RE-ENGINEERING O&M PRACTICES TO GET NITROGEN & PHOSPHORUS REMOVAL WITHOUT FACILITY UPGRADES

GRANT WEAVER, PE & WASTEWATER OPERATOR

WISCONSIN WASTEWATER OPERATORS ASSOCIATION
WISCONSIN DELLS, WI – OCTOBER 11, 2012
Re-Engineering O&M to get N+P Removal

Nitrogen Removal Science
Design Theory
Phosphorus Removal Science
Design Theory
O&M Strategies
Case Studies
Traditional Approach

Rules

Civil Engineering
The profession for intelligent people

your design solution
{ web video print app }
Cost of Facility Upgrades

$85 billion taxpayer dollars
spent building 15,000 wastewater treatment plants (1972-Present).

$250 billion
“needed” to fix existing treatment plants and CSO pollution (2010 EPA 20-year Needs Assessment).
Wastewater One-Percenters

Connecticut’s Nitrogen Trading Program (2002-2012)
1% of the Capital Cost
No Facility Upgrade
10 of 80 plants: Process changes @ $50,000 per plant
6 mg/L total-N

99-Percenters; Everybody Else
Facility Upgrades
48 of 80 plants: N-Removal upgrades @ $6.15 Million per plant
6 mg/L total-N

Phosphorus Experience
Re-Engineering

Existing equipment is used differently to provide better habitats. Making the treatment plant a good “home” for bacteria.

BOD/TSS Removal

Biological Nitrogen Removal
  Aerobic - Ammonia Removal
  Anoxic - Nitrate Removal

Biological Phosphorus Removal
  Anaerobic - VFA production
  Aerobic - bio-accumulation
How to make any treatment plant remove Nitrogen & Phosphorus

Oxygen-Rich, low BOD environment
Nitrogen
Ammonia Removal – Nitrification
Phosphorus
Dissolved Phosphorus converted to TSS (particulate Phosphorus)

Oxygen-Poor, high BOD environment
Nitrogen
Nitrate Removal – Denitrification
Phosphorus
Volatile Fatty Acid (VFA) production; if anaerobic/fermentative

TSS Removal
Nitrogen
12% of MLSS is Nitrogen (8 mg/L TSS = 1 mg/L total-N)
Phosphorus
3-5% of MLSS is Phosphorus (2 mg/L TSS = 0.1 mg/L total-P)
Case Study
Plainfield (CT) Village Plant – ReEngineered for N&P Removal

Design Flow: 0.5 MGD
Actual: 0.2 MGD

Effluent total-N
Before Changes: 20 mg/L
(10 TKN, 8 Ammonia, 10 Nitrite + Nitrate)
After Changes: 6 mg/L
(2.5 TKN, 0.5 Ammonia, 3.5 Nitrite + Nitrate)

Effluent total-P
Before Changes: 3 mg/L
After Changes: 0.75 mg/L
Plainfield Village

AERATION → Secondary Clarifier → Gravity Thickener
Plainfield Village
Gravity Thickener as Post-Anoxic Denitrification

AERATION ➔ Secondary Clarifier ➔ Gravity Thickener

ANOXIC

Gravity Thickener
Nitrogen and Phosphorus Removal

Costly Facility Upgrade!

... or ...

Process Changes?

Compliance may be easier and
and more affordable than you’ve
been led to believe...

trust yourself. you know
more than you think you do.
(dr. spock)
Let's begin
**Biological Nitrogen Removal**

Organic-Nitrogen (org-N)

↓

Ammonia (NH₃)

↓

Nitrate (NO₃)

↓

Nitrogen Gas (N₂)

**Ammonia Removal** - Nitrification:
Bacteria Convert Ammonia to Nitrate

**Nitrate Removal** - Denitrification:
Bacteria Convert Nitrate to Nitrogen Gas
Re-Engineering O&M for Nitrogen Removal

Ammonia Removal

Nitrate Removal
Ammonia Removal

Ammonia → Nitrite → Nitrate

Oxygen → Ammonia

Alkalinity → Nitrite

Oxygen
Ammonia Removal - Nitrification

Create a Habitat to motivate and support Bacteria that remove Ammonia (NH₃)

Dissolved Oxygen (DO)
+100 ORP
Low BOD
Old Sludge (High MLSS, High MCRT/SRT; Low F:M)
Alkalinity to keep pH from dropping
Time (HRT)
Temperature
Ammonia Removing Technologies

Extended aeration

Dissolved Oxygen (DO) & ORP
Old sludge (High MLSS / MCRT / SRT; Low F:M)
Low BOD
Time (HRT)
Alkalinity to keep pH from dropping

Two-stage trickling filter
Nitrate Removal

BOD → Nitrate → Nitrogen Gas → Oxygen

Nitrate → Alkalinity
**Nitrate Removal - Denitrification**

Create a Habitat so the Bacteria that Remove Nitrate (NO₃⁻) will be motivated to do it...

