BNR to Enhanced Nutrient Removal

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BNR to Enhanced Nutrient Removal

7 Contact Hours
9 CC10 Hours

Upgrading sewage treatment plants for nutrient removal is one of Maryland's top environmental priorities. This course addresses the implications of upgrading from Biological Nutrient Removal (BNR) to Enhanced Nutrient Removal (ENR). Topics covered will include: a review of the basics of nitrification, denitrification, and phosphorus removal; various process configurations will be discussed to accomplish the required levels of nutrient removal; and process control testing and adjustments will also be examined to optimize ENR plant performance.

1. To discuss Biological Nutrient Removal (BNR) and Enhanced Nutrient Removal (ENR) options
2. To distinguish Biological Nutrient Removal (BNR) process trains from Enhanced Nutrient Removal (ENR) process trains
3. To discuss the evolution of Biological Nutrient Removal (BNR) processes to Enhanced Nutrient Removal (ENR) processes
4. To stress the effects that nutrient effluent requirements have on treatment options and costs
5. To share nutrient removal applications and ideas

Agenda
Morning

A. Introduction - Overview
   - Nutrients – Phosphorus and Nitrogen
   - Why remove nutrients?
   - Conditions in the Chesapeake Bay
     - ✓ Submerged aquatic vegetation (SAV)
     - ✓ Loadings – phosphorus, nitrogen, and sediments

B. Nutrient Removal Options
   - Phosphorus
     - ✓ Forms, sources, and typical concentrations
     - ✓ Chemical precipitation
     - ✓ Biological uptake
   - Nitrogen
     - ✓ Forms (Nitrogen Cycle), sources, and typical concentrations
     - ✓ Nitrification
     - ✓ Denitrification
   - Biological Nutrient Removal (BNR)
     - ✓ TN requirement < 8.0 mg/l
     - ✓ With and without carbon (Methanol) addition
   - Enhanced Nutrient Removal (ENR)
     - ✓ TN requirement < 3.0 mg/l
     - ✓ With carbon addition
     - ✓ With tertiary treatment options

C. Evolution of BNR to ENR
   - TN effluent requirement from < 8.0 mg/l to < 3.0 mg/l
   - Nutrient loadings to the Bay still unacceptable

- Chemical addition for Phosphorus removal to < 0.3 mg/l is achievable
- New technologies are available to achieve TN limit of < 3.0 mg/l

Afternoon

D. Phosphorus Removal Options
   - Chemical precipitation
     - ✓ Aluminum salts
     - ✓ Iron salts
   - Biological uptake in both BNR and ENR options
     - ✓ Anaerobic zone for Phosphorus release
     - ✓ Aerobic zone for Phosphorus uptake
   - Maximize biological uptake where possible to minimize costs for chemicals and related chemical sludge disposal
   - Limit of Technology – 0.05 mg/l
   - Anticipated permit levels – 0.1 mg/l to 0.3 mg/l

E. Biological Nutrient Removal Options
   - TN requirement < 8.0 mg/l
   - Typically, three stage, anaerobic, anoxic, aerobic processes installed
     - ✓ Phosphorus release
     - ✓ Denitrification
     - ✓ Nitrification
     - ✓ Phosphorus uptake
   - Common BNR processes:
     - ✓ Ludzak-Ettinger - Three stage
     - ✓ A_20 – three stage
     - ✓ Bardenpho
       - o Three stage
       - o Modified five stage
     - ✓ University of Cape Town (UCT)
       - o Three stage
       - o Modified four stage
     - ✓ Virginia Initiative Project (VIP)
   - Suspended growth, fixed film, oxidation ditch, and batch reactor designs have been used
   - With and without carbon addition
   - Limit of Technology – 5.0 mg/l
   - Anticipated permit levels – 6.0 mg/l to 8.0 mg/l

F. Enhanced Nutrient Removal Options
   - TN requirement < 3.0 mg/l
   - Anaerobic, anoxic, aerobic process train usually installed with additional denitrification capability
     - ✓ Phosphorus release
     - ✓ Deitrification
     - ✓ Nitrification
     - ✓ Tertiary denitrification
     - ✓ Phosphorus uptake

- Common ENR processes:
  - ✓ Bardenpho – modified five stage
  - ✓ University of Cape Town (UCT) – modified four stage
  - ✓ Alterations/add-on options to BNR processes:
    - o Integrated Fixed-Film Activated Sludge (IFAS) Hybrid Systems (e.g., rope media, sponge media, or web media)
    - o High-rate Denitrification Biofilters (e.g., Tetra's CoLox System)
    - o Moving Bed Biofilm Reactors (MBBR) using plastic elements w/o return sludge (e.g., AnoxKaldnes)
    - o Membrane Filters (Zenon)
- With carbon addition
- Limit of Technology – 1.5 mg/l to 2.0 mg/l (Depends on Organic Nitrogen concentration)
- Anticipated permit levels – 3.0 mg/l

G. Regulations, Tributary Strategies, and the Chesapeake Bay

BNR and ENR

Presented by
Bill Shreve

Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD

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Introduction

Administrative

https://en.wikipedia.org/wiki/List_of_abbreviations_used_in_sanitation

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Process Training Sessions

Before class starts, please:

- **Check in**

During classes, please:

- **Asks questions**
- Feel free to get up at any time (i.e., rest rooms, phone calls, etc.)
- **Answer questions** on class evaluation and post quiz

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Housekeeping

- Start class – 8:00 am
- 10-minute Breaks – every hour
- Lunch – 1 hour, 11:30 am to 12:30 pm
- End class ~ 3:00 to 3:30 pm

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Ice Breaker

- Before we start, let's…
  - Name one thing you know or want to know about:
    - Biological Nutrient Removal (BNR)
    - Enhanced Nutrient Removal (ENR)
    - "Biological Reactor Basins (BRB)" 1 – 5
    - "Biological Reactor Basin (BRB)" 6

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Instructor Expectations

- Begin and end class on time
- Be interactive
- Share experiences and needs
- ***Make this an enjoyable and informative experience!***

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Groundrules

- Participate at your own comfort level
- Use terms we all understand
- Everyone is different, so please show respect for others
- Listen with an open mind
- Express opinions
- Maintain confidences

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Introduction

Definitions and Acronyms

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Acronyms

- BNR – Biological Nutrient Removal
- ENR – Enhanced Nutrient Removal
- CBP – Chesapeake Bay Program
- TMDL – Total Maximum Daily Loading
- WLA – Waste Load Allocation
- MLE – Modified Ludzack-Ettinger Process (BNR)
- EMLE- Enhanced Modified Ludzack Process (ENR)
- SBR – Sequencing Batch Reactor
- MBBR – Mixed Bed Bioreactor
- COMAMMOX – COMplete AMMonia OXidation
- ANAMMOX – ANaerobic AMMonia OXidation

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Nutrients

- TN – Total Nitrogen
  - Soluble and particulate
    - Organic nitrogen - N_{org}
    - NH_3 – Ammonia
    - NO_2 – Nitrite
    - NO_3 - Nitrate
- TP – Total Phosphorus
  - Soluble and particulate
    - PO_4 – Ortho-phosphorus
    - Organic
    - Polyphosphates

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Nutrients

- TN – Total Nitrogen ($N_{org} + NH_3 + NO_3 + NO_2$)
- TP – Total Phosphorus ($PO_4 + P_{org} + P_{poly}$)

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Microorganisms

- **Aerobic** (Oxic) - Organisms requiring, or not destroyed, by the presence of free oxygen
- **Anoxic**: Organisms requiring , or not destroyed, by the absence of free oxygen; nitrates (NO_3) are present.
- **Anaerobic** - Organisms requiring, or not destroyed, by the absence of free oxygen and NO_3
- **Facultative** - Organisms able to function both in the presence or absence of free oxygen
- **Heterotrophic** - Organisms that use organic materials as their source of cell carbon
- **Autotrophic** - Organisms able to use carbon dioxide and other inorganic matter as their source of carbon
- **Filamentous** – Bulking organisms that grow in thread or filamentous form

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Introduction

Objectives, Focus, and Agenda

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Learning Objectives

- Objective 1 - To discuss the Chesapeake Bay restoration efforts and regulatory "drivers" for BNR and ENR
  - Bay conditions in the 1970s and early 1980s
  - 1987 Bay Agreement (Begin using BNR)
  - 2000 Bay Agreement (Begin using ENR)
  - 2010 TMDL (Imposed by EPA)
- Objective 2 - To discuss methods for nitrogen and phosphorus removal
- Objective 3 - To discuss the evolution of BNR technologies to ENR

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Participant Focus

- What information can you use at your work location?
  - ENR fundamentals
  - Troubleshooting ENR processes
  - Meeting nutrient discharge standards
- What information can you contribute to the discussion?
  - ENR experiences and practices
  - Step feed ENR issues

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OUTLINE

- Water quality in the Chesapeake Bay
  - 1970s and early 1980s condition
  - Need for 40 percent reduction in nutrient loadings to restore Bay conditions
- Regulatory Background
  - 1987 and 2000 Bay Agreements
  - 2010 Agreement - TMDL (EPA)
- BNR and ENR configurations – Overview
- BNR configurations
- ENR configurations
- Summary

Expected Learning Outcomes

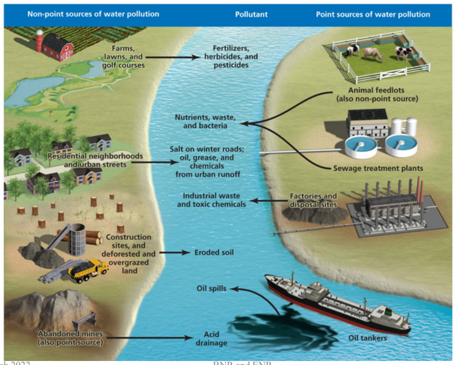
Participants will be able to:

- Discuss the regulatory framework for nutrient removal in the Chesapeake Bay watershed
- Discuss major BNR processes
- Discuss major ENR processes
- Discuss options to upgrade BNR facilities to ENR
- Discuss process control options
- Discuss trouble-shooting options

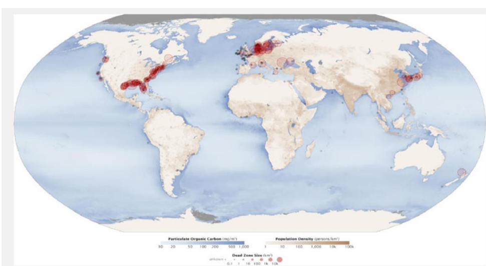
Chesapeake Bay

Bay Health and Regulations

Pollution Sources



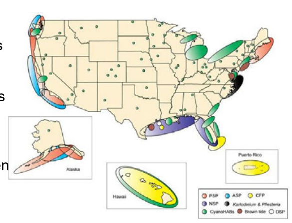
Excess Nutrients are a Global Concern



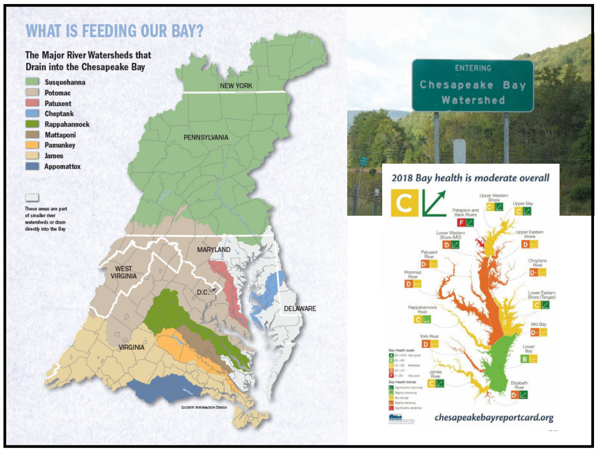
NASA Earth Observatory

Extent of N&P Impacts

- 14,000 Nutrient-related Impairment Listings in 49 States
- ~80% of Assessed Continental U.S. Coastal Waters exhibit eutrophication
- ~50% of streams have medium to high levels of nitrogen and phosphorus



Occurrence of Excess Algae throughout the U.S.



Water Quality Conditions

University of Maryland
Center for Environmental Science

University of Maryland Center for Environmental Science

- "Bay Health" Annual Reports (Since 2007)
- Bay health affected by elevated nutrient and sediment loads, which results in water quality and biotic (biological) degradation

Aquaculture and Restoration Ecology Laboratory at Horn Point Laboratory, Cambridge, Maryland; Photo by Kirsten Frese

Chesapeake Bay Health

- Bay Health - progress of six indicators towards established ecological thresholds.
- Water quality indicators/Index (WQI) are:
  - Chlorophyll *a*
  - Dissolved oxygen
  - Water clarity
- Biotic indicators/Index (BI) are:
  - Submerged aquatic vegetation (SUV)
  - Benthic Index of Biotic Integrity
  - Phytoplankton Index of Biotic Integrity

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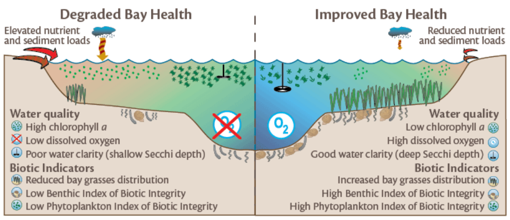
Chesapeake Bay Health

- Bay Health Index (BHI) - average of Water Quality Index (WQI) and Biotic Index (BI) scores for each reporting region



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Key Water Quality Indicators

- Chlorophyll a
- SAV – Submerged aquatic vegetation
- Dissolved Oxygen
- All three are showing degrading trends

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The Chesapeake Bay Program

- In the late 1970s, a rapid loss of aquatic life was reported in a 5-year study of Bay conditions
- The study identified excess nutrient pollution as the main source of the Bay's degradation
  - Ammonia toxicity also contributed to degradation
  - Loss of submerged aquatic grasses was key observation

Submerged Aquatic Vegetation

- SAV areas are important habitats for fish and molting crabs
- SAV contributes to the reduction of shoreline erosion and the trapping of sediments and nutrients from overlying waters, which leads to improved water quality and clarity
- A decline in SAV populations began in the 1960s and became a problem in the 1970s

Submerged Aquatic Vegetation

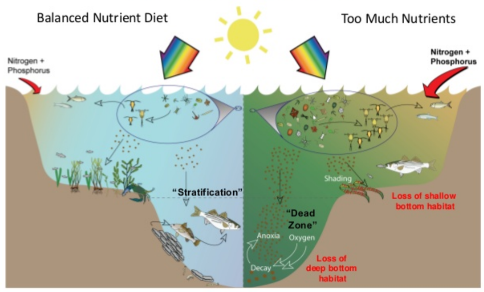
- SAV is rooted vegetation that grows under water in shallow zones where light penetrates

Wild celery
Upper Bay

Redhead grass
Mid-Bay

Eel grass
Lower Bay

How Too Much Nutrient Pollution Impacts the Chesapeake Bay Ecosystem



Development of Chesapeake Watershed Models

Model Revision	Characteristics: Watershed	Characteristics: Bay	Advances	Simulation Period	Decisions Supported
Phase I (1985)	5 land uses; 64 segments	Steady state	First coupling of watershed, hydrodynamic, and water quality models	Summer data - 1965, 1984, and 1985	General goal of 40% reductions of controllable loads (CBP, 1987)
Phase 2 (1992)	Expanded agriculture simulation detail	Dynamic 4,000 grid cells	Integrated sediment flux model; included atmospheric deposition	4 continuous years (1984 – 1987), hourly time intervals	Nutrient load reductions to achieve CBP (1987) allocation goals
Phase 4.3 (2003)	9 land uses; 94 segments	Dynamic 13,000 grid cells	Integrated simulation of land and soil contaminant runoff processes; included SAV and benthic deposit models	14 continuous years (1985 – 1994)	Nutrient load allocations
Phase 5.3 (2010)	25 land uses; 899 segments	Dynamic 57,000 grid cells	Enhanced segmentation, land uses, and mechanistic detail	21 continuous years (1985 – 2005)	TMDL

Chesapeake Bay Program

- Bay degradation findings led to the formation of the Chesapeake Bay Program in 1983 as a governance means to restore water quality in the Bay

Chesapeake Bay Program
Science. Restoration. Partnership.

