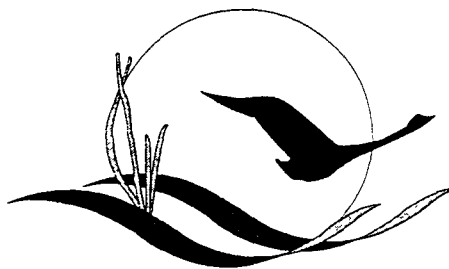


CBP/TRS 288/99
EPA-R-99-020
September 1999

Final Report

Evaluation of Wastewater Treatment Plants for BNR Retrofits Using Advances in Technology



Chesapeake Bay Program



100% recycled/recyclable paper

50% post consumer fiber using vegetable based inks

EPA Report Collection
Regional Center for Environmental Information
U.S. EPA Region III
Philadelphia, PA 19103



Regional Center for Environmental Information
US EPA Region III
1650 Arch St
Philadelphia, PA 19103

Printed by the U.S. Environmental Protection Agency For the Chesapeake Bay Program

FINAL REPORT

EVALUATION OF WASTEWATER TREATMENT PLANTS FOR BNR RETROFITS USING ADVANCES IN TECHNOLOGY

Submitted to

**THE POINT SOURCE WORKGROUP
NUTRIENT REMOVAL SUBCOMMITTEE
IMPLEMENTATION COMMITTEE
CHESAPEAKE BAY PROGRAM**

Prepared by

**Clifford W. Randall, PhD
Zeynep Kisoglu, MS
Dipankar Sen, PhD
Pramod Mitta, MS
Ufuk Erdal, MS**

**ENVIRONMENTAL ENGINEERING
VIRGINIA TECH
BLACKSBURG, VA 24061-0246**

U.S. EPA REGION III
Regional Office Environmental
1600 ... (2052)
P.O. Box ... 2003

CONTENTS

	Page
INTRODUCTION	1
Scope of Project	1
SUMMARY OF THE EVALUATIONS	2
Pennsylvania WWTPs	4
Maryland and New York WWTPs	5
Virginia WWTPs	6
Summary Tables	
ADVANTAGES AND DISADVANTAGES OF BNR	26
BNR PROCESS SCHEMATICS	27
BNR EVALUATION SUMMARIES	28
APPENDIX I:	
BNR Process Schematics	1
APPENDIX II:	
SUMMARIES OF BNR EVALUATION REPORTS	
Maryland Reports	1
New York Reports	20
Pennsylvania Reports	24
Virginia Reports	55

EVALUATION OF WASTEWATER TREATMENT PLANTS FOR BNR RETROFITS USING ADVANCES IN TECHNOLOGY

INTRODUCTION

This project was initiated on June 1, 1995 for the purpose of stimulating efforts towards the reduction of point source nutrient discharges to the waters of the Chesapeake Bay Watershed. Prior to the project, a few engineering firms had developed reports wherein they estimated the total costs for biological nutrient removal (BNR) retrofits at the wastewater treatment plants (WWTP) throughout the Watershed. The estimates indicated that implementation of nutrient removal throughout the Watershed would be very costly. The USEPA Chesapeake Bay Program Office and the responsible State Offices perceived that further conventional point source nutrient removal implementation efforts were likely to meet with considerable political resistance because of the projected costs, and sought possible BNR alternative designs and configurations based upon technological and knowledge advancements.

The cost estimates developed prior to this project were based on conventional BNR design approaches. These approaches typically assume that process volume requirements for biological nitrification are very large for near complete nitrification under typical winter conditions, and that most existing secondary clarifiers are too small for the increased solids loadings likely to occur as operational changes are made to obtain nutrient removal. There also was uncertainty regarding the performance and reliability of BNR processes in general, which added to the conservative nature of the cost estimates. Meanwhile, the Virginia Tech BNR research group had been working with several full-scale WWTPs in Virginia and Maryland to demonstrate that BNR processes can be reliably operated, can be more economical to operate than fully nitrifying processes, and that retrofits can be relatively inexpensive to implement. The group had successfully experimented with fixed film media integrated into activated sludge at the Annapolis, Maryland WWTP to reduce the aeration basin and clarifier capacities needed for implementation of nitrogen removal at that facility. The successful demonstration reduced the construction needs from a one-third increase in aeration volume and a 150% increase in clarifier volume to no increase in aeration volume and a 50% increase in clarifier volume. Consequently, the Point Source Work Group of the Chesapeake Bay Program Nutrient Removal Subcommittee, at the urging of the EPA Chesapeake Bay Program Office, requested that the Virginia Tech BNR research group undertake the task of evaluating selected plants throughout the Watershed for BNR retrofits utilizing recent advances in knowledge and technology.

Scope of Project

The primary emphasis of the BNR retrofit recommendations was to be enhancement of nitrogen removal, but would include biological phosphorus removal if deemed economically favorable. The research group agreed to do the project, and a total of 51 WWTPs located in the states of Maryland, Pennsylvania and Virginia were designated for evaluation. Subsequently, two WWTPs located in the Susquehanna Basin of New York were selected for evaluation and substituted for two in Maryland. The project was funded by Chesapeake Bay Program funds administered by the USEPA Chesapeake Bay Program and Region III Offices. The evaluations generally assumed that the desired effluent TN concentration was 8 mg/L or less. When phosphorus removal was included, the target effluent TP concentration was 2 mg/L or less.

The distribution of WWTPs by state was 16 in Pennsylvania, 9 in Maryland, 24 in Virginia, and 2 in New York. Fifteen of the Pennsylvania WWTPs are located in the Susquehanna River Basin

and only one, Chambersburg, in the Potomac River Basin. The 16 PA plants are designed to treat 222.4 million gallons per day (MGD) of wastewater, and were discharging 163.2 MGD with a total nitrogen loading of 23,385 lbs/d at the time of the evaluations. The permitted requirements for the 16 PA plants, and all other plants that were evaluated, are summarized in Table 1.

The Virginia Tech BNR Group, working with the Maryland Department of the Environment and with the Public Utilities Division of Anne Arundel County, Maryland, had already evaluated a large number of WWTPs in Maryland. Additionally, other plants, particularly some of those in the Patuxent River Basin, had been evaluated and upgraded to nutrient removal by consulting engineers. Consequently, the nine Maryland plants selected for this project had relatively small flows, with one exception. The nine plants selected are designed to treat a total of 22.75 MGD, but one of the plants, Mattawoman, was designed for 15 MGD. Of the remaining eight, only two are permitted for flows that average more than 1 MGD. Currently, the nine plants are treating a combined flow of only 12.19 MGD, i.e., only 54% of their permitted flows. The permitted flows and effluent concentrations for the nine WWTPs are summarized in Table 1. The plants are widely scattered over the state, from the Winebrenner WWTP near the Pennsylvania border in Washington County, to the Elkton WWTP near the Delaware border in Cecil County, to the Crisfield WWTP on the Eastern Shore near the Virginia border.

The two New York plants are permitted for flows of 20 and 8 MGD, respectively. However, current flows average 24.9 and 7.39 MGD, respectively, illustrating that both facilities are ready for expansion. Their permitted flows and effluent concentrations are listed in Table 1, located at the end of the following section of text.

The 24 Virginia WWTPs are all located in the Potomac River Basin, with nine of them located along the main stem of the Potomac, and 15 in the Shenandoah River Basin. The results of the evaluations for the 24 plants are listed in Table 1. These plants vary in design capacity from 0.325 to 54 MGD, for a total of 164.6 MGD, but all but five are designed for flows of less than 5 MGD. Twelve are designed for flows of 2 MGD or less. The combined plants currently are treating flows totaling 130.8 MGD. The permitted flows and effluent concentrations of these 24 WWTPs are listed in Table 1.

SUMMARY OF THE EVALUATIONS

Full reports for each BNR evaluation were filed with the EPA Chesapeake Bay Program Office, the State Office with responsibility for Chesapeake Bay activities and enforcement, and the owner & manager of the evaluated WWTP. Summarized reports of each of the plant evaluations are attached in Appendix II of this report. The overall results of the BNR evaluations have been summarized in Tables 2, 3, & 4, located at the end of this section of the text. More than one technology option was developed for many of the plants. The lowest cost modification option for each of the WWTPs that would achieve a substantial reduction in effluent nitrogen, i.e., to 8 mg/L or less, is listed in Table 5, also located at the end of this section of text. Detailed facility reports for all plants evaluated can be obtained from the USEPA Chesapeake Bay Program Office.

The costs of nitrogen removal were very plant specific and the cost per pound of additional nitrogen removal ranged from a projected savings of \$0.79/lb to a cost of \$5.92/lb. The average costs per additional pound of nitrogen removal projected from implementation of the recommended BNR modifications are summarized in Table 6 for each state and for all plants. These numbers were determined by subtracting the projected effluent TN concentration from the current effluent TN concentration, and escalating the influent flow so that design or projected flow is reached after 20 years. Projected flows were used only if supplied by the owner or

managers. The costs per pound of additional nitrogen removed were flow weighted to determine the average for each state and for all plants evaluated.

Table 6. Projected Nitrogen Removal and Cost per Pound of Additional Nitrogen Removal

STATE	Current Flow	Current Nitrogen Discharged	Additional Nitrogen Removal*	Average Cost per Additional lb of N Removal
	MGD	Lb/year	Lb/year	\$/lb
PA	163.2	6.593×10^6	4.579×10^6	0.97
MD	12.2	561,735	455,750	1.31
NY	32.3	1.437×10^6	662,850	2.49
VA	130.8	5.935×10^6	4.285×10^6	0.48
Total/Average	339.0	14.527×10^6	9.982×10^6	0.94

*Annual average over a 20 year period assuming flow increase to design or projected flow

The results in Table 6 are conservative for additional nitrogen removal because the numbers are based on the most economical modification that would reduce the effluent TN to 8 mg/L or less, even when a small increase in cost would decrease the effluent TN substantially below 8 mg/L. Also, the effluent TN concentration used for the calculations was the concentration that would be achieved under the most limiting conditions, e.g., winter temperatures, and lower effluent concentrations could be obtained, if desired, during warmer weather, resulting in a lower average for the year.

The results project that implementation of the recommendations of this report would result in the following percent reductions in nitrogen discharge from the evaluated WWTPs, by state: 60% for PA, 54% for MD, 45% for NY, and 55% for VA. The overall projected percent reduction in nitrogen discharge for the evaluated WWTPs is 56%, for a 20 year average total reduction of 9.982×10^6 lbs/year, at an average cost of \$0.94 per pound of projected additional nitrogen removal.

The results show that there was a very wide variation in the recommended modifications and their projected costs. All costs were based on present worth for an amortization period of 20 years, and the value of the dollar during the year the evaluation was performed. Some plants required no or very little modification to comply with the Chesapeake Bay Program target standards of 8 mg/L TN and 2 mg/L TP. Most of these simply needed changes in the method of operation, and several of them would realize a reduction in annual O & M costs if the changes were made. For a few of the plants the O & M savings would be sufficient to pay for the entire costs of modification to BNR operation. Net savings would be realized by several more of the WWTPs if the modifications were based on current flows rather than design and/or desired maximum flows. That is to say, the costs of operating those plants could be reduced sufficiently to pay for all modifications in a short time period (<10 years), with a net savings for the modifications until the influent flow reaches a magnitude that requires major construction modifications to preserve the pre-BNR capacity. The Throop, Pennsylvania, Mattawoman, Maryland and Opequon Creek, Virginia WWTPs are three examples of such plants. All three could be easily and economically modified for very good BNR for the foreseeable future, i.e., 10 years or more, based on current flows and likely increases, but will require substantially more expensive BNR retrofits if modified to maintain the pre-BNR design capacities. Also, a significant percentage of the plants evaluated could be inexpensively but adequately modified for BNR by "temporary modifications", i.e., modifications with a projected equipment life of 5 to 15 years, if the owners were willing to accept such modification standards until plant expansion is needed. Instead, the

modification costs in this report were based on the "permanent modification" standards of each owner, if such standards were known.

Pennsylvania WWTPs

The results of the 16 Pennsylvania WWTP evaluations are summarized in Table 7.

Table 7. Pennsylvania WWTPs Evaluated for BNR Removal

WWTP	BNR Design Flow MGD	Total Capital Costs \$	Capital Cost/Flow \$/MGD	Cost per lb Add. N Removal
Altoona City (E)	9.0	1.230×10^6	136,667	\$0.51
Altoona City (W)	13.5	1.233×10^6	91,333	0.42
Chambersburg	4.5	6.347×10^6	1,410,444	2.69
Greater Hazleton	8.9	7.84×10^6	880,899	3.24
Hanover	4.5	0.060×10^6	13,333	0.08
Harrisburg	30.0	25.448×10^6	848,250	2.00
Lancaster	29.7	1.077×10^6	36,263	0.19
Lebanon	8.0	4.039×10^6	504,875	1.19
Scranton	16.0	2.815×10^6	175,938	0.76
State College (UAJA)	6.0	0.780×10^6	130,000	0.33
Susquehanna (Lancaster Area)	12.0	1.619×10^6	134,917	1.12
Throop	7.0	3.320×10^6	474,285	1.68
Williamsport (C)	7.2	6.339×10^6	880,417	1.36
Williamsport W)	4.5	5.246×10^6	1,165,778	2.58
Wyoming Valley	32.0	0.763×10^6	23,843	0.18
York City	26.0	1.780×10^6	68,462	0.42
Total/Average	218.8	69.936×10^6	319,634	\$0.946

The 16 Pennsylvania WWTPs can be easily classified into two categories based on the capital costs of the needed modifications for BNR. Six of the plants, accounting for only 29% of the post BNR design flows, would account for 79% of the total capital costs. Of the six, the Harrisburg plant, alone, accounts for 36% of the total projected capital costs. The six plants, their post BNR design flows, their projected capital costs for BNR, and the BNR modification costs per MGD, are listed in Table 8. The capital cost per MGD would be nearly \$900,000, and the cost per pound additional N removal projects to \$2.09/lb.

Table 8. Pennsylvania High Cost BNR Modification Plants

WWTP	BNR Design Flow MGD	Total Capital Costs \$	Capital Cost/Flow \$/MGD	Cost per lb Add. N Removal
Chambersburg	4.5	6.347×10^6	1.4104×10^6	\$2.69/lb
Greater Hazleton	8.9	7.840×10^6	880,899	\$3.24/lb
Harrisburg	30.0	25.448×10^6	848,250	\$2.00/lb
Lebanon	8.0	4.039×10^6	504,875	\$1.19/lb
W'nsport Central	7.2	6.339×10^6	880,474	\$1.36/lb
W'nsport West	4.5	5.246×10^6	1.166×10^6	\$2.58/lb
Total/Average	63.1	55.26×10^6	875,737	\$2.09/lb

The high capital investment and cost per pound projections suggest that these plants are good candidates for nutrient trading with non-point source controls or other WWTPs, if such an option is developed.

In contrast to the six plants listed in Table 8, the 10 other plants account for 155.7 MGD (71%) of the post BNR design flow, but only $\$14.676 \times 10^6$ (21%) of the projected capital costs, for a modification cost of only \$94,258 per MGD. Also, five of these 10 plants would have a reduction in annual O&M costs from converting to BNR. The projected average cost per pound of additional N removal by these 10 plants is only \$0.41/lb. It is unlikely that non-point controls could even remotely approach these costs, and obviously could not promise the same reliability of N reduction. Clearly, these plants are good candidates for economical BNR modification and operation.

Maryland and New York WWTPs

The nine Maryland WWTPs included in this draft report are small scale plants, with one exception, and, consequently, the projected costs per additional pound of nitrogen removed are very high for most of them. The information is tabulated in Table 9. The two New York plants are relatively large, but one is a trickling filter (TF) plant, and the other has very severe site constraints. Consequently, the projected costs for implementing BNR at the two NY plants are high. Their data also are included in Table 9.

Table 9. Maryland and New York WWTPS Evaluated for BNR Removal

WWTP	BNR Design Flow MGD	Total Capital Costs \$	Capital Cost/Flow \$/MGD	Cost per lb Add. N Removal
Brunswick	0.7	390,000	557,143	\$0.50/lb N
Chestertown	0.9	1.350×10^6	1.50×10^6	\$5.92/lb N
Crisfield	1.0	1.949×10^6	1.949×10^6	\$4.95/lb N
Elkton	2.7	1.970×10^6	729,630	\$1.87/lb N
Federalsburg	0.75	1.525×10^6	2.033×10^6	\$3.34/lb N
Georges Creek (Alleghany Cty.)	0.6	1.663×10^6	2.772×10^6	\$3.55/lb N
Indian Head	0.49	532,000	1.085×10^6	\$2.90/lb N
Mattawoman	15	4.250×10^6	283,333	\$0.07/lb N
Winebrenner	0.6	1.480×10^6	2.467×10^6	\$3.77/lb N
MD Totals/Avg.	22.74	15.109×10^6	0.664×10^6	1.31/lb N
Binghampton	25	13.057×10^6	522,280	\$2.24/lb N
Endicott	8	6.656×10^6	832,000	\$3.35/lb N
NY Totals/Avg.	33	19.713×10^6	597,364	\$2.49/lb N

Only two of the Maryland WWTPs, Brunswick and Mattawoman, have the potential for low cost BNR modification. This is because most of the other plants have fixed-film biological processes, either trickling filters or rotating biological contactors, or are old facilities that need substantial upgrading before BNR is possible. One, Chestertown, is an aerated lagoon system that cannot maintain nitrification during the winter months. The cost per pound of additional nitrogen removed is relatively small for the nine plants collectively, but that is because the Mattawoman flow dominates the total flow, and it potentially can be modified for BNR very economically. The seven WWTPs other than Brunswick and Mattawoman account for only 31% of the design

BNR flow, but 69% of the projected capital costs. The cost per additional pound of N removal for the seven "high cost" plants averages \$3.36/lb N, which is substantially higher than the \$2.09/lb N average of the high cost Pennsylvania WWTPs. Clearly, it would be economical to upgrade the Brunswick and Mattawoman WWTPs for BNR. The other plants do not fall into the low cost category based on cost per additional pound of potential nitrogen removal, and non-point pollution reduction trading may be more attractive. However, this cost per pound is still considerably less than the estimates for some types of non-point source controls. Also, some of the Maryland plants are in need of upgrades for conventional treatment. If they are to be upgraded or expanded, it may be possible to economically include modifications that enable BNR along with the expansions and upgrades.

Virginia WWTPs

The twenty-four Virginia WWTPs are primarily small plants, as shown by the data listed in Table 10.

Table 10. Virginia BNR Modification Plants

WWTP	BNR Design Flow MGD	Total Capital Costs \$	Capital Cost/Flow \$/MGD	Cost per lb Add. N removal
Arlington	30	560,000	18,667	\$0.605/lb
Colonial Beach	2.0	90,000	45,000	-\$0.065/lb
Dahlgren	0.325	30,000	92,000	-\$0.12/lb
Dale Services#1	3.0	220,000	73,000	\$0.29/lb
Dale Services#8	3.0	220,000	73,000	\$0.29/lb
DuPont, Waynesboro	2.0	0	-	-\$0.11/lb
Fishersville	2.0	790,000	395,000	\$2.20/lb
Front Royal	4.0	50,000	13,000	\$0.02/lb
Harrisonburg	16	4.688 x 10 ⁶	293,000	\$0.54/lb
H. L. Mooney	18	490,000	27,222	\$0.063/lb
Leesburg	4.85	2.980 x 10 ⁶	614,000	\$0.68/lb
Lower Potomac	67.0	20.800 x 10 ⁶	310,448	\$0.50/lb
Luray	2.0	0	0	N/A
Merck and Co.	1.2	0	0	0
Middle River/Verona	4.5	150,000	33,000	\$0.30/lb
Opequon	6.25	570,000	91,000	\$0.16/lb
Parkins Mill	2.0	97,000	49,000	-\$0.79/lb
Purcellville	1.0	1.3 x 10 ⁶	1.3 x 10 ⁶	\$1.80/lb
Rocco Foods, Edinburg	1.2	4.480 x 10 ⁶	3,733,000	\$0.338/lb
Strasburg	0.975	120,000	123,000	-\$0.14/lb
Stuarts Draft	1.4	1.240 x 10 ⁶	886,000	\$2.36/lb
Waynesboro	4.0	3.500 x 10 ⁶	875,000	\$1.27/lb
Woodstock	1.0	70,000	70,000	-\$0.22/lb
Total/Average	173.7	42.445 x 10⁶	244,358	\$0.48/lb

Four of the Virginia plants are large and collectively will be designed to treat 131 MGD by BNR, which is 75% of the Virginia total. The other 20 WWTPs treat an average flow of only 2.14 MGD and twelve of them are designed to treat 2 MGD or less. Although the plants are relatively small, they should be much more economical to modify for BNR removal than the typical Maryland WWTP. This is because nearly all of them are activated sludge (AS) process facilities, and several of them are oxidation ditch AS systems. Oxidation ditches typically are easy to operate for biological nitrogen removal, simply by changing the operating approach. The primary expense for most of them is the purchase and installation of timer switches for the aerators. Also, most of the Virginia facilities are not near design flow, and can be easily modified for BNR with the existing activated sludge basin volumes and clarifier capacities. However, the recommended constructive or operative modifications may lead to a downsizing of the plants' hydraulic design capacity. Therefore, the resulting BNR process might have a shorter useful service life (as plant flow increases) than a more permanent retrofit designed to maintain the existing permitted design capacity. The savings accumulated during the interim years, however, may be sufficient to pay for much of the subsequent expansion. Regardless, the average cost per additional pound of N removed for the Virginia plants is projected as only \$0.48/lb, the lowest of the three states. Even this figure is misleading because most of the projected capital costs would be expended on six of the WWTPs, and three plants project much higher costs per additional pound of N removed than the rest. The seven high capital outlay and/or high N removal cost plants are listed in Table 11.

Table 11. Virginia High Cost BNR Modification Plants.

WWTP	BNR Design Flow MGD	Total Capital Costs \$	Capital Cost/Flow \$/MGD	Cost per lb Add. N removal
Fishersville	2.0	790,000	395,000	\$2.20/lb
Harrisonburg	16	4.688×10^6	293,000	\$0.54/lb
Leesburg	4.85	2.980×10^6	614,000	\$0.68/lb
Lower Potomac, Fairfax County	67.0	20.8×10^6	310 448	\$0.50/lb
Rocco Farm Foods, Edinburg	1.2	4.480×10^6	3,733,000	\$0.338/lb
Stuarts Draft	1.4	1.240×10^6	886,000	\$2.36/lb
Waynesboro	4.0	3.500×10^6	875,000	\$1.27/lb
Total/Average	96.45	38.478×10^6	398,942	\$0.61/lb

The seven plants listed above account for only 56% of the total discharge flow, but nearly 91% of the projected BNR modification capital costs. In spite of the high capital costs, the projected average cost per additional pound of nitrogen removed is only \$0.61/lb. The other 17 Virginia plants would have a cost per lb additional N removed of only \$0.27, and six of these plants should save money over 20 yrs by implementing the recommended BNR approach. Two of the evaluated plants, Merck, Inc. and Luray, have no reason to implement BNR because their wastewaters are nitrogen deficient for biological wastewater treatment, which necessitates nitrogen addition.

Table 1. Summary List of Plants and NPDES Permit Requirements

Maryland	Plant	Permit Flow MGD	BOD5 mg/L	TSS mg/L	NH4-N mg/L	TN mg/L	TP mg/L	DO mg/L	pH	NOTES
	Brunswick	0.7	30	30	-	-	2	>5.0	6.5-8.5	
	Chestertown	0.9	30	90	-	-	-	>5.0	6.5-8.5	
	Crisfield	1.0	30	30	-	-	2	>5.0	6.5-8.5	
	Elkton	1.6	30	30	20*	-	2	>5.0	6.5-8.5	*TKN
	Federalburg	0.75	30	30	-	10	2	>5.0	6.5-8.5	
	Georges Creek	0.6	30	30	-	-	2	>5.0	6.5-8.5	
	Indian Head	0.49	16	30	8*	-	2	>5.0	6.5-8.5	*TKN
	Mattawoman	15	30	30	-	-	0.18	>5.0	6.5-8.5	
	Winebrenner	0.6	10	10	0.65	-	2	>5.0	6.5-8.5	
	TOTAL	21.64								

All permits include a goal of a yearly average 8 mg/L TN, which go into effect once the average annual plant flow exceeds 0.50 MGD.

Pennsylvania	Plant	Permit Flow MGD	BOD5 mg/L	TSS mg/L	NH4-N mg/L	TN mg/L	TP mg/L	DO mg/L	pH	NOTES
	Altoona City(E)	9	20	25	2.5	4		>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr.
	Altoona City(W)	9	20	25	2.5	4		>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr.
	Chambersburg	4.5	15	25	3.5	10		>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr.
	Greater Hazleton	8.9	25	30					6.0-9.0	I: All Year Round
	Hanover	5.5	15	25	1.5	4.5	2	>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr; V: All Year Round
	Harrisburg	30	25	30	15		2	>5	6.0-9.0	I and V: All Year Round; III: May-Oct;
	Lancaster City	29.7	15	25	2.5	7.5	2	>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr; V: All Year Round
	Lebanon	8	10	20	2.5	7.5	2	>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr; V: All Year Round
	Scranton	20	25	30	3	9		>5	6.0-9.0	I: All Year Round; III: May-Oct; IV: Nov-Apr.
	State College (UAJA)	6	10	10	1	varies	0.13	>5	6.0-9.0	III-Jul-Nov; IV: 2.5-5.5 mg/L; V: Dissolved P, Mar-Oct; I: All Year Round
	Susquehanna (Lancaster Area)	12	25	30	15		2	>5	6.0-9.0	I and V: All Year Round; III: May-Oct.
	Throop	7	25	30	4.5	13.5		>5	6.0-9.0	I: All Year Round; III: May-Oct; IV: Nov-Apr.
	Williamsport(C)	7.2	25	30					6.0-9.0	I: All Year Round
	Williamsport(W)	4.5	54	50					6.0-9.0	I: All Year Round
	Wyoming Valley	32	25	30					6.0-9.0	I: All Year Round
	(Luzerne County)									
	York City	26	15	20	1.7	2.1	2	>5	6.0-9.0	I and III: May-Oct; II and IV: Nov-Apr.
	TOTAL	218.3								

Table 1. Summary List of Plants and NPDES Permit Requirements

New York										
Plant	Permit Flow MGD	BOD5 mg/L	TSS mg/L	NH4-N mg/L	TN mg/L	TP mg/L	DO mg/L	pH	NOTES	
Binghamton-Johnson City Village of Endicott	20	24*	24*	11					*At 25 MGD (i.e. the limit is 5004 lbs/d) ; III: Jun-Oct	
	8	30	30	12.5*					*At 8 MGD (i.e. the limit is 830 lbs/d) Jun-Oct	
TOTAL 28										
Virginia										
Plant	Permit Flow MGD	BOD5 mg/L	TSS mg/L	NH4-N mg/L	TN mg/L	TP mg/L	DO mg/L	pH	NOTES	
Arlington	30	10	10	1		0.18	>6.0	6.0-9.0	III: Year Round	
Colonial Beach	2	21	28	4.63	-	-	>6.5		III: Apr-Sep	
Dahlgren	0.325	30	30	1.35	-	2	>5.0	6.0		
Date Services; #1	3	2	3			0.1*			*PO4-P	
Date Services; #8	3	2	3			0.1*			*PO4-P	
DuPont, Waynesboro	2	218.84*		0.689	0.801	-			*kg/d; All maximum values Temp 31 C; III Jun-Dec; IV Jan-May.	
Fishersville	1.4	24	24	8.14	10.6		>5.0	6.5-9.5	III: Jun-Dec; IV: Jan-May	
Front Royal	4	30	30	7	13	-		6.5-9.0	III: Jun-Dec; IV: Jan-May	
H.L. Mooney, Prince William Cty.	18	10	10	1		0.18	>6.0	6.0-9.0	III: Year Round	
Harrisonburg	16			4*	9*				*TKN ; III: Jun-Dec, IV: Jan-May.	
Leesburg	4.85	12	20	3	6*	2	>5.0	6.5-8.5	*TKN for May-Oct ; III: May-Oct	
Lower Potomac, Fairfax Cty.	54	10	10	1	-	0.18	>6.0	6.0-9.0	I and III: Year Round	
Luray	2	22.5	30	3			>6.5	6.5-9.0		
Merck&Co, Inc., Elkton	11.5#	1567	2664	496	1291*	Monitor	>4.5	6.5-9.5	All values in kg/d; *TKN; Total Cyanide=2.9kg/d, Temp= 37 C	
Middle River/Verona	4.5+	25	30	3.1	3.8		>5.0	6.5-9.5	III: Jun-Oct; IV: Nov-May	
Opequon, Winchester	6.25	6	18.4	0.44	0.9		7.1	6.5-9.5	I: Jun-Sep; II: Oct-May, III: May-Jan, IV: Feb-Apr	
Parkins Mill	2	7.5	23	1.5	1.7	-	7.2	6.5-9.5	I and III: May-Nov, II and IV: Dec-Apr	
Purcellville, New	1	14.5	14.5	1	8	1.5	>6.0	6.0-9.0		
Purcellville, Old	0.5	14.5	14.5	-		-	>6.0	6.0-9.0		
Rocco Farm Foods, Edinburg	1.2	6	30	1.95	6.84	4.15 / 50.0*		6.5-9.5	*TKN for Jun-Dec, Jan-May; I and III Jun-Dec, II and IV: Jan-May	
Strasburg	0.975	30	30	4.9*	10.4*			6.5-9.5	*Maximum; III: Jun-Dec, IV: Jan-May	
Stuarts Draft	1.4	14.5	25	30	4*		>7.1	6.5-9.5	*TKN; I and III: Jun-Dec, II and IV: Jan-May	
Waynesboro	4	7.5	15	2	-	-	>6.0		I and III: Jun-Oct, II Nov-May	
Woodstock	1	30	30	-	-	-	7.2	6.5-9.5		
TOTAL 164.6										

Includes cooling water.

Table 2. Summary of Projected Nitrogen Removals and Costs

	Qcurrent MGD	Qdesign MGD	Ncurrent lb/d	Nreduc. lb/20yrs in thousand	Cost \$/lb N
Maryland					
BRUNSWICK WWTP	0.325	0.7	68	530	0.5
CHESTERTOWN WWTP	0.65	0.9	58	247	5.92
CRISFIELD WWTP	0.7	1	91	379	4.95
ELKTON WWTP	1.37	2.7	206	1452	1.87
FEDERALSBURG WWTP	0.355	0.75	54	507	3.34
GEORGES CREEK WWTP, ALLEGANY COUNTY	0.626	0.6	107	457	3.55
INDIAN HEAD WWTP	0.314	0.5	43	219	2.9
MATTAWOMAN WWTP	7.55	15	869	4913	0.07
WINEBRENNER WWTP, WASHINGTON COUNTY	0.3	0.6	44	411	3.77
<i>Maryland Totals/Average</i>	<u>12.19</u>	<u>22.75</u>	<u>1540</u>	<u>9115</u>	<u>1.31</u>
New York					
BINGHAMTON-JOHNSON CITY JOINT SEWAGE TREATMENT PLANT	24.9	25	3011	9965	2.24
VILLAGE OF ENDICOTT WWTP	7.39	8	924	3292	3.35
<i>New York Totals/Average</i>	<u>32.29</u>	<u>33</u>	<u>3935</u>	<u>13257</u>	<u>2.49</u>
Pennsylvania					
ALTOONA CITY AUTHORITY EASTERLY PLANT	6.67	9	645	3185	0.51
ALTOONA CITY AUTHORITY WESTERLY PLANT	9.14	13.5	1052	3880	0.42
CHAMBERSBURG WWTP	4.5	4.5	563	2841	2.69
GREATER HAZLETON JOINT SEWER AUTHORITY WWTP	6.2	8.9	765	3860	3.24
HANOVER AREA REGIONAL WWTP	3.46	3.65**	568	3046	-0.08
HARRISBURG WWTP	24	30	4003	27635	2.00
LANCASTER CITY WWTP	23.4	29.7	1971	9230	0.19
LEBANON WWTP	5.7	8	870	4652	1.19
SCRANTON SEWER AUTHORITY WWTP	13.8	16	1266	4464	0.76
STATE COLLEGE UAJA WWTP	4.5	6	582	3330	0.33
SUSQUEHANNA WWTP, LANCASTER AREA AUTHORITY	9.45	12	796	2288	1.12
THROOP WWTP, LACKAWANNA RBSA,	4.5	7	499	1982	1.68
WILLIAMSPORT SANITARY AUTHORITY CENTRAL PLANT	8.98	7.2	1296	6600	1.36
WILLIAMSPORT SANITARY AUTHORITY WEST PLANT	3.5	4.5	686	3200	2.58
WYOMING VALLEY SANITARY AUTHORITY WWTP, LUZERNE CTY.	22.3	32	1213	5575	0.17
YORK CITY SEWER AUTHORITY STP	13.1	26	1289	5806	0.36
<i>Pennsylvania Totals/Average</i>	<u>163.2</u>	<u>218</u>	<u>18064</u>	<u>91574</u>	<u>0.97</u>

Table 2. Summary of Projected Nitrogen Removals and Costs

	Qcurrent MGD	Qdesign MGD	Ncurrent lb/d	Nreduc. lb/20yrs in thousand	Cost \$/lb N
Virginia					
ARLINGTON WWTP	32.4	30	2432	1973	0.605
COLONIAL BEACH WWTP	0.64	2	72	431	-0.065
DAHLGREN WWTP	0.28	0.325	41	218	-0.12
DALE SERVICES Section 1 WWTP	3	3	300	730	0.29
DALE SERVICES Section 8 WWTP	2.12	3	210	500	0.29
DUPONT WAYNESBORO WWTP	0.491	2	188	3184	-0.11
FISHERSVILLE WWTP	1.3	2*	121	260	2.2
FRONT ROYAL WWTP	2.27	4	284	1023	0.02
HARRISONBURG WWTP	8	16	1334	8712	0.54
H.L. MOONEY WWTP, PRINCE WILLIAM COUNTY	12.8	18	1858	8820	0.06
LEESBURG WATER POLLUTION CONTROL FACILITY	2.86	4.85	382	1560	0.68
LOWER POTOMAC WWTP, FAIRFAX COUNTY	45	54/67	5630	34,094	0.5
LURAY WWTP	1.5	2	300	NA	NA
MERCK AND CO., INC. WWTP	0.906	1.2	27	NA	0
MIDDLE RIVER/VERONA WWTP	3.65	4.5#	180	420	0.3
OPEQUON WRF, CITY OF WINCHESTER	5.14	6.25*	857	5328	0.16
PARKINS MILL WWTP	1.09	2	82	200	-0.79
PURCELLVILLE EXISTING WWTP	0.315	0.5	63	-	-
PURCELLVILLE NEW DESIGN WWTP	-	1	67	720	1.8
ROCCO FARM FOODS WWTP	1.1	1.2	1238	8840	0.338
STRASBURG WWTP	0.6	0.975	75	4366	-0.14
STUARTS DRAFT WWTP	0.98	1.4*	85	484	2.36
WAYNESBORO WWTP	3.63	4	424	3548	1.27
WOODSTOCK WWTP	0.77	1	77	292	-0.22
<i>Virginia Totals/Average</i>	<u>130.8</u>	<u>164.2</u>	<u>16260</u>	<u>85703</u>	<u>0.48</u>
GRAND TOTALS	339	438	39799	199649	0.94
*Average daily flows **Design flow less than permit flow #Combined Effluent NA: Not Applicable					

