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Biological Nutrient Removal: Tools, Tips and Lessons Learned

Thursday, October 29, 2020
1:00 – 3:00 PM ET

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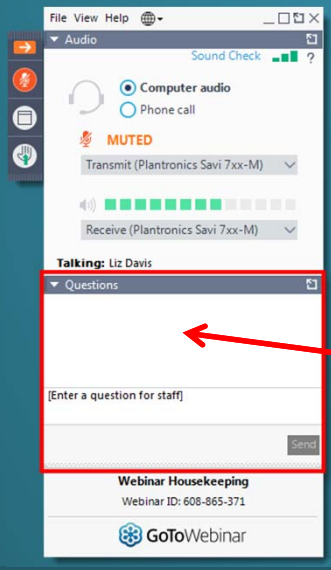
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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Today's Moderator

John B. Copp Ph.D.
Primodal Inc.
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Primodal
Earth Essential Technologies

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Nutrient Removal – Oct. 29, 2020

An MRRDC Short Course:

Biological Nutrient Removal:
Tools, Tips and Lessons Learned

- Topics:
  - Instrumentation Use for BNR
  - BNR Instrumentation – Consultant's Perspective
  - Case Studies
    - BNR Small Communities
    - BNR Operation with Instrumentation

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Nutrient Removal – Oct. 29, 2020

An MRRDC Short Course:

Biological Nutrient Removal:
Tools, Tips and Lessons Learned

Ben Barker
Xylem

Rob Smith
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Jon Vandommelen
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Biological Nutrient Removal and Instrumentation Overview

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Why is nutrient removal important?

- Excess nutrients are harmful to the environment
- They can lead to eutrophication in rivers, lakes and estuaries
  - Oxygen dead zones
  - Fish kills
  - Harmful Algal Blooms (HABs)
- Water Resource Recovery Facilities (WRRFs) are required to remove nutrients from wastewater

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How are nutrients removed?

Biological Nutrient Removal (BNR)

- Definition: The removal of nitrogen and phosphorus by the use of, proliferation and selection of certain microbial populations (“bugs”)
- Different wastewater processes create the proper environment to select and enhance the growth of the desired bacteria
  - Example: Aerobic, anoxic, and anaerobic environments
- These wastewater processes are arranged in many different configurations to achieve the desired treatment

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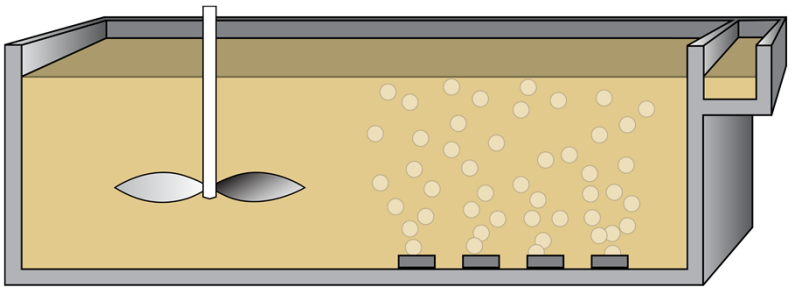
Activated Sludge Process

Aerobic

Anoxic

Anaerobic



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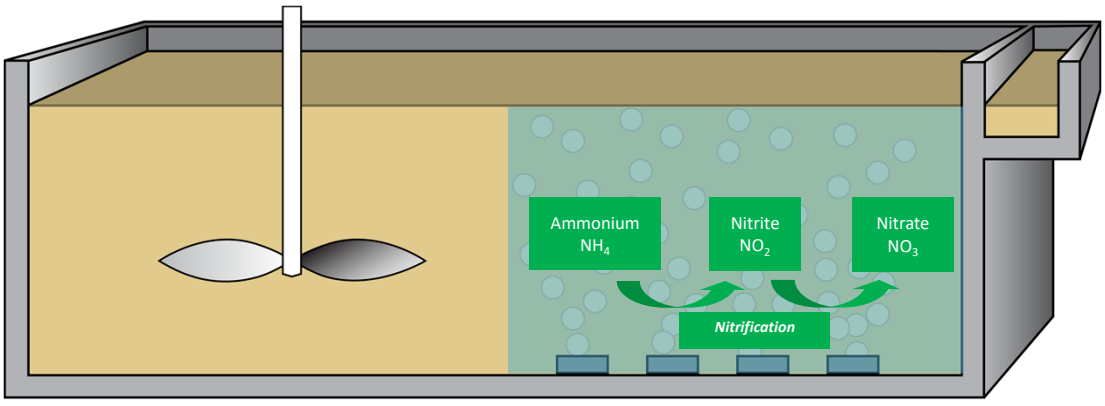
Aerobic Zone

- The aerobic zone (oxic) provides an oxygen-rich environment for which nitrifying bacteria can proliferate



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Aerobic Zone

- The aerobic zone (oxic) provides an oxygen-rich environment for which nitrifying bacteria can proliferate
  - *Nitrosomonas:* NH_4^+ *to* NO_2^-
  - *Nitrobacter:* NO_2^- *to* NO_3^-
- In most BNR configurations, aerobic zones will follow anoxic and anaerobic zones
- Aeration is provided by blowers/diffuser systems or mechanical aerators

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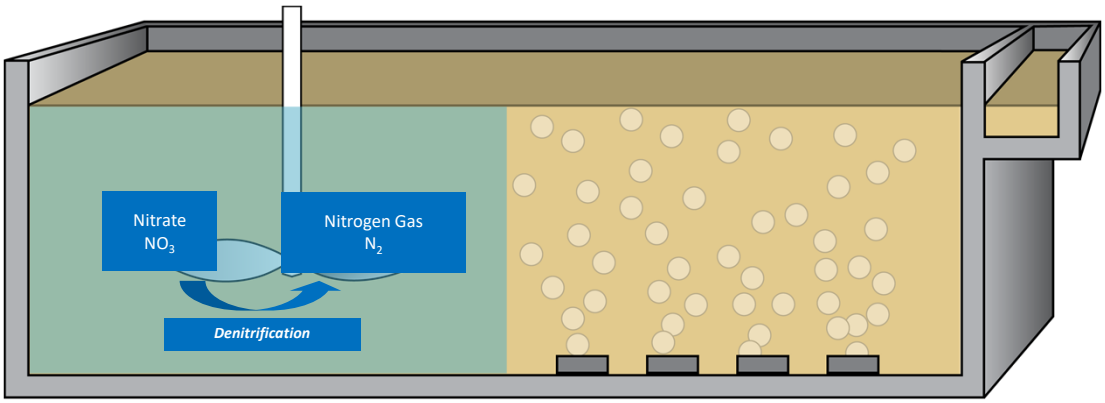
Anoxic Zone

- The anoxic zone provides a low-oxygen environment with nitrate (NO_3^-) still present as the source of oxygen



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Anoxic Zone

- The anoxic zone provides a low-oxygen environment with nitrate (NO_3^-) still present as the source of oxygen
  - *Pseudomonas: NO_3^- to N_2*
- Anoxic zones require a carbon source (BOD)
- No aeration, but mixing is still required (submersible or vertical mixers, big bubble mixer systems)

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Anaerobic Zone

- The anaerobic zone provides a very low oxygen and low-nitrate environment
- The primarily used in BNR systems for biological phosphorus removal
- Two step process in which phosphorus accumulating organisms (PAOs) go through an anaerobic zone, followed by an aerobic zone

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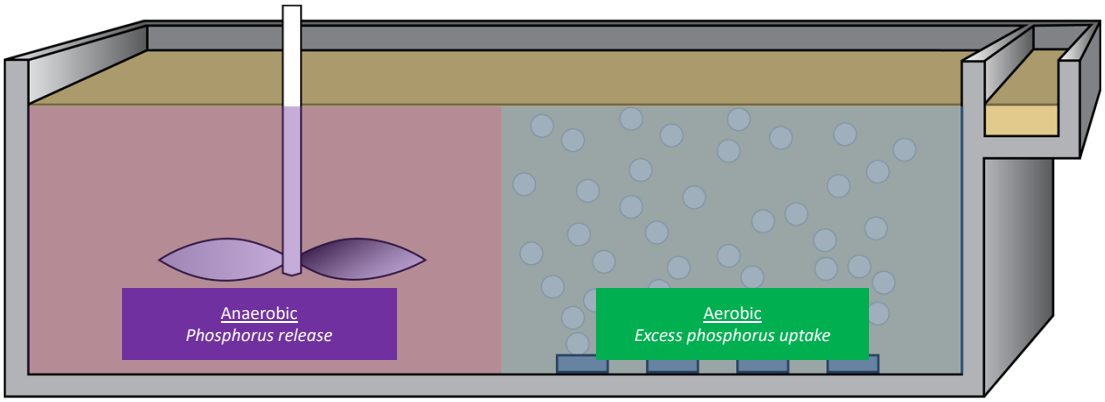
Anaerobic Zone

- The anaerobic zone provides a very low oxygen and low-nitrate environment



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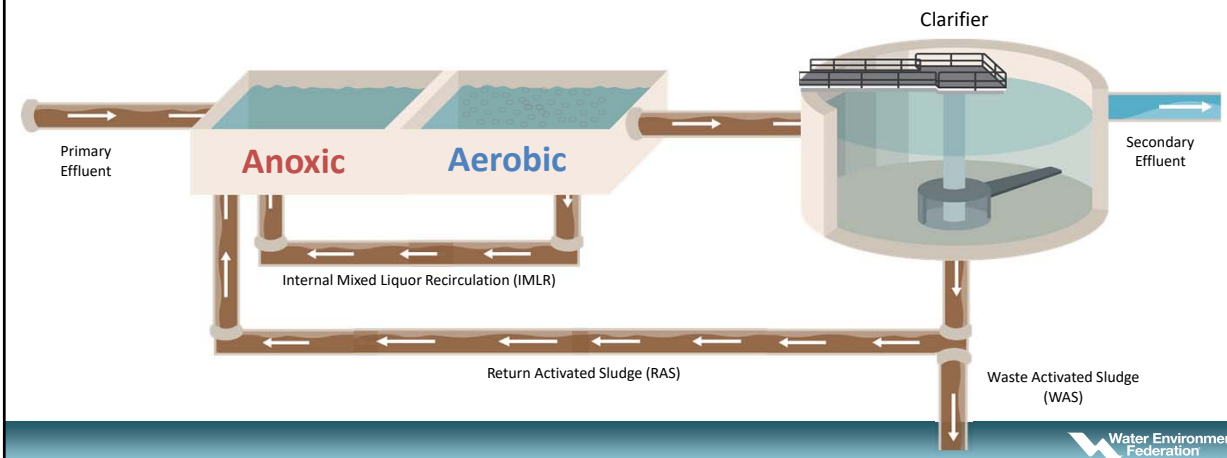
Elements of an Activated Sludge System



