Phosphorus Control at GLWA’s High Purity Oxygen WRRF

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GLWA WATER RESOURCE RECOVERY FACILITY

Serves 35% of Michigan’s population
• ~3.5 million people in 77 communities
• over a 946 sq. miles of service area

Only one GLWA WRRF in system
• Treatment Capacity: 1700 MGD primary
• 930 MGD secondary treatment
• 658 MGD average flow

Solids Disposal Requirements
• Average day - 450 dry tons
• Peak day – 850 dry tons
During dry weather, all wastewater flows to the WRRF for complete treatment. As wet weather flows increase beyond the WRRF’s capacity, retention basins capture the 1st flush. If the capacity of these Combined Sewer Overflow (CSO) Retention Basins is exceeded, primary treated and disinfected CSO flow is sent to the river. During wet weather, when treatment or hydraulic capacity is exceeded, some untreated CSO flows are diverted to the river.

Annually, the WRRF treats enough wastewater to fill 375,000 Olympic swimming pools and removes enough solids from the wastewater to fill all the box cars on a train over 30 miles long.
Phosphorus

Impact on the Environment
Increasing population requires better phosphorus management

“The phosphorus content of our land, following generations of cultivation, has greatly diminished. It needs replenishing. I cannot over-emphasize the importance of phosphorus not only to agriculture and soil conservation, but also the physical health and economic security of the people of the nation. Many of our soil deposits are deficient in phosphorus, thus causing low yield and poor quality of crops and pastures...."

- President Franklin D. Roosevelt, 1938
2012 Great Lakes Water Quality Agreement

Additional research to address excess Cladophora

Reduce TP loads 40% to control hypoxic “Dead Zone”

Reduce spring TP and OP loads 40% to control cyanobacteria
**Can we close the phosphorus cycle?**

### A Valuable Resource
- Critical for plant growth
- Mined and shipped
- Finite resource
- Necessary for agricultural
- Not evenly distributed globally
- Geopolitical issue

### An Environmental Pollutant
- Excess phosphorus in waterways causes harmful algae blooms
  - Runoff from agricultural fields
  - Runoff from CAFOs
  - Effluent WWTP.
  - Failing septic systems

### Phosphorus Conservation
- Phosphorus can be captured and reused
- Manage manure spreading
- Increase capture in WWTP
- Manage biosolids spreading
- Recovery of phosphorus fertilizers from WWTP side streams and/or biosolids
Sustaining Michigan’s Water Heritage

*A Strategy for the Next Generation*

*October 2016*

**Vision Statement**

**Ecosystems Approach**

**A Sampling of the Goals**

- Protect and restore aquatic ecosystems
- Ensure clean and safe waters
- Invest in water infrastructure

*Personal take away:* Achieve a 40% reduction in the phosphorus loads to Western Lake Erie Basin by 2025
Phosphorus Control

At wastewater treatment facilities
Phosphorus Species

Total P

Dissolved P
- Ortho P (Reactive P)
- Inorganic Condensed P
- Soluble Organic P

Particulate P
- Particulate Reactive P
- Particulate Acid Hyd P
- Particulate Organic P
Objective: Convert Soluble P to Particulate P
Phosphorus Control in WWTP Effluents

**Chemical phosphorus removal**

Chemical precipitation is used to remove the inorganic forms of phosphate by the addition of a coagulant to wastewater

- Calcium
- Aluminum
- Iron

**Biological phosphorus removal**

Sewage treatment configuration applied to activated sludge systems for removal of phosphate

- Soluble and particulate phosphorus

  BPR is achieved by growing PAOs in anaerobic to aerobic conditions.
Typical Chemical Treatment Opportunities
Ferric Reaction with Phosphorus

The following illustrates a “stoichiometric reaction” of Fe+++ with P

\[
\text{FeCl}_3 + \text{H}_3\text{PO}_4 = \text{FePO}_4 + 3\text{HCl}
\]

1 mole of Fe reacts with 1 mole P

→ 5.2 mg ferric chloride per 1 mg P
→ 0.92 mg alkalinity per mg of ferric chloride
But the precipitation is not linear

- Initial removal - Stoichiometric
- Equilibrium control – need higher dose

Break ~ 1 mg/L
Biological Phosphorus Removal

Uses Phosphorus Accumulating Organisms (PAOs) in an anaerobic–aerobic system

Under anaerobic conditions

- Proliferation of PAOs occurs
- PAOs assimilate fermentation products (acetate) into storage products (polyhydroxybutyrate – PHB) and concomitantly release stored polyphosphate as ortho phosphate

In the aerobic tank

- PHB is oxidized and concomitantly phosphate is stored within the cell – luxury phosphorus uptake

*Stoichiometrically about 10 grams of bCOD is needed for the removal of one gram of phosphate*
Enhanced biological phosphorus removal (EBPR)

- **PO₄**
  - From wastewater

**Anaerobic**
- Poly P
- PHB
- Volatile Fatty Acids

**Aerobic**
- Poly P
- PHB
- O₂
Typical Biological Phosphorus Removal

Primary effluent → Anaerobic/Fermentative tank → Aerobic tank → Secondary clarifier → Disinfection

