

## Realizing the Promise of Nutrient Recovery

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Notes:

Case Study 2 included in this manuscript provides an update on the case study originally presented in “NUTRIENT RECOVERY AT THE F. WAYNE HILL WATER RESOURCES CENTER: EXPERIENCE AND LESSONS LEARNED AFTER 18 MONTHS” (Latimer, et al. 2017)

### KEYWORDS

Nutrient Recovery, Phosphorus, Struvite

## 1 BACKGROUND

### 1.1 Introduction

During digestion, sludge stabilization solubilizes organic material producing a bulk solution with high concentrations of ammonia (NH<sub>3</sub>-N), calcium, iron, hydrogen, potassium, magnesium (Mg) and phosphorus (P), among other compounds. High concentrations of these constituents combined with high pH and temperatures can stimulate precipitation of numerous minerals in the digested sludge matrix. Many of these minerals have a high specific gravity and can precipitate within a digester complex. Additionally, many of these minerals have a high potential for forming at the air/water interface, resulting in the development of nuisance scaling.

One of the most common precipitates formed in water resource reclamation facilities (WRRFs) employing bio-P and anaerobic digestion is struvite (magnesium ammonium phosphate). Mitigating nuisance precipitate formation can be achieved using a combination of several strategies that can be broadly classified into four main categories:

- Maintenance post precipitate formation
- Chemical addition to prevent precipitate formation
- Process changes to minimize precipitate formation
- Resource recovery to minimize precipitate formation

### 1.2 Phosphorus Recovery Benefits

Phosphorus is a key component of fertilizers and demand for it is projected to increase worldwide based on population growth and increased demand in developing markets. Thus, the recovery and sale of recovered phosphorus (as struvite) may allow a WRRF to recover some of the operating costs associated with struvite generation. In addition to the potential economic benefits, recovery of phosphorus from WRRFs can allow facilities to:

- Reduce operating costs by offsetting aeration, supplemental carbon (where applicable) and metal salt coagulant (where applicable).
- Reduce sludge and biosolids production.
- Reduce nuisance precipitate scaling.
- Reduce the impact of sidestream nutrient loads on the mainstream biological process.
- Regain capacity/lost volume/pumping capacity by reducing scaling.
- Improve sludge dewaterability thereby reducing dewatering polymer demand and increasing the cake dryness.
- Offset operating costs by selling the recovered product.
- Alter the phosphorus and nitrogen content of the biosolids product.

### **1.3 Phosphorus Recovery Overview**

Phosphorus recovery approaches aim to convert phosphorus into a chemical nutrient product that can be extracted from the WRRF streams. In general, phosphorus recovery requires three main stages:

- 1) Accumulation – Nutrients first accumulate in biomass through the bio-P process. This accumulation is captured via WAS. This step is necessary to concentrate nutrients from the raw influent wastewater.
- 2) Release – The accumulated nutrients are released into a low flow nutrient-rich stream via WAS phosphorus release, anaerobic digestion, thermal hydrolysis and/or some combination of all three process.
- 3) Extraction – The released nutrients are then recovered in the form of a nutrient product using physical-chemical processes.

Presently, the most common extraction step for phosphorus recovery involves chemical crystallization to form struvite. There are over 30 operating full-scale facilities worldwide that are recovering struvite from waste streams (domestic and industrial).

Phosphorous recovered via collection of struvite at WRRF can have a resale value ranging from \$100-\$600 per dry ton. Resale value is dependent on product characteristics and regional market conditions. Other nutrient products can also be recovered from WRRFs, including hydroxyapatite and brushite. However, the technologies designed to recover these products require further development to mature (no full-scale installations currently in the USA) and to assess their technical viability.

### **1.4 Commercially Available Phosphorus Recovery Technologies**

There are multiple commercially-available options for phosphorus recovery in the US. These technologies vary in reactor type, efficiency and product formed; however, the principle behind the processes are similar. In each system, struvite is precipitated in a dedicated reactor where the pH, conductivity, temperature and chemical feed (e.g., magnesium, caustic) is used to stimulate supersaturated conditions that promote precipitation. The specific reactor configuration and control strategies vary among the different technologies; however, all have the ability to remove 80% to 90% of soluble phosphates and 10% to 30% of the soluble ammonia.

