840	66,235	0.898	2,071,261	0.790	120,578	0.840

1. Nonlinear regression results showed and R^2 above 0.99 for all the equations.

Table I-3 Planning Level Retrofit Cost Equations[1]: Year-Round TN Revomal (Phosphate Ban Areas)

$$Capital=a(Flow)^b$$

$$O\&M=c(Flow)^d$$

Plant Type	Design Flow Range (mgd)	High Level Nutrient Discharge TP = 2.0 mg/l TN = 8.0 mg/l				Low Level Nutrient Discharge TP = 0.5 mg/l TN = 3.0 mg/l			
		Capital		O&M		Capital		O&M	
		a	b	c	d	a	b	c	d
Extended Aeration	0.5 - 5.0	614,199	0.475	37,058	0.541	2,817,148	0.550	94,994	0.649
	5.0 - 30.0	461,461	0.669	30,941	0.696	2,196,746	0.670	61,658	0.899
Activated Sludge	0.5 - 5.0	1,704,511	0.560	72,899	0.622	5,364,240	0.640	187,999	0.578
	5.0 - 30.0	1,317,491	0.720	57,154	0.758	4,108,540	0.780	125,301	0.812
Activated Sludge with Nitrification	0.5 - 5.0	1,083,394	0.510	35,475	0.592	4,394,274	0.610	113,815	0.670
	5.0 - 30.0	879,898	0.659	22,828	0.866	3,648,391	0.710	90,377	0.816
Fixed Film	0.5 - 5.0	3,295,913	0.620	119,815	0.521	7,233,929	0.640	183,985	0.556
	5.0 - 30.0	2,261,245	0.840	65,451	0.897	5,551,488	0.790	117,863	0.833

1. Nonlinear regression results showed anc R^2 above 0.99 for all the equations.

Table I-4 Planning Level Retrofit Cost Equations[1]: Year-Round TN Removal (Non-Phosphate Ban Areas)

$$Capital = a(Flow)^b$$

$$O\&M = c(Flow)^d$$

Plant Type	Design Flow Range (mgd)	High Level Nutrient Discharge TP = 2.0 mg/l TN = 8.0 mg/l				Low Level Nutrient Discharge TP = 0.5 mg/l TN = 3.0 mg/l			
		Capital		O&M		Capital		O&M	
		a	b	c	d	a	b	c	d
Extended Aeration	0.5 - 5.0	614,199	0.475	37,984	0.551	2,817,148	0.550	98,654	0.660
	5.0 - 30.0	461,461	0.669	31,323	0.712	2,196,746	0.670	64,613	0.905
Activated Sludge	0.5 - 5.0	1,704,511	0.560	73,782	0.627	5,364,240	0.640	191,710	0.586
	5.0 - 30.0	1,317,491	0.720	57,710	0.764	4,108,540	0.780	127,862	0.819
Activated Sludge with Nitrification	0.5 - 5.0	1,083,394	0.510	36,393	0.602	4,394,274	0.610	117,470	0.678
	5.0 - 30.0	879,898	0.659	23,535	0.873	3,648,391	0.710	93,009	0.825
Fixed Film	0.5 - 5.0	3,295,913	0.620	120,757	0.525	7,233,929	0.640	187,761	0.565
	5.0 - 30.0	2,261,245	0.840	66,235	0.898	5,551,488	0.790	120,578	0.840

1. Nonlinear regression results showed and R^2 above 0.99 for all the equations.