Energy & Nutrient Optimization
of NC Municipal Wastewater Treatment Plants

February 11, 2021
10:00 - 11:45 AM

Brendan Held
US EPA Region 4

Terry Albrecht
Corey Basinger
Ron Haynes
NC DEC

Larry Moore, PhD
University of Memphis, Retired

Grant Weaver
CleanWaterOps
Energy & Nutrient Optimization of NC Municipal Wastewater Treatment Plants

Today: Overview & Introductions
Biological Nitrogen Removal, Part 1
Feb 18: Nitrogen Removal, Part 2
Feb 25: Activated Sludge, Part 1 - Oxygen Demand and Supply
Mar 4: Activated Sludge, Part 2 - Bio-Tiger Model
Mar 11: Biological Phosphorus Removal, Part 1
Mar 18: Biological Phosphorus Review, Part 2
Mar 25: North Carolina Case Studies, Part 1
Apr 8: North Carolina Case Studies, Part 2
Apr 15: Energy Management, Part 1
Apr 22: Energy Management, Part 2
Apr 29: North Carolina Case Studies, Part 3
Why North Carolina operators should care about Nitrogen Removal

From North Carolina’s 2019 Nutrient Criteria Development Plan

Development and adoption of nutrient criteria for the following by 2025:

- High Rock Lake / Yadkin River Basin
- Albemarle Sound / Chowan River Basin
- Central portion of the Cape Fear River

Adoption of nutrient criteria statewide by 2029
High Rock Lake / Yadkin River Basin
Albemarle Sound / Chowan River Basin
Central Portion of Cape Fear River
Introducing a new way of thinking: **Facility upgrades** aren’t the only way to get phosphorus removal... **Empowered operators** achieve amazing results!
Change day-to-day operations to create ideal habitats for bacteria to remove phosphorus
<table>
<thead>
<tr>
<th>State</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecticut</td>
<td>Colchester-East Hampton, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Iowa</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Kansas</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Kentucky</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Montana</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>South Carolina</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Tennessee</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Texas</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Virginia</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
<tr>
<td>Wyoming</td>
<td>Colchester, East Haddam, East Hampton, Groton, New Canaan, New Hartford, Plainfield North, Plainfield Village, Suffield, Windham</td>
</tr>
</tbody>
</table>
Gauging your N-smarts
MONTANA
Montana's Municipal Wastewater Treatment Plants
Effluent Nitrogen: 2011-2019

Designed for Nitrogen Removal: 23 wwtps
Montana's Municipal Wastewater Treatment Plants
Effluent Nitrogen: 2011-2019

- Chinook, MT
- Designed for Nitrogen Removal: 23 wwtp
- Not designed for N Removal: 7 wwtp

Effluent total-Nitrogen (mg/L)

Years: 2011 to 2019
TENNESSEE
Cookeville, Tennessee    Population: 33,500    15 MGD design flow
Cookeville
Norris, Tennessee
Population: 1,450
0.2 MGD design flow
Norris
Norris, Tennessee
Effluent Nitrogen:
July 2017 - December 2020
Harriman, Tennessee

Population: 6,200

1.5 MGD design flow
Harriman, Tennessee

<table>
<thead>
<tr>
<th>Actual Flow (MGD)</th>
<th>Effluent Nitrogen (mg/L)</th>
<th>Effluent Phosphorus (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>21.5</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>Historical Average</td>
<td>After Optimization</td>
</tr>
<tr>
<td></td>
<td>Historical Average</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Wastewater Science
Alkalinity and pH
ORP (Oxygen Reduction Potential)

Wastewater Science
DO and ORP

DO (Dissolved Oxygen)
What Does ORP Tell Us About Our Process?

- Anaerobic
- Anoxic
- Oxic
- Nitrification
- BOD removal
- ‘P’ uptake
- Denitrification
- Fermentation
- ‘P’ release

ORP, mV

-400 -300 -200 -100 0 +100 +200 +300 +400
Questions?
Comments?
Nitrogen Limits?
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Nitrogen
Biological Nitrogen Removal:  
Convert LIQUID to GAS ...