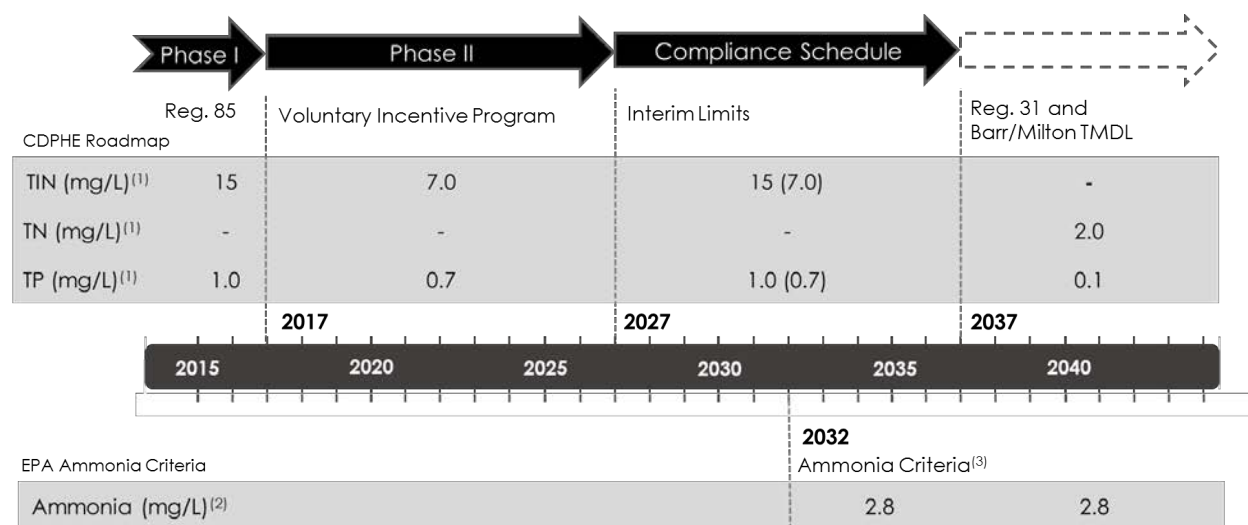
Phosphorus recovery technologies can be broadly categorized as either pre-dewatering recovery or post-dewatering recovery. For pre-dewatering technologies, struvite formed in the system can be harvested from the digested sludge using classifiers. For post-dewatering technologies,

struvite particles formed in the reactor can be harvested. Alternatively, struvite formed can be retained in the cake. Different commercial companies offer a variety of options for purchasing recovered struvite including buy-back of struvite and third party purchasing. The following case studies relate to a pre-dewatering recovery system in construction and a post-dewatering system in operation.

## 2 CASE STUDY 1: METRO WASTEWATER RECLAMATION DISTRICT

### 2.1 Existing Conditions

The Robert W Hite Treatment Facility (RWHTF) operates with permitted hydraulic and organic capacities of 220 million gallons per day (mgd) on a maximum month (30-day) flow (MMF) basis, and 212 tons per day (tpd) of 5-day carbonaceous biochemical oxygen demand (cBOD<sub>5</sub>) on an annual average load (AAL) basis. The proposed nutrient removal regulatory timeline based on currently available information is presented in **Figure 1**.



1. Annual Median

2. Daily Maximum

3. Based on a pH of 8 and a temperature of 24°C

*Figure 1: Proposed Nutrient Removal Regulatory Timeline*

Primary and secondary solids generated from secondary treatment are pumped to a single common biosolids processing treatment train for thickening, stabilization and dewatering. Primary sludge is thickened by gravity thickeners (GVTs) and waste activated sludge (WAS) is thickened with dissolved air flotation (DAF) tanks. Stabilization is provided by 2-stage (acid + gas) mesophilic anaerobic digestion to exceed the Class B pathogen reduction requirements, as per Title 40 of the CFR, Chapter I – Part 503. Digester gas is conditioned and combusted in a combined heat and power (CHP) system. After stabilization and dewatering, the District beneficially applies biosolids to District-owned and contracted farmland in eastern Colorado. High nutrient-strength centrate from the dewatering process is equalized in the Centrate Storage Tank (CST) prior to treatment in either a moving-bed bioreactor deammonification (DMX) process and/or Centrate and RAS Reaeration Basins (CaRRBs) before returning centrate to secondary treatment basins.