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS						
Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
Maryland						
BRUNSWICK WWTP	AS	0.325	1. Conversion to MLE configuration 2. Operating with cyclic aeration	1. 430 2. 390	1. -112 2. -119	1. \$0.59 2. \$0.50
CHESTERTOWN WWTP	AS	0.65	Build sand filters after the aerated lagoons.	1,350	55	\$5.92
CRISFIELD WWTP	AS	0.70	1. Current configuration 2. Incorporating the aerobic digestion section into the activated sludge basin 3. Conversion of only a part of each aerobic digester into an AS basin AS basins be configured in anaerobic(15%)-anoxic(25%)-aerobic order with step feed.	1. 3,089 2. 1,949	1. -285 2. -257	\$7.40 at 1.2 MGD, and \$4.95 at 1.0 MGD with one secondary clarifier
ELKTON WWTP	"BioSpiral" RBCs	1.37	1. Construct a nitrification-denitrification filter downstream of the existing secondary clarifiers 2. Decommission the RBC units and construct an Oxidation Ditch System	1. 1,830 2. 1,970	1. 434 2. 759	1. \$2.75 2. \$1.87
FEDERALSBURG WWTP	AS	0.36	Build denitrification filters after the secondary clarifiers.	1,525	168.8	\$3.34
GEORGES CREEK WWTP	Oxidation Ditch	0.626	1. Improving aeration required for nitrification 2. Correcting overflow of raw influent and mixed liquor to the Creek 3. Providing redundancy to take part of the oxidation ditch out of service to remove grit 4. Adding a grit removal system to protect equipment such as diffusers	1,663	-42	\$3.55

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
INDIAN HEAD WWTP	AS	0.32	5. Adding a chemical P removal system and mixer blades 1. Conversion of existing AS basins to anoxic and aerobic zones 2. Conversion of existing primary aerobic digester to activated sludge tanks	1. 532	1. 104	1. \$2.90 2. \$4.18
MATTAWOMAN WWTP	AS	7.55	1. Modification of the AS basins to MLE system 2. Modifications of the AS system to three two pass step feed reactors with anoxic zones at the head of each pass	1. 8,500 2. 4,250	1. --3891 2. --3891	1 \$0.94 with Primary Clarifier addition and \$0.07 without the primary clarifier
WINEBRENNER WWTP	RBCs with multilayer stacked polyethylene discs	0.30	1. Construct an AS basin with anoxic zones upstream of the RBC units and integrate the RBC system with the AS system 2. Construct a denitrification filter downstream of the existing secondary clarifiers	1. 1,320 2. 1,480	1. 70 2. 141	1. \$4.96 2. \$3.77
New York BINGHAMTON- JOHNSON CITY JOINT SEWAGE TREATMENT PLANT	AS	24.9	1. Upgrade of existing AS system with moving bed of plastic media 2. Construction of a biological filter system to operate in parallel with the existing AS system 3. Replacement of entire AS system with	1. 13,057 2. 17,540	1. 5,372 2. 3,359	1. \$2.24 2. \$2.62

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWT, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
ENDICOTT WWTP	Rock media trickling filters	7.39	a two stage biological filters/anoxic-aerobic biological filters 1. Modifying existing trickling filters with plastic media and installing an AS/solids contact basin with sufficient anoxic volume 2. A. Retaining the rock media and installing an anoxic-aerobic AS basin B. option 2 with all new clarifiers 3. Installing an anoxic-aerobic biofilter system downstream of the trickling filters	1. 10,032 2a. 6,656 2b. 7,956 3. 8,004	1. 3,368 2a. 2,393 2b. 2,393 3. 2,236	1. \$4.91 2a. \$3.35 2b. \$3.86 3. \$3.83
Pennsylvania						
ALTOONA CITY AUTHORITY EASTERLY PLANT	AS	6.67	An anoxic zone will be created in the first cell of each flow train	1,230	30	\$0.51
ALTOONA CITY AUTHORITY WESTERLY PLANT	AS	9.14	An anoxic zone will be created in the first cell of each flow train	1,233	35	\$0.42
CHAMBERSBURG WWTP	rock media trickling filters in series, and nitrification filters with plastic media.	4.5	1. Trickling filters for BOD removal and nitrification, followed by denitrification filters using methanol 2. AS system with MLE configuration for BOD removal, nitrification and denitrification	1. 6,347 2. 8,060	1. 2,270 2. 2,474	1. \$2.69 2. \$4.55
GREATER HAZLETON JOINT	Trickling filters	6.2	1. Addition of extra AS volume and clarifiers	1. 7,900 2. 7,840	1. 2,318 2. 2,318	1. \$3.26 2. \$3.24

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
SEWER AUTHORITY WWTP	followed with AS system		2. Addition of biofilters			
HANOVER AREA REGIONAL WWTP	Oxidation Ditches	3.46	<ol style="list-style-type: none"> 1. Create anoxic conditions over a section of the ditch; 2. Cycling brush aerators on and off to create anoxic and aerobic conditions at different times; 3. Combination of 1 and 2 	59.8	-323	-\$0.08
HARRISBURG WWTP	Pure oxygen AS system	24	<ol style="list-style-type: none"> 1. Operation of AS basins in the MLE configuration, and addition of an 18 MGD Biostyr train 2. Operation of pure oxygen system as a high rate system without nitrification. Addition of aerated biological filters like Biostyr, Biofor, or Safe for nitrification, and fluidized bed filters or additional Biostyr filters for denitrification. 	<ol style="list-style-type: none"> 1. 27,638 2. 25,448 	<ol style="list-style-type: none"> 1. 9,446 2. 22,344 	<ol style="list-style-type: none"> 1. \$2.19 2. \$2.00
LANCASTER CITY WWTP	Anaerobic- oxic with pure oxygen	23.4	<ol style="list-style-type: none"> 1. Fluidized bed or static bed upflow / downflow denitrification filters 2. Conversion of anaerobic zones to anoxic zones with supplemental modifications in the reactor and implementation of chemical P removal 3. Conversion of reactors to incorporate anaerobic, anoxic and aerobic zones for biological N and excess P removal. 	<ol style="list-style-type: none"> 2. 1,077 3. 2,885 	<ol style="list-style-type: none"> 2. 353 3. -685 	<ol style="list-style-type: none"> 2. \$0.190 without step feed, and \$0.373 with step feed. 3. \$0.331 without step feed, and \$0.455 with step feed.

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of W'WTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
LEBANON WWTP	AS	5.7	1. An anoxic-aerobic configuration within existing AS basins with primary effluent bypass around the trickling filters, 2. An anoxic-aerobic configuration with the addition of a fifth AS basin in parallel to the existing four, 3. Addition of a denitrification filter, in addition to the modifications of Option 1	1. 1,539 2. 4,039 3. 6,289	1. -2.43 2. 286 3. 1,241	1. \$0.61 2. \$1.19 3. \$1.39
SCRANTON SEWER AUTHORITY WWTP	AS	13.8	Conversion to MLE configuration.	2,815	-252	\$0.76
UNIVERSITY AREA JOINT AUTHORITY	A/O	4.5	Conversion of the A/O tanks to MLE configuration	780	80	\$0.33
SUSQUEHANNA WATER POLLUTION CONTROL PLANT, LANCASTER AREA SEWER AUTHORITY	Anaerobic- aerobic sequence	9.45	Installation of anoxic zones immediately after the anaerobic zones	1. 1,619	1. 23	1. \$1.12 (Chem-P) 2. \$1.24 (Bio-P)
THROOP WWTP, LACKAWANNA RIVER BASIN SEWER AUTHORITY	AS	4.5	Modification of the existing basins to MLE configuration, besides other improvements at the plant.	1. 3,320 2. 1,100	1. -416 2. -278	1. \$1.68 @7MGD 2. \$0.58@5.5MGD
WILLIAMSPORT SANITARY AUTHORITY CENTRAL PLANT	AS	8.98	Installation of three anoxic cells in each train.	6,339	700	\$1.36
WILLIAMSPORT SANITARY AUTHORITY WEST	AS	3.5	1. an anoxic-aerobic sequence 2. Single Stage Activated Sludge System 3. Separate Stage Fixed Film	5,246	1,500	\$2.58

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of W/TP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
PLANT			4. Integrated Fixed Film AS (IFAS) Process			
WYOMING VALLEY SANITARY AUTHORITY WWTP	Anoxic-oxic sequencing	22.3	1. 50% of denitrification taking place in the aerobic zone via cyclic aeration. 2. MLE cyclic aeration.	1. 100 2. 763	1. 0 2. 66	1. \$0.023 2. \$0.167
YORK CITY SEWER AUTHORITY STP	A/O	13.1	1. Cyclic aeration of the first two aerobic cells with / without a nitrate recycle system: 2. Conversion of the first aerobic cell in each activated sludge tank to an anoxic cell with a nitrate recycle; 3. Conversion of the anaerobic cells to anoxic cells with the addition of a nitrate recycle; addition of ferrous sulfate for chemical phosphorus removal.	1. 30 2. 1,780 3. 1,780	1. -300 2. -217 3. 383	1. - \$0.06 2. \$0.36 3. \$0.42
Virginia						
ARLINGTON WWTP	AS	32.4	Step Feed Anoxic-Oxic Configuration w/Baffles&Mixers	560	528	\$0.605
COLONIAL BEACH WWTP	AS	0.64	cyclic aeration	90	-118	-\$0.065
DAHLGREN WWTP	Single Orbal-type oxidation ditch	0.28	Placing the appropriate number of discs on the aerators in the three ditches and further control by cycling aerators on and off	30	-56	-\$0.12
DALE SERVICES WWTPs (2) Sections 1 and 8	Contact Stabilization AS systems	S1. 3.0 S8. 2.13	1. adjustment of alkalinity and pH for implementation of nitrification, 2. separation of an anoxic zone in the aerobic digester,	1. 330 2. 220 3. 1,080	1. 4,566 2. -1,483 3. -1,907	1. \$0.68 2. \$0.29 3. \$0.55

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
			3. use of the whole volume of the digester for anoxic zone			
DUPONT WAYNESBORO WWTP	AS	0.491	1. Operating with cyclic aeration a. Implemented manually, b. Automated control, c. Mixers in the AS tanks besides aeration control system, 2. MLE configuration. 3. Bardenpho Process	1.a. \$0 b. \$290 c. \$400 2. \$560 3. \$630	1.a. -\$114 b. -\$114 c. -\$50 2. -\$19 3. \$56	1.a. -\$0.11 b. \$0.17 c. \$0.33 2. \$0.51 3. \$0.54
FISHERSVILLE WWTP	AS	1.30	Create an anaerobic/anoxic switch zone followed by an anoxic and an anoxic/aerobic switch zone at the influent end by turning off the air	a. 790 b. 980	a. 24 b. 98	a. \$2.20 w/o Chem-P b. \$2.90 with Chem-P
FRONT ROYAL WWTP	AS	2.27	Addition of two more AS basins and operating with cyclic aeration	a. 50 b. 2,010	a. -29 b. -33	a. \$0.02 current Q b. \$1.16 design Q
HARRISONBURG WWTP	AS	8.0	Dedicated anoxic zones constructed using baffles in the AS basins	4,688	-9	\$0.54
H.L. MOONEY WWTP	AS	12.8	Convert to 2 Pass Step-Feed MLE Process	490	-120	\$0.063
LEESBURG WATER POLLUTION CONTROL FACILITY	Trickling filters (roughing filters) followed by an AS system	2.86	1. No additional tanks. Modifications will be limited to changes within the existing AS system. 2. a) Modifications of the existing AS system and replacement of two of the roughing filters with new AS basins. b) Nitrogen removal with BPR	1. 290 2.a. 2,770 b. 2,980	1. 15 2.a. -11 b. -412	1. \$0.13 2.a) \$0.73 b) \$0.68
LOWER POTOMAC, FAIRFAX COUNTY	AS	45.0	Implementation of Step Feed Anoxic- Aerobic Operation and Expansion from 54	20,800	(- 10%)	\$0.50

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
LURAY WWTP	OD	1.5	to 67 MGD Capacity. Construction of 6 New Secondary Clarifiers and 3, 6-Pass AS Basins. Four New Blowers.	NA	NA	NA
MERCK AND CO., INC. WWTP, ELKTON	AS	0.91	No Change, Nitrogen Deficient wastewater 1. Level 1 N load: the plant does not require any modifications 2. Level 2 N load: a Bardenpho system 3. Level 3 N load: in addition to "2", add a supplemental carbon source.	1. NA 2. 840 3. 1,440	1. NA 2.-718 3. 2,192	1. \$0.0 2. NA 3. NA
MIDDLE RIVER /VERONA WWTP	Oxidation ditches	3.65	cyclic aeration	150	0	\$0.30
OPEQUON WRF, CITY OF WINCHESTER	AS	5.14	1. 10 to 15 mg/L of effluent TN without BPR: Step-feed, operating the first 60 ft of each pass anoxically by turning off the air and rearranging the diffusers. 2. 8 to 10 mg/L effluent TN without BPR: A dedicated anoxic zone shall be created. 3. Effluent TN less than 8 mg/L, without BPR: In addition to item 2, submersible nitrate recycle pump would be installed. 4. Effluent TN less than 8 mg/L with BPR to less than 1 mg/L: In addition to modifications of item 3, an anaerobic zone with an HRT of 1.5 hours is recommended.	1. 0 2. 370 3. 510 4. 570	1. 0 2. 189 3. 254 4. 254	1. \$0 2. \$0.13 3. \$0.17 4. \$0.16

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS						
Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
PARKINS MILL WWTP	Oxidation ditches	1.09	1. cyclic aeration 2. modify the ditches to operate them in the Bio-Denitro configuration	1. 97 2. 680	1. -318 2. -254	1. -\$0.79 2. \$0.96
PURCELLVILLE (Existing) PURCELLVILLE (New)	AS/TF AS	0.31 1.0	1. Located in Flood Plain, Abandon 2. Construct Step Feed MLE Process for 1.0 MGD Design Flow	1. NA 2. 1,300	1. NA 2. NA	1. NA 2. \$1.80
ROCCO FARM FOODS WWTP	Anaerobic lagoon followed by an AS system	1.10	1. A dedicated anoxic zone outside the existing AS reactor; MLE configuration 2. A dedicated anoxic zone inside the existing AS reactor; MLE configuration 3. A dedicated anoxic zone upstream of the existing AS reactor and a pumping station to divert a portion of the anaerobic lagoon influent to the anoxic zone to enhance denitrification 4. An anoxic tank upstream of the AS basin, and a denitrification filter downstream of the secondary clarifier with methanol addition 5. An additional Schreiber reactor to operate the AS process with cyclic aeration controlled by the DO probe system	1. 2,020 2. 610 3. 2,200 4. 4,480 5. 1,740	1. -1,700 2. -1,763 3. -1,861 4. -1,225 5. -1,929	1. \$0.038 2. -\$0.137 3. \$0.038 4. \$0.338 5. -\$0.021
STRASBURG WWTP	Oxidation ditches	0.60	cyclic aeration	120	-180	-\$0.14
STUARTS DRAFT	Oxidation	0.98	cyclic aeration	1,240	-96	\$2.36

Table 3. SUMMARY OF TREATMENT PLANT BNR EVALUATIONS

Name of WWTP, Listed by State	Current Treatment System	Current Flow Rate Reaching the Plant (MGD)	Suggested Treatment Process Modifications for improved nutrient removal	Total Capital Costs for each Suggested BNR Modification (\$ in thousands)	20 Year Change in the Operation and Maintenance Costs (\$ in thousands)	Total Costs of the Suggested Modifications per lb of additional N removed
WWTP	ditches					
WAYNESBORO WWTP	high rate trickling filters followed by RBCs with polyethylene disks	3.63	Addition of tertiary denitrifying filters with methanol addition.	a. 3,500 b. 3,500	a. 796 b. 1027	a. \$1.61 for 8 mg/L of effluent TN; b. \$1.27 for 4 mg/L of effluent TN
WOODSTOCK WWTP	Oxidation ditches	0.77	One brush aerator operated continuously, while the other is cycled on and off in accordance with the BOD loading	70	-135	-\$0.22

Table 4. Summary of Recommended Modification Options for Nitrogen Removal

Plant	Inf Flow MGD	Inf TN mg/L	Current Eff TN mg/L	Modified Effluent TN			Additional TN Removal			Cost		
				I	II	III	I	II	III	I	II	III
Brunswick	0.33	33.9	92	8.0	8.0	22	530	530	530	0.59	0.50	
Chesterdown	0.33	NA	NA	5.5	30	30	247	247	247	5.92		
Crisfield ¹	0.70	25.1	147	9.6	56	56	379	342	342	7.40	4.95	1.34
Elkton	1.37	27.8	318	8.0	30	34	968	1452	1452	2.75	1.87	
Federalsburg	0.36	40.0	118	3.0	9	9	507			3.34		
Georges Creek	0.63	29.1	152	8.0	42	42		457				3.55
Indian Head	0.32	29.4	78	8.0	21	21	219			2.90		
Mattawoman ²	7.55	28.1	1770	7.8	491	491	4913	4913	4913	0.94	0.07	
Winebrenner	0.30	25.0	63	8.0	20	8	282	411	411	4.96	3.77	
Totals	12.20	2737	1538	782	611	457	8045	7648	457			

(shaded values were estimated)

¹Cost for option III is at current influent flow of 0.7MGD

NA = not available

²"Influent TN" represents primary effluent value

Plant	Inf Flow MGD	Inf TN mg/L	Current Eff TN mg/L	Current Eff TN lb/d	Modified Effluent TN			lb/d	Additional TN Removal			Cost		
					I	II	III		I	II	III	I	II	III
Altoona City(E)	6.67	15.4	857	11.6	5.1	284	284	284	3185			0.51		
Altoona City(W)	9.14	18.3	1395	13.8	6.8	518	518	518	3880			0.42		
Chambersburg	9.14	25.0	938	15.0	4.0	150	150	263	3907	2841		2.69	4.55	
Greater Hazleton	6.20	25.0	1293	14.8	6.8	352	352	352	3860	3860		3.26	3.24	
Hanover ¹	3.46	32.1	926	19.7	6.0	173	173	801	3046			-0.08		
Harrisburg	24.00	31.9	3903	20.0	8.0	1601	1601	800	20726	27635		2.19	2.0	
Lancaster City	23.40	19.5	3808	19.1	4.1	41	41	800	9230	9230		0.19	0.33	
Lebanon ¹	5.70	27.0	1284	18.3	8.5	35	35	404	4652	6746		0.61	1.19	1.39
Scranton ¹	13.80	20.0	2302	11.0	6.0	691	691	4464				0.76		
UAJA	4.50	41.1	1542	15.5	5.5	206	206	3330				0.33		
Lancaster Area ²	9.45	29.0	2286	10.1	6.9	544	544	544	2288			1.12	1.24	
Throop ³	4.50	28.8	1081	13.3	6.8	255	255	255	1982			1.68	0.58	
Williamsport(C) ⁴	8.98	29.0	2172	17.3	5.3	397	397	6600				1.36		
Williamsport(W)	3.50	37.0	1080	23.5	8.5	248	248	3200				2.58		
Wyoming Valley	22.30	26.6	4947	6.5	4.0	744	744	5575	5910			0.023	0.167	
York City	13.10	11.6	1257	11.8	9.8	1071	1071	688	5806	6424		0.96	0.36	0.42
Totals	163.20	31078	18064	7771	6.3	1655	4720	74139	64204	22400				

(Shaded values were estimated)

¹Influent TN values are for Primary Effluent

²1st option: Bio-P removal; 2nd option: Chem-P removal

³1st option: at design flow=7.0MGD; 2nd option: at current flow=5.5MGD

⁴Effluent TN values are for Secondary Effluent

⁵1st option: at current flow=24MGD; 2nd option: at design flow=32MGD; Correct number for the 2nd cost option is \$0.167/lb TN removal

Table 4. Summary of Recommended Modification Options for Nitrogen Removal

Plant	Inf Flow MGD	Inf TN mg/L	Inf TN lb/d	Current Eff TN mg/L	Current Eff TN lb/d	Modified Eff TN mg/L	Modified Eff TN lb/d	AddTNRem thousands of lbs /20 yrs	Cost		
									\$/lb additional N removed	II	III
Binghamton-Johnson City Village of Endicott ²	24.90	14.5	3011	14.5	3011	8.0	1661	9655	2.24	2.62	
Totals	32.29	19.3	4198	15.0	924	8.0	493	3292	3.35	3.83	

¹Influent TN is observed as a range from 10mg/L to 20mg/L

²Primary Effluent TN is 18 mg/L

Plant	Inf Flow MOD	Inf TN mg/L	Inf TN lb/d	Modified Effluent TN					Additional TN Removal Thousands of lbs/20 years					Cost							
				I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V			
Kirlington	32.4	27.2	7350	9	2432	6	2162	1973										0.605			
Colonial Beach	0.64	13.4	72	13.5	72	8.0	14	431										-0.065			
Dahlgren	0.28	37.0	86	17.6	41	6.0	14	218										-0.12			
Dale Services #1	3.00	40.0	1001	12.0	300	12.0	300	200	730	1460								0.29	0.55		
Dale Services #6	2.12	40.0	707	11.9	210	12.0	212	141	500	1000								0.68	0.29	0.55	
DuPont ¹	6.00	63.0	258	46.0	168	8.0	8.0	33	2880	2880	2880	2000	3184					0.68	0.17	0.33	0.51
Fayetteville	1.30	17.0	184	11.2	121	8.0	8.0	87	260	260								0.11	0.17	0.33	
Front Royal	2.27	21.3	402	15.0	263	8.0	151	1023	1705									2.2	2.9		
Harrisburg ¹	6.00	34.0	2268	20.0	334	8.0	534	8712										0.02	1.16		
HL Moore ¹	12.80	35.1	3747	17.4	1858	8.0	854	8820										0.54			
Lebanon	2.86	23.0	549	15.0	393	13.0	167	522	1560	1560								0.063			
Lower Potomac	45.00	39.0	12385	15.0	5630	5.0	1877	34094										0.13	0.73	0.68	
Luray	1.50	39.0	488	24.0	300	N/A	N/A	N/A										0.5			
Metcalf & Eddy	0.91	98.0	740	3.5	26	N/A	N/A	N/A										N/A			
Middle River/Vermont	3.65	22.0	670	5.9	180	4.0	122	N/A										N/A	0		
Opportunity ¹	5.14	25.8	1106	9.0	243	12.0	386	420	3044	4182	4562	5328						0.3			
Patterson Mill	1.09	38.0	345	9.0	82	6.0	55	36	200	436								0	0.13	0.17	0.16
Purcellville Existing WWTP	0.31	32.6	85	10.0	24	6.0	16											-0.79	0.96		
Purcellville New Design	1.0 ¹	36.0	300	13.0	300	6.0	67														
Racco Farm Foods	1.10	137.0	1257	135.0	1238	20.0	183	110	28	110								1.8			
Shiraham	0.60	25.0	125	15.0	75	8.0	30	8400	8400	8400	8400	8400	8400					-0.038		0.038	0.338
Stuart Draft	0.98	31.0	253	10.4	85	4.5	37	4366										-0.14			
Waynesboro	3.63	20.1	609	14.0	324	8.0	242	484	2664	3548								2.36			
Woodstock	0.77	20.4	131	12.0	77	6.0	39	292										1.61	1.27		
Totals	190.84	35119	16260				7881	7881										-0.22			

Note: Negative costs imply savings on the project (shaded values were estimated)

¹Design Flow

²Influent TN represents aerobion feed values

³Effluent TN represents secondary clarifier effluent values

⁴Wet weather flows can reach 24.25 MGD

⁵Average daily values

⁶Influent TN is after addition of ammonia

N/A: Not applicable, i.e. no modification needed

Table 5. Lowest Cost Options for all the Wastewater Treatment Plants Under Study

Maryland												
WWTP Name	Type of Process	Current Flow MGD	Design Flow MGD	Current Eff. TN Ann. Avg. mg/L	Current Eff. TN lb/d	Projected BNR Eff. TN Ann. Avg. mg/L	Projected BNR Eff. TN Max. Month. mg/L	Projected BNR Add. TN Rem. 1st Year thousands lbs/yr	Projected BNR Add. TN Rem. 20 yr. Total thousands lbs	BNR Capital Cost thousands \$	BNR Change In O&M Costs thousands \$	Cost per lb N Rem. 20 yr. Avg. \$
Brunswick	AS	0.33	0.7	25.0	68	8	8	17	530	390	-119	0.5
Chestertown	AS	0.65	0.9	10.7	58	5.5	8	10.3	247	1350	55	5.92
Crisfield	AS	0.70	1	15.6	91	9.6	8 to 10	13	379	1949	-257	4.95
Elkton	RBC	1.37	2.7	18.0	206	3	8	63	1452	1970	759	1.87
Federalsburg	TF	0.36	0.75	18.0	54	3	8	16.4	507	1525	169	3.34
Georges Creek	OD	0.63	0.6	20.5	107	8	8	24	457	1663	-42	3.55
Indian Head	AS	0.32	0.5	16.0	43	8	7.5 to 9.0	7.8	219	532	104	2.9
Mattawoman	AS	7.55	15	13.8	869	7.8	8 to 10	138	4913	4250	-3891	0.07
Winebrenner	RBC	0.30	0.6	17.5	44	3	8	13.2	411	1480	141	3.77
Total/Average		12.2	22.8	17.23	1539	6.21		303	9115	15109	-3081	1.31

Pennsylvania												
WWTP Name	Type of Process	Current Flow MGD	Design Flow MGD	Current Eff. TN Ann. Avg. mg/L	Current Eff. TN lb/d	Projected BNR Eff. TN Ann. Avg. mg/L	Projected BNR Eff. TN Max. Month. mg/L	Projected BNR Add. TN Rem. 1st Year thousands lbs/yr	Projected BNR Add. TN Rem. 20 yr. Total thousands lbs	BNR Capital Cost thousands \$	BNR Change In O&M Costs thousands \$	Cost per lb N Rem. 20 yr. Avg. \$
Altoona (E)	AS	6.67	9.0	11.6	645	5.1	8 to 10	132	3185	1230	30	0.51
Altoona (W)	AS	9.14	13.5	13.8	1052	6.8	8>	195	3880	1233	35	0.42
Chambersburg	TF	4.50	4.5	15	563	4	8	151	2841	6347	2270	2.69
G Hazleton	TF+AS	6.20	8.9	14.8	765	6.8	8 to 9	151	3860	7840	2318	3.24
Hanover	OD	3.46	3.65**	19.7	568	6	8	144	3046	59.8	-323	-0.08
Harrisburg	AS	24.00	30.0	20	4003	4	3 to 5	1169	27635	25,448	22,344	2.00
Lancaster City	A/O	23.40	29.7	10.1	1971	4.1	8 to 10	427	9230	1077	353	0.19
Lebanon	AS	5.70	8.0	18.3	870	8.5	7 to 10	170	4652	4039	286	1.19
Scranton	AS	13.80	16.0	11	1266	6	8	210	4464	2815	-252	0.76
State Coll. UAJA	A/O	4.50	6.0	15.5	582	5.5	8	137	3330	780	80	0.33
Susq. Lanc. Area	A/O	9.45	12.0	10.1	796	6.9	8	92	2288	1619	23	1.12
Throop	AS	4.50	7.0	13.3	499	6.8	8	89	1982	3320	-416	1.68
Williamsport (C)	AS	8.98	7.2	17.3	1296	5.3	8 to 10	328	6600	6339	700	1.36
Williamsport (W)	AS	3.50	4.5	23.5	686	8.5	10	160	3200	5246	1500	2.58
Wyoming Valley	Anx/O	22.30	32.0	6.52	1213	4	8 to 10	171	5575	763	66	0.17
York City	A/O	13.10	26.0	11.8	1289	6.3	8	219	5806	1780	383	0.42
Total/Average		163.20	214.3	14.52	18064	5.9		3945	91574	69936	29397	0.95

permut Flow

**Permit Flow

Table 5. Lowest Cost Options for all the Wastewater Treatment Plants Under Study

New York

WWTP Name	Type of Process	Current Flow MGD	Design Flow MGD	Current Eff. TN Ann. Avg. mg/L	Current Eff. TN Ann. Avg. lb/d	Projected BNR Eff. TN Ann. Avg. mg/L	Projected BNR Eff. TN Max. Month. mg/L	Projected BNR Add. TN Rem. 1st Year thousands lbs/y	Projected BNR Add. TN Rem. 20 yr. Total thousands lbs	BNR Capital Cost thousands \$	BNR Change In O&M Costs thousands \$	Cost per lb N Rem. 20 yr. Avg. \$
Binghamton-Johnson City	AS	24.90	25	14.5	3011	8	8 to 10	493	9965	13057	5372	2.24
Village of Endicott	TF	7.39	8	15	924	8	8 to 10	157	3292	6,656	2393	3.35
Total/Average		32.3	33.0	14.8	3936	8		650	13257	19713	7765	2.49

Virginia

WWTP Name	Type of Process	Current Flow MGD	Design Flow MGD	Current Eff. TN Ann. Avg. mg/L	Current Eff. TN Ann. Avg. lb/d	Projected BNR Eff. TN Ann. Avg. mg/L	Projected BNR Eff. TN Max. Month. mg/L	Projected BNR Add. TN Rem. 1st Year thousands lbs/y	Projected BNR Add. TN Rem. 20 yr. Total thousands lbs	BNR Capital Cost thousands \$	BNR Change In O&M Costs thousands \$	Cost per lb N Rem. 20 yr. Avg. \$
Arlington	AS	32.40	30	9	2432	8	8	99	1973	560	528	0.605
Colonial Beach	AS	0.64	2	13.4	72	8	8	10.5	431	90	-118	-0.065
Dahlgren	OD-Orbal	0.28	0.325	17.6	41	6	8	10	218	30	-56	-0.12
Dale Services #1	AS	3.00	3	12	300	8	8	36.5	730	220	-1483	0.29
Dale Services #8	AS	2.12	3	11.9	210	8	8	25	500	220	-1483	0.29
DuPont	AS	0.49	2	46	188	8	8	57	2880	0	-114	-0.11
Fishersville	AS	1.30	2	11.2	121	8	8	13	260	790	24	2.2
Front Royal	AS	2.27	4	15	284	8	8	48	1023	50	-29	0.02
Harrisonburg	AS	8.00	16	20	1334	9	8	268	8712	4688	-9	0.54
H L Mooney	AS	12.80	18	17.4	1858	8	8	366	8820	490	-120	0.063
Leesburg	TF+AS	2.86	4.85	16	382	7	8	78	1560	2980	-412	0.68
Lower Potomac	AS	45.00	54/67	15	5630	5	8	1370	34094	20800	-10%	0.5
Luray	OD	1.50	2	24	300	NA	NA	NA	NA	NA	NA	NA
Merck & Co *	AS	0.91	1.2	3.5	27	NA	NA	NA	NA	NA	NA	0
Middle River/Verona	OD	3.65	4.5	5.9	180	4	8	21	420	150	0	0.3
Opequon	AS	5.14	6.25	20	857	6	8	219	5328	570	254.3	0.16
Parkins Mill	OD	1.09	2	9	82	6	8 to 10	10	200	97	-318.2	-0.79
Purcellville Existing WWTF	AS/TF	0.31	0.5	24	63	-	-	-	-	-	-	-
Purcellville New Design	AS	-	1	8	-	6	8	17	720	1300	NA	1.8
Rocco Farm Foods	An Lag +AS	1.10	1.2	135	1238	3	8	442	8840	4480	-1225	0.338
Strasburg	OD	0.60	0.975	15	75	6	8	16	4366	120	-180	-0.14
Stuarts Draft	OD	0.98	1.4	10.4	85	4.5	8	18	484	1240	-96	2.36
Waynesboro	TF/RBC	3.63	4	14	424	4	8 to 10	110.5	3548	3500	1027	1.27
Woodstock	OD	0.77	1	12	77	6	8	14	292	70	-135	-0.22
Total/Average		130.85	150.60	20	16260	6.50		3249	85399	42445	-3945	0.48

AS= Activated Sludge
OD= Oxidation Ditch
TF= Trickling Filter
An Lag = Anaerobic Lagoon
An/O= Anoxic/Oxic Process
A/O= Anaerobic/Oxic Process
RBC= Rotating Biological Contactors
* Nitrogen deficient wastewater, effluent N dominantly non-biodegradable

NA = Not Applicable

ADVANTAGES AND DISADVANTAGES OF BNR

The most important advancement in biological wastewater treatment since the invention of the activated sludge process has been the invention and development of biological nutrient removal (BNR) processes. Historically, the activated sludge process has been the method of choice for the efficient removal of biodegradable organic matter from wastewaters, and for producing effluents low in BOD and suspended solids. However, increasing urbanization and larger populations have resulted in conditions that show that the removal of BOD and suspended solids is insufficient treatment for the protection of the nations receiving waters, and that the removal of the nutrients, phosphorus and nitrogen, is also needed. Biological nutrient removal processes can be used to reduce both phosphorus and nitrogen to low effluent concentrations without the utilization of chemicals and the resulting increases in waste sludge production, oxygen requirements, and other operational costs.

There are several advantages to implementing BNR at activated sludge wastewater treatment plants, even without consideration of the reduction of environmental impacts. For example, most activated sludge plants now are required to obtain near complete nitrification, i.e., the oxidation of ammonia to nitrate, all 12 months of the year. The requirement to completely nitrify typically increases the oxygen transfer requirements, and therefore the electrical energy costs for transferring oxygen, by 50 to 100% more than the requirements for the removal of BOD, alone. However, the oxygen transfer requirement can be reduced by a substantial fraction by utilizing denitrification with recycled nitrates to remove influent BOD. All BOD removed this way does not require subsequent oxygen transfer for its removal. The electrical energy costs of a fully nitrifying municipal WWTP typically can be reduced by approximately 20% by implementation of denitrification with the influent BOD as the necessary organic carbon source. Furthermore, denitrification will restore some of the alkalinity destroyed during nitrification, and this will reduce or eliminate alkalinity addition for pH adjustment. Additionally, denitrification utilizing the influent BOD will reduce the total amount of waste activated sludge (WAS) produced for a given SRT.

The advantages of nitrification-denitrification processes in activated sludge systems may be summarized as follows:

1. Reduces or eliminates organic chemical addition for denitrification.
2. Reduces or eliminates alkalinity addition to replace that consumed during nitrification.
3. Reduces aeration requirements and equipment because of BOD stabilization using oxidized nitrogen as the terminal electron acceptor instead of DO.
4. Reduces WAS production because less sludge is produced by denitrification metabolism relative to DO metabolism.
5. Reduces the potential for filamentous growth by reducing the amount of available organics entering the aerobic zone.

Plant operators also should note that controlled cycling of aeration during aerobic digestion will reduce both the electrical energy costs of digestion and the amount of nitrates recycled with the digester supernatant, without reducing the amount of solids destroyed during the digestion process.

Potential disadvantages of implementing nitrification-denitrification are:

1. May require additional capital costs, i.e., for baffles and mixers in a conventional plug flow activated sludge system, plus mixed liquor recycle pumps and lines for the internal recycle of nitrates.
2. Incorporation of non-oxic zones shortens the aerobic SRT of the activated sludge process, and this may require increasing the total reactor volume and/or clarifier capacity.
3. Increases the design and operating complexity of the activated sludge system.

