“25 years of BNR and ENR Implementation in the Chesapeake Bay Watershed and a Look to the Future”

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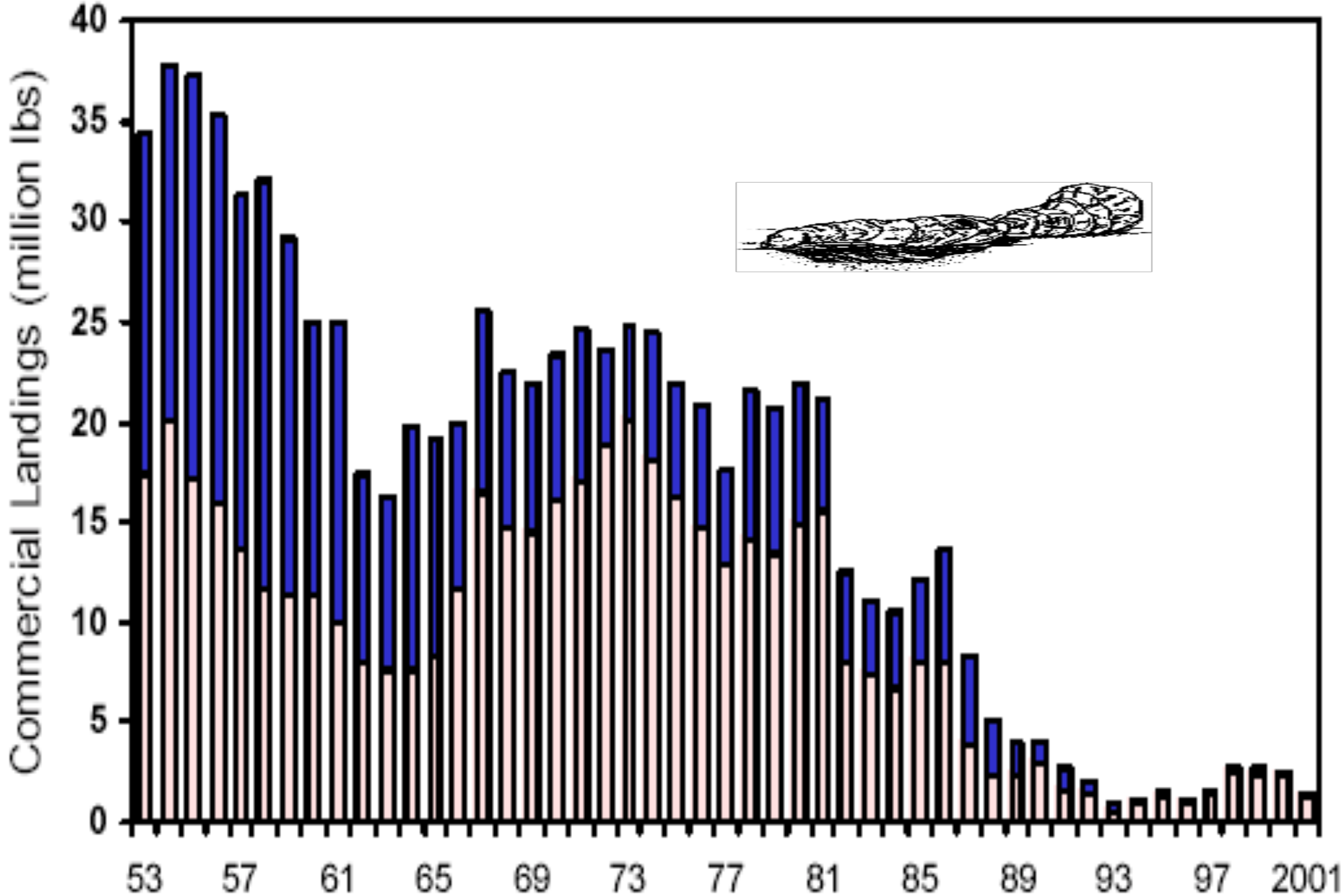
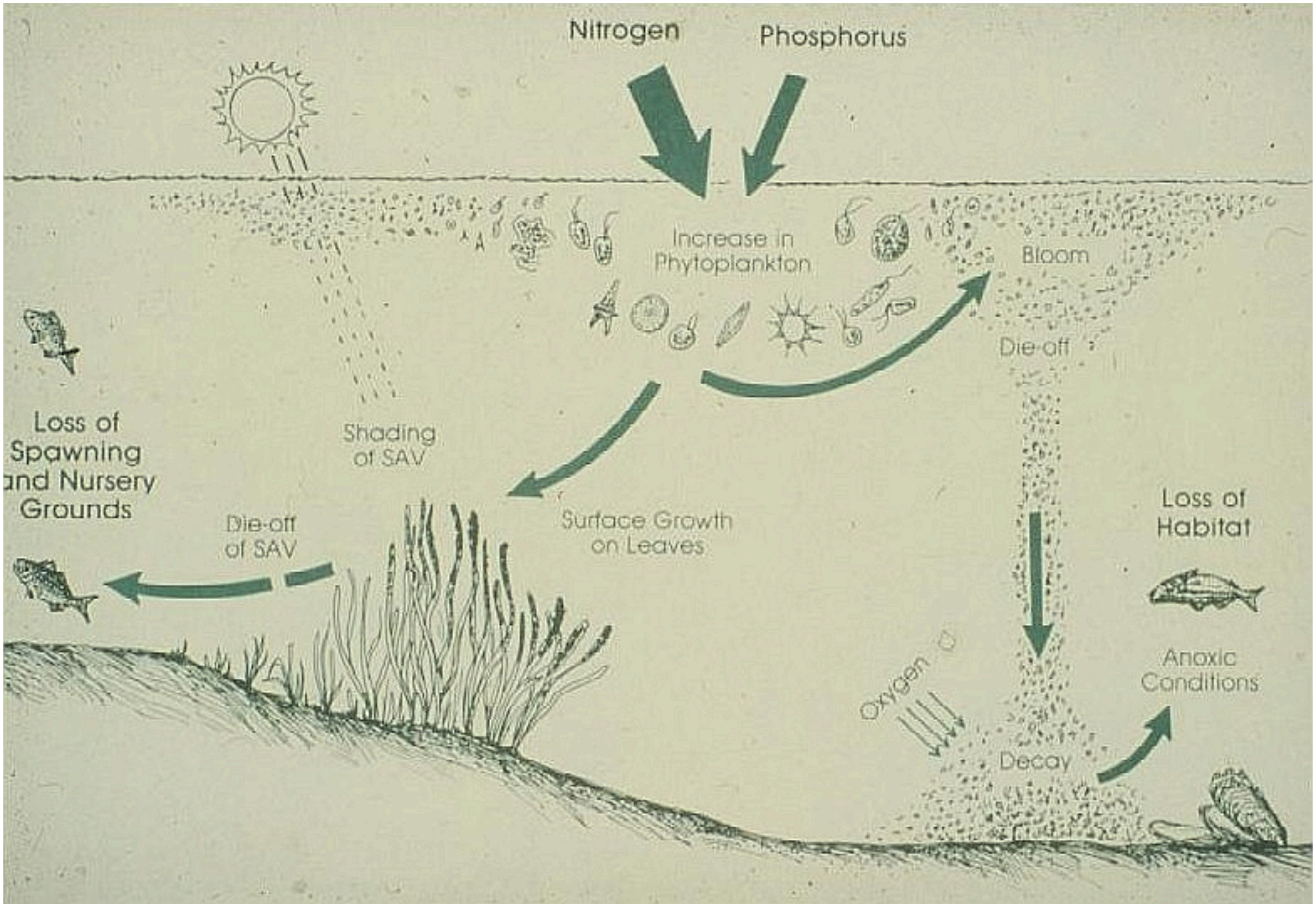


FIGURE 8. Chesapeake Bay oyster landings by year

CAUSES OF WATER QUALITY AND FISHERIES DECLINE IN THE CHESAPEAKE B



IMPACTS OF NUTRIENTS ON WATER QUALITY AND AQUATIC LIFE

Nutrients

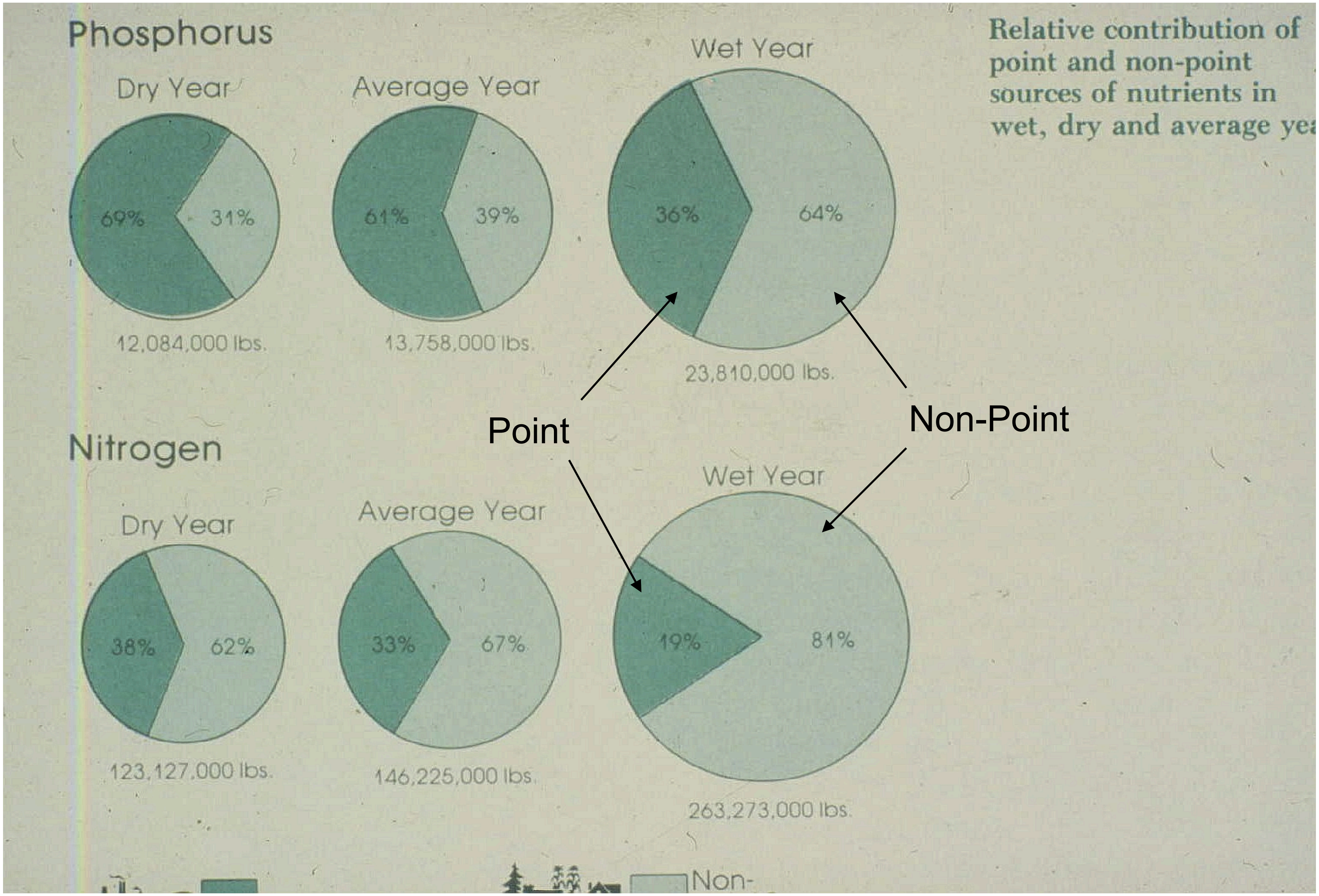
Nitrogen

and

Phosphorus

- Can cause excessive growth of phytoplankton (e.g. Algae) and rooted aquatic plants in rivers, lakes and reservoirs.
- At any given time and place, one of them will control the rate and amount of growth, i.e. will be the “limiting

