Conversion or Removal of Nitrogen from Sewage

Maryland Center for Environmental Training
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www.mcet.org

Conversion or Removal of Nitrogen from Sewage

7 Contact hours
9 CC10 hours

Why and how is nitrogen removed (or converted to a less objectionable form) from wastewater? Treatment operators will gain an increased understanding and operational skills regarding treatment processes; taking into account structural requirements, chemical requirements, operational strategies, and performance standards: nitrification; denitrification; breakpoint chlorination; ion exchanges; ammonia stripping; nitrogen sources and forms; biological exchange; and combined phosphorus and nitrogen removal systems technology.

1. Define Nutrients, Nitrification, Nitrogenous Oxygen Demand. Denitrification, Kjeldahl Nitrogen, Oxidized Nitrogen, Total Nitrogen, Aerobic, Anoxic, Anaerobic, Facultative, Heterotrophic, Autotrophic, Filamentous
2. List the various chemical forms of nitrogen and for each form identify that characteristic that makes it objectionable to the Cheasapeake Bay.
3. Describe the following treatment processes, taking into account structural requirements, chemical requirements, operational strategies, and performance standards: nitrification, denitrification, breakpoint chlorination, ion exchanges, and ammonia stripping, Biological Nutrient Removal systems, and Enhanced Nutrient Removal systems.

Morning 8:00 am – 11:45 am

A. Introductions (8:00 am – 8: 30 am)
   - Purpose of class and objectives
   - Ice breaker – introduce yourself
   - Ground rules
   - Pre-test
B. Overview (8:30 am – 9:00 am)
   - Nutrients – Phosphorus and Nitrogen
   - Benefits of nutrient removal
   - Chesapeake Bay Requirements
     - ✓ Regulations
     - ✓ Tributary Strategies
     - ✓ TMDLs
   - Limits of Technology (Depends on organic concentrations)
     - ✓ Phosphorus – 0.05 mg/l
     - ✓ Nitrogen - 1.5 mg/l to 2.0 mg/l
   - Anticipated permit levels
     - ✓ Phosphorus - 0.1 mg/l to 0.3 mg/l
     - ✓ Nitrogen - 3.0 mg/l
C. Nutrient removal – Basics (9:00 am – 9:30 am)
   - Phosphorus
     - ✓ Forms, sources, and typical concentrations
     - ✓ Phosphorus removal
       - o Chemical precipitation
       - o Biological uptake

        - Limiting factor – organic phosphorus fractions
  - Nitrogen
    - ✓ Forms, sources, and typical concentrations
    - ✓ Nitrogen removal
        - Nitrification
        - Denitrification
        - Limiting factor – organic nitrogen fractions

D. Break (9:30 am – 9:45 am)

E. Phosphorus Removal with Chemicals (9:45 am – 10:30 am)
  - Fundamentals
    - ✓ Chemical options:
        - Aluminum salts
        - Iron salts
    - ✓ Theories of removal:
        - Co-precipitation:
            i. $Al + PO_4 = AlPO_4$
            ii. $Al + 3OH = Al(OH)_3$
            iii. $2Al + PO_4 + 3OH = AlPO_4 + Al(OH)_3$
            iv. Mole ratio – minimum 2:1; as high as 6:1
        - Phosphorus adsorption on metal hydroxide flocs
  - Operational issues:
    - ✓ Chemical of choice
        - Liquid
        - Dry
    - ✓ Chemical feed equipment
        - Liquid feed systems
            i. Storage tanks
            ii. Feed methods
                - Metering pumps
                - Peristaltic (hose) pumps
                - Piping and valves
        - Dry feed equipment
            i. Storage
            ii. Feed methods
    - ✓ Chemical costs
    - ✓ Chemical addition
        - Effect on alkalinity and pH
        - Location of choice
        - Chemical dosages
            i. Jar tests
            ii. Field verification
            iii. Math - Example dosing calculations
    - ✓ Sludge generation
    - ✓ Sludge handling
        - Thickening and dewatering
        - Disposal

F. Biological uptake in ENR options (10:30 am - 11:30 am)
  - Fundamentals
    - ✓ Heterotrophic bacteria
    - ✓ Phosphate accumulating organisms (PAOs)
    - ✓ Readily biodegradable organic carbon
      - o Volatile fatty acids (VFAs)
      - o Poly-β-hydroxy-butyrate (PHB) in bacteria cells
    - ✓ Polyphosphate (Poly P) storage in bacteria cells
    - ✓ Recycling anaerobic and aerobic conditions
  - Environmental conditions
    - ✓ Anaerobic zone for Phosphorus release
      - o No oxygen
      - o Minimal nitrate concentrations
      - o Monitor RAS and Nitrate recycle streams to anaerobic zones
      - o pH > 5.5 but < 8.0; 7.0 +/- 0.2
      - o Temperatures >15 to < 25ºC
      - o HRT - 1 to 2 hours
      - o Carbon-to-TP ratios:
        - i. COD – 40 to 45
        - ii. BOD - 20
        - iii. rbCOD – 10 to 16
        - iv. VFA – 4 to 16
    - ✓ Aerobic zone for Phosphorus uptake
      - o Oxygen concentrations > 2.0 mg/l
      - o Aeration requirements
      - o SRT > 3 to 4 days
  - Operation problems:
    - ✓ Release of phosphorus in the aerobic zone – extended aeration
    - ✓ Release of phosphorus in anaerobic sludge treatment processes
  - Maximize biological uptake where possible to minimize costs for chemicals and related chemical sludge disposal

Lunch 11:30 am – 12:30 pm

Afternoon 12:30 pm – 4:00 pm

G. Biological Nitrogen Removal – Overview (12:30 pm – 1:15 pm)
  - Reference the Nitrogen Cycle
  - Show how nitrification and denitrification fit in the Nitrogen Cycle
  - Technologies:
    - ✓ Suspended growth (Activated sludge)
      - o Activated sludge zone environments - Anaerobic, anoxic, aerobic processes usually installed with options to feed supplemental carbon and having additional denitrification and aeration capability
        - i. Anaerobic zone - Phosphorus release and BOD uptake
        - ii. First stage anoxic zone – Denitrification
        - iii. Aerobic zone – Nitrification and phosphorus uptake
        - iv. Second stage anoxic zone - Tertiary denitrification

        v. Second stage aerobic zone, post aeration zone
- ✓ Attached growth (Fixed film)
    - o Nitrification using Biological Aerated Filters (BAFs)
    - o Denitrification Filters
        i. Downflow
        ii. Upflow continuous backwash

H. Nitrogen removal fundamentals (1:15 pm – 1:45 pm)
- – Nitrification
    - ✓ Microbiology
    - ✓ Reactions
    - ✓ Temperature effects on nitrification
    - ✓ Oxygen requirements
        - o 4.6 lbs O_2 required per lb of NH_4-N oxidized
    - ✓ Effects of nitrification on alkalinity and pH
        - o Need to add alkalinity
        - o pH 7.0 +/- 0.2
        - o 7.14 lbs of alkalinity per lb of NH_4-N oxidized
- – Denitrification fundamentals
    - ✓ Microbiology
    - ✓ Reactions
    - ✓ Carbon requirements
    - ✓ Effects of denitrification on alkalinity and oxygen
        - o Adds back alkalinity
            i. 3.57 lbs of alkalinity as $CaCO_3$ produced per lb of NO_3-N reduced
        - o Adds back oxygen
            i. 2.86 lbs of O_2 added per lb of NO_3-N reduced

I. Break (1:45 pm – 2:00 pm)

J. Nitrification and denitrification in single process units (2:00 pm – 3:30 pm)
- – Biological Nutrient Removal (BNR)
    - ✓ TN < 8.0 mg/l
    - ✓ Usually without carbon supplement
- – Enhanced Nutrient Removal (ENR)
    - ✓ TN < 3.0 mg/l
    - ✓ Usually with:
        - o Second anoxic stage
        - o Carbon supplement
- – Common ENR processes:
    - ✓ Suspended growth:
        - o Modified Ludzack-Ettinger (MLE)
        - o 4 or 5-stage Bardenpho
        - o Modified University of Cape Town (MUCT)
        - o Oxidation ditch with anoxic zone(s)
        - o Step feed activated sludge
        - o Sequencing Batch Reactor (SBR)
    - ✓ Attached growth or hybrid:

        - Integrated Fixed-Film Activated Sludge (IFAS) Hybrid Systems (e.g., rope media, sponge media, or web media)
        - Moving Bed Biofilm Reactors (MBBR) using plastic elements w/o return sludge (e.g., AnoxKaldnes)
- With carbon addition
    - ✓ Biology and chemistry
    - ✓ Carbon requirements
        - Methanol
        - Glycerin
        - Chemical dosages
            1. Chemistry
            2. Math - Example dosing calculations
            3. Field verification
- Operational issues
    - ✓ Aeration requirements
        - Blowers
        - Diffusers
    - ✓ Effects of temperature and weather on process
    - ✓ Carbon addition
        - Location of choice
        - Chemical handling
        - Chemical dosages
    - ✓ MCRT
        - Calculated based on MLSS under aeration and WAS rates
        - 10 to 20 days minimal
        - Longer under cold temperature conditions
    - ✓ MLSS
    - ✓ F:M ratio
    - ✓ Filamentous organisms
        - SV and SVI
        - Foaming
        - Clarification

K. Summary (3:30 pm – 3:45 pm)
L. Post Test (3:45 pm – 4:00 pm)
M. Class evaluations

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Conversion and Removal of Nitrogen in Wastewater

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Process Training Sessions

Before class starts, please:

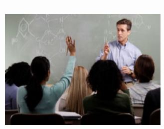
- **Check in**

During class, please:

- **Asks questions**
- Feel free to get up and leave the classroom at any time (i.e., rest rooms, phone calls, etc.)
- **Answer questions** on post test

After class, please:

- **Fill out** a Class Evaluation
- **Answer questions** on post quiz



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Housekeeping

- 1–day class
- Start class – 8:00 am
- 10-minute Breaks – every hour
- Lunch ~ 11:30 am – 12:30 pm
- End class ~ 3:30 to 4:00 pm

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Instructor Expectations

- Begin and end class on time
- Be interactive – participate at your own comfort level
- Share experiences and needs
- Less lecture, more discussions
- Keep it simple
- ***Make this an enjoyable and informative experience!***

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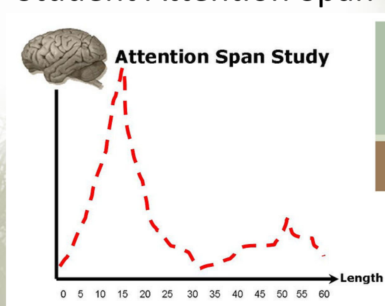
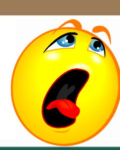
Student Attention Span - Lectures





Source: based on a study by Richard Mayer

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How this Class is Structured

- This 1-day class will be more class discussion, less lecture
- The class will be structured around three teaching components:
  - Establishing rapport (Trainer as facilitator)
  - Stimulating student interest (Trainer as motivator)
  - Structuring classroom experiences (Trainer as designer)

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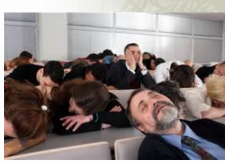
Discussions

- Student involvement in class discussions is encouraged:
  - To keep students attentive
  - To help students retain information



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The <u>Guiding</u> Expectation

"Things should be made as simple as possible -- but no simpler."

Albert Einstein

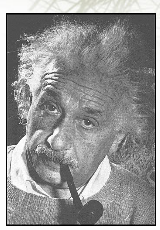

Image source: www.physik.uni-frankfurt.de/~jr/physpiceinstein.html

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Ground Rules

- Discussion is encouraged; share experiences
- Use terms we all can understand
- Everyone is different, so please show respect for others in the room
- Express opinions - of things, not people
- Maintain confidences

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Ice Breaker

- Before we start, let's introduce ourselves.
  - Name,
  - What do you do, and
  - How do you remove nitrogen at your WWTP?

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Introduction

Objectives, Focus, and Agenda

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Agenda

- Sources, Forms of Nutrients (N & P)
- Fundamentals of:
  - Ammonification
  - Nitrification
  - Denitrification
- Biological/Enhanced Nutrient Removal (BNR/ENR) processes
- Recycle side stream treatment of nutrients

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Learning Objectives

Participants will be able to discuss:

- Nitrogen removal processes
- **Sources and forms of Nitrogen**
- **Regulatory framework for Nitrogen Removal from wastewater** in the Chesapeake Bay
- Biological and enhanced **(BNR/ENR)** nutrient removal processes

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Participant Focus

- What information can you use at your work location?
  - **Nitrogen removal technologies**
  - Nitrogen discharge **standard limits**
  - **Operating and trouble shooting** recommendations
- What information can you contribute to the discussion?
  - TN removal with **BNR/ENR** processes

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Introduction

Definitions and Acronyms

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Wastewater Characteristics

- Q – Flow, gpd, gallons/day (or gpm, MGD)
- BOD – Biochemical Oxygen Demand, mg/l
  - cBOD – Carbonaceous BOD
  - nBOD – Nitrogenous BOD
- DO – Dissolved Oxygen, mg/l
- Suspended Solids, mg/l:
  - TSS – Total Suspended Solids
  - VSS – Volatile Suspended Solids

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Acronyms

- BNR – Biological Nutrient Removal
- ENR – Enhanced Nutrient Removal
- TMDL – Total Maximum Daily Loading
- MLE – Modified Ludzack-Ettinger BNR Process
- IFAS – Integrated Fixed Film Activate Sludge
- MBBR – Mixed Bed Bioreactor
- COMAMMOX – COMplete AMMonia OXidation
- ANAMMOX – ANaerobic AMMonia OXidation

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Microorganisms

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

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Introduction

Nutrients - Overview

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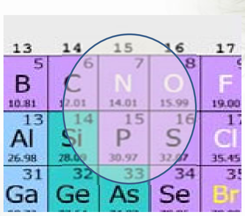
Nutrients - Overview

Part of the Periodic Table



- ✓ Both Phosphorus and Nitrogen are considered essential for plant and animal life
- ✓ Both are called nutrients

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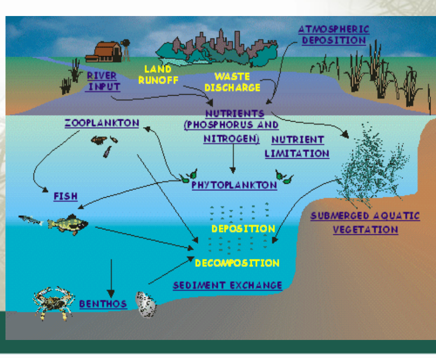
Nutrients - Overview



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Nutrients in Wastewater

- In watersheds, **Nutrients (nitrogen and phosphorus)** contribute to algae growth
- Excess nutrients leads to excess algae growth
- Excess algae growth depletes oxygen and blocks sunlight penetration in water
- Submerged aquatic vegetation (SAV) dies off due to lack of sunlight (photosynthesis)
- Marine organisms die-off due to lack of DO

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Nutrients in Wastewater

- Total Nitrogen – TN
  - Soluble & particulate
    - N_{org} – Org-N
    - NH_3 – Ammonia
    - NO_3 – Nitrate
    - NO_2 – Nitrite

$TN = N_{org} + NH_3 + NO_3 + NO_2$

- Total Phosphorus – TP
  - Soluble & particulate
    - PO_4 – Ortho-P
    - P_{org} – Org-P
    - P_{poly} -Polyphosphates

$TP = PO_4 + P_{org} + P_{poly}$

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Nutrients in Wastewater

- Nutrients stimulate algae production in receiving waters and need to be removed
- Depending on I/I, typical Bay area raw wastewater concentrations today range from:
  - TN – 35 to 45 mg/L
  - TP – 4 to 6 mg/L

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Forms of Nitrogen

- Typical Forms
  - Organic -N – mostly in solids form; some troublesome soluble forms
  - Ammonia - soluble
  - <1% Nitrites/Nitrates
- Quantities
  - 4 lbs/day/100 people
  - 40 mg/L TN; 25 mg/L NH_3-N
- Recycle Streams:
  - Digester Supernatant
  - Thickener Overflow

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Forms of Phosphorus

	Phosphate	Polyphosphate	Organic Phosphate
Chemical form	Orthophosphate Reactive phosphate	Condensed phosphates	Organically bound (part of proteins)
Soluble or particulate	Soluble / may be adsorbed to particles	Soluble / may be adsorbed to particles	Soluble, colloidal, or particulate