District staff have experienced significant nuisance struvite precipitation in the digester complex resulting from bio-P. To manage nuisance struvite and provide proper operation of the digesters, digester cleanouts have typically been performed on a 5-year basis (approximately 2 digester cleanings per year). In addition, the District has dosed ferric chloride and modified operation to limit bio-P to control struvite accumulation, but neither approach represents a sustainable long-term solution.

## 2.2 Technology Evaluation

The Project Team evaluated two proven approaches for struvite recovery including (1) pre-dewatering recovery, and (2) post-dewatering (i.e., centrate) recovery against a baseline approach where a metal salt (ferric chloride) would bind with the phosphate and remove it from the treatment plant.

Phosphorus recovery at a WRRF typically consists of the precipitation of phosphorus with magnesium and ammonia to generate struvite crystals. Generally, magnesium limits the reaction, thus excess magnesium is added to ensure nearly complete removal of dissolved phosphorus through the conversion to struvite. Both pre- and post-dewatering technologies seek to generate struvite in dedicated reactors with struvite harvesting and cleaning systems of varying levels of complexity. Process flow diagrams for pre- and post-dewatering recovery options are indicated in **Figure 2**.

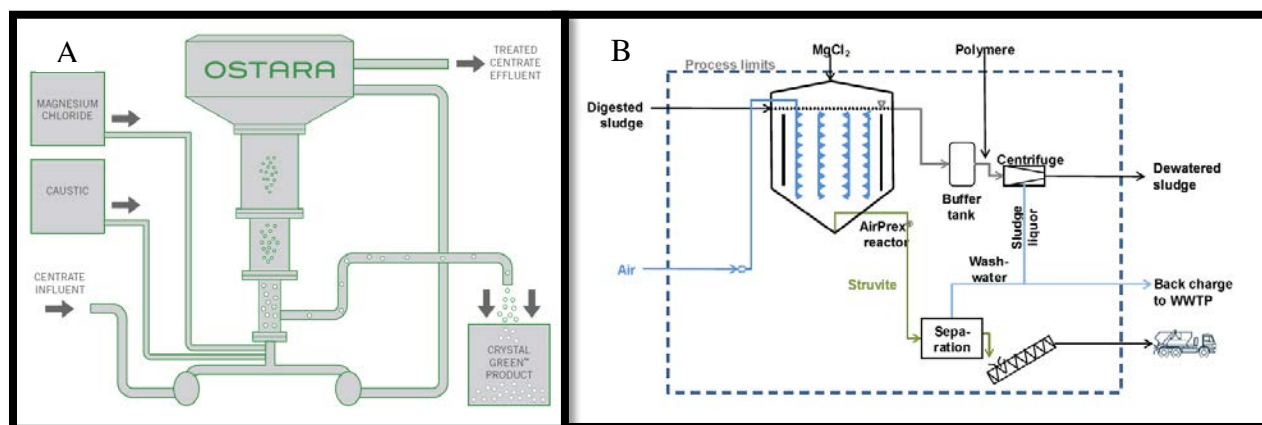


Figure 2: Process flow diagrams of A. Ostara Pearl® Pre-Dewatering Struvite Recovery System, and B. AirPrex™ Post-Dewatering Struvite Recovery System

Pre-dewatering struvite recovery technologies mix digested sludge in a dedicated reactor using coarse bubble aeration. The aeration mixes the tank contents and increases the pH by stripping carbon dioxide (CO<sub>2</sub>) from the sludge. Orthophosphate concentrations in the digested sludge are reduced by more than 90% through the precipitation of soluble phosphorus, magnesium, and ammonia to struvite crystals. Reactor effluent sludge is dewatered downstream of the reactor and dewatered centrate is returned to the head of the plant. Pre-dewatering phosphorus recovery systems were developed in Europe and several systems are currently being designed/constructed in North America.

Post-dewatering recovery consists of a dedicated reactor receiving centrate (i.e., filtrate or liquor) from dewatering/thickening processes to convert soluble phosphorus into struvite. As an option, post-dewatering struvite recovery can include a waste activated sludge (WAS) phosphate stripping reactor, which allows for greater conversion of phosphorus into struvite. Stripped WAS filtrate and centrate are combined in the struvite recovery reactor. pH adjustment is achieved via air stripping or sodium hydroxide addition. As with pre-dewatering recovery, magnesium chloride ( $\text{MgCl}_2$ ) is added to achieve orthophosphate reductions of at least 90%.