Biological phosphorus removal (BPR) implementation also has several advantages, which can be enumerated as follows:

1. Reduces or eliminates chemical addition for phosphorus precipitation and removal.

2. Reduces or eliminates the need for alkalinity addition by preventing alkalinity consumption by chemical precipitation.
3. Improves the settling properties of the activated sludge by selecting for high specific weight phosphorus-storing flocculating bacteria instead of filamentous forms.
4. Reduces aeration requirements and equipment by 10% or more.
5. Retrofits are simple, and frequently can be accomplished without increases in reactor or clarifier volumes.

Potential disadvantages of BPR are as follows:

1. Typically requires some additional capital costs, i.e., baffles and mixers in an anaerobic zone.
2. Requires more careful design.
3. More sensitive to operate because nitrate and DO recycles must be controlled, and clarifiers need to be operated to prevent phosphorus release.
4. Sludge handling requirements may be more complex.

It is possible to implement either BPR or biological nitrogen removal independently from the other, but the processes are more efficient, stable, and economical when implemented together, for most municipal wastewaters.

BNR PROCESS SCHEMATICS

There are several ways the biological reactors of WWTPs can be configured and/or operated to obtain BNR. Some of the more common ones are illustrated in Appendix I. The simplest of these are the Modified Ludzack-Ettinger (MLE) and Anaerobic/Oxic (A/O) processes for biological nitrogen and biological phosphorus removal, respectively. Plug-flow activated sludge plants can be easily modified to either schematic by the installation of baffles, mixers, and, for nitrogen removal, an internal recycle. The effluent concentrations that will be produced will depend primarily upon the wastewater BOD:TP ratio for BPR, and upon the BOD:TN ratio and the amount of internal recycle for nitrogen removal. Typically, effluent concentrations of less than 1.0 mg/L phosphorus and less than 8 mg/L nitrogen can be obtained with these simple schematics, without effluent filtration. Frequently, BPR can produce effluent TP concentrations of less than 0.5 mg/L without substrate addition or chemical precipitation. For example, the Bowie, Maryland oxidation ditch BPR system averaged 0.21 mg/L during 1997 without chemical addition or effluent filtration. This plant simultaneously produces effluent total nitrogen concentrations of less than 4 mg/L, year round. If insufficient BOD is available in the wastewater relative to the phosphorus for low effluent concentrations, the BOD can be supplemented by fermenting the primary sludge to produce volatile fatty acids such as acetic and propionic. If effluent nitrogen concentrations less than 5 mg/L are desired, a second anoxic zone, as incorporated into the Bardenpho and Modified Bardenpho schematics, can be installed.

While it frequently is advantageous to modify the process schematic by installing baffles, mixers and recycles, many plants can be upgraded to BNR just by changing the method of operation. This is particularly true for oxidation ditches and small extended aeration plants. The oxidation ditches typically can be operated for BNR, with very efficient nitrogen removal, just by controlling the oxygen inputs. This can be accomplished by cycling brush aerators on and off, for example. If phosphorus levels to less than 1 mg/L are desired, however, a separate anaerobic zone needs to be installed ahead of the ditch, as shown in the process flow schematic for the VT2 process.

Small extended aeration plants can be operated for very good nitrogen removal simply by cycling the aerators on and off. The operator first has to determine the optimum on-off cycle for his

system and its loading conditions for successful operation. Aerobic digesters also can be operated this way to reduce energy costs and increase nitrogen removal. Actually, nitrogen removal can be improved at most plants by cycling the air on and off, but there is little reason to do so with a plug flow configuration because it easily can be operated for nitrogen removal without air cycling, i.e., by establishing an anoxic zone.

It is especially easy to modify a plug-flow activated sludge process for BNR if the reactors have multiple passes, and can be operated with step feed. Anoxic zones can be established at the head of each pass without the installation of baffles and mixers to accomplish denitrification. The feed is fed in steps into each anoxic zone. An anaerobic zone with a baffle and mixers is recommended at the head of the reactor to accomplish BPR.

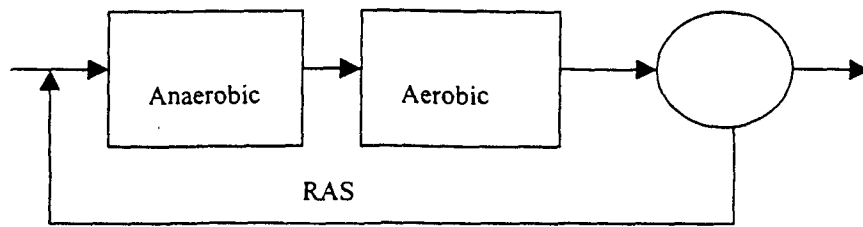
New plants can be constructed as full BNR plants, i.e., with both nitrogen and phosphorus removal, for an additional cost of less than 5 % in comparison with a fully aerobic, complete nitrifying activated sludge plant. The VIP and Nansemond plants owned and operated by the Hampton Roads Sanitation District (HRSD) are examples.

BNR EVALUATION SUMMARIES

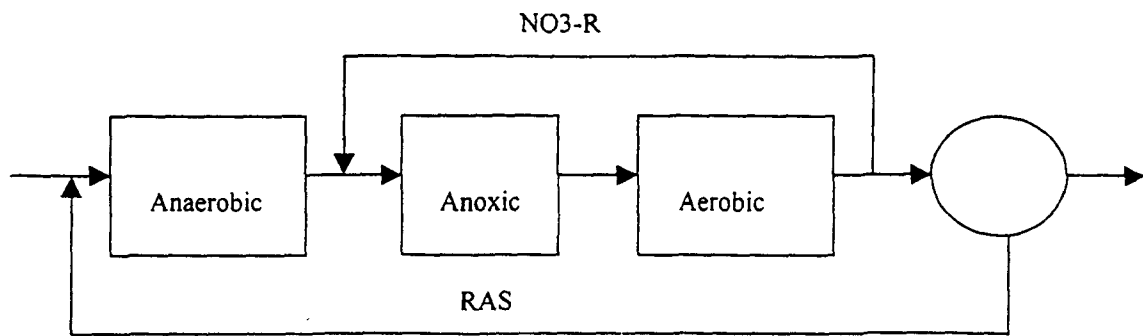
Descriptive summaries of the completed BNR evaluations are given in Appendix II.

APPENDIX I

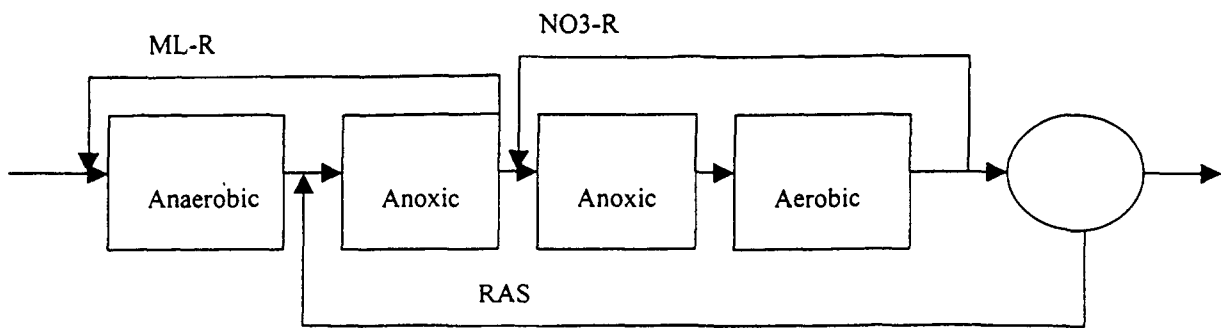
BNR PROCESS SCHEMATICS



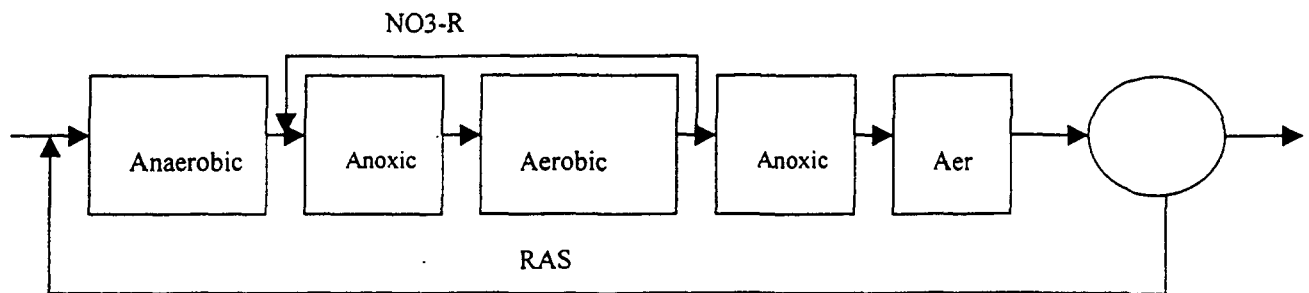
Anaerobic/Oxic (A/O) Process for Biological Phosphorus Removal



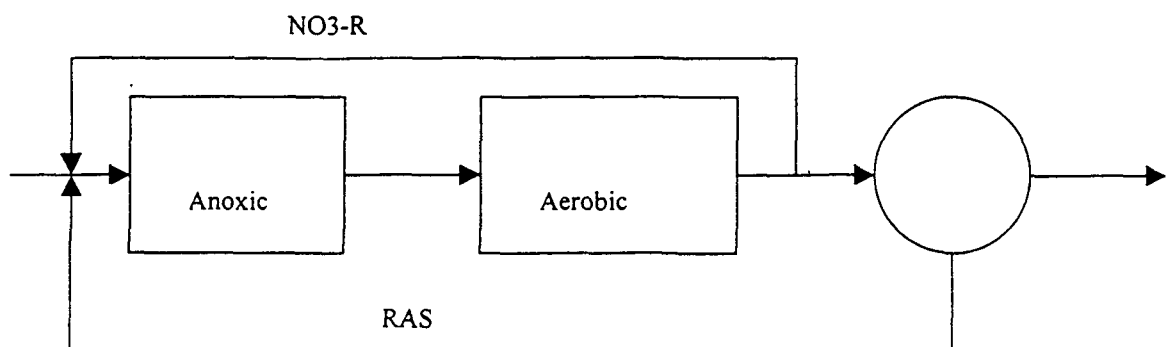
Anaerobic/Anoxic/Oxic (A2/O) Process for Combined Biological Nitrogen and Phosphorus Removal



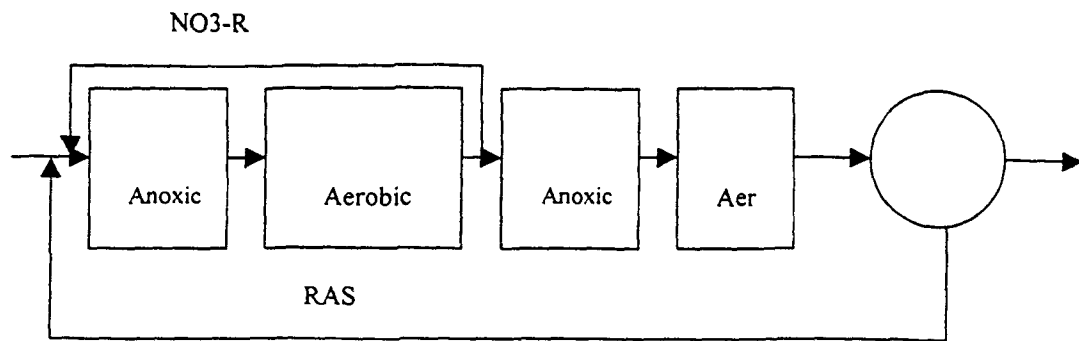
Modified UCT Process for Combined Biological Nitrogen and Phosphorus Removal



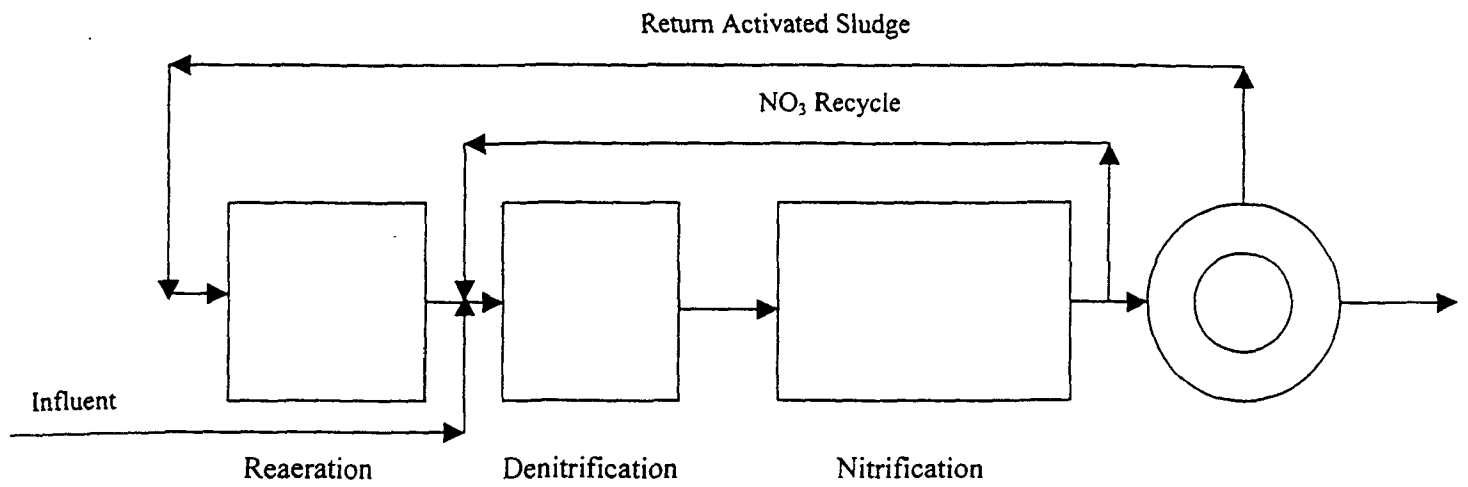
Modified Bardenpho Process for Combined Biological Nitrogen and Phosphorus Removal



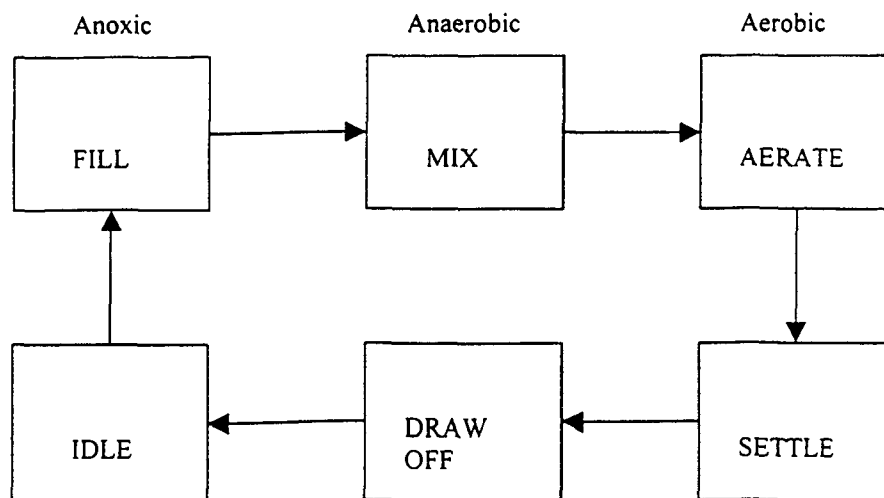
Modified Ludzack-Ettinger (MLE) Process for Biological Nitrogen Removal



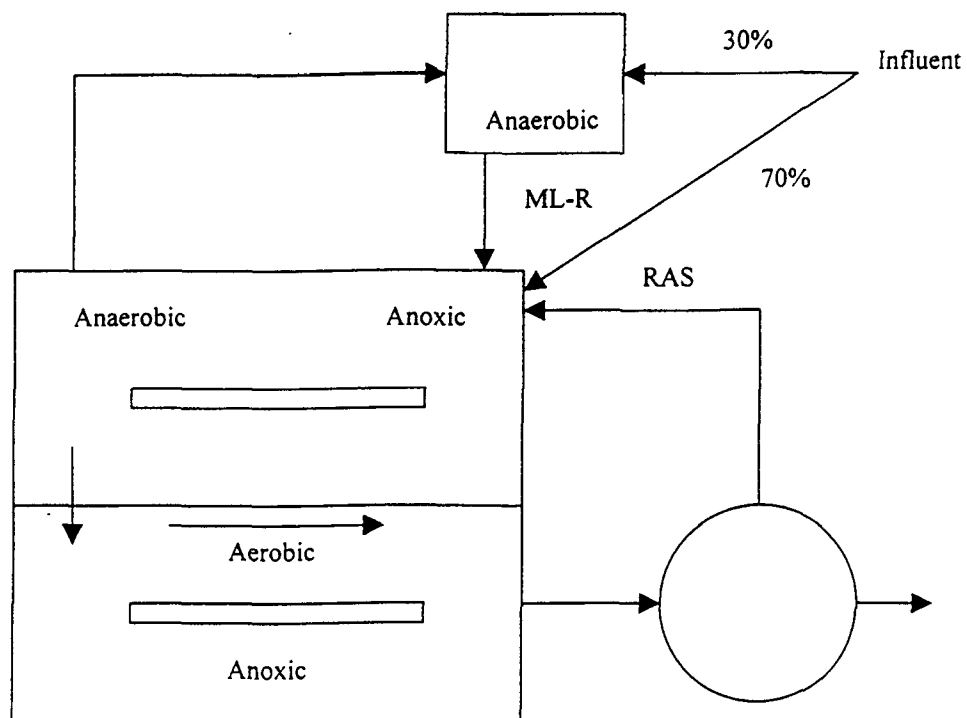
Bardenpho Process for Biological Nitrogen Removal



R - D - N Process for Biological Nitrogen Removal



**Sequencing Batch Reactors (SBR)
Suitable for Combined Biological Nitrogen and Phosphorus Removal**



**VT2 Process for Oxidation Ditch Modification for Combined
Biological Nitrogen and Phosphorus Removal**

APPENDIX II

SUMMARIES OF BNR EVALUATION REPORTS

	Page
Maryland Reports	1
New York Reports	20
Pennsylvania Reports	24
Virginia Reports	55

Maryland Reports - Potomac River Basin

CITY OF BRUNSWICK WWTP, BRUNSWICK, MD

The Brunswick WWTP is an activated sludge facility located in Frederick County, Maryland and it discharges to the Potomac River. The plant is permitted for an average flow rate of 0.7 MGD; however, the current annual average flow is only approximately 0.325 MGD. Routine monitoring of the influent wastewater is conducted only for BOD₅. For this reason, the analysis of the plant's nitrification capacity was performed based on a BOD₅ to COD ratio of 1 to 2, and ammonia, TKN and TP values measured in September 1990. The plant is currently accomplishing complete nitrification, as the effluent ammonia concentrations are less than 1 mg/L year round.

Preliminary treatment at the plant includes a communitor, an influent pumping station, grit removal and an aerated flow equalization tank. Secondary treatment follows the equalization tank, and consists of two activated sludge basins and two secondary clarifiers. The volume of each activated sludge basin is 117,000 gallons, and provides a retention time of 8.0 hours at the design average flow rate of 0.7 MGD, and 17.3 hours at the current average flow rate of 0.325 MGD. Coarse bubble diffusers are used for aeration. The diameter and the side water depth of each secondary clarifier is 30 ft and 13 ft, respectively, yielding an SOR of 495 gpd/ft² at the design average flow, and 230 gpd/ft² at the current average flow rate. The RAS pumping system is adequate for both current and future flow conditions. Sludge is wasted from the RAS line into an aerobic digester. Secondary effluent is chlorinated and dechlorinated in two contact tanks.

The two aeration basin-secondary clarifier trains are completely separate. The current configuration of the plant does not offer the flexibility of taking an aeration tank out of service while operating with two clarifiers, or to take a clarifier out of service and operate with two aeration basins. MLE and cyclic aeration processes were considered for BNR. The existing basins do not have adequate hydraulic retention time to incorporate excess P removal at design flow. Therefore a chemical P removal system is recommended for both BNR systems.

For implementing the MLE configuration, baffle walls would be constructed in the existing aeration basins to create dedicated anoxic zones in the influent end of each basin. The anoxic zone would occupy approximately 40% of the AS basin volume. A submersible mixer should be installed in each of the anoxic zones to keep the biomass solids suspended. A submersible pump also should be installed for nitrate recycling to the anoxic zone. A DO control system (DO probes and a programmable logic controller) is recommended to maintain an optimum DO level around 3 mg/L in the aerobic zone at all times. The anticipated effluent TN concentration would be 8 mg/L at a nitrate recycle flow rate of 1.0 MGD per basin.

Implementation of cyclic aeration would require a system to shut off the air to the AS basins to establish anoxic conditions for denitrification. Typical aerobic and anoxic cycle times would range from 60 to 90 minutes of the total cycle time of 120 to 180 minutes. The aerobic and anoxic cycle times should be programmed so that when one tank is operating in the aerobic mode, the other is in the anoxic mode. A DO control system similar to the one recommended for the MLE configuration also is recommended for this option to control air flow rates. It is recommended that submersible mixers be installed in each aeration tank to be used during anoxic periods.

Capital costs for implementing nitrogen and phosphorus removal are similar for both options: \$430,000 and \$390,000 for MLE and cyclic aeration, respectively. Both alternatives would reduce the O&M costs for the plant. The estimated annual decrease in O&M costs are \$6,100 and \$6,700 for the respective alternatives at design flow. The cost per lb N removed is \$0.59 for MLE operation and \$0.50 for cyclic aeration.

CHESTERTOWN WASTEWATER TREATMENT PLANT

The Chestertown treatment plant is a two stage aerated lagoon system that serves Chestertown and surrounding communities in Kent County, on the Eastern Shore of MD, and discharges to the tidal Chester River. The plant is designed to treat a flow of 0.9 MGD, and currently receives an average flow of 0.60 MGD. The plant consists of two very large lagoons aerated through plastic tubing. The last section of the second lagoon is relatively quiescent to encourage settling of suspended biomass solids. Data for the period from Jan 97 – May 98 was obtained for evaluation.

During the evaluation period, effluent BOD₅ and TSS values averaged 16.1 and 37.3 mg/L, respectively. Very good DO concentrations were maintained in the aerated lagoons, and the effluent NH₄ and TP concentrations were within the discharge limits. Complete nitrification was obtained during warm weather but not throughout the winters. However, while the ammonia levels sometimes exceeded 7 mg/L during the winter, the plant discharged a year round average NH₄-N value of only 3.0 mg/L. Effluent NO_x concentrations also were low indicating substantial denitrification of the formed nitrates within the aerated lagoons. However, effluent organic nitrogen concentrations frequently reached significant values, such as 19 mg/L in April 98. It appears that substantial algae growth occurs in the lagoons, and are discharged in the effluent rather than settling. Because of the high organic nitrogen content, the average TN concentration in the final effluent was 10.7 mg/L. Effluent TP averaged 2.9 mg/L.

The main units of the plant are two aerated lagoons, an anaerobic digester and a chlorine contact tank. The surface areas of the lagoons are 23 and 32 acres, and each lagoon has a side water depth (SWD) of 6 feet. The liquid depth can vary by as much as two inches. Each lagoon is equipped with two 100 HP blower. An anaerobic digester with a volume of 280,000 gallons was designed to digest the sludges produced in the aerobic lagoons. The final treatment unit is a five-pass chlorine contact tank designed for disinfection of the effluent before discharge.

The plant is already accomplishing nitrification and denitrification to an extent sufficient to comply with the Chesapeake Bay goal of 8 mg/L on an annual average. However, the effluent contains excessive amounts of total nitrogen because of the biomass suspended solids being discharged in the effluent. Thus, it is recommended that a deep bed sand filter be added to the treatment system between the second aerated lagoon and the chlorine contact basin to remove the suspended solids and thereby reduce the effluent organic nitrogen concentration. In addition to reducing the organic nitrogen in the effluent, some removal of organic phosphorus is expected, even though the soluble phosphorus PO₄ and the TP values in the effluent usually were approximately the same except during April and May 98. Nonetheless, an average TP value of 2.9 mg/L suggests that the plant does not need any modification to reduce to remove phosphorus.

Analysis of the data indicates that installation and operation of deep bed sand filters will reduce the effluent TN to an average of 5.5 mg/L at both current and design flow rates. It

is estimated that the capital cost of the deep bed filters, including filter influent pumps, backwash pumps, air scour blowers and control units, plus site work, yard piping and electrical upgrade, will be \$ 1,350,000. Estimated changes in annual M&O cost total \$ 4,500. Estimated additional TN removals following the upgrade are 9,500 and 14,250 lbs/yr for current and design flowrate conditions, respectively. The estimated cost per additional pound nitrogen removed is \$5.92/lb.

CITY OF CRISFIELD WWTP

The Crisfield WWTP is a contact stabilization design activated sludge plant located on the southern end of the Eastern Shore of Maryland. It discharges into the Chesapeake Bay. Because the plant is located at or just above sea level, it suffers from infiltration-inflow of seawater during high tides in addition to normal infiltration-inflow. The plant is permitted for a flow of 1.0 MGD, and effluent concentrations of 30 mg/L BOD₅, 30 mg/L TSS and 2.0 mg/L TP. There are no effluent ammonia or nitrogen requirements in the current permit.

According to 1995 data, the loading and flow decrease substantially in winter, to almost 75% of summer flows and loads. Raw influent BOD₅ and TSS samples are collected twice a week, whereas only one or two sets of samples are analyzed each month for TKN and TP tests. The average BOD₅/TKN and BOD₅/TP ratios were 5.93 and 42.4, respectively. The average BOD₅ value for the year 1995 was 125 mg/L at an average raw influent flow of 0.6 MGD.

The raw influent is screened through a 1/2 inch mechanical bar screen and flows from there to a rectangular grit chamber, or to an influent surge tank that is used during high flows. The grit chamber does not perform adequately and during high flows some of the grit enters the AS tanks and accumulates at the bottom. The AS basins are contact stabilization units designed in a donut shape with clarifiers in the middle. The outer ring has three chambers: reaeration, contact and aerobic digester zones. The basins are aerated with coarse bubble diffusers installed on swing-arms. The nominal HRT is 7.8 hours at 1.2 MGD and 9.4 hours at 1.0 MGD. Without any primary clarifiers, the AS basins have to treat a higher load for the same flow as compared to facilities with primary clarifiers. In 1995, the plant maintained complete nitrification all year round at flows of 0.5 MGD in winter and 0.65 MGD in summer. The effluent NO_x averaged 13.6 mg/L with an average TN of 15.6 mg/L.

The plant has two secondary clarifiers with SORs of 622 gpd/ft² at 1 MGD and 750 gpd/ft² at 1.2 MGD wastewater flow. These rates exceed the MDE guidelines for a conventional WWTP, which are 600 gpd/ft², and would correspond to a flow of 0.9 MGD. The solids loading rate exceeds 20 lb/d/ft² at MLSS of 2600 mg/L with an influent flow rate of 1.0 MGD and a RAS flow rate of 50% of influent. The plant does not have the flexibility to take a clarifier out for maintenance. Additional secondary clarifier capacity is necessary to operate with nitrification at design flows of 1.0 or 1.2 MGD. The secondary effluent is chlorinated in two parallel contact tanks with an HRT of 65 minutes. It is dechlorinated and reaerated before discharge. Two aerated holding tanks are used for sludge digestion. Typically a MLSS below 10,000 mg/L is maintained.

Besides the suggested modifications for operational improvement to the headworks and grit chambers, three options were considered for AS basin modifications for BNR:

1. Operation of the AS basin volume of 0.2 MG in each tank (current configuration),

2. Conversion of the two AS basins to a volume of 0.305 MG each by incorporating the aerobic digestion section into the activated sludge basin. The digestion section would be moved into the existing clarifiers, with new units constructed to replace the existing units;
3. Conversion of only a part of each aerobic digester into an AS basin to provide a total volume of 0.235 MG for aerobic digestion. Each AS basin would have a volume of 0.255 MG.

It is recommended that the AS basins be reconfigured into anaerobic(15%)-anoxic(25%)-aerobic order with step feed capabilities for handling high flows. The RAS would be sent to the head of the anaerobic zone. The nitrate recycle could be fed to the head of the anoxic cell for BPR in addition to nitrogen removal, or to the first anaerobic cell for nitrogen removal with chemical P removal. Based on the analyses performed, it is recommended that one AS basin be taken out of service in winter while operating with both clarifiers when the flows decrease to 75 % of summer flow. The coarse bubble diffusers should be replaced with membrane or ceramic fine bubble diffusers. With the addition of two new clarifiers, the system should be able to operate satisfactorily for one month with one clarifier out of service in winter when both AS basins are in operation. A RAS pump station that can independently control flows from individual clarifiers would have to be designed to operate with the new clarifiers. The station should have WAS pumps, also. Existing secondary clarifiers shall be converted to aerated sludge holding tanks that can be used as aerobic digesters. It is proposed that a ferric chloride or alum feed system be available as a backup for BPR.

Cost estimates were made without including the grit removal system modifications. They include construction of RAS and WAS pump stations. Total capital cost was estimated to be \$3.0 M at 1.2 MGD, and \$2.0 M at 1.0 MGD. Total change in operating costs at 0.7 MGD is \$9,894. The total cost per additional lb of N removed is \$7.40 at 1.2 MGD, and \$4.95 at 1.0 MGD with one secondary clarifier.

TOWN OF ELKTON WWTP

The Town of Elkton WWTP is a rotating biological contactor (RBC) plant located in Cecil County. The current permit is based on a maximum monthly average wastewater flow of 1.6 MGD, and limits the BOD₅ to 30mg/L, TKN to 20 mg/L, and TP to 2.0 mg/L on a monthly average. Furthermore, the permit specifies an effluent TN level of 8 mg/L which should be achievable through installation of biological nutrient removal (BNR) facilities designed to meet a seasonal (May through October) average of 8 mg/L. Actual dry weather and wet weather flows are 1.4 MGD and 2.5 to 3.0 MGD, respectively.

The WWTP is rated for an average flow rate of 2.7 MGD, whereas the monthly average and maximum flow rates to the plant during the period of July 1997 through June 1998 were 1.37 MGD and 1.70 MGD, respectively. The monthly average of raw influent BOD₅ was 172 mg/L for this period, and TKN averaged 28 mg/L. The primary effluent has not been monitored at the Elkton WWTP. For this reason, primary effluent characteristics were calculated using typical removal efficiencies of primary clarifiers (BOD₅: 35%; TKN: 20%; TP: 15%). The data show that the plant is not able to achieve good nitrification, as both the annual average and the monthly average values of ammonia concentration in the final effluent are all 9.0 mg/L or greater. The DO levels in the RBC troughs seemed to be sufficient for nitrification; hence, other approaches should be considered to improve nitrogen removal. NO_x, on the other hand averaged 4.1 mg/L monthly.

Preliminary treatment consists of an Aqua Guard screen with 0.5inch openings, a comminutor, a grit collector, and two primary clarifiers. The grit chambers were not operating at the time of the visit, but the flow passes through them. The SOR and HRT at the average flow of 1.37 MGD with both units operating are 242 gpd/ft² and 2 hours, respectively. The clarifiers are operated with an 8 inch sludge blanket, and the sludge is pumped directly to the belt filter press at a rate of 6 hours per day and 3 days per week. Polymer is added for sludge conditioning, and eventually the sludge is composted. Clarifier effluent is by-passed to an aerated surge tank during high flow times, whereas the regular flow goes to the RBCs after alum addition. The overflow is then diverted from the surge tank to the pump station and then recycled back to the headworks. There are two banks of "BioSpiral" RBCs and two banks of two rectangular secondary clarifiers. Each bank of RBCs is made up of four trains of three RBCs. Eight of the twelve RBCs have standard media shafts at 100,000 ft² and four have high density shafts at 150,000 ft². The RBC troughs are aerated in order to increase sloughing. C116 Polytreat polymer is added to the effluent of the contactors to improve settling properties. Mixed liquor from the RBCs flows into two banks of two secondary clarifiers each, one of which is in operation in each bank. Each clarifier has an SOR of 360 gpd/ft² and an HRT of 1.26 hours at 1.37 MGD, with two of the clarifiers operating. Link belt sludge and scum collection is employed. The sludge is returned back to the primary clarifiers for settling. There is also a sludge recycle line from each clarifier to the flow control chamber immediately upstream of the RBCs. Two chlorine contact tanks are used for disinfection purposes, and the center channel between them is used for dechlorination.

The tanks have a contact time of 35 min. at peak flow. Caustic is also fed to the secondary effluent with chlorine. Cascade aeration of the effluent is used to maintain a final effluent minimum DO concentration of 5 mg/L. Final effluent is then discharged to Big Elk Creek.

The following two process alternatives were considered for implementing BNR:

1. *Construct a nitrification-denitrification filter downstream of the existing secondary clarifiers:* BOD removal would occur in the RBCs and both nitrification and denitrification would occur within the attached growth of the biological filters. Examples of nitrification-denitrification filters are Biofor® Filters, which use expanded shale as the filter media; Biostyr® Filters, which use lighter than water plastic media; and the Kaldnes Process, which uses polyethylene media with a density slightly less than that of water. Because the BOD present in the influent is removed in the RBCs, a methanol feed system would be constructed to provide an organic carbon source for denitrification in the tertiary filters.
2. *Decommission the existing RBC units and Construct an Oxidation Ditch Activated Sludge System:* It is recommended that an oxidation ditch system with two parallel ditches be constructed to replace the existing RBC units in the treatment train. Oxidation ditches are high internal recycle systems that can be operated for excellent nitrogen removal by optimizing the oxygen inputs. Typically, effluent TN concentrations of less than 5 mg/L are easily achievable. If it is desired to implement biological phosphorus removal as well, an anaerobic reactor could be constructed upstream of the ditches. This configuration at Bowie, Maryland typically averages <0.3 mg/L TP and <4 mg/L TN. Other types of BNR activated sludge processes such as A2/O, VIP, modified UCT or sequencing batch reactors also would perform satisfactorily and could be used instead of the oxidation ditch configuration if desired. If the oxidation ditch system is constructed, the primary clarifiers become extendable and could be modified into anaerobic reactors for biological phosphorus removal. The existing secondary clarifiers probably could be used for activated sludge operation, but should be examined and evaluated for this purpose because they have shallow side water depths (10 ft.). They are likely to be usable for current flows, but may become limiting as the influent flow approaches the design flow of 2.7 MGD.

The estimated capital costs for the two alternatives are \$3,019,030 and \$3,674,720, respectively. The cost of Alternative 2 would increase to \$4,271,720 if the anaerobic reactor is included. Alternative 1 would have very high energy costs because it would not be possible to reduce aeration costs in the RBCs, and additional organics would have to be purchased for denitrification. Additionally, there would be the cost of aerating the nitrifying filters, the costs of backwashing the filters, air sour blowers, and the cost of purchasing an organic carbon source such as methanol for denitrification. Consequently, the O&M costs for Alternative 1 are projected as \$80,500 per year. The O&M costs for Alternative 2 are projected to be only \$10,700, for the maintenance of the aeration brushes and RAS pumps. The estimated total costs for implementing nitrogen removal is \$2.72 for Alternative 1 and \$2.62 for Alternative 2, per lb additional N removal.

FEDERALSBURG WWTP

The Federalsburg WWTP is a trickling filter plant located in Caroline County on the Eastern Shore of Maryland. It discharges into Marshyhope Creek, which eventually flows into the Nanticoke River, a tributary of the Chesapeake Bay. The current permit is valid until August 1999, and it limits the WWTP discharge to average TKN and TP concentrations of 10 mg/L and 2 mg/L, respectively. The average effluent BOD limit is 30 mg/L for the period from October 1st through April 30th, and is 20 mg/L for May 1st through September 30th. The current average wastewater flow to the plant is 0.36 MGD, and the design flow is 0.75 MGD.