Source – Water Environmental Foundation

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Sources and Forms

Nitrogen

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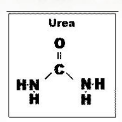
Sources of Nitrogen in Wastewater

- Human Wastes
  - Digested/wasted food (Proteins)
    - Vegetables
    - Meats
  - Urea (converted Ammonia)
- Cleaning products (Ammonia)



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Forms of Nitrogen

- Ammonia(um) (NH_3/NH_4^+)
- Organic Nitrogen (Org-N)
- Nitrogen Gas (N_2) ↑
- Nitrite (NO_2^-)
- Nitrate (NO_3^-)

TKN (Un-oxidized): Ammonia(um) and Organic Nitrogen

NO_x (Oxidized): Nitrite and Nitrate

Total Nitrogen (TN) = TKN + NO_x

TKN = Total Kjeldahl Nitrogen

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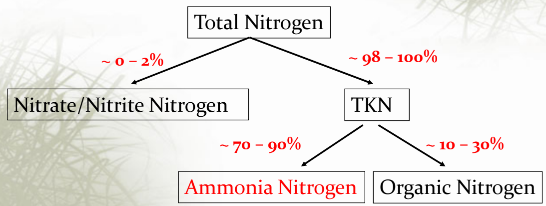
Forms of Nitrogen in Wastewater



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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)

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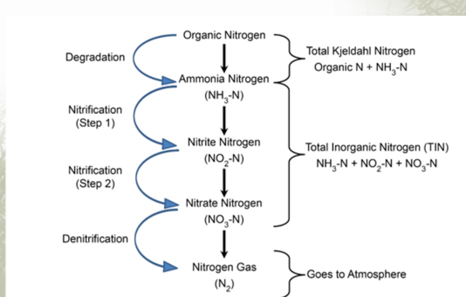
Forms of Nitrogen



Source – Water Environmental Foundation

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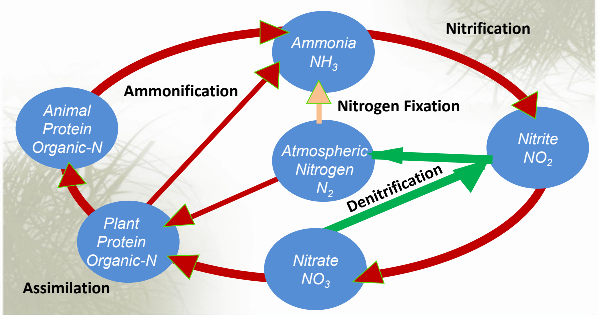
Simplified Nitrogen Cycle in Nature



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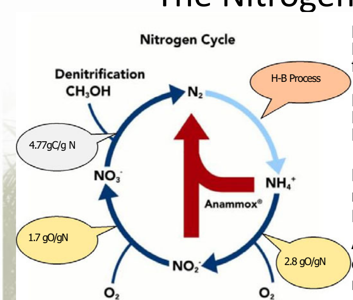
The Nitrogen Cycle



H-B process: Haber-Bosch nitrogen fixing (chemical) process

N/DN Uses O_2 for Nitrification, Carbon for Denitrification

N/DN can be reduced if not going all the way to Nitrate

Anammox bacteria can eliminate carbon while reducing oxygen to 60%

Nitrification by slow growing temperature sensitive autotrophs

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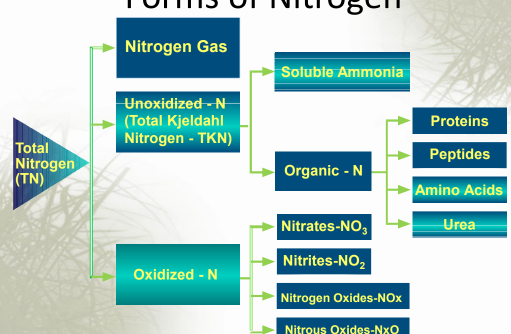
Forms of Nitrogen



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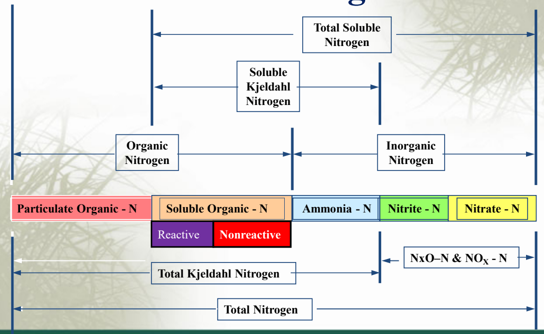
Forms of Nitrogen



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Nutrient Removal

Overview

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Nutrient Removal Overview

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

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Nutrient Removal Overview

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

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Nutrient Removal "Driver"

Chesapeake Bay & CWA[1] Regulations

1. CWA – 1972 Clean Water Act

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Nutrient Removal

- **<u>Why remove Nutrients? (nitrogen and phosphorus):</u>**
  - 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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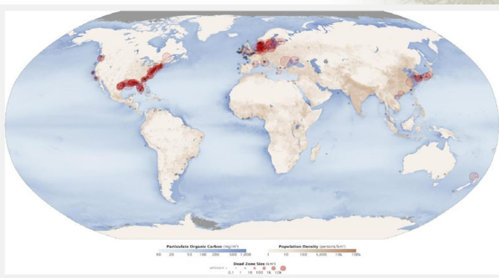
Excess Nutrients are a Global Concern



NASA Earth Observatory

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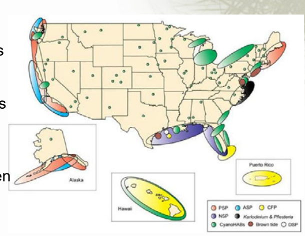
Extent of N&P Impacts

- 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 Algae throughout the U.S.

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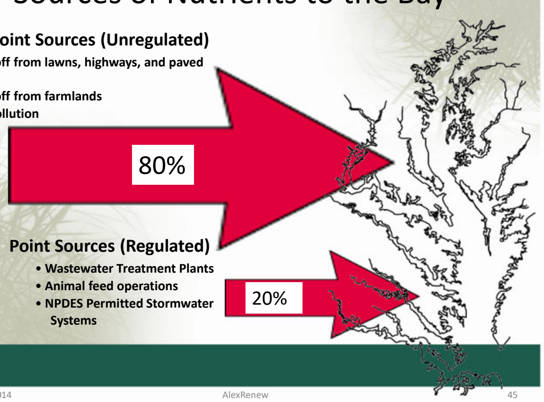
Sources of Nutrients to the Bay

Nonpoint Sources (Unregulated)

- **Run-off from lawns, highways, and paved areas**
- **Run-off from farmlands**
- **Air pollution**



Point Sources (Regulated)

- **Wastewater Treatment Plants**
- **Animal feed operations**
- **NPDES Permitted Stormwater Systems**

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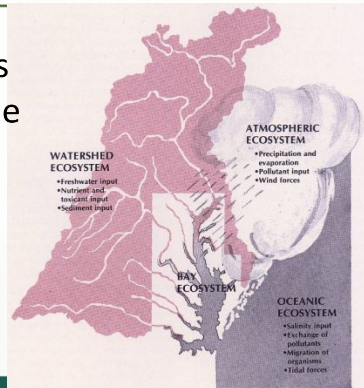
Ecosystems Affecting the Bay



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Chesapeake Bay Watershed

- The largest estuary system in the contiguous United States
- Watershed is almost 64,000 square miles
- Surface area of the Bay is 3,830 square miles
  - Of these, 153 square miles are tidal fresh waters
  - 3,562 square miles constitute the mixing zone
  - 115 square miles are salt waters

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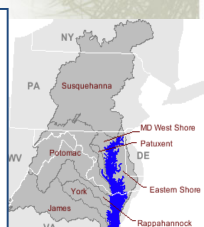
The Chesapeake Bay Program

- In 1983, the Chesapeake Bay Program (CBP) created
  - In a 1987 Agreement, water quality targets (40% less than 1985 conditions) for 2000 were established
- Chesapeake Bay 2000 Agreement
  - 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
  - States develop plans (Tributary Strategies) and implement actions
  - 2010 - Target Date to meet water quality standards, remove the Bay from the impaired waters list, and to avert the need for TMDLs
- **Beyond 2010 – TMDLs and consent decrees**
  - **2017 is new interim target date**
  - **2025 is new target date**



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Water Quality Conditions

University of Maryland
Center for Environmental Science

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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

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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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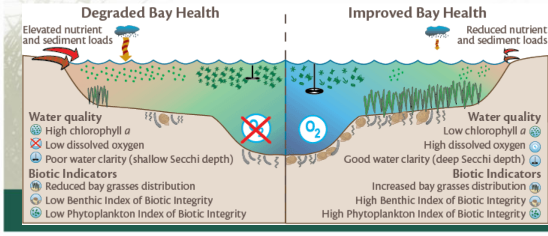
Chesapeake Bay Health

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



52

Key Water Quality Indicators

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

53

Chlorophyll a

- Chlorophyll *a* is used to determine algae quantities present in the Bay
- Algae, a food chain foundation, is necessary for a balanced Bay ecosystem
- Too much algae:
  - Can block sunlight from reaching underwater grasses
  - Reduce habitat and oxygen needed for underwater life
- The range of acceptable chlorophyll a concentrations varies by season and salinity

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Chlorophyll a

- The current Chlorophyll *a* threshold limit for SAV is 15 micrograms per liter
- Bay Goal -100 percent of Chesapeake Bay tidal waters below acceptable threshold concentrations of chlorophyll *a* for SAV
- The area of the Bay meeting (i.e., less than or equal to) chlorophyll threshold concentrations has generally shown a decreasing (degrading) trend

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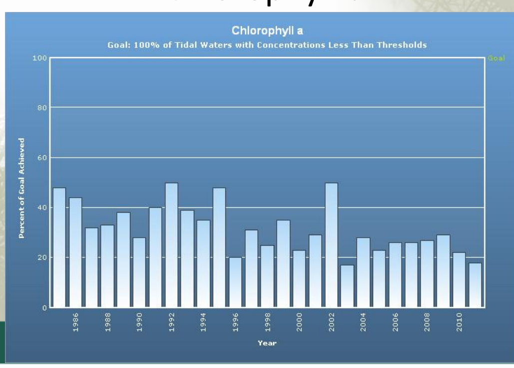
55

Chlorophyll a



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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

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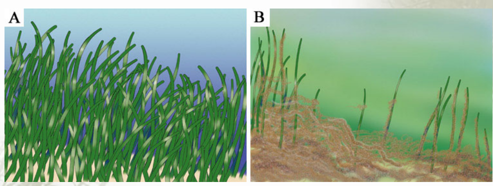

a) A healthy bay grass bed

b) An unhealthy bay grass bed shaded and overgrown by phytoplankton and algae as a consequence of increased nutrients

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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

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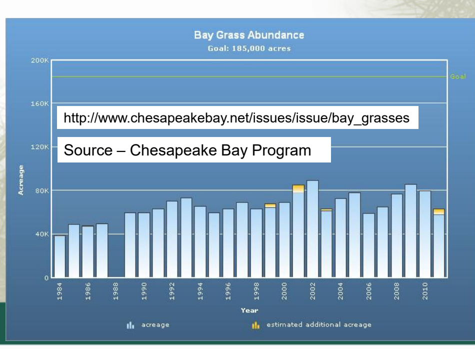
Variances of Bay Grasses



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60

SAV Decline

- Increased turbidity resulting from water quality degradation has been reported as the primary cause of the SAV decline in the Bay
- Restoration of SAV is key to improving the overall health of the Chesapeake Bay and its tributaries

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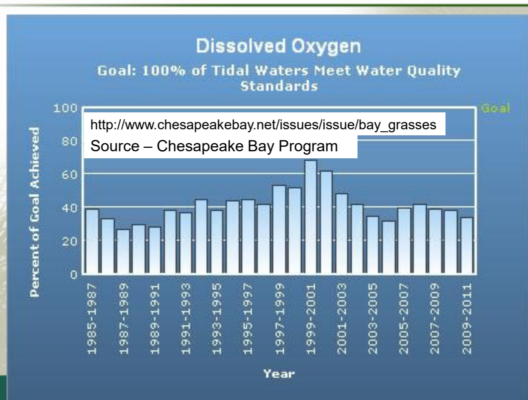

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Introduction

Nutrient Removal – 30 Year Trend

January 2023 TN Removal 63

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BNR Program

- EPA created the Chesapeake Bay Program in 1983; first Chesapeake Bay agreements signed in 1987
- BNR Programs initiated by Bay states
- 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

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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” anoxic zones to already existing nitrification processes for partial denitrification

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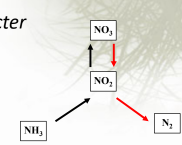
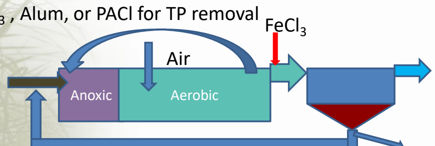
Nutrient Removal

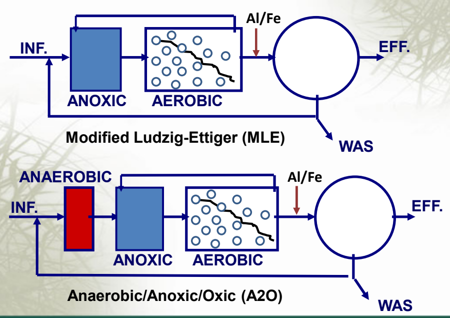
- Nitrification (*Nitrosomonas, Nitrobacter and Nitrospira*)
  $NH_3 + O_2 \rightarrow NO_2^- \rightarrow NO_3^-$
- Denitrification
  $NO_3^- + \text{organics} \rightarrow CO_2 + N_2$
- BNR Process – MLE
- $FeCl_3$, Alum, or PACl for TP removal





66

Biological Nutrient Removal



67

ENR Program

- New Chesapeake Bay Agreement enacted in 2000; ENR Program began in that same year
- 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

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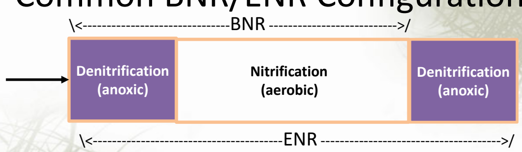
Common BNR/ENR Configurations



- 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
  - Sequencing Batch Reactors

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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

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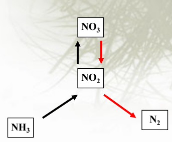
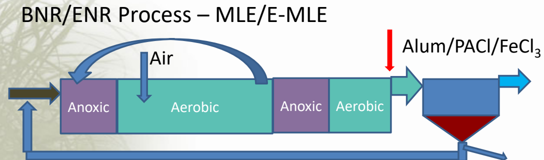
Nutrient Removal Strategies

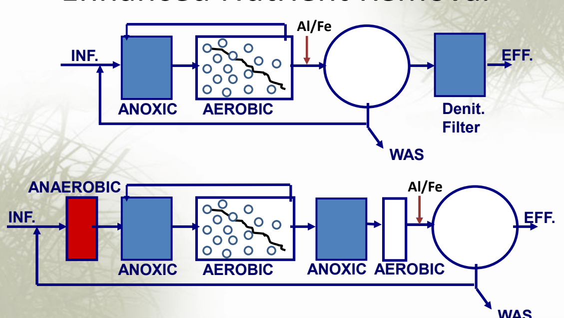
- Nitrification (*Nitrosomonas, Nitrobacter, and Nitrospria*)
  $NH_3 + O_2 \rightarrow NO_2^- \rightarrow NO_3^-$
- Denitrification
  $NO_3^- + \text{organics} \rightarrow CO_2 + N_2$
- BNR/ENR Process – MLE/E-MLE





71

Enhanced Nutrient Removal



72

Enhanced Nutrient Removal (ENR)

- Over the past two decades, BNR facilities have been upgraded to improve nitrogen removal efficiencies:
  - Mixed Bed Bio-reactors (MBBR)
  - Integrated Fixed Film Activated Sludge (IFAS)
  - Biological Aeration Filters (BAF) for nitrification
  - Tertiary denitrification filters

