Dewatering Optimization
Near-Term Savings and Long-Term Capital Planning

Richmond, VA; May 11, 2017

Liam Cavanaugh, Director of Operations
Outline

• Robert W. Hite Treatment Facility in Denver, CO
• Phosphorus Regulations and Impacts
• Dewatering Optimization: Why We Care
• Full-scale Dewatering Optimization
• Bench-scale Dewatering Optimization and Research
• Metro District’s Phosphorus Initiative
• Current Implementation Status
Robert W. Hite Treatment Facility

- 1.8 million population equivalent service area, 220 MGD
- Separate secondary processes, converting to A2O
- Combined solids processing creates significant sidestream
### Phosphorus Regulations and Drivers

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ammonia (Effective 2015)</strong></td>
<td>4.6 mg N/L (30 day average)</td>
</tr>
<tr>
<td></td>
<td>12.7 mg N/L (daily maximum)</td>
</tr>
<tr>
<td><strong>Nitrate+Nitrite (Effective 2015)</strong></td>
<td>8.7 mg N/L (7 day average)</td>
</tr>
<tr>
<td><strong>Total Nitrogen</strong></td>
<td>2.0 mg N/L (long-term)</td>
</tr>
<tr>
<td><strong>Total Phosphorus</strong></td>
<td>1.0 mg P/L (near-term)</td>
</tr>
<tr>
<td></td>
<td>0.1 mg P/L (medium-term)</td>
</tr>
</tbody>
</table>

- **2016**: Phosphorus Recovery Pilot Study
- **2015**: Phosphorus SROI and Tool for Evaluating Resource Recovery (TERRY)
- **2012**: EBPR Pilot Study
- **2011**: District Adopted Sustainable Return on Investment (SROI) model
- **2010**: CDPHE Proposed Nutrient Criteria
• 2011-2012 pilot study determined that effluent quality stability was determined directly related to digested sludge dewatering recycle loads.
Biological Phosphorus Removal Impacts

- Significant decrease in dewatered cake solids and increase in polymer demand were observed, in addition to struvite deposition.
- Piloting allowed staff to rapidly increase knowledge about effluent quality requirements and other side-effects and cost impacts.
Biological Phosphorus Removal Impacts

- Managing phosphorus in the solids processes and recycle stream became increasingly important to account for multiple drivers.
Dewatering Optimization: Why We Care

- $2.5 – $3.5M in annual dewatering polymer costs
- Complexity includes multiple variables
  - Targeted biosolids cake %TS – Hauling and land application regularity
  - Targeted dewatering capture efficiency
  - Polymer type and preparation
  - Centrifuge feed and mechanical settings
  - Sludge dewaterability

- Continuous optimization builds datasets for cost savings and future comparative evaluations

### Total District Combined Treatment and Hauling / Land Application Expenses - Emulsion Polymer

<table>
<thead>
<tr>
<th>Dewatered Cake TS%</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hauling/Land App</td>
<td>$4,031,977</td>
<td>$3,549,763</td>
<td>$3,316,589</td>
<td>$3,226,443</td>
</tr>
<tr>
<td>Polymer</td>
<td>$2,244,565</td>
<td>$2,694,699</td>
<td>$3,144,832</td>
<td>$3,594,965</td>
</tr>
<tr>
<td>Total</td>
<td>$6,276,543</td>
<td>$6,244,462</td>
<td>$6,461,421</td>
<td>$6,821,408</td>
</tr>
</tbody>
</table>
Full-scale Dewatering Optimization

• Increased attention to dewatering performance following biological phosphorus removal pilot.

• Developed a Standard Centrifuge Testing program.
  ➢ Monthly, with 2 dedicated centrifuges.
  ➢ 6 torque set points, 2 throughputs.
  ➢ 2 polymer types (dry, emulsion).
  ➢ Measured polymer dose, cake %TS, centrate TSS.