SOURCES OF NUTRIENTS

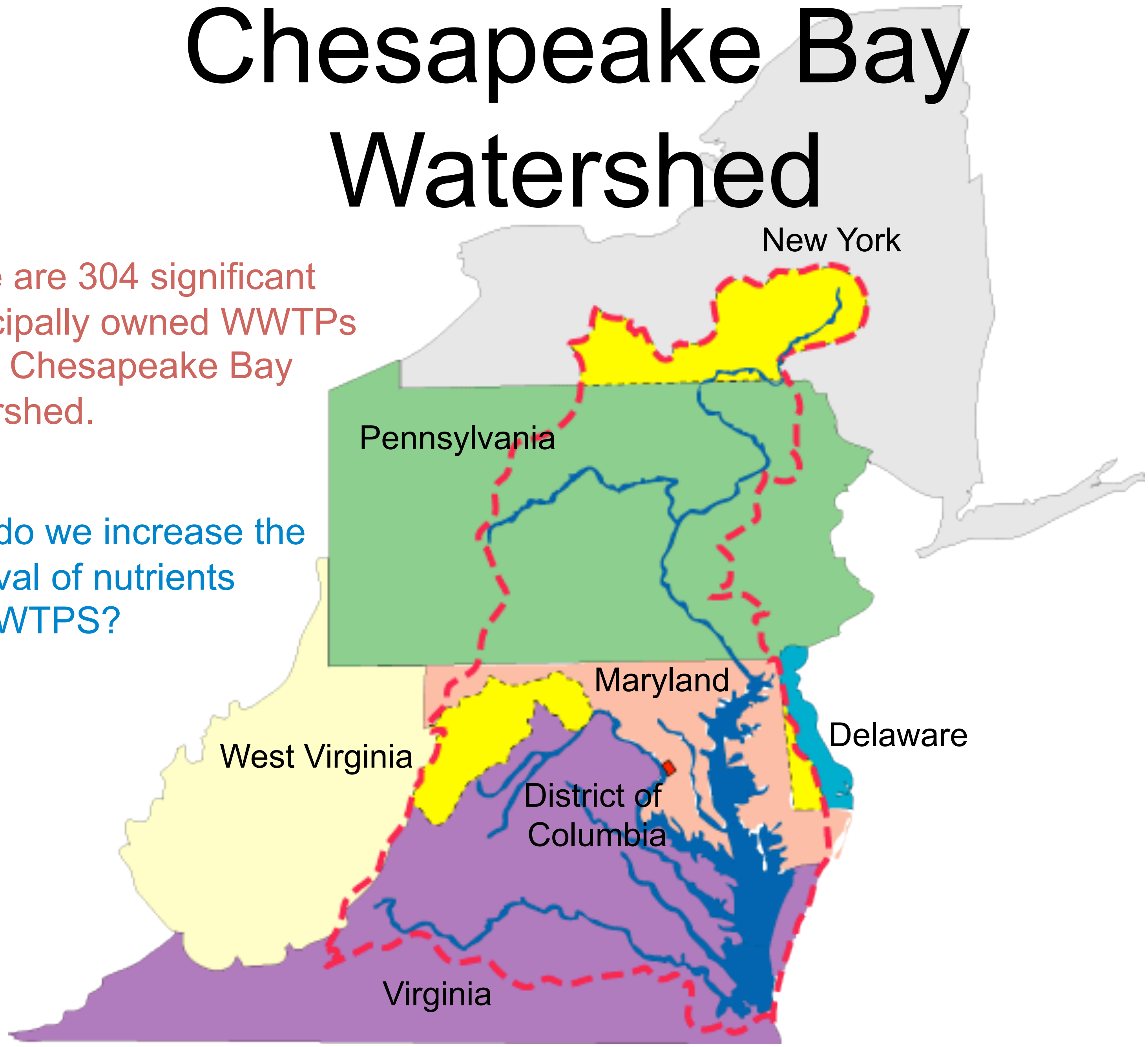


VARIATION IN YEARLY POINT AND NON-POINT NUTRIENT POLLUTION

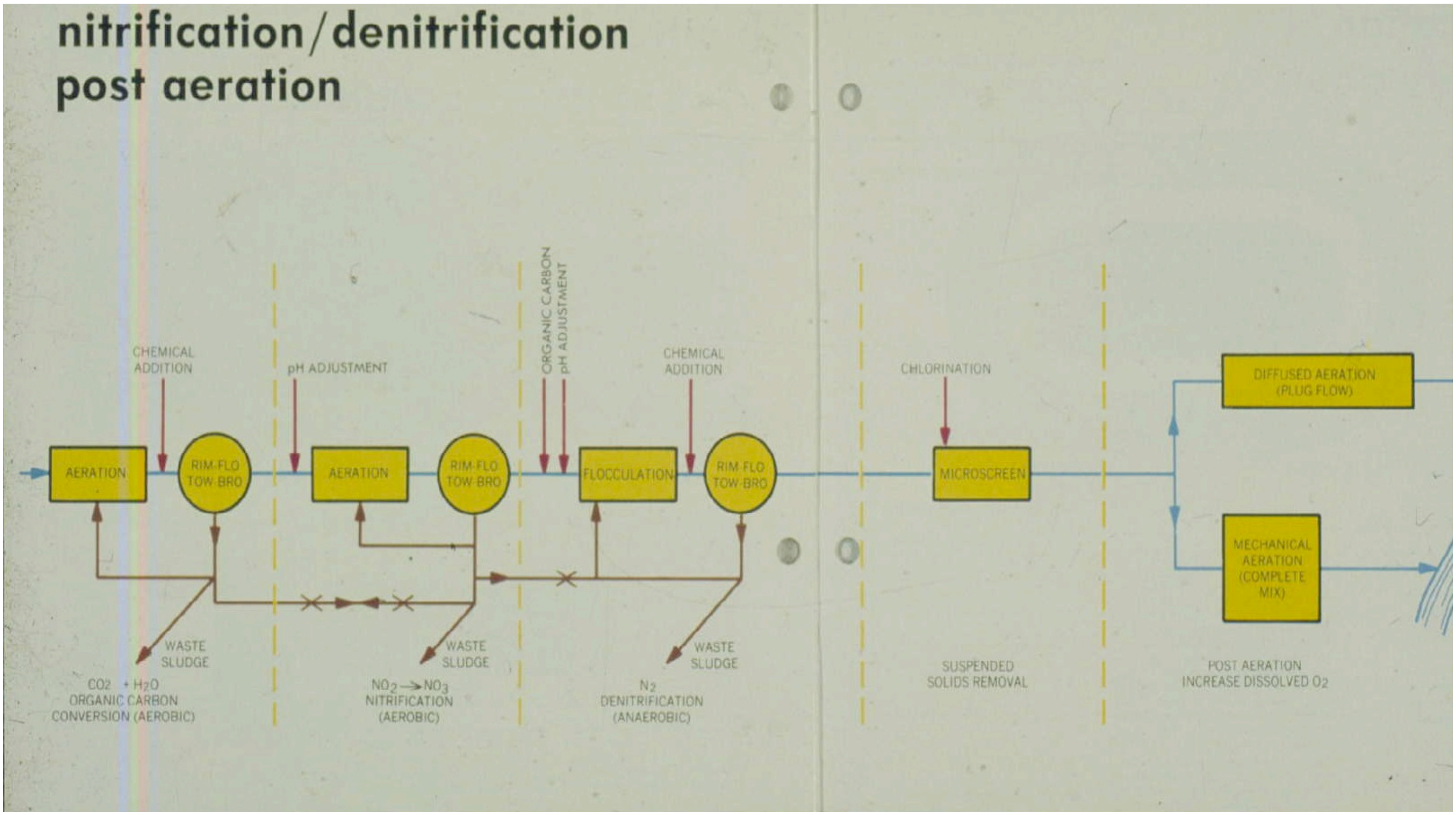
Chesapeake Bay Watershed

There are 304 significant Municipally owned WWTPs In the Chesapeake Bay Watershed.

How do we increase the removal of nutrients by WWTPS?



1970s Technology-Three Stage Treatment System for Nitrogen Removal - Huge Increase in Costs for Retrofits



PHOSPHORUS REMOVAL FROM WASTEWATER

- 1980 Technology - CHEMICAL Precipitation with Fe, Al or Ca
- Options
  - Precipitation in Primary Clarifier
  - Simultaneous Precipitation in Activated Sludge
  - Tertiary Precipitation and Settling
  - Effluent Filtration for TSS removal
- Problem, large increases in Waste Sludge Production plus cost of chemicals

INCREASE IN WASTE SLUDGE FROM PHOSPHORUS PRECIPITATION – Canadian Great Lakes Program

Influent TP = 6.8 mg/L & Effluent TP <1 mg/L

- **Primary Addition of alum, iron and lime**

  - **waste sludge mass increased by an average of 40%** at 7 primary plants (from 999 to 1407 lbs/MGD) but the <u>solids concentration decreased from 6 to 5.3%</u>

- **Secondary Addition of alum and iron**

  - **total sludge mass (primary+WAS+chemical) increased by an average of 26%** at 15 conventional activated sludge plants (from 1441 to 1807 lbs/MGD) but <u>solids concentration decreased from 4.5 to 4.2%</u>

- 30 grams per capita per day increase for both Primary and Secondary plants, i.e. 5 grams increase for every 1 mg/L of phosphorus removed

INCREASE IN WASTE SLUDGE FROM PHOSPHORUS PRECIPITATION

Influent TP = 6.8 mg/L & Effluent TP ≤1 mg/L

- **CAS Plant Digested Sludge Production**
  - **total anaerobically digested sludge mass increased by an average of 33%** for 23 CAS plants using simultaneous precipitation with metal salts

Reference: N.W. Schmidtke (1981). Proceedings of the 2nd European Symposium on Characterization, Treatment and Use of Sewage Sludge. Reidel Publishing Co.

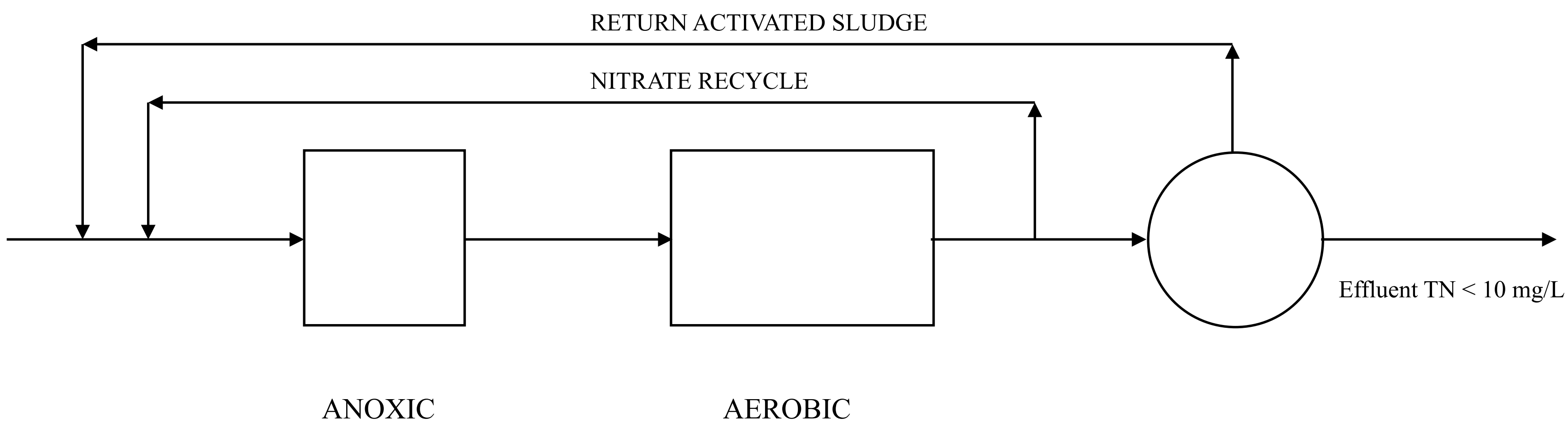
NOT GREEN ENGINEERING!!

BIOLOGICAL NUTRIENT REMOVAL (BNR) PROCESSES

- Green Engineering: Utilization of Technology that improves or is highly compatible with the environment, eliminates or minimizes secondary impacts, and minimizes the cost of implementation
- BNR: Economical nutrient removal wastewater treatment processes that minimize secondary impacts.
  - Reduce energy usage, reduce sludge production, reduce or eliminate chemical usage.