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Wastewater Nutrient Removal

- Enhanced (ENR) **Total Nitrogen (TN)** removal is now required:
  - BNR standard, 5 to 8 mg/L of TN is not adequate
  - **Bay 2010 TMDL Target: < 3.0 mg/L TN**
  - TMDL – Total maximum daily loading
  - Low threshold - Limit of Technology /State of the Art (LOT/SOA) is about 1.0 mg/L TN (soluble Org-N)

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Wastewater Discharge Limits

Typical **Total Nitrogen** Standards, mg/L

- Moderate 3.0 – 5.0 (BNR)
- **Bay Target < 3.0 (ENR)**
- Severe < 2.5
- Very Severe < 1.5
- LOT/SOA(a) < 1.0

(a) Limit of Technology/State of the Art

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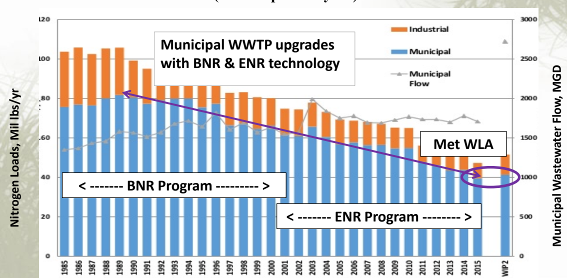
TN Loadings to the Chesapeake Bay Wastewater

(Million pounds/year)



Chesapeake Bay Program – May 2016

January 2019 TN and TP Removal 76

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Wastewater Nutrient Removal

- **Total Phosphorus (TP)** is removed to high degree with chemicals:
  - Less than 0.3 mg/L TP; even less than 0.1 mg/L
  - **Bay 2010 TMDL Target: < 0.3 mg/l TP; at Potomac River WWTPs, < 0.18 mg/L TP**
  - TMDL – Total maximum daily loading
  - Low threshold - Limit of Technology /State of the Art (LOT/SOA) is less than 0.05 mg/l TP (soluble Org-P)

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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

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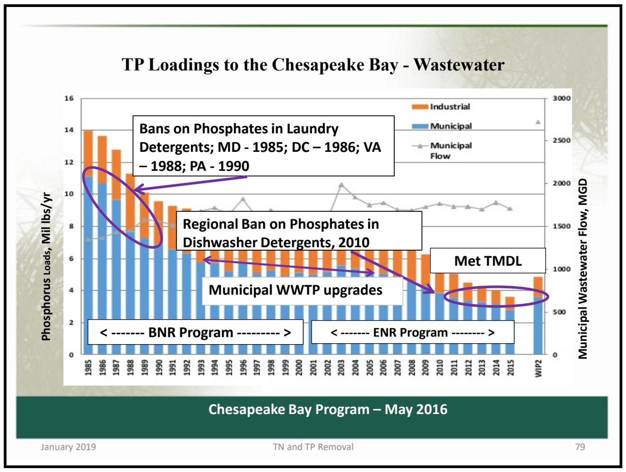
TP Loadings to the Chesapeake Bay - Wastewater
Industrial
Municipal
Municipal Flow
Bans on Phosphates in Laundry Detergents; MD - 1985; DC – 1986; VA – 1988; PA - 1990
Regional Ban on Phosphates in Dishwasher Detergents, 2010
Met TMDL
Municipal WWTP upgrades
< ------- BNR Program --------- >
< ------- ENR Program -------- >
Phosphorus Loads, Mil lbs/yr
Municipal Wastewater Flow, MGD
Chesapeake Bay Program – May 2016
January 2019
TN and TP Removal
79

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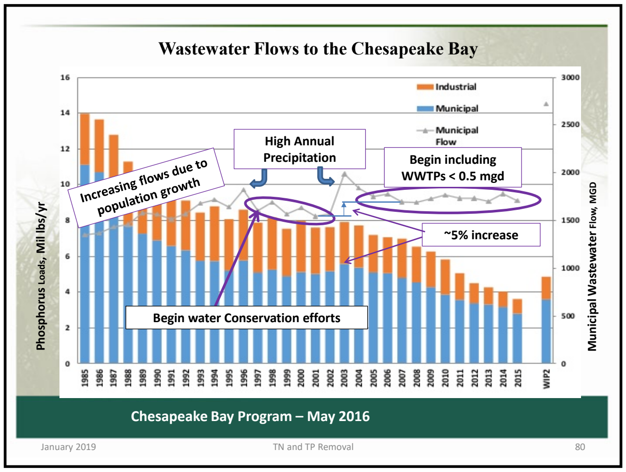
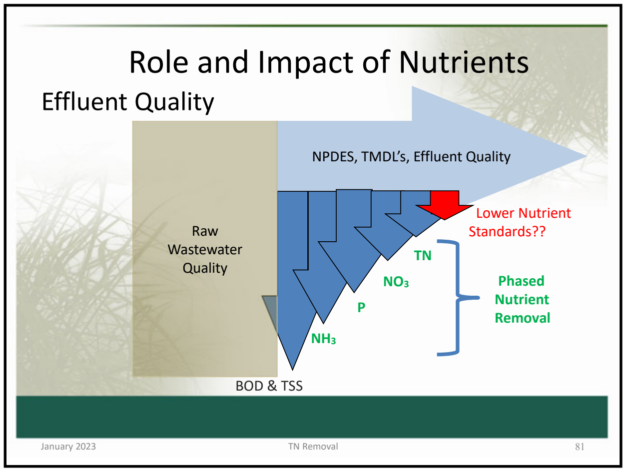

Wastewater Flows to the Chesapeake Bay
Industrial
Municipal
Municipal Flow
Increasing flows due to population growth
High Annual Precipitation
Begin including WWTPs < 0.5 mgd
~5% increase
Begin water Conservation efforts
Phosphorus Loads, Mil lbs/yr
Municipal Wastewater Flow, MGD
Chesapeake Bay Program – May 2016
January 2019
TN and TP Removal
80

80


Role and Impact of Nutrients
Effluent Quality
NPDES, TMDL's, Effluent Quality
Raw Wastewater Quality
Lower Nutrient Standards??
TN
NO3
P
NH3
Phased Nutrient Removal
BOD & TSS
January 2023
TN Removal
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How will future regulations affect Nutrient Removal Requirements?

Regulatory Challenges:

- Clean Water Act (CWA)
- Chesapeake Bay Program
- State Ordinances
  - Nutrients
  - Sludge
- Local Ordinances

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Nitrogen Removal Processes

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Historical Overview

- 1920s - 1960s
  - cBOD Removal
  - Nitrification
- 1980s to 2000 – Nitrification with pre-denitrification development (BNR)
- Past 20 years – BNR to ENR (with post denitrification)

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Background Removal

- Background removal of particulate organic nitrogen
  - 15 to 40% of particulate nitrogen can be removed in settled sludge (Primary Treatment)
  - Nutrients are removed from the treatment process when sludge is wasted

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Assimilative Uptake

- Assimilative uptake of ammonia for biomass growth
  - 15 to 30% of ammonia nitrogen can be removed by assimilative uptake (Secondary Treatment)
  - Nutrients are removed from the treatment process when excess biomass is removed

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Nutrient Removal

- Particulate organic nitrogen removal and assimilative uptake combined cannot meet low effluent nitrogen limits
- To meet low nitrogen effluent limits, nitrification and denitrification processes are needed

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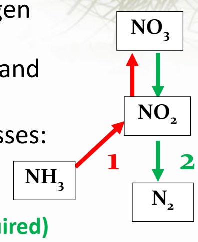
Nitrogen Removal - Basics

Nitrification + **Denitrification** = Nitrogen Removal

- BNR/ENR converts TKN nitrogen (primarily ammonia) in wastewater to nitrite/nitrate and ultimately ***nitrogen gas***
- BNR/ENR requires two processes:
  - 1: Nitrification (O_2 & HCO_3 required)
  - 2: Denitrification (Carbon required)



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Nitrification-Denitrification

Nitrification improves oxygen in receiving waters:

Ammonia + Oxygen → (Autotrophs) → Nitrate

Denitrification removes nitrogen:

Nitrate + Food → (Heterotrophs) → Nitrogen gas ↑

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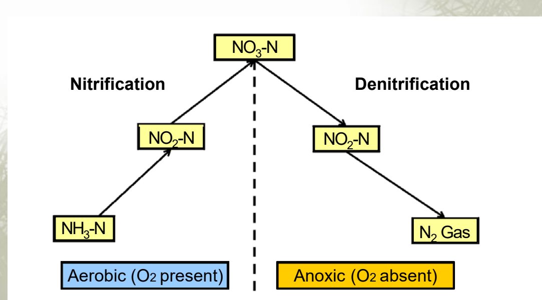
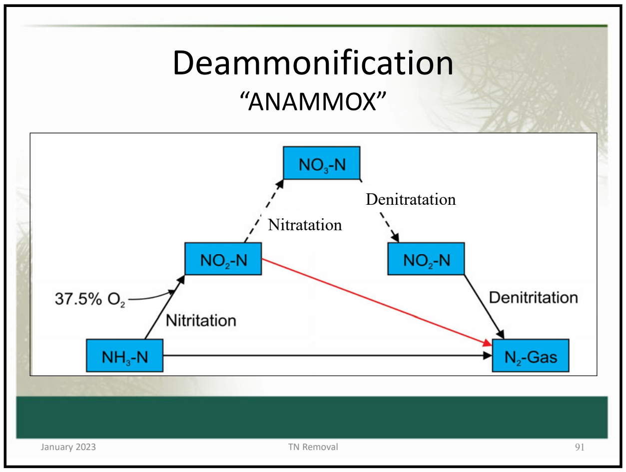
Simplified Nitrogen Removal



90


Deammonification
"ANAMMOX"
NO3-N
Denitratation
Nitratation
NO2-N
NO2-N
37.5% O2
Denitritation
Nitritation
NH3-N
N2-Gas
January 2023
TN Removal
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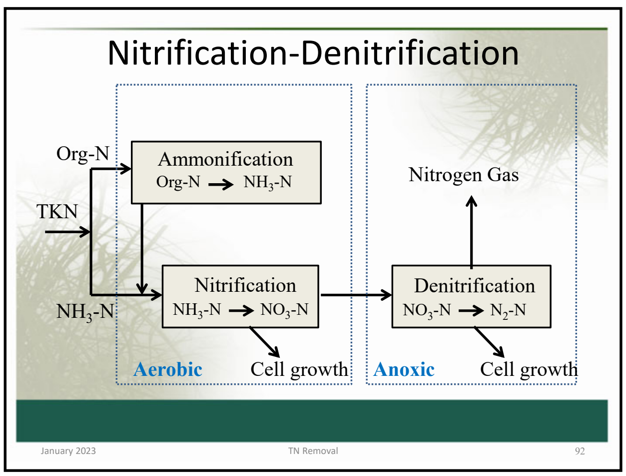
Nitrification-Denitrification
Org-N
Ammonification
Org-N → NH3-N
Nitrogen Gas
TKN
Nitrification
NH3-N → NO3-N
Denitrification
NO3-N → N2-N
NH3-N
Aerobic
Cell growth
Anoxic
Cell growth
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TN Removal
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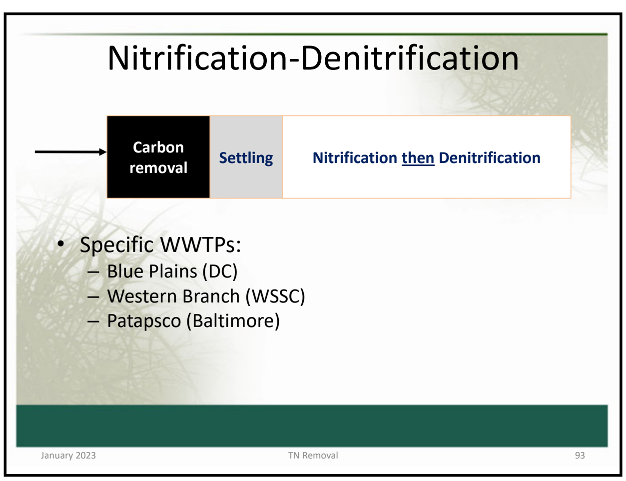
Nitrification-Denitrification
Carbon removal
Settling
Nitrification then Denitrification
• Specific WWTPs:
– Blue Plains (DC)
– Western Branch (WSSC)
– Patapsco (Baltimore)
January 2023
TN Removal
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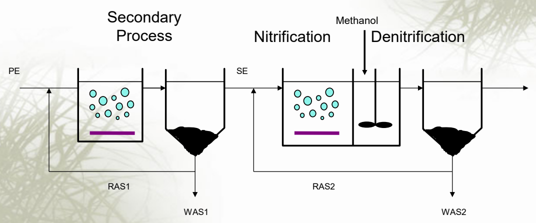
Two Sludge System for BOD Removal and Nitrogen Removal to <5 mg/L



Blue Plains, DC Water 370 MGD (beginning early 1990s)

January 2023 TN Removal 94

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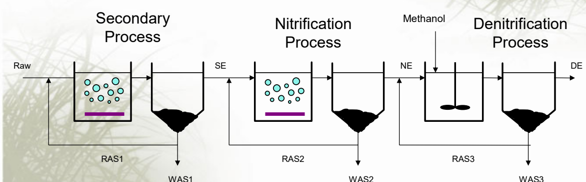
Three Stage System for BOD Removal and Nitrogen Removal to <3 mg/L



Western Branch WWTP, WSSC 30 MGD (late 1980s)

January 2023 TN Removal 95

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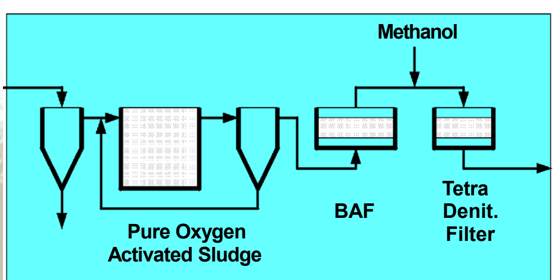
Patapsco WWTP (2018)

Baltimore, MD



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Process Control

- Three physical properties are typically monitored in wastewater:
  1. Liquid flow: Influent/effluent, recirculation, return activated sludge (RAS), sludge wasting quantities, chemical addition
  2. Constituent Concentrations: DO, MLSS, BOD_5, TSS, nutrients, sludge solids
  3. Gas volumes: air, digester gas

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Common Controlled Variables

- Aeration
  - Set DO levels in different sections of process
  - Control aeration time (cyclic aeration)
- BOD_5 and TSS loadings
  - Maximize removal of BOD_5 and TSS before nitrification/denitrification
- Ammonia, Nitrate, and Phosphate mass loadings
  - Avoid overloading unit processes

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Common Controlled Variables

- Chemical Addition
  - Methanol, Ferric/Alum, alkalinity feed rates
- Internal Recycles (MLE processes)
  - Set recycle flow rates based on process conditions
- Low water level to fill level (SBRs)
  - Set fill level/volume based on process conditions
- Sludge Wasting Rate
  - Control Solids Retention Time – One of the most important parameters for advanced BNR

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Before You Can Control a Process Variable, You Must be able to Monitor It with Reliable Sensors

100

What are sensors?

