Excellence in Engineering Since 1946
The City of London
A Look into Nutrient Removal Design

Presented by:
Jamie Mills, E.I.
Strand Associates, Inc.®
Presentation Outline

• About City of London WWTP
• City of London - Nutrients
• Process Exploration
  ‒ Total Nitrogen Removal
  ‒ Biological Phosphorus Removal
  ‒ Chemical Phosphorus Removal
  ‒ Bench Testing
  ‒ Design
• Paths Forward
Presentation Outline

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City of London WWTP

London WWTP Service Area:

- London Population 10,100
- Two State Correction Institutions
  - 4750 Inmates
- Average Flow 2.68 MGD

Map Data: Google

Source: Ohio Department of Transportation
City of London WWTP

- Upgrade in 2007
- Design Flow 5.8 MGD
- Peak Flow 17.1 MGD
- Cost $24M+
Existing WWTP Liquid Train

- Screening and Grit Removal
- Primary Clarifiers
- Influent Pumping
- Flow Splitting
- Activated Sludge
- Final Clarifiers
- Post Aeration and UV Disinfection
- Effluent Pumping
Existing WWTP Solids Train

Primary Sludge

Sludge Concentration Building

Waste Activated Sludge (WAS)

Anaerobic Digestion and Sludge Storage

Gravity Thickener

Sludge Dewatering

Map Data: Google
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City of London – Nutrients

Total Phosphorus Loading

Plant Data - 3 Months
Total Phosphorus

<table>
<thead>
<tr>
<th></th>
<th>Influent</th>
<th>Primary</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>3.86</td>
<td>4.01</td>
<td>1.76</td>
</tr>
<tr>
<td>Daily Maximum</td>
<td>8.94</td>
<td>10.2</td>
<td>3.66</td>
</tr>
</tbody>
</table>
Total Phosphorus Loading

2016 Septic Hauling
• WWTP received 2,753,615 gallons
• Septic TP: Approximately 15 lbs TP/day

2018 Septic Hauling
• WWTP received 3,617,541 gallons
• Septic TP: Approximately 20 lbs TP/day

2019 Septic Hauling (Up to May)
• WWTP received 1,879,270 gallons
• Septic TP: Approximately 26 lbs TP/day

With Permission of: Dan Leavitt

STRAND ASSOCIATES
City of London – Nutrients

- City of London WWTP discharges to Oak Creek
  - Oak Creek is a tributary of Deer Creek lake

- Oak Creek flows in Comparison to WWTP flows
  - Low flow Stream: 1.5 MGD
  - Design flow: 5.8 MGD
  - Average Flow: 2.8 MGD
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# Nutrient Removal Options

<table>
<thead>
<tr>
<th><strong>Physical/Chemical Processes</strong></th>
<th><strong>Phosphorus Control</strong></th>
<th><strong>Nitrogen Control</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Chemical precipitation</td>
<td>• Air or steam stripping</td>
</tr>
<tr>
<td></td>
<td>• Clarification/filtration</td>
<td>• Ion exchange</td>
</tr>
<tr>
<td></td>
<td>• Media adsorption/ion exchange</td>
<td>• Break-point chlorination</td>
</tr>
<tr>
<td></td>
<td>• Chemicals + UF membranes</td>
<td>• Activated carbon</td>
</tr>
<tr>
<td></td>
<td>• Reverse osmosis</td>
<td>• Struvite precipitation</td>
</tr>
<tr>
<td></td>
<td>• Struvite precipitation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Biological Processes</strong></th>
<th><strong>(Enhanced) Biological Phosphorus Removal</strong></th>
<th><strong>Nitrogen Control</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Ammonification (hydrolysis)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Nitrification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Denitrification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Deammonification (anammox)</td>
<td></td>
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</tbody>
</table>
Total Nitrogen Removal

Aerobic Zone
- Food Source = NH$_4^+$
- Energy Source = DO

Anoxic Zone
- Food Source = BOD
- Energy Source = Nitrate

Nitrification
$\text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^-$

Active microbes:
Nitrosomonas, Nitrobacter

Denitrification
$\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$

Active microbes:
Pseudomonas, Achromobacter, Micrococcus

Source: Maryland Biochemical Company
Total Nitrogen Removal Benefits

- Increased Settleability
- Nitrogen Removal (Good for the receiving streams)
- Alkalinity Restoration
- Oxygen Credit/Energy Savings
- Increased Oxygen Transfer
- Beneficial for BPR
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Biological Phosphorus Removal (BPR)