Multiple alternatives were developed and evaluated for each pre-dewatering and post-dewatering struvite recovery approach. The alternatives development and evaluation built on work the District previously completed, including the following:

- Review of historical data
- Bench-scale WAS phosphorus release testing.
- Sampling to supplement characterization of nutrient and cation mass balances
- Development and utilization of a steady state calibrated process model utilizing BioWin™ modeling software (Version 5.1), and thermodynamic models to estimate struvite formation potential for alternative evaluations.
- Pilot testing of phosphorus recovery from digested sludge followed by sludge dewaterability assessment.
- Pilot testing of WAS phosphorus release
- Business case evaluation of alternatives using the District's Financial and Sustainable Return on Investment (FROI/SROI) tool

A Request for Information (RFI) specific to the PAR 1280 project was issued to three technology vendors, including: (1) AirPrex™, pre-dewatering recovery, (2) NuReSys®, both pre- and post-dewatering recovery, and (3) Ostara Pearl®, post-dewatering recovery. Information provided by vendors was supplemented with full-plant steady state process modelling, thermodynamic modelling, pilot experiments, historic RWHTF data, comparable case studies and significant input from District staff for the business case evaluation.

### 2.3 Piloting

The District performed the following pilot studies to better understand the factors associated with bio-P and phosphorus recovery that influence dewaterability and nuisance struvite formation:

- In 2011, the District conducted pilot testing of Ostara's Pearl® phosphorus recovery process. The Ostara Pearl® system was able to achieve an average of 82% conversion of orthophosphate into struvite within the reactor.
- In 2016, the District conducted bench testing to understand the potential of phosphorus stripping pretreatment to reduce orthophosphate, magnesium, and potassium loading to the digesters.
- In 2016, the District conducted an AirPrex™ struvite recovery pilot system. The AirPrex pilot was able to achieve greater than 90% conversion of orthophosphate in the reactor. Treatment of digestate by AirPrex™ resulted in a 15% to 20% reduction in dewatering polymer demand and 2 to 3.5% increase in cake solids concentrations, indicating 7 to 10% reduction in facility hauling requirements could be expected.

**Figure 3** displays photographs of the Pearl® and AirPrex™ pilots at the RWHTF.



Figure 3. Images of A. Ostara Pearl® Pilot and B. AirPrex™ Pilots at RWHTF

## 2.4 Modeling

The existing RWHTF process model was modified to calibrate to the observed nutrient and magnesium balances in both liquids and solids processes. Steady state calibrations were performed for several periods including April 2015, August 2015, and December 2015. These periods were chosen after a review of historical monthly mass balances and discussions with District staff. The final calibrated model was used for alternatives analysis. Thermodynamic modeling was also performed using Visual MINTEQ to estimate struvite formation potential in and downstream of the digesters for the various alternatives.