Conditions required for Economical Nitrogen Removal Wastewater Treatment

1. Nitrification followed by denitrification
2. Nitrification requires Aerobic Conditions (DO as an electron acceptor)
3. Denitrification requires Anoxic Conditions (NOx as electron acceptor), and biodegradable organic carbon (COD)
4. Biological approach uses wastewater COD for organic carbon source

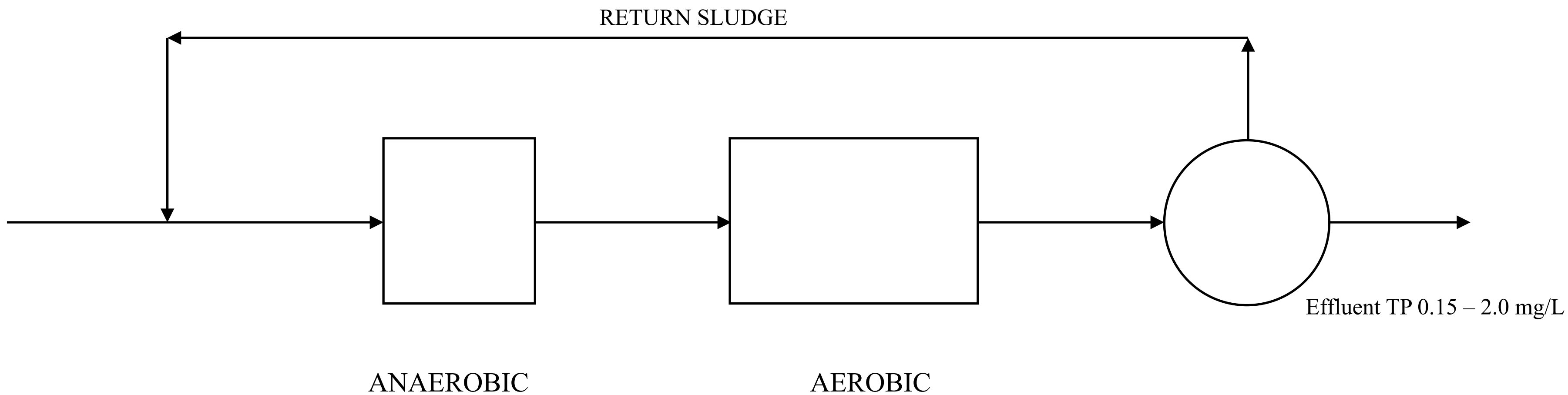


MODIFIED LUDZAK-ETTINGER (MLE) CONFIGURATION

BASIC BIOLOGICAL NITROGEN REMOVAL CONFIGURATION

The Basic Configuration for Biological Phosphorus Removal

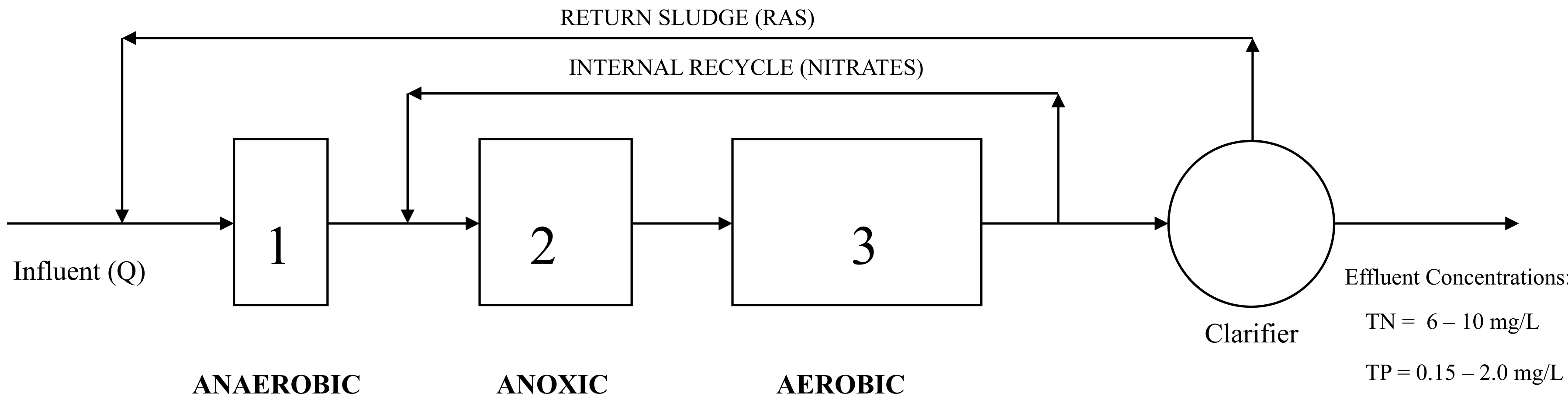
1. Anaerobic – Aerobic Sequencing of Activated Sludge
2. VFAs Available in Anaerobic Zone, i.e. in influent or produced in Zone



Effluent TP a function of influent Bioavailable COD:TP ratio

PHOREDOX CONFIGURATION
aka A/O CONFIGURATION IN USA

SINGLE-SLUDGE COMBINED EBPR AND BIOLOGICAL NITROGEN REMOVAL PLUG-FLOW ACTIVATED SLUDGE BNR PROCESS CONFIGURATION



A2/O CONFIGURATION (USA)

IMPLEMENTATION STRATEGY for the Chesapeake Bay WWTPs

- Establish need for Point Source Nutrient Controls
- Introduce BNR Concepts and Design Methodologies
- Determine the ‘Limiting Nutrient’ for Bay Waters
- Demonstrate BNR technology
- Promote economic benefits of BNR

Implementation of BNR in the Chesapeake Bay Watershed

1984: Introduction of BNR through seminar & design workshop during summer, Richmond, VA

1985-86: VIP Pilot Plant Study – HRSD Lambert's Point Primary Treatment Plant

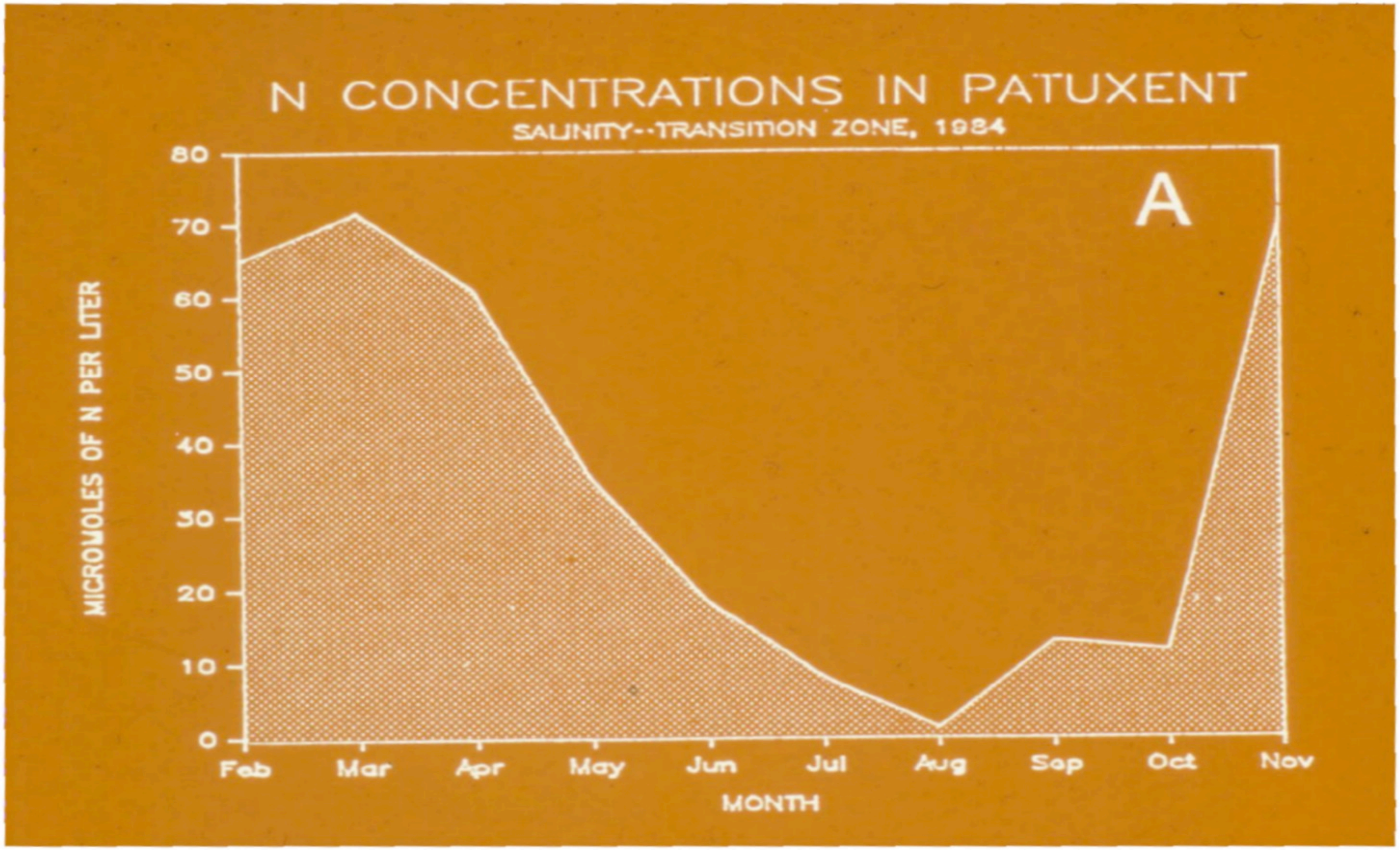
1985-86: Established N as the primary 'Growth Limiting Nutrient' in Bay Estuarine Waters

1986-90: A/O, A2/O & VIP full scale BNR demonstrations, HRSD York River WWTP

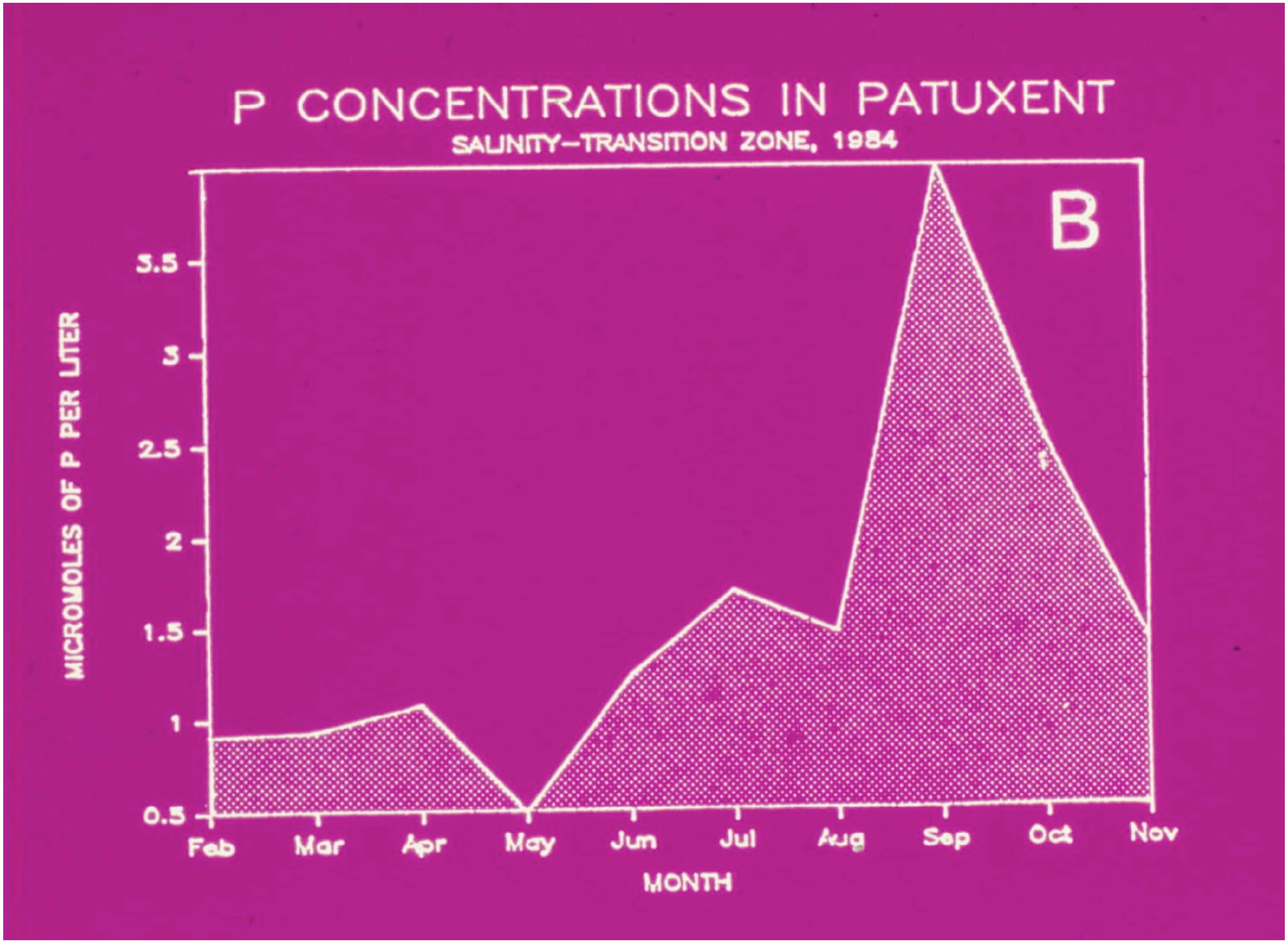
1987-90: Full scale BNR demonstrations, Bowie & Anne Arundel County, MD; Charlottesville, VA.

1990-2000: Developed BNR retrofit designs for >100 WWTPs in Chesapeake Bay Watershed using funding from the Chesapeake Bay Program.

ESTABLISH GROWTH LIMITING NUTRIENT FOR BAY WATERS



SEASONAL CHANGES IN NITROGEN CONCENTRATIONS
D'Elia et al. 1986



SEASONAL CHANGES IN PHOSPHORUS CONCENTRATIONS
D'Elia et al. 1986

- The omnipresence of P has resulted in N becoming the **limiting** nutrient in estuaries and coastal ocean waters throughout North America and around the world during much of the annual growing seasons.
- Nitrogen as the limiting nutrient was accepted by EPA and much of the USA engineering community after the publication and distribution of research results from studies within the Chesapeake Bay (STAC, 1986).
- **Reduction of Nitrogen inputs accomplishes reduced eutrophication until Phosphorus is limiting. Then Phosphorus reduction establishes control of water quality.**

IMPLEMENTATION OF BNR IN THE CHESAPEAKE BAY WATERSHED (con’t)

- Technology was never the problem. Major Obstacles were Politics, Policies and Perceptions
  - Limited regulation of effluent P loadings
  - No regulation of effluent N loadings
  - Implementation efforts limited to
    - Financial Carrots
      - Some Implementation of N Removal, mostly Maryland
    - Voluntary Goals Policy
      - Halted Implementation in Virginia
  - Implementation Strategy: Emphasized economic benefits of BNR: 1987-2000.

