WELCOME TO THE MARCH EDITION OF THE 2013 M&R SEMINAR SERIES
BEFORE WE BEGIN

• SILENCE CELL PHONES & SMART PHONES

• QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION

• PLEASE FILL EVALUATION FORM

• SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE

• STREAM VIDEO WILL BE AVAILABLE ON MWRD WEBSITE
  (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)
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Current: Principal Engineer, Metropolitan Council Environmental Services, Minneapolis/St Paul, MN

Experience: More than 24 years of environmental engineering experience with Metropolitan Council Environmental Services
Research and development department (2 yrs):

Support services business group (22 yrs):

Enhanced Biological Phosphorus Removal Full-Scale Test and Retrofit Track, analyze, trouble shoot and optimize treatment systems at all MCES treatment facilities.

Education: B.S. in Civil Engineering, University of Minnesota, Minneapolis, MN

Professional: Registered Professional Engineer in Minnesota
George Spouse, Ph.D., PE

Current: Manager of Process Engineering Group, Metropolitan Council Environmental Services (MCES), Minneapolis/St Paul, MN

Experience: Manager of Process Engineering Group

- Manage a group of 8 engineers and scientists whose mission is to track, analyze, trouble shoot and optimize treatment systems at all MCES treatment facilities.

- Project Manager, Technical Services Group, MCES
- Process Engineer, at MWH, Chicago, IL
- Process Engineer, at Baxter and Woodman, Cristal Lake, IL

Education: B.S. & M.S. in Civil/Environmental Engineering, University of Illinois, Champaign-Urbana, IL

- Ph.D. in Civil/Environmental Engineering, Northwestern University, Evanston, IL

Professional: Registered Professional Engineer in California, Illinois, Minnesota and Wisconsin
Implementation and Operation of Enhanced Biological Phosphorus Removal at the Metropolitan WWTP

Christine Voigt
George Sprouse

MWRDGC  April 5, 2013
Presentation Outline

• Brief background on Metropolitan Council Environmental Services (MCES)

• History of effluent phosphorus removal implementation at the Metropolitan WWTP (Metro)

• Enhanced biological phosphorus removal at Metro
  – Configuration and systems
  – Operational history
  – Lessons learned – Metro and other MCES P-removal plants

• The future
Formed in 1967
Seven county area - (3,000 square miles)
17 member board
Operates regional wastewater, transit and parks system
Coordinates regional planning and guides development
Phosphorus Removal at the Metro Plant

• 1988 drought provided the impetus

• Phosphorus reduction efforts at the Metro Plant have their origins back in 1988. That’s when the state suffered its worst drought in years and a massive algae explosion in Lake Pepin was blamed in large part on phosphorus discharged from the Metro Plant.

• As a result of negotiations with the Minnesota Pollution Control Agency (MPCA) and the U.S. Environmental Protection Agency, the Council began a series of studies in 1990. Among the goals were to determine both the contribution that the Metro Plant makes to phosphorus loads in the Mississippi River and the most effective way to reduce phosphorus discharged from the plant.
Metropolitan Council Environmental Services

- Provides regional wastewater conveyance and treatment for the 7 county metropolitan area of the Twin Cities, MN
  - Provides service to 2.5 million people and 104 communities
- Owns and operates 7 wastewater treatment plants with 1 under construction:

<table>
<thead>
<tr>
<th>Facility/River</th>
<th>Permitted WW Flow</th>
<th>Phosphorus and Nutrient Effluent Limits/Phosphorus Removal Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan Mississippi</td>
<td>314 mgd</td>
<td>1.0 mgTP/l*; seasonal ammonia limits Enhanced biological phosphorus removal activated sludge system (EBPR) (2005)</td>
</tr>
<tr>
<td>Blue Lake Minnesota</td>
<td>42 mgd</td>
<td>1.0 mgTP/l*; seasonal ammonia limits EBPR (2008) with ferric chloride addition capabilities</td>
</tr>
<tr>
<td>Seneca Minnesota</td>
<td>38 mgd</td>
<td>1.0 mgTP/l*; seasonal ammonia limits EBPR (2008) with alum addition capabilities</td>
</tr>
<tr>
<td>Empire Mississippi</td>
<td>28.6 mgd</td>
<td>1.0 mgTP/l*; seasonal ammonia limits EBPR (2006)</td>
</tr>
<tr>
<td>Eagles Point Mississippi</td>
<td>11.9 mgd</td>
<td>1.0 mgTP/l*; seasonal ammonia limits EBPR (2003) with alum addition capabilities</td>
</tr>
<tr>
<td>St Croix Valley St Croix</td>
<td>5.8 mgd</td>
<td>0.8 mgP/l monthly TP Alum addition chemical system</td>
</tr>
<tr>
<td>Hasting Mississippi</td>
<td>2.7 mgd</td>
<td>Monitor only</td>
</tr>
<tr>
<td>East Bethel (under const.)</td>
<td>0.47 mgd</td>
<td>1.0 mgP/l monthly TP; 10.0 mgN/l monthly TN (TKN+nitrate, nitrite) MBR with EBPR and chemical addition capabilities</td>
</tr>
</tbody>
</table>

* 12 month moving average
MCES 12-Month Moving Average Effluent TP from Permit Limited Plants
Phosphorous Load Contributions in the Metro Area

Phosphorus Load (tons/year)

Metro Nonpoint
Metro Rivers
Metro WWTPs
Metropolitan Wastewater Treatment Facility

- Current: 180 MGD
- Design Avg: 251 MGD
- Primary Treatment
- Activated Sludge
  - Nitrification
  - Biological Phosphorous Removal
- Disinfection
- Solids Dewatering
- Incineration
Phosphorus Removal - Implementation

• 1990 - 1991
  • Evaluate alternatives

• 1992 – 1993
  • Demonstration Projects
    • chemical removal
    • biological removal

• 1997 – 2001
  • Full scale demonstration of biological phosphorous
    • 25% of secondary treatment converted
  • Year+ data gathering and evaluations of bio-P system and settling tank improvements
Phosphorus Removal - Implementation

- 2001 - 2005
  - Remaining facility converted to biological phosphorous
- 2003
  - Permit limit 3 mg/l monthly
- 2005
  - Permit limit 1 mg/l annual
- 2002 – 2006
  - Solids systems upgrades including decommissioning of thermal conditioning
- 2005 -2012
  - Actual 0.6 – 0.4 mgTP/l
Enhanced Biological P Removal

Key items:
- Availability of VFAs
- Absence of Nitrates (nitrates allow other organisms to grow and compete with PAOs for VFAs)
Initial (and on-going) Bio-P evaluations include monitoring VFA concentrations.
Bio-P Major Modifications:

• Converted all aeration tanks to fine bubble diffusers

• Converted step feed aeration nitrifying activated sludge system to plug flow Bio-P configuration
  – Feed Pipe
  – Baffles and mixing
  – RAS splitter box

• Modified final settling tanks
  – Replaced cross collector with suction header
  – Implemented channel flocculating baffling
  – Implemented FST influent energy dissipation, flocculation baffling
Final Settling Tanks

- Efficient removal of sludge from tank to eliminate potential for P release
- Limit is **Total P** and TSS will be >5% Phosphorus with Bio-P: excellent TSS capture and performance required at settling
Bio-P Modes

BIO-P MODE 1
SUMMER OPERATION

BIO-P MODE 2
SPRING/FALL OPERATION

BIO-P MODE 3
WINTER-WARM OPERATION

BIO-P MODE 4
WINTER-COLD OPERATION

AERObIC SLUDGE RETURN (RAS REAERATION)

ANAEROBIC CONTACT

ANOXIC SLUDGE RETURN

AERATED (AEROBIC) CONTACT
**Bio-P Configuration Zones**

**Anaerobic Contact**
- PAOs use energy stored in phosphate bonds (releasing phosphate) to collect volatile fatty acids and form internal organic storage products.