Chesapeake Bay Program

- The Chesapeake Bay Program includes:
  - Signers of the original 1983 Bay Agreement:
    - Maryland
    - Virginia
    - Pennsylvania
    - The District of Columbia
  - EPA - sets Chesapeake Bay water quality limits
  - The U.S. Department of Agriculture
  - Headwater jurisdictions:
    - Delaware
    - New York
    - West Virginia

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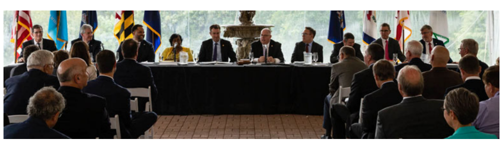
Chesapeake Bay Program

- The Program is led by the Chesapeake Executive Council, which includes:
  - The EPA Administrator
  - Governors of Maryland, Pennsylvania, and Virginia
  - The mayor of the District of Columbia



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Chesapeake Bay Program

- CBP Agriculture and Wastewater Workgroups
  - Model Bay watershed improvements (since 1985)
- Water quality restoration efforts:
  - Implementing pollution reduction practices on urban and suburban lands
  - Reducing air pollution deposited in the watershed

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1987 Chesapeake Bay Agreement

- In a 1987 Chesapeake Bay Agreement:
  - Nutrient water quality targets for 2000 were set (40% less than 1985 conditions)
  - USEPA, MD, VA, DC, PA and the Chesapeake Bay Commission – Signatories to agreement
  - USEPA has the lead on setting water quality standards for the Bay:
    - Based on water quality needs
    - Based on nutrient removal technology available

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2000 Chesapeake Bay Agreement

- In a 2000 Chesapeake Bay Agreement:
  - The 40 percent reduction goal would continue beyond 2000 to 2010
  - Signatories would include Delaware, New York, and West Virginia
  - States and DC began planning for nutrient removal at their source – tributary strategies

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Total Maximum Daily Load (TMDL)

- In December 2010, EPA established Total Maximum Daily Loads (TMDL) for the Bay watershed
- The 2010 Bay TMDL was prompted by insufficient progress and continued poor water quality in the Chesapeake Bay and its tidal tributaries
- Nutrient load allocations (million pounds/year):

	2000	2010 TMDL
Nitrogen	175	186
Phosphorus	12.8	12.5

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2010 Chesapeake Bay Agreement

- In a 2010 Chesapeake Bay Watershed Agreement:
  - States and DC committed to meet sector reduction **goals**
    - Total Maximum Daily Load, or TMDL
    - Waste Load Allocation, or WLA
  - The 40 percent nutrient removal reduction goal would continue beyond 2010 to 2025
    - EPA would review progress by 2017

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Total Maximum Daily Load (TMDL)

- TMDL pollution limits are designed to ensure:
  - Restoration of the Bay and its tidal rivers by 2025
  - Best Management Practices (BMPs) in place by 2017 to meet 60 percent of pollution reductions
- Annual TMDL Bay watershed limits:
  - 185.9 million pounds of nitrogen (excludes tidal water atmospheric deposition of nitrogen)
  - 12.5 million pounds of phosphorus
  - 6.45 billion pounds of sediment

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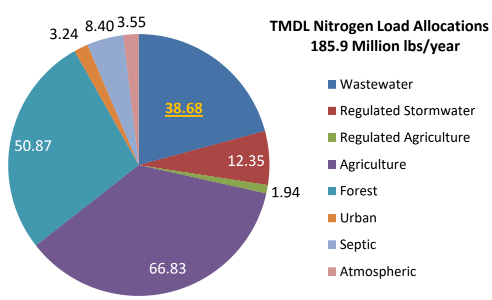
TMDL Nitrogen Load Allocations



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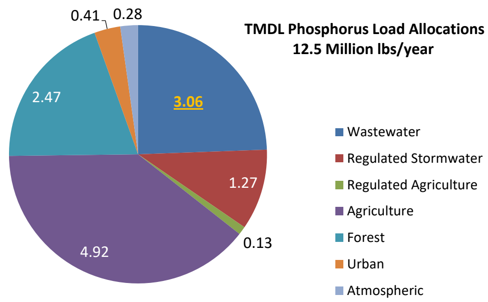
TMDL Phosphorus Load Allocations



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Wastewater Sector Waste Load Allocations

- Nitrogen: 38.7 million pounds/year
- Phosphorus: 3.06 million pounds/year
- Interim target date: 2017 for 60% reductions (from 2010)
- Target date: 2025 for achieving WLAs

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Total Maximum Daily Load (TMDL),

- Progress in implementing the Bay Total Maximum Daily Load (TMDL) is tracked by the CBP's "ChesapeakeStat"
- Elements of a TMDL:
  - "Waste load allocations" for point sources
    - Sewage treatment plants
    - Regulated urban stormwater systems
    - Regulated animal feeding operations
  - "Load allocations" for non-point sources
    - Runoff from agricultural lands
    - Non-regulated stormwater from urban/suburban lands

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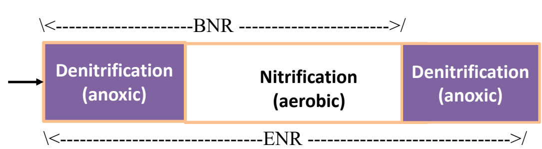
Wastewater Nutrient Removal

- **Total Phosphorus (TP)** has been removed well in the past
  - Less than 0.3 mg/l TP; even less than 0.1 mg/l
  - **Bay 2010 TMDL Target: Less than 0.3 mg/l TP**
  - Low threshold - Limit of Technology /State of the Art (LOT/SOA) is less than 0.05 mg/l TP (soluble Org-P)
  - TMDL – Total maximum daily loading

Nutrient Removal

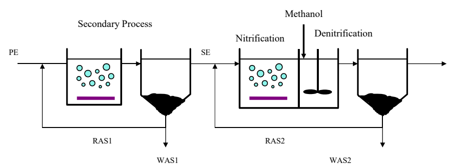
Nutrient	Removal Process
• Nitrogen	• Nitrification – Ammonia Conversion – NH_3^+-N to NO_3^-N – Oxygen and alkalinity needed • Denitrification – Nitrate Removal – NO_3^--N to Nitrogen gas (N_2) – Carbon source needed
• Phosphorus	• Biological Uptake – Conventional – Excess • Chemical Precipitation

Common BNR/ENR Configurations



- BNR:
  - Modified Ludzack-Ettinger (MLE)
  - Anaerobic/Anoxic/Oxic (A2O)
  - University of Cape Town Process (UCT)
- ENR:
  - Enhanced MLE/4-stage Bardenpho
  - MLE with Denitrification Filter

Two Sludge System for BOD and Nitrogen Removal



Example: Blue Plains, DC Water 370 MGD

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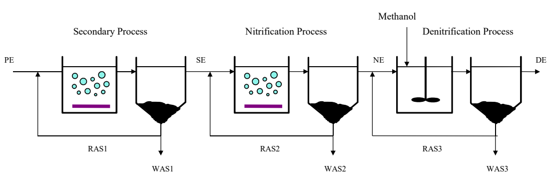
Three Stage System for BOD and Nitrogen Removal

Post Denitrification w/Methanol



Example: Western Branch WWTP, WSSC 30 MGD

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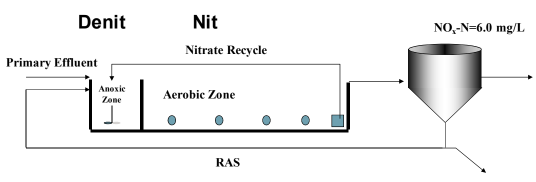
Basic BNR Process



Nitrogen removal:

- Basic biological denitrification-nitrification process
- Complete denitrification is not possible

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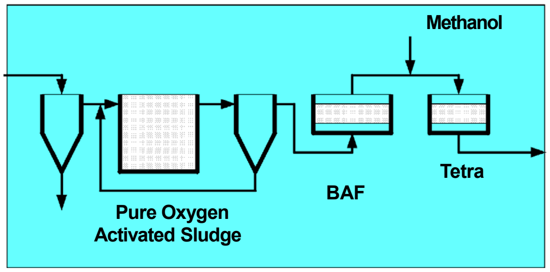
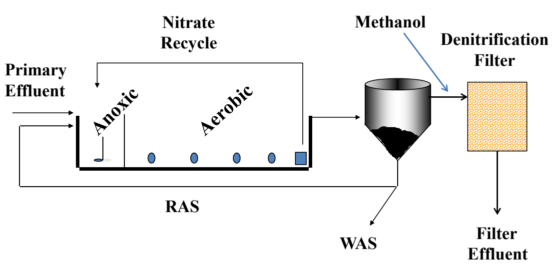
Patapsco WWTP – ENR Process

Baltimore, MD



Back River WWTP – ENR Process

Baltimore, MD

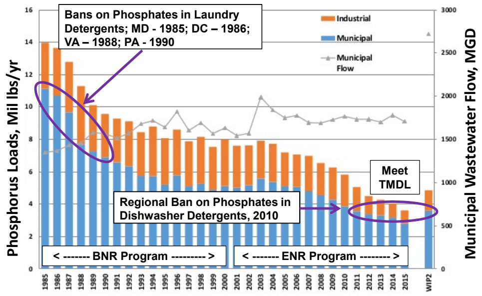


Nutrient Removal

FORM	Removal Mechanism	LOT[1], mg/L
TN		**< 1.5**
NH_3-N	Nitrification	< 0.1
NO_3-N	Denitrification	< 0.1
Org-N:		
Particulate	Solids Separation	< 0.5
Soluble	Ammonification	0.5 – 1.0
TP		**< 0.05**
Particulate	Solids Separation	< 0.05
Soluble	Biological uptake and chemical precipitation	< 0.05

[1] LOT – Limit of Technology

TP Loadings to the Chesapeake Bay - Wastewater



Wastewater Discharge Limits

Typical **Total Phosphorus** Standards, mg/l

- Moderate 0.5 - 1.0 (BNR)

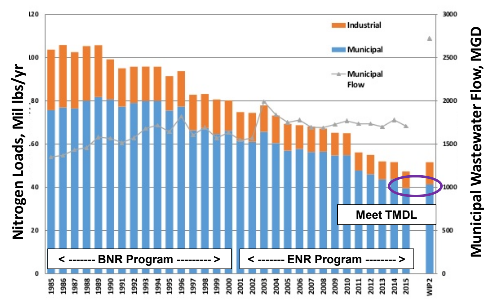
  Bay Target < 0.3 (ENR)
- **Potomac River < 0.18 (ENR)**
- Very Severe < 0.1
- LOT/SOA(a) < 0.05

  (a) Limit of Technology/State of the Art

Wastewater Nutrient Removal

- Enhanced (ENR) **Total Nitrogen (TN)** removal is now required:
  - Current 3 to 5 mg/L of TN is not adequate (BNR)
  - **Bay 2010 TMDL Target: Less than 3.0 mg/l TN**
  - Low threshold - Limit of Technology /State of the Art (LOT/SOA) is about 1.0 mg/l TN (soluble Org-N)
  - TMDL – Total maximum daily loading

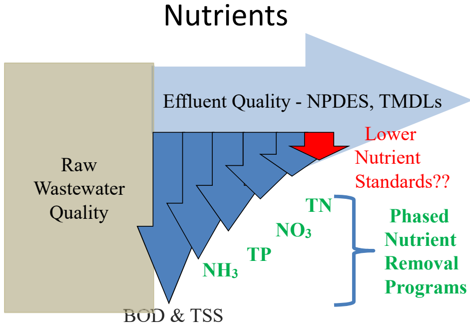
TN Loadings to the Chesapeake Bay - Wastewater



Wastewater Sector

- Wastewater sector nutrient removal goals were met in 2015 because of:
  - BNR upgrades from 1985 – 2000
  - ENR upgrades from 2000 – 2015
- In 2016, EPA announced the wastewater sector's 2025 nutrient removal goals had been effectively met a decade early…!

Future - Role and Impact of Nutrients



How will future regulations affect Nutrient Removal Requirements?

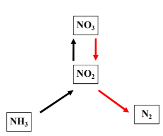
Regulatory Challenges:
- Clean Water Act
- Chesapeake Bay Program Regulations
- State Regulations
  - Follow EPA lead
  - Nutrients
  - Sludge
- Local Ordinances

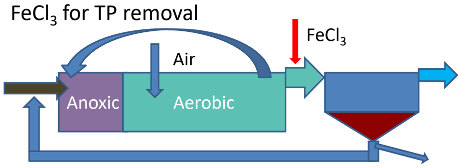
Nutrient Removal

Overview

Nutrient Removal

- Nitrification (*Nitrosomonas* and *Nitrobacter*)
  $NH_3 + O_2 \rightarrow NO_2^- \rightarrow NO_3^-$
- Denitrification
  $NO_3^- + \text{organics} \rightarrow CO_2 + N_2$
- Process adaptation – MLE
- $FeCl_3$ for TP removal





Nutrient Removal

- **Why remove Nutrients (nitrogen and phosphorus):**
  - Nutrients contribute to algae growth
  - Excess algae growth (Eutrophication) causes water quality issues:
    - Loss of water clarity
    - Limitation on sunlight penetration
    - Oxygen depletion
    - Fish and marine life die-off
    - Submerged aquatic vegetation (SAV) die-off

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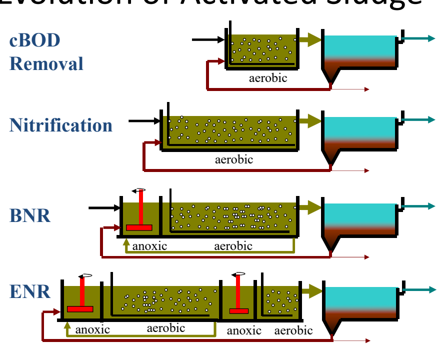
Historical Overview

- 1920s - 1960s
  - cBOD Removal
  - Nitrification
- 1970s – Chemical addition for phosphorus removal
- 1980s to 2000 – BNR development and application
- Past 20 years – BNR to ENR

March 2022 BNR and ENR 65

Evolution of Activated Sludge



March 2022 BNR and ENR 66

Nutrient Removal

Nutrient

- Nitrogen

Removal Process

- Nitrification
  - Ammonia Conversion
  - NH_3^+-N to NO_3^--N
  - Oxygen and alkalinity needed
- Denitrification
  - Nitrate Removal
  - NO_3^--N to Nitrogen gas (N_2)
  - Carbon source needed

Nutrient

- Phosphorus

Removal Process

- Biological Uptake
  - Conventional
  - Excess
- Chemical Precipitation

Nutrient Removal

FORM	Removal Mechanism	LOT[1], mg/L
TN		**< 1.5**
NH_3-N	Nitrification	< 0.1
NO_3-N	Denitrification	< 0.1
Org-N:		
Particulate	Solids Separation	< 0.5
Soluble	Ammonification	0.5 – 1.0
TP		**< 0.05**
Particulate	Solids Separation	< 0.05
Soluble	Biological uptake and chemical precipitation	< 0.05

[1] LOT – Limit of Technology

Meeting Nutrient Discharge Limits Process Strategies

1. **Multiple barriers for TN removal**
   - Pre-anoxic zone (first stage denitrification)
   - Nitrification – aerobic zone
   - IFAS (enhanced nitrification, optional))
   - Post anoxic zone (second stage denitrification)
   - Denitrification filters (in lieu of post anoxic zone)
2. **Multiple barriers for TP removal**
   - Biological uptake
   - One (maybe two) chemical application points
   - Filtration for TSS (particulate TP) removal

Nutrient Removal

Nitrogen

March 2022 BNR and ENR 70

Forms of Nitrogen

Organic Nitrogen

Complex Compounds
- Protein (plant & animal)
- Amino Acids
- etc.