- Devices which measure a target variable
- Two components
  - Sensing Element
    - Tracks the variable being measured
    - Sends signal to transmitter
  - Transmitter
    - Converts signal for use on local display
    - Sends signal to controller/SCADA

Sensor image from:
http://www.capitolscientific.com/core/media/media.nl?id=51573&c=1250437&h=767af71ece59e1f9ec11

101

Nitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- Solids ret. time (SRT)
- pH/alkalinity
- ORP
- Airflow distribution
- DO probe(s)
- DO conc., mg/L
- Ammonia probe(s)
- Ammonia conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

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Denitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates
  - Inflows
  - Internal Recycle
- pH/alkalinity
- ORP
- DO probe(s)
- DO conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

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BNR and ENR Processes

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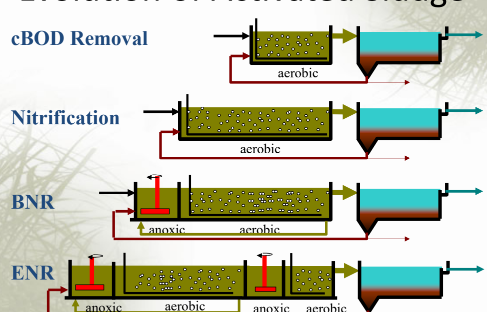
Evolution of Activated Sludge



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BNR & ENR Processes

- Anaerobic-aerobic (AO)
- Modified Ludzack-Ettinger (MLE)
  - Anoxic-aerobic
- Anaerobic-anoxic-oxic (A2O and UCT)
- Bardenpho
  - Anoxic-aerobic-anoxic-aerobic
- Step feed
- Sequencing Batch Reactors
- Oxidation ditch

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BNR Processes

Process	Nitrogen	Phosphorus	Comments
MLE	Good	None	- Moderate basin volume
Step Feed	Good	None	- No nitrate recycle
SBR	Moderate	Inconsistent	- No nitrate recycle
A2O	Good	Good	- Moderate basin volume - Sensitive to DO in return
Oxidation Ditch	Excellent	Good	-Long HRT and SRT - Tight DO controls necessary

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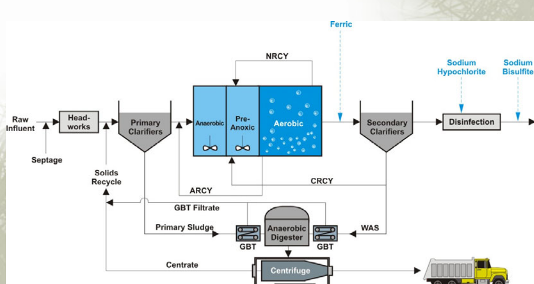
Typical BNR Activated Sludge System



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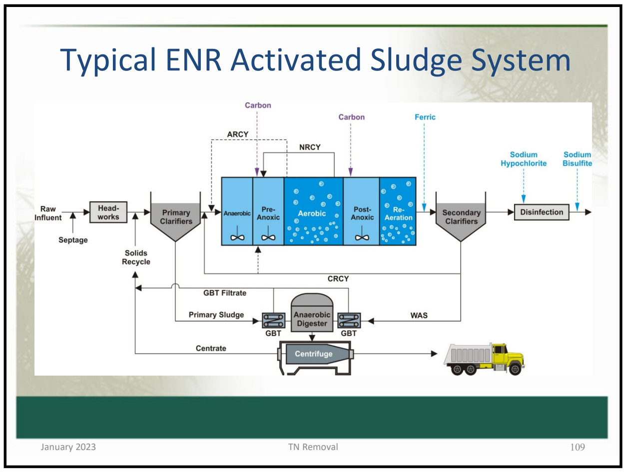
Typical ENR Activated Sludge System
Carbon
Carbon
Ferric
ARCY
NRCY
Sodium Hypochlorite
Sodium Bisulfite
Raw Influent
Head-works
Primary Clarifiers
Anaerobic
Pre-Anoxic
Aerobic
Post-Anoxic
Re-Aeration
Secondary Clarifiers
Disinfection
Septage
Solids Recycle
CRCY
GBT Filtrate
Primary Sludge
Anaerobic Digester
GBT
GBT
WAS
Centrate
Centrifuge
January 2023
TN Removal
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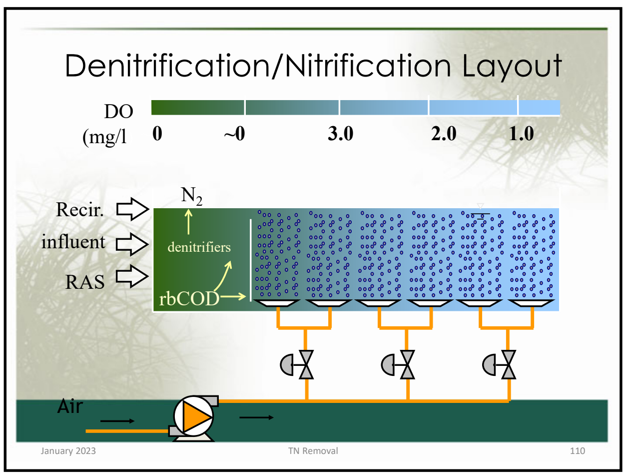
Denitrification/Nitrification Layout
DO (mg/l
0
~0
3.0
2.0
1.0
N_2
Recir.
influent
RAS
denitrifiers
rbCOD
Air
January 2023
TN Removal
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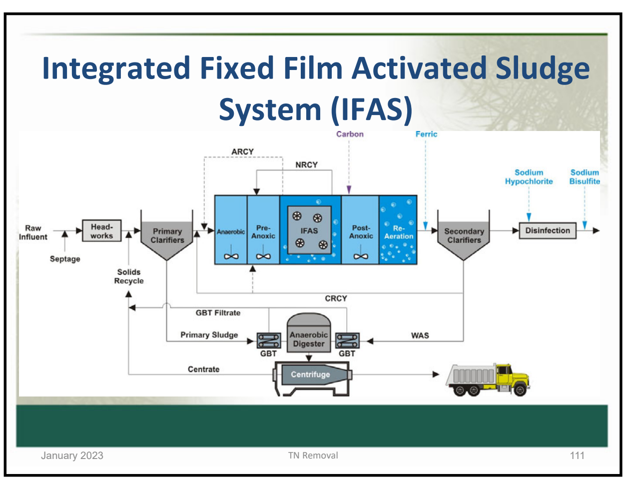
110


Integrated Fixed Film Activated Sludge System (IFAS)
Carbon
Ferric
ARCY
NRCY
Sodium Hypochlorite
Sodium Bisulfite
Raw Influent
Head-works
Primary Clarifiers
Anaerobic
Pre-Anoxic
IFAS
Post-Anoxic
Re-Aeration
Secondary Clarifiers
Disinfection
Septage
Solids Recycle
CRCY
GBT Filtrate
Primary Sludge
Anaerobic Digester
GBT
GBT
WAS
Centrate
Centrifuge
January 2023
TN Removal
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111

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)



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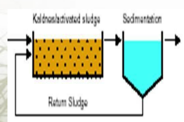
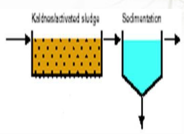
Difference Between IFAS and MBBR

IFAS



1. Fixed film and suspended growth
2. Includes RAS

MBBR



1. Fixed film only
2. No RAS

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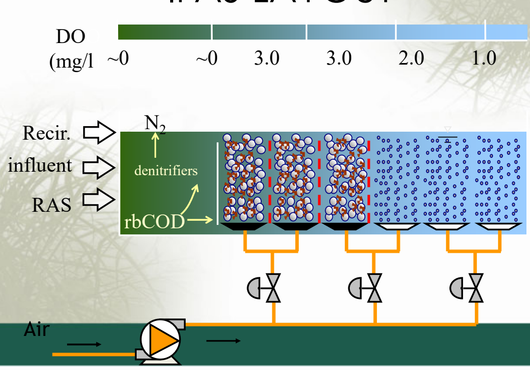
IFAS LAYOUT



114

Oxidation Ditch

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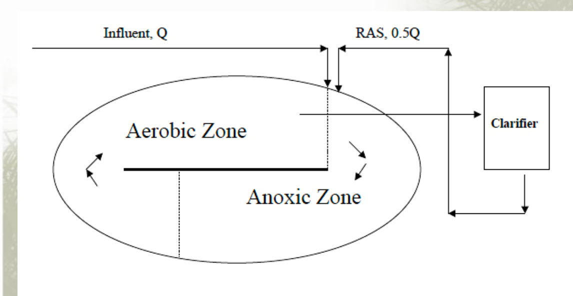
Oxidation Ditch



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Oxidation Ditch

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Sequencing Batch Reactor

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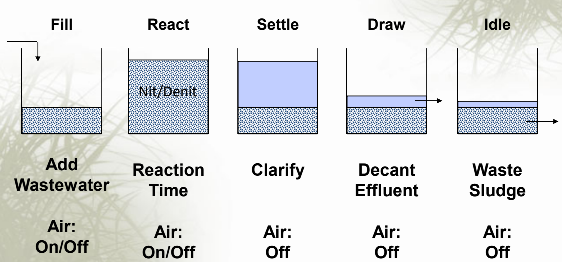
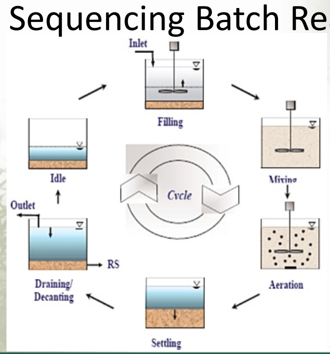
Sequencing Batch Reactor



119

Sequencing Batch Reactor



Denitrification

Nitrification

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Sequencing Batch Reactor

- TKN enters the SBR during the "Fill-mix" stage
- TKN is converted to nitrates during the "aerated react" stage
- Most nitrates formed remain in the "low-water" remaining after clarification
- Nitrates in the "low water" are converted to nitrogen gas during the "Fill-mix" stage
- ORP plus nitrate probes would be helpful to determine absence of nitrates

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ORP Ranges for Processes

Biochemical Reaction	ORP, mV
Wastewater Treatment:	
Nitrification	+100 to +350
cBOD degradation with air (O_2)	+50 to +250
Denitrification	+50 to -50
Anaerobic Digestion:	
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

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Sequencing Batch Reactor

- Nitrates are converted to nitrogen gas during the "Fill-mix" stage in the absence of oxygen
- Percent nitrate removal in the "Fill-mix" stage is a function of low water volume:
  - % Nitrate Removed = Low water volume / (Low water + cycle fill Volumes)
- Optimum nitrate removal occurs with multiple SBR tanks in service, e.g., large low water volumes

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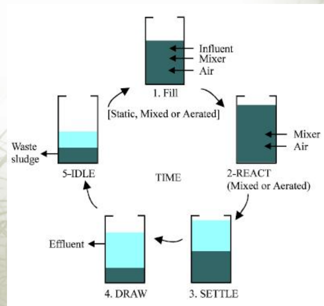
Sequencing Batch Reactor



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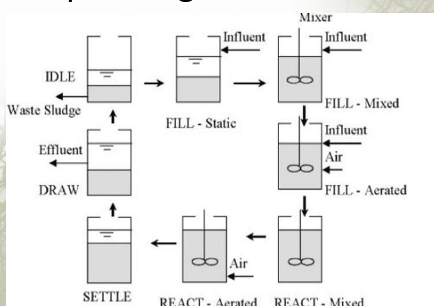
Sequencing Batch Reactor



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Sequence	Volume taken up (as a % of capacity)	Sequence duration (as a % of cycle)	Cycle stage	Object of the sequence	Air
1	60 to 100	33	Influent, Feed	Substrate input (denitrification)	With or without (optional)
2	100	33	Reaction	Carbon removal (and nitrification)	With
3	100	16	Settle	Clarification	Without
4	100 to 65	14	Decant, Effluent	Treated water removal	Without
5	65 to 60	4	Idle	Excess sludge	Without

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Nitrification

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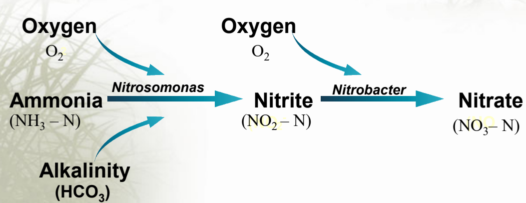
Two-step Nitrification

- For 125 years, nitrification was believed to be solely a two-step process:



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Two-step Nitrification

- Two-step nitrification depends on two organisms, which was the basis for hundreds of studies on nitrification in wastewater treatment
- A single microbe capable of catalyzing both nitrification steps may actually be a benefit by conserving more energy

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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 organisms were first predicted in 2006
- In 2015, the presence of such organisms was confirmed within *Nitrospira*
- The Nitrogen cycle has since been updated

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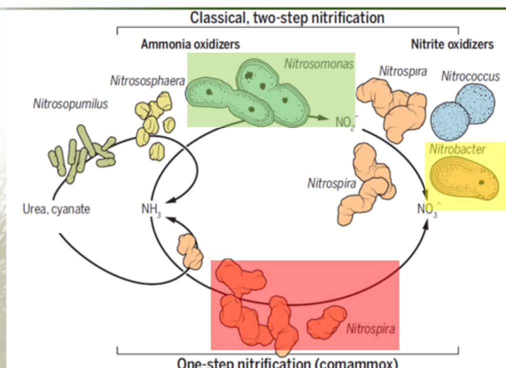

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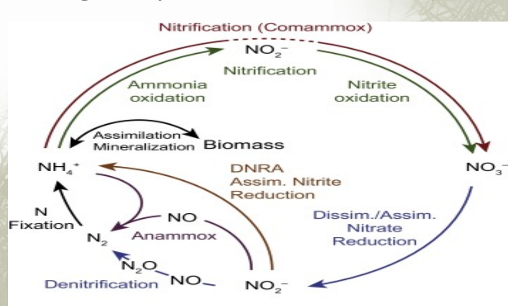
Nitrogen Cycle in Wastewater (2016)



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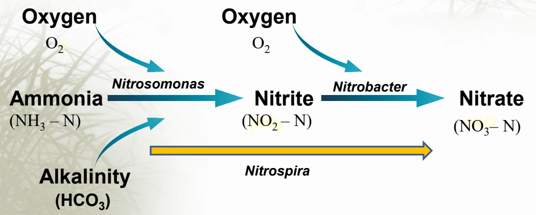
Nitrification

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



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Nitrification Configurations

- Suspended Growth
  - Extended aeration AS
  - Oxidation ditch
  - Step feed AS
  - Sequencing Batch Reactor (SBR)
- Fixed Film
  - Up flow Biological Aerated Filters (BAF)
  - Moving Bed Biofilm Reactors (MBBR)
  - Integrated Fixed Film Activated Sludge (IFAS)

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Denitrification

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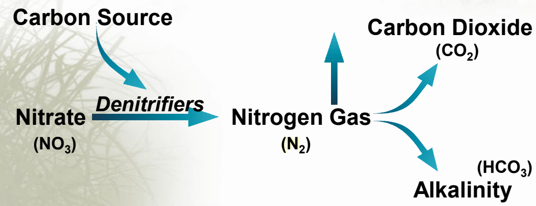
Denitrification

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



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Denitrification Configurations

- Suspended Growth
  - Pre and post Anoxic zones in AS processes:
    - MLE
    - Bardenflo
    - Oxidation ditch
    - Sequencing Batch Reactor (SBR)
- Fixed Film
  - Up flow denitrification filter
  - Down flow denitrification filter
  - Anoxic Moving Bed Biofilm Reactors (MBBR)

January 2023 and post TN Removal 137

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Nitrogen Removal

Nitrification – Process Control

January 2023 TN Removal 138

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Environmental Conditions for Nitrification

- Nitrifying (Autotrophic) Bacteria
- CO_2 Carbon Source for Growth
- Sufficient MCRT > 10 days
- Adequate Oxygen > 2.0 mg/l
- Adequate Alkalinity to prevent pH drop > 70 mg/l
- Process operating pH range – 6.5 to 8.0
- No Toxics or inhibitory compounds
- Temperature has a significant impact on process

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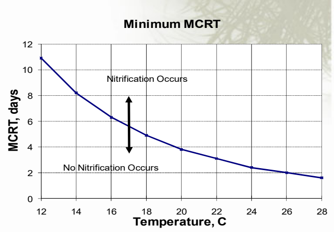
Nitrification Process Monitoring

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



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

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Effect of Temperature on Nitrification

As temperature increases, nitrifier growth rate increases (within the range of 4° C to 35° C).

T ↑ μ ↑

As nitrifier growth rate increases, required MCRT decreases.

μ ↑ MCRT ↓

<u>Rule of Thumb</u>:
For every 10°C increase in temperature, nitrifier growth rate doubles, required MCRT is cut in half and required MLSS concentration is also reduced.

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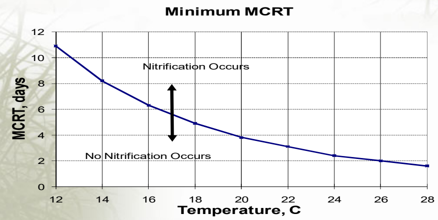
Nitrification Process Monitoring

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



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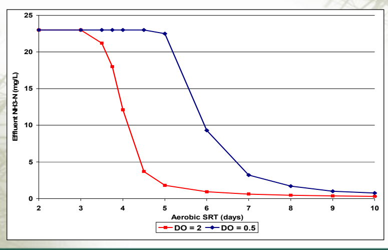
Nitrification Process Monitoring

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



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Effect of Dissolved Oxygen Concentration on Nitrification

As dissolved oxygen increases, nitrifier growth rate increases up to DO levels of about 5 mg/L.