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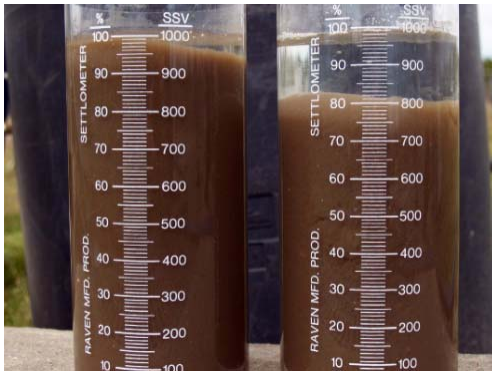
Requirements for Activated Sludge

- **Microorganisms ("bugs")**
  - Community of different microbes and bacteria
- **Food**
  - Organic matter (BOD) or any carbon source
- **Oxygen (or no oxygen)**
  - Oxygen is required nitrification
  - Low oxygen environment is required for denitrification
- **Proper mixing**
  - Sufficient mixing maintains a suspended floc and uniform environment
  - Dependent on process, some require varying levels of mixing
- **Solids Management**
  - Control for how many microorganisms are present
  - Return Activated Sludge and Waste Activated Sludge



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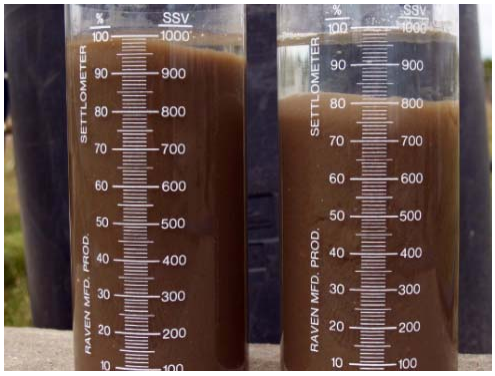
Process Parameters

- **MLVSS**
  - Mixed Liquor Volatile Suspended Solids
  - How many bugs do we have in the system?
- **F:M Ratio**
  - Food to microorganisms ratio
  - Food = BOD: Microorganism = MLVSS
  - Do we have the right amount of bugs in the system for our incoming food?
- **SRT**
  - Solids Retention Time (days)
  - Are we allowing the appropriate amount of time for the bugs to reproduce to maintain their population?
- **Sludge Settleability (SVI)**
  - Is our sludge in good condition? How well does it settle?



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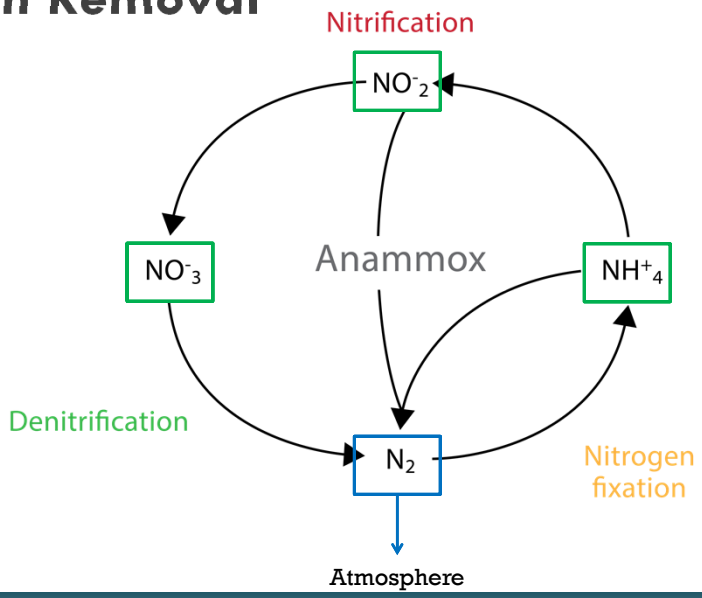
Nitrogen Removal



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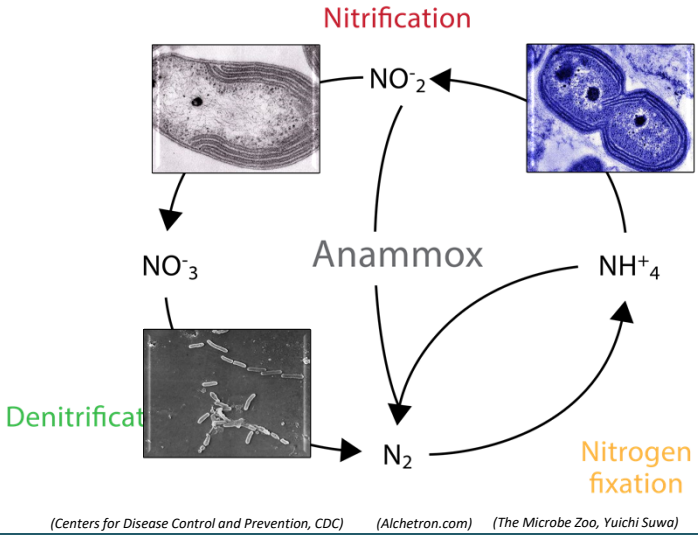
Nitrogen Removal



(Centers for Disease Control and Prevention, CDC) *(Alchetron.com)* *(The Microbe Zoo, Yuichi Suwa)*

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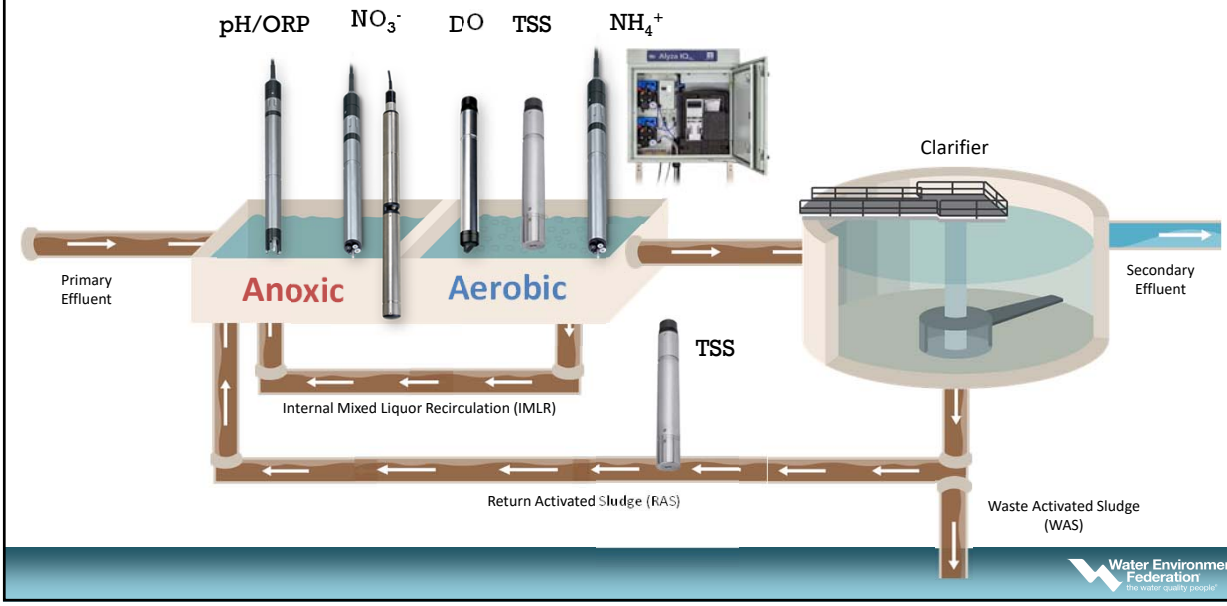
Instrumentation for Nitrogen Removal



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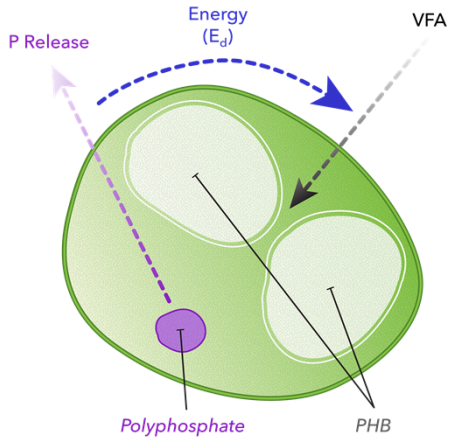
Enhanced Biological Phosphorus Removal

EBPR = Enhanced biological uptake of phosphorus by selected microorganisms called phosphorus accumulating organisms (PAOs)



Anaerobic Phase

- No dissolved oxygen or nitrate
- Polyphosphate store released for Energy
- Energy used to take up Volatile Fatty Acids (VFAs) from water
- Stored as Poly-Hydroxybutyrate (PHB)

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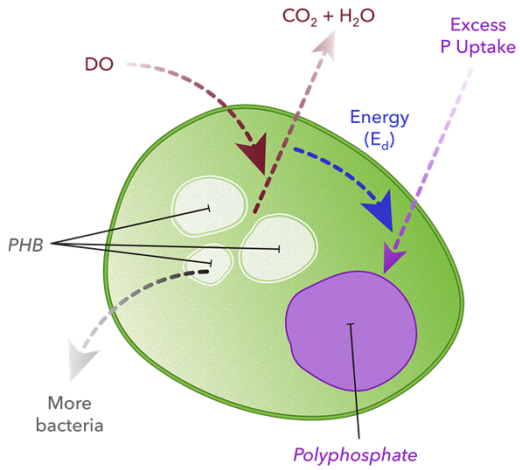
Enhanced Biological Phosphorus Removal



Aerobic Phase

- Dissolved oxygen present
- DO and PHB metabolized for Energy
- Energy used for reproduction
- Energy used for Luxury Phosphorus Uptake

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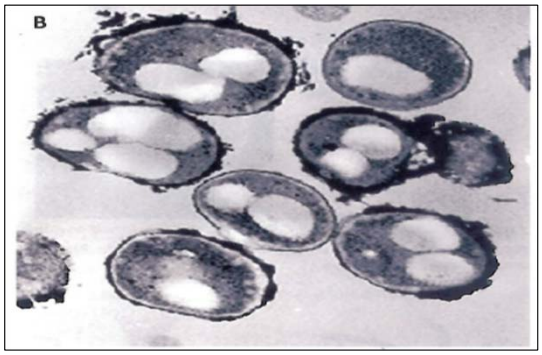
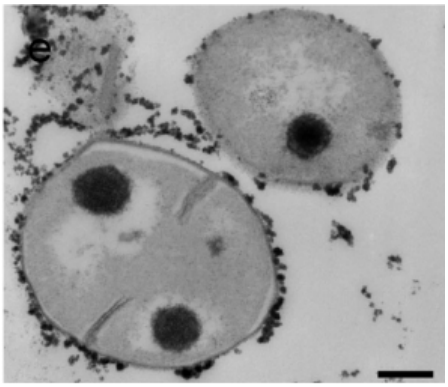
Enhanced Biological Phosphorus Removal