- Little to Zero DO
- -100 ORP
- Surplus BOD (High F:M)
- Time (HRT)

They give back one-half of the Alkalinity that the Nitrifiers removed
Nitrate Removal Habitats
Nitrate Removing Technologies

Post-Anoxic Denitrification

Pre-Anoxic Denitrification (MLE: Modified Ludzack-Ettinger)

SBR, or Cycling between Nitrification and Denitrification

Oxidation Ditch (Bardenpho)

HABITAT

Little to Zero DO
-100 or lower ORP
Surplus BOD (High F:M)
Time (HRT)
Post-Anoxic Denitrification
Pre-Anoxic: MLE Process
Sequencing Batch Reactor (SBR)
Oxidation Ditch: Bardenpho Process
Nitrogen Removal Simplified

Ammonia Removal - Nitrification
- High DO / ORP
- Low BOD
- Plenty of Alkalinity
- High Sludge Age
- Long Retention time

Nitrate Removal - Denitrification
- Low DO / ORP
- High BOD
- Long Retention time
- Gives back alkalinity
P

15

Phosphorus

30.974
Phosphorus: Soluble and Particulate

Soluble Phosphorus
- Convert to TSS (Particulate)
- Biological P removal
- Chemical P removal

Particulate Phosphorus
- Remove phosphorus by removing TSS
Phosphorus Removal Strategy

Convert up to 0.05 mg/L of Soluble Phosphorus to TSS (Particulate)

   Biologically
   Chemically

Particulate Phosphorus

   Remove as much TSS as necessary to meet Phosphorus Limit

   Rule of Thumb: 2 mg/L TSS = 0.1 mg/L t-P
**TSS Removal Requirements**

If all but 0.05 mg/L of Soluble Phosphorus is Converted to Particulate Phosphorus (Biologically and/or Chemically)

And, if Effluent TSS is 5% total-Phosphorus, Effluent TSS cannot exceed the numbers shown in the table...

<table>
<thead>
<tr>
<th>P Limit</th>
<th>max TSS</th>
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<tbody>
<tr>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>0.2</td>
<td>3</td>
</tr>
<tr>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td>0.4</td>
<td>7</td>
</tr>
<tr>
<td>0.5</td>
<td>9</td>
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<tr>
<td>0.6</td>
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<tr>
<td>0.7</td>
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<tr>
<td>0.8</td>
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<tr>
<td>0.9</td>
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<td>1.0</td>
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<td>1.1</td>
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<tr>
<td>1.2</td>
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</tr>
<tr>
<td>1.3</td>
<td>25</td>
</tr>
<tr>
<td>1.4</td>
<td>27</td>
</tr>
<tr>
<td>1.5</td>
<td>29</td>
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</table>
Habitats

Anaerobic Zone
Volatile Fatty Acid (VFA) production

...followed by ...

Aerobic Zone
Phosphorus Uptake by PAOs
(“Luxury Uptake”)
Anaerobic Zone -
Volatile Fatty Acid (VFA) formation

Bacteria create VFAs . . .

AND

. . . In the process, the Bacteria release some of their cellular Phosphorus into solution
**Aerobic Zone**

Phosphorus Accumulating Organisms (PAO) concentrate soluble Phosphorus.

PAOs contain 3 times as much Phosphorus as “regular” bacteria do. The phosphorus concentration in the mixed liquor increases from <2% total-P to as much as 5% total-P.
Biological Phosphorus Removal

ANAEROBIC zone for VFA production

... followed by

AEROBIC zone for Phosphorus uptake by PAO bacteria
**Anaerobic Zone (Fermentation)**

**Mainstream**
- Pre- Anaerobic Zone
- Modify Pre-Anoxic
- Modify Existing Tanks

**Sidestream**
- RAS piping
- Gravity Thickener
- Primary Sludge
- WAS
- Combined Primary & Secondary Sludge Storage
- Septage
Chemical Phosphorus Removal

Soluble ortho-Phosphate is taken out of solution and made into TSS. The particulate Phosphorus is settled.