The effluent characteristics were summarized from operating data for the period from November 1996 through April 1998. The average effluent concentrations for BOD, TSS, TKN and NO_x-N were 6.6, 12.1, 2.4, and 15.5 mg/L, respectively. The plant achieved complete nitrification throughout the period with effluent ammonia values well below 1.0 mg/L most of the time. The total nitrogen discharged from the plant, mostly in the form of oxidized nitrogen, was 53 lbs/day in an average flow rate of 0.355 MGD. The average effluent TP concentration of 1.9 mg/L was slightly less than the permit limit.

Preliminary treatment processes at the Federalsburg WWTP include 3 Celco type static screens and 2 Evtac Teacup grit removal units. The screens have a mesh size of 0.10 inches, and their flow capacities are 750 gpm each for a total of 2250 gpm. The centrifugal grit removal units have a flow capacity of 900 gpm each. The design of the grit removal system was based on the removal of 95% of particles 100µm and larger. Flow from the grit removal units is combined with secondary sludge flow and diverted to the primary clarifiers through 3 flow distribution pits, only one of which was in operation at the time of this evaluation. There are 2 primary clarifiers with sufficient space for one more unit. However, currently only one clarifier is in use. The design sludge production rate was 2708 gpd at 3% solids concentration. The clarifiers have diameters of 50 ft with surface areas of 1963 ft² and surface overflow rates of 275 gal/day/ft² at the design flow of 750 gpm.

Following an equalization step, biological treatment at the Federalsburg WWTP is achieved with 2 parallel trickling filters filled with synthetic high cone media. The media depth and surface area are 13.5 ft and 30 ft²/ft³. The current total recycle rate around the filters is 1200 gpm, and the full recycle capacity is 1200 gpm per filter. The design total and soluble BOD loadings to the trickling filters are 1038 and 769 lbs/day. The design ammonia loading, on the other hand is 125 lbs/day. Two secondary clarifiers with diameters of 50 ft and minimum side water depths of 12 ft are operated for solids separation. The surface overflow rate at a design flow rate of 375 gpm per unit is 275 gpd/ft². The secondary sludge concentrated to 0.5%, and is pumped to the primary clarifiers at a design rate of 16,306 gpd by pumps that operate for 10 min. every hour.

Secondary effluent is disinfected by chlorination in a contact tank with a hydraulic retention time of 60 minutes. Following dechlorination, treated water passes through a 6-

step cascade aerator prior to discharge. Combined primary and secondary sludge is further treated anaerobic digestion. The digester volume 249,000 gallons and the waste sludge production rate at 3% solids concentration is 5,017 gal/day. The digester contents are mixed with 2 mixers. The digested sludge goes to two sand drying beds of 9,220 ft² surface area for dewatering.

Because complete nitrification was successfully achieved throughout the period of evaluation, the installation of a tertiary denitrification filter built downstream of the secondary clarifier is recommended for enhanced nitrogen removal. In this alternative BOD removal and nitrification will take place in the existing trickling filters and denitrification will be accomplished in the tertiary bio-filters. Operation of the denitrification filters will require the addition of an external carbon source. Methanol is the most widely used organic carbon in similar situations because it usually is the most economical. Examples of denitrification filters are Tetra® filters, which use sand as the filter media, and Biofor® filters which use expanded shale as the filter media. A pumping station would be needed to pump the clarifier effluent to the denitrification filters. A methanol feed system is also needed.

The capital cost for implementing nitrogen removal at the Federalsburg WWTP was estimated to be \$1.5 M. This amount includes concrete structure and manufacturer's equipment. The cost for the methanol feed system includes storage tank, chemical metering pumps, containment area, fire suppression system, safety equipment, piping and a prefabricated enclosure to house pumps. On the other hand, the estimated changes in annual M&O costs were calculated to be \$11.3K at current flow, and \$18.8K for the design flow. The overall cost for the removal of each additional pound of nitrogen is \$3.37.

GEORGES CREEK WWTP, ALLEGANY COUNTY

The Georges Creek WWTP is an oxidation ditch activated sludge facility permitted to treat a flow of 0.6 MGD, and the annual flows and loads are close to the design capacity. Operating data for 1995 was analyzed for the purposes of this study. The plant received an average flow of 0.626 MGD, and the average monthly BOD₅ was 146 mg/L. In the absence of data for TKN and TP, they were estimated to be 29.1 mg/L and 4.9 mg/L, respectively, using the ratios for BOD₅/TKN (5:1) and BOD₅/TP (30:1) that are typical for Maryland. The plant did not have any data on ammonium-N, NO_x or TP in the final effluent.

The influent enters the plant through a wet well and then it is pumped to the oxidation ditch. As the plant does not have a grit removal unit, grit accumulates in the wet well and in the ditch. The ditch is aerated and mixed with jet aerators. The velocity of the water in the ditch is not enough to keep grit in suspension. Based on operating information, a significant volume (10% or higher) of the ditch may now be filled with grit. Because there is only one ditch, the plant cannot take it out of service for maintenance. Ditch effluent is controlled manually with a valve. The pipe carrying the mixed liquor from the ditch to the clarifier is smaller than the influent pipe, and this causes a hydraulic bottleneck, which causes the ditch to overflow. The overflow should be corrected to prevent nitrifier loss and discharge of mixed liquor to Georges Creek. Because only one blower is used for aeration of the ditch, the DO concentrations are only 1 mg/L close to the jets. It is even lower between the jets. The plant has two secondary clarifiers with SORs of 565 gpd/ft² at design flow with both units in operation. With a SWD of 8 ft, this SOR is high for a nitrifying mixed liquor. The plant cannot operate with one clarifier, and it has to bypass as much as half of the normal flow around the facility to prevent solids washout. Sludge is wasted through a Wye connection on the RAS line. Secondary effluent is disinfected using a UV system, which has to be replaced or upgraded to allow the peak design flow of 2.1 MGD to pass through the plant.

Based on DO levels in the ditch and an evaluation of the existing aeration system, it appears that nitrification would be limited by the capacity of the aeration system. Because of anoxic conditions at the lower depths of the ditch, any generated NO_x would get denitrified.

The following modifications should be considered to implement BNR:

1. *Improve the aeration system for nitrification:* According to the calculations, the jet aeration system already in use can provide 1440 lb of oxygen per day. However, due to clogging of the jet nozzles this capacity is probably only about 85% of design at present. For an MLE configuration, the oxygen demand for BOD and nitrogen removal will be 1440 lbs per day at average load. For BOD removal alone, 1150 lbs of oxygen are needed daily. Therefore the current system needs to be upgraded for nitrification. One alternative is the installation of two 25 HP brush aerators, with timers or PLCs and DO probes. The brush aerators will also help increase the liquid

velocities in the ditch, reducing the quantity of grit settling out. Another alternative is the installation of a ceramic or membrane fine bubble diffuser system with new piping. The peak demand could be met with two 30 to 35 HP blowers.

2. *Correct the overflow of raw influent and mixed liquor to the Creek by providing the plant with the capacity to treat the MDE recommended peaking factors for a facility of this size:* Construction of a new clarifier with its own RAS system must have the highest priority. Flow distribution boxes and appropriate piping must also be considered.
3. *Provide redundancy to take part of the oxidation ditch out of service to remove grit:* This will prevent loss of nitrification capacity when the system needs to be taken out of service. The ditch can be partitioned into two U-shaped AS basins, and 30% of each basin should be anoxic according to the calculations. The nitrate recycle pump should be able to operate in a range from 120 and 300 % of the influent flow.
4. *Add a grit removal system to protect equipment such as diffusers and mixer blades:* Two grit removal systems were found to be feasible: a Schreiber channel type grit removal system and a Pista-grit system on the influent sewer line upstream of the influent wet well.
5. *Add a chemical P removal system:* Predictable Biological P removal would require an anaerobic reactor before the oxidation ditch. Chemical P removal would decrease the capital costs.

The cost calculations were done for each item listed above. Implementation of N removal, at a minimum, requires that the aeration system be improved as recommended under Item 1, and sufficient redundancy be established to permit an activated sludge unit to be taken off line, as recommended in Item 3. It is recommended that the approach of Item 3 be considered instead of Item 1 to provide the plant with a desired level of operability. Item 5 has to be implemented for P removal. The capital costs of the five items are \$456,000; \$1,156,000; \$1,663,000; to be estimated; and \$1,920,000, respectively, corresponding to the items listed in the above order. Additional operating costs with nitrification and denitrification sum to \$1,748, and the projected total cost per lb of additional N removed excluding P removal is \$3.55.

INDIAN HEAD WWTP

The Indian Head WWTP is a small, activated sludge plant located in Charles County, Maryland, and it services the Town of Indian Head. The plant is permitted for a flow of 0.49 MGD, and the current permit requires the plant to maintain seasonal nitrification. The plant discharges to Ginny Creek, which is a tributary of the Mattawoman River and a sub-tributary of the Potomac River. At present, the plant receives an annual average flow that is 50 to 60 % of the design flow of 0.5 MGD.

In 1995, the raw influent BOD₅ averaged 287 mg/L, which is a fairly high value for the Mid-Atlantic region. For the purposes of this design, a COD/BOD ratio of 1.5 was assumed; however, if in the future the COD/BOD ratio exceeds 2.0, the plant may have difficulty nitrifying without addition of media in the existing tanks or adding additional tanks. The raw influent BOD/TKN ratio averages 12.0.

The raw influent enters the facility through three separate sewer lines into a Parkson Aquaguard screen. Following screening, the wastewater is degrittied in a Pistagrit unit and sent to the AS basins. The AS basins are an old package plant with a concentric clarifier that has since been retrofitted to operate with external clarifiers. The outer ring is partitioned to yield two semicircular basins, each of which can be step fed. The HRT in the basins is 14.2 hours at the design flow of 0.5 MGD. Aeration is accomplished with ceramic disc diffusers. The mixed liquor leaves the basins through a submerged port that does not allow foam to pass through to the secondary clarifiers. The two clarifiers have SORs of 354 gpd/ft² at 0.5 MGD. A telescopic valve is used to control the RAS flow rate from each clarifier, and RAS is then pumped to the AS basins. The flow rates for RAS and WAS are controlled by a Programmable Logic Controller. Secondary effluent is disinfected with chlorine gas and dechlorinated with sulfur dioxide prior to discharge to Ginny Run.

The secondary clarifiers located in the midst of the AS basins were converted to primary aerobic digesters, and aerated with coarse bubble diffusers. Thickened and digested sludge is pumped into a secondary digester. Supernatant is returned to the AS basins. Sludge is then trucked to Mattawoman WWTP at the rate of three truck-loads each day.

Two alternatives for BNR were evaluated. Both alternatives use the entire AS tank volume; therefore, a separate surge tank or effluent pumping is required to overcome the hydraulic limitations downstream of the secondary clarifiers, which causes the weirs to become submerged and solids to overflow:

1. *Conversion of existing AS basins to anoxic and aerobic zones:* The design calculations showed that the plant would have to operate at MLSS levels of 2800 mg/L during average month loads in winter and 3750 mg/L during a peak month. Because of limited aeration volume, a dedicated anaerobic zone was not included for biological P removal. P removal can be accomplished by chemical precipitation. It is recommended that two anoxic cells, each with a volume of 12.5 % of the AS tank

volume be installed. The ceramic plates of the existing diffusers would be removed. In the second cell, the ceramic discs would be replaced with membranes diffusers, which will allow the second cell to be aerated in case one AS basin is taken out of service. A side mounted submersible mixer should be installed to prevent settling. It is recommended that a nitrate recycle (60 to 150 % of influent) pump and piping be installed in each aerobic basin. To maintain proper aeration with DO levels above 2 mg/L, an automated DO control system, including DO probes, a PLC and motor control on blowers, should be installed. The SORs and solids loadings on the existing clarifiers are adequate for operation with BNR. However, it is necessary to provide independent control of RAS withdrawal from each clarifier.

2. *Conversion of existing primary aerobic digester to activated sludge tanks:* The additional AS tank volume can be used as an anoxic tank in the MLE configuration. If BPR is included, the tank can be used as an anaerobic zone with raw influent and RAS feed. The mixed liquor would flow out of the anaerobic zone to anoxic zones incorporated into the two trains of the AS basin. The final design should insure equal distribution of flow leaving the anoxic zone between the two aerobic zones. An automated DO control system should be installed, including DO probes, a PLC, and motor control on the blowers. A side mounted submersible mixer should be installed to prevent settling. It is recommended that a nitrate recycle (60 to 150 % of influent) pump and piping be installed in each aerobic basin. The SORs and solids loadings of the existing clarifiers are adequate for operation with BNR. WAS would be repiped to a mechanical thickening device. Elutriant from thickening would be pumped to the headworks. Either BPR or chemical P removal can be implemented.

The first alternative can be implemented at a lower cost but it has a lower safety factor when one AS tank is taken out of service. This will be overcome by sacrificing some denitrification and applying step feed operation. The operating costs for BNR are similar to current costs. The cost of chemical P removal would be additional. The total capital cost for BNR is \$532,000, and the additional costs of chemical and biological P removal are \$158,000 and \$60,000, respectively. The change in annual operating costs is estimated as \$5,757. The cost per lb of additional N removed would be \$2.90 excluding the P removal costs.

The second alternative provides a higher safety factor when one tank is taken out of service. The capital cost for the project would be \$1,158,000 with an additional cost for chemical P removal of \$127,000. The change in the annual operating costs would be on the positive side with savings of \$13,480, resulting in a cost per lb of additional N removed of \$4.18.

MATTAWOMAN WWTP

The Mattawoman WWTP is an activated sludge plant that services most of Charles County. The plant is rated for a flow of 15 MGD. Currently the flow ranges from 7.5 MGD in dry months to 10 MGD in wet months, including the recycle flows from filter backwash, belt filterate, and gravity thickener overflow, which adds up to an average of 1.28 MGD. Operational data for the year 1995 was analyzed for this study.

Raw influent BOD₅ averaged 182 mg/L during 1995. The primary effluent measurements for BOD₅ and TKN were 104 and 28.1 mg/L, respectively. There was a large increase in primary effluent TKN from June through October, possibly due to increased trucking of sludge from other facilities and septage. Final effluent nitrogen concentrations were determined by averaging the two consecutive samples analyzed each month. Although ammonium-N concentrations averaged 3.46 mg/L, presence of a substantial amount of nitrification between June and February is apparent from the other nitrogen species. The average organic N concentration was 3.30 mg/L, which is higher than the averages at other facilities in the region. The difference may be a result of low MCRTs (3 to 4 days) causing incomplete hydrolysis of organic nitrogen to ammonium-N. Effluent TN averaged 13.8 mg/L, which is much lower than primary effluent TKN, indicating the presence of denitrification. The amount of denitrification taking place was calculated from a nitrogen mass balance to be 7.28 mg/L. The reduction in primary effluent BOD₅/TKN ratio should be monitored as it can adversely affect denitrification because of insufficient organic carbon levels.

The WWTP has screening and grit removal for preliminary treatment. The wastewater leaving the grit chamber enters a wet well where it mixes with the recycle flows. Primary clarification takes place in four old and one new clarifier. The new clarifier has an SOR of 800 gpd/ft². The old clarifiers do not perform as efficiently as the new one at 800 gpd/ft² and a raw influent flow of 7.4 MGD. Without the large clarifier, the four small units are operated at 1800 gpd/ft², necessitating the addition of coagulants for suitable operation. There are six parallel rectangular AS basins with a nominal HRT of 6.0 hours at the design flow rate of 15 MGD. Aeration is achieved by coarse bubble diffusers. The basins have a submerged pipe outlet for the mixed liquor to pass to six clarifiers; four old and two new. The SOR at the design flow of 15 MGD is 550 gpd/ft² and the solids flow rate at 3000 mg/L MLSS and 50% RAS flow rate is 21 lb/d/ft², both of which are higher than normal design practice. Therefore, additional secondary clarification is recommended. The plant uses a P removal tertiary system that includes four clariflocculators followed by final effluent filters. Ferric chloride is used for precipitation.

Primary and WAS are thickened in two open gravity thickeners. The thickened sludge is held in aerated holding tanks prior to dewatering. Belt presses are used for solids dewatering.

A review of the plant operation data showed that the plant nitrified at low MCRTs, and the kinetics of nitrification can be enhanced by the plug flow pattern of flow in the AS basins by operating with the DO maintained between 4 mg/L (summer) and 8 mg/L (winter). The observed denitrification may be a result of reduced aeration with high temperature, low DO zones in the basin created by the plug flow pattern, and low operating MCRTs, which cause a relatively high biodegradable SCOD in the first half of the basin. Data from 1995 show a substantial increase in primary effluent TKN in summer without a corresponding increase in BOD₅, which indicates an inadequate organic carbon source for denitrification. Besides, as the plant approaches design flow, nitrification is expected to decrease. For this reason, septage receiving procedures must be examined and COD/TKN ratios must be monitored.

In order to achieve a seasonal average goal of 8 mg/L effluent TN, two alternatives were developed:

1. *Modification of the AS system to six parallel basins with anoxic and aerobic zones (MLE configuration); flexibility to take one AS basin out of service between June and December; flexibility to take one clarifier out of service; step feed to handle high flows above 25 MGD:* Modifications are recommended to pump septage to either the gravity thickeners or an aerobic digester when the raw influent flow exceeds 12.5 MGD. It is recommended that an additional primary clarifier of the same size as the existing large clarifier be added for the design primary effluent rate of 17.5 MGD. This will reduce the SOR to 650 gpd/ft² at a primary effluent flow rate of 17.5 MGD when two large units are in service. Without a new clarifier, Stamford baffles and chemical coagulant addition can enhance primary settling when the large clarifier is out of service. A minimum of two anoxic cells are recommended in the first 25 to 40 % of the AS basin. An anoxic volume of 45% is recommended to maintain denitrification during periods of low COD/TKN ratio in the primary effluent. The nitrate recycle pump should be capable of pumping a maximum of 250% of the raw influent flow. Automated DO control is optional. The existing secondary clarifiers are shallow for BNR (10 ft). It is recommended that an additional secondary clarifier be constructed to upgrade the plant. The RAS from the new clarifier will be piped to the secondary sludge pump station. The plant can use two point chemical addition for P removal, using the final clarifiers as secondary clarifiers.
2. *Modification of the AS system to three, two-pass step feed reactors with anoxic zones at the head of each pass; addition of one secondary and one primary clarifier; the flexibility to take one AS basin out of service at any time of the year; flexibility to take one clarifier out of service at any time of the year:* The influent to the two pass system will be step fed to the beginning of the first pass and the beginning of the second pass. An anoxic zone will be created at the beginning of each pass, followed by a multi-cell aerobic zone. Effluent soluble organic N is expected to be 0.5 mg/L higher than Alternative 1. Without a nitrate recycle the effluent TN may be higher than 8 mg/L during the months with peak nitrogen loads.

At the time the report was prepared, it was not clear whether the addition of wastewater flow contributions from a power plant would be considered to be a part of the 15 MGD of wastewater flow allocated for this facility. If it is not, the potential raw influent flow and primary effluent flow will increase by an additional 1.5 to 2.5 MGD, and this will have an impact on the primary and secondary clarifier requirements.

In the cost calculations for both alternatives, the modifications for septage handling and for constructing a common effluent channel are not included. The County would realize operational savings in excess of \$114,400 per year at 15 MGD by the conversion from coarse bubble to fine bubble aeration. Also, there would be additional savings of \$103,000 per year in sludge dewatering and hauling costs at 15 MGD because of an increase in operating MCRT from 3 days to 8 days. With the addition of a primary clarifier, the projected total capital costs for the project is \$8.5 M. Without the addition, the plant maintains its hydraulic capacity at 15 MGD and the capital costs of modifications is \$5.8 M. The cost per lb of additional N removed with Alternative 1 implementation, and with Primary Clarifier addition, is \$0.94 . Without the primary clarifier the cost per pound of N removed would be \$0.07.

WASHINGTON COUNTY WINEBRENNER WWTP

The Winebrenner WWTP is a rotating biological contactor (RBC) plant located at Fort Richie, Washington County, Maryland. Originally the plant was constructed to serve Fort Richie Military Base and the civilian population. The Base has been scheduled for closure and currently personnel are in the process of moving out of Fort Richie. The current permit based on an average flow of 0.6 MGD does not limit the TKN or TN discharge. The current average flow rate is approximately 0.3 MGD, and the plant discharges to Falls Creek, which flows into the Potomac River.

Raw influent COD, TKN and TP levels are not measured at this facility, and they were estimated based on typical ratios for municipal wastewater. The measured monthly average values for raw influent BOD₅ and NH₃ are 125 and 12.2 mg/L, respectively. Assuming a TKN to ammonia ratio of 2:1, the raw influent TKN concentration was estimated at 25 mg/L. The facility is currently accomplishing complete nitrification because the effluent ammonia concentration is less than 1.0 mg/L year round. Final effluent BOD₅, TKN, NO_x and NH₃ are 3.6, 3.0, 14.5, and 0.6 mg/L, respectively.

Preliminary treatment processes consist of a manually cleaned coarse bar screen followed by a communitor, aerated grit chamber, flow equalization tank and two primary clarifiers. The flow metering system consists of a Parshall flume and an ultrasonic level sensor. The SOR of the primary clarifiers is 611 gpd/ft² at the permitted flow rate of 0.6 MGD, which is an adequate value for the existing clarifier configuration. Secondary treatment consists of six RBCs with multilayer stacked polyethylene discs, and three circular secondary clarifiers. The RBCs can be operated as two parallel trains with three RBCs in each train, or as one train with six units in series. Coarse bubble diffusers provide supplemental aeration to the RBC units. The SOR of the secondary clarifiers is 283 gpd/ft² at the permitted flow rate of 0.6 MGD, so the clarifiers have excellent capacity. Overflow from the clarifiers flows into two chlorination tanks with an HRT of 55 minutes at 0.6 MGD, and then to the dechlorination unit with an HRT of 16.6 minutes at 0.6 MGD.

Two alternatives are proposed for the implementation of BNR:

1. *Construct an AS basin with anoxic zones upstream of the RBC units and integrate the RBC system into the AS system:* Because nitrification occurs in the RBC units, a nitrate recycle system would be constructed to recycle nitrified RBC effluent to the unaerated zones of the AS system. Submersible mixers will be needed in the anoxic zones to prevent settling of mixed liquor suspended solids. The RAS line would recycle solids from the final clarifier to the anoxic zones. The anticipated effluent TN concentration would be 8 mg/L year round.
2. *Construct a denitrification filter downstream of the existing secondary clarifiers:* Both BOD removal and nitrification will take place in the RBCs, and denitrification will take place in the tertiary filters (e.g.: Tetra or Biofor filters). A methanol feed system

would be needed because the BOD would be consumed before the flow enters the tertiary filters. The anticipated effluent TN concentration will be 3 mg/L year round.

Capital costs for the two alternatives are \$1,320,000 and \$1,480,000, respectively. The capital cost for the denitrification filter includes concrete structure and manufacturers equipment. The estimated change in O&M costs are \$5,700 for the first alternative, and \$10,200 for the second for current flow conditions, with the difference attributable to the methanol feed. All costs presented are for denitrification, as the plant is already nitrifying. The cost per lb of additional nitrogen removed for alternatives 1 and 2 are \$4.96 and \$3.77, respectively. Thus, alternative 2 removes more nitrogen at a lower unit cost.

New York Reports

BINGHAMTON-JOHNSON CITY JOINT SEWAGE TREATMENT PLANT

The Binghamton-Johnson City Joint Sewage Treatment Plant (BJCJSTP) is an activated sludge facility that receives wastewater from the City of Binghamton, Village of Johnson City, Town of Vestal and a number of other smaller towns and villages along Susquehanna River. The plant has an effluent permit for 20 MGD of flow. However, the annual average flow has exceeded this level, and primary clarifier influent flow was measured to be close to 25 MGD.

The plant has a new permit specifying the BOD and TSS discharge levels to be 30 mg/L at 20 MGD. The permit also specifies a seasonal ammonia limit of 11 mg/L as a monthly average, effective between June and October. As the plant influent TKN fluctuates between 10 mg/L in wet weather and less than 20 mg/L in dry weather, the plant was able to maintain the effluent ammonia below 11 mg/L during most months without nitrification with a high rate AS process. However, the high rate process discharges a significant amount of N as soluble organic N.

After screening through coarse bar screens, Binghamton wastewaters constituting 85 % of the total flow mixes with Johnson City wastewaters in the grit chambers. The flow then passes through comminutors and the combined influent mixes with plant recycles, and then fed to primary clarifiers. The performance of the clarifiers is not known. 24-hour composite samples shall be used in determination of the clarifier effluent quality. The plant has six rectangular primary clarifiers with an overflow rate of 1,365 gpm/ft² at 25 MGD. Six parallel AS basins follow the clarifiers. The HRT is 2.5 hours at a combined influent flow of 25 MGD. Such a short retention time does not allow the plant to maintain sufficient biomass in the basins. Aeration is achieved with coarse bubble diffusers. As the plant operates one blower at a time, the quantity of the oxygen transferred with one blower may be a limiting factor in treatment. There are seven rectangular secondary clarifiers after the AS basins. At the design flow, the SOR of the clarifiers is 820 gpm/ft², which is substantially higher than what is acceptable for nitrification systems operating without polymer addition. It is suggested that the covers of the secondary clarifiers be removed for the operators to be able to visually monitor the performance. Secondary effluent is chlorinated in a contact tank.

The combined sludge is thickened in a covered gravity thickener. Thickened sludge with 3.5 to 5 % total solids content is pumped to three anaerobic digesters. At an sludge flow rate of 0.085 MGD, the HRT in the digesters is 15 days. Digested sludge is dewatered in three belt filter presses, one or two of them operating at a time. Sludge is composted with an in-vessel system. It is recommended that the capacity of the whole solids handling system be evaluated, especially considering the future changes in sludge volume.

Three alternatives were suggested for the implementation of BNR:

1. *Upgrade of existing AS system with moving bed of plastic media:* Hollow plastic cylinders with serrated surfaces have to be installed in the AS basin to support additional biomass in biofilms. Sufficient media will be installed to support all the nitrification in the biofilm. Each aeration tank will be modified to operate with 25% anoxic volume and media will be installed in both anoxic and aerobic zones. The system can be operated with or without RAS. Each aeration tank will be compartmentalized into four cells with mixers. Nitrate recycle would be required to be 100 % of influent flow.
2. *Construction of a parallel biological filter system with 12.5 MGD treatment capacity to operate in parallel with the existing AS system which would be modified for nitrogen removal to treat 12.5 MGD of flow:* Biofor system and Biostyr system can be used for the filters. Biofor would be designed with anoxic filters upstream of aerobic filters. Biostyr, on the other hand, incorporates the anoxic and aerobic media in one filter. The filters will have a recycle from the aerobic zone to the anoxic zone. Each aeration tank will also be modified to include 25 to 33 % anoxic volume. A nitrate recycle system should be installed in each tank.
3. *Replacement of entire AS system with a two stage biological filters/anoxic-aerobic biological filters for BOD and N removal:* Half of the secondary clarifiers can be used as additional primary treatment units, while the other half is demolished with the AS system.

The estimated capital costs of the three alternatives are \$13,057,000; \$17,541,000; and \$24,541,000, and the estimated annual change in the O&M costs are \$266,875; \$166,875; and \$226,046. The estimated costs of additional nitrogen removal are \$2.24 and \$2.62 per lb N removed, for Alternatives 1 and 2, respectively. It is recommended that Alternatives 1 and 2 be evaluated further. Alternative 2 may be the easiest to operate, provided that qualified instrumentation staff is available at the plant.

VILLAGE OF ENDICOTT WWTP

The Village of Endicott in Broome County, New York operates an 8 MGD trickling filter wastewater treatment plant which has difficulty meeting the permit limit of 30 mg/L for BOD and TSS in winter. A seasonal ammonia permit valid between June and October limits the ammonia-N loads to 830 lbs/day. The annual average daily flow was 7.39 MGD for the 1995-1996 period, and the average daily loads of influent BOD and primary effluent TKN were 6585 lbs/day and 1187 lbs/day, corresponding to 107 mg/L and 19 mg/L, respectively. Wastewater flows and loads are higher in winter, with peak hourly flows exceeding 30 MGD.

The WWTP site is bordered by a landfill on two sides, and on the other two sides by wetlands which restricts the any plant expansions to remain within the property limits. The raw influent is treated through: a barminuter, an aerated grit chamber, and two primary clarifiers. The primary effluent is then fed to two 120 ft diameter rock media trickling filters operated in parallel. The effluent from the filters is sent to a pump station from where it is pumped to two secondary clarifiers. Secondary effluent flows to a chlorine contact tank from where it is discharged to Susquehanna River. The primary and secondary sludges are anaerobically digested and composted. At present, the trickling filters do not nitrify.

Three options were recommended for the implementation of BNR:

1. Modify the existing trickling filters with plastic media to increase the height to 18 ft. Then load the process with 50% of the primary effluent to allow year round nitrification. Install an AS/solids contact basin with sufficient anoxic volume (40% of the total volume) for denitrification, using the remaining 50% of the primary effluent as the organic carbon source. The aerobic volume could be used for nitrification of the ammonium-N present in the trickling filter effluent and in the primary effluent. Upgrade the secondary clarifiers by the addition of three new clarifiers to accommodate operation in this mode. A nitrate recycle is not required to maintain an effluent NO_x of 6 mg/L.
2. Retain the rock media and feed 50% of the primary effluent just for BOD removal. Install an anoxic-aerobic AS basin to treat a mixture of primary effluent and trickling filter effluent, and achieve nitrification and denitrification. Feed at least 50% of primary effluent to the AS basins to supply the organic carbon required for denitrification in the anoxic zone of the AS basin. Upgrade the secondary clarifier capacity to accommodate this operation. A nitrate recycle with a maximum capacity of 250% of the influent flow is necessary.

If the existing two shallow clarifiers are demolished, the space can be used for the new AS basins and for four new secondary clarifiers for the Options 1 and 2.

3. Install an anoxic-aerobic biofilter system downstream of the trickling filters. Operate the biofilters with 50 to 100% of the primary effluent, nitrify in the aerobic filter and recycle the nitrates to the anoxic filter upstream for denitrification. The effluent from the aerobic biofilter is to be discharged to the chlorine contact tank. An anoxic and aerobic filter sequence can be designed with Biofor expanded shale media or Biostyr polystyrene media. The maximum nitrate recycle rate required will be 2.2 Q. It is recommended that four Biostyr filters be installed and operated in parallel. This alternative does not use the trickling filter or the secondary clarifiers. However, it is possible to benefit by reducing some of the primary effluent BOD with the trickling filters.

Option 1 has the highest cost, \$10,032,000; Option 2 has the lowest cost as it does not include any modifications to the trickling filters, \$6,656,000. If the demolition of the existing clarifiers is to be included the additional cost will be \$1,300,000. Option 3 will cost \$8,004,000. The estimated changes in the O&M costs are \$168,381; \$124,003; and \$115,863 for the Options 1, 2 and 3. The total cost of additional N removal is \$3.35 per lb of N removed for Option 2. If Option 2 is implemented with new clarifiers, the cost will increase to \$3.86. The total cost of additional N removal is \$3.83 per lb of N removed for Option 3.

Pennsylvania Reports

ALTOONA CITY AUTHORITY EASTERLY PLANT

The Altoona Easterly WWTP is an activated sludge facility designed for an annual average flow of 9 MGD. The plant services the eastern sections of the City of Altoona and discharges to a tributary of the Susquehanna River.

The discharge permit sets the effluent $\text{NH}_4\text{-N}$ at 2.5 mg/L from May 1st to October 31st, and at 4.0 mg/L for the rest of the year. The plant has to and does nitrify year round to meet the monthly average limits for $\text{NH}_4\text{-N}$. The layout of the facility is amenable for implementation of nitrogen removal to achieve a TN value of 8 to 10 mg/L N.

The average flow for the July 1996 to June 1997 period was 6.7 MGD. Average raw influent BOD_5 was 77 mg/L, which is fairly dilute, indicating the presence of significant infiltration/inflow effects. It was assumed that the raw influent TKN was 20% of the raw influent BOD_5 , as the plant does not have any data on influent TKN values. An increase proportional to the increase in flow was assumed to take place for COD and TKN levels.

Preliminary treatment units consist of two mechanically cleaned screens, and two aerated flow holding tanks. The activated sludge system, on the other hand, consists of two separate trains of four basins each, which can be operated either in parallel or in series. Each cell is aerated with Sanitaire ceramic plate diffusers. The first cell has the highest density of diffusers. Foam entrapment occurs in the Easterly plant because of the configuration of the basins. There is an imbalance in flow distribution from the center channel to the aeration cells. Thus, it was recommended that one of the three influent gates be closed or the two flow trains be operated in series.

Mixed liquor leaving the aeration tanks flows to secondary clarifiers, each with a SOR of 346 gpd/ft² with all three units in service. The RAS drains into a common wet well and the plant does not have independent control of RAS withdrawal rate from each clarifier. WAS also is pumped out of the RAS wet well. Disinfection of the treated water is achieved by two Katadyn UV units. WAS is pumped to an Eimco gravity belt thickener, from where the RAS is discharged at 3 to 4 % TSS to two aerobic digesters, which are operated in series. Sludge from the digesters is dewatered using an Eimco belt filter press.

For the BNR modification assessment, TKN was assumed to be $20 \pm 2.5\%$ of the influent BOD_5 concentration. According to the calculations, at a ten day MCRT with maximum month COD loads in summer, the MLSS would be 2200 mg/L, and it would increase to 2500 mg/L if one of the eight activated sludge cells were taken out of service. The former value would be 3000 mg/L for the corresponding COD loads in winter at 15 day MCRT. For both conditions, 75 % of the activated sludge tank volume would be operated under aerobic conditions. The first cell of each train will be operated anoxically with mixers installed to minimize settling. The density of the diffusers in the first aerobic

cell should be increased to have 33% more aeration capacity. The automated DO control system also would be upgraded and put in service.

Nitrate recycle pumps, designed for a maximum flow rate of 1.5 times the influent flow of 9.0 MGD should be installed in the last aerobic cell of each train. It is recommended that the plant be operated at a RAS flow rate of 75 to 100 % of the influent flow, and a chlorination system be used to maintain SVIs below 175 mL/g. The modifications also should consider the prevention of foam entrapment in the activated sludge basins.

The capital costs of the suggested modifications at an average daily flow of 9.0 MGD total \$1,230,452. The change in operating costs following conversion will be small at \$1,733 per year. Although there will be energy savings from a decrease in aeration requirements, they will be offset by the energy cost of the mixers in the anoxic zones. The estimated cost per pound of additional nitrogen removed over a 20 year period is \$0.51 per lb N.

ALTOONA CITY AUTHORITY WESTERLY PLANT

The Altoona City Westerly WWTP is an activated sludge plant that went online in 1991 with a design flow of 9 MGD, and it services the western sections of the City of Altoona and the Alleghany Township. It discharges to the Beaverdam Branch of Juniata River, a tributary of the Susquehanna River. According to the discharge permit, the plant has to nitrify on a year round basis to meet average limits for ammonium-N of 2.5 mg/L from May 1st to October 31st, and 4.0 mg/L for the rest of the year. The plant has nitrified since start-up, and the layout is amenable for nitrogen removal. Because of high infiltration/inflow rates from combined sewers in old sections of Altoona, the target average effluent TN will be 8 to 10 mg/L on an annual basis.