BOD and TSS Removal:  
Convert LIQUID to SOLID ...
**Step 1: Convert Ammonia (NH₄) to Nitrate (NO₃)**

Oxygen-rich Aerobic Process
Don’t need BOD for bacteria to grow
Bacteria are sensitive to pH and temperature

**Step 2: Convert Nitrate (NO₃) to Nitrogen Gas (N₂)**

Oxygen-poor Anoxic Process
Do need BOD for bacteria to grow
Bacteria are hardy
Ammonia Removal
Ammonia (NH$_4$) is converted to Nitrate (NO$_3$)
Ammonia Removal

Oxygen ($O_2$) → Ammonia ($NH_4$)
Ammonia Removal

Oxygen (O$_2$) → Ammonia (NH$_4$) → Alkalinity → H$^+$
Ammonia Removal

Oxygen ($O_2$)

Ammonia ($NH_4^+$) → Nitrite ($NO_2^-$)

Alkalinity

H$^+$
Ammonia Removal

Ammonia (NH₄⁺) → Nitrite (NO₂⁻)

Oxygen (O₂) → Nitrite (NO₂⁻)

Alkalinity → Ammonia (NH₄⁺)

H⁺
Ammonia Removal

Ammonia (NH₄⁺) → Nitrite (NO₂⁻) → Nitrate (NO₃⁻)

Oxygen (O₂) → Ammonia (NH₄⁺) → Nitrite (NO₂⁻) → Nitrate (NO₃⁻)

Alkalinity → Ammonia (NH₄⁺) → Nitrite (NO₂⁻)

H⁺ → Nitrite (NO₂⁻) → Nitrate (NO₃⁻)
Nitrification:
Ammonia (NH₄) is converted to Nitrate (NO₃)

**Oxygen Rich Habitat**
MLSS* of 2500+ mg/L (High Sludge Age / MCRT / low F:M)
ORP* of +100 to +150 mV (High DO)
Time* (high HRT ... 24 hr, 12 hr, 6 hr)
Low BOD

Consumes Oxygen
Adds acid - Consumes 7 mg/L alkalinity per mg/L of NH₄ → NO₃

*Approximate, each facility is different.
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Biological Nitrogen Removal:
Next step:
the Nitrate (NO$_3$) created during Nitrification ...
is converted to Nitrogen Gas (N$_2$)
Nitrate Removal

Nitrate
(NO₃)
Nitrate Removal

BOD

Nitrate
(NO₃)
Nitrate Removal

Nitrate ($\text{NO}_3^-$) → BOD → Nitrogen Gas ($\text{N}_2$)
Nitrate Removal

BOD → Nitrate (NO$_3$) → Oxygen → Nitrogen Gas (N$_2$)
Nitrate Removal

Nitrate $(\text{NO}_3)$ → Nitrogen Gas $(\text{N}_2)$

- Adds DO (dissolved oxygen)
- Consumes BOD
- Gives back alkalinity ... beneficially raises pH

BOD → Oxygen

Alkalinity → Nitrogen Gas $(\text{N}_2)$
**Denitrification:**
*Nitrate (NO$_3$) is converted to Nitrogen Gas (N$_2$)*

**Oxygen Poor Habitat**
- ORP* of -100 mV or less (DO less than 0.3 mg/L)
- Surplus BOD* (100-250 mg/L: 5-10 times as much as NO$_3$)
- Retention Time* of 1-2 hours

Gives back Oxygen
Gives back Alkalinity (3.5 mg/L per mg/L of NO$_3$ → N$_2$)