Oxygen Demand
Nutrient Source

March 2022 BNR and ENR 71

Forms of Nitrogen

Ammonia – NH_3

Toxic
Oxygen Demand

Nitrite – NO_2^-
Chlorine Demand

Nitrate – NO_3^-
Health Concern

All Are Nutrients (fertilizer)

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Forms of Nitrogen

FORM	REMOVAL PROCESS
• Organic-N	• Converts to ammonia; **a small soluble portion is non-reactive (1.0 mg/l)**
• Ammonia(um) (NH_3/NH_4^+)	• Most abundant form; converts to nitrites/nitrates under aerobic conditions (nitrification)
• Nitrite (NO_2^-)/Nitrate (NO_3^-)	• Converts to N_2 under anoxic (no oxygen) conditions (denitrification)

Forms of Nitrogen

- Ammonia(um) (NH_3/NH_4^+)
- Organic Nitrogen (Org-N)

TKN (Un-oxidized)

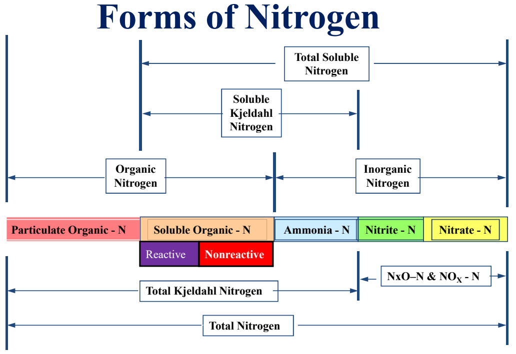
- Nitrogen Gas (N_2) ↑
- Nitrite (NO_2^-)
- Nitrate (NO_3^-)

NO_x (Oxidized)

Total Nitrogen (TN) = TKN + NO_x

TKN = Total Kjeldahl Nitrogen

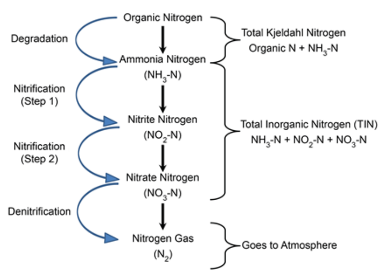
Forms of Nitrogen



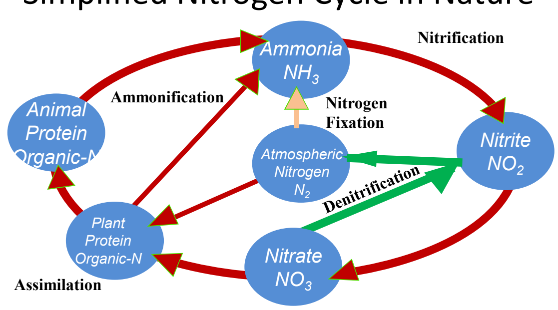
Background Uptake

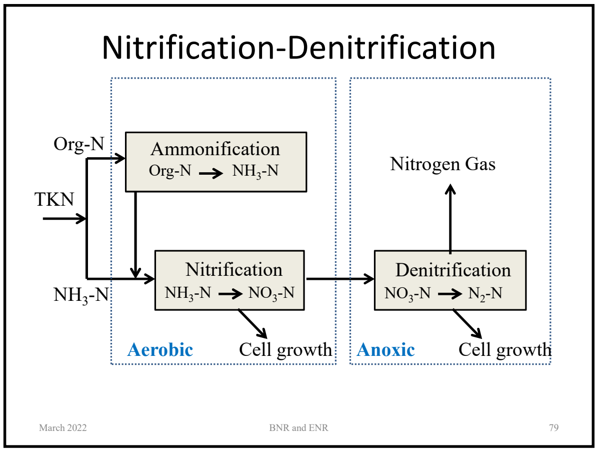
- Physical removal of particulate organic nitrogen
- Conventional biological assimilation of NH_3
  - To satisfy biological needs
- Nitrification/Denitrification
  - Aerobic zones
  - Anoxic zones

Nitrogen Cycle in Nature



Simplified Nitrogen Cycle in Nature




Nitrification-Denitrification
Org-N
TKN
NH3-N
Ammonification
Org-N → NH3-N
Nitrification
NH3-N → NO3-N
Nitrogen Gas
Denitrification
NO3-N → N2-N
Aerobic
Cell growth
Anoxic
Cell growth
March 2022
BNR and ENR
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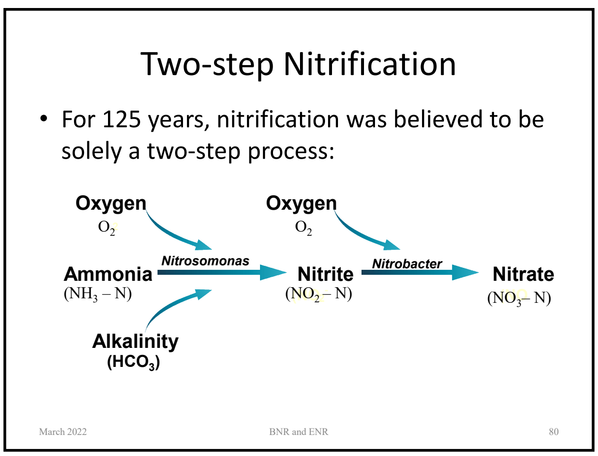
Two-step Nitrification
• For 125 years, nitrification was believed to be solely a two-step process:
Oxygen
O2
Oxygen
O2
Ammonia
(NH3 – N)
Nitrosomonas
Nitrite
(NO2 – N)
Nitrobacter
Nitrate
(NO3 – N)
Alkalinity
(HCO3)
March 2022
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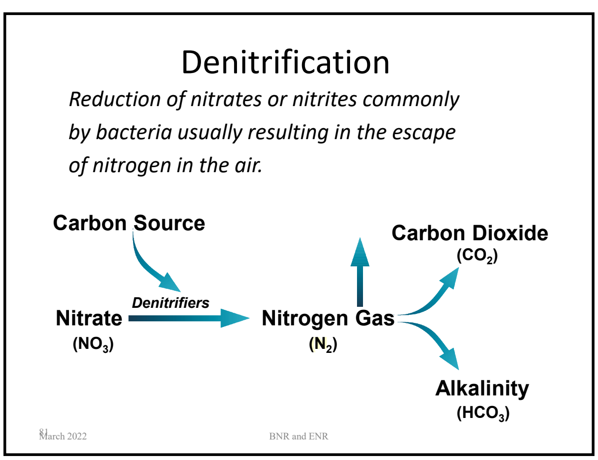
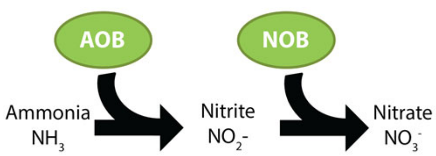

Denitrification
Reduction of nitrates or nitrites commonly by bacteria usually resulting in the escape of nitrogen in the air.
Carbon Source
Carbon Dioxide
(CO2)
Nitrate
(NO3)
Denitrifiers
Nitrogen Gas
(N2)
Alkalinity
(HCO3)
March 2022
BNR and ENR

Two-step Nitrification

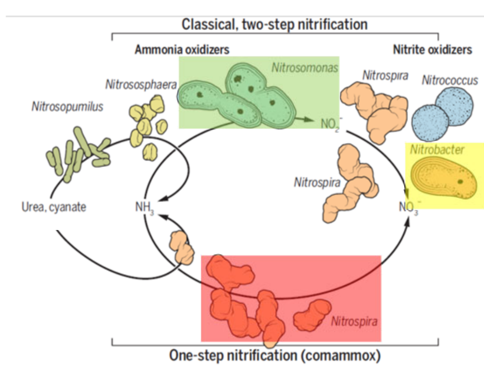
- Two-step nitrification depends on two organisms, *Nitrosomonas and Nitrobacter* which was the basis for hundreds of studies on nitrification in wastewater treatment
- A single microbe capable of catalyzing both nitrification steps may actually conserve energy

March 2022 BNR and ENR 82

Nitrification



March 2022 BNR and ENR 83



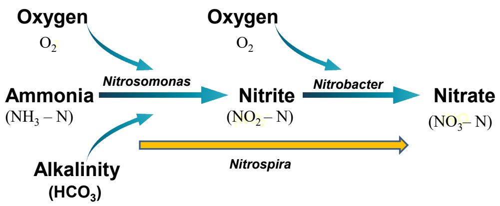
March 2022 BNR and ENR 84

One-step Nitrification - Comammox

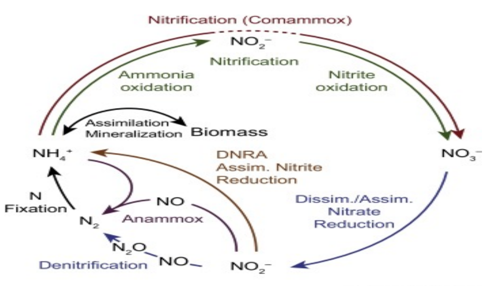
- **Comammox** (COMplete AMMonia Oxidixer) is the name for a single organism that can convert ammonia into nitrite then nitrate
- Existence of comammox bacteria were first predicted in 2006
- In 2015, *Nitrospira* bacteria were confirmed as comammox organisms in nitrification
- The Nitrogen cycle has since been updated…!

Nitrification

The oxidation (as by bacteria) of ammonia and organic nitrogen to nitrites (NO_2) and then further oxidation of nitrites to nitrates (NO_3).



Nitrogen Cycle in Wastewater (2016)



Nitrification Process Monitoring

- Oxygen requirements:
  - 4.6 mg/mg NH3-N converted
  - Maintain DO in process between 2.0 – 4.0 mg/l
- Alkalinity requirements:
  - 7.1 mg/mg NH3-N converted
  - Maintain alkalinity >70 mg/l $CaCO_3$

Nitrification

***Heterotrophic** Bacteria Break Down Organics*
Generate NH_3, CO_2, and H_2O

*Autotrophic Bacteria Utilize Inorganic Compounds
(and CO_2 as a Carbon Source)

Nitrification

Nitrification of Ammonia Occurs in Two Steps

*Autotrophic Bacteria Utilize Inorganic Compounds
(and CO_2 as a Carbon Source)

NH_3-N Ammonia N → NO_2-N Nitrite N

Nitrosomonas

NO_2-N Nitrite N → NO_3-N Nitrate N

Nitrobacter

Operational Controls for Nitrification

Air Requirements

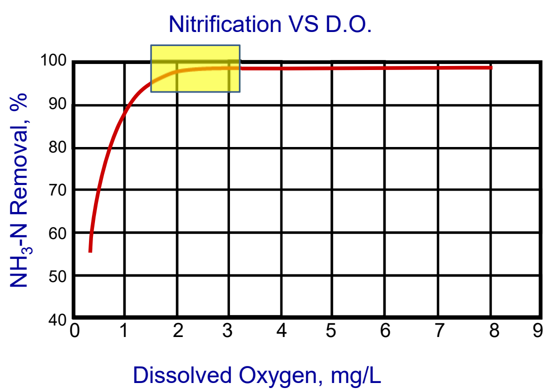
1.5 lbs O_2 / lb BOD

4.6 lbs O_2 / lb TKN

Minimum D.O. in Aeration Tank

2 - 3 mg/L

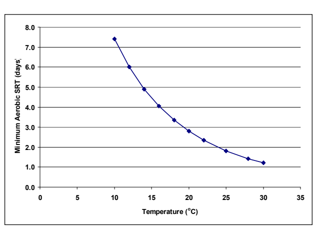
March 2022 BNR and ENR 91



March 2022 BNR and ENR 92

Nitrification Process Monitoring

- Key Factors:
  - Slow growth requires adequate **aerobic SRT**
  - **DO** typically >2mg/L
  - **pH** 6.5-7.5
    - Target effluent alkalinity of 50 to 75 mg/L as $CaCO_3$



- Overall Reaction:
  - $NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

March 2022 BNR and ENR 93

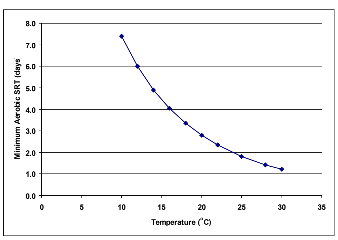
Nitrification Control Parameters

Temperature

- Nitrifiers lose about ½ their activity for each 10ºC temperature drop
- In winter, put additional aeration tanks on line, or increase MLSS
- Either action will increase MCRT

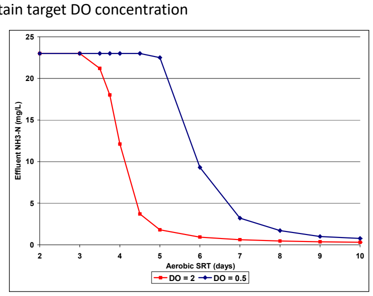
Nitrification Process Monitoring

- **Key Factor 1**
  - Slow growth requires adequate aerobic SRT
  - MAINTAIN ADEQUATE SOLIDS INVENTORY



Nitrification Process Monitoring

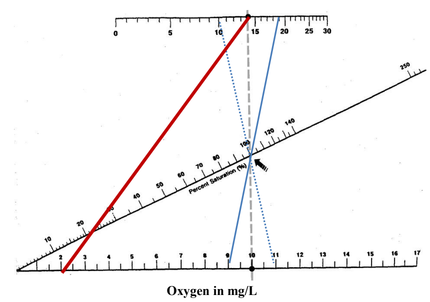
- **Key Factor 2**
  - Maintain target DO concentration



Importance of Dissolved Oxygen

- Oxygen is sparingly soluble in water
- DO is a growth-limiting substrate
- *Critical oxygen concentration* is about 10% to 50% of DO saturation in water
  - 10% minimum saturation for BOD removal (> 1.0 mg/l DO)
  - 20% minimum saturation for ammonia conversion (> 2.0 mg/l DO)

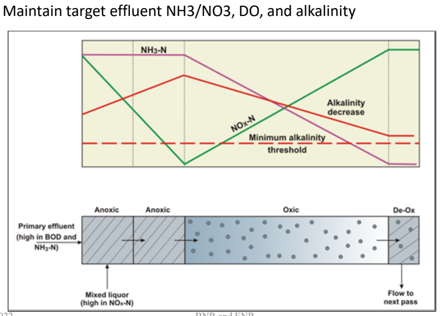
D.O. - Percent Saturation in Water



Source: Department of Fisheries and Aquatic Sciences, University of Florida

Nitrification Process Monitoring

- **Key Factors – NH3/NO3, D.O., SRT, and Alkalinity**
  - Maintain target effluent NH3/NO3, DO, and alkalinity



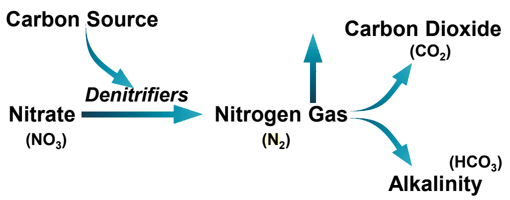
Nitrification Problems - Summary

Possible Causes	Solution
Insufficient MCRT (target – varies with temperature)	Increase MCRT to establish nitrification by reducing sludge wasting or increasing MLSS levels
Insufficient DO in aerator (target - 2.0 mg/l goal)	Increase aeration by adjusting air valves, increasing blower output, or turning on another blower.
Insufficient alkalinity (target – NLT 70 mg/l $CaCO_3$)	Add supplemental alkalinity to maintain target $CaCO_3$ concentrations in effluent
Chemical inhibition of nitrifiers	Trace source of improper discharge of nitrification inhibitors and eliminate at source

March 2022 BNR and ENR 100

Denitrification

Reduction of nitrates or nitrites commonly by bacteria usually resulting in the escape of nitrogen in the air.



March 2022 BNR and ENR 101

Denitrification

Note: (Almost) all nitrates returned to the pre-anoxic zones should be denitrified.

The “goal” NO_3-N concentration in the effluent from the last anoxic zone should be between 0 and 0.5 mg/L.