The average flow for the June 1996-June 1997 period was 9.1 MGD, which is almost the design value set for the plant. The average raw influent BOD₅ of 92mg/L is indicative of a very dilute influent and also indicates the presence of excessive infiltration/inflow. The plant does not have any data on raw influent TKN. For this reason, it was assumed that the raw influent TKN was 20 % of the raw BOD₅, yielding an average value of 18.3 mg/L. The final effluent data shows that the plant completely nitrifies as the average NH₄-N concentration was 0.24 mg/L. The average final effluent total nitrogen value was 13.8 mg/L for the 1996-1997 period.

The raw influent is first screened by two Envirex mechanically cleaned bar screens with 1 inch openings and then passes through three aerated grit chambers. The wastewater is then sent to the activated sludge basin through an aerated channel. During high flow conditions, 2.5 MG aerated holding tanks and the primary clarifiers and activated sludge tanks of the old plant are used for holding, and the maximum instantaneous flow is limited to 20 MGD (13,890 gpm). Secondary treatment has two trains of four cells each. These cells with a nominal HRT of 9 hours can be operated in parallel or in series. Each cell is aerated with Sanitaire ceramic plate diffusers, and each cell has installed DO probes. The configuration of the plant has caused *Nocardia* problems (foaming) from time to time. There are three secondary clarifiers, with a combined SOR of 315 gpd/ft² at 9 MGD. The plant does not have independent control of the RAS withdrawal rate from each clarifier as the RAS drains into a common wet well. The RAS flow is typically set at 100% of the influent flow. The WAS is removed from the RAS wet well by six pumps. The secondary effluent is disinfected by two Katadyn UV units, each unit rated at 10 MGD. Waste sludge is pumped to a Komline Sanderson gravity belt thickener that is operated 24 hours per day. Thickened sludge is discharged at 3 to 4 % TSS to two aerobic digesters. Sludge from the digester is sent to a Komline Sanderson press and the dewatered sludge is stored in a covered area and land applied.

The desired effluent TN was set at 7 to 9 mg/L for the BNR implementation analysis and the effluent NO₃ was set at 5 to 7 mg/L, on an annual basis. To achieve these values, an anoxic zone will be created in the first cell of each flow train with mixers installed, and 75% of the activated sludge tank volume will be operated under aerobic conditions. The ceramic diffuser caps should be replaced with membrane disks. One downcomer should

be installed to feed the diffusers in each anoxic cell. The density of the diffusers in the first aerobic cell should be increased to be 33% greater than the average density. The automated DO control system should be put back into service.

Nitrate recycle pumps, designed for a maximum flow rate of 1.5 times the influent flow of 13.5 MGD, should be installed in the last aerobic cell of each train. It is recommended that the plant be operated at a RAS flow rate of 75 to 100 %, and a chlorination system be used to maintain SVIs below 150 mL/g. The modifications also should consider the prevention of foam entrapment in the activated sludge basins.

The capital costs of the suggested modifications for the flow of 13.5 MGD total \$1,232,956. The change in operating costs following conversion will be small; \$1,733 per year. Although there will be energy savings in the aeration requirements, they will be offset by the energy cost of the mixers in the anoxic zones. The estimated cost per pound of additional nitrogen removed amortized over a 20 year period is \$0.42 per lb N.

CHAMBERSBURG WWTP

The Chambersburg WWTP is a three stage trickling filter plant designed to treat an average flow of 4.5 MGD with both BOD/COD removal and nitrification. The wastewater is domestic sewage with a substantial amount of flow from food processing industries.

The treatment train includes flow equalization, grit removal, primary clarifiers, two rock media trickling filters in series, secondary clarifiers, nitrification filters with plastic media, final clarifiers, tertiary filters, and chlorination.

The BNR evaluation considered two options:

1. *Trickling filters for BOD removal and nitrification, followed by denitrification filters using methanol:* In order to increase the capacity from 4.5 to 6.8 MGD, it is recommended that the rock media in the primary filters be replaced with plastic media. Also, a forced draft aeration system should be constructed to improve DO levels at the surface of the biofilm. The secondary filters used for nitrification should have sufficient surface area for reliable performance. The ammonium-N concentration average would vary between 1 and 5 mg/L in winter. A third and larger secondary clarifier should be constructed. An additional effluent sand filter would be installed in parallel to the first effluent filter. Methanol would be added to the influent to the filters. This would help develop a biofilm for denitrification on the deep bed filters. The effluent TN would be reduced from 15 mg/L to 4 mg/L. The nitrogen removal for each year was calculated for denitrification of an additional 11 mg/L of nitrogen at the flow projected for that year.
2. *An AS system for BOD removal, nitrification and denitrification:* The AS system would replace the primary filters, secondary filters, final clarifiers, and tertiary filters. Two examples of several possible AS configurations are MLE and oxidation ditch systems. Based on site constraints, a MLE process with an HRT of 12 hours is recommended. Use of membrane diffusers is recommended over surface aerators to reduce the long term operating cost. One or two additional secondary clarifiers would have to be constructed at a recommended SOR of 400 gpd/ft² at average flow.

The capital costs of implementing Option 1 would be \$6,347,250 in 1995 dollars, with an increase in annual operating costs of \$129,096. The cost per lb of additional N removed is estimated to be \$2.69. For Option 2, the capital costs are estimated as \$8,060,000 and the total incremental annual operating costs as \$137,660. For this option, the cost per lb of additional N removed would be \$4.55.

GREATER HAZLETON JOINT SEWER AUTHORITY WWTP

The Greater Hazleton WWTP is an activated sludge plant located in Luzerne County, Pennsylvania. The plant is adjacent to an industrial park and receives a combination of municipal and industrial wastes (18%). It is rated for an average flow of 8.9 MGD and a maximum flow of 14.6 MGD. Flows above 14.6 MGD can be bypassed. Currently, the flows vary from 5.0 MGD during a dry month to an excess of 9.0 MGD during a wet month. The plant discharges to Black Creek, which is a tributary of the Susquehanna River. Because of two textile plants that do not pre-treat their dye wastewaters, the influent to the plant is colored, and it causes Black Creek to be colored and the aquatic life to be in a sharp decline downstream of the discharge point. The facility has not nitrified even though the MCRTs has been increased above 5 days during warm weather. This may be because of a lack of adequate AS tank volume and/or some possible inhibition from the industrial wastewaters. However, as of June 1996, most of the industries had implemented pre-treatment systems. The only major dischargers yet to implement pretreatment were the textile plants.

Ammonium-N or TKN are not among the routinely measured parameters like BOD₅ and TSS. The only final effluent nitrogen species concentrations available were from the Chesapeake Bay Nutrient Sampling Program for the year 1994. Those data indicated that the plant accomplished limited nitrification from July to October 1994, as the effluent ammonium-N concentrations ranged between 9 and 10 mg/L for flows between 5 to 8 MGD. Maximum effluent NO_x was 3.6 mg/L, with an average TN value of 16 mg/L at an average flow of 6.2 MGD.

The raw municipal wastewater is pre-screened by a coarse manual bar screen, and sent to a rectangular aerated grit chamber. Then the industrial wastewaters combine with the pre-treated municipal wastewater, and pass through a second coarse screen before entering a building where it is screened with two mechanically cleaned Dorr Oliver screens. The flow passes through a Parshall flume and enters a chamber with three sluice gates, two of which divert the flow to two primary clarifiers that have SORs of 1007 gpd/ft² at 8.9 MGD. Primary effluent is then pumped to two trickling filters, which can be bypassed if necessary. The effluent from the filters enters a distribution box with automated valves that can bypass flows above 9.4 MGD. BOD₅ removal in the trickling filters reduces the primary effluent BOD₅ to 90 mg/L from 110 mg/L. Two rectangular AS basins, with nominal hydraulic retention times of 2 hours at 8.9 MGD follow the filters. Each basin can be step fed through four gates spaced 30 ft apart. Basins are aerated with ceramic fine bubble diffusers arranged such that there is a decrease in density from the front end to the downstream end. The effluent from the two activated sludge basins enters a box with four telescopic valves that distribute the flow to four secondary clarifiers. The SOR is 550 gpd/ft² at design flow. The plant does not have separate piping from each clarifier to adequately control RAS flow rates. As a result, one of the clarifiers has a tendency to accumulate sludge. Secondary effluent is then chlorinated in two contact tanks with HRTs of 34 minutes at design flow.

RAS pumps withdraw sludge from a central collection box. At an average flow rate of 5 MGD, RAS averages 35 %. It decreases to 25 % when flow increases to 8.9 MGD in a wet month.

The WWTP does not have adequate AS tank volume and secondary clarifier capacity for nitrification. Thus, any upgrade for BNR will have to provide the capacity for nitrification and denitrification. A nitrification rate test should be conducted to see whether one or more of the industrial wastes are inhibitory. Should the magnitude of inhibition be such that it results in a substantial increase in volume requirements, the compounds causing the inhibition will have to be removed by pre-treatment.

There are two options for enhancing the secondary treatment system:

1. *Addition of extra AS volume and clarifiers:* It may be difficult to implement this option because of space limitations. The existing basins would be modified to an anoxic-aerobic configuration for denitrification, with nitrate recycle. The HRT of the existing basins would be 5 hours. Two new AS tanks with a HRT of 6.5 hours would have to be constructed, also in an anoxic-aerobic configuration. A circular clarifier with a diameter of 75 ft or a rectangular clarifier with a surface area of 4500 ft² would be added. These additions would require construction of a flow distribution structure. A new RAS pump station is also proposed. The aeration system would have to be upgraded to service the new basins.
2. *Addition of biofilters:* A Biostyr aerated filter, or equivalent, arranged in an anoxic-aerobic configuration could be added. Nitrification rate will determine the size of the filter. With the small footprint of the filters, this option would not cause any space problems. The effluent from the filter would have a TSS of 10 to 15 mg/L, eliminating the need for new clarifiers. The existing RAS system would not be modified. Existing secondary clarifiers would be treating only 3.4 MGD, which would reduce the SOR below 200 gpd/ft².

The capital and annual O&M costs for modifying the existing AS basins and adding the Biostyr system are \$7.84 M and \$130 K, respectively. The annual operating costs are for 8.9 MGD. The cost per lb of N removed was calculated from the Net Present Value of annual costs, and was found to be \$3.24.

HANOVER AREA REGIONAL WWTP

The Hanover Area Regional WWTP services Penn Township, most of the Borough of Hanover, all of the Borough of McSherrystown and all of Conewago Township. The facility is an oxidation ditch activated sludge plant that is permitted to treat a maximum monthly average flow of 5.5 MGD, and discharge to the South Branch of Conewago Creek. The permit limits are based on an average daily flow of 4.5 MGD. The plant has a monthly average ammonium-N permit of 1.5 mg/L from May 1st to October 31st, and 4.5 mg/L for the rest of the year. Thus, the plant has to nitrify year round. The corresponding CBOD permits are 15 and 25 mg/L, respectively.

The raw influent and primary effluent flows and loads were analyzed for the year 1995, during which the average flow was 3.46 MGD and the average raw influent BOD₅ was 201 mg/L. The estimated contribution of industries to the organic load was 40 %. The ammonium-N levels in the primary clarifier effluent averaged 24 mg/L, 20 to 30 % of which possibly was from the recycles (digester supernatant and belt filtrate). MCRTs were maintained between 9 and 14 days. Effluent ammonium-N averaged less than 1 mg/L for 1995, and the effluent TN averaged 19.7 mg/L for the same period. Mass balances were performed on the nitrogen species for different conditions in the oxidation ditches. It was found that partial denitrification was taking place in the ditches.

Raw influent is screened by an automatic bar screen with 1 inch openings. Wastewater then flows through a Parshall flume into a wet well. Recycles from solids dewatering and filter backwash are also brought into the same well. Influent is then pumped into a grit chamber. There are two primary clarifiers following grit removal, with SORs of 630 gpd/ft² at a flow rate of 4.2 MGD. A flow distribution box is used to distribute the raw influent between the two clarifiers. The plant has two oxidation ditches, each with two passes. The average length of liquid flow path is 487 ft. Operating volume of each ditch is 1.43 MG. Aeration is achieved by brush aerators with variable submergence. Two secondary clarifiers with SORs of 475 gpd/ft² at a flow rate of 4.2 MGD follow the ditches. Secondary effluent is filtered, then chlorinated and aerated prior to discharge into a 7000 ft long outfall pipe.

The primary sludge is pumped directly to the anaerobic digesters, and the WAS is thickened in two DAF thickeners to 4 % solids and pumped into the digesters. The primary digester has a fixed cover, and the secondary digester has a floating top. Digested sludge is dewatered by two presses of different sizes.

The following options were considered for the implementation of BNR:

1. Continuous aeration with three or four brush aerators while adjusting the water level in the oxidation ditches with a moveable effluent weir to create anoxic conditions over a section of the ditch;
2. Cycling brush aerators on and off to create anoxic and aerobic conditions at different times;

3. A combination of 1 and 2 to allow mixing and aeration with variable DO levels at different times, resulting in anoxic and aerobic zoning.

One concern about the first option is that the DO levels may not decrease rapidly enough and may cause low DO filamentous organisms to grow. Considering the length of the liquid path the wastewater will follow, it is possible that the time is not sufficient to insure a substantial drop in DO levels. Operation with one or two aerators may be feasible to allow an adequate DO drop. However, this alternative is not recommended.

In cyclic mode of operation all four brush aerators can be cycled. During off-cycle, DO is allowed to drop throughout the ditch to create anoxic conditions for denitrification. Off cycles shall be short enough to prevent settling. During the on cycle all four brushes will be turned on at high speed to aerate the ditch. The durations of the on and off cycles can be adjusted based on effluent ammonium-N and NO_x levels. According to the calculations, the aerators can be turned off 30 to 50 % of the time, and still achieve complete nitrification.

The third option allows the operator to run one brush aerator continuously while others are cycled off in a staggered pattern. The on and off times can be controlled by a Programmable Logic Controller or individual electronic timers.

Both options 2 and 3 are viable if filamentous bacteria growth at low DO is inhibited by high DO during aerobic periods. Automated DO control is not recommended in any option unless DO levels are used to cycle the brush aerators on and off. A DO control system can be used to control the levels of the weirs. The weir level would be adjusted when the on times or off times exceed preset maximum values.

The capital cost for using a logic controller, installing DO probes and automated liquid level adjustment is estimated to be \$250,000. The annual savings in the operation of the plant would be \$16,227 because of reduced aeration requirements. The plant has sufficient alkalinity to nitrify without the aid of alkalinity recovery from denitrification. The effluent TN would be reduced from 19.7 mg/L to 6 mg/L. The cost per pound of additional N removed over a 20-year period is estimated to be \$0.08 based on 1996 dollars.

HARRISBURG WWTP

The Harrisburg WWTP is a pure oxygen activated sludge plant designed for a flow rate of 30 MGD, located on a compact site adjacent to the Susquehanna River. Nitrification is not achieved any time of the year, with effluent unoxidized nitrogen levels averaging between 17 and 22 mg/L during dry weather. P is removed chemically with ferric chloride addition to the primary clarifier effluent to meet a permit limit of 2 mg/L for TP.

Raw wastewater enters the plant through grit chambers, then flows to four flocculation chambers upstream of the rectangular primary clarifiers, which SORs of 975 gpd/ft² at an average daily flow rate of 30 MGD. Primary effluent is pumped to a distribution box which feeds three parallel AS basins. At design flow, the nominal HRT is only 2.5 hours. The mixed liquor from the AS basins flows through a second set of flocculating chambers to secondary clarifiers with SORs of 610 gpd/ft² at the design flow of 30 MGD. The secondary effluent is disinfected in two chlorine contact tanks prior to discharge to the Susquehanna River. The AS basins are aerated with pure oxygen, but the installed automated DO control probes are not currently being used. Primary and secondary sludges are thickened in gravity thickeners and sent to two heated primary anaerobic digesters. The primary digesters are followed by two secondary digesters.

Considering the low MCRTs used at the plant (2 to 3 days), the mix of industrial and municipal wastes received in the influent, and DO levels less than 2 mg/L in the first cell of each AS basin, it is not surprising that the plant does not nitrify. The final effluent TKN typically ranges between 18 and 21 mg/L during dry weather flow. The available space limits the alternatives for the implementation of BNR to two:

1. The flow through the pure oxygen basins would have to be reduced to 12 MGD. These trains would be operated in the MLE configuration for nitrogen removal at a design HRT of 6.25 hours. A parallel 18MGD Biostyr train would be constructed for nitrogen removal. Primary effluent organic carbon would be used for denitrification. This alternative could produce a year round effluent quality of 8 to 10 mg/L TN.
2. The pure oxygen system would continue to be operated as a high rate system without nitrification as designed at present. Aerated biological filters like Biostyr, Biofor, or Safe would be added for nitrification. These would be followed by denitrification in fluidized bed filters or additional Biostyr filters. The cost estimates are based on using fluidized bed filters. This alternative uses methanol for denitrification and it can meet an effluent TN of 3 to 5 mg/L on a year round basis.

The capital and operating costs for the two alternatives are similar. For Alternative 1, these costs are \$27,637,740 and \$499,772, respectively, and the cost of additional N removal is \$2.19. For alternative 2, capital and operating costs are \$25,447,500 and \$1,182,222, respectively, and the cost of additional N removal is \$2.00 per lb N removed.

LANCASTER WWTP

The Lancaster WWTP is an activated sludge plant that is rated at a capacity of 29.7 MGD, and it is required to nitrify to satisfy an effluent permit of 2.5 mg/L ammonium-N from May 1st to October 31st, and a winter permit of 7.5 mg/L. The newer section of the plant treats a flow that averages 20.7 MGD. It has four anaerobic-oxic pure oxygen trains followed by three circular clarifiers, each with a diameter of 150 ft, whereas the older section treats 9 MGD and has three anaerobic-oxic pure oxygen trains followed by two circular clarifiers each with a diameter of 100 ft. The secondary effluents from the two systems combine immediately prior to the chlorine contact tanks.

In older trains, the ratio of the anaerobic volume to the total reactor volume is 14.5 %, which is adequate for biological P removal. However, it is on the low side for conversion to an anoxic zone for biological nitrogen removal except in instances where the primary effluent has substantial concentrations of readily biodegradable organic carbon for rapid denitrification. The average primary effluent TKN is possibly between 17 and 22 mg/L. On dry days (20 to 23 MGD), effluent NO_x has ranged between 7 and 10 mg/L. Thus, it is possible that denitrification occurs in the anaerobic cells with nitrates recycled via RAS, and in the third cell of the aerobic zone which has low DO levels. It should be possible to achieve nitrification and denitrification with nitrate recycle. To overcome the lack of sufficient organic carbon in the third aerobic cell, step feeding can be practiced. The secondary clarifiers have an SOR of 575 gpd/ft² at 9 MGD, which is somewhat high for a BNR plant. Precautions shall be taken to maintain an SVI less than 85 mL/g.

There are four new trains that have anaerobic cells which occupy 16.5% of the total volume of the AS basins. This percentage is also on the low side for operation as an anoxic zone. Twenty (20) to 30 % of the dry weather primary effluent flow should continue to be step fed to the third aerobic cell. The three secondary clarifiers have SORs of 390 gpd/ft² at 20.7 MGD, and they have adequate capacity at design flow for SVIs up to 150 mL/g.

Ferric chloride can be used for chemical P removal as it produces the least amount of solids when compared with alum and lime. Experience with BNR facilities shows that the dose of ferric chloride required for satisfying an effluent TP permit can be less than 20 gallons per MGD of wastewater treated.

Three options for implementing BNR are proposed:

1. Fluidized bed or static bed upflow/downflow denitrification filters;
2. Conversion of anaerobic zones to anoxic zones with additional modifications in the reactor and implementation of chemical P removal;
3. Conversion of reactors to incorporate anaerobic, anoxic and aerobic zones for biological N and excess P removal.

The cost of biological nitrogen removal with chemical P removal without step feed (Option 2) is the lowest of the options evaluated. Without step feed, the capital costs would be \$1,077,180, and with step feed it will be \$2,381,054. The predicted annual change in operating costs is \$20,944 for both feeding configurations. The cost per lb of additional N removed is estimated as \$0.190 without step feed, and \$0.373 with step feed.

Capital costs for implementing biological nitrogen removal with excess P removal within the available reactor volume (Option 3) are \$2,884,630 and \$3,762,304 for without and with step feed to the third aerobic cell. The annual change in operating costs is projected to be \$40,669 for both feeding configurations. The cost per lb of additional N removed is \$0.331 without step feed, and \$0.455 with step feed.

CITY OF LEBANON WWTP

The City of Lebanon WWTP is an activated sludge plant that serves seven municipalities in the Lebanon area of central Pennsylvania. These include the City of Lebanon, Cleona and Cornwall Boroughs, North Cornwall, North Lebanon, South Lebanon and West Lebanon Townships. The plant is rated for a capacity of 8 MGD, and it has to nitrify all year round because it discharges to Quittapahilla Creek, which is in the Susquehanna River watershed. The permitted effluent ammonium-N is 2.5 mg/L for summer and 7.5 mg/L for winter. The TP limit is 2 mg/L. The uniqueness of the Lebanon WWTP comes from its configuration: primary effluent is pretreated in 21.5 ft tall trickling filters with vinyl core plastic media. Then the effluent is treated in four AS tanks for nitrification. Phosphorus is removed chemically with waste pickle liquor.

The wastewater flows through an aerated grit chamber where lime is added to supplement alkalinity. It then flows through a coarse bar screen for rag removal and through a Parshall flume for the measurement of the flow rate. Following this, the flow is valved to a rapid mix basin and flocculation tank. Waste pickle liquor is added to the rapid mix basin for chemical P removal. Two primary clarifiers with an SOR of 800 gpd/ft² follow P removal. The clarifiers are shallower than depths used in current design practice. Addition of lime, waste pickle liquor and a polymer enhances the BOD₅ and solids removal across the clarifiers. Primary sludge is withdrawn at an average solids content of 3% and it is fed to an anaerobic digester. Primary effluent is pumped up to two trickling filters, each with a diameter of 39.5 ft and a media depth of 21.5 ft. A minimum flow rate of 3000 gpm is maintained through the filters. Four rectangular AS basins follow the trickling filters with a hydraulic retention time of 5.0 hours at 8 MGD. Each basin is aerated with five 25 HP vertical turbine aerators, and the DO levels are maintained in a range between 2 and 4 mg/l. The plant has two old, shallower (8ft) clarifiers and two new, deeper clarifiers (12ft). The plant has four effluent filters to which the secondary effluent is pumped. Currently, the filters are operated as single media anthracite coal filters. The filters are not kept in service during normal operation, and they are put into service for only a few days each year to be tested.

All four clarifiers drain to a common return sludge well. The plant has difficulty maintaining satisfactory control over RAS withdrawal rate from individual clarifiers because of the lack of independent sludge pumping from each clarifier. WAS is discharged to primary clarifiers where it is co-thickened. Primary sludge is then pumped to a primary digester where the storage time is 30 to 60 days. The sludge is then dewatered with an Envirodyne filter press and land applied. Digester supernatant and filtrate from the belt filter press are recycled to headworks.

Data from 1995 were evaluated for this study. The plant operates the AS basins at MCRTs of 6 days in summer and 15 days in winter. The operating MLSS increased from 2000 mg/l in summer with all basins in service to 4000 mg/L in winter. The monthly average of raw influent and primary effluent BOD₅ were 310 and 197 mg/L respectively. These numbers are higher than typical values because the influent includes industrial

wastewaters as well. The data shows that a substantial reduction in BOD and COD loading to AS basins can be achieved if intermediate clarifiers are installed between the trickling filter and the AS basins. Overall, the percent reduction in COD in the primary clarifiers and trickling filters increases from 46 % to 71 %. The COD available in the trickling filter effluent will limit the quantity of nitrates that can be denitrified in the anoxic zones.

Final effluent ammonium-N concentrations show that the plant is capable of maintaining complete nitrification all year round at the present flows of 5.7 MGD. A mass balance for nitrogen indicates that 20 to 25 % of the primary effluent TKN is removed in the WAS and trickling filter waste solids. If there were no denitrification, complete nitrification would result in an effluent NO_x of 16.4 mg/L and TN of 18.3 mg/L. The accuracy of the mass balance is confirmed by the TN concentration of 18.5 mg/L calculated for 5.7 MGD of flow.

To improve denitrification it will be necessary to bypass a certain amount of primary effluent feed directly to the AS basins. The organic load will increase the secondary sludge and it will be limited by the AS tank volume. The mixture of 10% primary effluent and 90% trickling filter effluent should contain at least 20 mg/L of additional biodegradable COD for denitrification, which will help denitrify an additional 4 to 5 mg/L of NO_x. Trickling filter effluent COD will increase from 129 mg/L to 175 mg/L as a result of the bypass.

For BNR implementation three options were considered:

1. *An anoxic-aerobic configuration within the existing AS basins with primary effluent bypass around the trickling filters, to remove an additional 7 mg/L of nitrogen and to achieve a TN level of 11 mg/L on an annual average.* The dedicated aerobic zone will occupy 60% of the tank volume, and nitrates will be recycled from the end of the aerobic zone to the anoxic zone. Nitrate recycle could be eliminated by increasing the RAS flow to 70% of the influent flow. The Recommended MCRT is 8 days in summer and a maximum of 16 days in winter. The MLSS is expected to be 3800 mg/L at an MCRT of 16 days.
2. *An anoxic-aerobic configuration with the addition of a fifth AS basin in parallel to the existing four and with a 20 to 25 % bypass, to yield an effluent TN of 8.5 mg/L.* The configuration of the fifth basin will be similar to that of Option 1, but the increased bypass will bring in additional organic carbon that would increase the quantity of denitrification. The capacity of the nitrate recycle pumps will, therefore, be increased from 40% to 200%.
3. *Addition of a denitrification filter, preferably in addition to the modifications of Option 1, to denitrify 14 mg/L of nitrates:* This option will allow denitrification to yield an effluent NO_x concentration of about 2 mg/L. Existing filters can be modified with methanol addition, but it needs to be examined in a pilot study.

The capital costs of the three options in the order of 1, 2 and 3 are as follows: \$1,251,600; \$3,501,600; and \$5,501,600. There is a wide gap between the changes in the annual operating costs with nitrification and denitrification of the three options: \$153; \$15,837; and \$64,927. Option 2 and 3 has the mixing requirement, which is estimated to cost about \$20,000 and Option three has the cost of methanol addition to the filters of \$49,090. Finally, the cost per additional nitrogen removal for Options 1, 2 and 3 are \$0.61, \$1.19, and \$1.39, respectively. The costs and the amount of nitrogen removed are in an increasing order, the lowest being Option 1.

SCRANTON SEWER AUTHORITY WWTP

The Scranton Sewer Authority WWTP is an activated sludge facility that services the population of both Scranton and Dunmore in North East Pennsylvania, and discharges to the Lackawanna River, a tributary of the Susquehanna River. The plant was permitted to treat a flow of 20 MGD. In 1995, the annual average primary effluent flow was 13.8 MGD, including 1 MGD of recycle flow. The average raw wastewater flow was 12.9 MGD. The BNR study was based on an annual average flow of 16 MGD, with a maximum month flow of 20 MGD.

TKN has not been among the parameters measured at the plant, and therefore it was assumed to be 1/5.5 of the BOD₅ concentration (110 mg/L) in the primary effluent, for an average TKN concentration of 20 mg/L. According to the effluent data, the plant nitrified all year round. Effluent NO_x concentrations were measured by Hach colorimetric method and they averaged just below 7.0 mg/L in November and December of 1995. For comparison, NO_x measured at other plants by the Cadmium reduction column method and Hach kit showed that the Hach kit yields 20 to 40 % lower results. Chesapeake Bay Nutrient Sampling Data showed an effluent TN of 9.9 to 11.9 mg/L at 12.3 to 14 MGD.

The plant has two Parkson Aquaguard screens with 3/4 inch mesh, and two rectangular non-aerated grit chambers. There are four rectangular primary clarifiers with SORs of 819 gpd/ft² at 16 MGD. The primary effluent flow rate is monitored by a flow meter in the channel connecting each clarifier to an activated sludge basin. Each AS basin is divided into two separate passes operating in parallel, each with five downcomers from a 650 tubular membrane diffuser system. Based on a primary effluent flow rate of 16 MGD, the nominal HRT is 9.83 hours. Each basin has the flexibility to be step fed, with primary effluent introduced at ten locations. The RAS is also fed to the front end of the basin. Operation at a RAS flow of 8 MGD results in a substantial recycle of NO_x to the first third of the basin. The plug flow configuration encourages denitrification of some of the recycled nitrates. Overall, the existing arrangement can denitrify 25 % of the nitrates generated. The four rectangular secondary clarifiers that follow the four AS basins have SORs of 490 gpd/ft² at 16 MGD. The plant uses a Stranco ORP meter to control the chlorine dose for disinfection. For sludge thickening, two DAF units are used, and filter presses are used for further dewatering. Lime is added to dewatered sludge to stabilize it, and the sludge is then landfilled.

Nitrogen mass balance evaluation based on a primary effluent TKN of 20 mg/L shows that as much as 14 mg/L of NO_x can be generated through nitrification. After denitrification of 25 % of the generated NO_x, the average effluent NO_x concentration will be 10.5 mg/L. To overcome possible *Nocardia* problems, the plant has installed an RAS chlorination system that is used at high SVIs. Magnesium hydroxide slurry is used to supplement alkalinity.

The Scranton WWTP is an excellent candidate for BNR, as the plug flow nature of the AS basins allows nitrogen removal to be implemented using the MLE configuration.

According to the plant data, effluent temperature averaged 8°C in January. Therefore BNR evaluations were performed for an MLE configuration and water temperatures of 8 to 23°C. The operating MCRT required for nitrogen removal varied from 7 days in summer to 12 days in winter. The maximum predicted MLSS was 2750 mg/L in winter. An annual average effluent TN value of 6 mg/L can be maintained with MLE configuration which represents a reduction of 5 mg/L in the TN from the present average of 11 mg/L. TN levels of 7 mg/L and lower are expected at temperatures lower than 10°C. The anoxic volume used in the calculations was 30 % of the AS tank volume. A nitrate recycle rate of 100 % was selected for design purposes. The nitrate recycle pumps should be connected to variable frequency drives which can vary the flow rate from 40 to 100 % of the influent flow. Each anoxic section would be mixed with submerged mixers. Nitrogen removal for flows up to the existing capacity of 20 MGD also is feasible with the existing volume of the AS tanks and clarifiers with the use of Integrated Fixed Film Activated Sludge (IFAS) process. The cost of implementing an IFAS process with sponge media would be about \$3.0 Million.

As a result of denitrification, the cost of aeration is expected to decrease by 15 to 20 %. This will result in 100 HP less power draw by the blowers. However, the operation of 12 mixers and nitrate recycle pumps will result in an additional power requirement of 96 HP. Therefore, the aeration savings will be almost negated by the increase in power requirement for mixers and nitrate recycle pumps. The plant also will realize an alkalinity recovery as a result of denitrification, which will reduce or eliminate the need for magnesium hydroxide addition.

The capital costs for modification of eight passes in four tanks to the MLE configuration is \$2.816 M. The cost of maintenance on mixers and pumps is expected to average \$6,000 per year. The annual savings in magnesium hydroxide as a result of alkalinity recovery from denitrification would increase from \$18,000 in Year 1 to \$34,700 in Year 20. The present worth of annual savings, discounted at 3 %, is \$252,325. The total present worth cost of the project over a 20 year period would be \$3,283,076. Additional nitrogen removed would be 4.463 M lb over a 20 year period, yielding a cost of \$0.76 per lb of additional N removed.

STATE COLLEGE, UNIVERSITY AREA JOINT AUTHORITY

The University Area Joint Authority (UAJA) WWTP is an A/O process plant rated for a flow of 6 MGD, and the existing permit requires nitrification and seasonal phosphorus removal. The plant discharges to Spring Creek, which is a tributary of the Susquehanna River.

Data collected from January 1996 to June 1997 were analyzed for the study. The plant receives higher flows when the University is in session. The flows and loads decrease 20% during the period between May and August, the summer break for the school. Raw influent BOD₅ concentration averaged 257 mg/L for the year 1996 and 294 mg/L for the January 1997 to June 1997 period, which was relatively dry. The NH₄-N content was approximately 10% of BOD₅, and the TKN was estimated to be 1.5 times the NH₄-N concentrations. The average NH₄-N concentration in the final effluent was 0.9mg/L, showing that the plant achieves complete nitrification all year round. However, when the infiltration from snowmelt runoff resulted in a sharp and sudden decrease in liquid temperature, the effluent NH₄-N concentration increased above 20 mg/L in April of 1996.

Average effluent TN for 1997 was 15.5 mg/L, and 13.0 mg/L of this was NO_x remaining after denitrification. According to the nitrogen mass balance, nitrification converted 75% of the TKN present in the primary effluent to oxidized-N, and denitrification then reduced the N concentration to 11.8 mg/L (57% of NO_x formed). Phosphorus removal is achieved via alum addition, and after filtration effluent P content is below the permit requirement of 0.13 mg/L. However, during winter months when the permit is not in effect, alum addition is ceased and the effluent rises above 3 mg/L, because the anaerobic zones are kept anoxic instead of anaerobic with the introduction of NO_x in the RAS.

Raw wastewater enters the plant through a Worthington comminutor and passes through primary clarification. A flow distribution box is used to distribute the primary effluent and RAS between the two circular and one rectangular activated sludge tanks, all with A/O configuration. The anoxic cells are mixed to prevent settling, and aerobic cells are aerated with membrane disc diffusers. Preceding the three secondary clarifiers is a flash mix and flocculation tank for alum addition. The clarifiers have SORs of 400 gpd/ft² at the design flow. Secondary effluent is then filtered in dual media filters in eight filter cells, which use anthracite as the top layer and sand as the lower layer. Disinfection (chlorination) is the next and final step in the treatment train.

The upgrade will consist of conversion of the A/O tanks to the MLE configuration by creating anoxic zones with inclusion of a nitrate recycle. According to the nitrogen balance, the average concentration of NH₄-N nitrified to NO_x was 27 mg/L. For a TN concentration of 8 mg/L, 6 mg/L of which is TKN, 21 mg/L of NO_x will be denitrified following modification. In order to prevent *Nocardia* foams, gates can be installed at the surface of each baffle located within the aerobic zone. A chlorine spray system is also suggested. Alum would continue to be used for P removal.

The estimated total capital cost is \$783,793, based on 1997 dollars. O/M costs would increase to \$4,634, although there would be savings in aeration energy costs. The overall cost of BNR upgrade at State College WWTP would be \$0.33 per lb of additional N removed.

SUSQUEHANNA WATER POLLUTION CONTROL PLANT LANCASTER AREA SEWER AUTHORITY

The service area of the Lancaster Area Sewer Authority is located south of Route 30 and to the east of the Susquehanna River in Eastern Pennsylvania. The activated sludge plant owned and operated by this authority is located near the Susquehanna River, but discharges to Dry Run which is a very small tributary of the River. During dry weather, the entire flow in Dry Run is made up of the plant effluent. The plant has an effluent total P permit of 2 mg/L, and the ammonium-N permit is 12 mg/L from May 1st to October 31st. The ammonium-N permit is being changed to 5 mg/L as a monthly average applicable over the same period.