*Approximate, each facility is different.
# Nitrogen Removal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Step 1: Nitrification (Ammonia Removal)</th>
<th>Step 1: Denitrification (Nitrate Removal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO: Dissolved Oxygen</td>
<td>1 mg/L or more</td>
<td>Less than 0.2 mg/L</td>
</tr>
<tr>
<td>ORP: Oxygen Reduction Potential</td>
<td>+100 mV or more +</td>
<td>Less than -100 mV</td>
</tr>
<tr>
<td>MLSS: Mixed Liquor Suspended Solids</td>
<td>2500 mg/L or more</td>
<td>Same</td>
</tr>
<tr>
<td>HRT: Hydraulic Retention Time</td>
<td>6 or more hours</td>
<td>1 or more hours</td>
</tr>
<tr>
<td><strong>BOD: Biochemical Oxygen Demand</strong></td>
<td>less than 20 mg/L</td>
<td>100 mg/L or more</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>60 mg/L or more</td>
<td><strong>Alkalinity is gained</strong></td>
</tr>
</tbody>
</table>

*Alkalinity is lost*  

Note: All numbers are approximations, “rules of thumb”
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Plant Size
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Technology!
Post Denitrification
Ammonia (NH₄) Removal
Target: NH₄ < 0.5 mg/L

Nitrate (NO₃) Removal
Target NO₃ in Anoxic Tank: 0.5-2 mg/L
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
MLE Process
(Modified Ludzack-Ettinger)
MLE (Modified Ludzack-Ettinger) Process

Anoxic Zone

Internal Recycle

Aerobic Zone

NH₄ → NO₃

Return Sludge

Secondary Clarifier
MLE (Modified Ludzack-Ettinger) Process

Anoxic Zone

Internal Recycle

NH₄

Aerobic Zone

NO₃

Secondary Clarifier

Return Sludge
MLE (Modified Ludzack-Ettinger) Process

Anoxic Zone

Internal Recycle

N\textsubscript{2}

Aerobic Zone

NH\textsubscript{4}

Secondary Clarifier

Return Sludge

Ammonia (NH\textsubscript{4}) Removal
Target: NH\textsubscript{4}: 0.5 mg/L

Nitrate (NO\textsubscript{3}) Removal
Target NO\textsubscript{3} in Anoxic Tank: 2 mg/L
MLE (Modified Ludzack-Ettinger) Process

MLE Process Control:
Proper Internal Recycle Rate; not too much / not too little.
ORP of +100 mV in Aerobic Zone for Ammonia (NH$_4$) Removal.
ORP of -75 to -150 mV in Anoxic Zone for Nitrate (NO$_3$) Removal.
Enough BOD to support Nitrate (NO$_3$) Removal.
MLE with not enough Internal Recycle

**Ammonia (NH$_4$) Removal**
Excellent Aerobic Habitat: ORP +150 mV
NH$_4$ < 0.5 mg/L

**Nitrate (NO$_3$) Removal**
Great Anoxic Habitat: ORP -150 mV or lower
NO$_3$ > 4 mg/L because too little NO$_3$ is returned to Anoxic Zone
Ammonia (NH₄) Removal
- Good Aerobic Habitat: ORP +100 mV
- NH₄ < 0.5 mg/L

Nitrate (NO₃) Removal
- Stressed Anoxic Habitat: ORP 0 to -100 mV
- NO₃ > 4 mg/L: bacteria will not convert Ammonia (NH₄) to Nitrate (NO₃)
MLE with way too much Internal Recycle

**Ammonia (NH₄⁺) Removal**
Poor Aerobic Habitat: ORP +50 mV
NH₄⁺ > 0.5 mg/L

**Nitrate (NO₃⁻) Removal**
Poor Anoxic Habitat: ORP 0 mV or higher
NO₃⁻ > 4 mg/L
Sequencing Batch Reactor
SBR
Sequencing Batch Reactor (SBR)
Ammonia (NH₄) Removal: Nitrification

Air ON

SBR #1

NH₄ → NO₃

Sludge Storage

SBR #2

Idle

Ammonia (NH₄) Removal
Target: NH₄ < 0.5 mg/L
Sequencing Batch Reactor (SBR)  
Nitrate ($\text{NO}_3$) Removal: Denitrification