March 2022 BNR and ENR 102

Denitrification

- Requires three conditions:
  - Organic carbon must be available
  - DO concentrations must be low
  - HDT must be sufficient

March 2022 BNR and ENR 103

Conditions for Denitrification

No oxygen:
DO less than 0.2 mg/L
No aeration
Carbon source:
Primary Effluent
Endogenous
Methanol or other carbon source
Mixing:
Submersible mixers
Vertical mixers

March 2022 BNR and ENR 104

Denitrification

- Many different types of bacteria can denitrify
- The process requires organic carbon and produces 3.57 mg of alkalinity as $CaCO_3$ for every 1 mg/L nitrate (NO_3-N) denitrified
- Between 2.7 and 3.3 mg/L of methanol is needed for every 1 mg/L NO_3-N

March 2022 BNR and ENR 105

Denitrification

- **If effluent nitrate-nitrogen is above the goal:**
  - Verify nitrate recycle pumps are running.
  - Check nitrate recycle pump speed.
  - Verify very low DO in the anoxic zones.
  - Consider if low influent BOD or slowly degradable influent BOD could be inhibiting the process.

Keys to Successful Nitrogen Removal

- **Nitrification**
  - Adequate Aerobic SRT – **Keep Solids High!**
  - Adequate D.O./oxygen transfer
  - Adequate Alkalinity/pH
- **Denitrification**
  - **Successful nitrification**
  - Anoxic zones
  - No D.O
  - Carbon

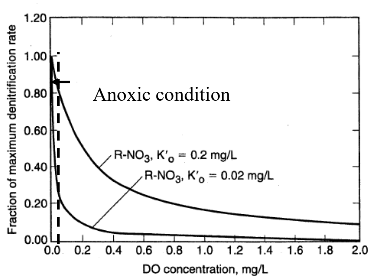
Inhibition of Denite Process

- Environmental Conditions
  - pH
  - Temperature
  - **Aerobic Conditions!** Keep DO< 0.2 mg/L
- Insufficient amount of rbCOD (Carbon Substrate).
- Presence of Chemical Inhibitors:
  - Substrates, intermediates, and products of denitrification
  - Synthetic organic chemicals
  - Heavy metals - Hg, Ni, Pb, etc.

High DO in the Anoxic Zones

- High DO in the anoxic zones may be more of a problem during the winter because more DO can be absorbed by colder water and biological kinetics are reduced.
- Lower the nitrate recycle rate in the winter if necessary

Reduction in rate of Denite as a function of D.O.
(K'o is oxygen inhibition constant)



Carbon for Denitrification

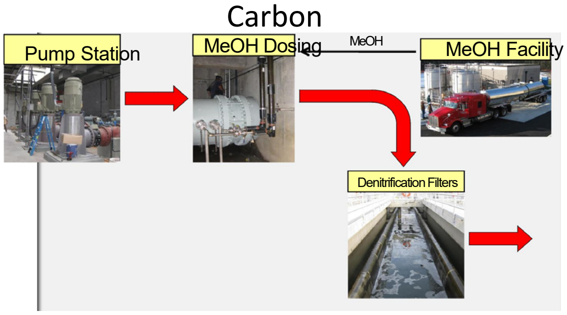
- Influent WW Carbon
  - Utilized in first anoxic zone
  - EBPR can compete for carbon
  - Limited carbon available for secondary anoxic zones – and effective denite
- Endogenous Carbon
  - Slow kinetics – limited denite in post-anoxic zones
- Supplemental Carbon
  - Methanol typically used
    - But requires methylotrophic population!
  - Alternatives to methanol – ethanol, acetic acid, glycerin, sugars, mono-propylene glycol, proprietary products

Other Carbon Sources

- Alcohols
  - Methanol
  - Ethanol
- Glycerol/glycerin – (Biodiesel by-products)
- Acetates - (Acetic acid, sodium acetate)
- Carbohydrates - (Sucrose, sugar water, corn syrup)
- MicroC™ – Carbohydrate (1000), glycerin (2000), alcohol based blends (3000)

March 2022 BNR and ENR 112

Let's Focus on Adding Supplemental Carbon

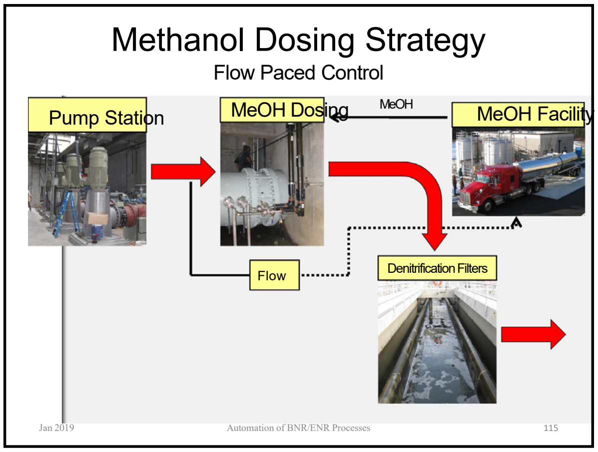


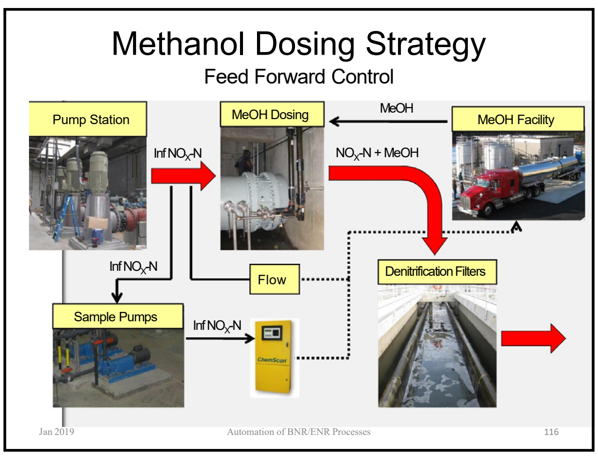
Jan 2019 Automation of BNR/ENR Processes 113

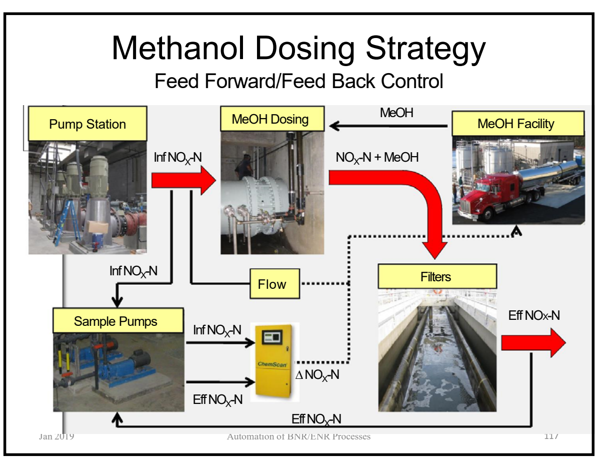
Adding Supplemental Carbon

- Typical control modes for supplemental carbon addition:
  - **Manual mode** – operator sets feed rate
  - **Flow-paced** – feed forward control: dose determined by desired nitrate removal – feed rate based on flow
  - **Nutrient-paced** – dual point control: paced based on nitrate load into anoxic zone; speed adjusted based on effluent nitrate concentration

Jan 2019 Automation of BNR/ENR Processes 114

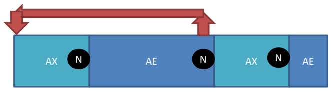

Methanol Dosing Strategy
Flow Paced Control
Pump Station
MeOH Dosing
MeOH
MeOH Facility
Flow
Denitrification Filters
Jan 2019
Automation of BNR/ENR Processes
115


Methanol Dosing Strategy
Feed Forward Control
Pump Station
MeOH Dosing
MeOH
MeOH Facility
Inf NOx-N
NOx-N + MeOH
Inf NOx-N
Flow
Denitrification Filters
Sample Pumps
Inf NOx-N
Jan 2019
Automation of BNR/ENR Processes
116


Methanol Dosing Strategy
Feed Forward/Feed Back Control
Pump Station
MeOH Dosing
MeOH
MeOH Facility
Inf NOx-N
NOx-N + MeOH
Inf NOx-N
Flow
Filters
Eff NOx-N
Sample Pumps
Inf NOx-N
ΔNOx-N
Eff NOx-N
Eff NOx-N
Jan 2019
Automation of BNR/ENR Processes
117

Adding Supplemental Carbon

- Nutrient-paced mode is the most accurate
  - Requires nitrate analyzers; locate in/out of anoxic zone and filters
  - With DO probe can account for DO entering the zone to improve results



Jan 2019 Automation of BNR/ENR Processes 118

Nutrient Removal

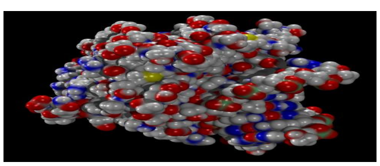
Phosphorus

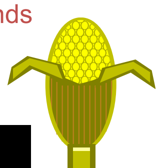
March 2022 BNR and ENR 119

Forms of Phosphorus

<u>Organic Phosphorus</u>

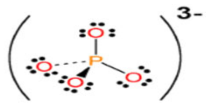
- Complex organic compounds
- Soluble or particulate
- Decomposes to Ortho-P





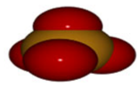
March 2022 BNR and ENR 120

Forms of Phosphorus



Orthophosphate

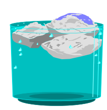
- Simple Phosphate, PO_4
- Soluble
- Phosphoric acid
- Conversion of organic and polyphosphate

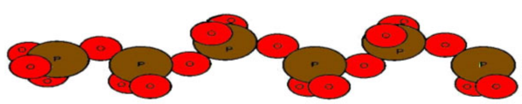


Forms of Phosphorus

Polyphosphate (condensed phosphate)

- Chained molecules
- Soluble
- Detergents (no longer…!)
- Potable water treatment
- Decomposes to Ortho-P

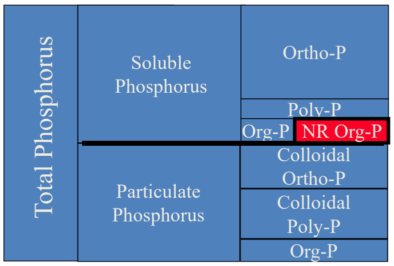




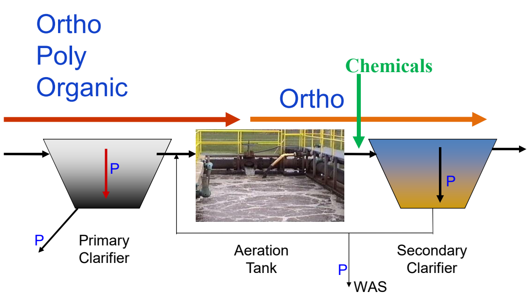
Forms of Phosphorus

FORM	REMOVAL PROCESS
• Organic-P	• Converts to polyphosphate and orthophosphate forms; **a small soluble portion is non-reactive (0.05 mg/l)**
• Orthophosphate	• Most abundant form; chemically reactive and consumed by biological growth
• Polyphosphates	• Possibly reacts with metal salts; can be used for biological growth

Forms of Phosphorus



Phosphorus Removal at WWTPs



Phosphorus Removal at WWTPs

- Physical:
  - Sedimentation and filtration for particulate phosphorus
  - membrane technologies
- Chemical:
  - Co-precipitation
  - Chemical adsorption
- Biological
  - Assimilation
  - Enhanced biological phosphorus removal (EBPR)

Background Uptake

- Physical removal of particulate organic phosphorus
- Conventional Biological Uptake
  - To satisfy biological needs
- Excess Biological uptake
  - Stress induced
  - Anaerobic zones
  - Release of phosphorus under anaerobic conditions
  - Uptake of phosphorus under aerobic conditions

March 2022 BNR and ENR 127

Phosphorus Removal Strategies

1. Source control: ban phosphates in detergents
2. Remove influent particulate P in primary clarifiers
3. Biologically convert soluble P to particulate forms
4. Chemically convert soluble P to particulate forms
5. Remove particulate P in final clarifiers and effluent filters
   - Particulate organic phosphorus
   - Biological (Phosphorus in microbial cells)
   - Chemical (Phosphate precipitates)

March 2022 BNR and ENR 128

Meeting Nutrient Discharge Limits Process Strategies

1. **Multiple barriers for TN removal**
   - Pre-anoxic zone (first stage denitrification)
   - Nitrification – aerobic zone
   - Post anoxic zone (second stage denitrification)
   - Denitrification filters (in lieu of post anoxic zone)
2. **Multiple barriers for TP removal**
   - Particulate P removal in primary clarifiers
   - Biological uptake (conventional, excess)
   - One (maybe two) chemical application points
   - Effluent filtration for particulate P removal

March 2022 BNR and ENR 129

Bans on Phosphorus in Detergents

- **By the mid-1970's, EPA** began advocating bans on detergent phosphates as practical and feasible approaches for reducing phosphorus loadings to the Great Lakes:
  - Bans on phosphates have met with consumer acceptance
  - Nitrilotriacetic acid and other phosphate substitutes have not proved to be a public health problem
  - Bans on phosphates reduce capital and operating costs (Chemical and sludge disposal) at WWTPs

March 2022 BNR and ENR 130

Bans on Phosphorus in Detergents

- States along the Great Lakes responded by:
  - Regulating phosphorus in detergents
  - Investing in more effective sewage treatment (e.g. phosphorus removal)
  - Developing and promoting best management practices for agriculture lands(e.g., minimizing surface runoff)

March 2022 BNR and ENR 131

Phosphate Bans in Detergents

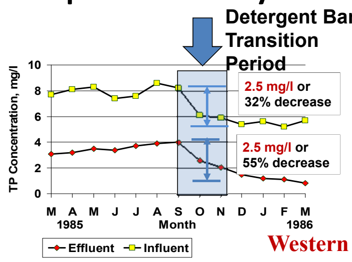
In the mid-1980's, Maryland, Pennsylvania, Virginia, and the District of Columbia instituted bans on phosphates in laundry detergents

Nearly 25 years later, a second regional ban became effective on phosphates in automatic dishwasher detergents

Phosphate Bans in Detergents

- Influent phosphorus concentrations to WWTPs were reduce more than 30% after the bans went into effect
- Effluent phosphorus concentrations from WWTPs were reduced more than 50%, after compensating for background uptake of phosphorus

Ban on Laundry Detergent Phosphates in Maryland -1985



Western Branch WWTP, WSSC

Phosphorus Removal in Clarifiers

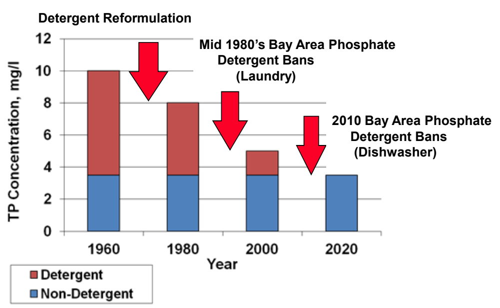
- Particulate organic phosphorus concentrations are likely high in “fresh” sewage
- Soluble phosphorus concentrations are likely high in “old” sewage
  - Conversion of particulate organic and condensed phosphorus forms to soluble phosphorus forms in the wastewater collection system

Phosphorus Removal in Clarifiers

- Some phosphorus will be removed in the primary sedimentation tanks, e.g., 10 to 30%
- Removal in the primary clarifiers depends on influent phosphorus composition:
  - Particulate organic phosphorus
  - Particulate condensed phosphates

March 2022 BNR and ENR 136

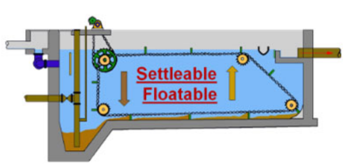
WWTP – Influent TP Trend



March 2022 BNR and ENR 137

Removal of Settleable Solids Provides Some Phosphorus Removal

Primary Sedimentation 10 - 30%



Biological Uptake

- Conventional Biological Uptake
  - To satisfy biological needs (2.0 to 3.0% by weight)
- Enhanced Biological uptake (5 to 7% by weight)
  - Stress induced
  - Release of phosphorus under anaerobic conditions
  - Uptake of phosphorus under aerobic conditions

March 2022 BNR and ENR 139

Biological Uptake

- **Assimilation** - Phosphorus removal from wastewater has long been achieved through incorporation of P as an essential element in the biomass