Anaerobic Zone
~~DO, NO_3~~

→

Aerobic
(DO)





(Günther et al, 2009)

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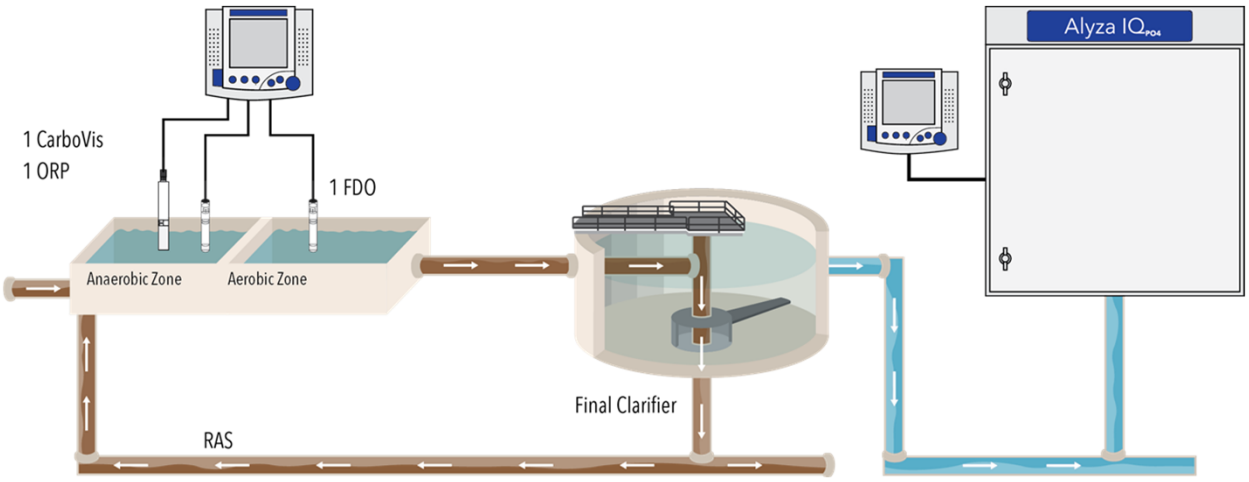
Instrumentation for Phosphorus Removal



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Instrumentation for Phosphorus Removal

- **Dissolved Oxygen (DO)**
  - Monitoring anaerobic and aerobic zone
- **Oxidation-Reduction Potential (ORP)**
  - Real-time control of EBPR process
- **COD /BOD**
  - Vital for maintaining the correct COD:P ratio in EBPR basins
- **Volatile Fatty Acids (VFAs)**
  - Required for effective EBPR process, VFAs can be added to process if needed

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BNR Process Configurations

- Wuhrman
- Ludzack-Ettinger
- Modified Ludzack-Ettinger
- Step-Feed A/O
- Simultaneous Nit/Denit
- Four-Stage Bardenpho
- Five-Stage Bardenpho
- A_2/O (Anaerobic, Anoxic, Oxic)
- A/O (Anaerobic, Oxic)
- Deammonification

And many more!

(EPA, 2013)

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Take-Home Points

- **Excess nitrogen and phosphorus causes eutrophication** in estuaries and coastal ecosystems, having an adverse effect on the ecosystem. Removing nitrogen from wastewater can help mitigate these effects.
- Biological Nutrient Removal (BNR) is an activated sludge process that requires careful control of the environment to **encourage nitrification, denitrification and P-uptake**, resulting in the removal of nutrient removal.
- Selecting the correct BNR configuration for your facility and **careful monitoring and control with online instrumentation** will lead to efficient and effective nutrient removal.

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BNR Monitoring System Design

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Topics

- Considerations for Specifying a BNR Process Monitoring System
- Phosphorus Removal
- Nitrogen Removal

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Keep Your Specs Up to Date

- Sensor type (measurement principle)
- Outputs and communications
- Environment
- Local interface
- Sample conditioning / delivery

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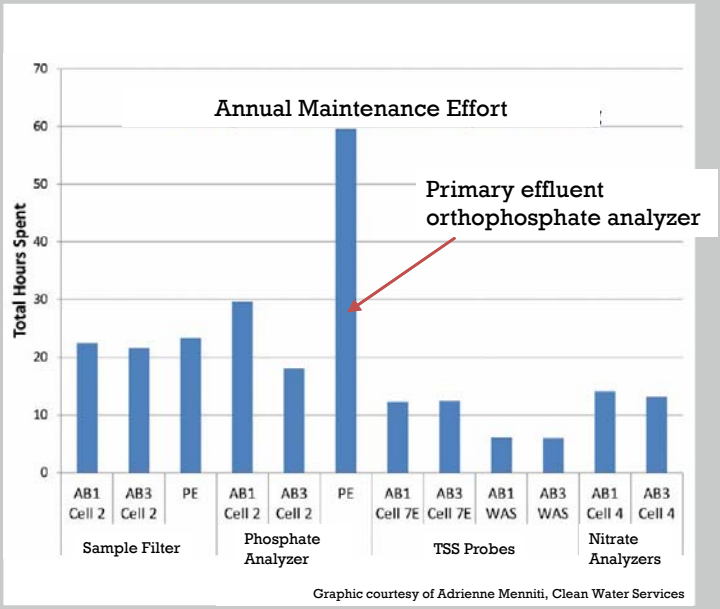

Graphic courtesy of Adrienne Menniti, Clean Water Services

Consider O&M

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Phosphorus Removal

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Ortho-Phosphate

- Technologies: Wet chemistry analyzer
- Usually requires a filter
- Total Phosphorus (TP) not usually necessary for control

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Oxidation Reduction Potential (ORP)

- Technologies: 2 electrodes vs. 3 electrodes

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Total Suspended Solids

- Optical
  - Versatility
  - Cost
- Microwave
  - Large measuring range

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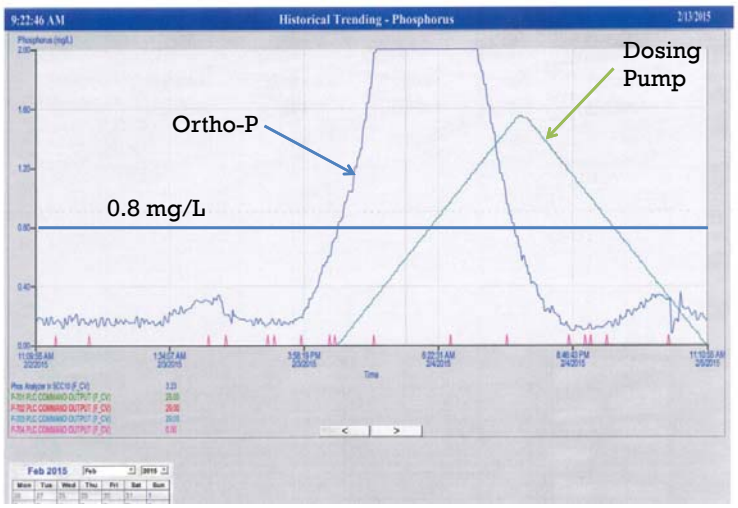
Chemical P Removal



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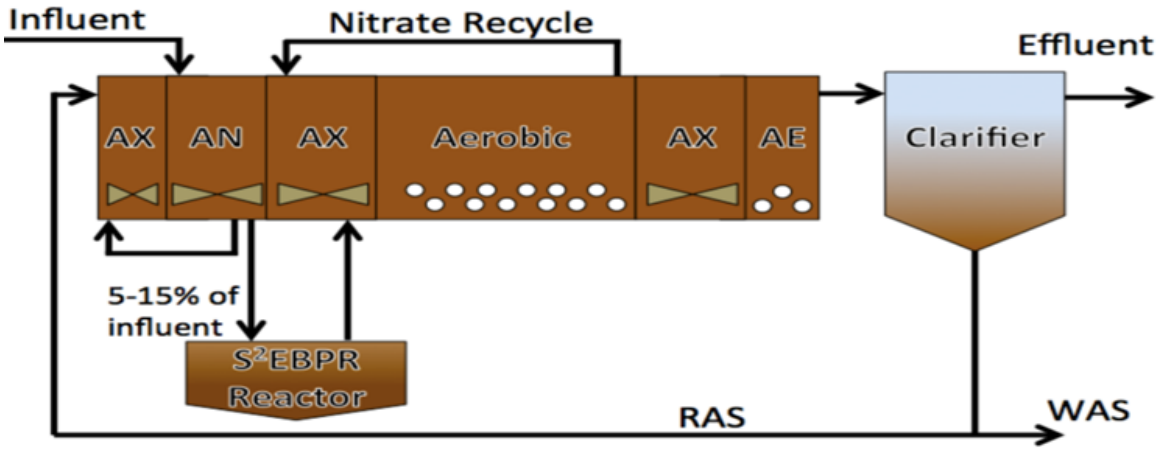
Biological P Removal Side-Stream EBPR

- Generate VFA for PAOs to uptake
- Facilitated by deep ORP (< -300 mV)
- Intermittent mixing for SRT control



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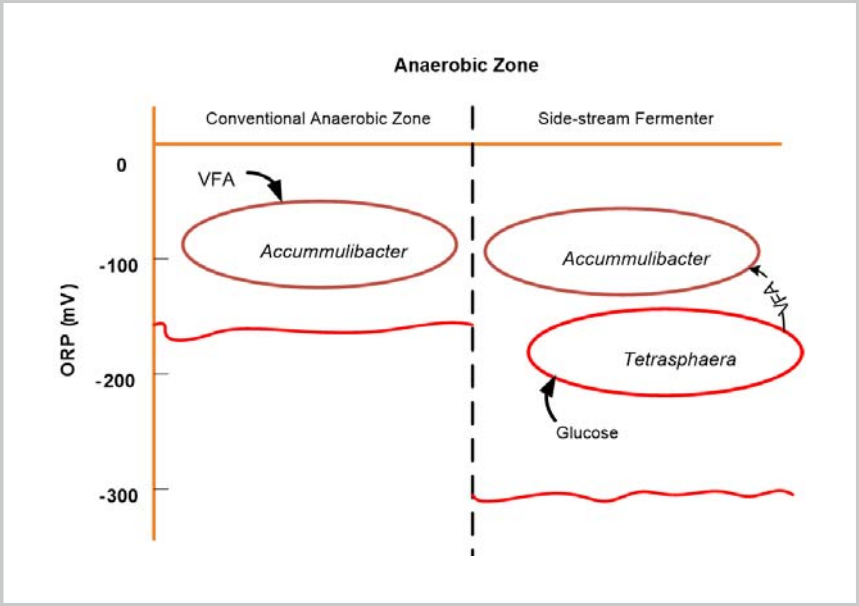
The Biology of Low ORP