DO ↑ μ ↑

<u>Rule of Thumb</u>:
Maintain dissolved oxygen concentration at 2.0 mg/l or higher for <u>complete</u> nitrification.

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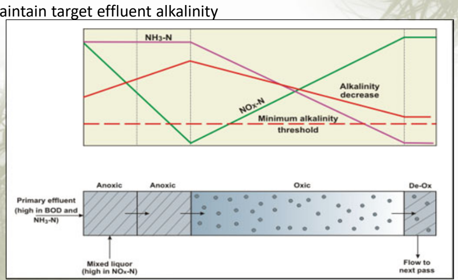
Nitrification Process Monitoring

- **Key Factor 3**
  - Maintain target effluent alkalinity



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Nitrification

Operations and Troubleshooting

January 2023 TN Removal 146

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Indications of Nitrification Issues

- Increased ammonia levels in effluent
- Without effective nitrification, subsequent denitrification will not occur resulting in poor TN removal
- **Nitrification is most sensitive nitrogen removal process**
- Multiple culprits for decreased nitrification
  - Solids Inventory(MLSS, SRT/MCRT, WAS)
  - D.O.
  - pH (alk)
  - Temp.
  - Inhibition

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Problems/Solutions

Problem: Not Nitrifying

Solution: Increase MCRT by raising MLSS

- pH > 6.8
- DO > 2.0 mg/l
- CHECK FOR TOXICS
- Alkalinity > 70 mg/l

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Nitrification- Operational Problems

- **If effluent ammonia-nitrogen is above the goal:**
  - Verify adequate DO in the aerobic zones.
  - Verify adequate alkalinity in the aeration tank effluent.
  - Consider if inhibitory compounds could be present.
  - If none of the above are true, increase aerobic MCRT.

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Obstacles to Achieving Nitrification

- Inadequate aeration capability
- Inadequate biomass quantity(MCRT)
- Poor clarifier hydraulics limiting MLSS in tanks
- Poor sludge settling/excessive filamentous bacteria
- Insufficient alkalinity
- Inhibitory chemicals

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Nitrification Control Parameters

Temperature

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

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Nitrification Control Parameters

Dissolved Oxygen

- Maintain MLDO at 2.0 – 3.0 mg/L

pH / Alkalinity

- Maintain MLpH > 6.8
- Maintain alkalinity residual NLT 70 mg/L, preferably > 100 mg/l

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Problems/Solutions

Problem: Low Dissolved Oxygen

Solution: Increase blower output

- Add more blowers
- Add more diffusers
- Replace diffusers with more efficient units
- Denitrify

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Problems/Solutions

Problem: Low pH

Solution: Add alkalinity to aeration tank using caustic soda, soda ash, lime, or magnesium hydroxide.

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Solids Inventory - Solutions

- Observe aerator and clarifier performance
- Measure BOD_{in} and MLSS; calculate:
  - ✓ BOD loadings, solids Inventory, and F:M
  - ✓ Compare F:M to SOP/benchmarks
- Wasting :
  - ✓ Adjust WAS to maintain target MLSS, SRT/MCRT
  - ✓ Aerobic SRT/MCRT – based on AEROBIC volume
  - ✓ Increase aerobic volume and/or MLSS to increase aerobic SRT/MCRT
- Develop plan to maintain inventory during wet weather

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MCRT Calculations

- **"Biomass in System (lbs.)"**
  – Usually, only the amount of "active" biomass in the aeration tanks is counted. However, biomass in the clarifiers will be included in calculations.
  – Technically, only active biomass should be considered, which is approximated by MLVSS (mixed liquor *volatile* suspended solids). However, because the MLVSS/MLSS ratio of the process is usually very consistent once steady-state operation is achieved, MLSS is often used in the calculation instead of MLVSS.

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MCRT or SRT

MCRT - Mean Cell Resident Time

or

SRT - Solids Residence Time

$$\frac{\text{Pounds of MLSS in aeration and clarifier tanks}}{\text{Pounds TSS wasted + Pounds TSS lost in eff.}}$$

$$\frac{\text{MLSS, mg/l x (aeration \& clarifier Vol) x 8.34}}{\text{Pounds TSS wasted + Pounds TSS lost in eff.}}$$

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Nitrification- SRT/MCRT

- **Ways to raise aerobic MCRT:**
  - Increase total MCRT by reducing sludge wasting, but do not allow rising MLSS to exceed clarifier capacity.
  - Increase percent volatiles (MLVSS) without increasing total MLSS by reducing the amount of inerts entering system through chemical feeds and sidestream loads (i.e. from septage or sludge thickening/digestion).
  - Increase MCRT without raising MLSS by bringing more aeration tanks on-line.
  - Increase <u>aerobic</u> MCRT without raising total MCRT by operating switch zones in the aerobic mode

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MCRT - Sludge Wasting

- Waste sludge from the process every day to maintain MCRT goal.
- Waste sludge pumps can be controlled automatically or manually.
- Extend sludge wasting period as long as possible by running waste sludge pumps at a slow rate – this will prevent sudden changes from impacting the BNR process.

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MCRT – Running Average

- Don't rely on a single day's MCRT
- Use a running average over a period approximately equal to the MCRT
  - For example, if MCRT is about 7 days, use a 7-day running average
  - Most operator's use a 3 to 5-day running average

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Nitrification

Aeration

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Let's Focus on Aeration

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Aeration

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DO-Related Process Controls

- Main header pressure
- Blower speed
- Number of blowers
- DO control valve positions
- DO probes
- Ammonia probe(s) (optional)

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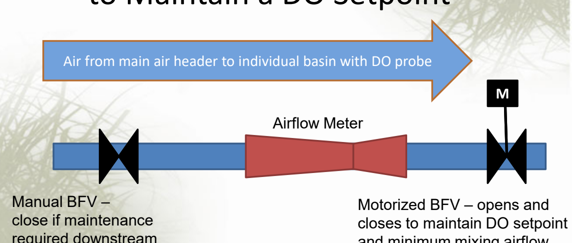
DO Control: Opening or Closing a MOV to Maintain a DO Setpoint



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Aeration

- Purpose of aeration:
  - To dissolve oxygen into wastewater so that microorganisms can utilize it to break down organic material
- Aeration is also used for mixing the activated sludge process and to enhance biological growth

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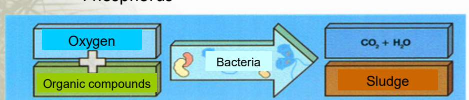
Aeration

- Oxygen is used for growth of suspended and attached biomass to remove:
  - Soluble Organics (cBOD, COD)
  - Organic Solids (TSS, VSS)
  - Nutrients
    - Nitrogen
    - Phosphorus



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Aeration

- Conventional biological processes are aerobic
- Many organisms in the activated sludge and fixed film processes need free oxygen (O_2) to convert food into energy for their growth
- Typical Dissolved Oxygen (DO) concentrations:
  - BOD removal - normal 1 to 2 mg/L
  - "Nitrification" - 2 to 4 mg/l

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Aerobic Processes

- Aerobic processes require O_2 for removal of organics (BOD) and conversion of ammonia-N to Nitrate-N (nitrification)
- Oxygen can be supplied by air or pure O_2
- Oxygen can be delivered through mechanical (surface) or diffused aerators

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Aeration

- BOD Removal
- Nitrification – convert NH_3 to NO_3

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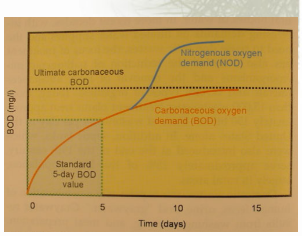
Oxygen Requirements

- Biological treatment:
  - <u>cBOD removal</u> – from organic matter and suspended solids
  - <u>nBOD removal</u> – Nitrification, convert ammonia nitrogen to nitrate nitrogen (before denitrification)



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Nitrification- Oxygen Required

- Ammonia oxidation
  - $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$
- Nitrite oxidation - $2NO_2^- + O_2 \rightarrow 2NO_3^-$
- Overall: $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ = 4.57 g O2/g N for complete oxidation

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Nitrification- Oxygen Required

- Ensure adequate D.O. during peak loads
  - D.O. Profiling
- Increase D.O. as needed – Blower Capacity?
- Ideal to implement automated, real-time D.O. control to maintain minimum D.O.'s in aerobic zones
  - Air delivery to match D.O. demand (load) variations
  - Reduce energy costs
  - Avoid D.O. bleed through to downstream anoxic zones in BNR/ENR processes.

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Air Demand Requirements, lbs/day

Treatment	Equation	lb O_2/lb oxidized
Organic Removal	$BOD_{oxidized} = BOD_{inf} - BOD_{eff}$	1.0 – 1.2
Nitrification	$TKN_{oxidizable} = TKN_{inf} - TKN_{assimilated}$ $TKN_{oxidized} = TKN_{oxidizable} - TKN_{eff}$	4.6

NPDES Effluent Requirement	OTR Equation
BOD_5 Limit	1.2 * $BOD_{oxidized}$
BOD_5 + NH_3-N Limit	1.2 * $BOD_{oxidized}$ + 4.6 * $TKN_{oxidized}$

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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 (~ 1.0 mg/l DO) for BOD removal to less than 15 mg/L
  - 20% minimum saturation (~ 2.0 mg/l DO) for complete nitrification

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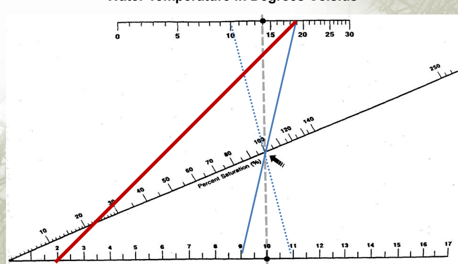
D.O. - Percent Saturation in Water

Water Temperature in Degrees Celsius



Oxygen in mg/L

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

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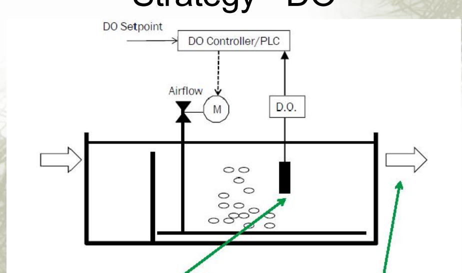
Typical MLE Aeration Basin Control Strategy - DO



DO setpoint chosen to minimize historical NH_3 breakthrough

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New Aeration Basin Control Strategies

- Ammonia-based DO control
- Nitrate-based DO control

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Objective of Ammonia-Based Aeration Control

- Aeration options:
  - Full nitrification
  - **Incomplete nitrification**
  - Reduce effluent ammonia peaks
- Potential benefits of incomplete nitrification include:
  - Decreased energy expenses (for aeration)
  - Possibly increased denitrification with less supplemental carbon addition
  - Possibly improved Bio-P removal

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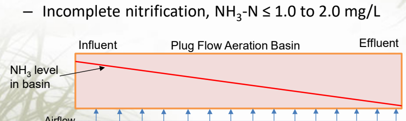
Ammonia-Based DO Control

- Operator selects effluent ammonia setpoint
  - Complete nitrification, NH_3-N ~ 0.1 mg/L
  - Incomplete nitrification, NH_3-N ≤ 1.0 to 2.0 mg/L



Just right

- When effluent ammonia is greater than setpoint, controller increases DO
- When effluent ammonia is below setpoint, controller decreases DO

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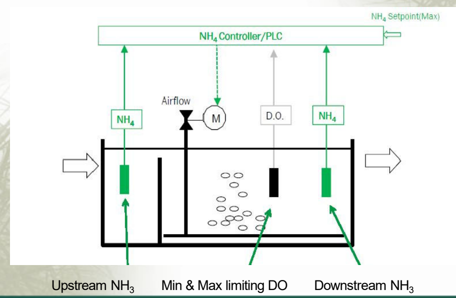
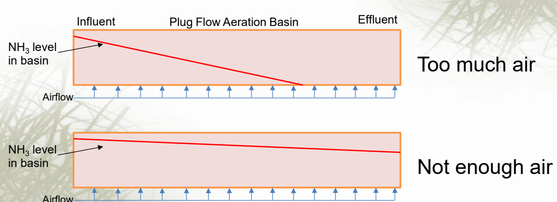
Ammonia Feed Forward – Feedback Control



181

Ammonia-Based DO Control



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Ammonia-Based DO Control

- As ammonia concentration increases above set point in the nitrification zone (e.g., ammonia breakthrough)
  - Increase aeration
  - To increase nitrification
  - To decrease ammonia concentration

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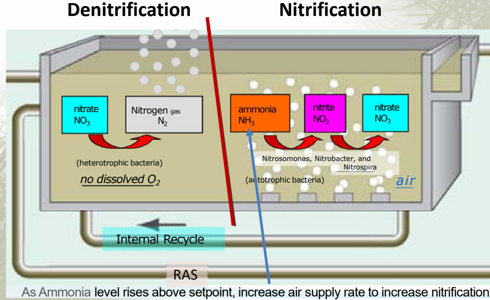
Biological Nitrogen Removal



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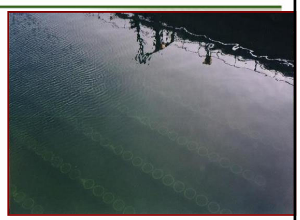
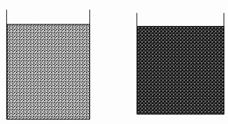
Gas transfer devices

Mechanical (surface) aerators of activated sludge process treating wastewater



Fine bubble



Fine bubble diffuser

Course bubble diffuser

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Diffuse Air – Oxygen Supply

Coarse bubble diffuser

Fine bubble diffuser

High efficiency fine bubble diffusers

- 15-25% transfer efficiency
- Porous diffusers (ceramic, flexible membrane)
- Jet mixers (discharge through nozzles)

Non-porous course bubble diffusers

- 5-8% gas transfer efficiency
- Perforated pipes

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Coarse Bubble

- Application
  - Nearly every process and wastewater
  - Industrial applications - zero maintenance
  - Stainless steel construction
  - 30 year design life
- Efficiency
  - Spiral roll
  - 0.7-0.9% SOTE per ft submergence
  - 3-4 lb oxygen/kwh
  - 60% greater power than fine bubble fixed
- Maintenance
  - Near zero maintenance
  - Required maintenance - hardware, grit, diffusers
  - Inspection every 3-5 years

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Fine Bubble

- Application
  - Nearly every process and wastewater
  - Media sensitivity
  - Low oil membrane disc
  - Membrane 8-10 year minimum life
  - Ceramic 10–20 year life w/ PM
- Efficiency
  - Most efficient device
  - Greater than 2-3% SOTE per ft submergence
  - 8-10 lb oxygen/kwh
- Maintenance
  - Required maintenance - hardware, grit, leaks, diffusers
  - Ceramic annual cleaning
  - Membrane cleaning every 2 - 3 years

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Nitrification- Nitrite Production

- During periods of partial nitrification, nitrites (NO_2-N), which are normally not present in the secondary effluent, may be present at measurable concentrations.
- Nitrites can cause very high chlorine demand for effluent disinfection.
- Avoid nitrite production by achieving complete nitrification.

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Nitrification- Alkalinity/pH

Nitrifiers utilize inorganic carbon/consume alkalinity:

– Aerobic chemoautotrophs

$NH_4^+ + 2HCO_3^- + 2O_2 \rightarrow NO_3^- + 2CO_2 + 3H_2O$

– Theoretically, 7.14 g alkalinity as $CaCO_3$ consumed for each g of ammonia nitrogen oxidized to nitrate.

– Typically, lime or caustic soda is added to make up for alkalinity loss.

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Nitrification – Temperature Impacts

- Need to plan for temperature transitions – especially in areas with significant seasonal changes.
- Build solids inventory, decrease F:M ratio, and increase MCRT/SRT as seasonal (cold weather) changes approach.