Return activated sludge (RAS)
## In Real Life: Phosphorus Removal Factors

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Biological</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Dose</td>
<td>– Anaerobic zone integrity</td>
</tr>
<tr>
<td>– pH</td>
<td>– Substrate availability</td>
</tr>
<tr>
<td>– Phosphorus profile</td>
<td>– Phosphorus vs. substrate limited</td>
</tr>
<tr>
<td>– Mixing</td>
<td>– Adequate Cations</td>
</tr>
<tr>
<td>– Contact time</td>
<td>– Aerobic zone</td>
</tr>
<tr>
<td>– Aging</td>
<td>– Secondary phosphorus release</td>
</tr>
<tr>
<td>– Alkalinity</td>
<td>– Solids separation</td>
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<tr>
<td>– Separation process</td>
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Phosphorus Permit Requirements

- Permit requirements for Total Phosphorus (TP)
- Secondary effluent is 0.7 mg/l with a seasonal limit of 0.6 mg/l from April – September
- Primary effluent - wet weather - 1.5 mg/l
GLWA-WRRF Phosphorous Control Protocol

- Maintain soluble phosphorous entering into aeration basins: 0.5 – 1.0 mg/l
- Maintain D.O. in last stage of aeration basins: 2.0 - 4.0 mg/l
- Maintain secondary clarifier’s hydraulic loading: 37 - 40 MGD
- Maintain sludge blanket depth in secondary clarifiers: 2 – 3 ft
- Maintain Sludge Retention Time (SRT) in gravity thickeners: <24 hrs
- Keep sludge aerated in storage tanks before it is sent for dewatering
- Dose Ferric Chloride: During dry weather @1.5 mg/l, wet weather 2.0 mg/l only if soluble phosphorous is above 1.0 mg/l entering into aeration basins

Outcomes: Phosphorus compliant, nutrient sufficient to prevent filamentous growth, prevent anaerobic activity in clarifiers for low effluent SS
Historical Phosphorus 1990-2017 YTD

Wastewater Treatment Plant Secondary Effluent Total Phosphorous Concentration

Generally works well
However at Seasonal Low Flows

Wastewater Treatment Plant Total Phosphorus Concentration

Effluent TP bumps against seasonal limit
Continuing Challenge to Improve

Drivers for improvement

• Control chemical costs – *always present!*
  - Ferric
  - Pure Oxygen

• Multiple opinions that ferric was being overfed *and multiple suggested changes to control scheme*

• Desire to continue good phosphorus removal at low flows

• Desire to push for lower phosphorus effluent levels
However: Questions Needed to be Answered

Data suggested biological phosphorus removal was present
  • Plant wasn’t designed for it and our control scheme did not account for it
  • What conditions in bioreactors promoted Bio-P?
  • Could Bio-P be maximized to reduce ferric feed?

Plant struggled to remove phosphorus during low flows < 500 MGD
  • Why?
  • Permit compliance becomes challenging in late summer
University-Utility Partnership

• Characterize the mechanisms of phosphorus removal, chemical and biological, with the goal optimizing performance and reducing costs for chemical additions
• Verify presence of bio-P organisms
• Characterize the profile of the phosphorus (total, colloidal, soluble) over time
• Measure kinetics in bioreactors
• Measure oxygen profile in all bio-reactors
• Update the process model to support further optimization efforts
Results to date

Preliminary
Conclusion: Plant definitely has Bio-P.
WR RF Constituent Mass Loadings Generally Independent of Influent Flow: Phosphorus

Relationship Between Plant Influent Flow and Phosphorus Loading

Data 2013 - 2016
Flow, Mass Loading Relationship Leads to Correlation of Flow and Concentration

Jan – Mid-Sept, 2017
TSP Removal (mg-P/L) Varies with Flow Rate Across Primaries

Begin to lose SP removal @ ~ 550 MGD

Jan – Mid-Sept, 2017
And, Chemical Use Efficiency Varies with Flow Rate Across Primary

In general mixing is poor, but improves slightly between 650 and 500 MGD.
Mixing Improvement Needed
TSP Removal by Biological Process Increases as Flow Decreases Because More TSP Available

Data 2013 - 2016
New hypothesis for control

- Primary SP removal decreases with decreasing flow, and Bio-P increases – maxes capability out.

- At much lower flow primary SP removal becomes *very bad* and Bio-P cannot remove more; phosphorus is higher in secondary effluent.

- To address poor SP removal at very low flow – now adding ferric at the end of aeration decks (*post aeration*)
Installed FeCl₃ Addition for Polishing
Plan to further lock in improvements

• Continue to refine control protocol for continued good phosphorus removal at low flow ---
• Add increased mixing to ferric addition points in PS 1 and PS2- need engineering
• Investigate two step ferric dosing as way to reduce ferric use after mixing upgrade
• Evaluate addition of ferric to side-streams
• Evaluate methods to increase Bio-P removal and reduce ferric addition
• Increase sensor and automated control for Ferric Chloride addition