**RAS Anoxic Contact**
- Heterotrophs use nitrate in respiration – removes nitrate and provides appropriate Bio-P conditions in the next zone.

**Aerobic Contact**
- PAOs use internal organic storage products to grow and collect phosphate into energy containing phosphate compounds.
- Nitrifiers use ammonia and produce nitrate.
- Ordinary Heterotrophs use remaining organics to grow.

**RAS Aeration**
- Residence time to allow nitrifiers to grow on remaining ammonia – maintain a nitrifier population through cold conditions. Concentrated Mass here allows lower MLSS to clarifiers at same SRT.

**Secondary Influent**

**Phosphorus Reduced Secondary Effluent**

**Phosphorus Enriched WAS**

**RAS**
Modes’ Design Concept

- **Mode 1**: SRT = 8 days, SRT = 10 days
- **Mode 2**: SRT = 8 days, SRT = 10 days
- **Mode 3**: SRT = 10 days, SRT = 12 days
- **Mode 4**: SRT = 10 days, SRT = 10-14 days

- Temperature (°C)
  - 12
  - 13
  - 14
  - 15
  - 16
  - 17
  - 18
  - 19
  - 20
  - 21

- Effluent Ammonia-Nitrogen (mg/L)
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12

Graph shows the relationship between temperature and effluent ammonia-nitrogen concentration for different modes of operation.
Metro made 2 mode changes during the period 9/97 through 9/98.
Metro made 4 mode changes during the period 1/00 through 3/01.
Mode Operation

• For general operation since process proving, **Mode 1** has been used under all temperature conditions and has:
  
  – achieved phosphorus effluent requirements

  – maintained adequate nitrifying population to allow seasonal adjustments as needed to the level of nitrification
Metro had 2 prevalent filamentous foaming organisms with the initial implementation of Bio-P, Norcardia & Microthrix Parvicella.

Nocardia is a **branched** filament that prevails during warm weather. M. parvicella is an **unbranched** filament that prevails during cold weather.
Foam is trapped at the end of each pass where mixed liquor goes under the Y-wall.
Foam is trapped at the tank outlet.
Metro controlled the foam by selective foam wasting in the RAS re-aeration zone, but design needed improvement.

- Foam is hard to pump
  - Rotary lobe pumps
- Did not remove foam in other passes
- Manual operation is difficult (16 tanks)
Improved foam wasting design provided 4 points for withdrawal & automatic foam level control
Foam and Filament Control at Metro

• Close observation of micro biology
• Operate at lower SRT, “Hydraulic” SRT for stable control of WAS rate
• Close observation of settleability parameters and conditions
  – SVI
  – Centrifuged volume
  – Blanket depth
• Selective use of RAS chlorination
~Bio-P Costs 2002 to present

<table>
<thead>
<tr>
<th>Facility</th>
<th>~Cost for Bio-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro</td>
<td>$36M*</td>
</tr>
<tr>
<td>Blue Lake</td>
<td>$9M</td>
</tr>
<tr>
<td>Seneca</td>
<td>$8M</td>
</tr>
<tr>
<td>Empire</td>
<td>$2M</td>
</tr>
<tr>
<td>Eagles Point</td>
<td>$0.9M</td>
</tr>
</tbody>
</table>

*Earlier phase include conversion of ¼ of the tankage for Bio-P testing as well as other significant modifications, rehabilitations and improvements (e.g. diffuser replacement). Total earlier phase program cost was ~ $38M
Observations and Lessons Learned

• Effluent TP variation – seasonal and weekly

• Impact of influent TP concentration

• Metro’s configuration and RAS aeration and non-aerated observations

• Bio-P response to extended reduction in wastage

• Importance of stable DO control (initial aerobic zones particularly)

• Recycle and load distribution between tanks

• Importance of influent soluble readily biodegradable COD

• Impact of RAS nitrates

• RAS chlorination impact on effluent P

• Dewaterability of anaerobically digested Bio-P sludge
Effluent P Variations - Seasonal