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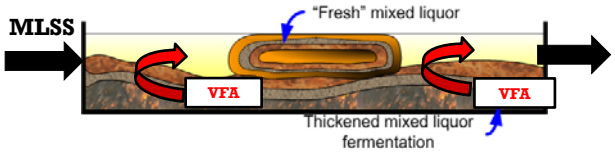
Fermenter Process Control - Mixer off to Generate VFA



Mixer "Off"

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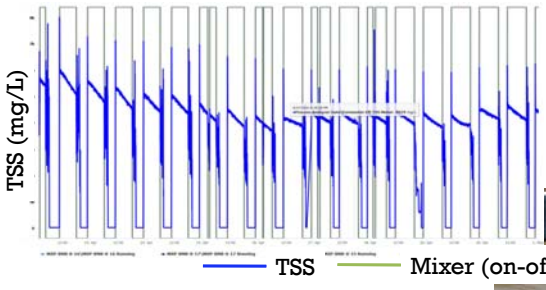
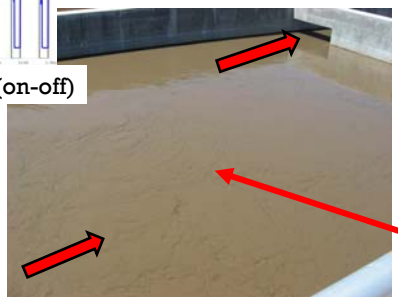
Fermenter Process Control – Mixer On to Waste





Minimal surface turbulence = deeper anaerobic conditions

Mixer "On"

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Nitrogen Removal

Dissolved Oxygen

- Electrochemical
  - Faster response
  - Larger range
- Optical
  - Simple operation

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Ammonia-Nitrogen

- ISE (probe)
  - Large measuring range
  - Fast response time
- Wet chemistry analyzer (cabinet)
  - Low concentration measurement*

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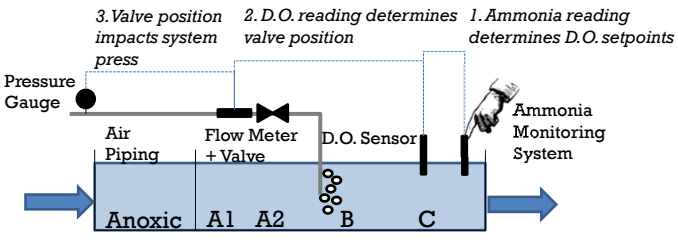
Nitrate-Nitrogen

- ISE (probe)
- Wet chemistry analyzer
- Optical (probe)
  - Simple operation

Ammonia Based Aeration Control (ABAC)

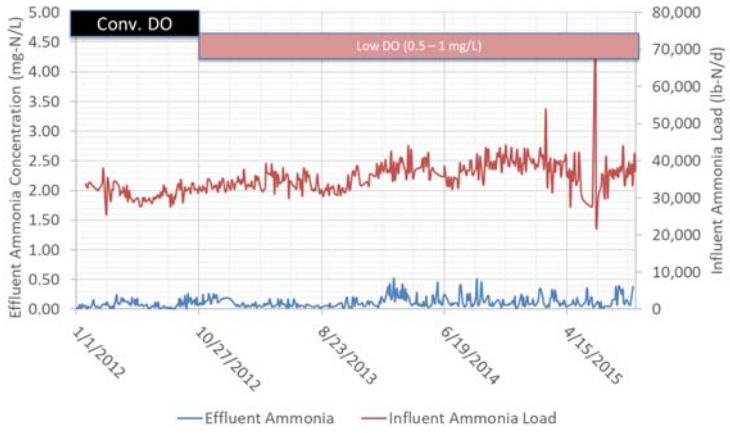


Example Setpoints

Zone	Low DO, mg/L	High DO, mg/L
A1	0.3	0.3
A2	0.5	0.5
B	0.9	1.5
C	1.2	1.7
Target NH_4		1.0

Low DO Operation

- Lower energy consumption
- Nutrient removal



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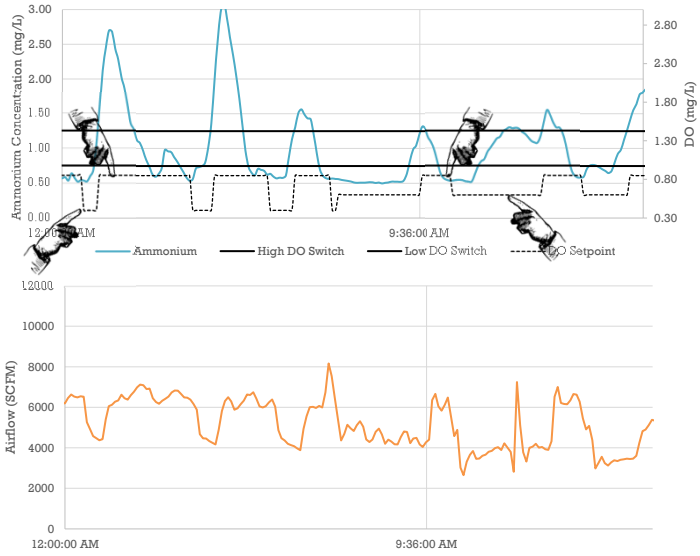
How Low is Too Low?



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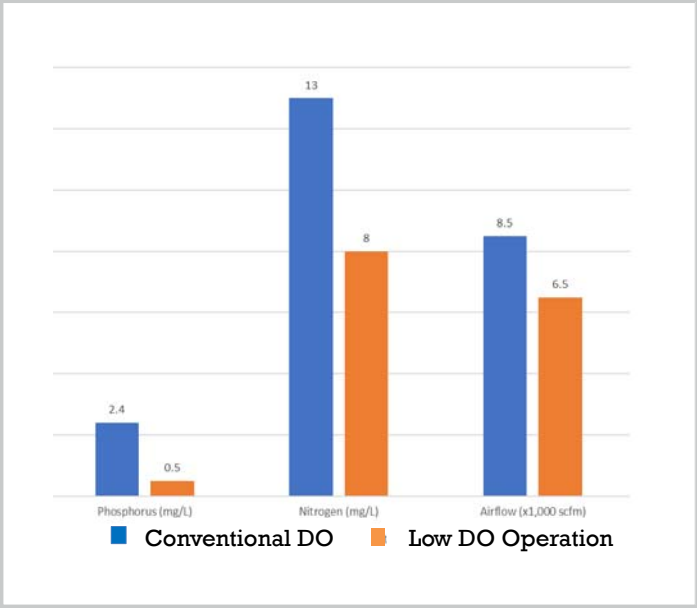

Nutrient Removal

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Ohio EPA Compliance Assistance Unit

Jon
van Dommelen

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Troubleshooting BNR Systems in Small Communities

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Troubleshooting BNR Systems in Small Communities

Causes of Noncompliance in Small BNR Systems:

1) **Small system operators are not trained very well to run BNR systems**

2) **Small systems typically do not have their own labs to run process control tests**

3) **Small systems are designed using textbook characteristics for influent waste streams**

4) **Small systems often suffer from inadequate soluble carbon that drives denitrification and orthophosphate release reactions**

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Troubleshooting BNR Systems in Small Communities

Today, we will look at a small community

- **That abandoned one wastewater treatment plant**
- **Constructed a new BNR wastewater treatment plant**
- **Suffered from nearly random compliance for 4 years**
- **Then reached out to the Compliance Assistance Unit to visit their BNR system.**

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Troubleshooting BNR Systems in Small Communities

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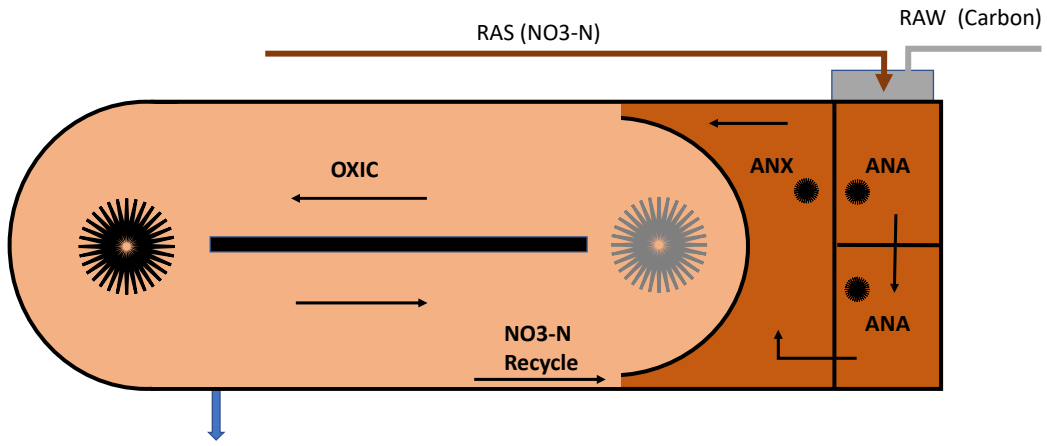
Troubleshooting BNR Systems in Small Communities

BNR (Carrousel type)



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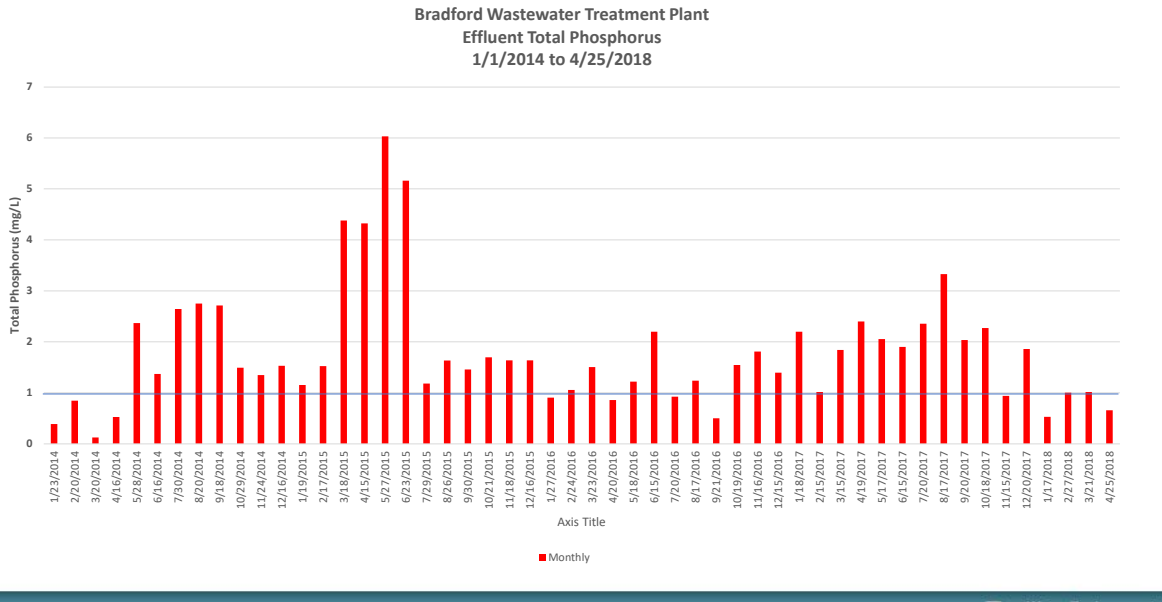
Bradford Wastewater Treatment Plant
Effluent Total Phosphorus
1/1/2014 to 4/25/2018
Total Phosphorus (mg/L)
0
1
2
3
4
5
6
7
1/23/2014
2/20/2014
3/20/2014
4/16/2014
5/28/2014
6/16/2014
7/30/2014
8/20/2014
9/18/2014
10/29/2014
11/24/2014
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6/15/2017
7/20/2017
8/17/2017
9/20/2017
10/18/2017
11/15/2017
12/20/2017
1/17/2018
2/27/2018
3/21/2018
4/25/2018
Axis Title
Monthly