• Determined results through multiple metrics.
  ➢ Provided full-scale side-by-side comparisons.
  ➢ Determined economically efficient dewatering process targets.
  ➢ Assessed seasonal changes in sludge dewaterability.
• Graphical representations of dewatering results showed the impacts of operational modifications.
• Gained additional confidence in operator understanding and attention to dewatering.
Bench-scale Dewatering Optimization

• In-house development of the “Limit Dryness Test” to develop optimal polymer dose estimates.
• Staff understanding that changes are relative.
• Goal of bench-scale modifications to recommend pilot-scale activities.
Bench-scale Dewatering Optimization

- Real-time measurement of water release rate.
- Repeatability is critical for gaining confidence.
Bench-scale Dewatering Optimization

- Optimal polymer dose testing targeted more than cake %TS.
- Changes captured over time with changing process conditions.
Bench-scale Dewatering Optimization

- Optimal polymer dose tracked well with full-scale performance.
- Normalized to pounds of dry polymer per dry ton @ 20% TS.
Bench-scale Dewatering Research

• Testing of MgCl₂ addition and aeration showed significantly improved dewaterability.
• Consideration of recycle phosphorus control processes to meet other goals.
  • 90% reduction in filtrate ortho-phosphate
  • 10-20% reduction in dewatering polymer demand
• Improvements led to decision to move forward with digested sludge phosphorus recovery pilot testing.
Metro District’s Phosphorus Initiative

4 Angles

1. **Liquid stream TP removal**
   - **BIOLOGICAL REMOVAL OF PHOSPHORUS**
     - Full-Scale Bio-P Performance ........................................... 2015–2019
     - Carbon Augmentation ...................................................... 2015
     - Fermentation Studies ..................................................... 2016
     - Sidestream Denitrification Support Studies ...................... 2017
     - Sidestream Bio-P (WERF Studies) ...................................... 2016–2018
     - North Secondary Clarifier Performance Improvements .... 2017–2018
   - **PHOSPHORUS MANAGEMENT**
     - Phosphorus Land Application Studies .............................. 2015–2017
     - Struvite Reduction Dewaterability Improvements Evaluation 2016–2017
   - **WATERSHED STUDIES**
     - Watershed-Based Management Strategies ......................... 2016–2017
     - Bioavailability of Nutrient Fractions Study ...................... 2018
   - **TERTIARY FACILITIES**
     - Pilot Evaluation of Tertiary Technology Options .............. 2018–2019

2. **Solids TP removal**
Metro District’s Phosphorus Initiative

GOAL
To find the most effective and sustainable phosphorus management approach through an intensive study phase of phosphorus recovery technologies under the phosphorus initiative.
Effective and Sustainable Phosphorus Management

5 Measures for Success

1. Break the phosphorus recycle loop
2. Biosolids dewatering costs
3. Struvite-scale issues for O&M
4. Phosphorus loading on soils
5. Recovery of a finite resource

1 lb of phosphorus equates to 8 lbs of struvite. 7,000 lbs of phosphorus enter the RWHTF each day!
AirPrex Pilot Testing

**Hypothesis:**
Will create a controlled environment to precipitate struvite from District solids to simultaneously address:

- Break P-Recycle Loop
- Biosolids Dewatering
- Struvite Issues
- Phosphorus Index
- Product Recovery
Proven Innovation

- **Full Scale Installations:**
  - 5 in Germany
  - 4 in the Netherlands
  - 1 Belgium
  - 1 in China

- **Other US Pilot Investigations:**
  - Miami, FL
  - Stevens Point, WI
  - Fox River, IL
  - Fond du Lac, WI
  - Meridian, Idaho
  - Pima County, AZ
How Does AirPrex Work?

Digester effluent is fed to AirPrex reactor. Reactor is aerated which strips the CO$_2$ from the reactor and raises the pH. Magnesium is dosed to the reactor causing struvite to precipitate.

AirPrex effluent, stripped of phosphorus, is sent to dewatering centrifuges.

Struvite settles and is pumped out and cleaned. Centrate is pumped back to the digester. Biosolids are sent for further processing.
AirPrex Pilot

- Pilot onsite from June 6\textsuperscript{th} through August 3\textsuperscript{rd}
- Reactor operated continuously at a flow of 11 gpm
- Centrisys CS10-4 centrifuge operated 6 – 8 hours per day
- Mg:P molar dosing ratio varied between 0.7:1 – 1.7:1
### Sampling and Testing Protocol

- Weekly water quality analyses
- Daily dewatering analyses
- Over 3000 water and solids analyses!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reactor</th>
<th>Centrifuge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Underflow</td>
</tr>
<tr>
<td>pH</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Temperature</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Total Solids (TS)</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Volatile Solids (TVS)</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Total Ca, Mg, Fe, K, Na</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Dissolved Ca, Mg, Fe, K, Na</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Orthophosphate</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Water Extractable Phosphorus</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Acid-cake Struvite Test</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ammonium</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Conductivity</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Total Alkalinity</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>COD\textsubscript{EPS}</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
Modeling