What are the differences between pre-2008 and post-2008?
Potential Causes for Seasonal TP Fluctuations

• Secondary influent characteristics
  – VFA and P concentrations
  – Recycle impacts

• Anaerobic Zone Effectiveness
  – VFA production, nitrate reduction

• DO Profile
  – P uptake and metabolism of intermediates

• P Release in FSTs
  – Solids retention

• Seasonal/temperature impacts on microorganisms
Weekly influent organic and/or nitrogen pattern impact/influence on Bio-P storage product cycle
Influent and Effluent TP

July 2010
Dishwashing P Ban

Graph showing the trend of Effluent TP (mg/l) and Influent TP (mg/l) from 2005 to 2013.
Period in NE Quad with No Aeration of Zone 1 – Low Air Mixing

**NE Quadrant:**

- **Influent**
  - Anoxic Zone (1)
  - Anaerobic Zones (2-4)
  - Aeration Zones (5-12)
  - **Effluent**
  - **Waste Sludge**
  - **Return Activated Sludge**

**Other Quadrants (SE, NW, SW):**

- **Influent**
  - Re-Aeration Zone (1)
  - Anoxic Zone (2)
  - Anaerobic Zones (3-4)
  - Aeration Zones (5-12)
  - **Effluent**
  - **Waste Sludge**
  - **Return Activated Sludge**
Period in NE Quad with No Aeration of Zone 1

- NE Quadrant – More consistent effluent phosphorus when exposed to increased phosphorus loads

- Observation of higher levels of filaments with the NE quadrant

- Not taxed in terms of nitrification during periods of operation in this mode
NE Bleach

NE zone 1 aerated, Influent added at start of zone 3
(Same mode as SE, SW, & NW)
2010 Metro Test of Reduced Wastage

- Reduced wastage from one quarter of the plant to evaluate potential full plant impacts to accommodate future solids handling train projects
  - WAS was decreased from 1 mgd to 0.5 MGD for ~3 months in one quadrant of the plant
Weekly Avg Effluent TP

- FST 20 TP
- FST 23 TP
- SE Waste Flow

SRT ~ 9 to 10 days

SRT ~ 20 days

FST Avg: 0.35 mg/L
FST Avg: 0.45 mg/L
FST Avg: 0.31 mg/L
Seneca plant – Existing configuration
Stable DO Concentrations/Control (Seneca)

- One DO probe per tank at the end controls airflow to each tank
- Unable to provide sufficient air at front of tank for Bio-P
Stable DO Concentrations/Control (Seneca)

Seneca Plant: Effluent TP and Total Aeration Airflow

Effluent TP (mg/L)

Total Aeration Airflow (KSCFM)

- Effluent TP
- Total Aeration Airflow
Soluble Readily Biodegradable Organics

• Eagles Point – difficult to maintain Bio-P and alum was used
  – Interceptor includes drop structures that may aerate the sewage and limit production of fermentation products
  – Plant includes a primary sludge gravity thickener/fermenter
    • Thickener/fermenter recently has been successful in producing and returning sufficient soluble readily biodegradable organics – required implementation of elutriation flow

• Empire
  – Receives 100 mgCOD/l soluble readily biodegradable in the influent from an industry
  – For a period this industrial contribution was diverted and the impact was apparent
Soluble Readily Biodegradable Organics
Response: Reduced RAS and the Nitrate Return

Empire Daily Data - Effluent TP

- Influent SBCOD Redirected
- Influent SBCOD Reintroduced

Effluent TP (mg/l)

RAS Ratio

- Effluent Effluent Tot Phos
- RAS Ratio

Date:
- 3/12/12 to 4/8/13
Experience with Bio-P and RAS Chlorination for Filament Control

- Effluent phosphorus increases when RAS is dosed with chlorine for filament control
Possible Relationship between Anaerobic Digestion of Bio-P Sludge and Dewaterability