March 2022 BNR and ENR 140

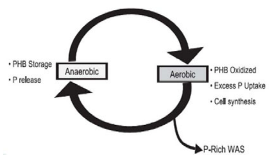
Phosphorus Forms – Soluble versus Particulate

- Removal of soluble forms:
  - Biological:
    - Assimilation (In microbial cells)
    - Excess uptake – Enhanced Biological Phosphorus Removal (EBPR); A2O
  - Chemical precipitation and adsorption
    - Fe and Al salts
    - Lime

March 2022 BNR and ENR 141

Enhanced Biological P Removal (EBPR)

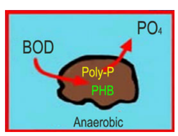
- Step 1: Anaerobic Phase
  - BOD removal
  - Phosphorus release
- Step 2: Aerobic Phase
  - Phosphorus uptake and creation of new PAOs
  - Phosphorus removal by sludge wasting



Enhanced Biological P Removal (EBPR)

Anaerobic Conditions

PAO Take Up VFAs and Covert them to Polyhydroxybutyrate (PHB)



PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

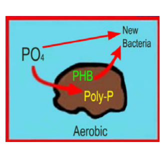
Ortho-P is Released Into Solution

Enhanced Biological P Removal (EBPR)

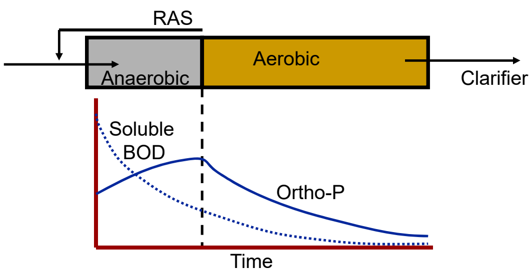
Aerobic Conditions

Rapid Aerobic Metabolism of Stored Food (PHB) Producing New Cells

PO_4 Used in Cell Production
Excess Stored as Polyphosphate
("Luxury Uptake")



Enhanced Biological P Removal (EBPR)



Phosphorus Removal with Chemicals

Chemical Reactions – two mechanisms:

- **Co-precipitation** (Remove TP to ~ 0.5 mg/l)
  - $\underline{2}Al + 3OH + PO_4$ ----> $\underline{2}Al(OH)_3PO_4 \downarrow$
- **Adsorption** (Remove TP < 0.5 mg/l to ~ 0.05)
  - $x\ (Al + 3OH)$ ---> $x\ (AlOH_3) \downarrow$
  - $x\ (AlOH_3) \downarrow + PO_4$ ----> $x\ (Al(OH)_3) \cdot PO_4 \downarrow$
  - $x > 2$; more chemical required as PO_4 levels drop
- Both reactions form Metal (Al or Fe)-Phosphate-Hydroxide floc

Co-Precipitation Iron Reactions

- $FeCl_3 + PO_4^{-3}$ ---> $FePO_4 + 3Cl^{-1}$
- $FeCl_3 + 3HCO_3^{-1}$ ----> $Fe(OH)_3 + 3CO_2 + 3Cl^{-1}$
- Simplified: $Fe + PO_4$ ------> $FePO_4$
  $Fe + 3OH$ ------> $Fe(OH)_3$
- Combined:
  $\underline{2}Fe + PO_4 + 3OH$ ----> $2FePO_4(OH)_3$ Complex $\downarrow$
  (Mole Ratio = 2.0)

Co-Precipitation Aluminum Reactions

- $Al_2(SO_4)_3 \cdot 14H_20 + 2PO_4^{-3}$ ------> $2AlPO_4 + 3SO_4^{-2} + 14\ H_2O$
- $Al_2(SO_4)_3 \cdot 14H_20 + 6HCO_3^{-1}$ ------> $2Al(OH)_3 + 6CO_2 + 14\ H_2$
- Simplified: $Al + PO_4$ ------> $AlPO_4$
  $Al + 3OH$ ------> $Al(OH)_3$
- Combined:
  $\underline{2}Al + PO_4 + 3OH$ ----> $2AlPO_4(OH)_3$ Complex ↓
  (Mole Ratio = 2.0)

Chemicals used for Phosphorus Precipitation

Chemical	Formula	Removal mechanism	Effect on pH
Ferric Chloride	$FeCl_3$ M.W. = 162.3	Metal hydroxides	Removes alkalinity
Aluminum Sulfate (Alum)	$Al_2(SO4)_3.14.3(H_2O)$ M.W. = 599.4	Metal hydroxides	Removes alkalinity
Ferrous sulfate (pickle liquor)	Fe_2SO_4	Metal hydroxides	Removes alkalinity
Poly Aluminum Chloride	$Al_nCl_{(3n-m)}(OH)_m$ $Al_{12}Cl_{12}(OH)_{24}$	Metal hydroxides	none
Lime	CaO, $Ca(OH)_2$	Insoluble precipitate	Raises pH above 10

Chemical Addition – Effects on pH

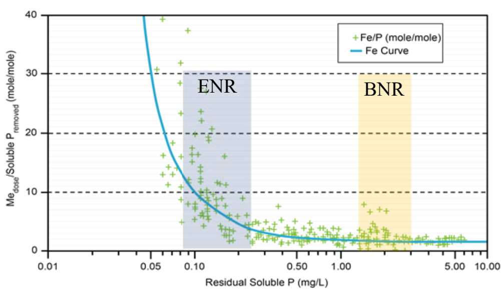
- Alum or iron salts will decrease alkalinity and pH, especially at higher dosages
- Lime raises pH
- PACl will not lower alkalinity or pH

Chemical Addition Rates

- Dependent on:
  - TP Discharge Limitations
  - Influx TP Loading
  - Biological P Removal Rates
  - Chemical to P Molar Ratios:
    - Al/Fe Salts, Range: 1.6- 2.1 to reach 0.5 mg/l P
> 3.0 to reach < 0.25 mg/l P
> 5.0 to reach < 0.2 mg/l P
>10 to reach < 0.15 mg/l P
    - Dependent on Alkalinity

March 2022 BNR and ENR 151

Chemical Removal of Phosphorus



Data from the Blue Plains Advanced Wastewater Treatment Plant, Washington, D.C. and Luedecke, C.; Hermanowicz, S.; Jenkins, D. (1987). Precipitation of Ferric Phosphate in Activated Sludge: A Chemical Model and Its Verification. Water Sci. Technol., 21, 325–338.

March 2022 BNR and ENR 152

Effluent Filtration Application

- Removes Residual Bio-Floc
- Removes Residual Chemical/Bio Floc
- Removes Residual Coagulation Particles in Phys-Chem Treatment

March 2022 BNR and ENR 153

Effluent Filtration Applications

- Gravity filters are needed to reduce effluent particulate phosphorus to less than 0.3 mg/L
- Membranes may be needed to reduce effluent particulate phosphorus to less than 0.1 mg/L

March 2022 BNR and ENR 154

Effluent Filtration Application

- Assuming that 2-3% of organic solids is P, then an effluent total suspended solids (TSS) of 10 mg/L represents 0.2-0.3 mg/L of effluent P.
- In plants with EBPR the P content is even higher
- Sand filtration or other method of TSS removal (e.g., membrane) is likely necessary for plants with low effluent TP permits

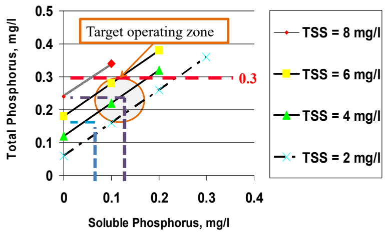
March 2022 BNR and ENR 155

TSS Removal Requirements

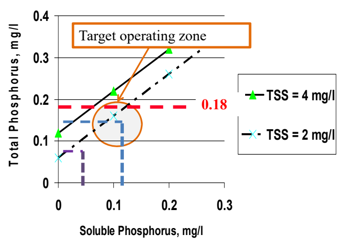
TP Limit, mg/L	Max TSS, mg/L
0.1	3.0
0.2	5.0
0.3	7.0
0.4	9.0
0.5	11

March 2022 BNR and ENR 156

Effluent TP versus Effluent TSS



Effluent TP versus Effluent TSS



What have you learned…

- What portion of TP is difficult to remove?

…non-reactive soluble Org-P

March 2022 BNR and ENR 159

What have you learned…

- List three ways to remove phosphorus from wastewater?

…source control

…background/biological uptake

…chemical addition

March 2022 BNR and ENR 160

What have you learned…

- The chemical dose for TP removal will depend on several factors; please list at least three…

…TP discharge limitations

…incoming TP loadings

…background/biological uptake rates of TP

…metal salt:TP mole ratio

March 2022 BNR and ENR 161

What have you learned…

- List two common chemicals used to precipitate phosphorus from wastewater…

…$FeCl_3$

…Alum

March 2022 BNR and ENR 162

BNR

Overview

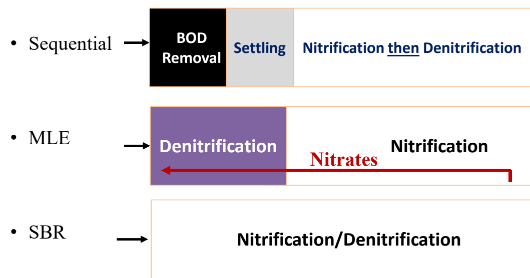
BNR Program

- To reduce total phosphorus concentrations, most WWTPs began adding chemicals like $FeCl_3$ or alum
- To reduce total nitrogen concentrations, most WWTPs initiated a capital improvement project to add “Pre” and/or “Post” anoxic zones to already existing nitrification processes for denitrification

Typical BNR Configurations

- USEPA model - Sequential BOD removal, Nitrification and Denitrification in separate basins
- South Africa model (MLE) – Modified Ludzack Ettinger process; Denitrification then Nitrification with nitrate recycle
- SBRs - Sequencing Batch Reactors; Nitrification then Denitrification in same basin; no nitrate recycle

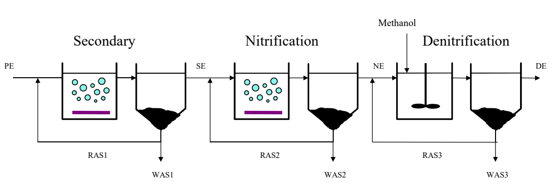
Typical BNR Configurations



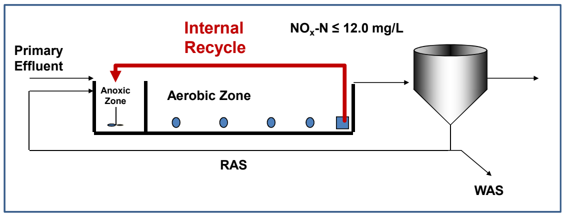
BNR Processes

Process	Nitrogen	Phosphorus	Comments
MLE	Good	None	- Moderate basin volume
Enhanced MLE (Bardenpho)	Excellent	None	- Large basin volume - Need for methanol
Step Feed	Good	None	- No nitrate recycle
SBR	Moderate	Inconsistent	- No nitrate recycle
A^2O	Good	Good	- Moderate basin volume - Sensitive to DO in return
Modified UCT	Good	Excellent	-Separate anoxic zone for RAS - Several nitrate recycle streams - Increased complexity
5-stage Bardenpho	Excellent	Good	- Larger reactor volume - Need for methanol
Oxidation Ditch	Excellent	Good	-Long HRT and SRT - Tight DO controls necessary

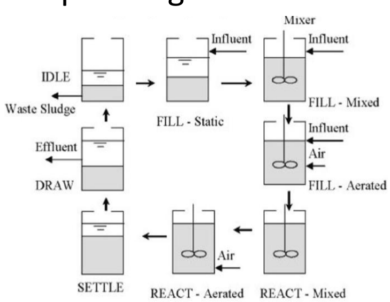
EPA "Model" for TN Removal



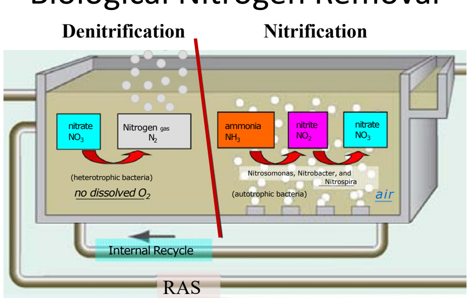
MLE with Internal Recycle



Sequencing Batch Reactor



Biological Nitrogen Removal



BNR Program

- BNR Programs in Bay watershed states began removing nutrients in 1985
- For WWTPs greater than 0.5 mgd:
  - 95% of wastewater discharged into the Bay
  - Grant funding available for WWTP upgrades
- WWTP discharge goals:
  - Reduce TP from ~ 6 mg/l to < 3.0 mg/l
  - Reduce TN from ~ 20 mg/l to < 8.0 mg/l

March 2022 BNR and ENR 172

Biological Nutrient Removal (BNR)

- BNR converts/removes Nitrogen (primarily ammonia – NH_3) in wastewater to nitrite (NO_2), nitrate (NO_3), and ultimately nitrogen gas (N_2).
- BNR is a two-step process:
  - Step 1: Nitrification
  - Step 2: Denitrification

March 2022 BNR and ENR 3

BNR

- Removes most nitrogen (TN) and phosphorus (TP) from wastewater
- BNR processes use microorganisms under different environmental conditions:
  - Anaerobic (w/o O_2 and NO_3-N)
  - Anoxic (w/o O_2)
  - Aerobic or oxic (with O_2)

March 2022 BNR and ENR 174

BNR Stages

- Anaerobic stage - No oxygen nor NO_3-N; Phosphorus is released; enhances greater TP uptake in the aerobic stage
- Anoxic stage – No oxygen; NO_3-N is converted to N_2 gas (Denitrification)
- Aerobic stage – Plenty of oxygen; NH_3-N is converted to NO_3-N (Nitrification)

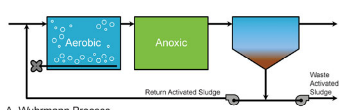
March 2022 BNR and ENR 175

Milestones

- 1954 Wuhrman proposes 2-stage, aerobic - anoxic process
- 1962 Ludzack and Ettinger proposes 2-stage, anoxic – aerobic process
- 1973 Barnard in South Africa develops the Modified Ludzack-Ettinger process

March 2022 BNR and ENR 176

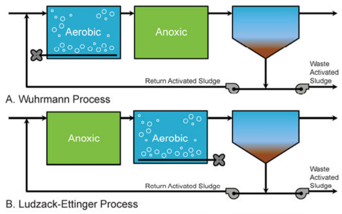
2-Stage BNR Process Evolution



1954

March 2022 BNR and ENR 177

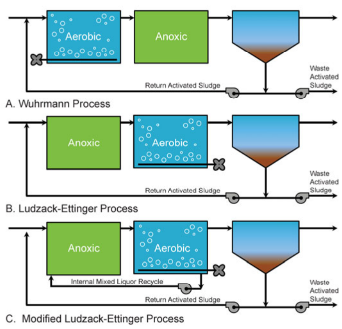
2-Stage BNR Process Evolution



1954

1962

2-Stage BNR Process Evolution

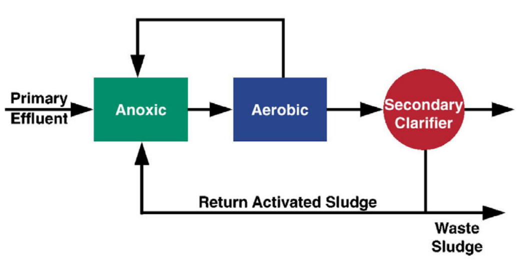


1954

1962

1973

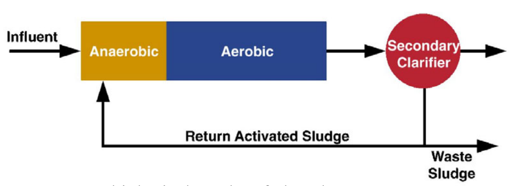
Modified Ludzack-Ettinger - MLE



Milestone

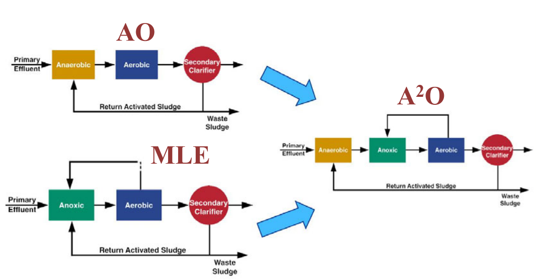
- 1976 Specter patents A/O® and A²/O® processes

AO

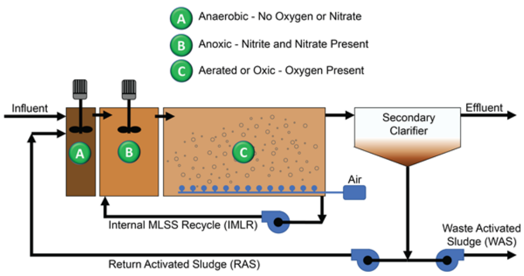


For biological uptake of phosphorus

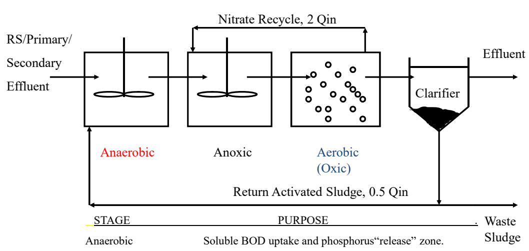
AO plus MLE = A^2O



3-Stage BNR Process



3-Stage BNR Process



STAGE	PURPOSE
Anaerobic	Soluble BOD uptake and phosphorus"release" zone.
Anoxic	Denitrification and nitrogen gasification zone
Aerobic (Oxic)	Nitrification and phosphorus "uptake" zone

Historical View of BNR

- Recent efforts for nutrient removal for WWTPs with limited space for expansion has led to:
  - Membrane reactors
  - Side-stream treatment for phosphorus removal:
    - Struvite precipitation
  - Side-stream treatment for ammonia removal:
    - ANAMMOX

What have you learned…

- What was the regulatory "drivers" for BNR programs in Chesapeake Bay states?