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Troubleshooting BNR Systems in Small Communities

Date Range	Monthly Average Reported	Compliant	% Compliant	Noncompliant	% Noncompliant
Jan 2014 to Mar 2018	51	11	21.6	40	78.4

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Troubleshooting BNR Systems in Small Communities

Location	COD	NH3-N	N03-N	P04-P
Standard (300 mg/L)	299			
Influent	190	19.0		1.27
Anaerobic Tank	119	4.5	11.9	1.01
Anoxic Tank	113	0.1	14.6	0.99
Oxic Tank		0.02	14.7	0.99
Final Effluent	99	0.09	13.9	0.79
RAS			14.2	
Note all samples are grab samples (Samples run on 3/15)				

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Nitrate Profile (mg/L)

	RAS	Anaerobic	Anoxic
3/15/2018	14.3	11.9	14.6
→ 3/19/2018	8.7	12.5	11.9
3/20/2018	11.6	7.9	11.8
3/21/2018	11.5	7.5	12.0
3/22/2018	8.6	8.2	11.1

Too much Nitrate everywhere

Solution: Manage the Nitrates

Troubleshooting BNR Systems in Small Communities

Solution: Manage the Nitrates

1) **Closed the nitrate recycle gate completely**
2) **Run vertical rotor at 38 Hertz**
3) **Turned 2nd Anaerobic Zone Mixer OFF for 3.5 hours, ON for 30 minutes**
4) **Turned Anoxic Zone Mixer OFF for 3.5 hours, ON for 30 minutes**
5) **Profile Ammonia, Nitrate, and Orthophosphate in each zone**

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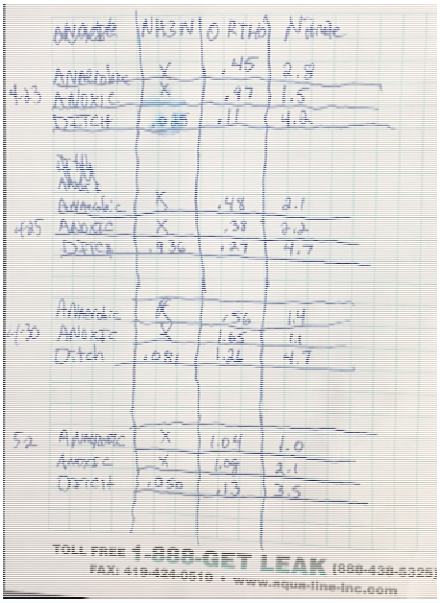
Troubleshooting BNR Systems in Small Communities



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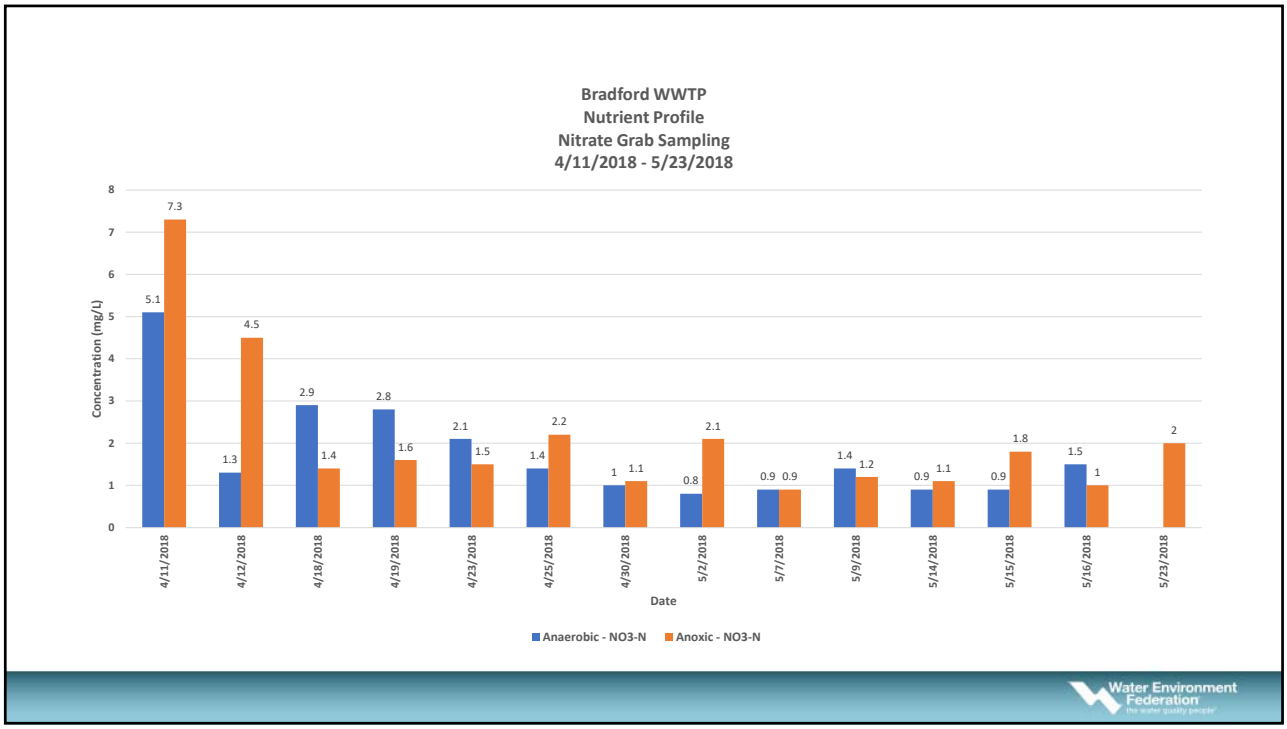
Bradford WWTP
Nutrient Profile
Nitrate Grab Sampling
4/11/2018 - 5/23/2018
Concentration (mg/L)
Date
Anaerobic - NO3-N
Anoxic - NO3-N
4/11/2018
4/12/2018
4/18/2018
4/19/2018
4/23/2018
4/25/2018
4/30/2018
5/2/2018
5/7/2018
5/9/2018
5/14/2018
5/15/2018
5/16/2018
5/23/2018
5.1
7.3
1.3
4.5
2.9
1.4
2.8
1.6
2.1
1.5
1.4
2.2
1
1.1
0.8
2.1
0.9
0.9
1.4
1.2
0.9
1.1
0.9
1.8
1.5
1
2
Water Environment Federation

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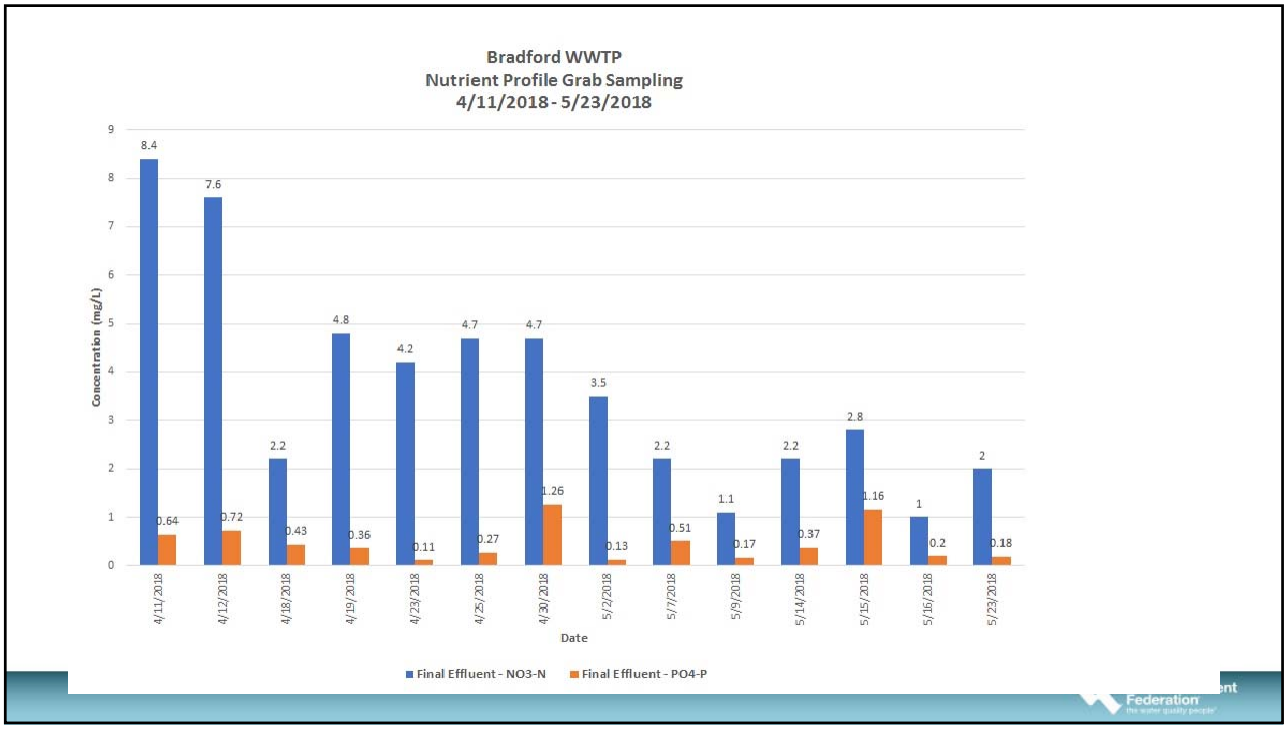
Bradford WWTP
Nutrient Profile Grab Sampling
4/11/2018 - 5/23/2018
Concentration (mg/L)
Date
Final Effluent - NO3-N
Final Effluent - PO4-P
4/11/2018
4/12/2018
4/18/2018
4/19/2018
4/23/2018
4/25/2018
4/30/2018
5/2/2018
5/7/2018
5/9/2018
5/14/2018
5/15/2018
5/16/2018
5/23/2018
8.4
0.64
7.6
0.72
2.2
0.43
4.8
0.36
4.2
0.11
4.7
0.27
4.7
1.26
3.5
0.13
2.2
0.51
1.1
0.17
2.2
0.37
2.8
1.16
1
0.2
2
0.18
Federation