<table>
<thead>
<tr>
<th>Empire – Belt Press Dewatering</th>
<th>Average Cake Solids ± 1 Std Dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition</strong></td>
<td><strong>Before: 2 Sludge (HR+Nit) with no Bio-P (2005)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>After: 1 Sludge with Bio-P (2009)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>After: 1 Sludge with Bio-P (2012)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Blue Lake – Centrifuge Dewatering</th>
<th>Average Cake Solids ± 1 Std Dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition</strong></td>
<td><strong>Before Anaerobic Digestion (2009)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Before Anaerobic Digestion (2010)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>After Anaerobic Digestion (2nd Half 2012, 2013 to date)</strong></td>
</tr>
</tbody>
</table>

Please note: There is a project on this subject underway by Charles Bott of Hampton Roads Sanitation District, Matt Higgins of Bucknell University, and others
The Future

- Potential for lower total phosphorus limits
- Potential for nitrate and/or total nitrogen limits
The Future

• Evaluating in-situ ammonium, nitrate probes
  – Further optimize aeration control and power use
  – Nitrate monitoring in possible future nitrate, TN limit configurations

• Pursuing further reduction of return phosphorus load
  – Management of thickened sludge storage to reduce release
  – Chemical treatment of dewatering, side stream

• Planning to determine/confirm important rates and parameters for next phases
  – nitrification rates, denitrification rates, phosphorus uptake

• Pilot digestion investigations of dewatering performance

• Real time monitoring of oxygen transfer efficiency
  – currently in place
  – Determine best use of information

• Evaluation of luminescent, fluorescent dissolved oxygen instruments
THANK YOU

Questions/Discussion
Other slides
The Metro Plant
Long-Term Wastewater Service Area Map
Formed in 1967
- Seven county area - (3,000 square miles)
- 17 member board
- Operates regional wastewater, transit and parks system
- Coordinates regional planning and guides development
The Metro Plant
### Some Milestones in Metro P removal

<table>
<thead>
<tr>
<th>Date</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 1990</td>
<td>NPDES permit issued. Required two-phase study of assessing P removal</td>
</tr>
<tr>
<td>June 1991</td>
<td>Completed Phase I Evaluation</td>
</tr>
<tr>
<td>Jan to Nov 1992</td>
<td>Plant Demonstration Testing of Chemical Removal (Ph II)</td>
</tr>
<tr>
<td></td>
<td>3 Full Scale Primary Sed Tanks with 3 Control</td>
</tr>
<tr>
<td>July 92 to Aug 1993</td>
<td>Plant Demonstration Testing of EBPR (Ph II)</td>
</tr>
<tr>
<td></td>
<td>2 Full Scale Test Aeration Basin and 3 Sed Tanks. A/O.</td>
</tr>
<tr>
<td>Nov 1993</td>
<td>NPDES permit issued. Achieve 4 mgTP/l; Design and construct SS treatment. Master Plan for 1 mgTP/l required before July 1997</td>
</tr>
<tr>
<td>Dec 1994</td>
<td>Final Facilities Plan</td>
</tr>
<tr>
<td></td>
<td>Seven side stream treatment alternatives evaluated</td>
</tr>
</tbody>
</table>
Table ES.1  Side stream treatment alternatives.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Description</th>
<th>Treatment type</th>
<th>Eff TP reduction (mgTP/l)</th>
<th>25-yr annualized cost (10^6 $/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Physical/chemical side stream treatment using dedicated flotation thickeners</td>
<td>Physical/chemical</td>
<td>1.2 – 1.4</td>
<td>3.5 – 6.3</td>
</tr>
<tr>
<td>2a</td>
<td>Co-thickening in flotation thickeners with side streams and chemical addition</td>
<td>Physical/chemical</td>
<td>0.7 – 1.0</td>
<td>screened out</td>
</tr>
<tr>
<td>2b</td>
<td>Co-thickening in flotation thickeners</td>
<td>Physical</td>
<td>0.2 – 0.4</td>
<td>screened out</td>
</tr>
<tr>
<td>3</td>
<td>Physical chemical side stream treatment using dedicated flocculation/sedimentation tanks</td>
<td>Physical/chemical</td>
<td>1.0 – 1.2</td>
<td>3.5 – 7.4</td>
</tr>
<tr>
<td>4</td>
<td>Physical/chemical side stream treatment using primary sedimentation</td>
<td>Physical/chemical</td>
<td>0.1 – 0.3</td>
<td>screened out</td>
</tr>
<tr>
<td>5a and 5b</td>
<td>Side stream biological phosphorus treatment</td>
<td>Biological P-reduction</td>
<td>0.5 – 0.7</td>
<td>14.3 – 14.6</td>
</tr>
<tr>
<td>5c</td>
<td>Liquid stream biological phosphorus treatment</td>
<td>Biological P-reduction</td>
<td>0.3 – 0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>6</td>
<td>Side stream load equalization</td>
<td>Equalization</td>
<td>0.2 – 0.4</td>
<td>na</td>
</tr>
<tr>
<td>7</td>
<td>Physical side stream treatment in flotation thickeners with waste activated sludge</td>
<td>Physical</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Brown and Caldwell (1994) Side Stream Treatment Phosphorus Reduction Metropolitan Wastewater Treatment Plant: Final Facilities Plan
## Some Milestones in Metro P removal