- Facilitate Growth of Phosphorus Accumulating Organisms (PAOs)

**ANAEROBIC**
- Organics (BOD)
- Facultative Microbes
- VFA's + Fermentation Products
- Soluble BOD
- Phosphorus Accumulating Organisms
- ADP/ATP
- PHB

**AEROBIC**
- O₂
- CO₂ + H₂O
- ADP/ATP
- PHB
- New Cells

**PHB: Storage Product**
**ATP: High Energy Phosphorus Compound**
Biological P Removal - Principles

Phosphorus cycle involves release in anaerobic zone, “luxury” uptake in aerobic zone

<table>
<thead>
<tr>
<th>TIME</th>
<th>CONC. (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 to 2 hrs</td>
<td>Soluble BOD</td>
</tr>
<tr>
<td>2 to 10 hrs</td>
<td>Soluble Phosphorus (Normal w/BPR)</td>
</tr>
</tbody>
</table>
Biological Phosphorus Removal (BPR)

Controls and Monitoring of PAOs

- ORP Range from Negative to Positive +

- Anaerobic Activity
- Anoxic Activity
- Aerobic Activity

- BOD Removal +50mV to +250mV
- Nitrification +50mV to +350mV
- Phosphorus Uptake +50mV to +350mV
- Denitrification -150mV to +50mV
- Phosphorus Release -150mV to +50mV
- Acid, Sulfide and Methane Formation -150mV to -400mV

Oxidation Reduction Potential Values and Corresponding Biochemical Reactions
Biological Phosphorus Removal (BPR)

Several Difference Tank Configurations Exist

- A2O Process
- Cape Town Process
- Bardenpho
- RAS Fermentation
Biological Phosphorus Removal (BPR)

Where is BPR a Good Candidate?

• Where BPR tends TO work
  – Plants with long sewers/force mains
  – High strength wastewater
  – Large industrial flows with high soluble BOD

• Where BPR tends NOT to work
  – Plants with low strength wastewater
    o Fermentation step or soluble BOD may need to be added
  – Attached growth plants
    o Trickling filters/Rotating Biological Contactors (RBCs)
  – Plants that use co-thickening
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Chemical Phosphorus Removal - Principles

- Chemical Phosphorus Removal
  - Add lime, iron, or aluminum salt
  - Precipitation of soluble phosphorus
  - Precipitated P removed during clarification, filtration
  - Relatively simple process
  - Higher sludge production

Courtesy of: Strand Associates, Inc.®
Chemical P Removal - Principles

CPR - Typical Schematic

Chemical Storage and Metering → Primary Clarification → Activated Sludge → Final Clarification → Tertiary Filtration

Primary Clarification → Sludge Processing Recycle

Activated Sludge
Chemical Phosphorus Removal (CPR)

Pros

• Simplicity
• Effectiveness

Cons

• Lowers pH
• Consumes alkalinity
• Increases sludge production 15-25%

Courtesy of: Strand Associates, Inc.®
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Bench-Scale BPR Testing - Purpose

- “Potential Testing” - Determine if wastewater has enough VFAs and soluble BOD to facilitate BPR
- Measure phosphorus release with target WWTP raw wastewater and biomass from BPR WWTP

Courtesy of: Strand Associates, Inc.®
Bench-Scale BPR Testing
Bench-Scale BPR Testing
Bench-Scale BPR Testing

Example - Ideal Testing Response

Phosphorus Concentration (mg/L) vs. Time (min)

- Chilton RW
- Chilton RW + Acetate
Bench-Scale BPR Test Results – City of London

- Anaerobic phosphorous release larger in spiked sample
- Moderate potential for BPR, limited by lack of “food” in influent
CPR Jar Test - Purpose

• Dose Rates – Identify the most economical chemical
• Dose Location
• Determine Side Effects
  — pH Depression
  — Alkalinity Loss

Courtesy of: Strand Associates, Inc.®
CPR Jar Test

Courtesy of: Strand Associates, Inc.®
CPR Jar Test Results – City of London

- Higher doses needed for influent vs mixed liquor
- Effectiveness at high doses decreases
CPR or BPR can meet 1 mg/L when implemented properly.

Important to understand pros and cons of each process before making decision.

