Nutrient Optimization in Activated Sludge WWTPs

Webinar for Tennessee Wastewater Operators
March 10, 2021

Grant Weaver, PE & wastewater operator
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Strategies for Optimizing Nutrient Removal

Week 1: Nitrogen Removal
Week 2: Phosphorus Removal
Week 3: N&P Review and Case Studies
Week 4: N&P Removal in Oxidation Ditches
Week 5: N&P Removal in SBRs

Today: Nitrogen & Phosphorus Removal in Conventional and Extended Aeration Activated Sludge wwtps

Mar 17: Brainstorming N&P Removal Opportunities for Tennessee Wastewater Treatment Plants
Rate your Activated Sludge knowledge
Questions?
Comments?

Grant Weaver
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Change day-to-day operations to create ideal habitats for bacteria to remove phosphorus
Nitrogen
Step 1: Convert Ammonia (NH$_4$) to Nitrate (NO$_3$)

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

Step 2: Convert Nitrate (NO$_3$) to Nitrogen Gas (N$_2$)

Oxygen-poor Anoxic Process
Do need BOD for bacteria to grow
Bacteria are hardy
Ammonia Removal - 1st Step of N Removal
Step 1: Ammonia Removal
pH of 6.5+
Plenty of DO: 2 mg/L
ORP of +150 mV
Little to no BOD
4+ hours retention time
Ammonia Removal

- Ammonia (NH₄⁺)
- Nitrite (NO₂⁻)
- Nitrate (NO₃⁻)
- Oxygen (O₂)
- Alkalinity
- H⁺
Nitrate Removal - 2nd Step of N removal
Step 2: Nitrate Removal
Little to no measurable DO
ORP of -100 mV
5-10 times more BOD than Nitrate
2+ hours retention time

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

Nitrogen
Nitrate Removal

Nitrate (NO₃⁻) → Oxygen → Nitrogen Gas (N₂) → Alkalinity

BOD
Nitrate Removal

- **BOD**
- **Oxygen**
- **Nitrate** \((\text{NO}_3^-)\)
- **Nitrogen Gas** \((\text{N}_2)\)
- **Alkalinity**

**Additions**
- Adds DO (dissolved oxygen)
- Consumes BOD
- Denitrifiers outcompete bio-P bugs for VFAs!
- Gives back alkalinity beneficially raises pH
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>+150 mV</td>
<td>-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><strong>100 mg/L or more ... VFAs preferred!</strong></td>
</tr>
<tr>
<td>Alkalinity</td>
<td>60 mg/L or more</td>
<td>Alkalinity is gained</td>
</tr>
</tbody>
</table>

Alkalinity is lost

Alkalinity is gained

Note: All numbers are approximations, “rules of thumb”
THREE steps
**Biological Phosphorus Removal**

**Step 1: prepare “dinner”**

VFA (volatile fatty acids) production in anaerobic/fermentive conditions
Step 1: VFA Production

ORP of -200 mV or more negative

25 times as much BOD as orthophosphate

Retention time ... long enough to go septic
Biological Phosphorus Removal

Step 1: prepare “dinner”
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

Step 2: “eat”
Bio-P bugs (PAOs, “phosphate accumulating organisms”) eat VFAs in anaerobic/fermentive conditions ... temporarily releasing more P into the water
Step 2: VFA uptake / P-release

MLSS and VFAs in same tank

ORP of -200 mV or more negative

Nitrate control

Process control tool: 3 times as much ortho-P leaving tank as coming in
Biological Phosphorus Removal

Step 1: prepare “dinner”
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

Step 2: “eat”
Bio-P bugs (PAOs, “phosphate accumulating organisms”) eat VFAs in anaerobic/fermentive conditions ... temporarily releasing more P into the water

Step 3: “breathe” and grow
Bio-P bugs (PAOs) take in almost all of the soluble P in aerobic conditions as they grow and reproduce
Step 3: P-uptake

ORP of +150 mV—no more DO than for ammonia removal

pH of 7.0+

Retention time ... enough to remove ammonia

Enough BOD to support bacteria growth
Optimizing Bio-P Removal: Mainstream or Sidestream Fermentation

Anaerobic Tank
2 hour HRT (hydraulic retention time)*
ORP of -200 mV*
25 times as much BOD as influent ortho-P*
Ortho-P release (3 times influent ortho-P)*

Aeration Tank
DO of 2.0 mg/L
ORP of +150 mV
pH of 7.0+*
Ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different
Questions? Comments?