The WPCP is rated at 12 MGD, and the average flow for the July 1995 - July 1996 period was 9.45 MGD. The plant receives a mixture of municipal and industrial wastewaters, with 10% of the flow and 30% of the BOD load originating from the industries. The influent BOD₅ averaged 169 mg/L, and the primary effluent BOD₅ averaged 110 mg/L during the period of evaluation. Raw influent TKN was 29 mg/L, and the primary effluent TKN was assumed to be 80 % of the raw value. The average effluent TKN and ammonium-N were 1.8 mg/L and 0.6 mg/L, respectively. The average effluent TN was 10.2 mg/L, which indicates that a substantial amount of denitrification is taking place in the anaerobic zones as a result of NO_x recycle with the RAS. A mass balance performed on the nitrogen species showed that 50% of the NO_x generated during nitrification was denitrified in the system as operated.

The raw influent is screened through 3/4inch screens and degritted in aerated grit chambers. Then, the wastewater passes through two Worthington comminutors. The plant has two 90ft diameter primary clarifiers, and a third clarifier (30ft diameter) was being added at the time the report was written. The plant then separates into two flow trains, and each train has three anaerobic cells (17 % of total volume) and three aerobic cells (83 % of total volume) connected in series. The nominal hydraulic retention time at a design flow of 12 MGD is 5.68 hours. The air diffusers are arranged for tapered aeration. The plant maintains an MCRT of 6 to 10 days. At these MCRTs, MLVSS is only 65 to 70 % of MLSS, which implies the presence of a substantial amount of inert material. There are two 100 ft diameter secondary clarifiers equipped with Rapid Sludge Removal (RSR) systems. The third clarifier has a 140 ft diameter and the sludge is removed via a Tow-bro unit. The SOR with all clarifiers in service is 385 gpd/ft² at 12 MGD.

The RAS flow rate from each clarifier can be controlled by telescopic valves. The WAS is collected in a wet well and from there it is pumped to the primary clarifiers where it is co-thickened and sent to the gravity thickeners. The average TP increases from a range of 3 to 7 mg/L in the raw influent to concentrations greater than 10 mg/L in the primary clarifier effluent because of release under anaerobic conditions. Thickened sludge is sent to belt filters and lime is added after dewatering to stabilize the sludge.

The proposed modifications are aimed at decreasing the average effluent NO_x concentration from 8.3 to 5 mg/L, and thus reduce the TN concentration from 10.2 to 7 mg/L. The proposed configuration includes anoxic zones immediately after the anaerobic zones and a nitrate recycle system for additional denitrification. The aerobic volume would decrease, however, and the density of the diffusers would need to be increased to maintain the current amount of oxygen transfer. The nitrate recycle system would be installed in each train to pump NO_x from the end of the aerobic zone to the beginning of the anoxic zone. It is recommended that the plant install a nitrate recycle system with a capacity of 17.5 MGD to handle denitrification requirements at a peak month flow rate of 15 MGD. A small increase in the ferrous sulfate dose to maintain 2 mg/L total P should be adequate.

The primary effluent BOD levels are expected to decrease with the addition of a third clarifier, and this reduction will provide adequate capacity to maintain performance as flows increase from an annual average of 9.5 MGD to 12 MGD. To accommodate further increases in flow, the anaerobic zone can be operated as an anoxic zone or a third AS train can be added.

The costs/savings of the proposed modifications would arise from:

1. Electrical costs of operating nitrate recycle pumps and mixers;
2. Electrical savings in aeration costs from denitrification of an additional 3.2 mg/L NO_x
3. Increase in chemical costs if the plant switches to chemical P removal;
4. Associated operator time for maintenance and the cost of repairs on new equipment.

The capital cost for N removal with biological excess P removal is \$1,618,500 and the operating costs are \$23,258. The cost per pound of additional N removed over a 20-year period is \$1.12 based on 1996 dollars. The annual operating costs would increase in proportion to the flow and at the rate of inflation. The capital and operating costs of N removal with chemical P removal would be the same as bio-P removal. However, an additional \$15,000 would be spent for the chemicals. Thus, the cost of an additional pound of N removed would increase to \$1.24.

THROOP WWTP, LACKAWANNA RIVER BASIN SEWER AUTHORITY

The Throop regional WWTP is an activated sludge plant that services municipal and industrial customers to the east and south of the City of Scranton. The plant is permitted to treat a flow of 7 MGD, and the design peak wet weather flow is 14 MGD. Plant operation during 1995 was examined, as the flow conditions were considered to be more representative of current conditions than those in 1996. The average flow was 4.26 MGD for 1995.

The raw influent BOD₅ averaged 105 mg/L, which is approximately 50 % of average levels observed at plants where the raw influent is transported through new sewers with low levels of infiltration/inflow. NH₄-N levels reaching the plant were 70 % of TKN, with an average TKN value of 29 mg/L. The effluent ammonium-N levels were less than 1 mg/L in 1995. A nitrogen mass balance showed that of 20 mg/L of TKN in the primary effluent, 4.5 mg/L was removed in the biomass, 1.5 mg/L was discharged as soluble organic nitrogen in the plant effluent, and the remaining 14 mg/L of ammonium-N was nitrified, resulting in a total of 11.1 mg/L of oxidized nitrogen. The resulting deficiency in alkalinity was satisfied by adding hydrated lime. Denitrification of 6.5 mg/L of oxidized-N will also recover 23 mg/L alkalinity as CaCO₃, which is equivalent to the alkalinity of 570 lb/day of pure lime added to a flow of 4.5 MGD.

The plant's headworks consist of two grit chambers, a Parshall flume and Weisflo mechanical bar screens. Primary clarification is achieved in four 93 ft by 33 ft tanks with SWD depths of 10 ft, yielding an SOR of 570 gpd/ft² at 7 MGD. The four activated sludge basins of 169ft x 29ft x 15ft have an HRT of 11.7 at 4.5 MGD and they are followed by four secondary clarifiers with 570 gpd/ft² SORs at 7 MGD. Space is available to the left of the existing units to add an additional secondary clarifier. The secondary effluent is chlorinated and aerated prior to discharge. From analysis of DO concentrations in the activated sludge tanks and the pattern of fluctuations observed in chlorine demand, it was concluded that during times of low DO, incomplete oxidation of NH₄-N to NO₃-N was occurring, resulting in NO₂-N consumption of chlorine. Primary and secondary waste sludges are processed in a DAF unit, a digester and a belt filter.

The evaluations showed that the activated sludge basin volume and secondary clarifier capacity are limiting factors for implementation of further removal of nitrogen. According to the calculations, an additional activated sludge basin and a clarifier are required at the design flow. Besides, the existing tanks need to be retrofitted to include anoxic and aerobic zones with nitrate recycle pumps. Therefore, it is recommended that all the activated sludge basins be converted to a Modified Lutzack Ettinger (MLE) configuration. The nitrate recycle pump should be sized to operate at flow rates of 50 to 200 percent of the influent flow to be able to supply sufficient oxidized-N to the anoxic zones where the denitrification will take place.

Following items were considered to be essential for the BNR upgrade at the design flow of 7.0 MGD:

- Improvement of plant hydraulics and flow distribution structures;
- Addition of a new activated sludge basin;
- Modification of the existing basins to MLE configuration;
- Addition of a new secondary clarifier;
- Upgrade of the RAS system to meet the needs of the new configuration;
- Upgrade of the aeration system.

The total estimated cost of these modifications is estimated to be \$3,320,000, whereas the change in annual operating costs show saving of \$26,588 due to denitrification energy reductions, and the overall cost of additional N removal would be \$1.68 per lb N removed.

BNR upgrade at 5.5 MGD calls for the retrofit of the existing tanks and clarifiers, which has an estimated capital cost of \$1,100,000 and an O/M savings of \$20,855. The overall cost of N removal would be significantly lower for this alternative: \$0.58 per lb.

WILLIAMSPORT SANITARY AUTHORITY CENTRAL PLANT

The Williamsport Central WWTP is an activated sludge facility located on a narrow tract of land between I-180 and a railroad track that runs parallel to the Susquehanna River. The plant is rated for a flow of 7.2 MGD, with most of the flow being from domestic sources. Currently, during wet weather periods, the flows can increase above 7.2 MGD because of infiltration/inflow, part of which comes from combined sewers.

Operating data from 1996 showed that the average flow rate of raw influent was 8.98 MGD and the plant has limited capacity for seasonal nitrification. Because denitrification causes problems with rising sludge in the secondary clarifiers, the plant operator prefers not to nitrify. Average raw influent BOD₅ was 102 mg/L, which represents a fairly dilute wastewater. This value was 175 mg/L during dry weather (August) when the influent flow averaged 6.50 MGD. Analysis of data showed that the maximum month to average month COD ratio was 1.17. Fluctuations in COD must be considered, as COD load determines the MLSS levels at which the AS basins should be operated at the MCRTs required for nitrogen removal. The plant was operated at the low MLSS value of 1318 mg/L during 1996, with a VSS percentage of 85.5%. Plant effluent data show partial nitrification of NH₄-N at warmer temperatures. Increased nitrification caused a 90 to 100 mg/L drop in effluent alkalinity.

Pretreatment consists of 3/4 inch mechanically cleaned screens followed by grit removal channels. The plant also has covered preaeration tanks that were built as part of the original primary treatment facility, and they are used to strip odors from the sewage. The three primary clarifiers following pretreatment are rectangular with SORs of 950 gpd/ft². The clarifiers accomplished 50% TSS and 25% BOD₅ removal at an average flow of 9.0 MGD in 1996. The plant has eight AS tanks (HRT of 5.27 hours at 7.2 MGD), arranged in two sets of four tanks on two sides of a feed channel, and under normal operation conditions all eight tanks are operated in parallel. Aeration of the basins is accomplished by two Sutorbilt positive displacement blowers. RAS can be fed either to the primary effluent channel or directly to the AS tanks. Three rectangular secondary clarifiers have a SOR of 667 gpd/ft² at the design flow. Sludge wastage is from the RAS lines and the WAS is sent to the gravity thickener. The Plant has two chlorine contact tanks located adjacent to the secondary clarifiers. Two of three digesters are used as primary anaerobic digesters, and the primary digested sludge is sent to the old elutriation tanks for further thickening. Sludge from the secondary digester is passed through a belt filter press and is landfilled.

Under these conditions, it was recommended that the AS system be designed with three anoxic cells in each train, all of which can be operated aerobically. The first two anoxic cells should be installed within the first aerobic tank. The third anoxic cell should be constructed within the second AS tank and occupy 33% of its volume.

A nitrate recycle system should be constructed for each flow train and the capacity should be 2.5 times the influent flow of 7.2 MGD. Operation at 4000 mg/L MLSS in winter and

at 2300 mg/L in summer necessitates two additional clarifiers. A flow distribution structure shall also be constructed to distribute flow between the existing and new clarifiers. Also a new RAS pumping station must be added. By increasing the dimensions of the new secondary clarifiers, step feeding the primary effluent under high flow conditions, and using fixed film media integrated into the activated sludge aerobic zone, a nitrogen removal safety factor can be obtained.

The capital costs of the modifications recommended for nitrogen removal implementation are estimated to be \$6,339,416. The operating costs would increase by \$36,675 per year because of the energy costs of operating the blowers, etc., compared to the current cost of operation. The cost of removing an additional pound of nitrogen would be \$1.36, in 1997 dollars.

WILLIAMSPORT SANITARY AUTHORITY WEST PLANT

The Williamsport West Plant is an activated sludge plant that receives wastewater from Duboistown, Old Lycoming Township, Parts of Loyalstock Township, and Western Williamsport on the westside of Lycomick Creek. The plant discharges to the Susquehanna River. Sixty-five (65) to 70 % of the load treated at this plant is from an industrial park. A significant portion of the fairly high COD load is not biodegraded during activated sludge treatment because of a high non-biodegradable organic fraction. It is not known if inhibitive compounds are present. The plant is permitted for a flow of 4.5 MGD, and for effluent concentrations of 2 mg/L TP, 2.5 mg/L ammonia-N, and 7.5 mg/L ammonia-N in winter.

The year 1996 was a fairly wet year with raw influent flows fluctuating between 2.2 and 4.6 MGD, with an average annual flow of 3.5 MGD. The primary effluent COD to BOD₅ ratio averaged 3.4, which is substantially higher than the corresponding ratio for municipal wastewater (1.5 - 2.5). This implies the presence of slowly biodegradable or non-biodegradable COD. Also, the COD of the plant effluent averaged 138 mg/L, which typically varies between 30 and 60 mg/L for municipal WWTP effluents. An analysis of secondary effluent showed the absence of oxidized nitrogen forms and the presence of high levels of NH₄-N (21 mg/L). Plant effluent NH₄-N averaged 57% of the primary effluent TKN, which further indicates the absence of nitrification.

Preliminary treatment consists of mechanical bar screens with 1/2 inch openings and a rectangular grit chamber. Raw influent is then pumped to a pre-aeration chamber used for scrubbing odors, especially from May to October. Two primary clarifiers follow, with SORs of 1500 gpm/ft² at the peak month flow of 4.5 MGD. Primary sludge is sent to the gravity thickener. Primary clarifier effluent is mixed with RAS before it is fed to the activated sludge system that is comprised of six tanks (cells). Each cell has an HRT of 5.3 hours at the design flow of 4.5 MGD, and they are aerated with Lightnin' draft tube aerators (DTAs). These aerators have a mixer with impellers located within an air sparge ring. Air is injected through nozzles in the ring. Each day the DO drops below 0.5 mg/L during peak load hours, which occur after 10 am when all of the industries have resumed operation. The AS basins are operated at MLSS levels of 1000 to 1500 mg/L, corresponding to an MCRT of 5 to 7 days, because the aeration system capacity is not capable of supporting higher biomass concentrations. Also, the secondary clarifiers cannot support higher SORs or SVIs between 200 and 400 mL/g. Flow from one half of the plant goes to two square secondary clarifiers, each with an SOR of 700 gpd/ft² at maximum flow. The remaining flow enters a secondary clarifier with an SOR of 950 gpd/ft², which is very high for an activated sludge system. WAS is pumped to the gravity thickener. The plant has two chlorine contact tanks for disinfection. Final effluent is not dechlorinated.

The Williamsport West Plant has the following limitations for the implementation of nitrification: limited space for new construction, absence of nitrification / denitrification under existing conditions, and possibly the presence of inhibitory compounds in the

influent. Two options are suggested for implementing nitrogen removal. The first option is designed to treat 130 mg/L of primary effluent BOD₅, and remove 300 mg/L of primary effluent COD. Effluent COD would average at 130 mg/L. The AS tank volume would be expanded to include the volume of the two existing square clarifiers. The total basin volume with eight cells would be 1.22 MG, and the nominal HRT at the flow of 3.5 MGD average daily flow would be 8.4 hours. The system would be designed in an anoxic-aerobic sequence, with the anoxic zone occupying 27% of the total tank volume. Nitrates would be recycled from the end of the last aerobic cell to the anoxic cell in each pass. The existing aeration system would be modified with membrane or ceramic fine bubble diffusers. Secondary clarifier capacity needs to be increased to be able to operate with MLSS levels of 3000 mg/L in summer and 4000 mg/L in winter. Two new rectangular clarifiers could be accommodated within the space available. The AS system must have a new instrumentation system for DO control. During some months supplemental alkalinity may have to be added to nitrify an average of 21 mg/L NH₄-N.

The second option is plant expansion to:

1. A Single Stage Activated Sludge System: Additional AS cells, possibly downstream of the existing tanks would be constructed. A third train of four cells also should be added in parallel to the existing ones. Three new clarifiers and a new RAS pump station should be added, too. A new chlorine contact tank would be added to provide adequate time for disinfection.
2. Separate Stage Fixed Film: Expansion will include two new clarifiers, and high rate biofilters such as Biofor or Biostyr. The advantages of separate stage treatment are the smaller footprint, and possibly removal/concentration reduction of inhibitory chemicals. The disadvantages are additional aeration energy consumption, additional alkalinity needs, and methanol addition for post-denitrification.
3. Integrated Fixed Film AS (IFAS) Process: This alternative would be insertion of Fixed film media into the aerobic zone. Floating sponges such as Linpor media or plastic Kaldnes media would be the most effective.

The cost of modifying the existing treatment system for Option 1 was estimated. The construction cost estimate totals \$5,245,557 based on 1997 dollars. Capital costs total \$6,800,000 based on a 20 year life. Annual operating costs would increase by an estimated \$72,675 per year. The present worth of the increased M&O would be \$1,500,000. Cost per pound of additional nitrogen removed would be \$2.58 per lb N removed.

WYOMING VALLEY SANITARY AUTHORITY WWTP

The plant services 35 municipalities in and around Luzerne County in Central Pennsylvania. The plant is designed to treat a dry weather flow of 32 MGD and wet weather flow of 50 MGD for conventional treatment, and it discharges to the Susquehanna River. In 1995, the dry weather flow averaged 19 MGD, and the annual average flow was 22 MGD. Evaluation of 1995 data showed that the plant maintained good nitrogen removal by operating at high MCRTs (above 25 days), and by maintaining MLSS concentrations of 5000 mg/L with AS basin DO concentrations of 0.5 to 1.5 mg/L. However, effluent ammonium-N will increase unless the plant undertakes modifications to maintain N removal at lower MCRTs.

In 1995, the raw influent BOD₅ and TKN values averaged 200.7 mg/L and 26.6 mg/L, respectively. Nitrification was limited by the capacity of the aeration system, as indicated by effluent ammonium-N levels that varied between 3 and 6.5 mg/L for several months of the year and averaged 2.21 mg/L. The effluent NO_x was low with a 2.24 mg/L average, indicating good denitrification in the reactors. Total N in the effluent was 6.52 mg/L.

During normal flows, the influent is screened through two Weismann Wiesflo fine screens prior to being pumped by centrifugal pumps to the grit chambers. When the flow exceeds the capacity of the centrifugal pumps or the Weisflo screens, the excess flow is diverted to a set of Archimedes screw pumps. The plant has four Schreiber grit and scum removal units. Following grit removal, the raw influent is distributed between four activated sludge flow trains. Each train has two circular activated sludge tanks designated as the Schreiber GRD (with central anoxic zone) and GRO basins (with intermittent aeration capacity) followed by a circular secondary clarifier. The flow is aerated in the outer ring of the GRD basin and it exits the GRD basin to enter the GRO basin. Each train has its own set of Aerzen positive displacement blowers. Basins have O₂ minimizers that control DO injection on the basis of change in turbidity resulting from the presence of unstabilized colloidal organics in the mixed liquor. It is used for cycling the aeration. However, due to poor mixing between the sludges in the different rings of the basins, the minimizers can not be used effectively for cyclic aeration purposes.

Analysis of the secondary clarifiers at the design flow rate of 8 MGD per train shows a surface overflow rate of 315 gpd/ft² which is lower than the typical design rate of 400 gpd/ft² used for secondary clarifiers at facilities which incorporate nitrification. The layout requires a clarifier to be taken out of service if a basin is taken out of service. Each train has three RAS archimedes screw pumps (Schreiber tube pumps, Model 1400) installed in a RAS well. Each pump can discharge at a maximum flow rate of 8 MGD. Therefore, in theory, the RAS flow rate can be increased to 200 percent with all pumps in operation. Optimum operation has been observed at RAS flow rates of 100 percent at the present average flow of 24 MGD. Each GRO and GRD basin has a pipe which can be used in the future as part of a nitrate recycle system. Because of extensive denitrification, the nitrate recycle required to maintain an effluent total nitrogen less than 8 mg/L at design flow is expected to be less than 100 percent of the influent wastewater flow.

Sludge is wasted by a telescopic valve located in the discharge box. Waste sludge enters a thickening pit located below the maintaining continuous WAS feed and clear liquid decanting, above 2% solids in the pit. This sludge is then dewatered in centrifuges, with the final sludge having a 24 % solids content. The dewatered sludge is then raised the pH prior to incineration at temperature.

BNR implementation will require operation at lower MCRTs and maintain complete nitrification. DO set point is expected to be 1 mg/L. This will decrease the denitrification in the aerobic zone and NOx unless cyclic aeration or a nitrate recycle system is also installed. The volume of the plant is only 20% of the total volume, but this is adequate amounts of NOx. Thus, it was recommended that 50% of the plant be placed in the aerobic zone via cyclic aeration. Cycle time can be determined by the monthly average effluent ammonium-N and NOx. Suggest a cycle time of 10 days in summer and 20 days in winter. Some structural modification will be required. Studies show that cyclic aeration does not have sufficient capacity for nitrogen removal at dry weather flows above 24 MGD.

The installation of programmable timers is the only modification required for nitrogen removal. The cost will be \$100,100 at 24 MGD, and the cost is projected as \$0.023/lb. For a dry weather flow of 32 MGD, a nitrogen aeration control system needs to be installed. The cost of this system is \$762,600, with the cost per lb of additional N removed being \$0.12.

YORK CITY SEWER AUTHORITY STP

The York City sewage treatment plant (STP) is a combination pure oxygen and A/O activated sludge plant that discharges to Codorus Creek in Manchester Township, York County, Pennsylvania. Codorus Creek is classified for warm water fish, recreation, water supply and aquatic life. Hence, the discharge permit regulates nitrogen species as follows: all year round nitrification is required with effluent ammonium-N values not to exceed a monthly average of 1.7 mg/L from May 1st to October 31st, and a monthly average of 2.1 mg/L for the rest of the year. Permitted weekly average and instantaneous maximum levels are 1.5 and 2.0 times the monthly average values, respectively. The total phosphorus permit of the plant is for 2 mg/L as a monthly average.

This plant was evaluated for the period from May 1995 through April 1996, during which the plant achieved complete nitrification all year round. The effluent ammonium-N averaged 0.1 mg/L, with a peak monthly concentration of 0.2 mg/L. A nitrogen balance revealed that total nitrification averaged 12.9 mg/L, and 2.2 mg/L of nitrogen was being denitrified. The phosphorus content of the WAS was 3.5 to 4.0 % on a VSS basis. The average influent flow to the plant was 13 MGD.

The York City STP was designed to treat a flow of 26 MGD. The treatment train consists of bar screens, grit removal, 8 primary clarifiers with a surface overflow rate of 960 gpd/ft², activated sludge basins and secondary clarifiers in three independent trains, secondary effluent filtration, and disinfection. The oldest section is an 8 MGD pure oxygen train with two tanks and receives raw influent. This train is used when the raw influent flow exceeds 18 MGD. The second train has a 7.5 MGD A/O™ process configured as two parallel tanks, and primary effluent is fed into this train. Finally, the third train also has an A/O™ configuration, but has three parallel tanks receiving a mixture of primary effluent and raw influent. The surface overflow rates of the secondary clarifiers of the trains are 630 gpd/ft², 318 gpd/ft², and 242 gpd/ft², respectively. Phosphorus removal is biological in Trains 2 & 3, but in Train 1 it is achieved chemically by the addition of ferrous sulfate.

With the existing flow arrangements, Train 1 cannot nitrify, and it would have to be down rated to 1.5 MGD and operated with 3600 mg/L MLSS in a peak month in winter to facilitate nitrification. Additionally, the hydraulic and load treatment capacity of the other two trains should be increased to accomodate the flow not sent to Train 1 with consideration given to the surface overflow rates of the secondary clarifiers. Besides the above suggestions, the following modifications were also suggested for the activated sludge basins for better nitrogen removal at York City STP:

1. *Cyclic aeration of the first two aerobic cells with / without a nitrate recycle system:*

With a cycle time of 30 min for the air on and off periods and without nitrate recycle 6 mg/L of N can be denitrified. With nitrate recycle, an additional 2 mg/L of N can be removed.

2. *Conversion of the first aerobic cell in each activated sludge tank to an anoxic cell with a nitrate recycle;*

With a modification of the surface aerators in Trains 2 and 3 to obtain anoxic cells that will be mixed a few minutes every 30 min to prevent settling. The pure oxygen supply in the first aerobic tank of Train 1 should be shut off.

3. *Conversion of the anaerobic cells to anoxic cells with the addition of nitrate recycle; addition of ferrous sulfate for chemical phosphorus removal.*

The anaerobic zones of Trains 2 and 3 will be made anoxic, with nitrate recycle. Phosphorus removal will be achieved chemically with ferrous sulfate addition to the raw influent.

The cost calculations showed that all alternatives that include denitrification result in savings because of reductions in aeration costs. The Capital cost of Alternative 1 without a nitrate recycle system and for treatment of 18 MGD of raw influent flow is \$30,000, and there will be substantial savings in operating costs (\$20,000 per year) because of denitrification. Alternatives 2 and 3 both include nitrate recycle systems, and their total capital costs are similar. Alternative 3 includes chemical phosphorus removal with the additional cost of ferrous sulfate addition. At the design flow of 26 MGD, the annual operating cost is \$30,000. The additional operating costs of nitrification and denitrification are \$25,993 to obtain an additional 5.5 mg/L of N removal, for a cost of \$0.42 per lb of N removed.

Virginia Files – Potomac River Discharges

ARLINGTON WWTP

The Arlington Wastewater Treatment Plant located in Northern Virginia is currently being expanded and upgraded for BNR. However, construction of the BNR upgrade is not expected to be completed by the year 2000, and thus, will not meet the goal of 40% reduction of controllable nitrogen inputs to the Chesapeake Bay agreed upon by the governors of the three states. Therefore, the USEPA and the Virginia Department of Environmental Quality are considering the option of implementing temporary BNR modifications at this facility in order to accomplish some degree of nutrient removal in the interim period before the final upgrades, if the upgrades can be accomplished at a reasonable cost.

The Arlington WWTP is rated for an average daily flow rate of 30 MGD. The facility is currently operating at its design capacity. The current average daily flow rate is 32.4 MGD, which exceeds the permitted flow and illustrates the need for a capacity upgrade. The facility has preliminary, primary, secondary, and tertiary treatment facilities. The secondary treatment process consists of three activated sludge basins and each basin has four passes. Coarse bubble diffusers are used in the activated sludge basins to aerate the mixed liquor. The hydraulic retention time (HRT) of the activated sludge basins is approximately six hours at the design average flow rate of 30 MGD. The activated sludge basins are followed by six circular secondary clarifiers. The secondary clarifiers have a diameter of 115 feet and a side water depth of 11 feet.

The facility is currently operated in the step feed configuration with four primary effluent feed points in each activated sludge basin. Approximately 25% of the influent is fed at each step feed point. The average effluent TN during the year of evaluation was 9.0 mg/L, which is only 1 mg/L higher than the Chesapeake Bay goal of 8.0 mg/L.

The current operation of the plant is optimized for nitrogen removal. However, the lack of baffle walls between the anoxic and aerobic zones results in back-mixing between the zones and promotes growth of low DO filamentous bacteria, causing poor activated sludge settlability. Installation of baffle walls could provide sufficient control of the filamentous bacteria and make improved nitrogen removal possible. This would reduce the effluent total nitrogen to a maximum of approximately 8.0 mg/L, and would result in a reduction of approximately 11% from the current average effluent TN level of 9.0 mg/L. It is likely that the annual average would be closer to 6 mg/L if the baffles and mixers were installed. However the following economic analysis assume that the effluent nitrogen would average 8 mg/L.

Capital cost for implementing interim nitrogen and phosphorus removal modifications is \$560,000, and it is planning level estimate with a 20% contingency. Since the plant is

already optimized for nitrogen removal, additional aeration cost savings will be negligible. The estimated 20 year increase in maintenance and operation cost is \$544,000. The overall cost for implementing nitrogen removal includes the cost of achieving denitrification only, and it is \$0.605 per pound of additional nitrogen removed.

COLONIAL BEACH WWTP

The Colonial Beach WWTP is an activated sludge facility that serves the town of Colonial Beach, and is located in Westmoreland County, VA. It discharges to Monroe Bay, an inlet of the tidal Potomac River. The current permit requires the plant to maintain an average BOD₅ and TSS of 21 mg/L and 28 mg/L, respectively, at all times. An effluent ammonia concentration of 4.63 mg/L or less must be met April through September. The DO concentration in the plant effluent must be no less than 6.5 mg/L and the permitted effluent flow rate is 2 MGD. At present the plant receives an average flow of 0.64 MGD.

The flows, concentrations and loads to the plant over the twelve month period from August 1996 through July 1997 were analyzed. The raw influent BOD₅ averaged 89 mg/L for that period. The influent TKN, NH₃ and TP values were usually measured once a month, and no TKN or NH₃ measurements were recorded on the same day during the period from March 1997 through July 1997. Therefore, in some months, the NH₃ values seemed to be higher than the TKN values, and these values were not considered in the analysis. The Influent TP values averaged 3.5 mg/L over an 8 month period. TP measurements were not available for the remaining 4 months. Effluent TKN and NOx concentrations averaged 0.44 and 13.1 mg/L, respectively.

A mechanical bar screen is installed in the influent channel. Following screening, grit is removed from the wastewater via a stirred grit chamber. The plant has two grit chambers, each of which is equipped with a 0.75 HP constant speed paddle mixer to control velocity in the chamber. Flow, then, enters a wet well that distributes the flow to the equalization tanks. The plant has two equalization tanks, but only one tank was in operation. These basins are equipped with a coarse bubble air diffusion system. Flow from the EQ basin enters activated sludge tanks. The facility has two completely mixed activated sludge (CMAS) tanks, currently, only one is operated at a time. Lime is fed to the tanks to control the pH. The flow passes to one of the two clarifiers in operation, and clarified water then enters one of the two chlorine contact units. A post aeration chamber is provided at the end of the chlorine contact unit to achieve dissolved oxygen concentration of at least 6.5 mg/L in the final effluent.

The plant has two aerobic digesters for waste sludges, and flow from the digesters enters the belt filter press. Dewatered sludge consisting of 17 % ODS (oven dried solids) is applied to landfill. Filtrates generated during filtration and supernatant from the aerobic digesters are returned to the equalization basin.

Considering the effluent values, complete nitrification of the ammonia formed from the complete ammonification of all the sources of organic-N was assumed to be possible. Because of the current low flows relative to design flow, it was concluded that successful nitrogen removal could be accomplished by cycling the aerators on and off in the CMAS tank. Thus, the capital costs will include a DO control system with a DO probe in each AS tank, a PLC, and electrical work for the installation, for the estimated sum of \$90,000. The estimated annual change in O&M costs would be a total reduction of \$7,100 at

current flow and \$15,500 at design flow. The estimated total cost for implementing BNR is for denitrification only, as the facility is capable of nitrifying year round, and it sums up to \$0.065 per lb additional N removed.

TOWN OF DAHLGREN WWTP

The Dahlgren Wastewater Treatment Plant (WWTP) is an Orbal configuration oxidation ditch activated sludge plant owned and operated by the Utilities Division of King George County, VA and it discharges to the Potomac River. The current permitted flow is 0.325 MGD, but an expansion scheduled for 1998 will increase the plant capacity up to 0.5 MGD. The plant received an average flow of 0.28 MGD from October, 1996 through October, 1997, which is about 86 % of the design flow of 0.325 MGD. Discharge permit limits effluent average ammonium-N concentrations to 1.35 mg/L, but the plant does not have a discharge limit on TN.

The raw influent BOD₅ averaged 251 mg/L over the thirteen month period, and during periods of high infiltration, BOD concentrations decreased down to monthly averages as low as 197 mg/L. The highest monthly average was 370 mg/L during August, 1997. The raw influent TKN values were not routinely measured during plant operation. However, influent ammonia concentrations were measured at least once a week. TKN values were estimated based upon an ammonia-TKN ratio of 0.7 was assumed.

The average water quality values for each month were in compliance with the permit requirements, except for May and June of 1997 when the effluent ammonia levels exceeded the permit requirement of 1.35 mg/L by 70% because of low DO concentrations in the mixed liquor. Effluent ammonium-N averaged 0.92 for the period of evaluation. Overall, the data indicate that the Dahlgren Orbal-like oxidation ditch system is capable of maintaining complete nitrification all year round for the current flows and loads.

The first unit of the WWTP is an equalization basin. From equalization, wastewater flows directly to the oxidation ditch. The existing equalization volume is sufficient to equalize the BOD and TSS of the influent wastewater, but it is operated as an overflow basin, which means it does nothing to equalize the flow. The biological process of the plant consists of a single Orbal-type oxidation ditch, with three concentric rings. Flow enters the inner ring of the oxidation ditch, and then flows successively through the middle and outer rings before exiting to the secondary clarifiers. The ditch has a hydraulic detention time (HRT) of 1.25 days at the design flow of 325,000 gpd, and will provide an HRT of 0.81 days for the planned flow of 0.5 MGD. Aeration is provided by vertical discs mounted on horizontal shafts. The number of discs on each rotor in each ring can be varied to control the amount of aeration within each ring. The facility has two solids-contact type secondary clarifiers, designed for an average overflow rate of 350 gpd/ft², and a weir loading rate of 2,500 gpm/ft. The overflow rate is very adequate for the current design flow of 0.325 MGD. When the flow is increased to 0.5 MGD, the overflow rate would be 536 gpd/ft². The plant has two aerobic digesters. Secondary effluent passes through a 3 pass chlorine contact tank. This provides an HRT of 50 minutes at design flow. Sludge dewatering is accomplished using a Model 3500 Envirex type belt filter press. Polymer is added during dewatering. Dewatered sludge is transported to a landfill 3 days a week.

The Orbal-type oxidation ditch operated at this facility was designed to accomplish substantial amounts of nitrogen removal if the oxygen inputs are carefully controlled. This can be accomplished by placing the appropriate number of discs on the aerators in the three ditches. If this proves to be too insensitive, further control can be accomplished by cycling aerators on and off. Once the appropriate disc configuration and on-off cycling periods are established, the cycling can be accomplished using timers to turn the aerators on and off throughout the day. The objective is to supply enough oxygen to remove much of the BOD and to completely nitrify all of the available ammonia, but limit the oxygen inputs so that a substantial fraction of the influent BOD will be removed by denitrification. It will be necessary for the operators to measure effluent ammonia and NO_x at least three times during the work day, and make appropriate adjustments to the timers for the rest of the 24 hour period, to optimize N removal. Once the patterns are determined, the adjustments will be simple to make. A Hach kit could be obtained and used by the operators to determine the ammonia and NO_x concentrations. The control of oxygen transfer for optimum nitrogen removal can be accomplished by adjusting the numbers of discs on the rotors so that the first ring acts as an anoxic zone with an internal nitrate recycle from the second ring, which will continue to be used as an aerobic zone.

Effluent total phosphorus (TP) concentrations exceeded the permit limit of 2.0 mg/L only one month during the thirteen-month evaluation period. Thus, no modifications are needed to improve phosphorus removal unless the managers/operators are interested in implementing biological phosphorus removal rather than chemical phosphorus removal.

Capital costs for implementing BNR are based on installing timers in the MCCs of the aerators to operate the aerators in cyclical aeration mode if necessary, and two DO probes for continuous DO monitoring in the ditch, yielding a total of \$30,000. The projected net decrease in O&M cost is \$4,900 as a result of savings from energy consumption reduction. The net additional cost/savings per lb of N removed is estimated as \$0.12.

DALE SERVICES SECTION 1 AND SECTION 8 WWTPs

The Dale Services Corporation operates two WWTPs designated as Section 1 and Section 8, and both discharge into a tributary of the Potomac River Tidal Estuary. The plants are contact stabilization activated sludge design facilities permitted for flows of 3 MGD each. At present the plants meet the P, BOD and TSS permit limits of 0.1 mg/L P, 2 mg/L BOD, and 3 mg/L SS. However, TKN concentrations in the effluent are 10 to 15 mg/L, which exceeds the ammonia limit as well as the TN concentration goals for effluents discharging into tributaries of the Chesapeake Bay.