POTENTIAL ECONOMIC BENEFITS OF BNR PROCESSES

Can be used to reduce operating costs if appropriately operated and optimized

- Reduce oxygen transfer energy requirements
- Reduce chemical requirements
- Reduce WAS production

WHY DOES THIS HAPPEN?

WHEN NITRATE IS USED AS THE ELECTRON ACCEPTOR FOR BOD METABOLISM INSTEAD OF DISSOLVED OXYGEN, BACTERIAL GROWTH IS LESS EFFICIENT AND ALKALINITY IS PRODUCED. EBPR REMOVES P WITHOUT CHEMICALS

Aerobic reaction:

$$BOD + NH_3\text{-}N + DO \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + NO_3\text{-}N + H^+ + \text{cells} + \text{energy}$$

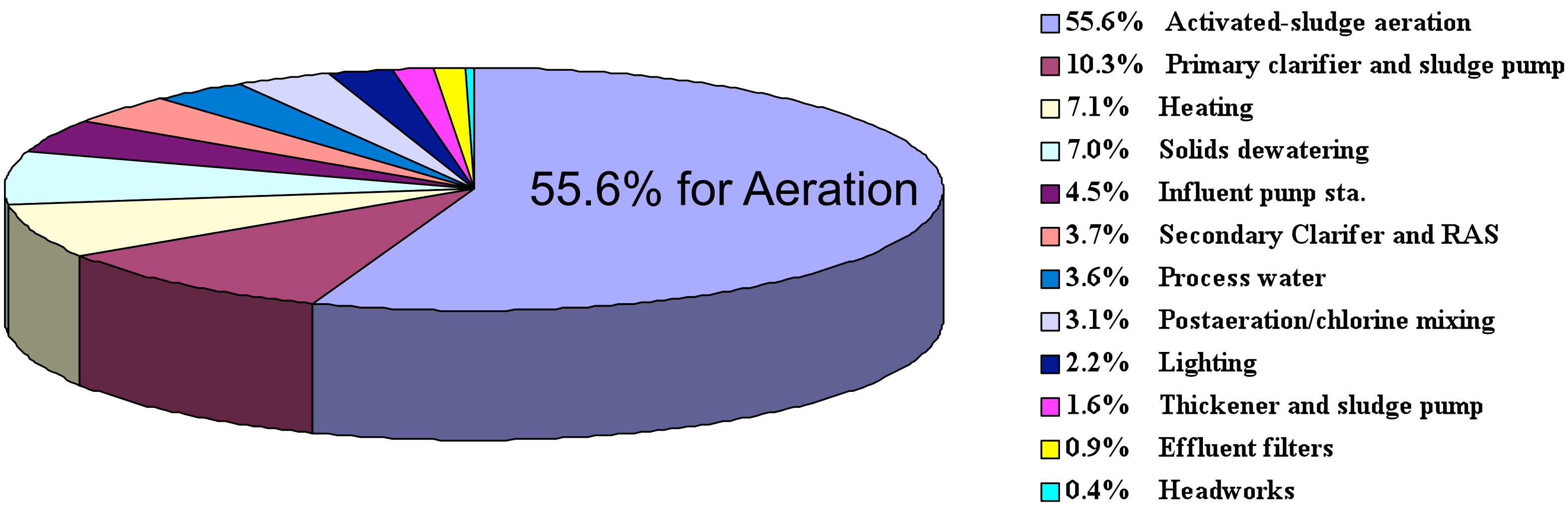
Anoxic reaction:

$$BOD + NO_3 \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + N_2 + 0.75\ \text{cells} + 0.8\ \text{energy} + \text{Alk.}$$

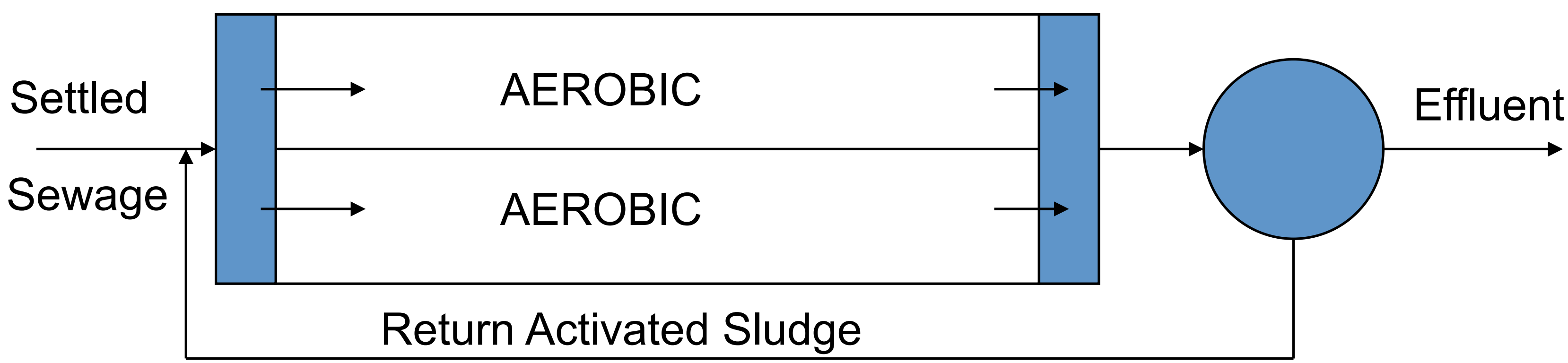
DEMONSTRATIONS OF ECONOMIC BENEFITS OF BNR

- 1982-83 Energy Reduction, Basingstoke WWTP – Thames Water Authority, England
- 1985-86 Cyclic Aeration – Melbourne, Australia
- 1987-88 Alkalinity Recovery – Charlottesville, VA
- 1987-90 Reduction of Chemicals - Bowie, MD
- 1993-96 IFAS Demonstration & Retrofit – Annapolis, MD, WWTP

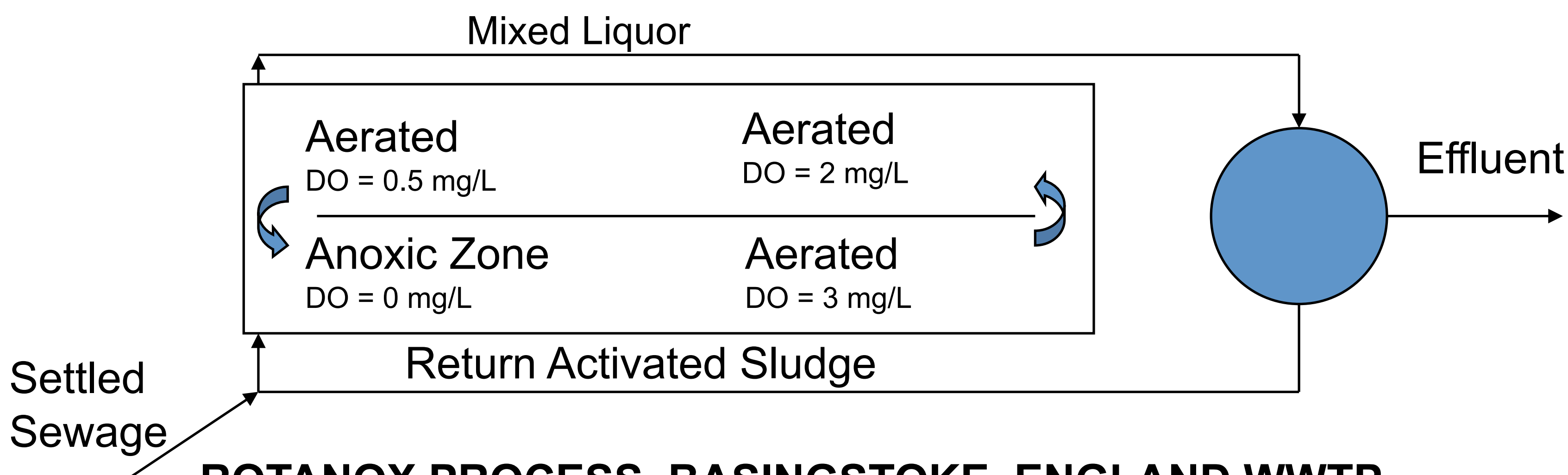
Distribution of Energy Usage for a Typical WWTP (EPRI, 1994)



BEFORE MODIFICATION



AFTER MODIFICATION

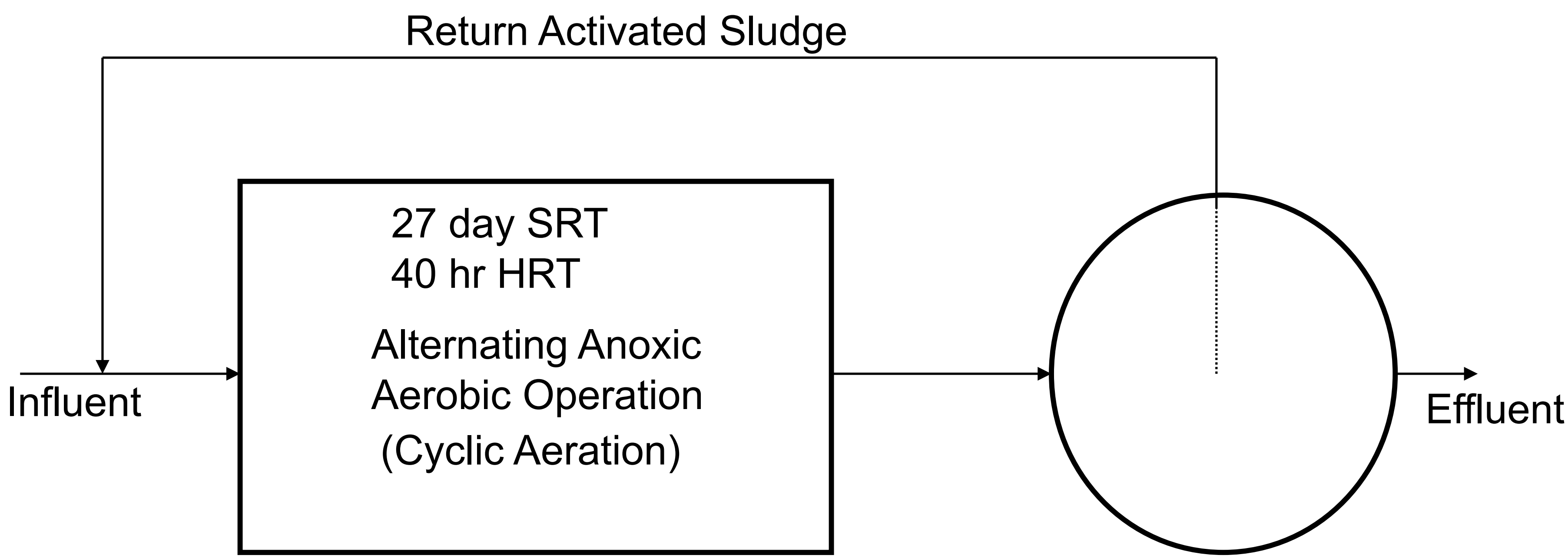


ROTANOX PROCESS, BASINGSTOKE, ENGLAND WWTP

Table 2. Comparison of Rotanox Process Performance with a Fully Nitrifying Control Sytem at the Basingstoke WWTP, UK (from Best, et al. 1984).