Iron
  Ferric
  Ferrous

Aluminum
  Alum
  PAC
  Sodium Aluminate
**Phosphorus Removal**

Convert soluble Phosphorus to particulate Phosphorus

- Biological: Anaerobic (Fermentation) followed by Aerobic
- Chemical: Iron or Aluminum compound

Remove the TSS that contains the particulate Phosphorus

Achieving low total-P compliance requires ...

- Low to almost zero soluble P
- Low to almost zero effluent TSS
Greater than 50% Nitrogen Reduction
Greater than 50% Phosphorus Reduction
Capital Cost: as little as ZERO
   No New Tanks
O&M: generally, a cost SAVINGS
   No Chemicals
Carbon Footprint: REDUCED
Re-Engineering O&M – Optimizing Existing Equipment

Ongoing Monitoring of...
  Ammonia
  Nitrite + Nitrate
  Alkalinity
  ORP

Using...
  In-line instrumentation connected to SCADA
  Hand-held equipment
  Field Test Kits such as Test Strips

And...
  Ongoing Process Changes to Optimize Habitats
Re-Engineering for Nitrogen Removal

<table>
<thead>
<tr>
<th>Location</th>
<th>t-N Before</th>
<th>t-N After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suffield, CT</td>
<td>6.7</td>
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<tr>
<td>Montague, MA</td>
<td>11</td>
<td>3.5</td>
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<tr>
<td>Windsor Locks, CT</td>
<td>6.5</td>
<td>4.5</td>
</tr>
<tr>
<td>East Hampton, CT</td>
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<td>5.5</td>
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<td>Plainfield Village, CT</td>
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<tr>
<td>Manhattan, MT</td>
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<td>7</td>
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<tr>
<td>Conrad, MT</td>
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<tr>
<td>Amherst, MA</td>
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<td>8</td>
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<tr>
<td>Plainfield North, CT</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Farmington, CT</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Chinook, MT</td>
<td>25</td>
<td>12</td>
</tr>
</tbody>
</table>
## Re-Engineering for Phosphorus Removal

<table>
<thead>
<tr>
<th>Location</th>
<th>t-P Before</th>
<th>t-P After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keene, NH</td>
<td>3.0</td>
<td>0.2</td>
</tr>
<tr>
<td>East Haddam, CT</td>
<td>3.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Montague, MA</td>
<td>5.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Suffield, CT</td>
<td>3.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Plainfield Village, CT</td>
<td>3.0</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Welcome to CASE STUDIES
Trickling Filters, Lagoons, etc.
Case Study – Nitrogen & Phosphorus Removal
Plainfield, Connecticut
Village Plant

Design Flow: 0.5 MGD
Actual: 0.2 MGD

Effluent total-N
Before Changes: 20 mg/L
(10 TKN, 8 Ammonia, 10 Nitrite + Nitrate)
After Changes: 6 mg/L
(2.5 TKN, 0.5 Ammonia, 3.5 Nitrite + Nitrate)

Effluent total-P
Before Changes: 3 mg/L
After Changes: 0.75 mg/L
Plainfield Village
Gravity Thickener as Post-Anoxic Denitrification

AERATION → Secondary Clarifier → ANOXIC Gravity Thickener
Plainfield Village
Case Study – Nitrogen & Phosphorus Removal
Montague, Massachusetts

Design Flow: 1.8 MGD
Actual: 1.0 MGD

Effluent total-N
Before Changes: 11 mg/L
(6.0 TKN, 4.2 Ammonia, 5.0 Nitrite + Nitrate)
After Changes: 3.5 mg/L
(2.0 TKN, 0.5 Ammonia, 1.5 Nitrite + Nitrate)

Effluent total-P
Before Changes: 2.5 mg/L
After Changes: 0.6 mg/L
Montague, Massachusetts
Primary Clarifiers → Aeration Tanks → Secondary Clarifiers

- Air ON
- Air OFF

Montague Process®
Montague Process®
Montague
Case Study – Nitrogen Removal
Plainfield, Connecticut
North Plant