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Technology:
Phosphorus removal in Conventional and Extended Aeration treatment facilities
Biological Phosphorus Removal: Mainstream Flow Fermentation Processes
Bio-P Removal: Mainstream Fermentation Process

In Anaerobic Tank ...

Bacteria break down complex BOD into VFAs (volatile fatty acids).
Bio-P Removal: Mainstream Fermentation Process

In Anaerobic Tank ...

Bacteria break down complex BOD into VFAs (volatile fatty acids).

PAO bacteria (phosphate accumulating organisms) take in VFAs as energy source & temporarily release $PO_4$ (phosphate) into solution.
**Bio-P Removal: Mainstream Fermentation Process**

In **Anaerobic Tank** ...

Bacteria break down complex BOD into VFAs (*volatile fatty acids*).

PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO$_4$ (*phosphate*) into solution.

In **Aeration Tank** ...

Energized PAO bacteria take PO$_4$ out of solution.
**Bio-P Removal: Mainstream Fermentation Process**

In **Anaerobic Tank** ...

- Bacteria break down complex BOD into VFAs (*volatile fatty acids*).
- PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release \( \text{PO}_4 \) (*phosphate*) into solution.

In **Aeration Tank** ...

- Energized PAO bacteria take \( \text{PO}_4 \) out of solution.
**Bio-P Removal: Mainstream Fermentation Process**

- **Primary Clarifier**
- **Anoxic Tank**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

**Gravity Thickener**

Pre-anoxic zone to ...

Strengthen anaerobic conditions in anaerobic tank

Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO₃⁻) to Nitrogen Gas (N₂) – by “feeding” influent to the denitrifiers.
Pre-anoxic zone to ...

*Strengthen anaerobic conditions in anaerobic tank*

*Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO₃) to Nitrogen Gas (N₂) – by “feeding” influent to the denitrifiers.*
**Bio-P Removal: Mainstream Fermentation Process**

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Pre-anoxic zone to...

Strengthen anaerobic conditions in anaerobic tank

Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO₃) to Nitrogen Gas (N₂) – by “feeding” influent to the denitrifiers.
Questions?
Comments?

Grant Weaver
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Troubleshooting Biological Phosphorus removal in Plants Designed for EBPR (enhanced biological phosphorus removal)
If Anaerobic Tank isn’t really anaerobic ... 
... turn off mixer(s)
Questions?
Comments?

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Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

**Flowchart Diagram:**
- Gravity Thickener
- Fermentation
- VFAs
- Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener → VFAs → Fermentation

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier

Anaerobic Tank

Fermentation

VFAs

Aeration Tank

Secondary Clarifier

Gravity Thickener

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener
Fermentation
PO₄

Sludge Storage
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

**Nitrogen Interference:**
Nitrate (NO₃) will consume VFAs

- **Gravity Thickener**
- **Fermentation**
- **PO₄**
- **Sludge Storage**
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anoxic Tank → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener → Fermentation

No Nitrogen Interference!

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

- Primary Clarifier
- Anoxic Tank
- Anaerobic Tank
- Aeration Tank
- Secondary Clarifier
- Gravity Thickener
- Fermentation
- VFAs

No Nitrogen Interference!

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

- Primary Clarifier
- Anoxic Tank
- Anaerobic Tank
- Aeration Tank
- Secondary Clarifier
- No Nitrogen Interference!
- PO₄
- Gravity Thickener
- Fermentation
- Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

- Primary Clarifier
- Anoxic Tank
- Anaerobic Tank
- Aeration Tank
- Secondary Clarifier
- Gravity Thickener
- Fermentation
- Sludge Storage

No Nitrogen Interference!

PO₄
Questions? Comments?

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Wastewater Operator License ... What Level?
BREAK TIME
Getting creative ...