Time Period	Parameter	Influent	Effluent or Performance		% Reduction
			Control	Rotanox	
4/82-3/83	BOD_5, mg/L	150	13	4	69
	SS, mg/L	105	30	11	63
	NH_3-N, mg/L	32	0.5	0.7	(40)
	NO_3-N, mg/L	0	29	7	76
	TN, mg/L	42	30	8	73
Aeration Energy, kWh/kg BOD_r			1.15	0.9	22
O_2 Transfer Eff., kg O_2/kg BOD_r			2.1	2.5	(19)
Mixing Energy, kWh/kg BOD_r				0.2	
Total Energy, kWh/kg BOD_r			1.37	1.11	19

Flow = 3500 m^3/day (0.925 mgd), HRT = 7.7 hrs, SRT = 12-18 days, RAS = 1:1
F/M = 0.11, MLSS = 4000 mg/L, Sludge Production = 0.7 kg/kg BOD_5,
RAS NO_3-N = 6 mg/L



YARRA GLEN WWTP, MELBOURNE, AUSTRALIA

Modified Operation of the Yarra Glen WWTP (Ip, et al., 1986)

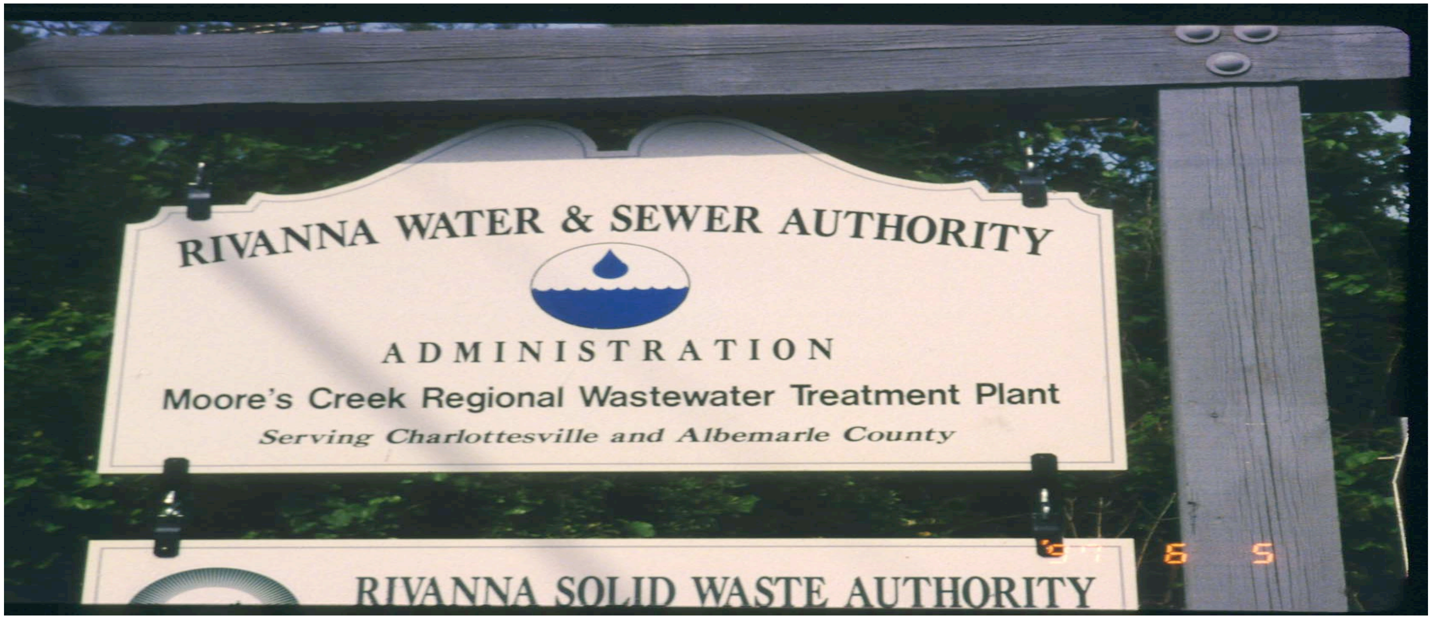
ECONOMIC BENEFITS OF CYCLIC AERATI

Table 3. Alternating Aerobic Anoxic Performance at Yarra Glen WWTP, Australia
(after Ip, et al. 1986)

Parameter	Influent	CMAS Effluent	AAA Effluent Air On/Off, hours 3/2	2/3	2/4	2/4 % Reduction
BOD_5, mg/L	396	5	7	3	3	40
SS, mg/L		15	20	15	15	0
TKN, mg/L	76					
NO_3-N, mg/L	0	25	20	10	7	72
MLVSS, mg/L	N.A.	3980	3500	2400	2400	40
Total Energy, kWhr/quarter		3400			2200	35

Flow was 21.2 m^3/d (3.9 gpm), Period of Study was 7/83-4/84

EXAMPLE



- CHARLOTTESVILLE, VA
  - Cost of Modification for N Removal & Alkalinity recovery
    - ≈ $100,000 for a 15 mgd conventional AS Process
  - Reduction in O&M of $55,000 per year:
    - Cost recovery time of 1.8 years

Aeration Basin Before Modification
Moore’s Creek WWTP, Charlottesville, Virginia

Aeration Basin After Modification
Moore's Creek WWTP, Charlottesville, VA

Moore's Creek WWTP Results

- Reduced Effluent Nitrogen

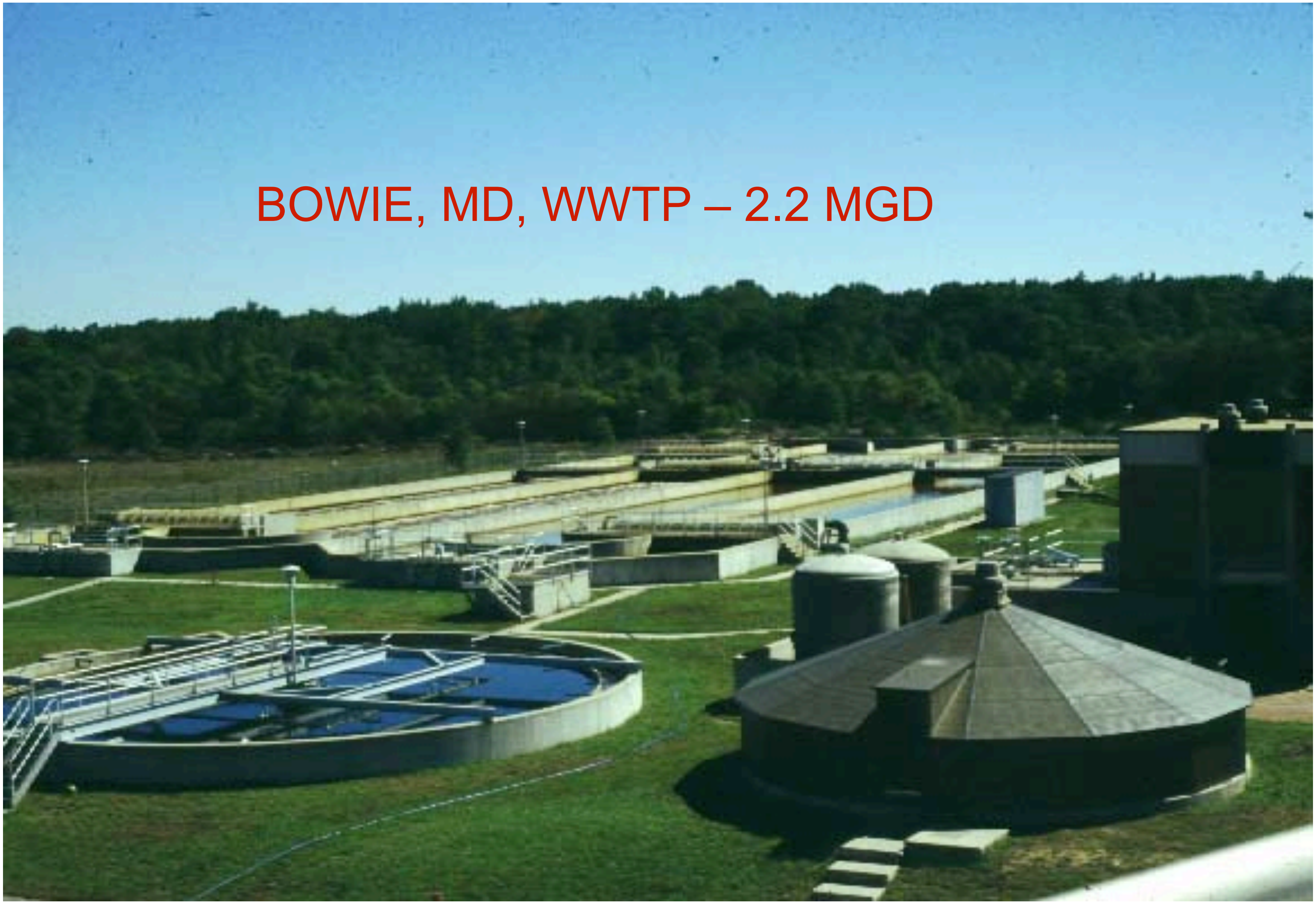
	TKN	NH_3-N	NO_3-N	TN	Nit	Denit
Inf, mg/L	25.3	16.6	0	25.3		
Eff, mg/L	4.5	0.9	8.7	9.6*	96%	47%

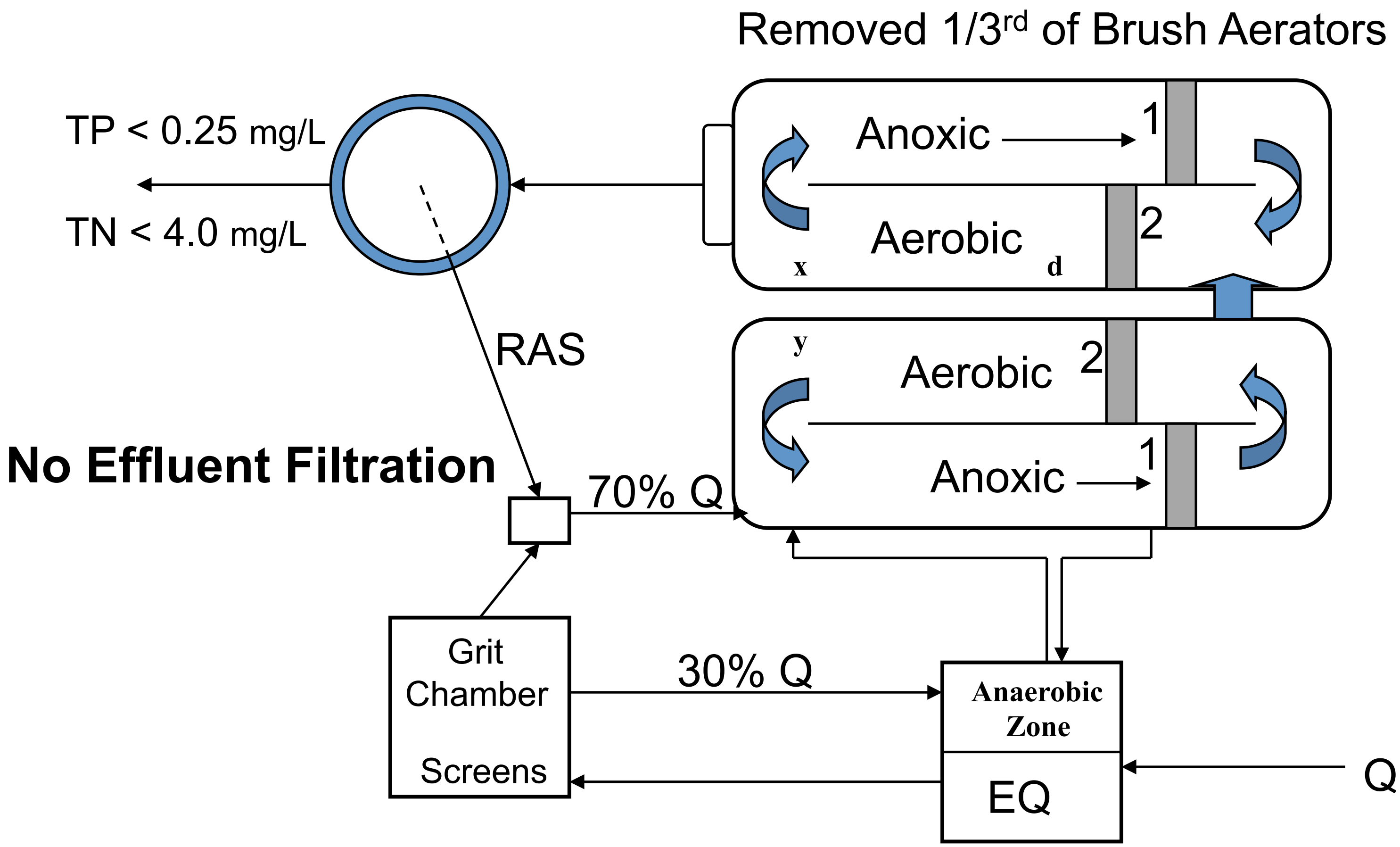
- Eliminated Alkalinity Addition
  - Cost Savings of $150/day ($54,750 per year)
- Improved Sludge Settling