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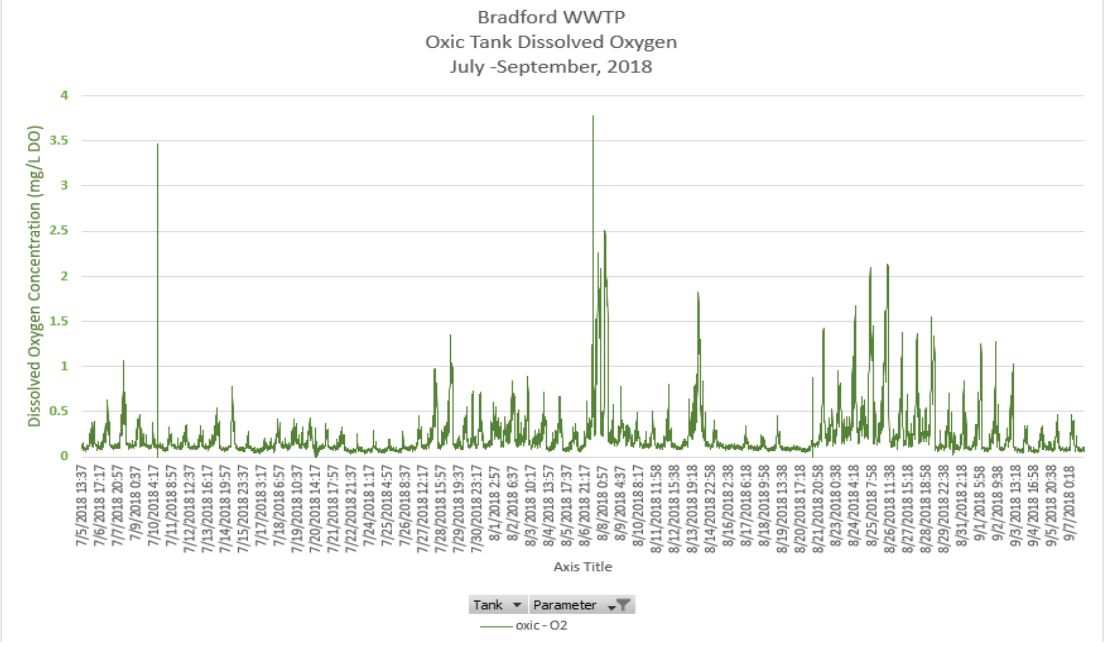
Bradford WWTP
Oxic Tank Dissolved Oxygen
July -September, 2018
Dissolved Oxygen Concentration (mg/L DO)
4
3.5
3
2.5
2
1.5
1
0.5
0
7/5/2018 13:37
7/6/2018 17:17
7/7/2018 20:57
7/9/2018 0:37
7/10/2018 4:17
7/11/2018 8:57
7/12/2018 12:37
7/13/2018 16:17
7/14/2018 19:57
7/15/2018 23:37
7/17/2018 3:17
7/18/2018 6:57
7/19/2018 10:37
7/20/2018 14:17
7/21/2018 17:57
7/22/2018 21:37
7/24/2018 1:17
7/25/2018 4:57
7/26/2018 8:37
7/27/2018 12:17
7/28/2018 15:57
7/29/2018 19:37
7/30/2018 23:17
8/1/2018 2:57
8/2/2018 6:37
8/3/2018 10:17
8/4/2018 13:57
8/5/2018 17:37
8/6/2018 21:17
8/8/2018 0:57
8/9/2018 4:37
8/10/2018 8:17
8/11/2018 11:58
8/12/2018 15:38
8/13/2018 19:18
8/14/2018 22:58
8/16/2018 2:38
8/17/2018 6:18
8/18/2018 9:58
8/19/2018 13:38
8/20/2018 17:18
8/21/2018 20:58
8/23/2018 0:38
8/24/2018 4:18
8/25/2018 7:58
8/26/2018 11:38
8/27/2018 15:18
8/28/2018 18:58
8/29/2018 22:38
8/31/2018 2:18
9/1/2018 5:58
9/2/2018 9:38
9/3/2018 13:18
9/4/2018 16:58
9/5/2018 20:38
9/7/2018 0:18
Axis Title
Tank
Parameter
oxic - O2

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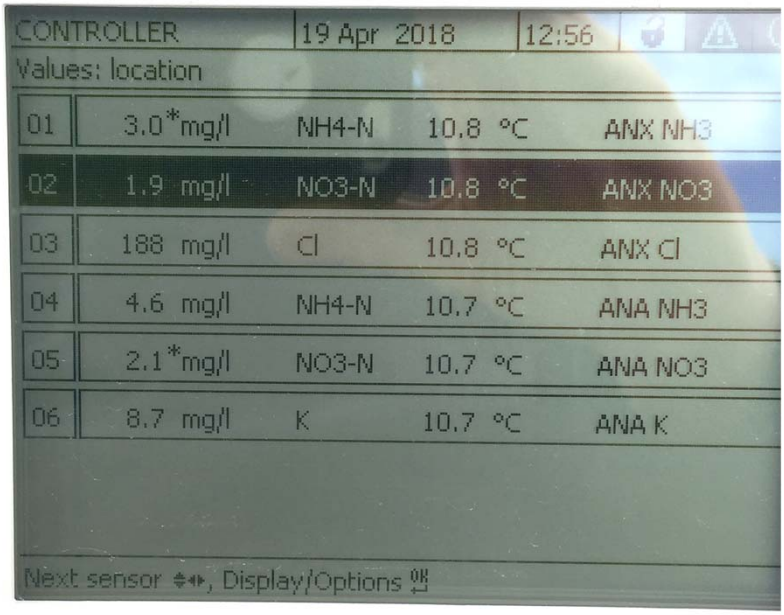
CONTROLLER
19 Apr 2018
12:56
Values: location
01 3.0*mg/l NH4-N 10.8 °C ANX NH3
02 1.9 mg/l NO3-N 10.8 °C ANX NO3
03 188 mg/l Cl 10.8 °C ANX Cl
04 4.6 mg/l NH4-N 10.7 °C ANA NH3
05 2.1*mg/l NO3-N 10.7 °C ANA NO3
06 8.7 mg/l K 10.7 °C ANA K
Next sensor, Display/Options

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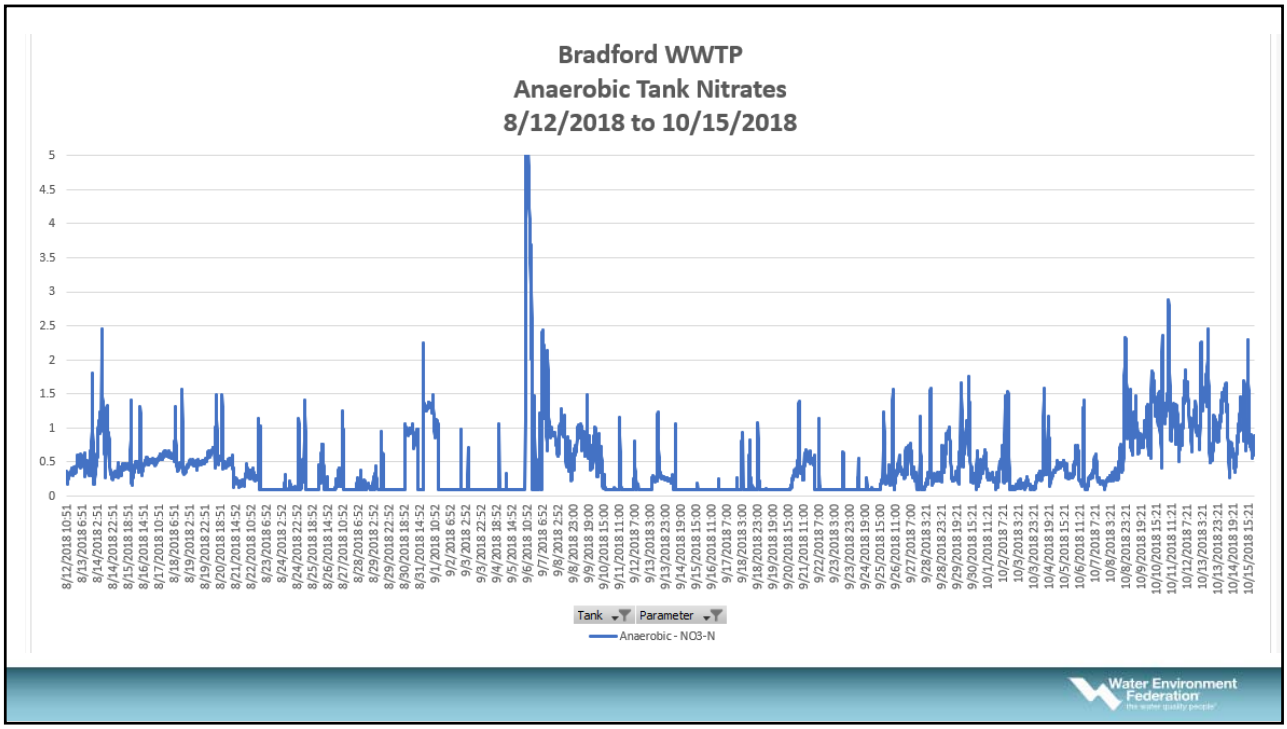
Bradford WWTP
Anaerobic Tank Nitrates
8/12/2018 to 10/15/2018
Tank
Parameter
Anaerobic - NO3-N
Water Environment Federation