## 2.5 Business Case Evaluation Conclusions and Site Visits

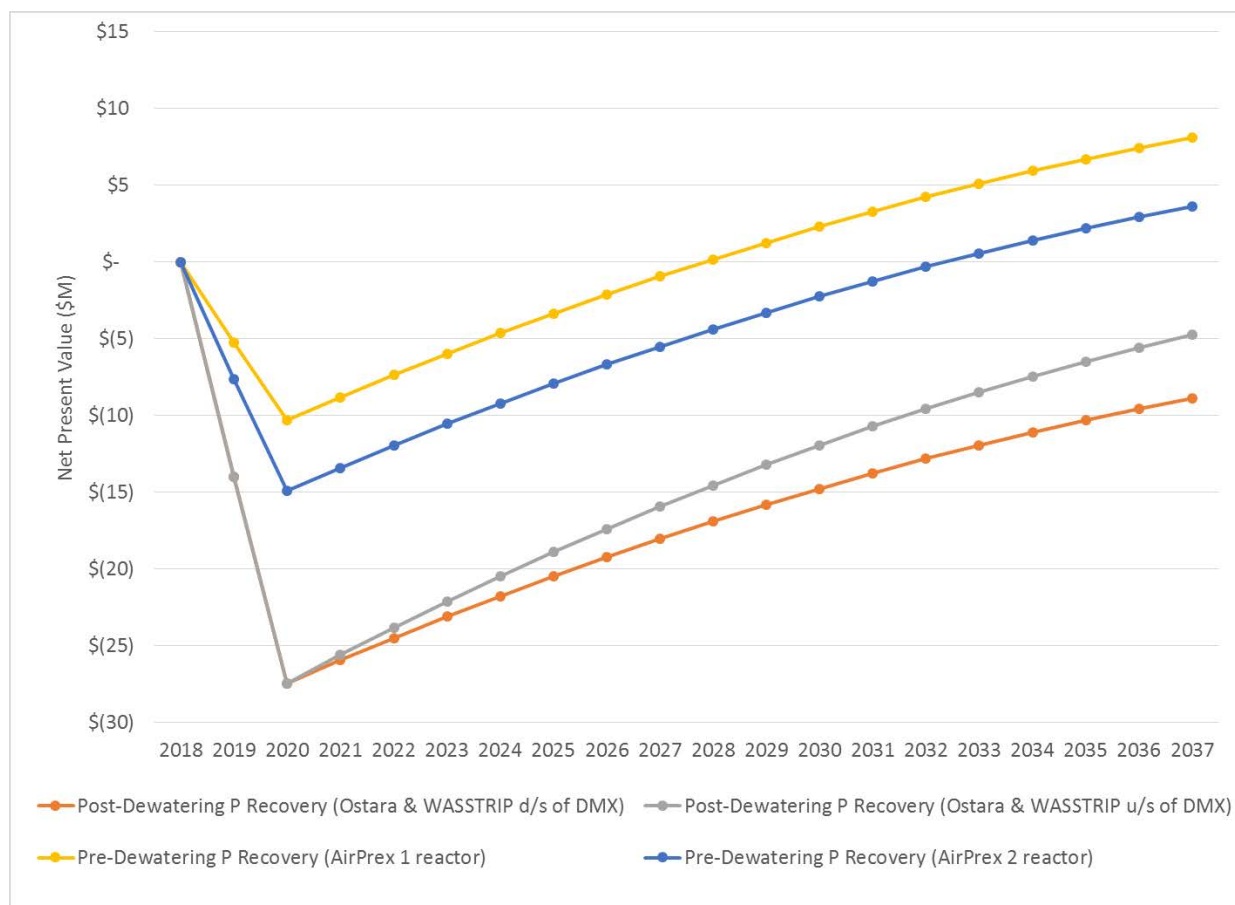
The Project Team performed cost and siting evaluations for phosphorus management approaches in the biosolids train to complement bio-P secondary treatment operation. The cost and siting evaluation results were incorporated into a FROI/SROI analysis, which was used to inform a best value selection of the near-term phosphorus management approach for implementation at the RWHTF. The FROI/SROI includes a net present value analysis of the alternatives as well as a determination of the simple payback.

All pre- and post-dewatering struvite recovery options evaluated to varying degrees, to the District's five measures of success for managing phosphorus once it's removed from the wastewater. Based on the results of the business case evaluation FROI/SROI analysis, the pre-dewatering phosphorus recovery scenarios have greater net present value for the District when



compared against post-dewatering phosphorus recovery as shown in **Figure 4** below. In addition, the pre-dewatering phosphorus recovery process will be less complex operationally, than the post-dewatering phosphorus sequestration/recovery process at the RWHTF due to the configuration of the secondary treatment process and the relatively low solids concentrations of the WAS (approximately 0.75% total suspended solids).

In addition, MWRD staff visited multiple pre- and post-dewatering phosphorus recovery facilities in Europe to further evaluate the competing technologies. The visits provided knowledge regarding phosphorus recovery design, construction, operation, and maintenance which helped MWRD identify which technology would be most compatible with their facility and their staff.



*Figure 4. Business Case Evaluation – Net Present Value Results of Phosphorus Recovery Options*

## 2.6 Phosphorus Recovery Facility Design and Construction

Based on the business case evaluation, the District decided to construct a pre-dewatering phosphorus recovery facility (PRF). The PRF's major components include:

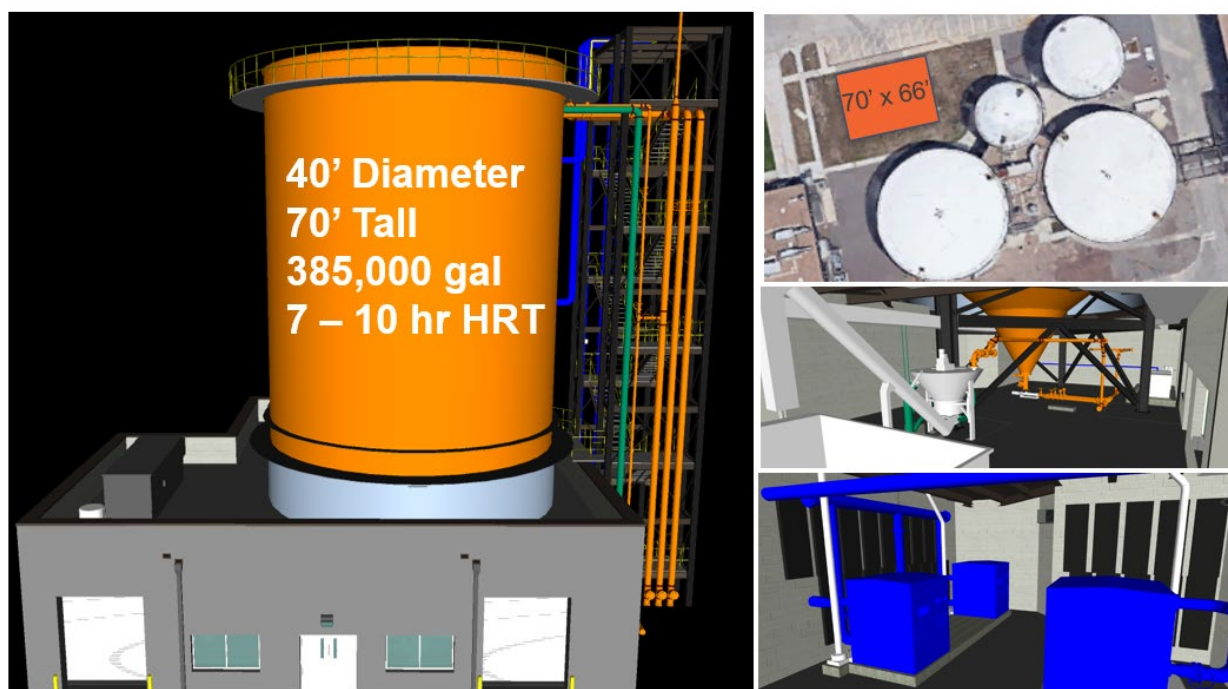
- One Reactor
- Process Aeration System
- Magnesium Chloride Dosing System
- Struvite Slurry Pumping

- Struvite Classifier
- Product Storage and Conveyance

**Figure 5** illustrates the design of the PRF now in construction. The site map shows the facility footprint measuring 70 ft x 66 ft, which demonstrates the phosphorus recovery does not need to be a space intensive process. The model image shows the recovery building constructed around the AirPrex reactor. The reactor has a volume of 385,000 gal to provide a 7 – 10 hr HRT to maximize struvite formation and recovery. The stairway on the right provides access to the top of the reactor and is used to support piping into and out of the reactor. The building below the reactor houses support equipment such as blowers,  $\text{MgCl}_2$  dosing pumps, struvite pumps, struvite classifier, and product handling and conveyance. The project team coordinated with the AirPrex<sup>TM</sup> manufacturer to use pilot testing results to establish full-scale performance criteria. Notable performance requirements include:

- At least 90% Ortho-P reduction via sequestration as struvite
- At least 20% recovery of struvite
- At least 15% reduction in dewatering polymer addition
- At least 2.5% increase in cake total solids

The PRF project is scheduled to be substantially completed in August 2020, at which point the District will start realizing the above benefits.



*Figure 5: RWHTF Phosphorus Recovery Facility Design*



### 3 CASE STUDY 1: GWINNETT COUNTY DEPARTMENT OF WATER RESOURCES

#### 3.1 Background

The F. Wayne Hill Water Resources Center (FHWRC) is Gwinnett County's largest and most advanced wastewater treatment facility with a capacity of 60 mgd. The FHWRC uses enhanced biological phosphorus removal and chemical trim to meet a stringent TP limit of 0.08 mg/L. Solids handling includes anaerobic digestion of blended co-thickened primary sludge and WAS.

Struvite precipitation had increasingly become a major issue at the FHWRC. Plant staff have used high pressure jetting of centrate lines in the past; however, struvite deposits were being found in the dewatering centrifuges and upstream of dewatering. Struvite control, beyond reactive blasting and jetting of centrate lines, was needed moving forward. In addition, sludge from Gwinnett County's 22 mgd Yellow River WRF is transferred to the FHWRC resulting in significant additional phosphorus loading at the site further exacerbating phosphorus recycle loads in the future.