	Before	After
SVI	180	80-110

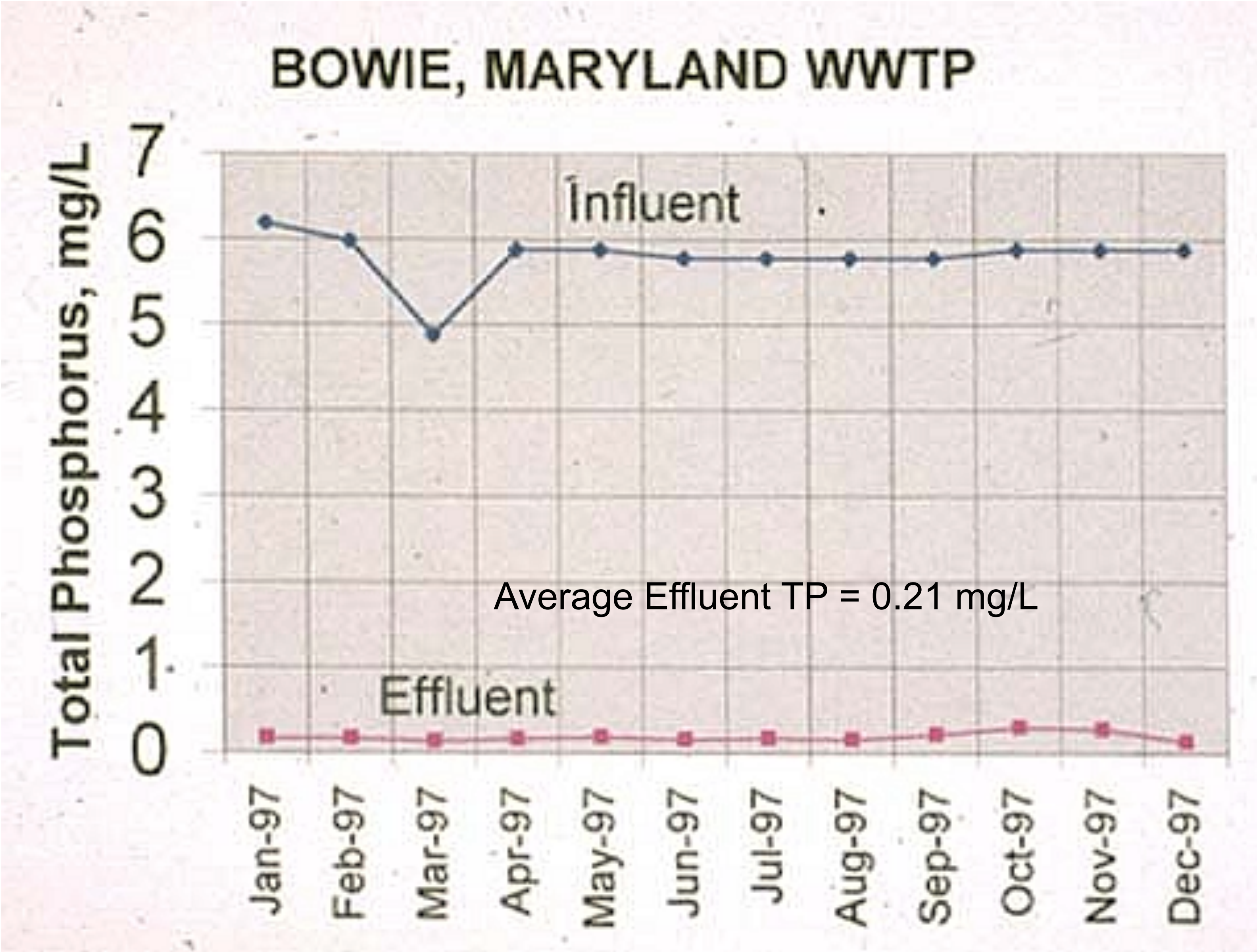
* Reactive N

MODIFICATION OF OXIDATION DITCH FOR COMBINED BNR (N&P) REMOVAL


BOWIE, MD, WWTP – 2.2 MGD



The Modified BNR WWTP Operated at Bowie, Maryland, 1988-2008


BOWIE, MARYLAND WWTP
Total Phosphorus, mg/L
7
6
5
4
3
2
1
0
Influent
Average Effluent TP = 0.21 mg/L
Effluent
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97

O&M COST SAVINGS WITH BNR, INCLUDING ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL

Table 5. Chemical Savings at the Bowie, MD, WWTP after BNR modifications

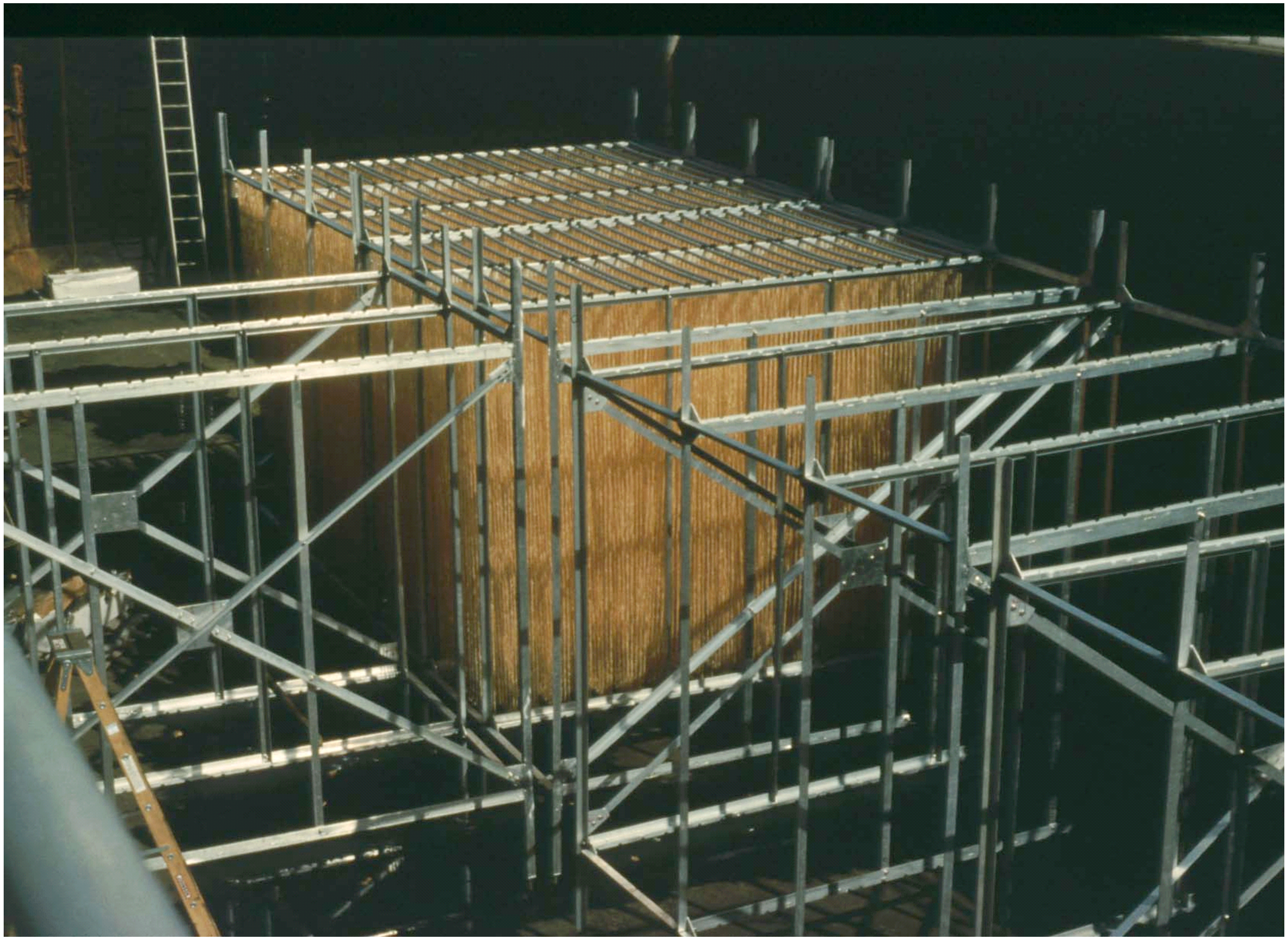
Cost Factor	Annual Costs, US $		Annual Savings
	Before BNR	After BNR	
Ferrous Sulfate	30,000	0	$30,000
Supplemental Alkalinity	37,500	0	37,500
Aeration Energy	57,706	50,260	7,446
Pumping Energy	0	7,227	-7,227
TOTAL ANNUAL SAVINGS			**$67,719**

Implementation of N & P BNR at BOWIE, MARYLAND

- Cost of Modification for N & P BNR:
  - ❖$230,000 for a 2.2 mgd Oxidation Ditch

- Reduction in O&M of $68,000 per year:
  - ❖Cost recovery time of 3.4 years
  - ❖ 20 YEAR SAVINGS: $1,124,000 (1988 $)

REDUCEDCONSTRUCTION COSTS WITH IFAS



RINGLACE INSTALLATION AT ANNAPOLIS, MARYLAND

REDUCED CONSTRUCTION COSTS USING IFAS – ANNAPOLIS WWTP

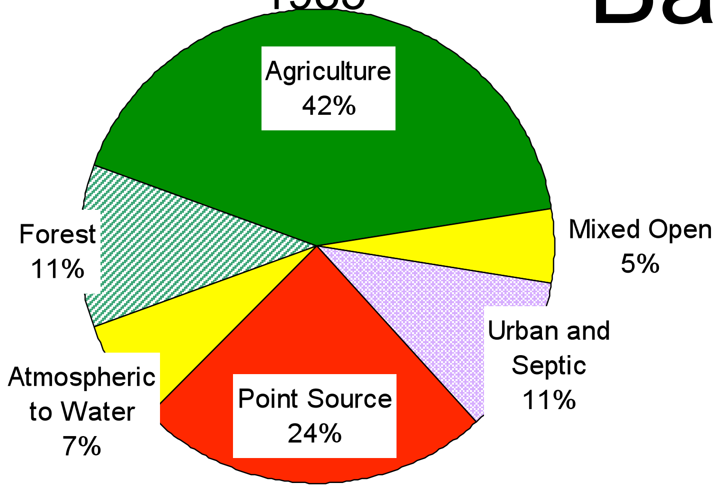
- ESTIMATED UPGRADE COSTS WITHOUT IFAS
  - $ 23 MILLION FOR HEADWORKS UPGRADE PLUS 1 AERATION BASIN & 3 SECONDARY CLARIFIERS
- TOTAL RETROFIT COSTS WITH IFAS
  - $9.2 MILLION FOR HEADWORKS UPGRADE PLUS IFAS INSTALLATION & 1 SECONDARY CLARIFIER
- IFAS INSTALLATION COSTS
  - $6.5 MILLION FOR RINGLACE INSTALLATION