### Phosphorus Removal Summary

<table>
<thead>
<tr>
<th>Factor</th>
<th>CPR</th>
<th>BPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Operation</td>
<td>Easier?</td>
<td>More Difficult?</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Higher Cost</td>
<td>Lower Cost</td>
</tr>
<tr>
<td>Reliability</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Sludge Costs</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Lower Limits</td>
<td>May Meet/Filtration</td>
<td>Add CPR/Filtration</td>
</tr>
</tbody>
</table>
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WWTP Liquid Train - Incorporating Nutrient Removal Design

- Screening and Grit Removal
- Primary Clarifiers
- Influent Pumping
- Flow Splitting
- Activated Sludge
- Final Clarifiers
- Post Aeration and UV Disinfection
- Effluent Pumping
- Flow Splitting
- Anaerobic Selector Tank
- Improved Anoxic Zones
- Chemical Dosing

Map Data: Google
WWTP Solids Train – Incorporating P-Removal Design

- Primary Sludge
- Sludge Concentration Building
- Waste Activated Sludge (WAS)
- Anaerobic Digestion and Sludge Storage
- Sludge Gravity Thickener Equalization Tank
- Sludge Dewatering

Source: Google
Incorporating BPR at London’s WWTP

Anaerobic Selector No.4
Anaerobic Selector No.3
Anaerobic Selector No.2
Anaerobic Selector No.1

PRE + RAS
PRE
RAS
Wet Weather Bypass
PRE
RAS

Tank Bypass Valve

Courtesy of: Strand Associates, Inc.®
Incorporating N-Removal at Londons WWTP

Tank Influent

Nitrate Recycle

Tank Effluent

Cell 1

Submersible Mixer

Cell 2

Submersible Mixer

Cell 3

Cell 4

Cell 5

Cell 6

Courtesy of: Strand Associates, Inc.
Incorporating CPR at Londons WWTP

Chemical Dosing to Final Clarifier Splitter Structure

Chemical Dosing to Sludge Digestion Facility

Chemical Dosing to Recycle Pump Station

2 inch PRC Feed from Chemical Storage Tank

Courtesy of: Strand Associates, Inc.®
Incorporating CPR at London’s WWTP

Splitter Structure
Outlet to Final Clarifier No.1

Splitter Structure
Outlet to Final Clarifier No.2

Splitter Structure
Outlet to Final Clarifier No.3

Splitter Structure
Outlet to Final Clarifier No.4

Chemical Dosing Location

Courtesy of: Strand Associates, Inc.®
Incorporating Solids Handling at London's WWTP

Courtesy of: Strand Associates, Inc.®
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Paths Forward

• Design is complete and now awaiting funding from WPCLF

• Design:
  • To year 2040 and projected population of approximately 18,000

• Nutrient Project includes
  — Add Denitrification for Total Nitrogen Removal
  — Implement A₂/O Process for Bio-P Removal
  — Implement Chemical Phosphorus Removal
  — Add Sludge Equalization Tank for Sludge Storage
Questions?

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Thank you!
BPR Process Understanding Still Evolving Today

• Conventional mainstream anaerobic zone promotes Accumulibacter PAO that needs supply of VFA (acetic and propionic)

• Mainstream conditions not ideal for symbiotic PAO species like Tetrasphaera, which can ferment glucose and amino acids and other higher carbon forms and also store phosphorus

• Sidestream anaerobic fermenter allows Tetrasphaera produce VFA that allows Accumulibacter to also function alongside

• Tetrasphaera denitrify under anoxic conditions

• Keys to the puzzle:
  — Need ORP < -300 mV; most anaerobic zones struggle to get -150 mV
  — Impossible to achieve with NO3 or DO present
  — Turbulence, air entrainment, air mixing prevent low ORP
Key Influent Data

- Minimum recommended influent concentrations and ratios
  - Readily biodegradable soluble COD: 60 mg/L
  - $\text{BOD}_5/\text{TP}$: 20
  - Soluble $\text{BOD}_5$/soluble phosphorus: 15
  - Total COD/TP: 50

London:
$\text{CBOD}_5/\text{TP} = 44 \text{ mg/L (Influent)}$
$\text{CBOD}_5/\text{TP} = 36 \text{ mg/L (Primary Effluent)}$
City of London – Nutrients

Total Phosphorus Recycle

Belt Press Filtrate

• Class A anaerobic digester system
• 2016 Sludge Press - 5.67 MG
• 22 lbs TP per day in the Filtrate