Wastewater Temperature Range (°C)	Target Food to Mass Ratio	Target Average Aeration MLSS (mg/L)	Typical MCRT/SRT, Days	NH_3, mg/l
14-18	0.05	3000	15	1 – 2
18-22	0.075	2500	10	0.5 – 1
22-25	0.1	2000	7	0.5 - 1

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Inhibitory/Toxic Compounds

- Difficult to identify – many sources
  - Raw wastewater
    - Industrial users
    - Periodic/random discharge
  - Return flows
  - Trucked waste loads
- Good industrial Pretreatment Program can help
- Demonstrate inhibition via:
  - Microscopy
  - Analytical scan of all suspect streams including SIUs
  - Microtox® Toxicity Assay (others)
  - Batch nitrification inhibition studies

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Inhibitory/Toxic Compounds

- **Organic Compounds**:
  - Acetone
  - Carbon Disulfide
  - Chloroform
  - Ethanol
  - Monoethanolamine
  - Ethylenediamine
  - Hexamethylene Diamine
  - Aniline
  - Phenol
- **Metals and Inorganic Compounds**
  - Zinc
  - Free Cyanide
  - Perchlorate
  - Copper
  - Mercury
  - Chromium
  - Nickel
  - Silver
  - Cobalt
  - Thiocyanate
  - Sodium Cyanide
  - Sodium Azide
  - Hydrazine
  - Sodium Cyanate
  - Potassium Chromate
  - Cadmium
  - Arsenic (trivalent)
  - Fluoride
  - Lead

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Inhibitory/Toxic Compounds

- Nitrification (and Denitrification) are both susceptible to inhibition
- Many compounds cause nitrification inhibition/ toxicity
  - Heavy metals: Ni^{2+}, and Zn^{2+}
  - Strong metal complexing agents : EDTA and NTA
  - Synthetic organic compounds: Surface active agents (SDBS, dodecylamine)
  - Cynide
  - Acetylene : strong inhibitor of nitrous oxide, N_2O reductase
- May manifest as increased nitrite (incomplete nitrification)
- Other processes may be impacted
  - Poor settling
  - Poor dewatering
  - Very high D.O. – no demand

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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

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Alternatives to Achieve Nitrification

- **Build more aeration tanks**
- **Add nitrifying filters**
- **Add fixed media to the existing aeration tanks (Integrated Fixed Film Activated Sludge, IFAS)**

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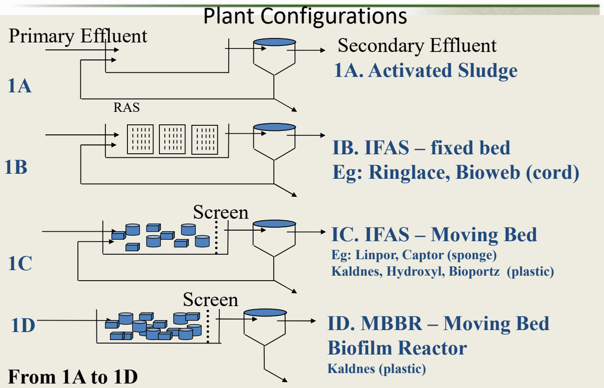
Plant Configurations



From 1A to 1D

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

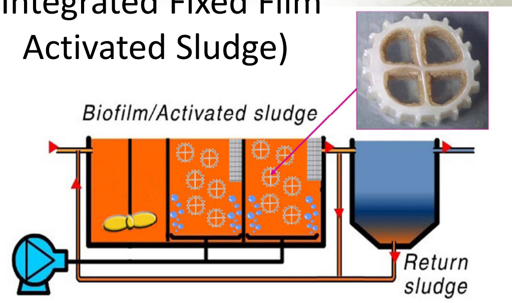
197

Why Use An IFAS Process ?

- **Increase capacity without more tankage**
- **Achieve nitrification in tankage which could not otherwise nitrify**
- **Achieve nitrogen removal in tankage which could not otherwise nitrify and denitrify**

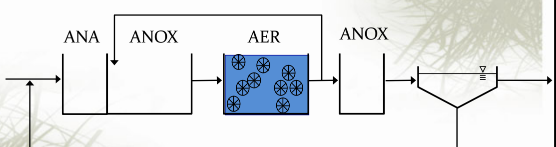
198

IFAS (Integrated Fixed Film Activated Sludge)



199

IFAS in Nutrient Removal



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

200

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 tankage**
- **Decrease required recycle rates**

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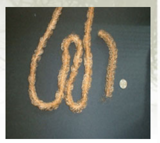
Types of IFAS Systems

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

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

202

Free Floating Media - Sponge

Lotepro – Linpor Process

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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

204

Nitrogen Removal

Denitrification

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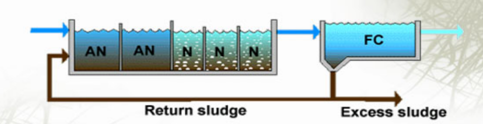
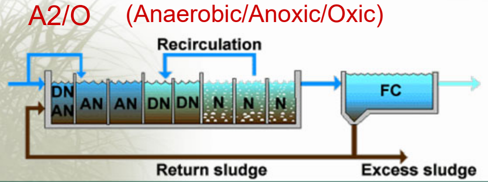
A/O Process (Anaerobic/Oxic)

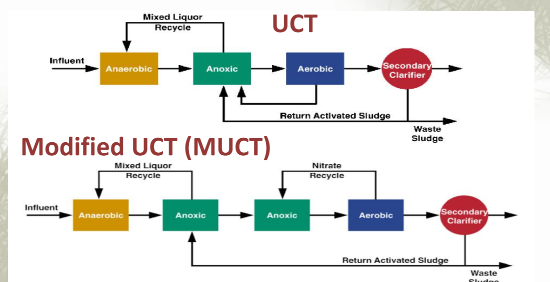


A2/O (Anaerobic/Anoxic/Oxic)



206

UCT Processes



For biological uptake of phosphorus and partial removal of nitrogen

207

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.

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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**

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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.

January 2023 TN Removal 210

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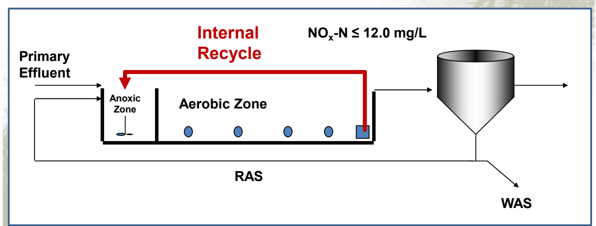
Let's Focus on Internal Recycle



211

Internal Recycle

- Internal recycle flow rates determine nitrate concentrations in BNR process effluent
  - The higher the recycle flow rate, the lower the effluent nitrate concentrations
  - Process effluent nitrate concentration "set points" can be used to control internal recycle flow rates

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Nitrate-Based Internal Recycle Control

- As nitrate concentrations increase above set point in the nitrification zone (e.g., excess effluent nitrates)
  - Increase internal recycle from nitrification to denitrification
  - To decrease nitrates in nitrification effluent
  - To fully denitrify

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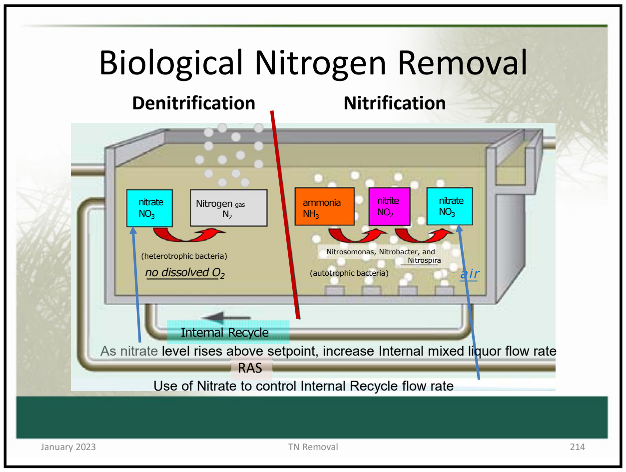
Biological Nitrogen Removal
Denitrification
Nitrification
nitrate NO3
Nitrogen gas N2
ammonia NH3
nitrite NO2
nitrate NO3
(heterotrophic bacteria)
no dissolved O2
Nitrosomonas, Nitrobacter, and Nitrospira
(autotrophic bacteria)
air
Internal Recycle
As nitrate level rises above setpoint, increase Internal mixed liquor flow rate
RAS
Use of Nitrate to control Internal Recycle flow rate
January 2023
TN Removal
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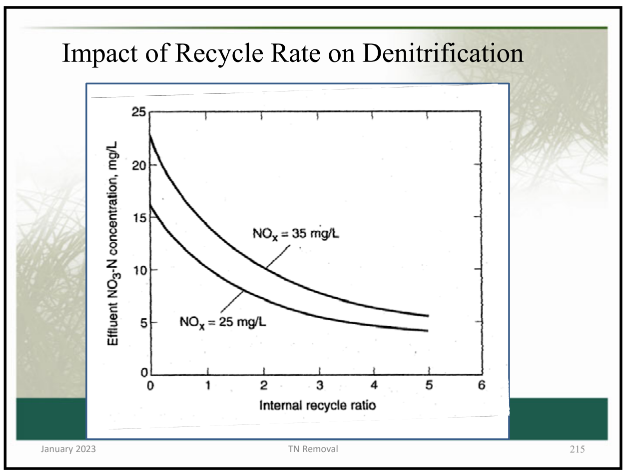
214


Impact of Recycle Rate on Denitrification
Effluent NO3-N concentration, mg/L
NOx = 35 mg/L
NOx = 25 mg/L
Internal recycle ratio
January 2023
TN Removal
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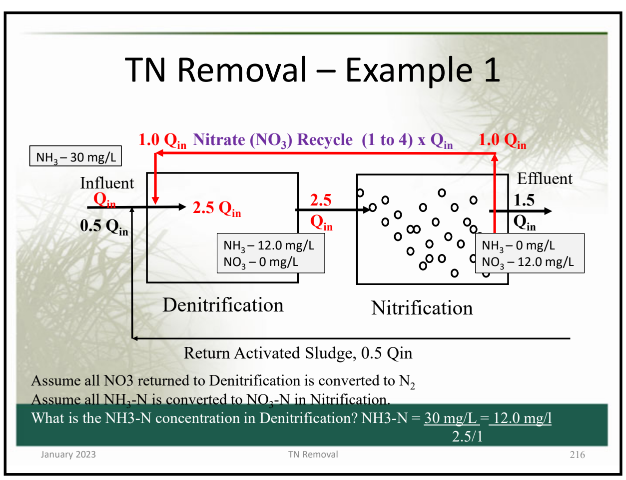
TN Removal – Example 1
1.0 Qin Nitrate (NO3) Recycle (1 to 4) x Qin 1.0 Qin
NH3 – 30 mg/L
Influent
Qin
0.5 Qin
2.5 Qin
2.5 Qin
Effluent
1.5 Qin
NH3 – 12.0 mg/L
NO3 – 0 mg/L
NH3 – 0 mg/L
NO3 – 12.0 mg/L
Denitrification
Nitrification
Return Activated Sludge, 0.5 Qin
Assume all NO3 returned to Denitrification is converted to N2
Assume all NH3-N is converted to NO3-N in Nitrification.
What is the NH3-N concentration in Denitrification? NH3-N = 30 mg/L = 12.0 mg/l
2.5/1
January 2023
TN Removal
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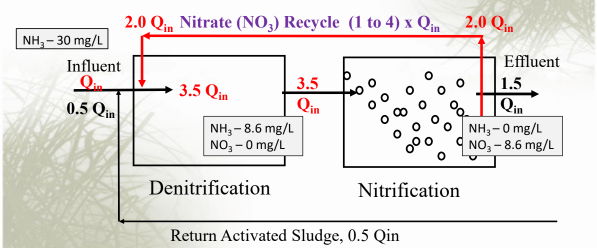
TN Removal – Example 2



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 = $\frac{30\ mg/L}{3.5/1}$ = 8.6 mg/l

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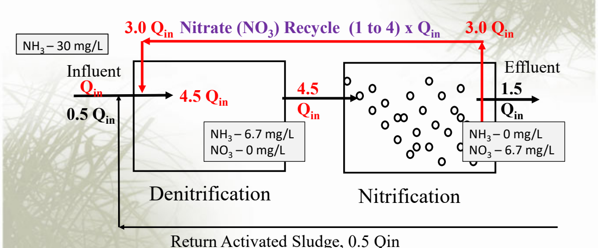
TN Removal – Example 3



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 = $\frac{30\ mg/L}{4.5/1}$ = 6.7 mg/l

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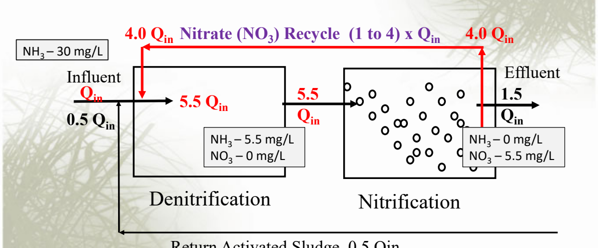
TN Removal – Example 4



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 = $\frac{30\ mg/L}{5.5/1}$ = 5.5 mg/l

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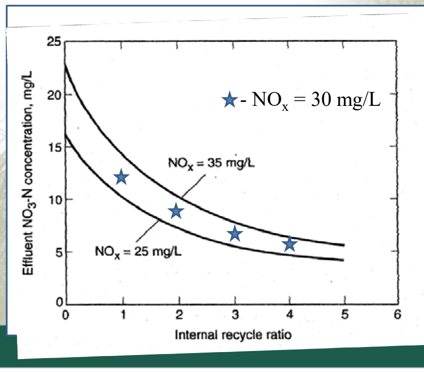
Impact of Internal Recycle on Effluent TN



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Nitrate Recycle Pump Control

- **Measure NO_3-N concentration in the effluent from the last anoxic zone:**
  - If NO_3-N is <u>less</u> than 0.5 mg/L and DO is <u>less</u> than 0.3 mg/L in this zone, <u>turn up</u> the nitrate recycle rate.
  - If NO_3-N is <u>more</u> than 0.5 mg/L and DO is <u>less</u> than 0.3 mg/L in this zone, <u>turn down</u> the nitrate recycle rate.
  - If DO is <u>more</u> than 0.3 mg/L in this zone and there is no other way to reduce DO, <u>turn down</u> the nitrate recycle rate if effluent NO_3-N goals are not being met.

January 2023 TN Removal 221

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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.

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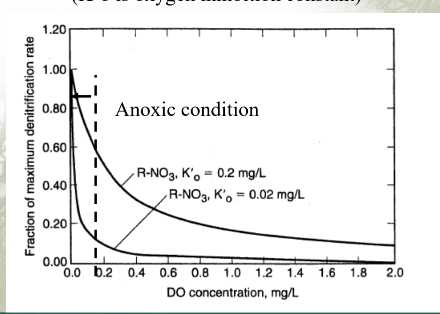
High DO in the Anoxic Zones

- 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

223

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



224

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

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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)

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Inhibition by specific Chemicals

- Strong Inhibitors
  - Acetylene (C_2H_2)
  - Sulfide (S^{2-})
  - Chlorate (ClO_3^-)
  - Heavy metals
  - Cyanide (CN^-) and Azide (N_3^-)

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Inhibitory/Toxic Compounds Sources

- As with Nite Inhibition - Difficult to identify
  - Raw wastewater -Industrial users
  - Return flows
  - Trucked waste loads
- Good industrial Pretreatment Program can help
- Demonstrate inhibition via
  - Microscopy – may indicate problem
  - Analytical scan of all suspect streams including SIUs
  - Microtox® Toxicity Assay (others)
  - Batch denite inhibition studies

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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.