Design Flow: 1.0 MGD
Actual: 0.4 MGD

Effluent total-N
Before Changes: 15 mg/L
(5 TKN, 2 Ammonia, 10 Nitrite + Nitrate)
After Phase I Changes: 8 mg/L
(2 TKN, 0.5 Ammonia, 6 Nitrite + Nitrate)
After Phase II Changes: 5 mg/L (anticipated)
(2 TKN, 0.5 Ammonia, 3 Nitrite + Nitrate)

Effluent total-P
Before Changes: 2.0 mg/L
After Phase II: 0.75 mg/L (anticipated)
Plainfield North
North Plant
Plainfield, Connecticut
Primary Clarifier → Aeration Tank → Secondary Clarifier

North Plant
Plainfield, CT
Cycling Aeration to create ideal habitats for Ammonia and Nitrate removal
North Plant
Plainfield, CT
Drover Process®
Drover Process®

Convert Primary Clarifiers to pre-Anoxic tanks (MLE)
Case Study – Phosphorus Removal
Keene, New Hampshire

Design Flow: 6.0 MGD
Actual: 3.0 MGD

Effluent total-N
Before & After: 8 mg/L
(3.5 TKN, 1.5 Ammonia, 4.5 Nitrite + Nitrate)

Effluent total-P
Before Changes: 3.0 mg/L
After Changes: 0.2 mg/L
Secondary Clarifier
Aeration Tank
Primary Clarifier
Keene, New Hampshire
PAC
PAC
PAC
PAC
Keene, New Hampshire
Keene, New Hampshire
Case Study – Phosphorus Removal
East Haddam, Connecticut

Design Flow: 0.055 MGD
Actual: 0.015 MGD

Effluent total-N
Before & After: 6.5 mg/L
(2 TKN, 0.5 Ammonia, 3.5 Nitrite + Nitrate)

Effluent total-P
Before Changes: 3-4 mg/L
After Changes: 0.35 mg/L
Decant

React

AERATION

ANOXIC

Settle

Decant

Fill

East Haddam, Connecticut
East Haddam, Connecticut
Case Study – Nitrogen Removal
East Hampton, Connecticut

Design Flow: 2.0 MGD
Actual: 1.5 MGD

Effluent total-N
Before Changes: 11 mg/L
(2 TKN, 0.5 Ammonia, 9 Nitrite + Nitrate)
After Changes: 6 mg/L
(2 TKN, 0.2 Ammonia, 4 Nitrite + Nitrate)

Effluent total-P
Before & After: 1-3 mg/L
East Hampton, Connecticut
East Hampton, Connecticut
Percent Nitrate Removal as Recycle Pump Rate Increases
Water Planet’s Observation
100% Recycle Rate
Mixed Liquor Recycle

PRE-ANOXIC

AERATION

Sludge Recycle

Secondary Clarifier

200% Recycle Rate
Mixed Liquor Recycle

PRE-ANOXIC

AERATION

Sludge Recycle

Secondary Clarifier

300% Recycle Rate
**Case Study – Nitrogen & Phosphorus Removal**
**Suffield, Connecticut**

Design Flow: 2.0 MGD  
Actual: 1.0 MGD

**Effluent total-N**  
Before Changes: 7 mg/L  
(3 TKN, 0.5 Ammonia, 4 Nitrite + Nitrate)  
After Changes: 2.0 mg/L  
(1 TKN, 0.1 Ammonia, 1 Nitrite + Nitrate)

**Effluent total-P**  
Before Changes: 3.0 mg/L  
After Changes: 0.7 mg/L
Suffield, Connecticut
AERATION

ANOXIC

Mixed Liquor Recycle

PRE-ANOXIC

AERATION

ANOXIC

RAS

Secondary Clarifier

Suffield, Connecticut
Re-Engineering O&M for Nitrogen & Phosphorus Removal

Oxygen-Rich, low BOD environment
Nitrogen
Ammonia Removal – Nitrification
Phosphorus
Dissolved Oxygen converted to TSS (particulate Phosphorus)

Oxygen-Poor, high BOD environment
Nitrogen
Nitrate Removal – Denitrification
Phosphorus
Volatile Fatty Acid (VFA) production; if anaerobic/fermentative

TSS Removal
Nitrogen
12% of MLSS is Nitrogen (8 mg/L TSS = 1 mg/L total-N)
Phosphorus
3-5% of MLSS is Phosphorus (2 mg/L TSS = 0.1 mg/L total-P)
Questions, Comments, Discussion
Making clean water affordable