Biological Phosphorus removal from plants not designed as EBPR (enhanced biological phosphorus removal) facilities
Home Grown Sidestream Fermenter

Primary Clarifier → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener → Fermentation

Sludge Storage
Home Grown Sidestream Fermenter

Primary Clarifier → Aeration Tank → Secondary Clarifier

Gravity Thickener → Aeration Tank

Sludge Storage
Questions?
Comments?

Grant Weaver
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Norris, Tennessee
Population: 1,450
0.2 MGD design flow
Norris, Tennessee
Norris, TN:
Nitrogen Removal

Nitrogen Removal
Raise MLSS concentration
Cycle aeration:
ON 2-3 hours
OFF 1½-2 hours
Norris, Tennessee
Effluent Nitrogen: 2011-2020

- Monthly Average
- Average of prior 12 months

Chart showing effluent total-Nitrogen (mg/L) from July 2017 to July 2020.
Norris, TN: First try at Phosphorus Removal

Phosphorus Removal
Recycle RAS through fermenters
Norris, TN: Second try at Phosphorus Removal

Phosphorus Removal
Create Fermentation Zone in Aeration Tank
Norris, TN: Third try at Phosphorus Removal

Phosphorus Removal
Recycle RAS through fermenters
- and -
Create Fermentation Zone in Aeration Tank
Questions?
Comments?

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Nashville Dry Creek

Nitrogen Removal
Increase BOD loading
Fewer Primary Clarifiers
Step feed
Cycle aeration in 2nd zone
Nashville Dry Creek

Nitrogen Removal
- Increase BOD loading
- Fewer Primary Clarifiers
- Step feed
- Cycle aeration in 2\textsuperscript{nd} zone
Nashville Dry Creek

Nitrogen Removal
Increase BOD loading
Fewer Primary Clarifiers
Step feed
Cycle aeration in 2nd zone
Nashville Dry Creek

**Nitrogen Removal**
- Increase BOD loading
- Fewer Primary Clarifiers
- Step feed
- Cycle aeration in 2nd zone

**Phosphorus Removal**
- Maintain selector
Questions?
Comments?
Harriman, Tennessee

Population: 6,200

1.5 MGD design flow
TENNESSEE: QUEST FOR ENERGY EFFICIENCY INSPIRES OPERATORS’ PURSUIT OF NUTRIENT REMOVAL

Energy Efficiency Measures Provide Opportunities for Nutrient Reduction

At many publicly owned treatment works (POTWs), operators experimenting with cost-saving energy efficiency find their plants also benefit from improved nitrogen removal. These successes provide staff with confidence to implement low-cost modifications and operational changes to further reduce effluent nutrient discharges. EPA’s National Study of Nutrient Removal and Secondary Technologies investigates optimization efforts across the country, and this fact sheet highlights achievements at the Harriman POTW in Tennessee.

In 2011, the Tennessee Water and Wastewater Energy Efficiency Partnership (TWEEP) was formed between many associations, including EPA and the Tennessee Department of Environment and Conservation (TDEC). The partnership supplied Tennessee wastewater utilities with energy efficiency tools and expertise to support operators in reducing energy costs and pollution. This included providing in-person technical assistance to staffs across Tennessee, including Harriman POTW in 2014.

Harriman POTW

Harriman POTW has a design capacity flow of 1.5 million gallons per day (MGD) and an average daily flow of 0.5 MGD. The plant has two equalization basins, two oxidation ditches, two secondary clarifiers, chlorine disinfection, and two aerobic digesters. Each ditch has two fixed-speed rotors, and no chemicals are added for phosphorus removal.

Prior to the partnership’s visit, aeration for Harriman POTW’s oxidation ditches and digesters consumed 43% of the plant’s total energy use. The four ditch rotors ran continuously and the digester blowers ran 16 hours each night during the week and continuously on weekends.

Harriman POTW’s staff started by following the partnership’s suggestion to cycle the four rotors 1 hour on/1 hour off, which decreased aeration energy use by 50%. They noticed a drop in effluent Total Nitrogen (TN), although concentrations were still high, averaging over 20 mg/L. Inspired to realize greater energy savings, staff continued to refine the plant’s aeration cycling on their own, resulting in a TN concentration consistently under 10 mg/L beginning in 2017.