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BNR and ENR

Overview

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Historical Overview

- 1920s - 1960s
  - cBOD Removal
  - Nitrification
- 1970s – Chemical phosphorus removal
- 1980s to 2000 – BNR development and application
- Past 15 years – BNR to ENR

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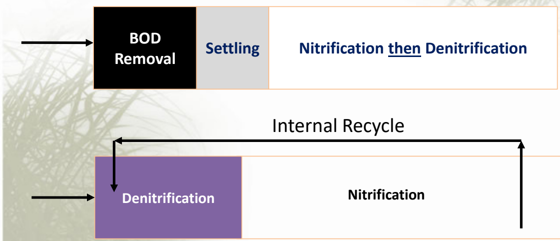
Typical BNR Configurations



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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

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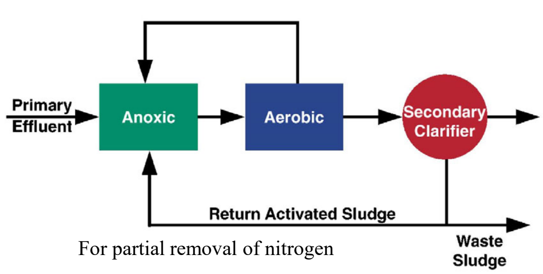
Modified Ludzack-Ettinger - MLE



For partial removal of nitrogen

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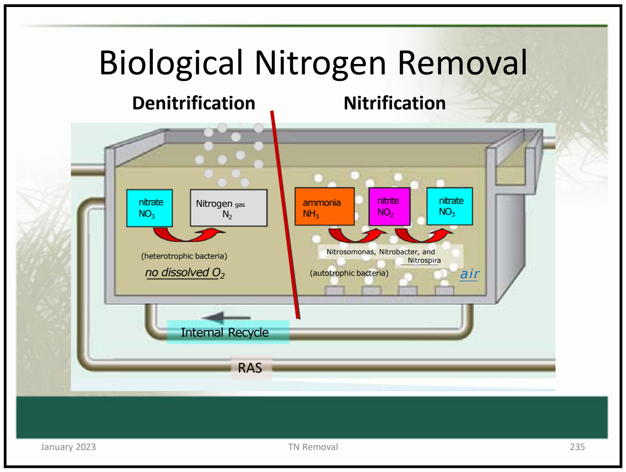
Biological Nitrogen Removal
Denitrification
Nitrification
nitrate NO3
Nitrogen gas N2
ammonia NH3
nitrite NO2
nitrate NO3
Nitrosomonas, Nitrobacter, and Nitrospira
(heterotrophic bacteria)
no dissolved O2
(autotrophic bacteria)
air
Internal Recycle
RAS
January 2023
TN Removal
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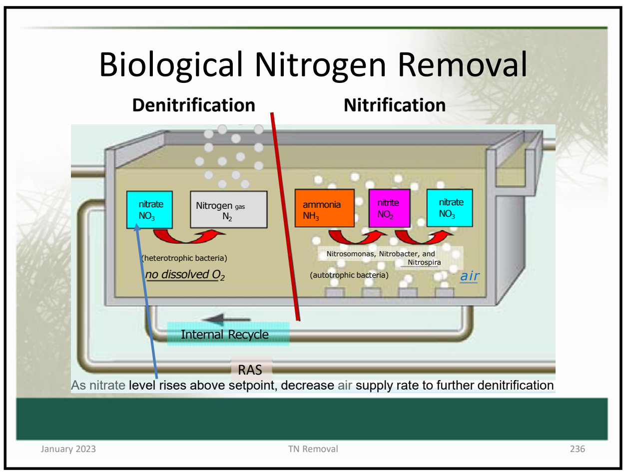
Biological Nitrogen Removal
Denitrification
Nitrification
nitrate NO3
Nitrogen gas N2
ammonia NH3
nitrite NO2
nitrate NO3
Nitrosomonas, Nitrobacter, and Nitrospira
(heterotrophic bacteria)
no dissolved O2
(autotrophic bacteria)
air
Internal Recycle
RAS
As nitrate level rises above setpoint, decrease air supply rate to further denitrification
January 2023
TN Removal
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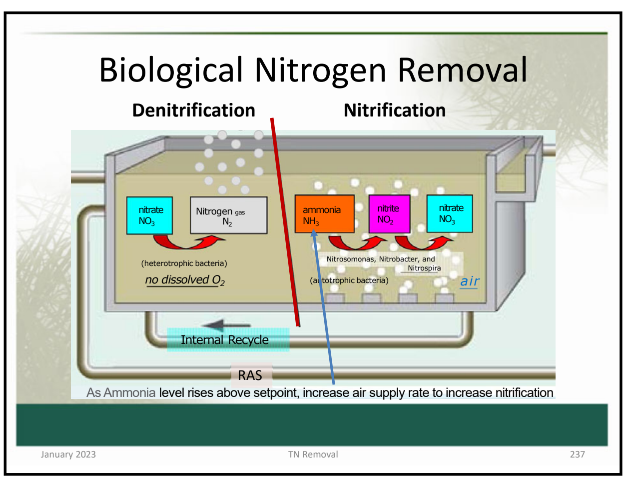
Biological Nitrogen Removal
Denitrification
Nitrification
nitrate NO3
Nitrogen gas N2
ammonia NH3
nitrite NO2
nitrate NO3
Nitrosomonas, Nitrobacter, and Nitrospira
(heterotrophic bacteria)
no dissolved O2
(autotrophic bacteria)
air
Internal Recycle
RAS
As Ammonia level rises above setpoint, increase air supply rate to increase nitrification
January 2023
TN Removal
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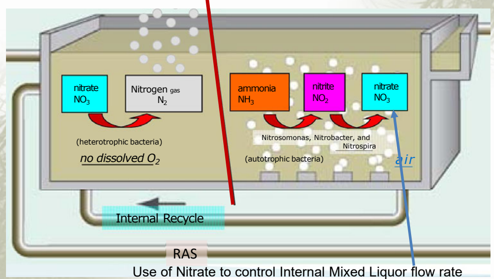
Biological Nitrogen Removal



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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

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BNR

- Removes total nitrogen (TN) and total 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)

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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)

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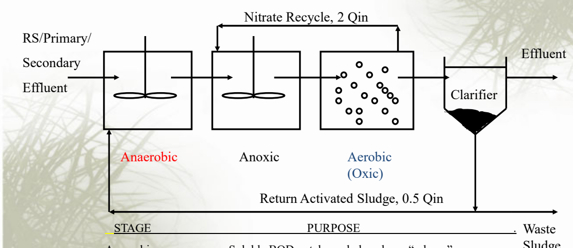
A20 Process

with Anaerobic Zone for Phosphorus Release



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

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Milestones

- 1954 Wuhrman proposes 2-stage, aerobic - anoxic process
- 1957 Davidson proposes 2-stage, anaerobic - aerobic Process
- 1962 Ludzack and Ettinger propose 2-stage, anoxic – aerobic process
- 1967 Leven patents Phostrip®, a sidestream phosphorus removal process

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Milestones

- 1968 Barth proposes 3-sludge, activated sludge process for nutrient removal
- 1970 Savage patents denitrification filter
- 1973 Barnard in South Africa develops the Modified Ludzack-Ettinger process, which becomes the standard for the wastewater industry

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Milestones

- 1975 Barnard patents Bardenpho® process
- 1976 Specter patents A/O® and A^2/O® processes
- 1977 Jervis develops fluidized bed denitrification reactor
- 1980 University of Cape Town (UCT) process developed

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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 - Seveeral 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

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Historical View of BNR

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

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BNR and ENR

BNR to ENR Evolution

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Enhanced Nutrient Removal (ENR)

- 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

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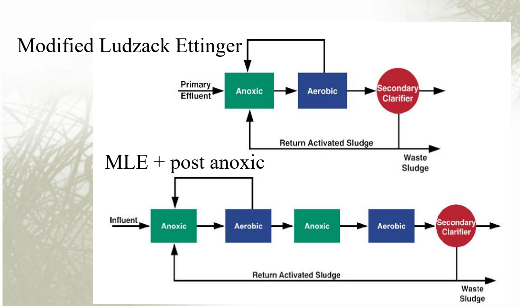
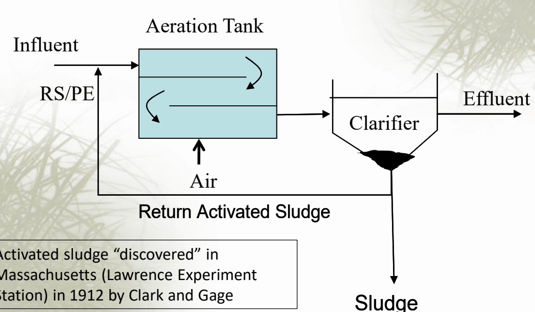
Example of BNR to ENR



250

Typical Activated Sludge Process

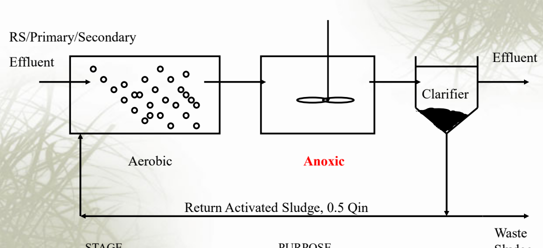


Activated sludge "discovered" in Massachusetts (Lawrence Experiment Station) in 1912 by Clark and Gage

251

Two Stage Wuhrmann BNR Process

Nitrification-Denitrification



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

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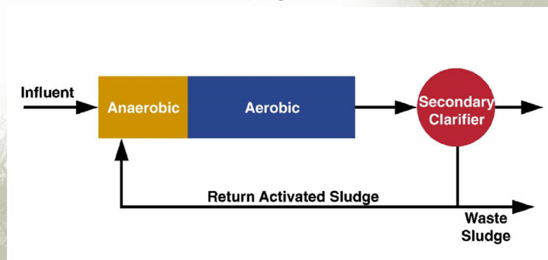
AO



For biological uptake of phosphorus

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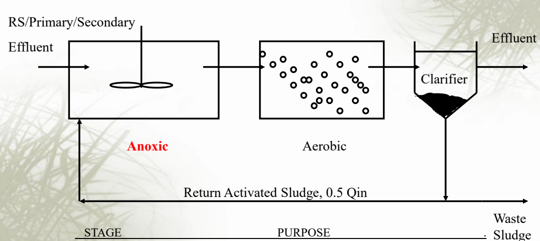
Two Stage Ludzack-Ettinger BNR Process

Denitrification-Nitrification



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

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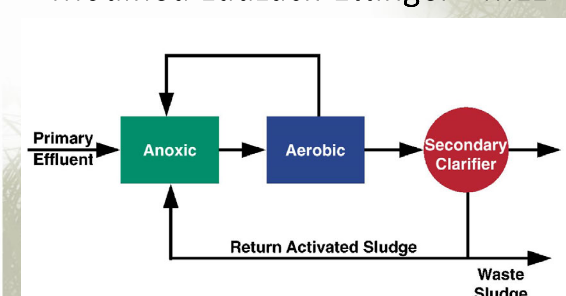
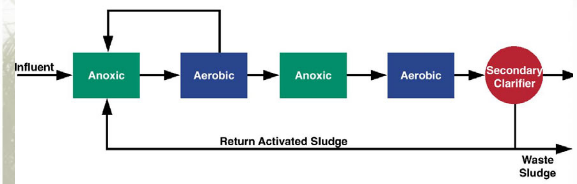
Modified Ludzack-Ettinger - MLE



255

Bardenpho
(Enhanced Modified Ludzack Ettinger)



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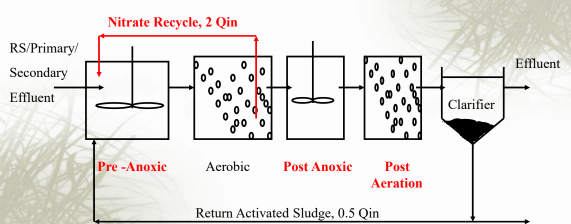
Enhanced Nutrient Removal Process
With Pre- and Post Denitrification and Aeration



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

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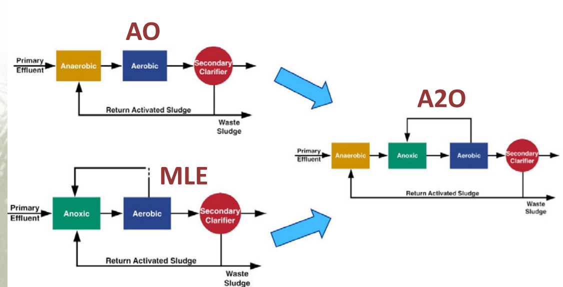
AO plus MLE = A2O



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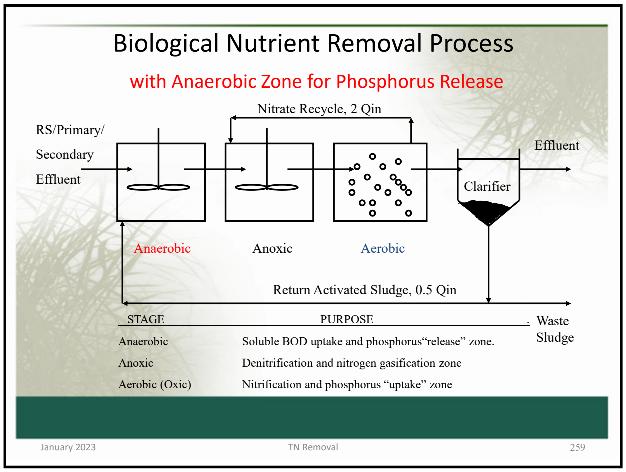
Biological Nutrient Removal Process
with Anaerobic Zone for Phosphorus Release
Nitrate Recycle, 2 Qin
RS/Primary/
Secondary
Effluent
Effluent
Clarifier
Anaerobic
Anoxic
Aerobic
Return Activated Sludge, 0.5 Qin
STAGE
PURPOSE
Waste
Sludge
Anaerobic
Soluble BOD uptake and phosphorus"release" zone.
Anoxic
Denitrification and nitrogen gasification zone
Aerobic (Oxic)
Nitrification and phosphorus "uptake" zone
January 2023
TN Removal
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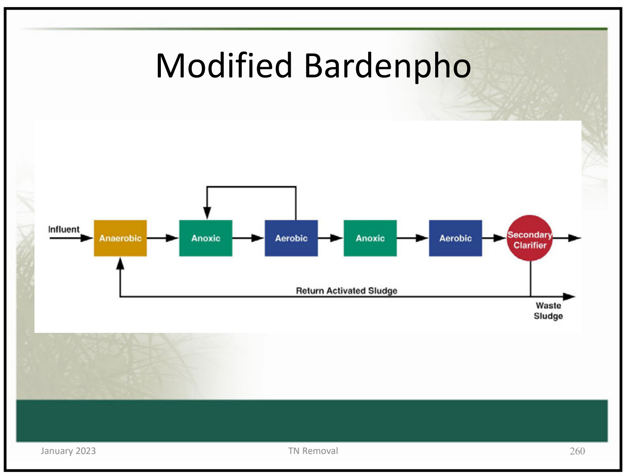
Modified Bardenpho
Influent
Anaerobic
Anoxic
Aerobic
Anoxic
Aerobic
Secondary Clarifier
Return Activated Sludge
Waste Sludge
January 2023
TN Removal
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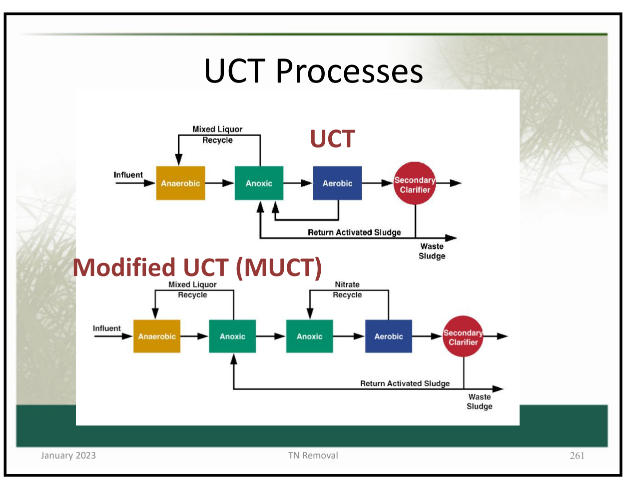
UCT Processes
Mixed Liquor Recycle
UCT
Influent
Anaerobic
Anoxic
Aerobic
Secondary Clarifier
Return Activated Sludge
Waste Sludge
Modified UCT (MUCT)
Mixed Liquor Recycle
Nitrate Recycle
Influent
Anaerobic
Anoxic
Anoxic
Aerobic
Secondary Clarifier
Return Activated Sludge
Waste Sludge
January 2023
TN Removal
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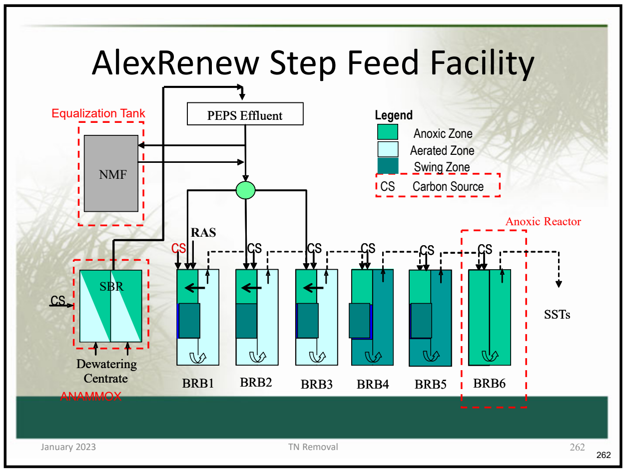
AlexRenew Step Feed Facility
Equalization Tank
NMF
PEPS Effluent
Legend
Anoxic Zone
Aerated Zone
Swing Zone
CS Carbon Source
Anoxic Reactor
RAS
CS
SBR
SSTs
Dewatering Centrate
ANAMMOX
BRB1
BRB2
BRB3
BRB4
BRB5
BRB6
January 2023
TN Removal
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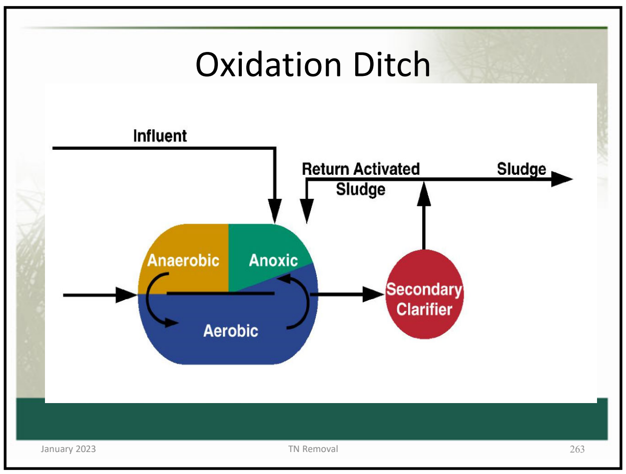
Oxidation Ditch
Influent
Return Activated Sludge
Sludge
Anaerobic
Anoxic
Aerobic
Secondary Clarifier
January 2023
TN Removal
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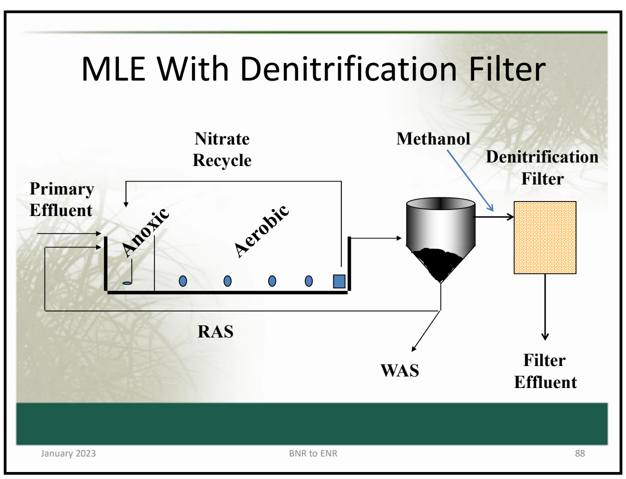
MLE With Denitrification Filter
Nitrate Recycle
Methanol
Denitrification Filter
Primary Effluent
Anoxic
Aerobic
RAS
WAS
Filter Effluent
January 2023
BNR to ENR
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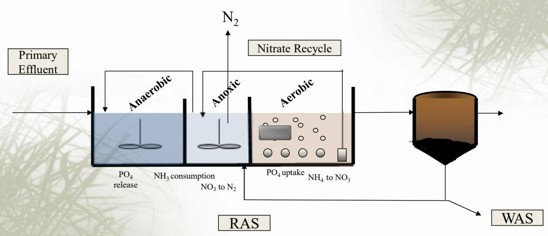
UCT BNR System