<table>
<thead>
<tr>
<th>Date</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>End of 1995</td>
<td>Completed design/initiated construction phase of Bio-P process proving facilities (STIP I)</td>
</tr>
<tr>
<td></td>
<td>- converted ¼ aeration tanks to of the plant to Bio-P and implemented test improvements to some final settling tanks</td>
</tr>
<tr>
<td>Sept 97 to Sept 98</td>
<td>Accomplished full scale Bio-P removal and final settling tanks process proving programs</td>
</tr>
<tr>
<td>July 1999</td>
<td>Completed and Submitted Facility Plan for Phase II Secondary Treatment Improvements with plans for and goals of meeting NPDES requirements of:</td>
</tr>
<tr>
<td></td>
<td>- Commence operation of Bio-P removal and meet 3.0 mgTP/l limit by Dec 2003</td>
</tr>
<tr>
<td></td>
<td>- Meet 1.0 mgTP/l annual average by Dec 2005</td>
</tr>
<tr>
<td>2003</td>
<td>Completed construction phase of Bio-P process systems in full plant liquid stream (STIP II)</td>
</tr>
<tr>
<td>March 2005</td>
<td><strong>Metro Plant 12-monthly rolling average effluent TP &lt; 1.0 mg/l</strong></td>
</tr>
<tr>
<td>2002 - 2006</td>
<td>Conversion to centrifuge dewatering, conversion from multiple hearth to fluidized bed incineration, thermal heat treatment systems decommissioned</td>
</tr>
</tbody>
</table>
**Enhanced Biological P Removal**

- Sequence the conditions such that a certain type of organisms (PAO – phosphate accumulating organisms) have a competitive advantage and proliferate within the system.

- In aerobic conditions ($O_2$) – PAOs use internal stored organics to grow and accumulate phosphate in internal poly-phosphate compounds.
  - Removing these organisms from the system at this point (with the WAS), reduces the concentration of phosphate in the liquid stream.

- In anaerobic conditions (no $O_2$ or $NO_3^-$) - PAOs use the energy stored in the poly-phosphate compounds, releasing phosphate to the liquid stream, gather readily biodegradable soluble organics (volatile fatty acids, VFAs) and generate the internal stored organics from the VFAs.
  - Key items:
    - Availability of VFAs
    - Absence of Nitrates (nitrate allow other organisms to grow and compete with PAOs for VFAs)
Aeration Tank Modifications

11 - Point Step Feed Tank (Typical of 12)

BIO-P TANK (Typical of 4)

Flexible Membrane Diffusers
Ceramic Disc Diffusers
Automatic Air Control Valves
Manual Air Control Valves
Influent and Effluent TP

July 2010 Dishwashing P Ban

Effluent TP (mg/l) - 28 day running average
Influent TP (mg/l) - 28 day running average