SBR #1  
$\text{NO}_3 \rightarrow \text{N}_2$

Air OFF

SBR #2

Idle

Nitrate ($\text{NO}_3$) Removal  
Target: $\text{NO}_3 < 4 \text{ mg/L}$

Sludge Storage
Sequencing Batch Reactor (SBR)
Settle, Decant & Waste Sludge

Establish cycle times that are long enough to provide optimal habitats.
And, short enough to allow all of the flow to be nitrified and denitrified.
Optimizing SBR cycle time

**Too short**
Will not reach +100 mV for Ammonia (NH$_4$) Removal.
Will not reach -100 mV for Nitrate (NO$_3$) Removal.
Note: Temperature and BOD affect Air OFF cycle.

**Too long**
Wastewater will pass through tank before all Ammonia (NH$_4$) converted to Nitrate (NO$_3$).
And, before all Nitrate (NO$_3$) is converted to Nitrogen Gas (N$_2$).

**Just right**
Good habitats ...
  ORP of +100 mV for 60 minutes
  And, ORP of -100 mV for 30 minutes.

  Bonus: Changing conditions will serve as a selector.
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com
Oxidation Ditch
Oxidation Ditch

Anoxic Zone → Aerobic Zone → Anoxic Zone → Aerobic Zone → Secondary Clarifier

NH_{4}
Oxidation Ditch

- **Anoxic Zone**
- **Aerobic Zone**
- **Anoxic Zone**
- **Aerobic Zone**
- **Secondary Clarifier**

Chemical reactions:

- $\text{NH}_4$
- $\text{NO}_3$
Oxidation Ditch

- Anoxic Zone
- Aerobic Zone
- Anoxic Zone
- Aerobic Zone
- Secondary Clarifier
Oxidation Ditch

Anoxic Zone → Aerobic Zone → Anoxic Zone → Aerobic Zone → Secondary Clarifier

NO₃
Oxidation Ditch

Anoxic Zone → Aerobic Zone → Anoxic Zone → Aerobic Zone → Secondary Clarifier

- NO₃
- N₂
Oxidation Ditch

Ammonia (NH₄) Removal
Target: NH₄ < 0.5 mg/L

Nitrate (NO₃) Removal
Target: NO₃ of 1-4 mg/L
Acknowledgements

US EPA
Brendan Held & Craig Hesterlee

NC DEQ
Terry Albrecht, Corey Basinger & Ron Haynes

U MEMPHIS
Larry Moore, PhD

MONTANA
Paul Lavigne (MDEQ Retired), Pete Boettcher (MDEQ), Josh Vial (MDEQ), Eric Miller (Chinook),
Keith Taut (Conrad) & Mark Fitzwater (Helena)

TENNESSEE
Karina Bynum (TDEC), Sherry Wang (TDEC), George Garden (TDEC), Jenny Dodd (TDEC), Brett Ward (UT-MTAS), Dewayne Culpepper (TAUD), Tony Wilkerson (Norris) & Doug Snelson (Norris), Ronnie Kelly (Cookeville), Tom Graham (Cookeville) & John Buford (Cookeville)

... and, many more!
Next Week’s Webinar
Nitrogen Removal, Part 2

Thursday, February 18
10:00 - 11:45 AM

Activated Sludge (2/25 & 3/4)
Phosphorus Removal (3/11 & 3/18)
NC Case Studies (3/25, 4/8 & 4/29)
Energy Management (4/15 & 4/22)
Next Week’s Webinar
Nitrogen Removal, Part 2

Thursday, February 18
10:00 - 11:45 AM

Activated Sludge (2/25 & 3/4)
Phosphorus Removal (3/11 & 3/18)
NC Case Studies (3/25, 4/8 & 4/29)
Energy Management (4/15 & 4/22)

Volunteers needed for Case Study sessions!
Grant Weaver

g.weaver@cleanwaterops.com