TRENDS IN POINT SOURCE NUTRIENT LOAD REDUCTIONS IN THE CHESAPEAKE BAY WATERSHED

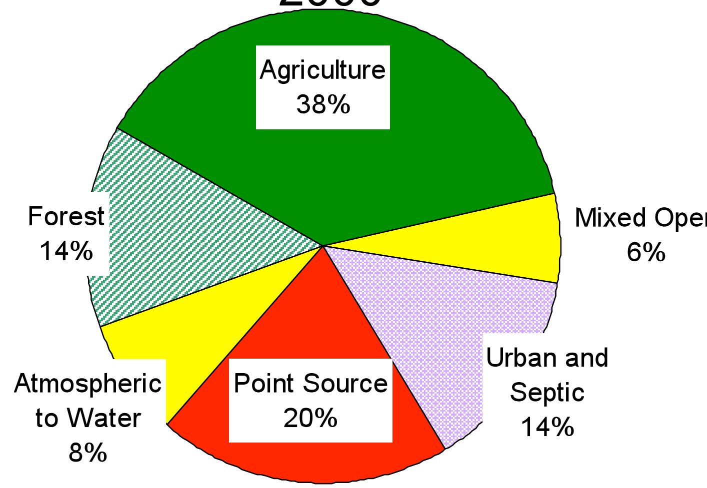
Sources of Nutrient Loads to the Bay

1985 | 2000

Nitrogen

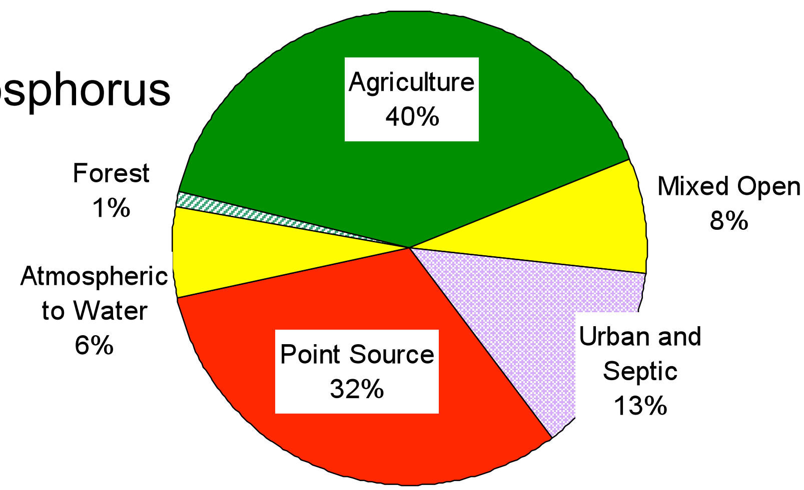


Total Load: 358 million pounds

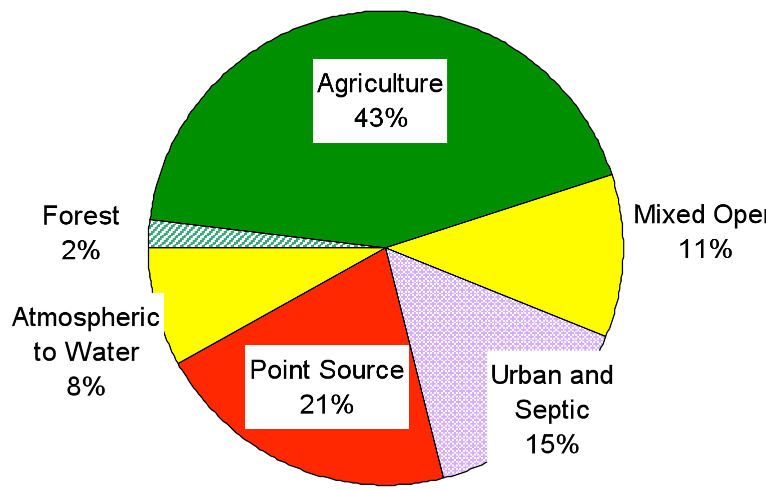


Total Load: 305 million pounds

Phosphorus



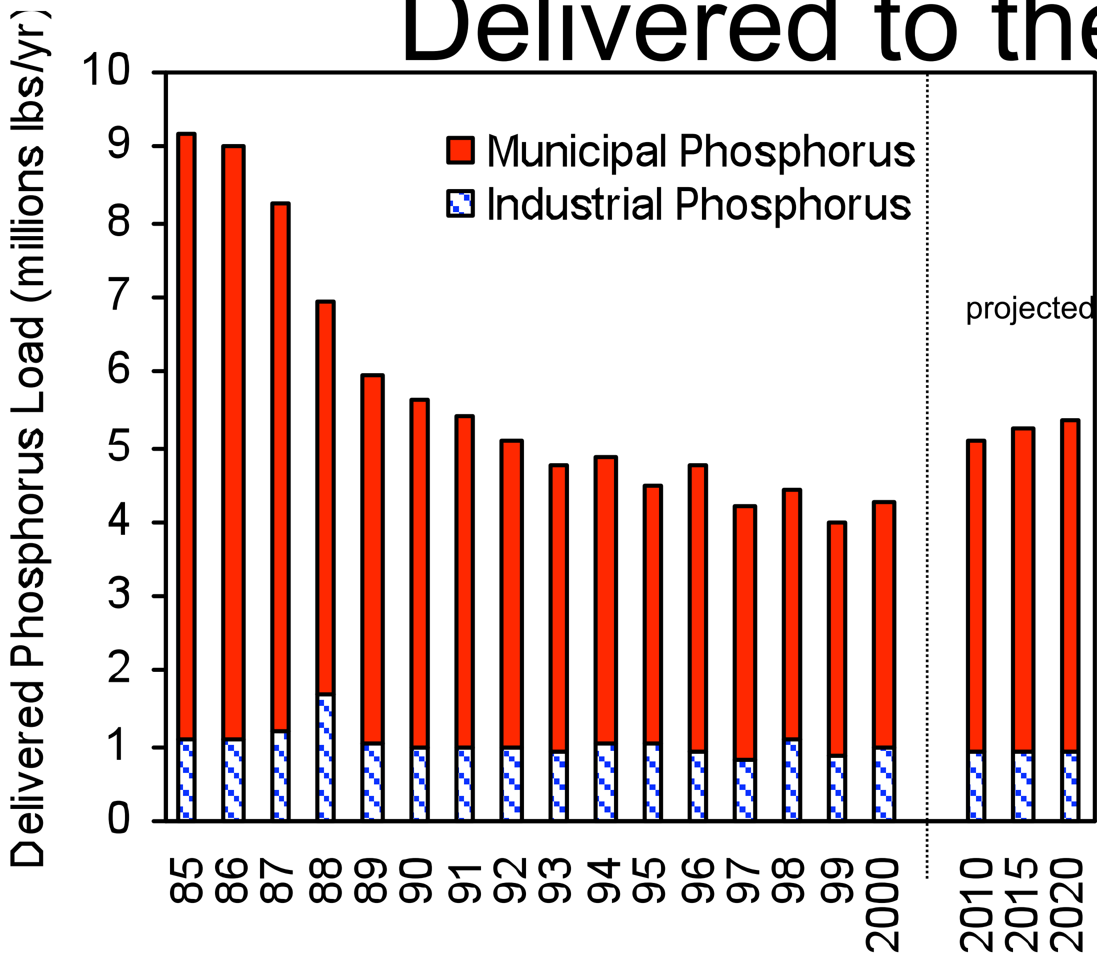
Total Load: 28.7 million pounds



Total Load: 20.7 million pounds

Source: Chesapeake Bay Program Phase 4.3 Watershed Model. Loads are from the entire watershed.

Point Source Phosphorus Loads Delivered to the Bay



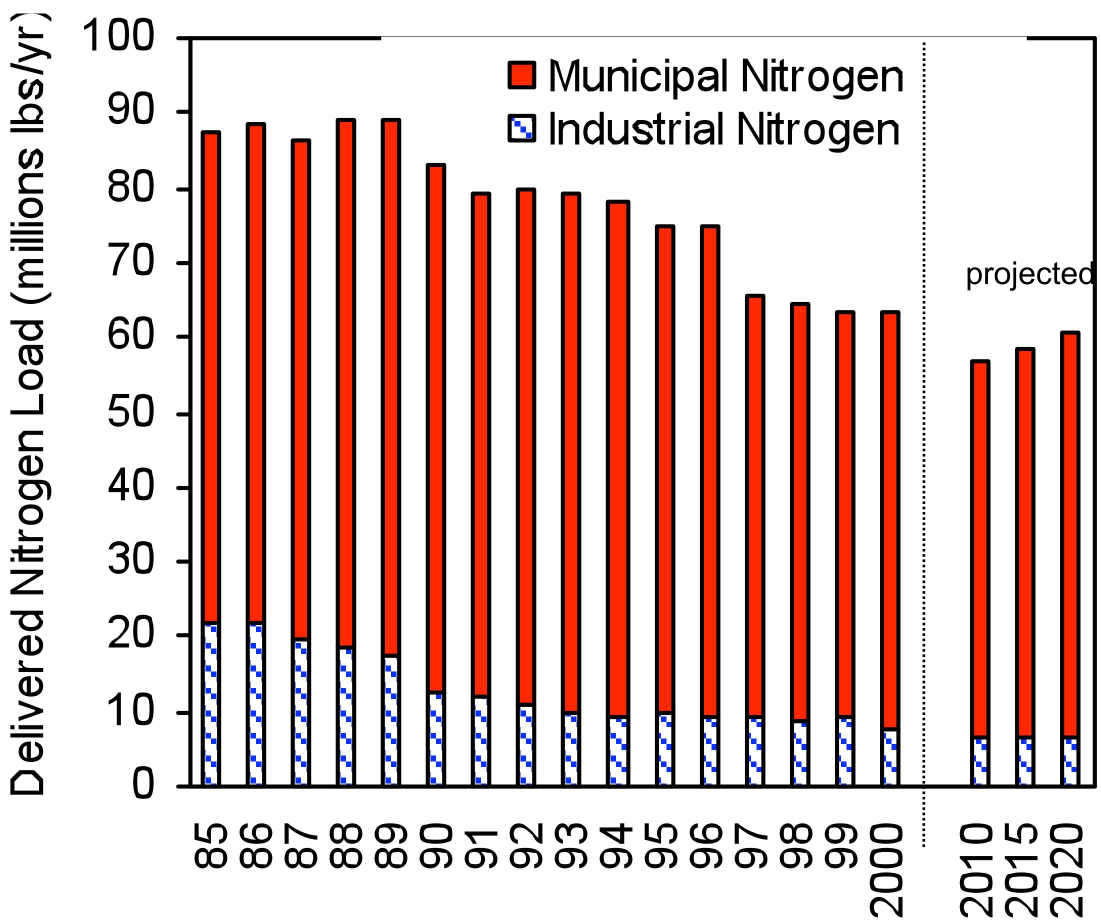
GOAL: Reduce point source phosphorus loads to support achievement of the nutrient reduction goal.

STATUS: Phosphorus loads declined 53% between 1985 and 2000 as a result of improved treatment capability and implementation of phosphate detergent bans (MD: 1985, DC: 1986, VA: 1988, PA: 1990).

If no further actions are taken, we anticipate increased loads in the future due to population growth.

Source: Chesapeake Bay Program Office Point Source Data Base, 6/02. Data used in chart are from all facilities in Chesapeake Bay Watershed. Data through 2000 are actual; 2010 and after are projections.

Point Source Nitrogen Loads Delivered to the Bay



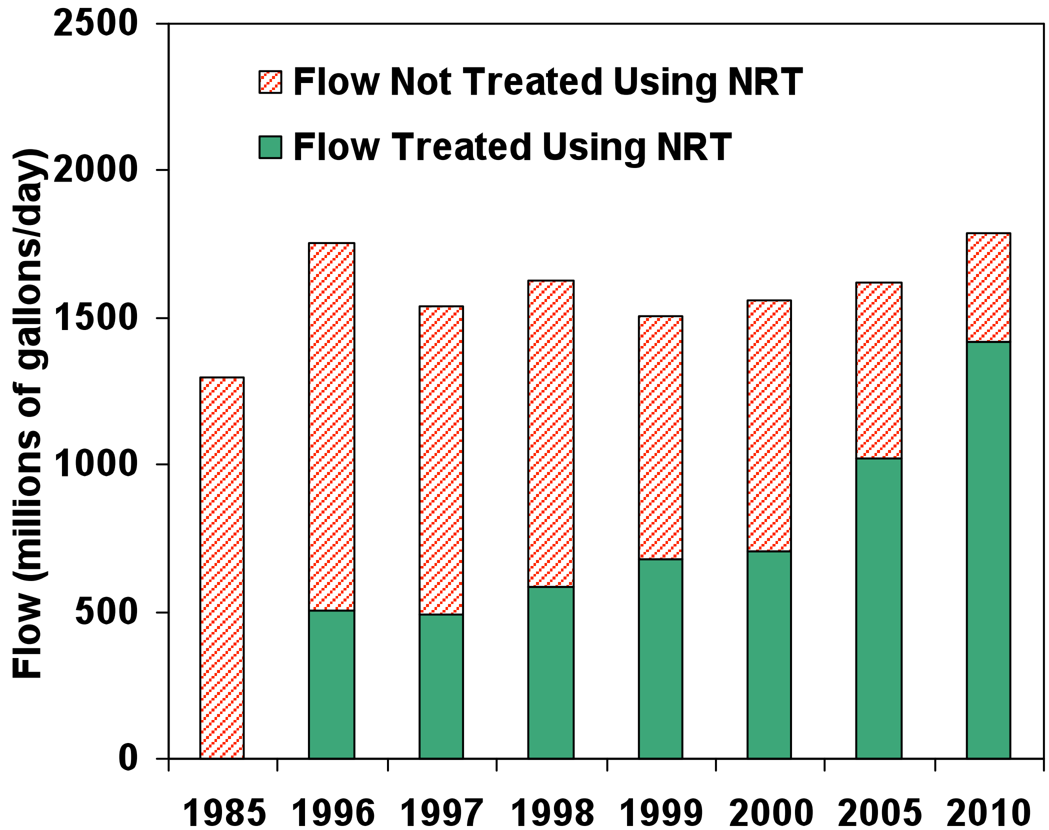
GOAL: Reduce point source nitrogen loads to support achievement of the nutrient reduction goal.

STATUS: Nitrogen loads declined 28% between 1985 and 2000 through industrial reductions and some installment of nutrient reduction technology (NRT) technology.

An additional 10% reduction is expected through 2010 due to increasing NRT implementation as well as general treatment efficiency improvements.

If no further actions are taken, we anticipate increased loads after 2010 due to population growth.

Municipal Wastewater Flow and Nutrient Reduction Technology in the Bay Watershed



Source: CBPO Point Source Data Bases, last updated 4/2/2002

1. A significant facility is defined here for MD as having a flow greater than 0.5 MGD or total nitrogen discharge greater than 75 lbs/day; for VA, having a design flow of 0.5 MGD or greater, and also all minor BFL facilities; for PA, having a 1985 annual flow of 0.4 MGD or greater; for NY, having design flow greater than 0.4 MGD; for WV and DE, having a design flow of 0.5 MGD or greater.
2. 2000 flow is used to calculate "current" flow under NRT. 2005 and 2010 flow projections used to calculate flow under NRT in 2005 and 2010 respectively.

GOAL: Reduce nutrient discharges from wastewater treatment facilities to support achievement of nutrient reduction goals.