To address the struvite issues and decrease the impacts of phosphorus recycle loads on the main liquid stream, while simultaneously recovering a sustainable fertilizer, Gwinnett County selected the OSTARA Pearl® nutrient recovery process with WASSTRIP. The OSTARA Pearl® process creates controlled conditions of struvite precipitation for P and N recovery as a high quality fertilizer (Crystal Green®). The WASSTRIP process combines dewatered centrate with phosphorus and magnesium-rich WAS filtrate (from a WAS P-Release Reactor) into the Pearl® process, increasing Crystal Green® production and reducing struvite in solids handling.

#### 3.2 Full Scale Design

The Nutrient Recovery System consists of the following elements: WASSTRIP, nutrient recovery reactors, centrate and filtrate storage tanks, transfer pumps, fertilizer product handling system, and chemical feed systems. A process flow diagram is provided in **Figure 6**. The WASSTRIP process consists of a holding tank where primary sludge and WAS react anaerobically for approximately 3 – 6 hours to facilitate release of P and Mg. The combined sludge is then thickened by rotary drum thickeners and the filtrate, which is phosphate and magnesium rich, is stored fed to the recovery reactors. The facility has two nutrient recovery reactors with space for a third one in the future. Each reactor has a nominal capacity of 4,400 pounds of struvite production daily.

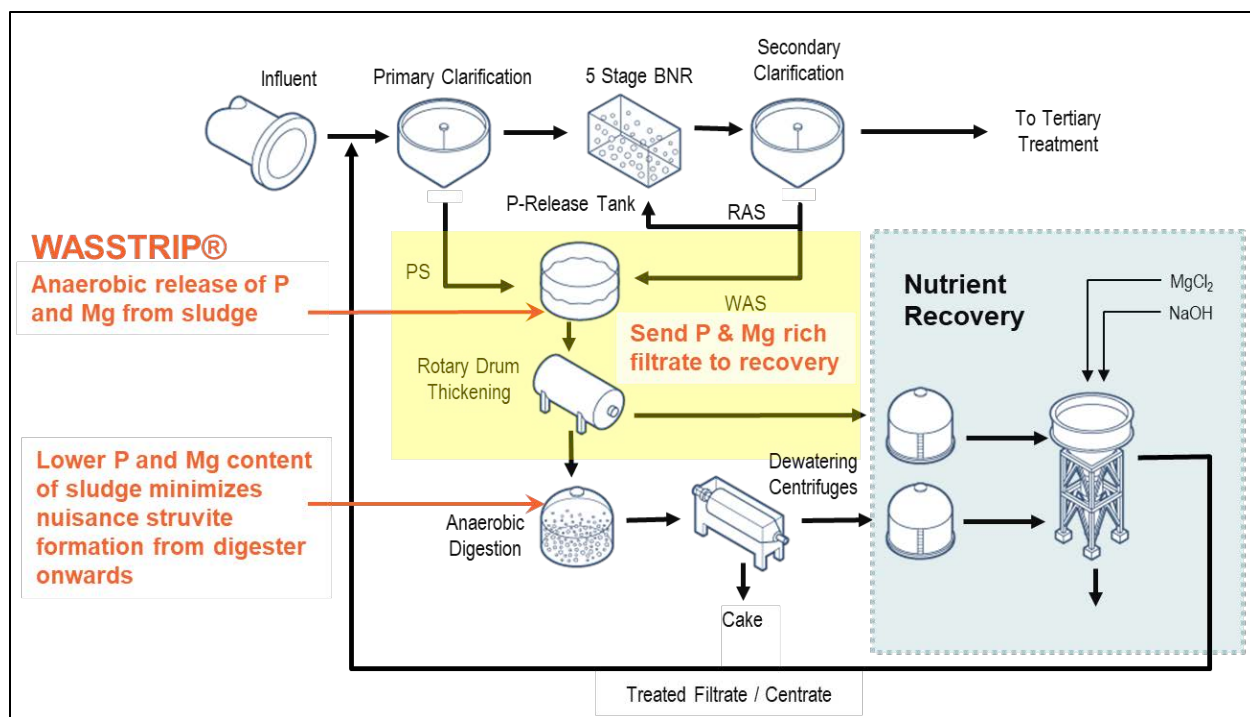


Figure 6: FWHWRC Process Flow Diagram

To further prevent unwanted struvite accumulation, the design also included PVC centrate pipes with removable sections in the dewatering building, parallel HDPE centrate pipes into the recovery facility, and an acid feed loop to allow periodic cleaning of the feed pipes. The equalization tanks were designed to allow heavy solids to settle and include automatic draining and washdown.