…EPA's Chesapeake Bay Program (1983)

…1987 Chesapeake Bay Agreement

March 2022 BNR and ENR 187

What have you learned…

- What was the regulatory "driver" for ENR programs in Chesapeake Bay states?

…2000 Chesapeake Bay Agreement

March 2022 BNR and ENR 188

What have you learned…

- When did Dr. Barnard develop the modified Ludzack- Ettinger (MLE) process? Why is this significant?

…1973 (added internal nitrate recycle)

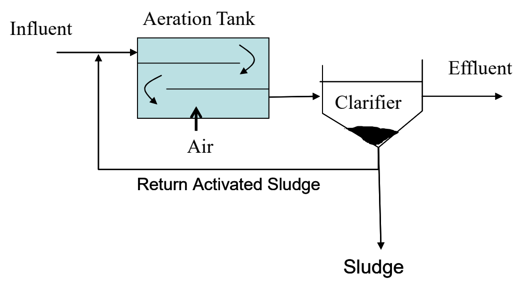
…The MLE concept is the standard for wastewater processes

March 2022 BNR and ENR 189

BNR

Process Details

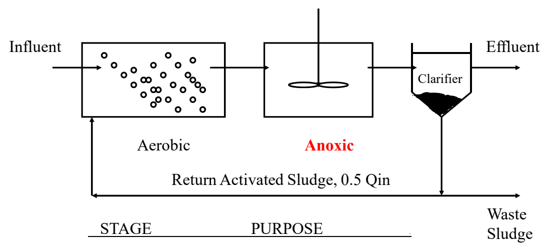
Typical Activated Sludge Process



BNR Processes

- Anaerobic-aerobic (AO)
- Modified Ludzack-Ettinger (MLE)
  - Anoxic-aerobic
- Anaerobic-anoxic-oxic (A^2O and UCT)
- Step feed
- Oxidation ditch

Two Stage Wuhrmann BNR Process

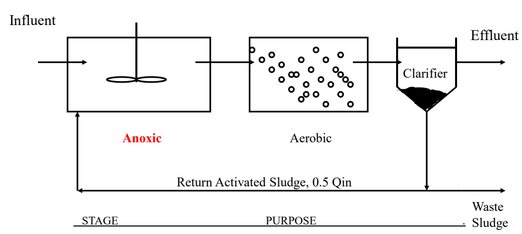


STAGE	PURPOSE
Aerobic (Oxic)	Nitrification
Anoxic	Denitrification and Nitrogen gas release

March 2022 BNR and ENR 193

Two Stage Ludzack-Ettinger BNR Process

Denitrification-Nitrification

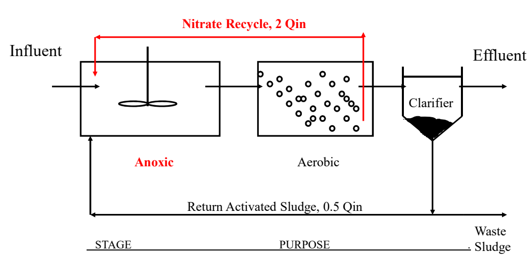


STAGE	PURPOSE
Anoxic	BOD Removal, Denitrification, and Nitrogen gas release zone
Aerobic (Oxic)	Nitrification zone

March 2022 BNR and ENR 194

Modified Ludzack-Ettinger BNR Process

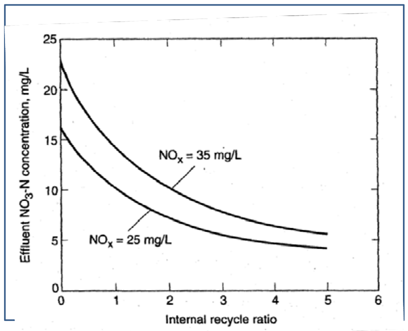
Denitrification-Nitrification with Nitrate Recycle



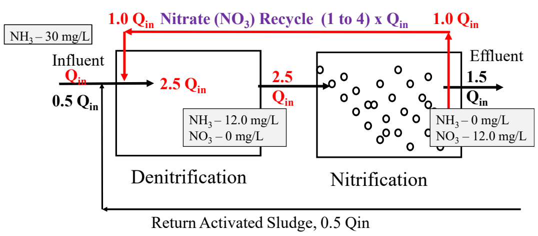
STAGE	PURPOSE
Anoxic	BOD Removal, Denitrification, and Nitrogen gas release
Aerobic (Oxic)	Nitrification zone

March 2022 BNR and ENR 195

Impact of Internal Recycle on Effluent TN

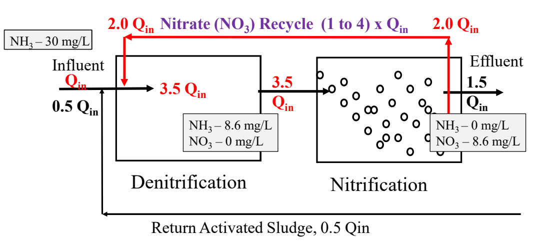


TN Removal – Example 1



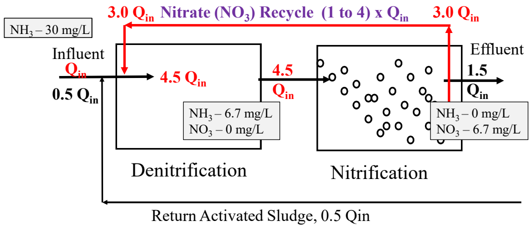
Assume all NO3 returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH3-N concentration in Denitrification? NH3-N = $\frac{30 \text{ mg/L}}{2.5/1}$ = 12.0 mg/l

TN Removal – Example 2



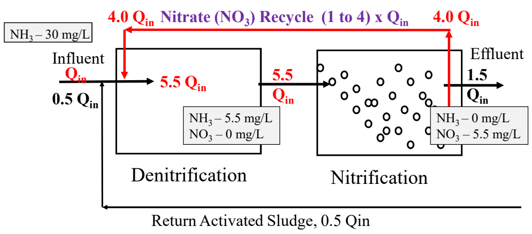
Assume all NO3 returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH3-N concentration in Denitrification? NH3-N = $\frac{30 \text{ mg/L}}{3.5/1}$ = 8.6 mg/l

TN Removal – Example 3



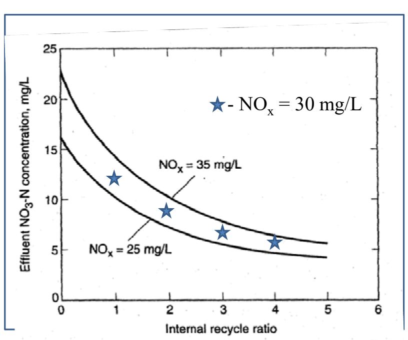
Assume all NO3 returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH3-N concentration in Denitrification? NH3-N = 30 mg/L = 6.7 mg/l
4.5/1

TN Removal – Example 4

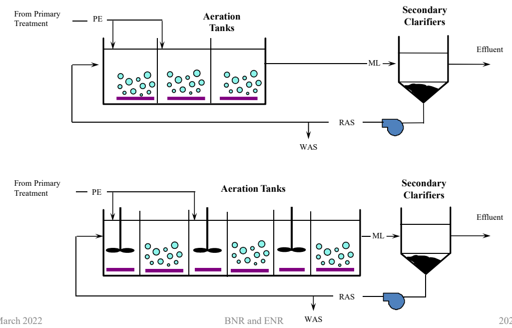


Assume all NO3 returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH3-N concentration in Denitrification? NH3-N = 30 mg/L = 5.5 mg/l
5.5/1

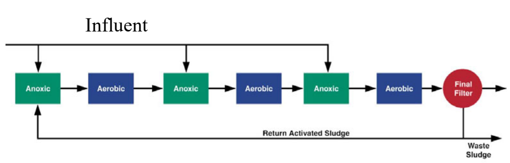
Impact of Internal Recycle on Effluent TN



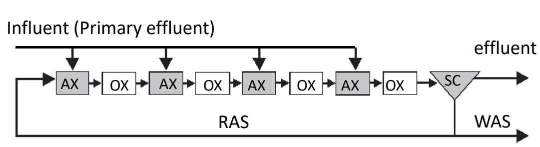
Step Feed Process



Step Feed

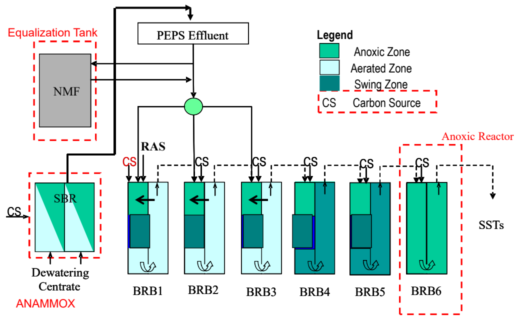


Step Feed

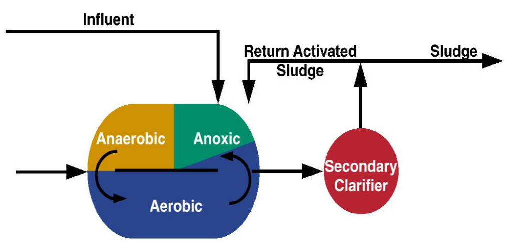


AX – Anoxic zone (denitrification)
OX – Oxic (aerobic) zone (nitrification)
SC – Secondary clarifier (solids separation)
RAS – Return activated sludge
WAS – Waste activated sludge

AlexRenew Step Feed Facility



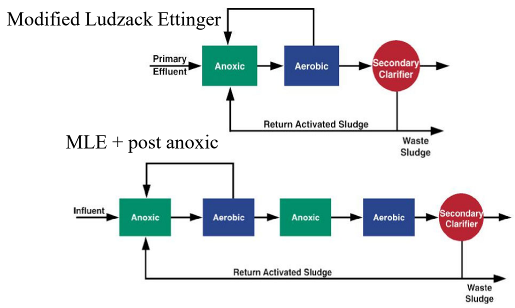
Oxidation Ditch



BNR to ENR

Evolution

Example of BNR to ENR



March 2022 BNR and ENR 208

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Milestones

- 1968 Barth proposes 3-sludge, activated sludge process for nutrient removal
- 1975 Barnard patents Bardenpho® process
- 1980 University of Cape Town (UCT) process developed

March 2022 BNR and ENR 209

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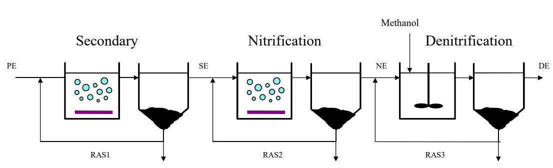
Three Stage System for BOD and Nitrogen Removal

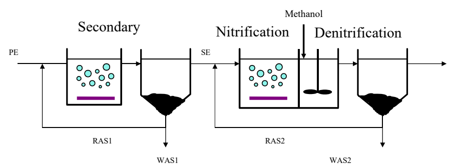
Post Denitrification w/Methanol



Example: Western Branch WWTP, WSSC 30 MGD

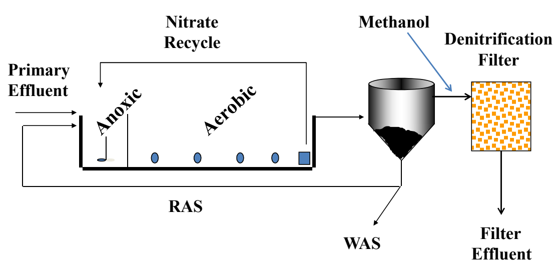
March 2022 BNR and ENR 210

Two Sludge System for BOD and Nitrogen Removal



Example: Blue Plains, DC Water 370 MGD

MLE With Denitrification Filter



What have you learned…

- What process is needed to go from BNR to ENR?

  …a post denitrification process

What have you learned…

- List three BNR/ENR processes that remove TN to less than 5.0 mg/L…

…MLE

…Enhanced MLE

…step feed

…UCT

…Oxidation ditch

March 2022 BNR and ENR 214

What have you learned…

- The amount of TN removal in BNR processes depends primarily on the…

…Nitrate recycle rate from nitrification to denitrification

…amount of nitrates returned to the denitrification process

March 2022 BNR and ENR 215

ENR

Overview

March 2022 BNR and ENR 216

ENR Program

- To further reduce total phosphorus concentrations, most WWTPs began adding increased quantities of chemicals
- To further reduce total nitrogen concentrations, most WWTPs initiated a capital improvement project to add "Post" anoxic zones to already existing BNR facilities

March 2022 BNR and ENR 217

ENR Program

- ENR Program began in 2000
- For WWTPs greater than 0.5 mgd
  - 95% of wastewater discharged into the Chesapeake Bay
  - Grant funding available for upgrades
- WWTP discharge reduction goals:
  - Reduce TP from < 3.0 mg/l to < 0.3 mg/l
  - Reduce TN from < 8.0 mg/l to < 3.0 mg/l

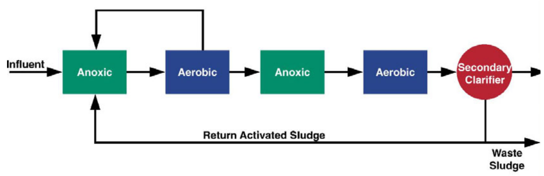
March 2022 BNR and ENR 218

Enhanced Nutrient Removal

- Over the past two decades, BNR facilities have been upgraded to improve nitrogen removal efficiencies:
  - Post anoxic zones for denitrification
  - Mixed Bed Bio-reactors (MBBR)
  - Fixed film biological filters for nitrification
  - Tertiary denitrification filters

March 2022 BNR and ENR 219

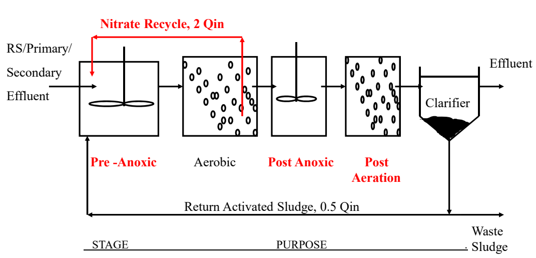
Bardenpho
(Enhanced Modified Ludzack Ettinger)



Enhanced Nutrient Removal

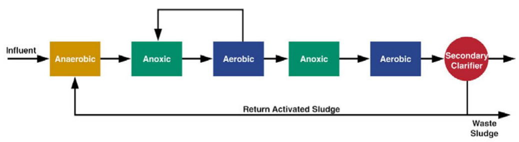
- For WWTPs to upgrade from BNR to ENR, and satisfy new LOT requirements for nitrogen removal, an additional post-denitrification stage is required; for example:
  - MLE + post anoxic
  - MLE + MBBR
  - MLE + Denit Filter
  - Step feed + post anoxic
  - Step feed + MBBR
  - Step feed + Denit Filter

Enhanced Nutrient Removal Process
With Pre- and Post Denitrification and Aeration



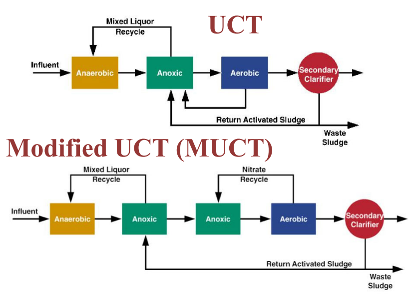
STAGE	PURPOSE
Anoxic	Denitrification and Nitrogen gas release zone
Aerobic (Oxic)	Nitrification zone

Modified Bardenpho



March 2022 BNR and ENR 223

UCT Processes



March 2022 BNR and ENR 224

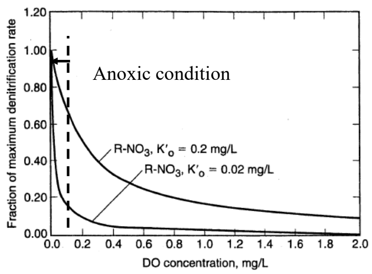
Denitrification

Note: (Almost) all nitrates entering anoxic zones should be denitrified

The effluent "goal" NO_3-N concentration from the last anoxic zone should be between 0 and 0.5 mg/L.