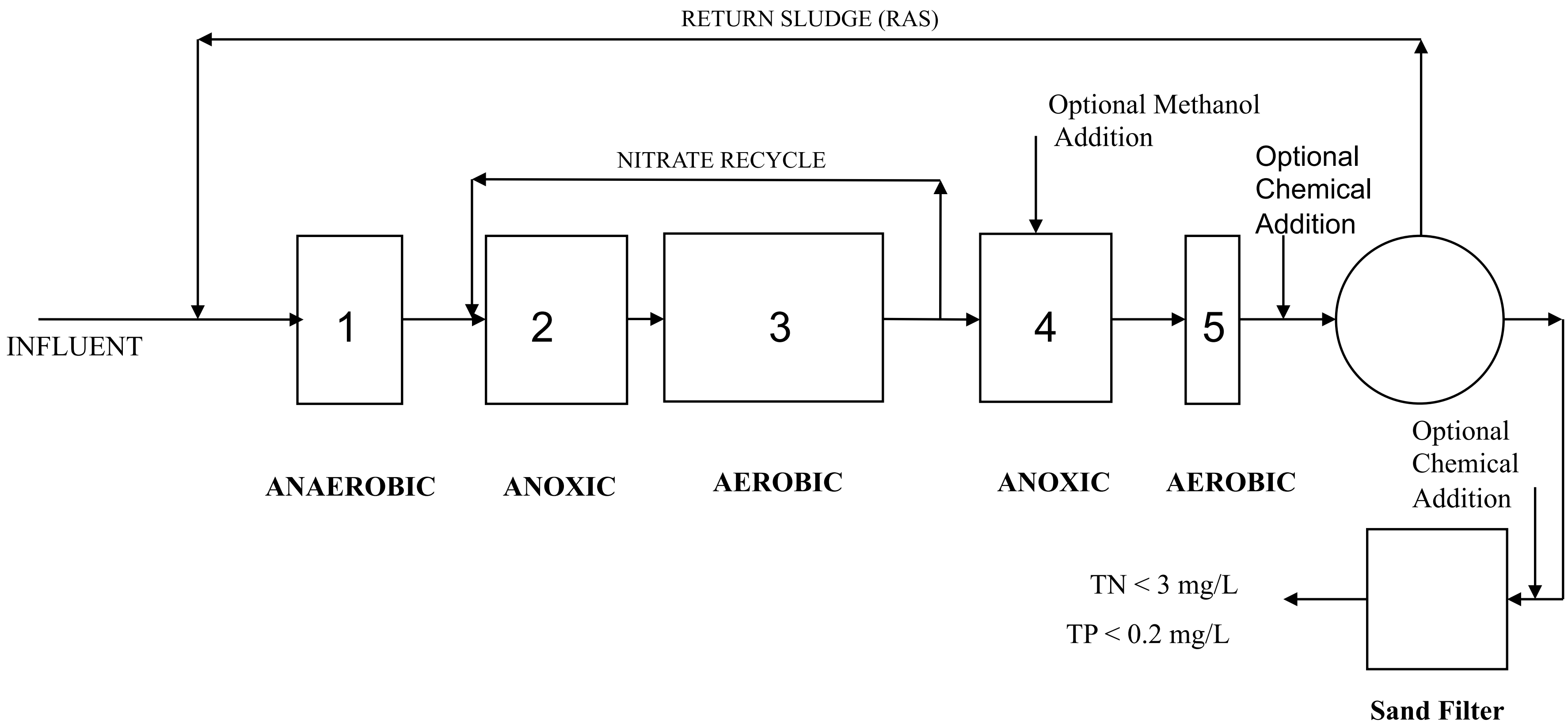
STATUS: Currently, 45% of the flow from significant facilities is treated using nutrient reduction technology (NRT). 63% of the flow will be treated using NRT by the year 2005. 79% of the flow will be treated using NRT by 2010.

IMPLEMENTATION OF ENR (LOT)

- EFFLUENT REQUIREMENTS
  - 0.1 – 0.3 mg/L TP
  - 3.0 – 4.0 mg/L TN
- ECONOMICS
  - Increased capital and O&M costs
- ADD REACTORS & CHEMICALS
- ADD TERTIARY TREATMENT

Additional Zones and Units can be added to each treatment train for ENR WASTEWATER TREATMENT

ENR Typically Requires a 15-25% Volume Increase



FIVE-STAGE BIOLOGICAL NUTRIENT REMOVAL (MODIFIED BARDENPHO) CONFIGURATION for BIOLOGICAL NITROGEN AND PHOSPHORUS REMOVAL

HOW SHOULD WASTEWATERS BE MANAGED TO REDUCE THE ECOLOGICAL, ECONOMICAL AND SOCIETAL IMPACTS OF NUTRIENT POLLUTION?

REDUCE, RECYCLE, RECOVERY & REUSE

WASTEWATERS CONTAIN LIMITED RESOURCES THAT SHOULD BE RECOVERED AND REUSED

- Water
- Nutrients
  - Phosphorus
  - Nitrogen
- Commercial By-Products

THE NEED FOR THE RECOVERY AND REUSE OF NITROGEN

- Nitrogen is the Most Likely Limiting Nutrient and Nitrogen Forms are the major cause of Eutrophication in Estuarine and Coastal waters.
- Recovery and Reuse of Nitrogen would reduce Nitrogen pollution of Estuaries and Coastal Waters and preserve fisheries.
- Recovery and Reuse of Nitrogen would reduce the Environmental and Economic Costs of Manufacturing Nitrogen Fertilizers.

The Need for Recovery and Reuse of Phosphorus

- Phosphorus is a major cause of eutrophication in water bodies.
- Growth of Biological Life on Planet Earth is limited by the availability of phosphorus (Asimov, 1975).
- Phosphorus is a limited, non-renewable resource. The primary source is mining.
- It eventually will be necessary to recover and reuse phosphorus. Why not now?

The Need to Recover and Reuse Water from Wastewaters

- Water is a Limiting Resource in many Land Areas of the World, and the need increases as population increases.
- Wastewaters can be renovated more economically than seawater can be desalinated.
- Recovery of Water reduces Flows and makes it more Economical to treat Wastewater Flows

SOME SUGGESTED METHODS FOR RECOVERY OF LIMITED RESOURCES FROM WASTEWATERS

- Recycle of anaerobically digested and composted EBPR sludge,
- Separation of urea from fecal matter for recovery and reuse of N,
- Membrane separation processes and water reuse,
- Water treatment and recycle in tall buildings,
- Production of commercial by-products, such as Biodegradable Plastics.

THE END

QUESTIONS?
COMMENTS?

Municipal Facilities in the Bay Watershed Using Nutrient Reduction Technology (NRT)

Jurisdication	# of Significant[1] Facilities (BY 2010)	# of Significant Facilities Currently Using NRT (as of 3/02)	# of Significant Facilities to be Using NRT by the Year 2005	# of Significant Facilities to be Using NRT by the Year 2010
Pennsylvania	123	22	34	38
Maryland	66	35	65	66
Virginia*	86	15	27	42
District of Columbia	1	1	1	1
New York	18	0	3	3
West Virginia	8	0	0	1
Delaware	3	1	1	2
Total[3]	305	73	131	153
		(total municipal flow under NRT = 706 MGD or 45%)[2]	(total municipal flow under NRT = 1024 MGD or 63%)[2]	(total municipal flow under NRT = 1419 MGD or 79%)[2]

Source: CBPO Point Source Data Bases, last updated 4/2/2002

1. A significant facility is defined here for MD as having a flow greater than 0.5 MGD or total nitrogen discharge greater than 75 lbs/day; for VA, having a design flow of 0.5 MGD or greater, and also all minor BFL facilities; for PA, having a 1985 annual flow of 0.4 MGD or greater; for NY, having design flow greater than 0.4 MGD; for WV and DE, having a design flow of 0.5 MGD or greater.
2. 2000 flow is used to calculate "current" flow under NRT. 2005 and 2010 flow projections used to calculate flow under NRT in 2005 and 2010 respectively.
3. There are 6 facilities that are federal: 3 in MD and 3 in VA. All will have NRT by 2010.

*This also includes 6 VA plants to be built by 2010.

HOW CAN THE RATE OF POINT SOURCE NUTRIENT REMOVAL MPLEMENTATION BE ACCELERATED?

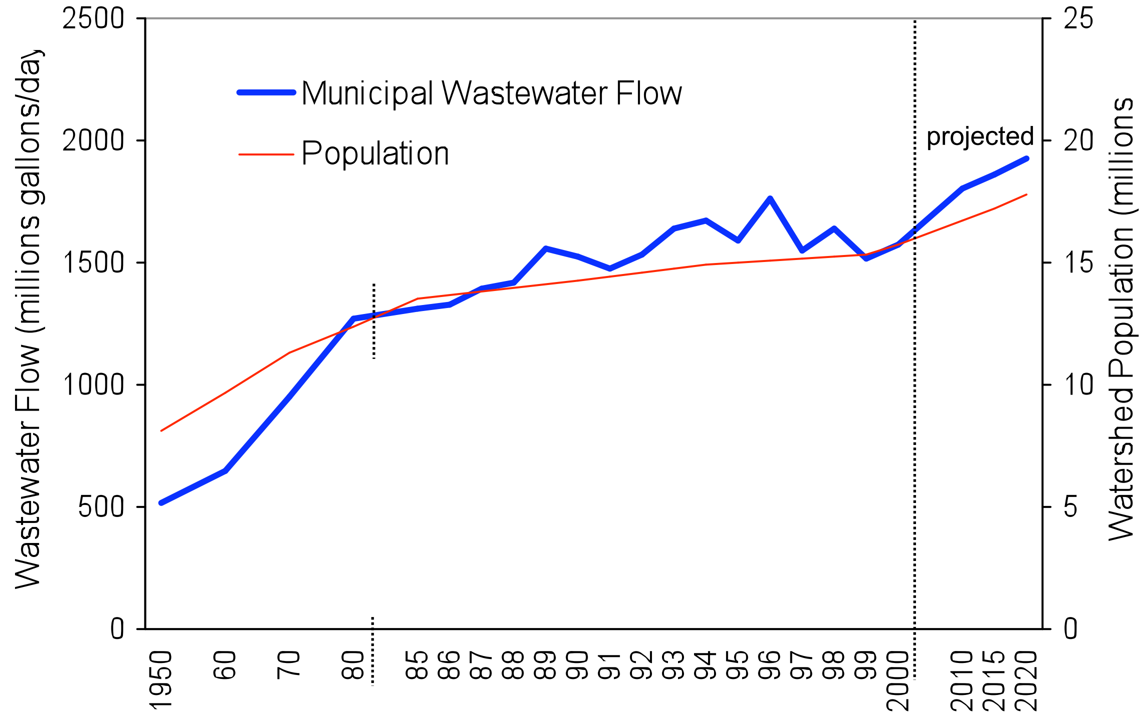
- Appropriate Technology is Available
    1. Biological Nutrient Removal
    2. Membrane Separation Wastewater Treatment
    3. Nutrient Recovery and Reuse

- Most Rapid Progress would be through Implementation of Known and Demonstrated Technologies

- Rapid Implementation Requires both a Carrot and a Stick
    - Financial Incentives plus Regulatory Requirements

- Also Need to Consider Innovative but Proven Technologies

Municipal Wastewater Flow and Population In the Chesapeake Bay Watershed



Source: Chesapeake Bay Program Office Point Source Data Base, 6/02. Data used in chart are from all facilities in Chesapeake Bay Watershed. Data through 2000 are actual; 2010 and after are projections.

Municipal wastewater treatment protects human and Bay health by providing improved treatment, which may include advanced treatment for nutrient removal.

The sharper rate of increase in municipal wastewater flow before 1980 resulted from the Clean Water Act Construction Grant Program.

RECOMMENDED STRATEGY TO REDUCE COSTS AND ACCELERATE IMPLEMENTATION OF BNR AND LOT.

1. Utilize Existing Excess Capacities of the Significant WWTPs to:

   a. Reduce the costs and accelerate implementation of BNR and LOT at the Significant WWTPs in the Bay Watershed.

   b. Enable Point-to-Point nutrient removal trading.

2. Inaugurate a Water Savings Program to further Increase Excess Capacity.

3. Supplement Excess Capacities w/ Innovative Treatment Technologies.

4. Utilize Centralized Sludge Processing wherever feasible.

5. Incorporate Recycle, Reuse and Recovery methodologies.

Advantages of Biological Nitrogen Removal Wastewater Treatment Using Influent BOD

1. Reduces oxygen requirements because BOD is removed by denitrification, therefore, reduces energy requirements. Approximately 20 % reduction is possible for municipal applications.
2. Reduces Waste Activated Sludge production because Bacteria obtain less energy from using oxidized nitrogen as an electron acceptor compared to dissolved oxygen. Approximately 25% reduction is typical.

Advantages of Biological Nitrogen Removal Wastewater Treatment (con't)

3. Improved sludge settleability because the anoxic zone acts as a selector against filamentous bacteria.
4. Improved oxygen transfer in the aerobic zone because of low initial DO concentration.
5. Denitrification restores half of the alkalinity destroyed during nitrification, i.e. 3.57:1.

$$NO_3 + CHO \rightarrow N_2 + CO_2 + H_2O + OH^-$$

NITROGEN REMOVAL NITRIFICATION and DENITRIFICATION

THE ECONOMICS OF NITROGEN REMOVAL

WASTEWATER TREATMENT

- DENITRIFICATION USING INFLUENT WASTEWATER BOD -Green Engineering: Utilization of Technology that improves or is highly compatible with the environment, eliminates or minimizes secondary impacts, and minimizes the cost of implementation
- DENITRIFICATION WITH SUPPLEMENTAL ORGANIC CARBON ADDITION, e.g. METHANOL

  Increases MLSS concentration & WAS production, therefore increases secondary clarifier requirements, energy costs for aeration and costs of WAS processing.