Nutrient	Influent	Anaerobic	Anoxic	Aerobic	Effluent
NH_3-N/NO_3-N	30/<1	20/<1	8/<1	<1/<8	<1/<8
PO_4-P	6	12	5	<2	<2

Sod Run WWTP, Harford County, MD 18.0 mgd

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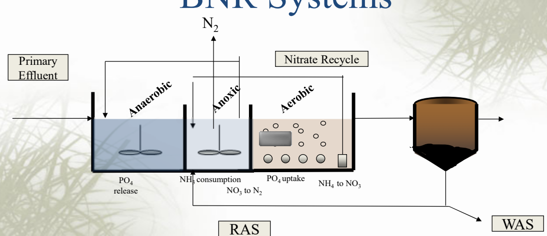
VIP and Modified UCT BNR Systems



Nutrient	Influent	Anaerobic	Anoxic	Aerobic	Effluent
NH_3-N/NO_3-N	30/<1	20/<1	8/<1	<1/<8	<1/<8
PO_4-P	6	12	5	<2	<2

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Anoxic Zone

- In both the VIP and MUCT processes, baffling or separate tanks are set up in the anoxic reactor.
  - First reactor (primary) receives underflow from settling tank
  - MLSS from first reactor is recycled to the anaerobic tank
  - Second anoxic reactor receives mixed liquor from aerobic tank

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Advantages and Disadvantages of BNR/ENR

- Advantages
  - No chemicals
  - No additional chemical sludge
  - retrofits well with any activated sludge process
  - Additional benefit of nitrogen removal
- Disadvantages
  - Except for Phostrip, phosphorus removal is a function of BOD:TP ratio
  - Not easily retrofitted to fixed film facilities
  - Standby chemical addition may be necessary as a backup

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Fixed Film Processes

Nutrient Removal

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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

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Fixed Film Processes

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

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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

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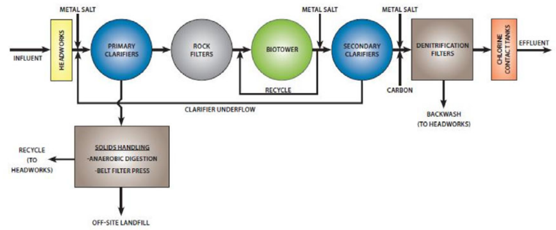
Process Configuration

ENR with Denitrification Filters



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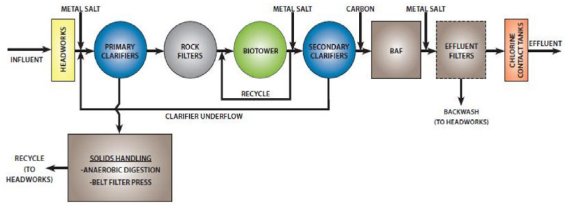
Process Configuration
ENR with Denit-BAF and Effluent Filters



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Fixed Film Nitrification

Biological Aerated Filter - BAF

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Submerged BAFs

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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

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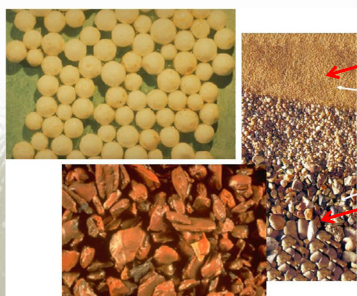
BAF Media



Fine material
- Good filtration
- Large, specific surface area

Coarse material
- Less clogging

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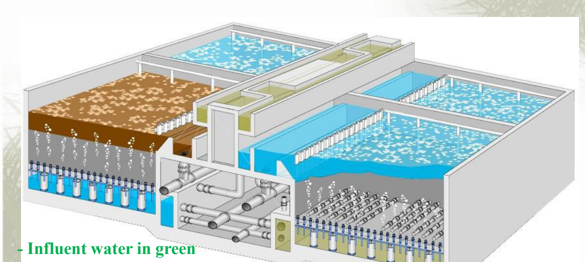
BIOFOR® Process View with One Cell in Backwash



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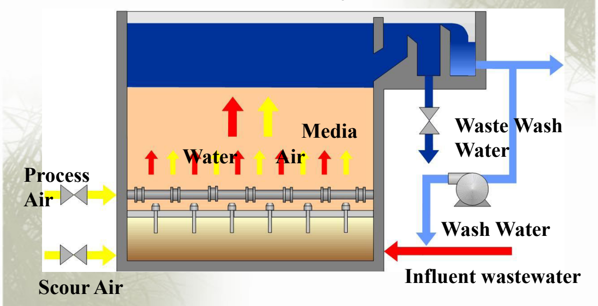
BIOFOR® Sequences



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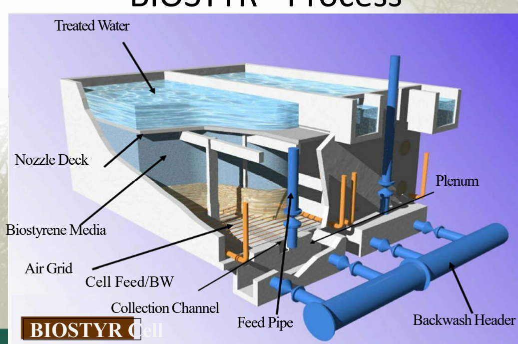
BIOSTYR® Process



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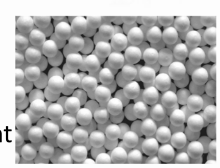
BIOSTYR® Media

- 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 biological film



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Denitrification

Denit Filters

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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)

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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 and Back River WWTPs.

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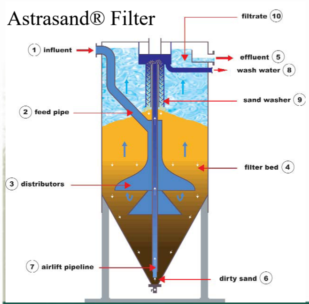
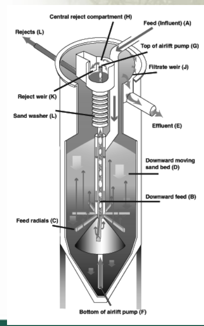
Up Flow Denit Filters





DynaSand® Filter

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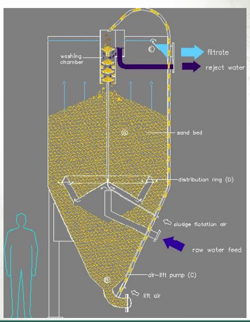
Up Flow Denit Filters



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Up Flow Denit Filters

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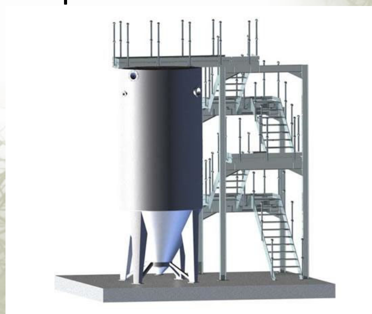
Up Flow Denit Filters



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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·ft^2); 5 scfm/ft^2	6 gal/min·ft^2 5 scfm/ft^2)	10 gal/min·ft^2); 5 scfm/ft^2)	Continuous through air lift and sand washer	Continuous through air lift and sand washer

* Source – Severn Trent

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Summary of Design Guidance for Denitrification Filters *		
Source	**Hydraulic loading rate (gal/min·ft^2)**	**Mass loading rate (lb NO3-N per ft^3/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

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Solids Handling Sidestreams

Nutrient Removal Systems

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What are Sidestreams

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

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Why consider sidestream 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

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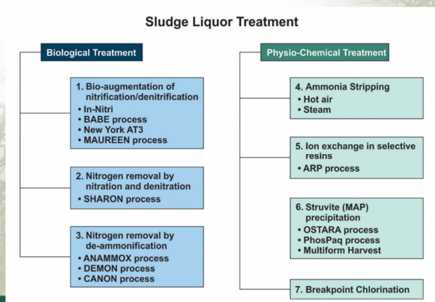
Common Sidestream Treatment Alternatives for N & P Removal



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Nitrogen Removal

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

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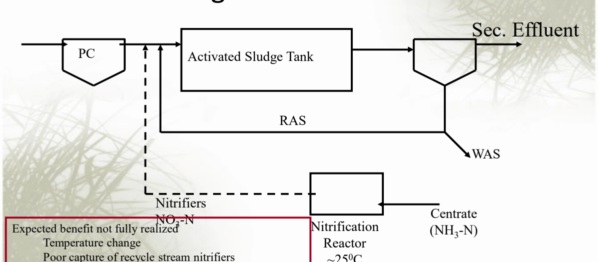
InNitri Process was the first bioaugmentation scheme



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

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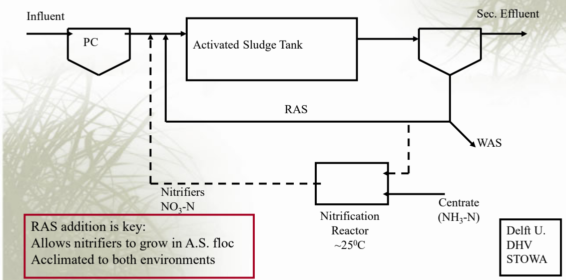
BABE Process
Bio-**A**ugmentation **B**atch **E**nhanced



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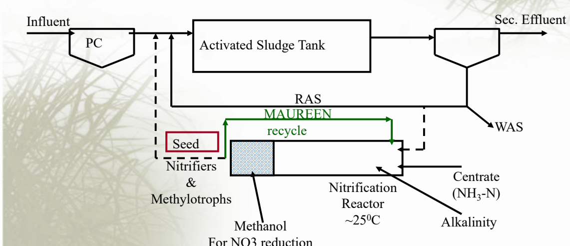
New York City AT-3 Process
MAUREEN IS A MODIFIED VERSION
(**M**ainstream **Au**totrophic **R**ecycle **E**nabling **E**nhanced **N**-removal)



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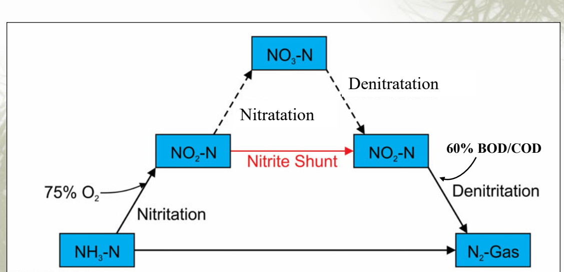
Nitritation/Denitritation
"SHARON"



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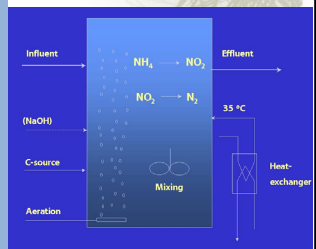
SHARON

- *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



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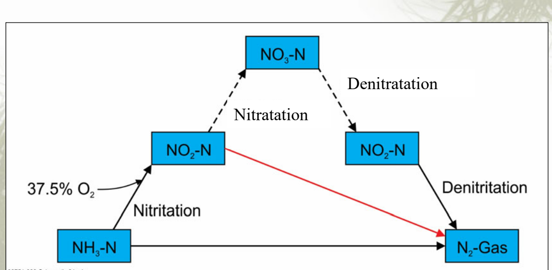
Nitritation/Deammonification

"ANANNOX"



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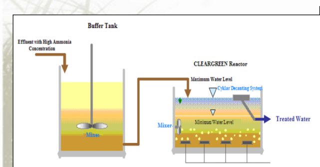
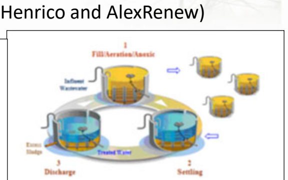
SBR-type Anammox Process: Cyclic Low Energy Ammonia Removal (CLEAR)GREEN™

- Three 8-hour Cycles per day
- Paris, France
- Currently used in Virginia (Henrico and AlexRenew)





Images Courtesy of IDI

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Summary

Helpful Hints - Final Comments

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Helpful Hints

- Consider multiple "barriers" for TP/TN removal
- Nitrification is "Key" to success of BNR/ENR processes
  - Keep DO ~ 2.0 mg/L, w/ and w/o NH_3 probes
  - Maintain proper MCRT
- Maintain < 0.2 mg/L D.O. in denitrification process to maximize denitrification rate

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Final Comments

- Many possible causes for poor nutrient removal
- Important to determine cause and act quickly
- Basic troubleshooting approaches are universal
- Each plant should develop troubleshooting protocols
- Side stream treatment can significantly reduce TP and TN loadings to mainstream process.

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Final Comments

- Recycle side stream treatment can provide more stable and effective nitrification
  - Equalization
- Recycle side stream treatment can increase nitrification capacity of existing system
  - BABE, InNITRI, AT-3, MAUREEN
- Recycle side stream treatment can help reduce carbon demand for nitrogen removal
  - **ANAMMOX**, SHARON, OLAND, CANON

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Questions?

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Thank You
Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD
January 2023
TN Removal
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