Raw wastewater arrives at the treatment plants to pass through a coarse bar screen and a Parshall flume. The flow proceeds to a splitter box where the flow is appropriately divided among three contact stabilization AS units. The flow is introduced into a contact (mixing) zone where the raw wastewater is mixed with AS using compressed air generated by blowers. The bioreactors perhaps can be more accurately described as "modified orbital systems". The flow then passes to the secondary clarifiers. The RAS is pumped to the reaeration zone where the bacteria are given time to stabilize any stored or trapped organics, and the flow is then re-introduced to the contact zone. The WAS is sent to a primary and then to a secondary aerobic digester, from where it is sent a gravity thickener for dewatering. Secondary effluent is pumped to chemical clarifiers for precipitation of phosphorus and coagulation of suspended solids with aluminum chloride. When necessary the pH of the clarified water can be adjusted with lime addition. Effluent is then pumped to four multi-media pressure filters, and further to the UV disinfection unit.

Although the wastewater quality was similar, the average flow to Section 8 was 2.12 MGD, whereas it was 3.0 MGD to Section 1 in 1996. The raw and final effluent TKN concentrations were 40 and 12 mg/L, respectively. Phosphorus concentration in the raw wastewater was 5.2 mg/L, and it was reduced to 0.08 mg/L after tertiary treatment. As the NO_x concentration in the effluent was below 1 mg/L, the TKN can be assumed to be a measure of the ammonia concentration in the final effluent, which is relatively high.

Although the reactors were designed to operate as Contact Stabilization Process Units, currently the contact and reaeration basins are operated at similar, but unusually high MLSS concentrations: 4200 to 6400 mg/L, and MLVSS constitute 75 % of MLSS. This is a result of strong backmixing and high RAS rates. The HRT of each one of the reactors in Section 1 can be approximated as 0.4 days (9.6 hours) at an average flow rate of 3 MGD. The HRT of the reactors in Section 8 are 0.56 days (13.4 hours) at an average flow of 2.15 MGD. As the flow will reach 3 MGD in 5 to 6 years, the calculations for both plants were made using 3 MGD. The operating MCRT was calculated to be 15 days. The raw influent pH varied at a low range of 6.7 to 6.9. Raw wastewater and bioreactor alkalinities were measured to be between 125 and 175 mg/L as CaCO₃, and 65 to 125 mg/L as CaCO₃. These numbers indicate either a high CO₂ partial pressure or alkalinity due to non-carbonate sources.

Full nitrification at Dale City WWTPs can be achieved by addition of alkalinity, maintaining the pH at 7.2 and the DO at 2.0 to 2.5 mg/L, without any changes in configuration and operation. For denitrification to take place, an anoxic zone of at least 2 hours HRT is required. It is recommended that part of the volume of aerobic sludge digesters be incorporated into the bioreactor zones, thereby increasing the total reactor volumes to 12 hours HRT. The designed air supply facilities at the Dale City WWTPs have a total capacity of 21,000 ft³/min. However, at present the real air supply capacity of the blowers is not known. These should be determined by testing. If denitrification can be achieved, the air requirements will be significantly lowered (approximately 20 %). A separate sludge digester at each plant shall be designed and constructed for treatment of WAS, as in the future the whole volume of the aerobic digesters will be needed for anoxic zone.

The capital costs for the three stages (adjustment of alkalinity and pH for implementation of nitrification, separation of an anoxic zone in the aerobic digester, and use of the whole volume of the digester for anoxic zone) of modifications are \$330,000; \$220,000; and \$1,080,000. Capital costs for second stage are based on an effluent TN concentration of 8.0 mg/L, and for third stage are based on an effluent TN of 4.0 mg/L. The estimated annual change in the O&M costs are an increase of \$430,000 for the first stage, and reductions of \$140,000 and \$180,000 for the second and third stages. The estimated total costs of additional N removal at the Dale City WWTPs are \$0.68 and \$0.29 per lb of N removed for the first and second stages. A cost calculation for the third stage is not presented.

H. L. MOONEY WWTP, PRINCE WILLIAM COUNTY AUTHORITY

The Mooney WWTP is rated for an average daily flow of 18 MGD. However, the existing tertiary filters can only treat up to 12 MGD, which is slightly less than the current annual average flow rate of 12.8 MGD. After preliminary and primary treatment, wastewater flows into four activated sludge basins, each with two passes and two baffle walls at the upstream and downstream ends. The hydraulic retention time (HRT) of the activated sludge basins is 6.3 hours at the design average flow rate of 18 MGD, and it is 9.4 hours at the current annual average flow rate of 12 MGD. Fine bubble membrane diffusers are used in the activated sludge basins to aerate the mixed liquor. The activated sludge basins are followed by four 95 foot diameter secondary clarifiers. Three of the secondary clarifiers have a side water depth of 12 feet, and the fourth clarifier has a side water depth of 16 feet.

In the current operating mode, both effluent from the primary clarifiers and the return activated sludge are fed into the first pass of the activated sludge basins. High chemical doses are used in the primary clarifiers to increase BOD and phosphorus removal. The two passes of the activated sludge basins are operated under aerobic condition to accomplish BOD removal and nitrification. However, nitrification has sometimes been inconsistent in the past. The facility is currently conducting a study to determine the cause for the occasional loss of nitrification. For the most part, the facility nitrifies year round. Mathematical analysis of the process shows that the facility can nitrify year round, unless nitrification is inhibited due to toxicity.

To accomplish denitrification it is recommended that the activated sludge basins be operated in the modified Ludzack-Ettinger (MLE) mode. All of the primary effluent and the RAS would be fed into the first zone of each basin, which would be an anoxic zone occupying 15% of the total basin volume. It is predicted that this would result in an effluent TN concentration of 14 mg/L or less. A second anoxic zone would decrease the TN concentration down to less than 8 mg/L year round. At design flow, the nitrification and denitrification capacity of the facility will be limited by the secondary clarifiers because of the high surface overflow rates and high solids loading rates. Additional secondary clarifiers will be required to maintain adequate treatment at design capacity. However, additional secondary clarifiers are not required to accomplish an effluent total nitrogen concentration of less than 8.0 mg/L at the current annual average flow rate. The modifications recommended will result in reducing the effluent total nitrogen by approximately 50% from the current level.

Capital cost for implementing interim nitrogen and phosphorus removal modifications is \$490,000, and it is a planning level estimate with a 20% contingency. The estimated 20 year decrease in maintenance and operation cost is \$124,000. The overall cost for implementing nitrogen removal includes the cost of achieving denitrification only, and it is \$0.063 per pound of nitrogen removed.

LEESBURG WATER POLLUTION CONTROL FACILITY

The WWTP of the Town of Leesburg is an in-series combination trickling filter-activated sludge facility with intermediate clarifiers. It currently is rated for an average daily flow of 4.85 MGD, and the facility discharges into the freshwater Potomac River. The plant has a discharge permit that regulates the ammonium-N and TKN concentrations in the final effluent. The monthly average ammonium-N concentration is required to be 3.0 mg/L or less between May and October, and the TKN concentration is required to be 6.0 mg/L or less for the same period. A review of the plant operating data from September 1995 to August 1996 showed that the facility received a current annual average flow of 2.86 MGD, and that the current monthly average BOD and TKN concentrations ranged from 124 to 247 mg/L and 15.3 to 30.7 mg/L, respectively.

Preliminary treatment facilities at the Leesburg WWTP include mechanical screens, raw sewage pumps and grit chambers. Flow then goes to three circular primary clarifiers with SORs of 572 gpd/ft² at the design average flow of 4.85 MGD. The secondary treatment process consists of four trickling filters and three circular intermediate clarifiers, followed by an AS system and two rectangular final clarifiers. The trickling filters are also known as roughing filters, two of which have plastic media in their entire filter depth of 4.0 ft whereas the other two filters have 1.0 ft of plastic media on top of 3.0 ft of rock media. Currently, the filters are removing 70 to 85 % of the BOD present in the primary effluent, and partially nitrifying at the current average flow. The intermediate clarifiers have SORs of 572 gpd/ft² at the design average flow. The clarifier effluent is pumped to two single pass AS basins, with a HRTs of 4.7 hours at the design average flow. They have a tapered aeration system with ceramic diffusers. The SORs of the final clarifiers are 379 gpd/ft² at the design average flow. The RAS flow rate from clarifier underflow varies between 60 and 150%. P removal is achieved by ferric chloride addition to the final clarifier influent. Tertiary treatment consists of mainly two automatic backwashing gravity sand filters. Filtered effluent is pumped to an outfall structure consisting of two cascade aerators, and flows by gravity to the Potomac River. Disinfection is achieved by chlorinating the final clarifier effluent. Sodium bisulfite is fed prior to discharge for dechlorination.

The existing roughing filters remove most of the BOD and insufficient amounts of organic carbon are left available for efficient denitrification. The Following modifications are recommended for implementation of BNR at the Leesburg WPCF:

1. *Level 1 - Effluent TN concentration of 9 to 12 mg/L in summer; 16 to 18 mg/L in winter. No additional tanks will be constructed, and the modifications will be limited to changes within the existing AS system, and roughing filters will be kept in service: An anoxic zone shall be created at the influent end of each of the two AS basins and a portion of the primary effluent shall be bypassed to the anoxic zones. Each anoxic zone shall occupy approximately 30% of the AS volume, with a HRT of 1.86 hours. The nitrate recycle pumping system shall be capable of pumping 50 to 150 % of the*

primary effluent. Bypassing 50% of the flow around the filters will decrease the loading on the filters, which would enable them to partially or completely nitrify during the warmer months. The anticipated range of effluent TN level is 9 to 12 mg/L, May through October. During the colder months, TN may range as high as 16 to 18 mg/L.

2. *a) Level 2 - Year round effluent TN concentrations of about 8 mg/L, and 6 to 8 mg/L from April to October. Requires modifications of the existing AS system and replacement of two of the roughing filters with new AS basins:* The remaining two filters would treat up to 1.0 MGD under average conditions, and would be able to nitrify year round. The total HRT of the AS system would increase from 4.65 hours to 9.3 hours. A MLSS concentration of 3000 to 3500 mg/L is anticipated in four parallel operating AS basins. Each basin will have an anoxic zone (30%) at the influent end. Submersible mixers are needed to keep mixed liquor in suspension. A nitrate recycle pumping system capable of pumping 100 to 300 % of the flow is required. P removal will be achieved with chemical addition.
3. *b) Level 2 - Nitrogen removal with BPR:* A2/O process is recommended. Two of the existing filters will be demolished and two additional AS basins constructed. A total HRT of the AS basins will be 9.3 hours. Anaerobic and anoxic zones would occupy approximately 15% and 30% of the basin volume, respectively. All other modifications and nitrogen removal capacity would be similar to Alternative 2. The effluent P level would range from 1.0 to 2.0 mg/L on a monthly average basis.

Capital costs of the three alternatives can be listed as \$290,000; \$2,770,000; and \$2,980,000 in the order presented above. The calculations for the estimated changes in the annual O&M costs showed that Alternative 1 results in an increase of \$1,400; whereas Alternatives 2 and 3 result in reductions of \$1,000 and \$38,900. The total cost of additional N removal are \$0.13; \$0.73; and \$0.68 per lb of N removed for the three alternatives.

LOWER POTOMAC POLLUTION CONTROL PLANT, FAIRFAX COUNTY

The Lower Potomac Wastewater Treatment Plant, originally rated for an average daily flow of 54 MGD, is currently being upgraded to a design flow rate of 67 MGD with biological nitrogen removal. The current annual average flow rate is approximately 45 MGD. The average BOD, TSS, TN and TP concentrations reaching the plant are 250 mg/L, 200 mg/L, 33 mg/L and 6.5 mg/L, respectively. The corresponding current average effluent concentrations are 4 mgBOD/L, 6 mgTSS/L, 12.5 mgNH₃-N/L, 2.0 mgNO₃-N/L, 15 mgTN/L, and 0.22 mgTP/L.

The original treatment system consists of preliminary, primary, secondary, and tertiary treatment processes. The secondary treatment process consists of six parallel step-feed design activated sludge basins, with three passes in each basin. The basins are equipped with medium bubble diffusers (Pearlcomb®) manufactured by FMC Corporation to aerate the mixed liquor. The hydraulic retention time of the activated sludge basins is approximately five hours at the design average flow of 54 MGD. Four of the existing eight clarifiers which were built as part of the most recent upgrade, have a diameter of 145 feet and side water depth of 16 feet. The four older clarifiers have a diameter of 120 feet and side water depth of 10.5 feet. The activated sludge basins were operated at the time of the evaluation by feeding all of the primary effluent at the beginning of the third pass, and by feeding the return activated sludge into the first pass. Therefore, the first two passes in each basin were used to reaerate the return sludge and the third pass was used as a contact stabilization basin for primary effluent. The purpose was to reduce the suspended solids loading to the clarifiers, because they were considered to be the primary treatment limitation. Because of the short hydraulic retention time and clarifier limitations, the facility was unable to nitrify in the current mode of operation when the mixed liquor temperature was slightly below 20 °C.

After dewatering, the sludge is incinerated onsite in a multiple hearth furnace. It is known that the incinerator stack scrubber water contains cyanide, and is recycled back to the headworks. It is possible this inhibits the nitrification rate.

The current upgrade is aimed primarily at increasing the plant capacity and resolving the secondary clarifier problems, but will include provisions for biological nitrogen removal. The plant capacity is being increased to 67 MGD, and six new rectangular clarifiers with a SWD of 16 ft are being built to replace the four old shallow ones. The total aeration basin volume is being expanded by 14.7 MG with a SWD of 22 ft. Three aeration basins will be step-fed into six passes with alternating anoxic-aerobic zones. The anoxic volume will be 5.1 to 7.3 MG total, i.e. 1.7 to 2.43 MG per basin. Four new blowers will be installed for increasing the air capacity in deep aeration basins. After the upgrade is completed, currently projected as January 10th, 2002, the plant is supposed to maintain an effluent TN concentration of 8 mg/L and less year round. This would remove an

additional 0.96 Mlbs of TN per year at the current average flow of 45 MGD, and an additional 1.43 Mlbs of TN per year at the design flow of 67 MGD.

The construction cost of the expansion and BNR upgrade is currently budgeted at \$20.8 M. Assuming the total costs are necessary for BNR implementation, the cost per pound of additional nitrogen removal would be approximately \$0.50/lb. In actuality, the flow expansion costs should be deducted and the cost per pound should be further discounted by the reductions in O&M costs that are likely to be realized by the implementation of denitrification.

PURCELLVILLE WWTP

The Purcellville Wastewater Treatment Plant is located in Loudoun County, Virginia, and it discharges into a small unnamed tributary of the north fork of Goose Creek which eventually flows into the Potomac River. The existing plant is going to be abandoned when the new plant under construction is completed, presumably by the end of the year 2001. The main reason for the construction of the new plant at a different location was that the existing plant is in the flood plain. Also, the new plant will double the capacity from 0.5 MGD to 1.0 MGD. The current average flow rate reaching the plant is 0.31 MGD.

The existing plant is an upgrade of a trickling filter (TF) plant, and it operates an activated sludge system and a trickling filter process in series for secondary treatment, with the TF serving as a polishing step. The new plant is going to be a step feed MLE system with 3-pass aeration basins. The activated sludge process will consist of a three-stage anoxic zone, and the last stage of it designed to be a swing zone which can be operated as either an aerobic or an anoxic zone. The preliminary and primary treatment units preceding the secondary treatment basins will consist of a mechanical bar screen, grit and grease removal unit and primary clarifiers. Chemical phosphorus removal will be achieved by addition of ferric chloride. Flow from the equalization basin downstream of the primary clarifier will be distributed between the activated sludge basins. The center feed secondary clarifiers have a side water depth of 14 ft, and are designed with large floc zones for secondary phosphorus precipitation. Downstream of the secondary clarifiers, will be AquaRobics disk filters, UV disinfection and cascade aeration prior to final discharge. Sludge from the primary clarifier and the waste activated sludge from the secondary clarifier will be sent to a gravity thickener, and then to two aerobic digesters and a sludge holding tank prior to disposal.

The projected cost of the new plant is between \$5.1 M and \$5.4 M without BNR, and it is between \$6.4 M and \$6.7 M with BNR. Thus, the cost of including BNR into the new plant will be \$1.3 M. The projected increase in nitrogen removal with the new plant is 17,000 lbs for the first year, and 720,000 pounds over the 20 year design life. The estimated cost per pound of additional nitrogen removed is \$1.80/lb over the 20 year period.

Virginia Reports – Shenandoah Valley WWTPS

DUPONT WAYNESBORO WWTP

The Du Pont Waynesboro nylon manufacturing plant, located in Waynesboro, Virginia, produces a variety of synthetic fibers, and the manufacturing processes generate a wastewater that has a high nitrogen content. The wastewater originating from the manufacturing processes had an average flow rate of 341 gpm from January-July, 1997, and this flow is treated on site in an activated sludge facility. The domestic wastewater generated within the facility is not mixed with the process wastes, and is directly discharged to the sewerage system of the town. Treated effluent from the Du Pont WWTP is discharged to the nearby South River, a tributary of the South Fork of the Shenandoah River, and flows to the Potomac River. The existing discharge permit limits ammonium-N to a maximum of 0.801 mg/L between January 1st and May 31st, and to a maximum of 0.689 mg/L between June 1st and December 31st.

Wastewater from the Lycra, Permasep, Nylon and DI sumps of the manufacturing processes has an average temperature of 31°C, and first flows into an equalization blend tank. The nominal EQ hydraulic retention time (HRT) for an average flow of 253 gpm is 8.2 days at maximum water level. The effluent maintains a temperature of 20°C even in cold month. Mixing is provided via the aeration system, which consists of blowers and Kenix mixers. Here, backwash water from the anthracite coal filters which provide final treatment of the effluent discharge, mixes with the process water. Flow from a wastewater retention tank also occasionally discharges to the blend tank. The filter backwash water provides a source of microbial seed for the aerated blend tank. Consequently, bacteria convert the organic nitrogen, present primarily as dimethyl acetamide (DMAc) and hexamethylene diamine (HMD), to ammonia (ammonification). Bacterial activity in the equalization tank also results in 30 % COD and 33 % TN removals. The aeration feed tank is the next step before six 0.25 MG aeration tanks and five clarifiers, i.e., the activated sludge process. Currently, only three aeration tanks and two clarifiers are being used, and only one clarifier is used at a time. There are plans to remove the two smaller of the remaining three clarifiers. Nominal volume of each circular aeration tank is 0.25 MG, yielding an HRT of 1.55 days at an average flow of 341 gpm. Mixing is provided via 4 ft Kenix static aerators, and 15 ft³/min per 1000 ft³ tank volume of air flow was used as mixing criteria. At average conditions, the F:M ratio was 0.052 for the first half of 1997. Alkalinity adjustments are accomplished by adding lime. When only one clarifier is used at average flow conditions (341 gpm), the SOR is 148 gal/ft²/day.

Secondary effluent from the clarifiers is passed through a 10 MG polishing tank, also aerated via Kenix mixers. Currently, Du Pont is planning to remove this tank as the effluent from the clarifiers is well nitrified and the large tank is no longer needed. Two parallel 2 ft deep anthracite coal filters follow the polishing tank before discharge. The filters are backwashed once daily, and the backwash water is sent back to the blend tank. Final effluent is combined with the effluent from the consolidated sump, which receives

process waters from a chemical sump, acid recovery ditch, textile sewer and pumphouse sewer. Storm water overflow is also combined at the final discharge point. Currently, the centrifuges are not in operation, and the sludge is settled periodically and land applied via spraying.

The average BOD₅ was 431 mg/L for the influent and 233 mg/L for the aeration feed effluent, indicating a 46 % reduction between the two points. TKN was not one of the measured parameters. Total nitrogen measurements were performed using an ANTEK 7000V Nitrogen Analyzer, and ammonia and nitrate nitrogen were believed to be absent in the blend tank influent, indicating that the nitrogen was almost entirely in the organic nitrogen form. The average concentration of nitrogen entering the AS process is 63 mg/L, and the effluent data shows that excellent nitrification is accomplished, and the effluent ammonia averaged only 0.09 mg/L during the period of evaluation. However, high levels of TN (46 mg/L) are discharged, and almost 100% of it is in the form of nitrates.

Two alternatives were considered for improved nitrogen removal:

1. Sequencing aerated/nonaerated periods in the existing aeration tanks, accomplished by cycling the air on and off. The tanks would continue to be used in parallel, and no structural modifications would be necessary.
2. Converting one of the aeration basins into an anoxic tank for denitrification, and keeping two tanks aerated for nitrification (Bardenpho Process). This alternative will require some piping work because the existing piping does not allow the operation of the basins in series. Methanol addition in a post-anoxic tank would be required in all cases to achieve an effluent nitrate nitrogen level of 5 mg/L. If desired, methanol can be added at the coal filters, converting them to denitrification filters. They would require methanol addition equal in amount to that of the post-anoxic tank.. The alternatives for the methanol application point should be field tested to determine the most suitable one.

The results of the cost calculations for each alternative are as follows:

1. If cyclic aeration is implemented manually by turning the aerators on and off, there would be no capital costs and it could result in an estimated 48% reduction in the amount of quicklime that has to be added for pH adjustment. The estimated benefit to the company would be \$0.11 per lb additional N removed.
2. If automated cyclic aeration is desired, a DO control system and instrumentation can be installed for approximately \$290,000, and the cost per lb of additional N removed would be \$0.17.
3. Capital costs for installing mixers in the AS tanks for Alternative 1, in addition to installation of an aeration control system and a PLC, would be \$400,000, and the net decrease in O&M would be \$4,300. The total cost per lb of additional N removed would be \$0.33.
4. Capital costs for Alternative 2 are for modifying the existing basins to operate as two

parallel trains of two tanks in series operating in the MLE configuration. The sum is \$560,000. Mixers, DO control and monitoring system, and a nitrate recycle pumping system are the items that need to be installed. The net decrease in O&M costs for this alternative is \$1,600, with a total cost per lb of additional N removed of \$0.51.

5. The existing basins would be modified to operate as two parallel trains, each basin consisting of three tanks in series operating in the Bardenpho configuration. The capital cost and the net increase in O&M costs would be \$630,000 and \$900, respectively. The total project cost per lb of additional N removed would be \$0.54.

FISHERSVILLE WWTP

The Fishersville WWTP is an activated sludge plant that is currently rated for an average daily flow rate of 1.4 MGD. It discharges into Christian Creek, which flows into Middle River, which is a tributary of the South Fork of the Shenandoah River. The discharge permit limits ammonium-N concentrations to a monthly average of 8.14 mg/L between June and December, and to 10.6 mg/L between January and May. The current annual average flow rate is 1.30 MGD, and the current annual average BOD and TKN concentrations in the plant influent are 135 mg/L and 17 mg/L, respectively.

After screening and grit removal, wastewater is pumped into a common channel that distributes the flow between two AS basins. The HRT of the basins at the design average flow of 2.0 MGD is 10.1 hours. The aeration system consists of medium bubble diffusers and three positive displacement blowers. The AS basins are followed by four rectangular secondary clarifiers with SORs of 550 gpd/ft² each at design average flow. Secondary effluent is chlorinated, dechlorinated and reaerated prior to discharge. The facility has four aerobic digesters equipped with coarse bubble diffusers. The sludge is then dewatered and land applied.

Flow distribution between the AS basins is accomplished in the influent channel. Rags and debris accumulate around the stem of the weir gate and obstruct the influent flow and affect the flow distribution between the basins. This unequal distribution causes difficulty in optimizing the process for best results. The effluent of the Fishersville WWTP has an average TN value of 11.2 mg/L and an average TP value of 2.5 mg/L. The N and P removal can be enhanced by operating the AS system in the A2/O configuration. Flexibility should be provided to operate the AS system in the MLE configuration for BNR and chemical P removal during the winter months. The following modifications are recommended:

1. Replace the existing weir gates with slide gates;
2. Create an anaerobic/anoxic switch zone followed by an anoxic and an anoxic/aerobic switch zone at the influent end by turning off the air;
3. Construct three baffle walls in each AS basin;
4. Install submersible mixers in the anaerobic and anoxic zones;
5. Install a DO control system;
6. Install a nitrate recycle system;
7. Install a chemical P removal system.

These modifications would enable the facility to meet a year round average of 8.0 mg/L for TN with both reactors in service.

The total capital costs of implementing BNR is \$980,000 with an estimated annual reduction in O&M costs of \$3,800 without chemical P removal, and an increase in O&M costs of \$2,600 with chemical P removal. The estimated total cost is \$2.20 and \$2.90 per lb of additional N removed annually, with and without chemical P removal, respectively.

FRONT ROYAL WWTP

The Front Royal WWTP is an activated sludge facility located in Warren County, VA, and it discharges to the Shenandoah River. The facility was upgraded to a 4.0 MGD treatment facility in 1992, and designed to handle a peak flow of 12.0 MGD. Average and maximum influent ammonia concentrations for the period from January to May usually vary from 13.0 to 16.6, and from 7.0 to 13.9 mg/L for the period from June through December, respectively. Nitrogen and phosphorus removals are not required under the current permit. At present the plant receives an average flow of 2.4 MGD.

During the 14 month evaluation period (September 96 - October 96), the raw influent BOD₅ and TSS concentrations averaged 143 mg/L and 182 mg/L, respectively. The raw influent TKN, NH₄-N and TP analyses were not performed during the evaluation period, so the BOD₅ to TKN ratio was assumed to be 6.7:1.

The first stage of the plant consists of equalization basins. Following equalization, two aerated grit chambers are provided, followed by primary clarification. Each grit chamber is provided with diffused aeration. Following grit removal, the plant has two rectangular primary clarifiers. The average detention time and the surface overflow rate at 2.04 MGD are 1.3 hours and 1,370 gpd/ft², respectively. There are four aeration basins, and the average detention time is 6.9 hours at 1.02 MGD per basin. Aeration is provided by two mechanical aerators in each basin. The plant has four final clarifiers. Two of the clarifiers have a diameter of 52 ft and the remaining two clarifiers have a diameter of 63 ft. The side water depth of all four final clarifiers is 12.5 ft. At 4.07 MGD, the surface overflow rate of all four final clarifiers is 503 gpd/ft² each. The weir loading rate of the smaller clarifiers are 4,260 gpd/ft² at 4.07 MGD, while the larger clarifiers operate at a weir loading rate of 6,770 gpd/ft² at the same flow rate. Each clarifier includes a circular sludge collector mechanism manufactured by Envirex. Aerobic digesters are used to digest both primary and secondary sludges plus foam. Primary clarifier sludges directly enter the digesters. However, the sludge from the secondary clarifiers first enter a gravity thickener before being transferred to the digesters.

The aeration basins have adequate capacity to accomplish both denitrification and complete nitrification at the current flow rate of 2.4 MGD. However, at design flow (4.0 MGD), two additional aeration basins will be needed to accomplish an effluent TN level of 8.0 mg/L year round. The minimum aeration basin HRT required at this facility is 9.0 hours to meet the TN goal of this project.

Calculations for the implementation of cyclic aeration to achieve nitrification and denitrification indicated that total cycle periods of 3.64, 3.35 and 3.06 hours with unaerated periods of approximately 46% would provide NO_x concentrations of 5, 6 and 7 mg/L, respectively, in the final effluent without nitrate recycle. However, pilot studies should be run to determine exact cycle durations for final design.

The capital cost for implementing nitrogen removal at current flow is based on installing a PLC for cyclical aeration and DO control, and sums up to \$50,000. The capital cost for installing nitrogen removal at design flow is based on constructing two additional aeration basins identical to the existing basins, a primary effluent flow distribution structure, and a secondary clarifier influent flow distribution, and sums up to \$2,010,000. The estimated annual changes in M & O costs at current flow and at design flow are \$2,500 and \$2,900, respectively. Cost savings due to alkalinity recovered from denitrification will not be realized at this facility because no chemicals are added to supplement alkalinity in the wastewater. The estimated total costs for implementing nitrogen removal are \$0.02 and \$1.16 per lb of additional N removed, for current flow and design flow conditions. All costs presented are for implementing denitrification only, not for nitrification, because the facility is already capable of year round nitrification.

HARRISONBURG WWTP

The Harrisonburg WWTP is an activated sludge plant designed for a flow rate of 16 MGD, and at present the plant receives flows of 7.5 to 8.0 MGD, with wet weather flows of 24 to 25 MGD. The plant is located off I-81, south of the City of Harrisonburg. At present, the plant receives 40% of its total load from industrial sources, which includes three large poultry processing facilities and one dairy. The Plant has a draft permit which requires it to nitrify and meet effluent TKN concentrations of 9 mg/L (January to May) and 4 mg/L (June to December).

The raw influent reaching the plant is screened through two mechanical bar screens, degritted in two sets of grit chambers, and flows by gravity to four primary clarifiers, each of which has an integrated DAF section. The clarifiers were designed with a SOR of 510 gpd/ft² at the design average flow. In the recently completed upgrade, the old primary clarifier flocculation basins were converted to anoxic/anaerobic selectors with a nominal HRT of 11.3 min at average flow. The selector effluent is distributed between eight AS basins, with a nominal HRT of 10 hours. Aeration is provided with ceramic fine bubble diffusers. There are four secondary clarifiers, with SOR of 379 gpd/ft² at average flow. The secondary effluent is pumped to eight anthracite filters, each with a loading rate of 1.65 gpm/ft² at 16 MGD. The effluent is chlorinated, dechlorinated and post aerated prior to discharge.

The plant is operated at aerobic MCRTs of 5 to 12 days. Between June and December, complete nitrification is achieved except a few instances where ammonium-N exceeded 4 mg/L between January and April. Effluent nitrate concentrations average at 16 mg/L.

In a pilot study being run for the evaluation of BNR, 25% of one of the AS basins has been converted to an anoxic zone by turning the air off without mixers. The only nitrate recycle was with the RAS operated at 75 %. The results showed that between November and December, an average denitrification of 3 to 4 mg/L of NO_x was achieved compared to a control basin without an anoxic zone.

Analysis of the raw influent BOD shows an average of 200 mg/L with a peak month value of 237 mg/L for the period between September 1994 and June 1995. Using a computer model and assuming a 70% aerobic volume, an effluent TN of 8 mg/L between May and November and 10 mg/L for the rest of the year, it was found that the average month MLSS would be 2900 mg/L, and during summer months one of the AS basins could be taken off service. Thus, the analysis shows that the plant can achieve nitrogen removal without any additional basins or clarifiers. Some features such as step feed could be added to handle high flows. RAS chlorination could be used to control SVIs when they are out of the upper boundary of the range of 60 to 125 mL/g.

Essentially, most of the modifications for BNR are in-basin modifications with some improvements for automated control. Two dedicated anoxic zones should be constructed using baffles in the AS basins, with one switch cell. The nitrate recycle pump should be

designed for a maximum recycle rate of 3 times the influent flow. Automated DO control may be included, with two DO probes to facilitate energy savings by preventing overaeration. The plant has sufficient alkalinity in its influent.

The capital costs of these modifications are calculated to be \$3,614,247, with an annual reduction of \$570 in the O&M costs. The cost per lb of additional N removed, based on a reduction of 11 mg/L in the effluent TN is \$0.54 per lb N removed.

LURAY WWTP

The WWTP for the Town of Luray is an oxidation ditch activated sludge system designed to treat a combined municipal-industrial wastewater with an average flow of 1.6 MGD, and a peak flow of 2.2 MGD. Average dry weather flow during 1997 was about 1.2 MGD, while average flow during wet months was about 2.0 MGD. Of this flow, between 650,000 and 750,000 gpd is wastewater from the Wrangler textile plant located in Luray. The typical Wrangler wastewater strength is BOD₅ 640 mg/L, COD 1280 mg/L, TSS 115 mg/L, NH₃-N 0.6 mg/L, and pH 6.8. However, the Wrangler wastewater contains very high non-biodegradable organic-N concentrations, i.e., 100 to 120 mg/L. Typical combined wastewater strength is BOD₅ 220 mg/L, COD 495 mg/L, TSS 125 mg/L, TKN 50 mg/L, NH₃-N 6.4, and pH 7.2. The combined wastewater is nitrogen deficient for activated sludge metabolism, and an available source of nitrogen has to be added to accomplish BOD removal.

The Luray plant is required to meet monthly average effluent concentrations of 30 mg/L TSS and 30 mg/L BOD₅, and weekly average effluent concentrations of 45 mg/L TSS and 45 mg/L BOD₅. In addition the minimum acceptable pH is 6.5, and the fecal coliforms should not exceed 200 per 100 mL. The facility had not effluent TN and TP requirements when this evaluation was performed, but limitations of 8 mg/L TN year round, and 1.5 mg/L TP year round.

The treatment system consists of: dual 40 inch Rotamat Fine Screens and a bar screen bypass in the head works, dual oxidation ditches with 8 20 HP, 16 ft Magna rotor brush aerators per ditch, dual 50 ft.dia. Spiraflo clarifiers with 8.5 ft. SWD and full surface skimming, dual 28 ft. dia. Hydro-Flow clarifiers with 9.75 ft. SWD, disinfection by UV, and cascade aeration. In addition, the plant has two stage dual thickeners for sludge processing, followed by aerobic digestion and belt filter press dewatering. The plant also is equipped with a septage pretreatment system, which consists of aeration. The dewatered solids go to the Page County landfill for final disposal.

The plant effluent concentrations from June 3 – July 10, 1996 averaged 44 mg/L BOD₅, 167 mg/L COD, 128 mg/L TSS, and 39 mg/L TKN, but only 0.29 mg/L NH₃-N. By contrast, effluent concentrations averaged 7.6 mg/L BOD₅, 30 mg/L COD, 10.6 mg/L TSS, and 0.25 mg/L NH₃-N during September, 1996. February, 1997 averages were 10 mg/L BOD₅, 40 mg/L COD, 20 mg/L TSS, and 0.22 mg/L NH₃-N. A review of the operating data for 1996 and 1997 indicated that these values were fairly typical, although during dry periods the plant performed much better. TKN data was not available for September and February.

The data show that the treatment processes work very well except when rainfall events occur. Then high infiltration and inflow results in very high flows through the treatment plant, and the washout of activated sludge solids from the clarifiers. The impacts of the TSS concentrations on the effluent concentrations of BOD and COD can be seen in the data listed above. Both parameters vary directly with the magnitude of the TSS

concentration. In contrast, the effluent ammonia concentration is not affected by the high TSS concentrations because ammonia is soluble. The data clearly show that the biological process is capable of near complete nitrification under nearly all conditions, including high flows. However, when the mixed liquor temperature dropped below 11^o C during December, 1996, the effluent ammonia concentration increased to as much as 7 mg/L, and averaged 5.8 mg/L over a seven day period. However, the average for the month was only 1.95 mg/L. Apparently the operating SRT was not high enough to prevent partial washout of the nitrifiers during the low temperature period.

A special investigation of the soluble effluent concentrations from the Luray WWTP was performed from 6/3 – 7/9, 1996. During the period the activated sludge process nitrified completely, to an average of 0.018 mg/L NH₃-N, the effluent oxidized nitrogen concentration was low (3.02 mg/L), and the soluble phosphorus concentration was typically below 2.0 mg/L. However, the soluble organic nitrogen was very high and averaged 42.2 mg/L. It was clear from the results that the biological process was effectively nitrifying and denitrifying all of the biologically available nitrogen, but a large quantity of non-biodegradable organic nitrogen was present in the wastewater. The effluent wastewater also has a dark blue color from the dyes used by Wrangler in the production of stone washed jeans, and these dyes are the likely source of the non-biodegradable organic nitrogen.