March 2022 BNR and ENR 225

Reduction in rate of Denite as a function of D.O.
(K'o is oxygen inhibition constant)



March 2022 BNR and ENR 226

Carbon for Denitrification

- Influent WW Carbon
  - Utilized in anoxic zones
  - Limited carbon available for secondary anoxic zones
- Supplemental Carbon
  - Methanol typically used
    - But requires methylotrophic population!
  - Alternatives to methanol – glycerin, sugars, and proprietary products

March 2022 BNR and ENR 227

Carbon for Denitrification

- If using methanol – may not have adequate methylotrophic population
  - Need well controlled anoxic volume
  - Methylotrophs require acclimation time
  - Methylotrophs are believed to be more sensitive to temperature
- Methanol is typically more sensitive to pH and may not be effective in very cold weather
  - Change carbon source – ethanol or glycerin
- Denitrification batch tests
  - Specific denitrification rates (SDNRs) – different carbon sources

March 2022 BNR and ENR 228

Other Carbon Sources

- Alcohols
  - Methanol
  - Ethanol
- Glycerol/glycerin – (Biodiesel by-products)
- Acetates - (Acetic acid, sodium acetate)
- Carbohydrates - (Sucrose, sugar water, corn syrup)
- MicroC™ – (Carbohydrate, glycerin, alcohol based blends)

Denitrification Problems

Possible Causes	Solution
Not enough nitrates being returned to anoxic zone	Increase nitrate recycle pump speed
Not enough BOD entering anoxic zone	- Bypass primary clarifiers, or - Add supplemental carbon (for example, methanol) to anoxic zone
BOD entering the anoxic zone breaks down too slowly	Add readily available carbon source such as methanol to anoxic zone or increase the anoxic zone hydraulic retention time
High DO in the anoxic zone	Try to limit backmixing of air from the aerobic zones or decreasing the DO in the AT influent. Decrease nitrate recycle rate if necessary.

What have you learned…

- List four distinct forms of nitrogen in wastewater making up total nitrogen (TN)…

…Org-N
…NH_3- N } TKN, un-oxidized nitrogen

…NO_2-N
…NO_3-N } Oxidized nitrogen

…TN = Org N + NH_3 + NO_2-N + NO_3-N

What have you learned…

- What portion of TN is difficult to remove?

…non-reactive soluble Org-N

March 2022 BNR and ENR 232

What have you learned…

- What are the two processes needed to remove TN?

…Nitrification

…Denitrification

March 2022 BNR and ENR 233

What have you learned…

- Below average wastewater temperatures (increase or decrease) the growth rate of nitrifiers…

…decrease

March 2022 BNR and ENR 234

What have you learned…

- List three factors key to nitrification…

…Maintain target solids residence times (SRT) or mean cell residence times (MCRT)

…Maintain target DO levels – 2 to 4 mg/l

…Maintain target alkalinity levels - > 70 mg/l $CaCO_3$

March 2022 BNR and ENR 235

What have you learned…

- What substance needs to be absent to assure denitrification?

…Dissolved Oxygen

March 2022 BNR and ENR 236

What have you learned…

- Which process is key to TN removal, nitrification or denitrification?

…Nitrification

March 2022 BNR and ENR 237

Fixed Film Processes

Nutrient Removal

Fixed Film Processes

- cBOD Removal
  - TF – Trickling Filters
  - RBC – Rotating Biological Contactor
- Nitrification
  - BAF – Biological Aerated Filter
  - IFAS – Integrated Fixed-Film Activated Sludge
  - MBBR – Moving Bed Biofilm Reactor
- Denitrification
  - Denit Filter
    - Down flow
    - Up flow

Fixed Film Processes

cBOD Removal	Nitrification	Denitrification
– TF	– TF & RBCs	– Denit Filters
– RBC	– BAF	– MBBR (w/o O_2)
– BAF	– IFAS	– BAF (w/o O_2)
	– MBBR	

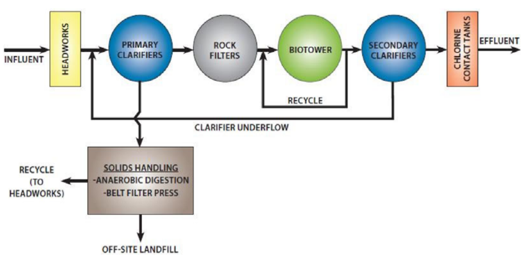
Fixed Film Processes

What can fixed film (a.k.a. attached growth) processes do?

1. ***Remove Nutrients***
   - Phosphorus
   - Nitrogen
2. **Remove BOD:**
   - Dissolved organic solids
3. **Remove TSS:**
   - Suspended particulate solids
   - Suspended organic solids

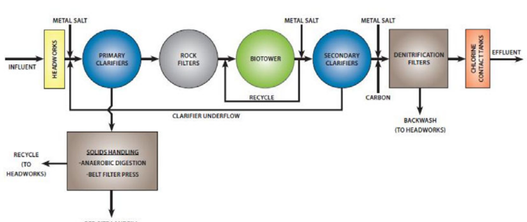
March 2022 BNR and ENR 241

Process Configuration
Nitrification



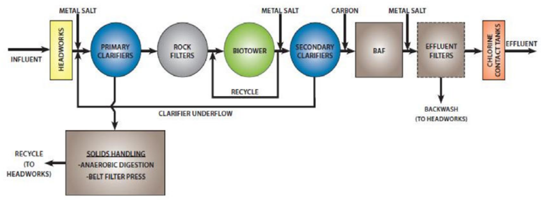
March 2022 BNR and ENR 242

Process Configuration
ENR with Denitrification Filters



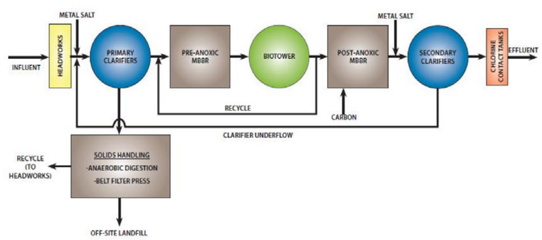
March 2022 BNR and ENR 243

Process Configuration
ENR with Denit-BAF and Effluent Filters



March 2022 BNR and ENR 244

Process Configuration
ENR with Pre- and Post-anoxic MBBR



March 2022 BNR and ENR 245

Fixed Film Nitrification

IFAS and MBBR

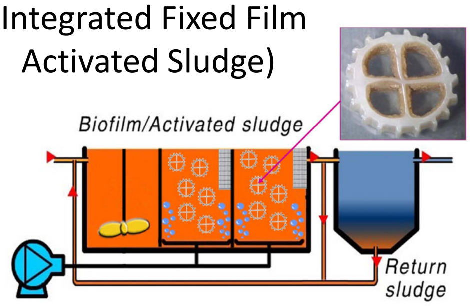
March 2022 BNR and ENR 246

Why Use An IFAS Process ?

- Increase capacity without more tanks
- Achieve nitrogen removal in tank, which could not otherwise totally nitrify and denitrify

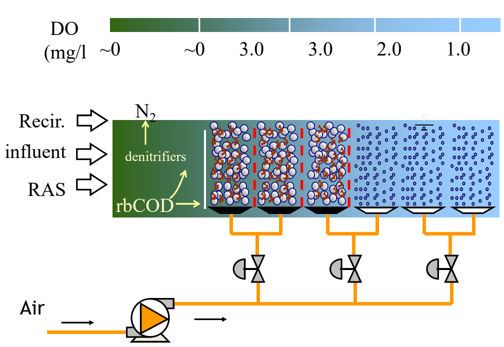
March 2022 BNR and ENR 247

IFAS (Integrated Fixed Film Activated Sludge)

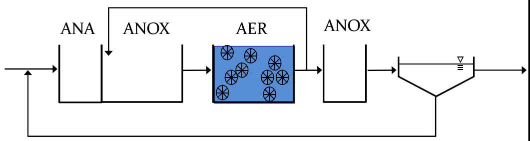


March 2022 BNR and ENR 248

IFAS LAYOUT



IFAS in Nutrient Removal

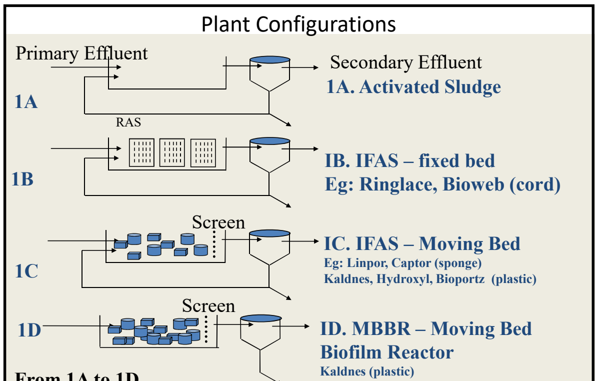


Typically an upgrade to implement BNR or increase Nitrification capacity at existing plants.

Benefits of IFAS Processes

- Increase total solids inventory without increasing solids loading to clarifier
- Minimize effects of solids washout under high hydraulic loadings
- Avoid cost of construction of new tanks
- Decrease required recycle rates

Plant Configurations



From 1A to 1D

Clarifier size requirements decrease; Operating MLSS HRT requirements decrease; Biofilm surface area increases

Types of IFAS Systems

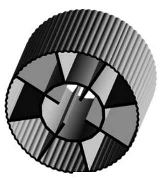
Fixed
- **Rope**
- **Plastic**

Free
- **Sponge**
- **Plastic**

March 2022 253

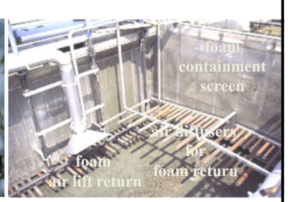
Free Floating Media - Plastic

Hydroxyl



March 2022 BNR and ENR

Free Floating Media - Sponge

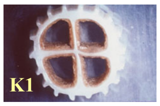


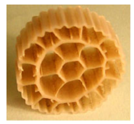
Lotepro – Linpor Process

March 2022 BNR and ENR 255

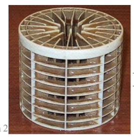
Plastic Media (Kaldnes)

		K1	K2	K3	Model O	Biofilm Chip
Length	(mm)	7.2	15	9	50	2
Diameter	(mm)	9.1	15	25	60	47
Specific Surface Area	(m2/m3)	500	350	480	94.5	1,200

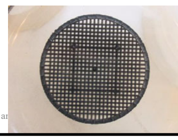




K3



Model O



Biofilm Chip

Integrated Fixed Film Activated Sludge System

- Media held in Aeration Basins to provide attached growth for Nitrifying biomass
- Typical Floating and Fixed IFAS Media
  - Kaldnes (plastic)
  - Linpor (sponge)
  - Ringlace (cord)

What have you learned…

- What does the acronym IFAS stand for?

…Integrated Fixed Film Activated Sludge

What have you learned…

- What does the acronym MBBR stand for?

…Moving Bed Bioreactor

March 2022 BNR and ENR 259

What have you learned…

- Why are IFAS systems used?

…to increase nitrification capacity without building more tanks

…to increase total solids inventory

…to minimize effects of solids washout under high hydraulic loadings

March 2022 BNR and ENR 260

Fixed Film Nitrification

Biological Aerated Filter - BAF

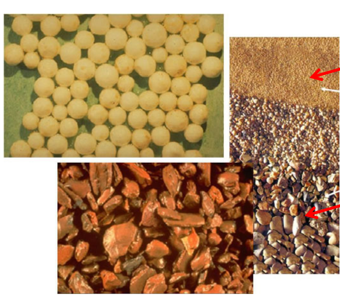
March 2022 BNR and ENR 261

Submerged BAFs

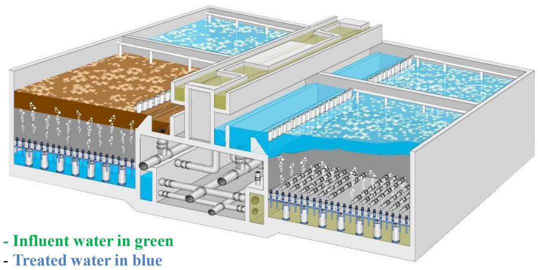
Submerged BAFs

- Biofor® - Up flow filter (Infilco Degremont)
  - Aerated, fixed bed
  - Dense granular clay media
  - "Sinking" media; 3 mm diameter for nitrification
- Biostyr® - Up flow filter (Veolia Water/Kruger)
  - Aerated, packed bed
  - Media less dense than water held in place by a screen
  - "Floating" media; 3 mm diameter for nitrification

BAF Media



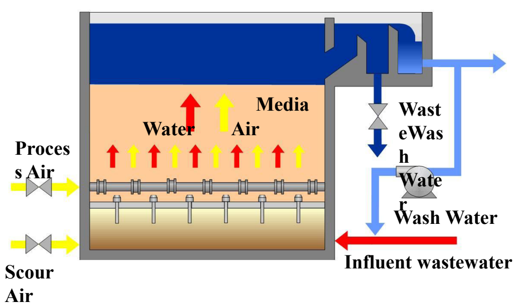
BIOFOR® Process View with One Cell in Backwash



- Influent water in green
- Treated water in blue
- Process air and air scour bubbles in white

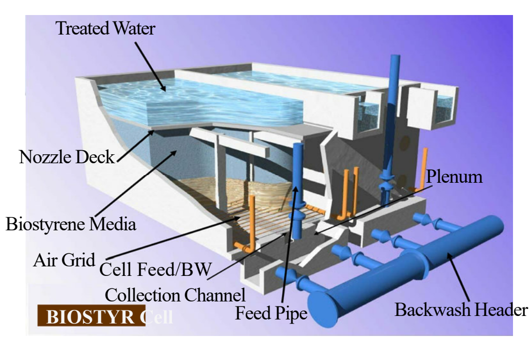
March 2022 BNR and ENR 265

BIOFOR® Sequences



March 2022 BNR and ENR 266

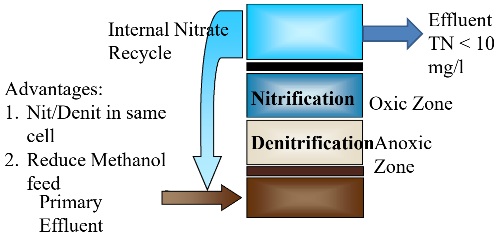
BIOSTYR® Process



March 2022 BNR and ENR 267

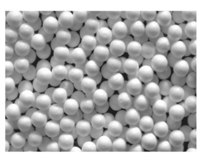
BIOSTYR® Process

Advantages:
1. Nit/Denit in same cell
2. Reduce Methanol feed



BIOSTYR® Media

- Bead diameter: 3.3 - 5.0 mm
- Clean bed porosity: 0.35 - 0.40 (void space as a fraction of total media bed volume)
- Bead density: 2.5 -3.1 lb/ft3
- Good uniformity coefficient (<1.25)
- Compatible with development of biological film



What have you learned…

- Are BAFs submerged or open to atmospheric air like trickling filters?