In July 2018, Ray Freeman took over as Chief Plant Operator, and, assisted by Operator Donnie Fitchugh, the two began a quest to drive effluent TN as low as possible. They experimented by ratcheting down rotor
run times in small increments and alternating the rotors’ operation. The plant now operates 1 rotor per ditch, cycling 1 hour on/2 hours off in the summer and 1 hour on/3 hours off in the winter.

“…I started by taking baby steps to reduce power consumption. In that process, I could see the reduction in nitrogen. I just kept altering DO levels and equipment run times until I could no longer reduce TN without negatively affecting other parameters, such as BOD.” — Ray Freeman

Dissolved oxygen (DO) readings are obtained with a hand-held probe near the influent inlet on the aft side of the first rotor. The DO upper set point averages 1.75 mg/L on the aft side of the rotor, with the lower set point targeted at 0.88 mg/L or less. The plant does not have a limited SCADA system that incorporates some timers for the digesters, but the two operators closely monitor and manage all aeration cycling in the ditches by hand. Beginning in 2020, the average effluent TN concentration was an impressive low of 2 mg/L.

Ray also adjusted the digester valves so only one blower is needed to aerate both digesters for six hours each night, further reducing plant energy costs. These aeration strategies save the plant $50,000/year in energy costs, achieving a total reduction in aeration energy use nearing 65%.

Ray and Dennis have now turned their attention to reducing total phosphorus (TP) effluent concentrations and improving the plant’s biological phosphorus removal. Over the summer, they began interrupting the 1 hour on/2 hours off schedule twice each day to let the rotors run for 2 hours to drive DO up to 2 mg/L. This was followed by 2 hours off before resuming the 1 hour on/2 hours off schedule. When the plant transitioned to the winter 1 hour on/3 hours off schedule, the 2 hours on/2 hours off cycle was introduced only once per day. Harriman POTW’s average effluent TP concentration has already been reduced 25% by these rotor cycling changes over the course of the year.

Harriman Daily Maximum Monitoring Data

<table>
<thead>
<tr>
<th></th>
<th>Effluent TN Concentration (mg/L as N)</th>
<th>Effluent TP Concentration (mg/L as P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 - Q4 2017*</td>
<td>9.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Q1 - Q4 2020*</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Percent Removal</td>
<td>77%</td>
<td>25%</td>
</tr>
</tbody>
</table>

*Monitoring data from the first phases of optimization (2014-2016) are not available.

Optimization Opportunities and Benefits

Optimizing existing treatment systems not only effectively reduces nutrient discharges from POTWs, but it can also result in significant energy and cost savings for utilities. Support from regulatory agencies, onsite consulting, and, most importantly, operator ambition and enthusiasm enabled these Tennessee POTW operators to reach both their nutrient reduction and energy efficiency goals.

Acknowledgements

Nutrient monitoring data were collected from EPA’s Integrated Compliance and Information System-National Pollutant Discharge Elimination System (ICE-NPDES) and internal plant records. Energy savings are also from internal plant records. IDEC, and the TWEEP Partnership Team aided POTWs in Tennessee in improving their energy efficiency and, in some cases, nitrogen discharges. Grant Weaver of CleanWaterOps has supported Harriman staff with improving biological phosphorus removal.

For more information, visit epa.gov/wq/national-study-nutrient-removal-and-secondary-technologies.
## 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></td>
<td>Historical Average</td>
<td>After Optimization</td>
</tr>
<tr>
<td></td>
<td>Historical Average</td>
<td>After Optimization</td>
</tr>
<tr>
<td>1.2</td>
<td>21.5</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>2.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>
KANSAS
Wichita, Kansas

Population: 390,000

54.4 MGD design flow
Wichita Pilot Study

Nitrogen Removal
Cycle aeration on/off in Aeration Basin 6

Phosphorus Removal
Side stream fermenter using abandoned centrate tanks

Increase BOD loading
Take Trickling Filters off-line
Questions?
Comments?