It was concluded from the investigation that the non-biodegradable organic nitrogen was not having an effect on the eutrophication of the receiving waters, and that any efforts to remove it would be very expensive. The most economical technically feasible treatment would involve the addition of activated carbon. Considering the unlikely environmental impact of the discharged nitrogen, it is recommended that no modifications be made to the Luray WWTP for purposes of nitrogen removal. The operator could operate the aerobic digesters cyclic aeration to reduce the electricity costs, and this would reduce the nitrogen in the digesters, but the impact on the effluent nitrogen concentration would be small. No other efforts to improve nitrogen removal are recommended. However, it is recommended that efforts be made to reduce the amount of inflow and infiltration into the town sewers, and it is noted that such a project is ongoing at the present time (1999).

THE MERCK AND CO., INC. WWTP

The Merck WWTP is an activated sludge plant with a permitted flow of 1.2 MGD. Merck & Co., Inc.'s facility in Elkton, VA is a pharmaceutical manufacturing plant, and it historically has been producing Amprolium, resulting in a high COD and nitrogen wastewater. Recently, however, the production line was switched to CRIXIVAN, and the wastewater now has a higher COD strength, but is nitrogen deficient. Consequently the activated sludge WWTP was upgraded to treat the high COD load with addition of ammonia to satisfy the nitrogen requirements. Nitrogen remaining in the final effluent is discharged to the receiving water. Currently, the average TN in the final effluent after mixing with cooling water is approximately 3.5 mg/L. Therefore, the facility does not have to implement any modifications to the existing treatment plant, as long as future changes in the raw water quality do not result in higher final effluent nitrogen levels. Hence, Merck should have a contingency plan to modify the existing system, when necessary.

Current operational data shows that the raw influent contains 98 mg/L of TKN and 45 mg/L of ammonium-N, after addition of ammonia. BOD and COD values are 2,402 and 5,077 mg/L, respectively, at an average flow of 0.906 MGD. Projected flows and loads of raw influent for maximum CRIXIVAN production indicate that influent concentrations will remain the same, but the influent flow rate will increase to 1.20 MGD, increasing the loads to the treatment plant. As the industry is unsure about the future nitrogen loads, BNR evaluation was performed at three different levels of N loading:

1. Current maximum month N load for maximum production.
2. Future N load of 2,400 lb/day which is approximately twice the current maximum month load.
3. Future N loads of up to 3,500 lb/day.

Current treatment processes start with equalization and neutralization (with phosphoric acid or magnesium hydroxide), and follow with two AS treatment trains. Each train has a maximum of three basins used in series for AS operation. The aeration system consists of coarse bubble diffusers in the basins and four centrifugal blowers. The effluent from the AS basins is distributed between two clariflocculators, the overflow from which is sent to two trickling filters as a polishing step. The underflow from the clariflocculators is recycled to the first AS basin in each train. Treated effluent from the trickling filters is distributed between two final clarifiers. The final effluent is then mixed with cooling water and discharged into a receiving stream.

WAS is pumped to the waste sludge storage tank and dewatered using two belt filter presses. The dewatered sludge can be dried, incinerated or both. Filtrate from the presses is fed to the trickling filters.

At Level 1 N load, the plant does not require any modifications for nitrogen removal as the water is nitrogen deficient and ammonia is externally added. Better monitoring of ammonia and nitrate levels in the treated effluent prior to mixing with cooling water is

recommended to minimize addition of excess nitrogen to the process. As the MCRT increases, the nitrogen requirement decreases due to a decrease in generated biomass. Therefore, Merck may choose to operate with three basins : each train and at high MCRTs.

At Level 2 N loads, a Bardenpho system is recommended to produce a final effluent TN concentration of 8 mg/L. The required modifications consist of creating an anoxic zone at the influent and effluent ends of each AS basin train and recycling nitrified mixed liquor from the aerobic zone effluent to the anoxic zone at the influent end. TN concentrations lower than 8 mg/L could be achieved by endogenous denitrification in the second anoxic zone. Furthermore, a 3 mg/L effluent TN level could be achieved by the addition of biodegradable COD to the second anoxic zone. Each of the two anoxic zones would occupy 16 % of the train volume. Submersible mixers would be installed in the unaerated zones to prevent settling of mixed liquor. A reaeration zone following the second anoxic zone would strip the nitrogen gas.

For Level 3 N loads, in addition to recommended modifications for Level 2 N loads, a feed system for a supplemental carbon source such as methanol should be provided. Implementation of denitrification at levels 2 and 3 would lower the aeration requirements because the denitrification process consumes COD under anoxic conditions.

There is no capital cost for treating the Level 1 nitrogen load. Capital cost for the Level 2 nitrogen load is for converting the system to a Bardenpho process, and it sums up to \$840,000. For Level 3, the modifications include a methanol feed system and an additional blower in addition to the requirements for Level 2 modifications. It sums up to \$1,440,000. The estimated changes in annual O&M costs for the Levels 1, 2, and 3 are \$0, \$37,000 reduction and \$113,000 increase, respectively. If the Bardenpho process is implemented for Level 3 with larger anoxic zones, methanol feed could be avoided. However, additional tank volume would be necessary. The total costs for additional nitrogen removal for this plant is \$0, as currently no modifications are required.

MIDDLE RIVER/VERONA WWTPS

The Middle River WWTP is an oxidation ditch activated sludge facility currently rated for an average daily flow rate of 4.5 MGD, and it discharges into the Middle River which is a tributary of the South Fork of the Shenandoah River. The Augusta County Sanitary Authority owns and operates the plant, and also owns and operates the much smaller Verona RBC WWTP which is located adjacent to the Middle River WWTP, and their final effluents are combined prior to discharge. The discharge permit limits ammonium-N concentrations to a monthly average of 3.1 mg/L between June and October, and to 3.8 mg/L between November and May. The current annual average flow rate to the plant is 3.65 MGD. The annual average BOD and TKN concentrations in the plant influent are 130 mg/L and 22 mg/L, respectively.

After preliminary treatment, the wastewater is pumped into two oxidation ditches each of which has an HRT of 1.2 days at the design average flow of 4.5 MGD. Two brush aerators are used in each ditch. The brush aerators in each one of the inner, middle and outer channel of the ditches are constructed with a common shaft. Thus, the operator does not have the flexibility to control the DO level in the ditches to optimize nitrogen removal. Mixed liquor then flows into two circular clarifiers with an overall SOR of 448 gpd/ft² at design flow rate. The secondary effluent is disinfected using UV light and reaerated using cascade aeration before discharge into Middle River. The WAS is aerobically digested in the inside channel of the oxidation ditches, then dewatered and land applied.

The effluent monitoring data from August 1996 to April 1997 showed that the facility currently accomplishes nitrogen removal to levels below 8.0 mg/L even after combining with the effluent from the Verona WWTP. The combined effluent of the Middle River and Verona WWTPs had an average TN value of 5.9 mg/L and an average TP value of 1.3 mg/L. The performance of the plant for BNR can be further improved by installing a DO control system consisting of a PLC and two DO probes in each ditch, to optimize the DO levels in the ditches for cyclic aeration. It is also recommended that the nitrified effluent from the Verona WWTP be combined with the raw influent to the Middle River WWTP so that the nitrates it contains are denitrified in the Middle River WWTP. These modifications would enable the plant to achieve an average effluent TN of 3.5 to 4.5 mg/L year round. A chemical P removal system is not necessary as the current effluent level is less than 2.0 mg/L.

The total capital costs of implementing controlled BNR would be \$150,000, with a negligible estimated annual change in O&M costs. The estimated total cost of additional N removed is \$0.30 per lb.

OPEQUON WRF, CITY OF WINCHESTER

The Opequon WRF is an activated sludge facility that was built for an average flow rate of 5 MGD, and the plant was recently re-rated for an average daily flow rate of 6.25 MGD. The facility discharges into Opequon Creek, which flows to the Shenandoah River and on to the Chesapeake Bay via the Potomac River. The current discharge permit limits the effluent monthly average ammonium-N concentrations to 0.9 mg/L from February 1st to April 30th, and to 0.44 mg/L from May 1st to January 31st. The current average daily flow rate for 1995 was 5.14 MGD, and maximum day average flows were 10 to 20 MGD. The 1995 average daily BOD and TKN concentrations were 210 and 25.8 mg/L.

Primary treatment consists of two circular clarifiers with SORs of 812 gpd/ft² at the design average flow of 6.25 MGD. The overflow then flows into two AS basins with a HRT of 10.9 hours at the design average flow. Basins have tapered aeration using fine bubble diffusers. Mixed liquor flows into two circular centerfeed secondary clarifiers with SORs of 550 gpd/ft² at the design average flow. Telescoping valves are used at the discharge end of the RAS line to control the RAS withdrawal rates. Secondary effluent flows into gravity filters for additional suspended solids removal, and is then disinfected using chlorine prior to discharge.

The RAS system is prone to operational errors resulting in unequal amounts of RAS being withdrawn from each clarifier, because the valves are adjusted manually. Step feeding in the AS basins can be implemented to decrease solids loading to the clarifiers. The facility has an excessive aeration capacity, and with the implementation of denitrification, the air demand will decrease from the current levels. Overaeration may then disrupt the denitrification process.

Within the step feed denitrification process, anoxic zones could be created at the beginning of each pass of the AS basins and primary effluent would be fed to each of the three anoxic zones. RAS, however, would be fed only at the beginning of the first pass to prevent dilution of RAS. Consequently, the MLSS would be highest in the first pass, intermediate in the second, and fully diluted in the third. Thus, step feed operation permits a higher MCRT without overloading the clarifiers. Although the nitrates in the RAS and those produced in the aerobic zones of first and second passes will be denitrified, most of the nitrates produced in the third aerobic pass will be discharged in the effluent.

Four different levels of modifications are recommended for different BNR goals:

1. *Level 1 - Operational changes that can achieve effluent concentrations of 10 to 15 mg/L of TN without BPR:* Step-feed operation for all three passes, and operating the first 60 ft of each pass anoxically by turning off the air and rearranging the diffusers. DO levels in the aerobic zones should be limited to 2 mg/L

2. *Level 2 - Modifications that can achieve 8 to 10 mg/L TN without BPR:* A dedicated anoxic zone shall be created in the first 60 ft of each pass by installing baffle walls and submersible mixers. DO concentrations in the aerobic zones should be limited to 2 mg/L.
3. *Level 3 - Modifications that can achieve effluent TN concentrations of less than 8 mg/L, without BPR:* In addition to the modifications of Level 2, a submersible nitrate recycle pump would be installed in the downstream end of the third pass aerobic zone. Greater control of denitrification could be achieved by installing baffles after all three anoxic zones.
4. *Level 4 - Modifications that can achieve effluent TN concentrations of less than 8 mg/L with BPR to less than 1 mg/L:* In addition to the modifications of Level 3, an anaerobic zone with an HRT of 1.5 hours is recommended at the beginning of the first pass for BPR. Greater control of denitrification could be achieved by installing baffles after all three anoxic zones.

Costs for level 1 were not calculated as it only includes operational modifications and diffuser relocations. The capital costs for the Levels 2, 3 and 4 are \$370,000; \$510,000; and \$570,000 respectively. The estimated annual increase are in O&M costs for the three Levels are \$6000; \$7000; and \$7000. The estimated total costs of additional N removal for Levels 1, 2, 3, and 4 are then \$0; \$ 0.13; \$0.17; and \$0.16, respectively.

PARKINS MILL WWTP

The Parkins Mill wastewater treatment plant is an oxidation ditch facility that consists of four ditches, and is located in Frederick County, VA, where it discharges to Opequon Creek. The design average flow rate is 2.0 MGD and peak flow (one day instantaneous) is 5.0 MGD. However, current average flow is approximately 1.09 MGD. The current discharge permit requires that the average ammonium-N concentration be 1.7 mg/L between December 1st and April 31st, and 1.5 mg/L from May 1st through November 31st. There are no limitations on TN levels.

Available plant operating data, influent wastewater characteristics, and performance data for the 12-month period from November 1996 to October 1997 were examined. Measurement of effluent $\text{NO}_3\text{-N}$ was not among the routine daily analyses. For this reason $\text{NO}_3\text{-N}$ was monitored between 12/29/97 and 1/9/98 at times corresponding to three different operational changes. Average flow for the above mentioned 12-month period was 0.98 MGD, with a minimum and a maximum monthly average of 0.82 and 1.60 MGD, respectively. The following ratios were assumed to be valid for the Parkins Mill WWTP to enable nitrogen balance analysis: CBOD to TKN of 5.5, CBOD to TP of 30, and TKN to $\text{NH}_4\text{-N}$ of 1.5.

Preliminary treatment consists of mechanical screens and a vortex grit chamber. Flow from the grit chamber is measured via a Parshall flume and sent to the wet well of the influent pump station. The influent pump station (3 pumps) sends the wastewater to the primary splitter from where it is distributed to four oxidation ditches. Flow is split between the four oxidation ditches, with 12.5 % going to each of ditches 1 and 2, and 37.5 % to each of ditches 3 and 4. Oxidation ditches 1 and 2 are the original units at the plant, and they are 56 % smaller than oxidation ditches 3 and 4. The hydraulic retention time (HRT) for secondary treatment at average flow conditions is 26.2 hours at the design average flow of 2.0 MGD. Return activated sludge (RAS) varies between 80 and 100 % of the influent flow. Currently, the aerators in all ditches are turned off for a 2 to 3 hour period every night. The plant has four clarifiers, two of which (C1 and C2) are used for waste sludge thickening. The two larger and newer clarifiers (C3 and C4) are used for secondary clarification. It is likely that additional clarification will be needed as flows approach 4.0 MGD. An additional 70 ft. diameter clarifier would provide an overflow rate of 346 gpd/ft², and a solids loading rate of 17.4 lbs/d/ft². Because the site is area limited, a better choice may be to use all four clarifiers for clarification and go to either a centrifuge or a belt filter for initial sludge thickening. Clarifier effluent is filtered by two sand filters that are operated continuously and backwashed one compartment at a time. A chlorine residual of 0.3 ppm is maintained on the filters, and because this residual is not sufficient for proper disinfection, the filtered water is passed through a UV disinfection step. The final effluent is further oxygenated by cascade aeration before being discharged to Opequon Creek.

Sludges wasted from clarifiers 3 and 4 and thickened in clarifiers 1 and 2 are pumped to the two aerobic digesters. They are operated with downcomer headers and coarse bubble

diffusers. A belt filter press follows the digesters for further thickening, and it dewateres the waste sludge up to a dry solids content of approximately 12 %. A high molecular weight cationic polymer is used as the flocculant aid. Thickened sludge is then transferred to a landfill via trucks.

NO₃-N measurements on 24-hour composite samples of plant effluent taken between 12/29/97 and 1/9/98 showed NO₃-N levels from 0.0 to 13.2 mg/L in the final effluent, with an average of 6.6 mg/L for 10 samples. Effluent samples from ditch 1 taken on the same days, but collected 15 minutes after the daily 2-hour shutdown, showed significant denitrification, i.e., zero NO₃-N values for 6 out of 10 days, with one high value of 17.6 mg/L, and an average value of 3.5 mg/L. However, denitrification was not occurring steadily and in a predictable way. This was probably because of the varying location of the aerobic and probable anoxic zones in the ditches, depending on the location of the resting brush aerator. In other words, the anoxic and aerobic zones are not fixed and do not ensure consistent nitrification and denitrification.

The first alternative recommended for BNR implementation is air-on/air-off cycling with short air-off periods and one brush operating at a slow pace to maintain forward flow in each ditch. The operators should determine the optimum air-on and air-off periods for combined nitrification and denitrification by experimenting with the system while monitoring the effluent nitrate and ammonia concentrations.

A second alternative for BNR implementation is to modify the ditches and operate them in the Bio-Denitro configuration, a process described by Randall *et al.*, (1992). Basically, the sequence is to alternatively operate one of the paired ditches as an anoxic reactor and the other as an aerobic reactor, with the influent being introduced into the anoxic ditch. During the remaining cycle time, both ditches are operated as aerobic reactors. Effluent should be discharged from the aerobic ditch at all times to obtain the best performance. Because the ditches have a common wall, piping work for this modification should be minor.

The capital costs for Alternative 1 include installation of an aeration control system with PLC based instrumentation and DO probes for cycling aerators on and off, and they sum up to \$97,000. Alternative 2 requires the modifications to be able to feed one anoxic ditch at a time, cycling of aerators in each ditch to provide completely anoxic or aerobic conditions in each one, and variable effluent withdrawal always from the aerobic ditch. Two submersible mixers are required in each ditch to provide mixing and water movement during anoxic periods. The capital costs sum up to \$680,000.

The estimated annual reductions in O&M costs for Alternatives 1 and 2 are \$31,400 and \$25,800, respectively. The estimated total costs for implementing BNR with Alternative 1 shows savings of \$0.79 per lb additional N removed, whereas with Alternative 2 the cost would be \$0.96 per lb additional N removed.

ROCCO FARM FOODS WWTP

Rocco Farm Foods Inc. in Edinburg, VA is a poultry-processing industry, and the WWTP is currently rated for an average flow rate of 1.2 MGD. The WWTP is a Schreiber Process activated sludge plant that discharges to Stoney Creek, which is a tributary of the North Fork of the Shenandoah River. The current discharge permit limits ammonium-N concentrations in the final effluent to 6.84 mg/L January through May, and to 1.95 mg/L June through December. The effluent TKN is limited to 50 mg/L and 4.15 mg/L for the same periods of the year, respectively.

Currently, the wastewater contains 34.6 mg/L ammonia, 140 mg/L TKN and 140 mg/L TN after preliminary treatment by dissolved air flotation (DAF), and the final effluent concentrations are 0.3 mg/L ammonia, 2.2 mg/L TKN, 125.5 mg/L NO_x and 128 mg/L TN. Phosphate phosphorus is reduced from 35 mg/L to 15.7 mg/L, as P, without chemical addition.

The pretreatment facilities at the Rocco WWTP include screening, flow equalization, and grease removal using DAF. Process wastewater then flows into a pumping station to combine with the plant storm water and domestic wastewater. Wastewater is pumped to an anaerobic lagoon, and most of the lagoon effluent is sent to an aerobic "Schreiber Process" AS basin. The remainder of the flow is sent to an equalization lagoon and then sent to the AS basin. The Schreiber basin has an HRT of 24 hours at the design flow rate of 1.2 MGD. The Schreiber basin is equipped with a DO probe to monitor DO levels continuously. Aeration is accomplished by stationary fine bubble diffusers. The mixed liquor flows into a circular secondary clarifier with an SOR of 211 gpd/ft² at the design flow. The underflow from the clarifiers goes to the RAS wet well, from where the WAS flow is also withdrawn. Part of the WAS is sent back to the anaerobic lagoon, with the rest sent to dewatering by filter press. The dewatered waste sludge is land applied. The secondary effluent flows into a chlorine contact tank for disinfection and subsequent dechlorination using sulfur dioxide.

The anaerobic lagoons remove 80 to 90 % of BOD present in the raw wastewater, but no significant nitrogen removal occurs. The BOD to TKN ratio in the influent to the AS basin is approximately 1.5, which is not adequate to accomplish denitrification to meet an effluent limit of 8 mg/L. Five alternatives were considered for implementation of BNR:

1. *Construct a dedicated anoxic zone outside the existing AS reactor and operate the resulting total AS process in the MLE configuration:* A new pumping station would be required to recycle the nitrified effluent from the aerated AS basin to the unaerated, anoxic basin. Submersible mixers would be installed in the anoxic tank to prevent settling of the mixed liquor. Since the anaerobic lagoon effluent has limited BOD, the amount of denitrification that can be achieved is also limited. The anticipated effluent TN would be 20 mg/L at a nitrate recycle flow rate of 5.8 MGD (4.8 Q).

2. *Construct a dedicated anoxic zone inside the existing AS reactor and operate the resulting AS process in the MLE configuration:* A concentric anoxic zone could be constructed inside the Schreiber reactor. Because most of the BOD is removed upstream in the anaerobic lagoon, the existing Schreiber reactor should have sufficient volume for the anoxic-aerobic configuration. The piping should be modified to feed the reactor from the center (i.e. the anoxic zone). Submersible mixers would not be necessary in the anoxic zone as the traveling bridge can be modified to have paddles for mixing. The anticipated effluent TN is 20 mg/L at a nitrate recycle flow rate of 5.8 MGD because of the limited BOD available after the anaerobic lagoon. One disadvantage of this alternative is that the Schreiber reactor would have to be taken out of service for the construction of the anoxic zone. Nitrification and denitrification can be accomplished in the existing reactor by some operational changes. These changes in the aeration patterns can be accurately determined only by experimenting with the Schreiber Process.
3. *Construct a dedicated anoxic zone upstream of the existing AS reactor and construct a pumping station to divert a portion of the anaerobic lagoon influent to the anoxic zone to enhance denitrification:* An in-line macerator would be installed on the suction piping of the anaerobic lagoon influent pumps to prevent large objects from being transferred to the anoxic tank. By bypassing approximately 0.05 MGD around the lagoon, the denitrification in the anoxic zone would be benefited. This alternative will require a nitrate recycle rate of 11.5 MGD to achieve an effluent TN concentration of 12 mg/L. Such a high recycle would also recycle excessive amounts of DO from the aerobic zone and would significantly reduce denitrification capacity.
4. *Construct an anoxic tank upstream of the AS basin, a nitrate recycle pumping system, and a denitrification filter downstream of the secondary clarifier for additional N removal with methanol addition:* In addition to the modifications presented in Alternative 1, a denitrification filter and a new pumping station would be constructed. Because the flow to the filter would be BOD deficient, a methanol feed system also would be necessary. The anticipated effluent TN is 3.0 mg/L.
5. *Construct an additional Schreiber reactor to operate the AS process with cyclic aeration controlled by the DO probe system:* The Schreiber Process is designed to remove nitrogen by simultaneous nitrification and denitrification accomplished through DO control. However, because the ammonia load is so high, the existing reactor cannot optimally achieve nitrogen removal. Therefore, a second reactor is needed. This alternative can produce an effluent with 12 mg/L of TN.

The capital costs of the alternatives are \$2,020,000; \$610,000; \$2,200,000; \$4,480,000; and \$1,740,000 for the Alternatives 1, 2, 3, 4, and 5, respectively. The calculations of the estimated annual changes in the O&M costs showed that each one of the Alternatives 1 through 5 will bring a reduction in O&M costs: \$148,200; \$153,700; \$162,200; \$106,800; and \$168,100, respectively. The calculations of estimated total costs of additional nitrogen removal indicated that Alternatives 1, 3, and 4 will bring an increase

in the costs of \$0.038; \$0.038; and \$0.338, respectively; whereas Alternatives 2 and 5 results in reductions of \$0.137 and \$0.021 per lb of additional N removed, respectively.

STRASBURG WWTP

The Strasburg WWTP is an oxidation ditch activated sludge facility currently rated for an average flow of 0.975 MGD, and the facility discharges to the North Fork of the Shenandoah River. The plant has a maximum ammonium-N permit limit of 10.4 mg/L between January and May, and 4.9 mg/L between June and December. Current annual average effluent flow from the facility is 0.6 MGD. The facility is currently accomplishing complete nitrification as the effluent ammonia concentration is less than 1 mg/L year round.

Preliminary treatment facilities include a mechanical screen installed in an influent channel in the headworks building. After screening, the wastewater flows into a manhole from which the flow is diverted to two oxidation ditches, which are operated in parallel with an HRT of 24.2 hours at the design average flow of 0.975 MGD. Aeration is accomplished via brush aerators. Mixed liquor from the ditches is distributed between two secondary clarifiers. The SOR of the clarifiers is 388 gpd/ft² at the design flow. The RAS and WAS flow rates are adjusted with a PLC, which is used to adjust the valves. Secondary effluent flows into a chlorine contact tank for disinfection, followed by dechlorination with sulfur dioxide.

WAS is pumped into an aerobic digester for VSS reduction. The underflow from the digester is pumped into a storage tank where sludge is mixed with polymer and then transferred to a Plate & Frame press for dewatering to a concentration of 25 to 30 % solids.

Because of the lack of a flow distribution structure, flow distribution between the ditches is sometimes uneven causing one of the ditches to be either under or over loaded, which also affects the BNR capacity.

BNR can be accomplished by operating the ditches with cyclic aeration, where two brush aerators in each oxidation ditch will be turned off periodically to establish anoxic conditions. The existing DO probes will be used to continuously monitor the DO levels. With a PLC installed, automatic adjustment of the effluent weir elevation will provide DO control at the set point. It is recommended that DO levels be maintained at 1 to 2 mg/L. The PLC will also control the timing sequence of the aerators to accomplish cyclic aeration. The cycle durations should be determined by the operators through full-scale pilot testing.

Capital costs are based on modifying the existing oxidation ditches to operate in a cyclic aeration mode, and total \$120,000. The estimated annual change in O&M costs would be a reduction of \$120,000. The estimated total costs for implementing BNR consist of denitrification costs as the plant is currently nitrifying. The savings per lb additional N removed is estimated to be \$0.14.

STUARTS DRAFT WWTP

The Stuarts Draft WWTP is an oxidation ditch activated sludge plant that is currently rated for an average daily flow rate of 1.4 MGD. It discharges into South River, which flows into the South Fork of the Shenandoah River. The discharge permit limits TKN concentrations to a monthly average of 4.0 mg/L between June and December, and to 12.6 mg/L between January and May. The required weekly averages are 6.0 mg/L and 18.9 mg/L for the same periods. The current annual average flow rate is 0.98 MGD, and the current annual average BOD and TKN concentrations in the plant influent are 198 mg/L and 31 mg/L, respectively.

After preliminary treatment, wastewater is combined with RAS and distributed between three oxidation ditches, of which two were part of the original design. The combined HRT of the ditches is 19.7 hours at the design average flow of 1.4 MGD. Each ditch is provided with brush aerators, and the mixed liquor flows into three circular secondary clarifiers. The SORs of the clarifiers are 396 gpd/ft² at design average flow. Following clarification, the wastewater is chlorinated, dechlorinated and reaerated prior to discharge. WAS is pumped into the aerobic digesters, dewatered using a mobile belt filter press, and land applied.

The influent flow distribution between the ditches is not even because headloss in the pipes varies at different flows. As a result of unequal flow distribution, some basins are over loaded. Improper loading also causes unequal loading to the secondary clarifiers, and as a result, the facility experiences a significant amount of solids washout. Because of these design limitations, the facility has not been able to accomplish consistent nitrogen removal. The effluent of the Stuarts Draft WWTP has an average TN value of 10.4 mg/L and an average TP value of 1.8 mg/L. The data for the period August 1996 through April 1997 was used for the BNR evaluations. BNR can be improved by:

1. Constructing a new oxidation ditch flow distribution structure, ensuring that the ditches are loaded in proportion to their volume.
2. Installing a DO control system for the oxidation ditches to operate them cyclically.
3. Constructing a new secondary clarifier influent flow distribution structure.
4. Constructing a 52 ft diameter secondary clarifier to ensure that excessive amounts of biosolids are not washed away.

These modifications will enable the facility to meet an effluent TN limit of 4.0 to 5.0 mg/L. A chemical P removal system is not necessary as the current effluent level is 2.0 mg/L.

The total capital costs of implementing BNR is \$1,240,000 with an estimated annual reduction in O&M costs of \$5,900. The estimated total cost is \$2.36 per lb of additional N removed annually.

CITY OF WAYNESBORO WWTP

The Waynesboro WWTP is a combination trickling filter-RBC that serves the City of Waynesboro, Virginia. The plant discharges to the South Fork of the Shenandoah River, which eventually flows into the Potomac River. The current permit requires the plant to maintain average effluent ammonia and BOD₅ concentrations of 2 mg/L and 7.5 mg/L, respectively, June through October. The average BOD₅ limit for November through May is 15 mg/L and there is no limit for ammonia for that period. At present, the plant receives an average flow of 3.63 MGD, which is more than 90 percent of the design flow of 4 MGD. The plant also has a severe I&I problem which can result in flows exceeding 9 MGD, which is the maximum flow that can be pushed through the plant.

The flows and loads received at the facility over the twenty two month period from January 95 through October 96 were analyzed for this evaluation. The raw influent BOD₅ averaged 135 mg/L for that period. The raw influent BOD₅ to TKN and BOD₅ to TP ratios were not determined during the period except for two TKN and TP measurements performed on June 1, 19 96. Based upon these measurements, BOD₅ to TKN and BOD₅ to TP ratios were calculated to be 6.7 and 75, respectively.

A Parkson Aquaguard type automatic screen is installed in the influent channel. The screen utilizes a continuous belt made up of filter elements that fit together providing horizontal and vertical clear spacings of 6 mm and 25 mm, respectively. Following screening, grit is removed from the wastewater via a Smith & Loveless Size 11 Pista Grit System. All flows then enter a wet well that was designed to maintain flow to the trickling filters. The plant has two primary clarifiers. Each clarifier has a diameter of 57 feet and a side water depth (SWD) of 10 ft. The design overflow rate is 790 gpd/ft² and the current overflow rate at average flow is 711 gpd/ft². The clarified liquid flows over the peripheral weir into a control well, from where it flows to the trickling filters. Sludge is pumped from the bottom of the clarifiers to the anaerobic digester. The plant has two high rate trickling filters that are 92 ft in diameter. Each filter contains 6 ft x 6 ft plastic media blocks, which have a very high void fraction (0.95%). Effluent from both filters returns to the control well where the flow is split and recirculated to the filters. The secondary clarifiers are similar in design to the primary clarifiers but slightly larger because trickling filter biomass solids do not settle and concentrate as readily as sewage organic solids. The design overflow rate is 600 gpd/ft² and the current overflow rate is 547 gpd/ft². During normal operation, clarified water enters the wet well of the tertiary pumping station. The tertiary pumps lift the flow to the inlet channels of the RBC's. There are two RBC trains, each containing 7 rotating assemblies. Each rotating assembly consists of a series of polyethylene disks (Walker Process Corporation, Model F-89 and F- 89 N). Flow from the RBC's next flows to the tertiary filters where suspended material is removed and returned to the treatment process. The plant utilizes 3 automatic backwash filters manufactured by Infilco. Disinfection is currently accomplished by chlorination, which is followed by dechlorination. Gas chlorination also is used when the tertiary treatment process is bypassed. To remove excess chlorine in the effluent, the

plant is equipped with a SO₂ feed system. To achieve a minimum of 6 mg/L dissolved oxygen (DO) in the effluent, flow passes over a 5 step cascade aerator. Aerated effluent is finally discharged to the South River via a 24 inch pipe.

The facility has two anaerobic digesters that are normally operated in series. The sludge is heated by means of an external heat exchanger. There is no mixing in the secondary digester. The sludge is drawn off the bottom of the secondary digester and sent to dewatering. Flow from the digester enters to the belt press, an Ashbrook-Simon-Hartley Klampress size 3, Type 85. Dewatered sludge is transported for land application.

Effluent characteristics for the period from January, 1995 through October, 1996 show that the WWTP successfully nitrifies all year round, and produces an average effluent ammonium concentration of 1.21 mg/L, with a monthly average range of 0.46 to 3.61 mg/L. Therefore, the wastewater could be denitrified by the addition of tertiary denitrifying filters, and the desired effluent nitrate concentration could be selected by controlling the addition of an organic carbon source such as methanol to accomplish denitrification. Thus, an effluent total nitrogen (TN) concentration of either 8 mg/L (Alternative 1; 329,000 lb methanol per year) or 4 mg/L (Alternative 2; 432,000 lb methanol per year) could be selected, as desired.

Capital costs include construction of the denitrification filters for both alternatives, and thus the total is same for each: \$3,500,000. The two alternatives vary in terms of O&M costs, with increases of \$69,400 and \$89,500 for alternatives 1 and 2, respectively. The estimated costs per lb of additional N removed is \$1.61 and \$1.27 for the first and second alternatives, respectively.

TOWN OF WOODSTOCK WWTP

The Town of Woodstock WWTP is an oxidation ditch activated sludge plant located in Shenandoah County, VA, and the treated wastewater is discharged to the North Fork of the Shenandoah River. It is an oxidation ditch activated sludge plant with a design capacity of 1.0 MGD, and the dry and wet weather flows received at the plant are approximately 0.6 MGD and 1.0 MGD. Operators are on site 10 to 11 hours every day. Current discharge permit does not put any limitations on effluent nitrogen species.

Data for the 12-month period from January 1997 to December 1997 were examined. Historically, measurements of effluent $\text{NO}_3\text{-N}$ have not been performed. Influent TKN, effluent ammonia-N and nitrate-N measurements typically are not performed at the plant, either. Effluent ammonia-N values from April 1992 through February 1993 were available, however, and these data were used for this evaluation. BOD_5 values showed a wide range of variance during the period under study; with the lowest and highest values being 77.5 mg/L (March 1997) and 224.6 mg/L (December 1997), respectively. The average raw influent TKN concentration, calculated from a for BOD_5 to TKN ratio of 6, was 20.4 mg/L. The effluent pH, BOD_5 and TSS concentrations routinely achieved by the plant are in compliance with the permit requirements. The effluent ammonia values varied between 0.02 mg/L and 0.43 mg/L, except for an average of 2.46 mg/L during November. Apparently nitrification was mildly upset that month, because it is believed that the Woodstock WWTP oxidation ditch AS system is capable of accomplishing year round nitrification.

The influent flow enters the treatment plant through a gravity main and, after screening, passes through a Rotating Hydro degritter unit. There is also a bypass line equipped with a Rotosheer™ screen unit with bar screens in a 2 ft wide channel. After flow measurement, flow is divided between the oxidation ditches via a splitter box. The facility has two 650,000 gal oxidation ditches identical in size and operation, and each ditch is equipped with two 30 HP brush aerators. Two identical rim-fed circular secondary clarifiers follow the ditches. The nominal hydraulic retention time (HRT) is 4 hours, and the actual HRT is 2.54 hours at the average influent and return activated sludge (RAS) flows of 0.77 and 0.45 MGD, respectively. At these average flow rates and with a total surface area of 1,816 ft^2 , the surface loading rate of the clarifiers is 672 gpd/ft^2 , which is high for BNR treatment with clarifiers of this design. A 27,000 gal chlorination tank follows the clarifiers. Following disinfection, the effluent is dechlorinated by the use of sulfur dioxide. The chlorinator and the sulfonator used are both Advance type. Final effluent is discharged to the North Fork of the Shenandoah River. Sludge is wasted to the two 20,000 gal capacity aerobic digesters three times a week. Digested sludge is hauled by trucks once per week for land application.

Because they have a large internal recycle rate (usually 80 to 120 times the influent flow), oxidation ditches can obtain near complete denitrification if anoxic zones can be established within the ditches. It is recommended that this primarily operational

modification be made at the Woodstock WWTP. Thus, it is recommended that one brush aerator be operated continuously, while the other is cycled on and off in accordance with the BOD loading. The operators need to determine the appropriate on and off periods by experimentation. Timers should be installed in the cycled aerators for ease of operation, especially when the operators are not at the plant. A system for the chlorination of the RAS flow should also be constructed. If efficient BEPR is desired in the future, it can be accomplished by building a small anaerobic reactor ahead of the oxidation ditch. An HRT of 2 to 4 hours with 30 to 50 % of the influent flow passing through this unit should be sufficient for efficient biological phosphorus removal.

Capital costs for implementing BNR are based on: installing a PLC to monitor DO in the ditches, operating the ditches in cyclical aeration mode, and installing a new return sludge chlorination system to control growth of filamentous bacteria in the ditches. Total capital costs for these modifications would total \$70,000. The estimated annual change in O&M costs are estimated to be \$11,000. The cost of additional N removal is estimated to be \$0.22 per lb.