  …submerged

What have you learned…

- Which direction is the flow through a BAF, up flow or down flow?

  …up flow

March 2022 BNR and ENR 271

Denitrification

Denit Filters

March 2022 BNR and ENR 272

Denit Filters

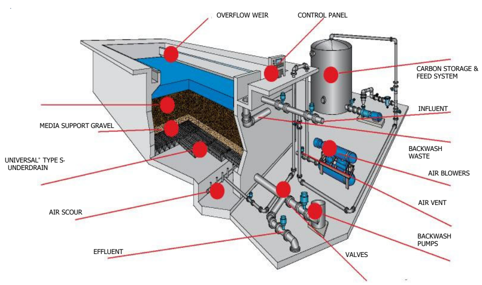
- Down Flow Denit Filters
  - Tetra Denite® System (Severn Trent)
  - Elimi-Nite® System (Leopold)
  - Davco Denitrification® System (Siemens)
- Up Flow Denit Filters
  - DynaSand® Filter (Parkson)
  - Astrasand® Filter (Paques/Siemens)
- Up Flow Fluidized Bed (Envirex)

March 2022 BNR and ENR 273

The TETRA® Denite® system from Severn Trent Services removes nitrate-nitrogen and suspended solids in a single step. It is used as a tertiary process on effluents from wastewater treatment plants. TETRA was recently awarded a contract to supply their TETRA® Denite® system for use at the Baltimore City Patapsco WWTP.

March 2022 BNR and ENR 274

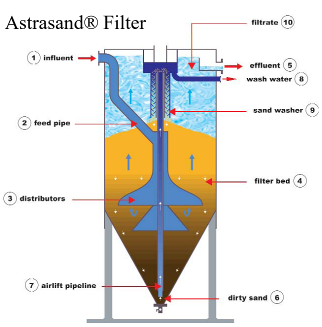
Leopold® elimi-NITE® Denitrification System

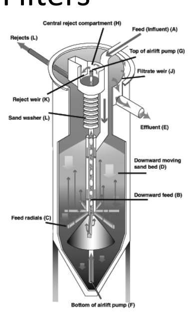


March 2022 BNR and ENR 275

Up Flow Denit Filters

Astrasand® Filter





DynaSand® Filter

March 2022 BNR and ENR 276

Comparison of Denitrification Filter Manufacturers and Equipment *

Manufacturer/ filter	Severn Trent Services/ TETRA® Denite®	F. B. Leopold/ elimi-NITE	USFilter/Davco	Parkson/ DynaSand	Paques and Siemens/ Astrasand
Flow regime	Downflow	Downflow	Downflow	Upflow	Upflow
Under drain	T-block; concrete-filled, HDPE jacket	Universal Type S HDPE block	Pipe lateral; or Multiblock HDPE block	None required	None required
Air header arrangement	SS box header; laterals beneath underdrain	SS header across filter; laterals	SS air header; 2-inch laterals	Vertical air lift	Vertical air lift
Media	18 inches graded gravel 6 ft of 6 × 9 mesh silica sand: uniformity coefficient - 1.35, 0.8 minimum Sphericity	15 inches graded gravel 6 ft of 6 × 12 mesh sand	2 layers support gravel, 6 ft of 6 × 9 mesh sand	1.35 to 1.45 mm subround media or 1.55 to 1.65 mm subangular media with uniformity coefficient of 1.3 to 1.6; 6.6-ft bed depth	1.2 to 1.4 mm sand, 6.6-ft bed depth
Nitrogen-release cycle	Initiated by headloss or time-controlled cycle; Speed Bump controls	Initiated by headloss or time-controlled cycle	Initiated by headloss or time-controlled cycle	None required	None required
Backwash water and air requirement	6 gal/min·ft²); 5 scfm/ft²	6 gal/min·ft² 5 scfm/ft²)	10 gal/min·ft²); 5 scfm/ft²)	Continuous through air lift and sand washer	Continuous through air lift and sand washer

* Source – Severn Trent

Summary of Design Guidance for Denitrification Filters *

Source	Hydraulic loading rate (gal/min·ft²)	Mass loading rate (lb NO3-N per ft³/d)
Manual: Nitrogen Control (U.S. Environmental Protection Agency, 1993)	1 to 2, 30 minutes empty bed contact time	0.018 to 0.1
Biological and Chemical Systems for Nutrient Removal, Special Publication (Water Environment Federation, 1998)		0.015 to 0.2 depending on temperature
Wastewater Engineering, Treatment and Reuse (Metcalf & Eddy, 2003)	1 to 2 at 20°C	0.087 to 0.112 at 20°C
	0.5 to 1.5 at 10°C	0.05 to 0.075 at 10°C
Severn Trent Services TETRA®Denite®	<3 at average flow; <7.5 peak hydraulic with one cell out of service	Determine using process model
F.B. Leopold	1 to 2	0.07
USFilter/Davco	2	NA
Parkson	4.5	0.015 to 0.12
Paques/Siemens	4.1	0.13

* Source – Severn Trent

What have you learned…

- Which direction is the flow through denit filters, up flow or down flow?

…down flow and up flow

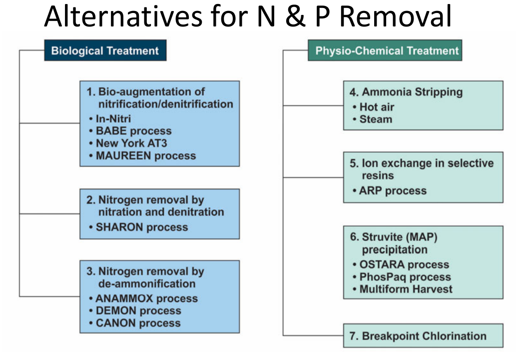
Solids Handling Side Streams

Nutrient Removal Systems

What are Sidestreams

- Any process flow resulting from the treatment of biosolids that flows back into the liquid treatment train
- Examples:
  - Gravity Thickener Overflow
  - Gravity Belt Thickener filtrate
  - Belt Filter Press filtrate
  - Centrate
  - Digester supernatant

Common Side-stream Treatment Alternatives for N & P Removal



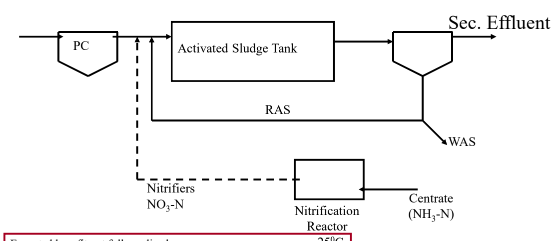
Why consider side-stream treatment?

- Concentrated nutrient load
- Usually economical when sidestreams contribute:
  - ≥15% of the influent TN
  - ≥20% and TP load
  - Typ. of plants with significant biological processes in the solids train (i.e., anaerobic digestion)
- Can often reuse existing infrastructure to reduce costs
- However, sidestream treatment is not economical in many cases

Nitrogen Removal

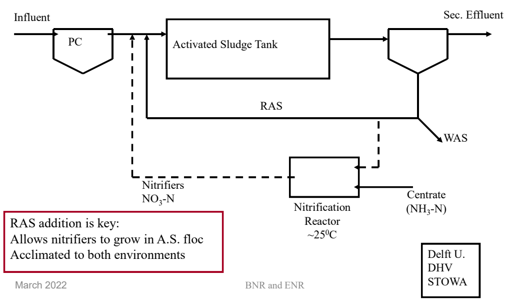
- Bioaugmentation
  - In-Nitri
  - BABE
  - NYC AT-3
  - MAUREEN
- Nitritation/Denitritation
  - SHARON
  - STRASS
- Nitritation/Deammonification
  - ANAMMOX
  - DEMON
  - CLEAR Green
  - ANITA Mox

InNitri Process was the first bioaugmentation scheme



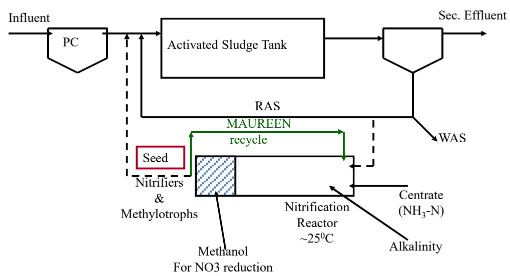
Expected benefit not fully realized
- Temperature change
- Poor capture of recycle stream nitrifiers
- Predation
- Change in total dissolved solids content –osmotic pressure

BABE Process
Bio-**A**ugmentation **B**atch **E**nhanced

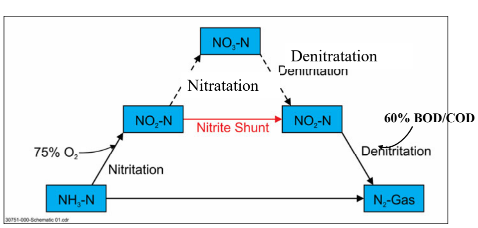


RAS addition is key:
Allows nitrifiers to grow in A.S. floc
Acclimated to both environments

New York City AT-3 Process
(MAUREEN IS A MODIFIED VERSION)
(**M**ainstream **Au**totrophic **R**ecycle **E**nabling **E**nhanced **N**-removal)

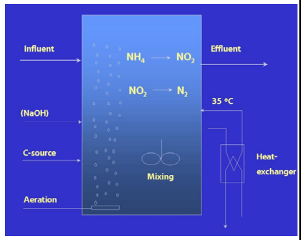


Nitritation/Denitritation
"SHARON"



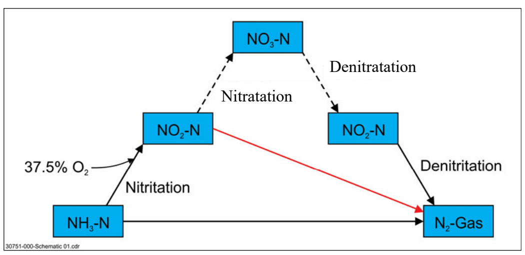
SHARON

- *SHARON™ Process (*Single reactor system for high ammonium removal over nitrite)
  - provides separate biological centrate nitrification and denitrification
- 85% to 90% Total Nitrogen Removal
- Denitrifies from nitrite, nitrate prevented from forming
- Provides a 25% reduction in O2 and a 40% reduction in Carbon requirements



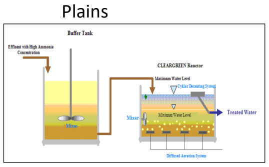
Nitritation/Deammonification

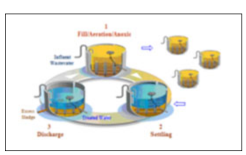
"ANAMMOX"



SBR-type Anammox Process: Cyclic Low Energy Ammonia Removal (CLEAR)GREEN™

- Three 8-hour Cycles per day
- Pilot finished in Paris, France
- Currently being piloted at Hampton Roads and Blue Plains





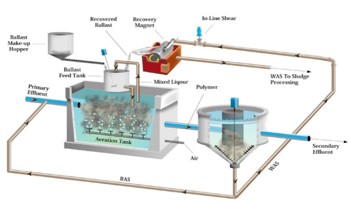
Images Courtesy of IDI

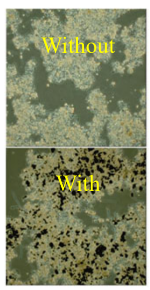
Key Drivers for Side-stream Phosphorus Removal Systems

- High side-stream contribution of phosphorus affecting biological phosphorus removal, usually coupled with low TP limits (< 0.3 mg/L)
- Land application program with limitations on agronomic rates of N or P application
- Severe struvite problems

BioMag™

The Next Generation of Biological Treatment





Cambridge Water Technology's BioMag Process® uses Magnetite (Fe_3O_4) as a flocculation aid to improve settling characteristics of activated sludge. With a specific gravity of 5.2 and a strong affinity for biological solids, magnetite can significantly decrease SVI's and increase MLSS settling rates to handle higher flows. Enhanced nutrient removals, especially phosphorus, are possible.

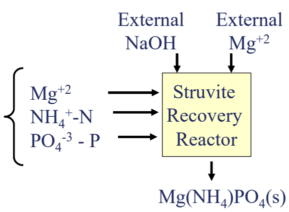
Side Stream Phosphorus Treatment: Two Alternatives

1. Coagulant-aided phosphorus precipitation
   - Forms aluminum phosphate and aluminum hydroxide
   - Non-proprietary
2. Struvite formation
   - Forms struvite
   - Proprietary
   - Ostara & Multiform Harvest

Of these two options, only struvite has been identified as a fertilizer additive with market value

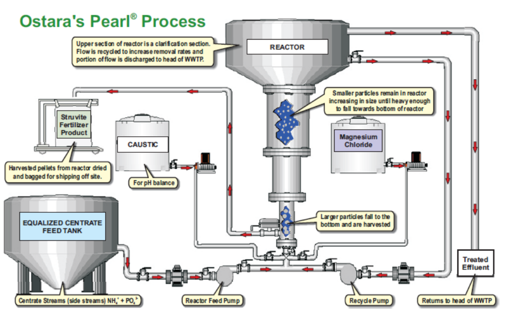
How Struvite Precipitation Works

- Struvite precipitation
  - N:P ratio in struvite = 0.45 lbs N required per lb P removed
  - N:P ratio in filtrate ~ 2.4-2.6, ammonia in excess



March 2022 BNR and ENR 295

Schematic of Ostara Process



March 2022 BNR and ENR 296

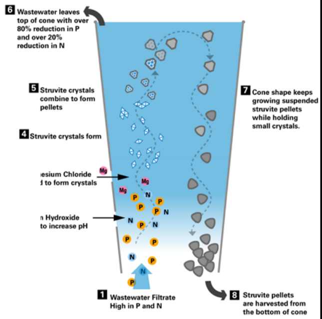
Crystal Green ™ fertilizer

- Fertilizer for parks and golf courses
- Specialized product
- Green attributes
  - Slow release fertilizer
  - Produced with minimal greenhouse gas emissions
  - Renewable source
  - Reduces mining of phosphorus for use in commercial fertilizers

March 2022 BNR and ENR 297

Multiform Harvest

- Simple process to operate – struvite processed offsite
- Filtrate passes through once



Ostara vs. Multiform product

Ostara Pearl | Multiform Harvest

$Mg^{+2} + NH_4^{+} + PO_4^{-3} + 6H_20 \rightarrow MgNH_4PO_4{*}6H_2O$ (struvite)

Summary

Helpful Hints - Final Comments

Helpful Hints

- Consider multiple "barriers" for TP and TN removal, e.g. post anoxic zone
- Nitrification is "Key" to the success of BNR/ENR processes when removing TN
- Nitrify completely – NH_3 < 0.1 mg/L; no NO_2^-
- Maintain < 0.2 mg/L D.O. in denitrification process to maximize denitrificatiion rate
- Allow for excess chemical addition (5 – 7 mole ratio) to meet TP levels < 0.18 mg/?

March 2022 BNR and ENR 301

Final Comments

- Many possible causes for poor nutrient removal performance
- Important to determine cause and act quickly to maintain chemical and biological processes
- Basic troubleshooting approaches are universal.
- Sidestream treatment can significantly reduce TP and TN loadings to mainstream process.

March 2022 BNR and ENR 302

Questions?

March 2022 BNR and ENR 303

Thank You

Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD

"Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science."

- John F. Kennedy

March 2022 BNR and ENR 304