- Thermodynamic modeling to model nuisance struvite formation potential upstream and downstream of the digesters and recovery technologies
- **Struvite Tool** (Office of Water Programs, Sacramento, California)
- **Visual Minteq** (KTH, Sweden)
- **BioWin**
- Effects of reduction in recycle phosphorus would have on Bio P performance
• OP and TP were observed to decrease in the centrate as the Mg:P molar dosing ratio increased to 1.4:1
• At 1.7:1 Mg:P molar ratio, OP was lowest while TP increased – potentially due to fines loss
• Reducing recycle soluble phosphorus concentrations from 400 mg P/L to 30 mg P/L would result in a decrease in secondary effluent OP
Driver 2: Dewatering Performance

- Cost Centers:
  - $ Polymer consumption
  - $ Wet mass of biosolids for hauling and dispersal

- Tracked cake total solids and polymer consumption
  - Polymer dose varied in 5 active pound/dry ton increments
  - Higher average centrifuge hydraulic pressures for AirPrex treated
Driver 2: Dewatering Performance

- Independent analyses conducted by Dr. Julia Kopp and Dr. Matt Higgins.
- Showed bench-scale improvements with AirPrex treated sludge.
- Collaboration with ongoing WERF project to understand mechanisms driving dewaterability.
Solids Correction – Dry Mass

NH₄MgPO₄•6H₂O Generated in AirPrex

Total solids = ΔOP * \( \frac{MW_{Struvite}}{MW_P} \)

Fraction of struvite in biosolids matrix - \( f_b \)
Fraction of struvite fines in centrate - \( f_c \)
Fraction of struvite that settles and is pumped out as product - \( f_p \)

\[ f_p + f_c + f_b = 1 \]
Acidification tests performed on dewatered biosolids to estimate total struvite:

- Untreated cake struvite content ~5.3%
- AirPrex treated cake struvite content ~11.7%
- ~6.4% increase in struvite - 80% retention in cake

Assumed negligible based on centrate TP at optimal operation.
Solids Correction

**NH₄MgPO₄•6H₂O**

Ammonia and water evaporate from struvite in the temperature range of 55 °C to 250 °C

\[ \text{NH}_4 + 6\text{H}_2\text{O} = 51.4\% \text{ of struvite mass} \]

Traditional TS concentration test measures a portion of struvite mass as water, underestimating total solids in sample

This affects metrics traditionally used for assessing sludge dewaterability
Solids Correction Method

- **Corrected TS concentration measurement**
  - Ongoing work to determine actual extent of struvite evaporation
  - Assumed **51.4%** loss of struvite due to evaporation

- **Digestate TS correction**:
  \[
  \%TS_{corrected} = \%TS_{measured} \times (1 + (0.053 \times 0.514))
  \]

- **AirPrex effluent TS correction**:
  \[
  \%TS_{corrected} = \%TS_{measured} \times (1 + (0.117 \times 0.514))
  \]

- **Wet tons calculation**:
  \[
  WTPD = \frac{DTPD}{\%TS}
  \]
AirPrex - Dewaterability Complete Dataset

- 297 data points analyzed
- 8.9 % reduction in wet tons hauled
AirPrex – Dewaterability
Sorted - 10 gpm, 90% OP removal

- 61 data points analyzed
- 12.44% reduction in wet tons hauled
AirPrex – Dewaterability Paired Dataset

- 20 data points analyzed
- 8.7% reduction in wet tons hauled
- 17.6% decrease in polymer consumption
Sensitivity Analysis of Assumptions

- Assumptions on product recovery and evaporated TS mass do impact the estimation of wet tons hauled per day
AirPrex Biosolids Dewatering Costs

- 8.7% reduction of biosolids hauled

**Untreated Biosolids**

*21 Hauled Truckloads*

**After AirPrex Treatment**

*19 Hauled Truckloads*

Difference of 2 truckloads per day or 730 truckloads per year!