Grant Weaver

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MONTANA
Conrad, Montana
Population: 2,500
0.5 MGD design flow
Conrad, Montana
Nitrogen Removal

Aeration Basin

Nitrogen Removal
Raise MLSS concentration
Cycle aeration:
ON 2-3 hours
OFF 1½-2 hours
Conrad, Montana
Effluent Nitrogen: 2011-2020

- Quarterly Average
- Average of prior 12 months
Conrad, Montana
Phosphorus Removal

1. Convert Digester to Fermenter and Circulate WAS
Conrad, Montana
Phosphorus Removal

1. Convert Digester to Fermenter and Circulate WAS
Conrad, Montana
Phosphorus Removal

Phosphorus Removal
1. Convert Digester to Fermenter and Circulate WAS
2. Fermentive zone(s) in Aeration Basin
Conrad, Montana
Effluent Phosphorus: 2011-2020

- Red: Quarterly Average
- Blue: Average of prior 12 months

Effluent total-Phosphorus (mg/L)
Questions?
Comments?

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Helena, Montana  
Population: 30,000  
5.4 MGD design flow
Helena, Montana
Nitrogen Removal

Nitrogen Removal
Raise MLSS concentration
Add third Aeration Basin
Monitor ORP, NH$_4$ & NO$_3$
Adjust Internal Recycle
Helena BioReactor
Helena, Montana
Phosphorus Removal, short term plan

Phosphorus Removal
Generate surplus VFAs in primary clarifier and feed to anoxic zone
Helena BioReactor

Aeration Tank

Anoxic Tank

NO₃ → N₂

VFAs

Aeration Tank

Aeration Tank

P
Helena BioReactor

Anoxic Tank

Nitrate to Nitrogen

Anaerobic Tank

Anoxic Tank

Aeration Tank

VFAs

Aeration Tank

Aeration Tank

Phosphorus
Helena, Montana
Phosphorus Removal, long term plan

Phosphorus Removal
Convert first anoxic zone to fermenter by relocating Internal Recycle to second anoxic zone
Helena BioReactor

- Anoxic Tank
- Aeration Tank
- Anoxic Tank
- Aeration Tank
- Anoxic Tank
- Aeration Tank
- Aeration Tank (P)
Helena BioReactor
Questions? Comments?

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Acknowledgements

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Karina Bynum, Sherry Wang, George Garden, Jenny Dodd, Jason Benton, Eddie Bouzied, Bryan Carter, David Duhl, Jordan Fey, Oakley Hall, Michael Murphy, Steve Owens, Rob Ramsey, Sherwin Smith, Robert Tipton, Sandra Vance, John West, Ariel Wessel-Fuss ...

HARRIMAN
Ray Freeman

NASHVILLE
Johnnie MacDonald & David Tucker

NORRIS
Tony Wilkerson & Doug Snelson

Brett Ward (UT-MTAS), Dewayne Culpepper (TAUD), Greg Hayes (Athens), Larry Gamblin (Bartlett), Danny Neely (Baileyton), David Harrison (Collierville), Nic Willis (Cowan), Ray Freeman (Harriman), Darryl Green (Henderson), Jack Hauskins & Rocky Hudson (Lafayette), Johnnie MacDonald (Nashville) ...

... and, many more!
Acknowledgements, continued

**KANSAS**  Tom Stiles, Rod Geisler (retired), Shelly Shores-Miller, Nick Reams & Ryan Eldredge (KDHE), Jamie Belden & Becky Lewis (Wichita)

**MONTANA**  Paul LaVigne (retired), Pete Boettcher, Josh Viall, Ryan Weiss, Bill Bahr (retired), Dave Frickey (retired) & Mike Abrahamson (DEQ), Keith Thaut (Conrad), Mark Fitzwater & entire staff (Helena)

**EPA**  Paul Shriner & Tony Tripp (HQ), Tina Laidlaw (R8), Brendon Held & Craig Hesterlee (R4), Sydney Weiss (R5)

... and, many more!
Rate your Activated Sludge knowledge
What we’ve learned &
Brainstorming Nutrient Removal
Opportunities in Tennessee
WWTPs: Case Studies
Wednesday, March 17
10:00 - 11:45 AM Central Time