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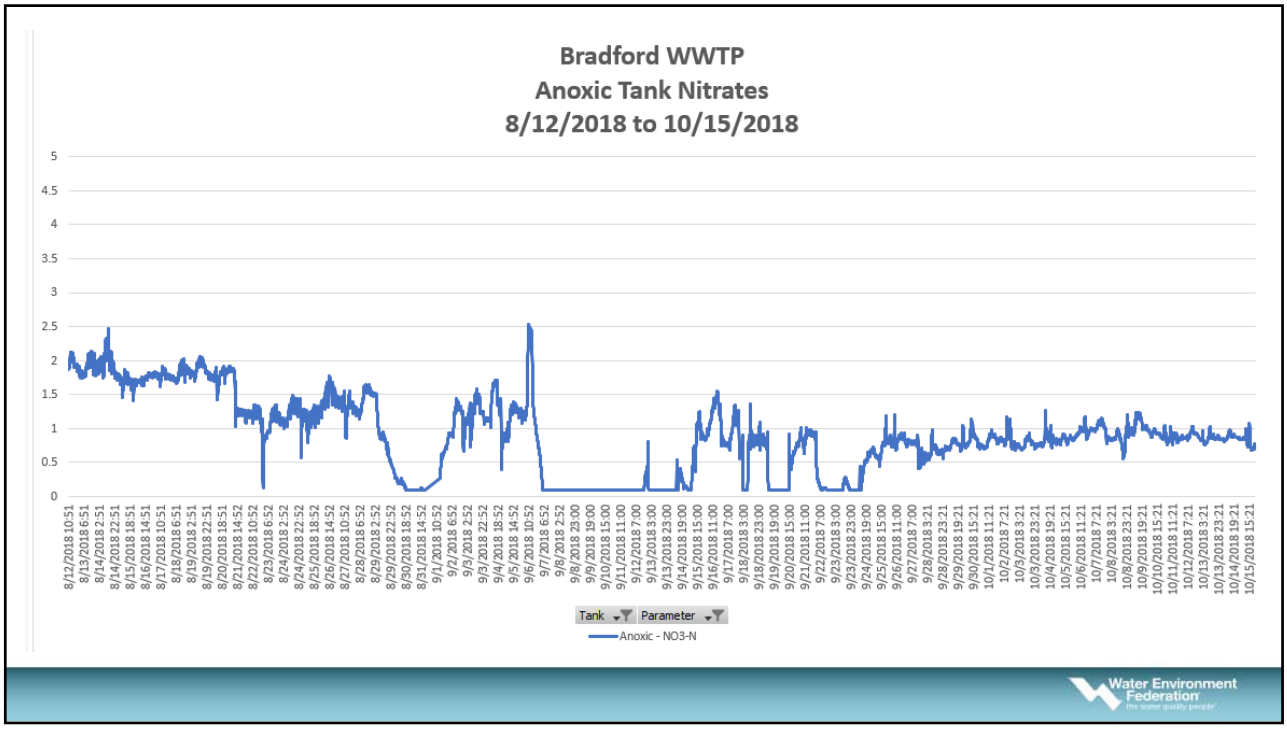
Bradford WWTP
Anoxic Tank Nitrates
8/12/2018 to 10/15/2018
Tank
Parameter
Anoxic - NO3-N
Water Environment Federation

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Troubleshooting BNR Systems in Small Communities

First April sample was high (1.25 mg/L), but the rest of the samples brought the monthly down to 0.66 mg/L

Alum feed was shut down 5/2

May 2018 another consecutive month of compliance for TP

In addition, the village was spending $800 - $1200/month for alum previously.

Electricity demand should also be reduced due to mixer turndown

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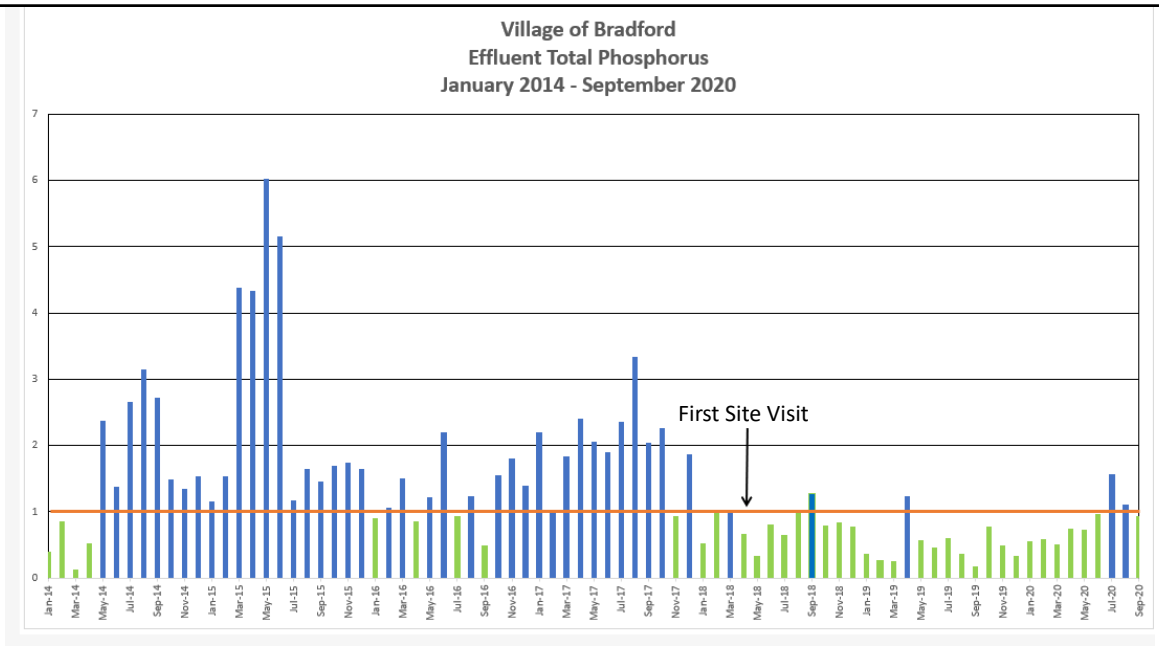
Digester Nutrient Profile

Ammonia Nitrogen	Dilution	Nitrate Nitrogen	Dilution	Orthophosphate	Dilution
Nondetect	**(1:4)**	**504 mg/L**	**(1:20)**	**220 mg/L**	**(1:200)**

81



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Troubleshooting BNR Systems in Small Communities

Date Range	Samples	Compliant	% Compliant	Noncompliant	% Noncompliant
Jan 2014 to Mar 2018	51	11	21.5	40	78.4
Apr 2018 to Sep 2020	30	26	86.7	4	13.3
Overall	81	37	45.7	44	54.3

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Troubleshooting BNR Systems in Small Communities

Keys to BNR:

Process Control!

1) Monitor the nutrients in the Inputs to each zone
2) Monitor the nutrients in Internal Recycles (Digester Supernatant)
3) If the Chemistry is correct in the zones, the bacterial response will be compliant.
4) **Know the chemical environment in each zone of the WWTP.**

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Shaun Thompson

Colorado Springs Utilities
Environmental Specialist
Resource Recovery Facilities

86

Using Technology for Operations in Wastewater Treatment

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Wastewater Treatment- Post Collection System

LVSWRRF

CSRRRF

JDPWRRF

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JDP Resource Recovery Facility

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Real-Time Monitoring (JDPWRRF)

- Parameters
  - Ammonia
  - ORP
  - DO
  - Nitrate
  - Nitrite
  - COD
  - BOD
  - TSS
  - Phosphorus
  - pH
  - NTU
  - UVT

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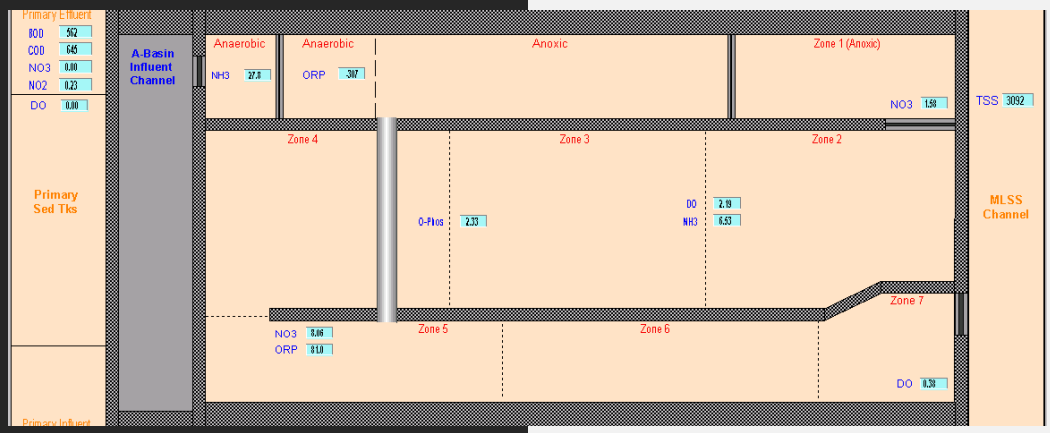
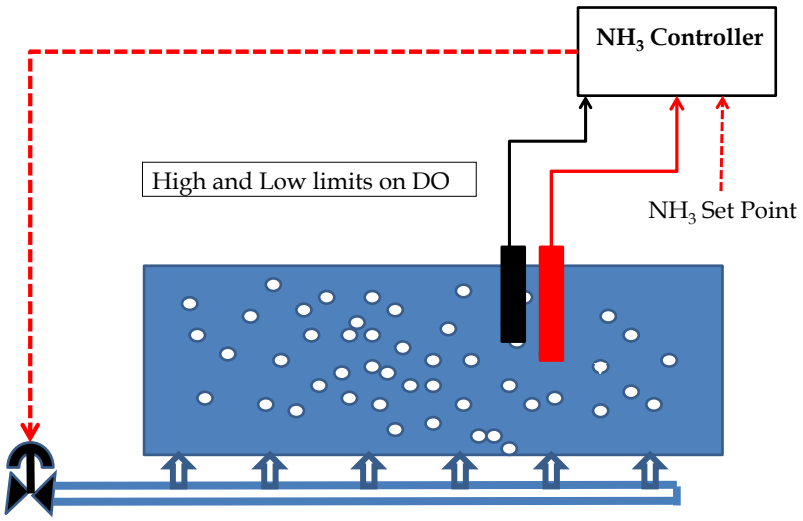
Not Your Typical A2O



91

PID Control for NH3



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Ammonia Control

- Advantages
  1. Energy cost savings with reduced blower operation
  2. Lower TSS due to flock shear reduction
  3. Direct control instead of theoretical control
  4. Reduced effects of plant upsets with automatic immediate response from ammonia control system