- Approximately 15–20% decrease in polymer use
Driver 3: Nuisance Struvite Reduction

Significant reduction of struvite mass predicted between untreated and AirPrex treated
Modeling efforts in BioWin show a reduction in struvite production from 18,000 lb/d to 13,000 lb/d with digestate phosphorus recovery
Driver 5: Product Recovery

- 150 tons of phosphorus recovered annually
- Potential distribution
  - Composters
  - Fertilizer manufacturers
- Potential uses
  - Turf grass
  - Alfalfa
## Driver 5: Product Recovery

### Struvite Product - Metals Analysis

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>&quot;High Quality&quot; Pollutant Concentration Limits (mg/kg)</th>
<th>Pilot MAP Results (ppm)</th>
<th>Lab Analysis from Previous Pilot (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>41</td>
<td>BDL²</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>89</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td>Copper</td>
<td>1500</td>
<td>71</td>
<td>19</td>
</tr>
<tr>
<td>Lead</td>
<td>300</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>17</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Molybdenum¹</td>
<td>&lt; 75</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>420</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
<td>BDL</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>2800</td>
<td>33</td>
<td>26</td>
</tr>
</tbody>
</table>

1. There is currently no limit for Molybdenum for High Quality while rules are awaiting EPA investigation. Ceiling limit is 75 ppm.
2. Levels were below detection limit

- Struvite product produced by Airprex is well below limits of “high quality” pollutant concentrations
Driver 5: Product Recovery
Struvite Product - Pathogen Testing

- Class A: maximum density of fecal coliform < 1000 MPN per gram total solids (dry-weight basis)
- 2 Samples were taken for pathogen testing using fecal coliforms
  - July 19: 1000 MPN/g TS
  - August 2: Investigate fecal coliform with drying time

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>Initial</th>
<th>24hr</th>
<th>48hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/2/2016</td>
<td>31</td>
<td>26</td>
<td>65</td>
</tr>
</tbody>
</table>

- Current testing of product shows Airprex struvite may be within Class A categorization for biosolids
### AirPrex Pilot Testing Results

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phosphorus Recycle Control</strong></td>
<td>Reliable OP and TP Reduction</td>
</tr>
<tr>
<td></td>
<td><strong>Polymer</strong></td>
</tr>
<tr>
<td></td>
<td>~17% polymer reduction</td>
</tr>
<tr>
<td><strong>Biosolids Dewaterability</strong></td>
<td><strong>Truck Hauls</strong></td>
</tr>
<tr>
<td></td>
<td>~8.7% reduction hauled mass</td>
</tr>
<tr>
<td><strong>Struvite Reduction</strong></td>
<td><strong>Digesters</strong></td>
</tr>
<tr>
<td></td>
<td>~25% reduction digester struvite</td>
</tr>
<tr>
<td></td>
<td><strong>Dewatering</strong></td>
</tr>
<tr>
<td></td>
<td>Significant reduction in dewatering nuisance struvite</td>
</tr>
<tr>
<td><strong>Phosphorus Index</strong></td>
<td><strong>Accumulation of phosphorus in biosolids</strong></td>
</tr>
<tr>
<td><strong>Product Recovery</strong></td>
<td>25% - 35% product recovery</td>
</tr>
</tbody>
</table>
### Preliminary Pilot Testing Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Digestate</th>
<th>Phosphorus Stripping</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phosphorus Recycle Control</strong></td>
<td>![Digestate]</td>
<td>![Phosphorus Stripping]</td>
</tr>
<tr>
<td>Polymer</td>
<td>![Polymer]</td>
<td>![Awaiting additional testing]</td>
</tr>
<tr>
<td>Truck Hauls</td>
<td>![Truck Hauls]</td>
<td>![~6.6% reduction hauled mass]</td>
</tr>
<tr>
<td>Digesters</td>
<td>![Digesters]</td>
<td>![~55% reduction digester struvite]</td>
</tr>
<tr>
<td>Struvite Reduction</td>
<td>![Struvite Reduction]</td>
<td>![Significant reduction in dewatering nuisance struvite due to limiting OP]</td>
</tr>
<tr>
<td>Dewatering</td>
<td>![Dewatering]</td>
<td>![Significant reduction in dewatering nuisance struvite due to limiting Mg]</td>
</tr>
<tr>
<td>Phosphorus Index</td>
<td>![Phosphorus Index]</td>
<td>![Improvement over chemical sequestration]</td>
</tr>
<tr>
<td>Product Recovery</td>
<td>![Product Recovery]</td>
<td>![70%+ product recovery]</td>
</tr>
</tbody>
</table>
Annual O&M Costs and Product Revenue