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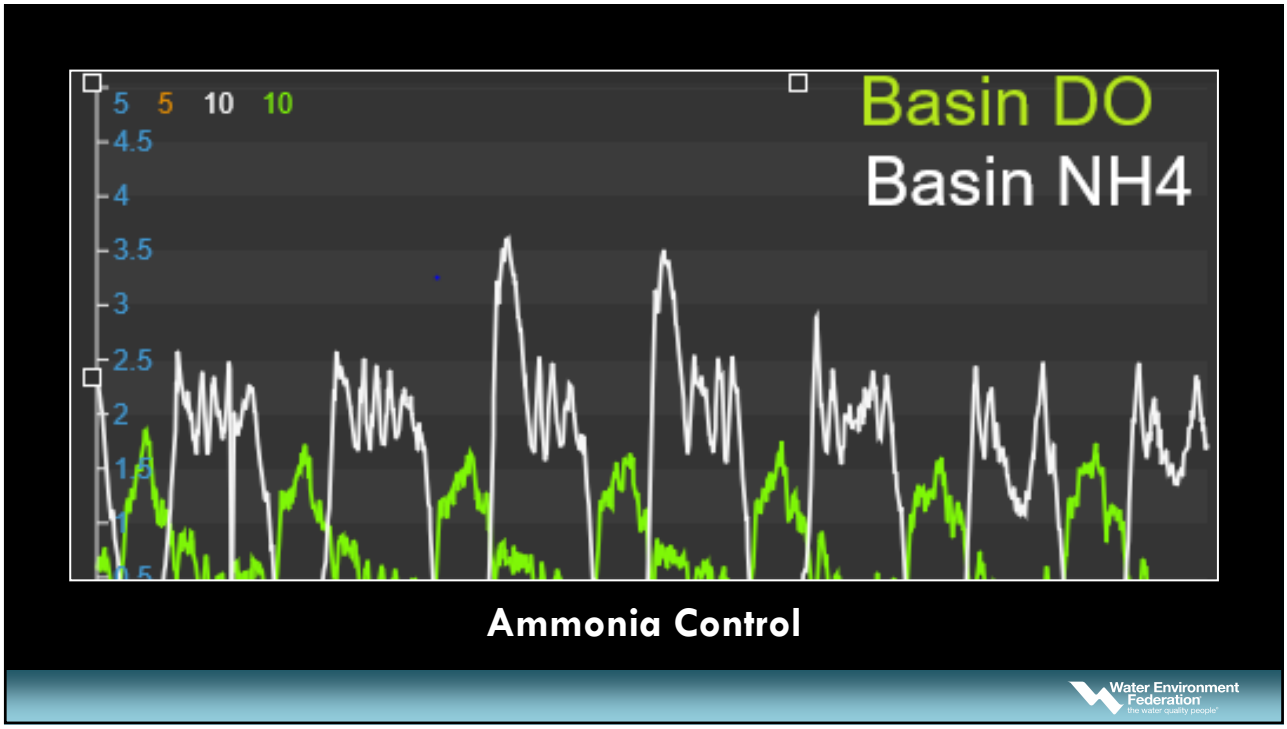

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Las Vegas Street Water Reclamation Facility

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Real-Time Monitoring (LVWRRF)

- Parameters
  - Ammonia
  - ORP
  - DO
  - Nitrate
  - Nitrite
  - COD
  - BOD
  - TSS
  - pH
  - NTU
  - UVT

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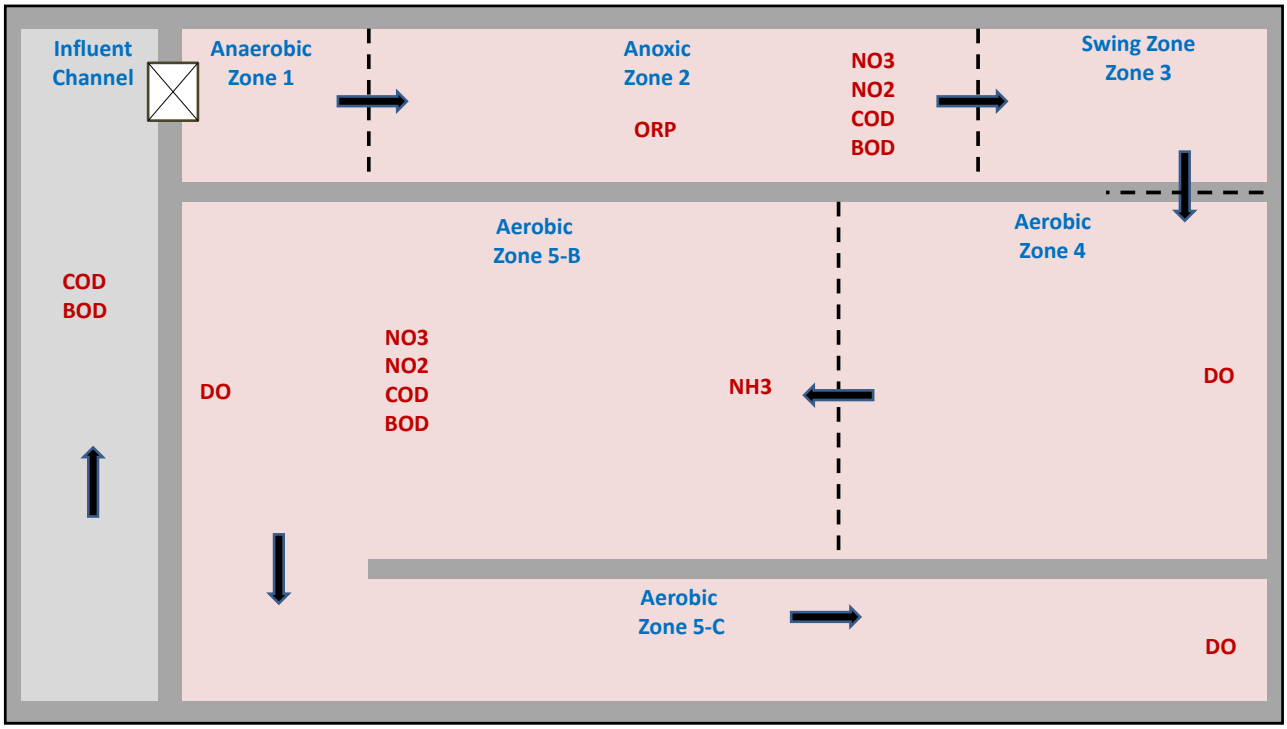
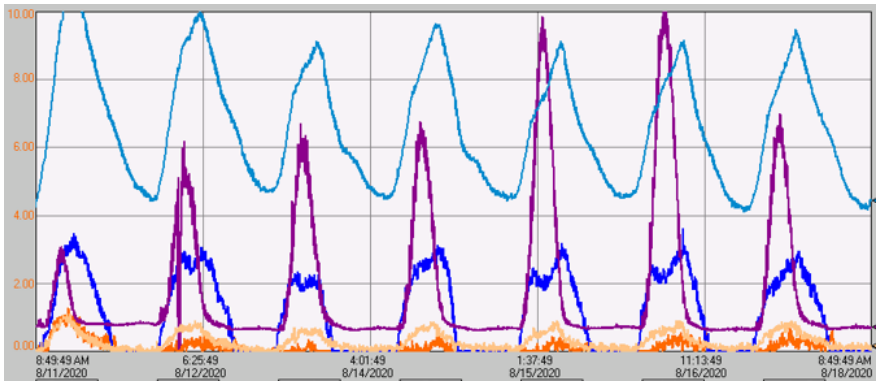
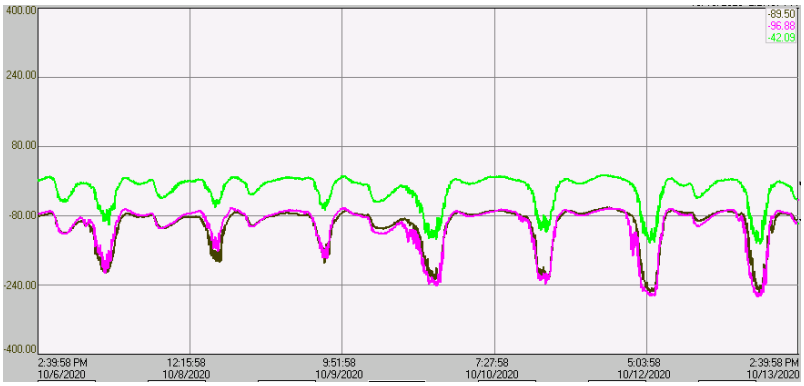


97



NO_2-NO_3 & NH_4

98



Anoxic ORP Monitoring

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Seeing an Unexpected BOD Load with Instrumentation

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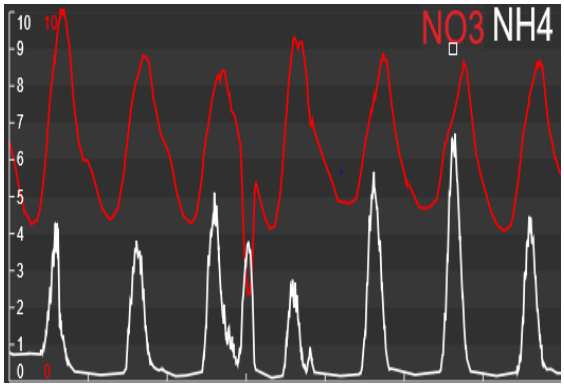
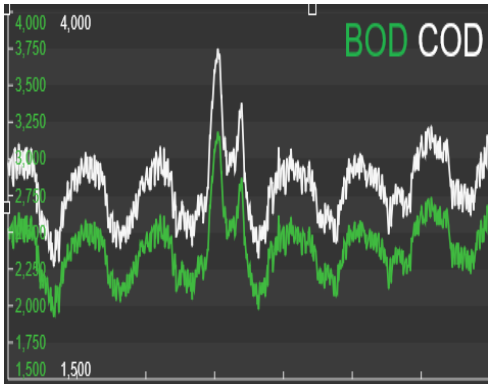
Unexpected BOD Loading

NO_3 & NH_4



COD & BOD



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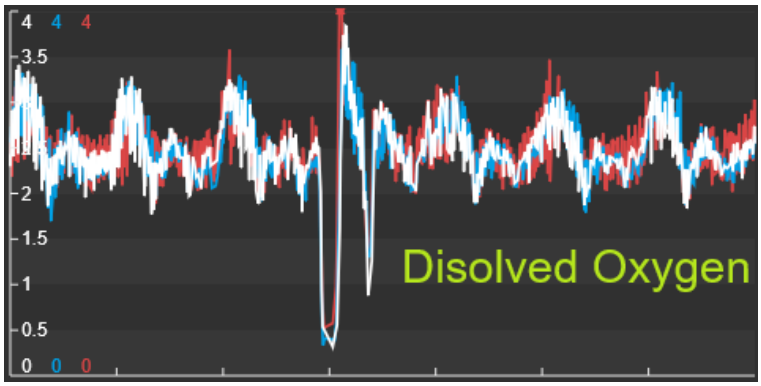

A-Basin DO

Unexpected BOD Loading

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Nutrient Removal – Oct. 29, 2020

An MRRDC Short Course:

Biological Nutrient Removal:
Tools, Tips and Lessons Learned

- Final Q & A:

Moderator	→	John Copp	Primodal
Principles	→	Ben Barker	Xylem
Instrumentation	→	Rob Smith	Black & Veatch
Application	→	Jon Vandommelen	EPA - Ohio
Application	→	Shaun Thompson	Colorado Springs Utilities

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