- Electricity Cost
- Dewatering Polymer Cost
- Caustic Soda Cost
- Ferric Chloride Cost
- Operational Labor Cost

- Natural Gas Cost
- Thickening Polymer Cost
- Magnesium Chloride Cost
- Annual Nuisance Struvite Cost
- Biosolids Hauling and Land Application Cost

Post-Dewatering P Recovery (Ostara & WASSTRIP d/s of DMX)
Post-Dewatering P Recovery (Ostara & WASSTRIP u/s of DMX)
Pre-Dewatering P Recovery (AirPrex 1 reactor)
Pre-Dewatering P Recovery (AirPrex 2 reactor)
Ferric Chloride Sequestering

Costs and Revenue ($M):
- $7
- $6
- $5
- $4
- $3
- $2
- $1
- $0
- $1
- $2

Yearly Costs and Revenue Values:
- $4.18
- $3.79
- $4.27
- $4.23
- $5.78
Questions

Liam Cavanaugh, Director of Operations—lcavanaugh@mwrddst.co.us
PHOSPHORUS WAS STRIPPING AND CENTRATE RECOVERY PILOT WORK
Ostara Pearl

First installation
2008

Calgary
Edmonton
Saskatoon
How Ostara+WASSTTIP Works

Phosphorus-striped WAS from the WASSTTIP reactor is thickened.

Phosphorus is released into the liquid stream and separated from the biosolids.

Low P

Anaerobic Digestion

Dewatering

Biosolids

Caustic is added to raise the pH.

Caustic

Magnesium is dosed to the reactor, causing struvite to precipitate.

Mg

Centrate from dewatering is high in ammonia and is combined with liquid stream from WASSTTIP.

Centrate

Ostara Pearl effluent, stripped of phosphorus, is recycled back to mainstream.

Ostara Pearl

Struvite pearls settle and are pumped out and cleaned.
Phosphorus Stripping Pilot Test

- Pilot October 2016 to ongoing
- Evaluate features and benefits of WAS phosphorus stripping
  - Dewatering performance
  - Nuisance struvite reduction
- Batch WAS phosphorus stripping reactor with thickening press
Phosphorus Stripping Pilot Test

- Control Train receives TWAS, test train receives stripped TWAS
- Two separate activated sludge trains allows for centrate recycle to be fed to North; control train reflects bio-P with recycle control
Nuisance Struvite and Dewaterability Improvements Project

![Graph showing the comparison of Secondary Effluent Soluble P and Centrate Recycle Soluble P across different processes.](image-url)

- **Secondary Effluent Soluble P, mg/L**
  - No Recovery: 0.25
  - Digestate: 0.1
  - Centrate & Stripped Filtrate: <0.1

- **Centrate Recycle Soluble P, mg/L**
  - No Recovery: 450
  - Digestate: 0
  - Centrate & Stripped Filtrate: 0

Legend:
- Blue bar: Secondary Effluent Soluble P
- Red bar: Centrate Recycle Soluble P
Digester Nuisance Struvite Production

Method of determination:
- Mass balance on measured analytes
- BioWin modeling
- XRD analysis
Biosolids Production

<table>
<thead>
<tr>
<th>Type</th>
<th>Dry Mass, dtpd</th>
<th>Total Mass, wtpd</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Recovery</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>Digestate</td>
<td>100</td>
<td>350</td>
</tr>
<tr>
<td>Centrate &amp; Stripped Filtrate</td>
<td>100</td>
<td>350</td>
</tr>
</tbody>
</table>

- Dry Mass, dtpd
- Total Mass, wtpd
Next Steps

- Complete WAS phosphorus stripping digester pilot
- Complete Business Case Evaluation for phosphorus recovery systems
- Select a path forward for near-term implementation
Product Recovery

**Classification leaving RWHTF**

- **Class A** – Demonstrated through VAR, pathogen, metals testing
- **Class B** – From digestion process

**Product Production**

- **Compost** – Blended with final product for custom high P product
- **Fertilizer** – Incorporated into blended product or sold as-is
- **Compost** – Added at beginning of process to create Class A product
- **Fertilizer** – Incorporated into blended product

**Potential Final Use**

- **Class A unrestricted use** – Turf grass, high P demand crops such as alfalfa
- **Class A unrestricted use** – Turf grass, high P demand crops such as alfalfa
- **Class A unrestricted use** – Turf grass, high P demand crops such as alfalfa
- **Class B restricted use** – Golf courses