### 3.3 Full Scale Performance

The FWHWRC nutrient recovery process is unique in that the utility adds  $Mg(OH)_2$  to the collection system for odor and corrosion control. Due to high concentrations of soluble magnesium in the primary sludge, magnesium does not need to be added to the Ostara process. The WASSTRIP tank is achieving high P-release with an HRT of 5 hours, as evidenced by the thickening filtrate P concentrations shown in **Figure 7**. The P mass sent to the Ostara process is on average 25% of the raw influent TP load.

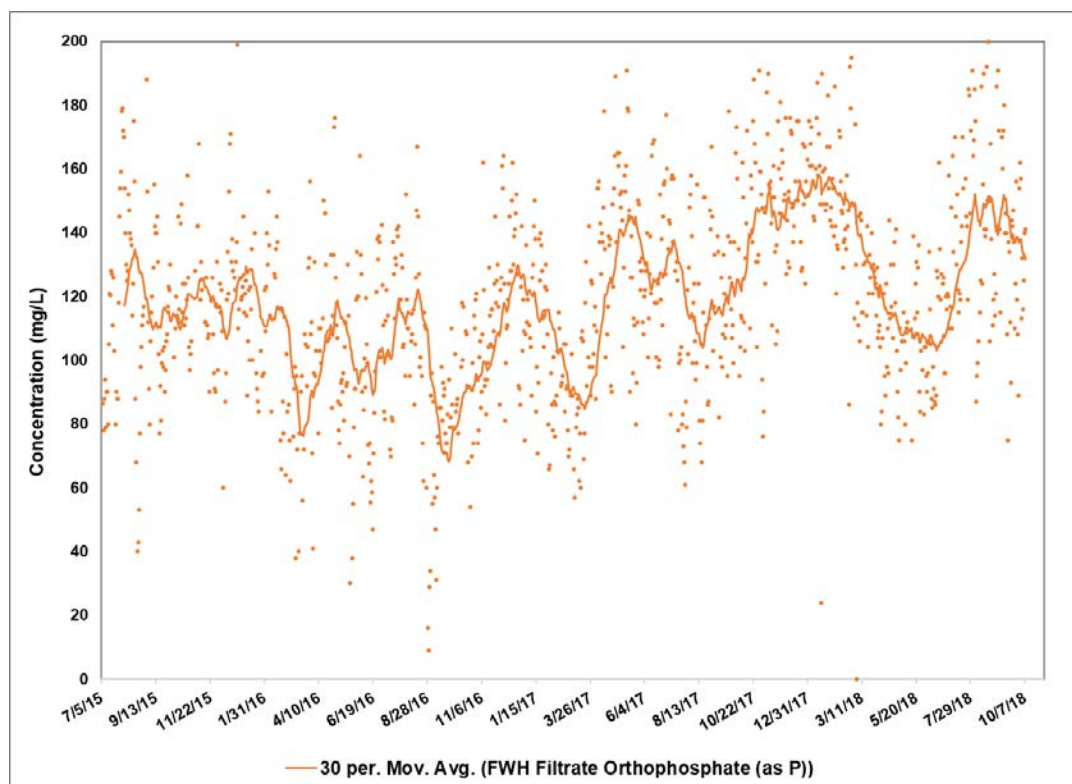


Figure 7: Thickening Filtrate  $PO_4-P$  Concentrations

The ortho-phosphate and magnesium concentrations in both individual and combined feed streams to the Ostara process and presented in **Figure 10** and **Figure 9**. WASSTRIP is on average diverting approximately 625 lb/day of Mg away from the digesters, which avoids 5,200 lb/day of potential struvite in the solids handling process/cake. The combined feed ammonia concentration has averaged 300 mg/L. **Figure 10** displays the ortho-phosphate removal efficiency. Excluding one process upset due to upstream issues, the Ostara process has averaged 70% ortho-phosphate removal and generated 55,000 lbs product/month.

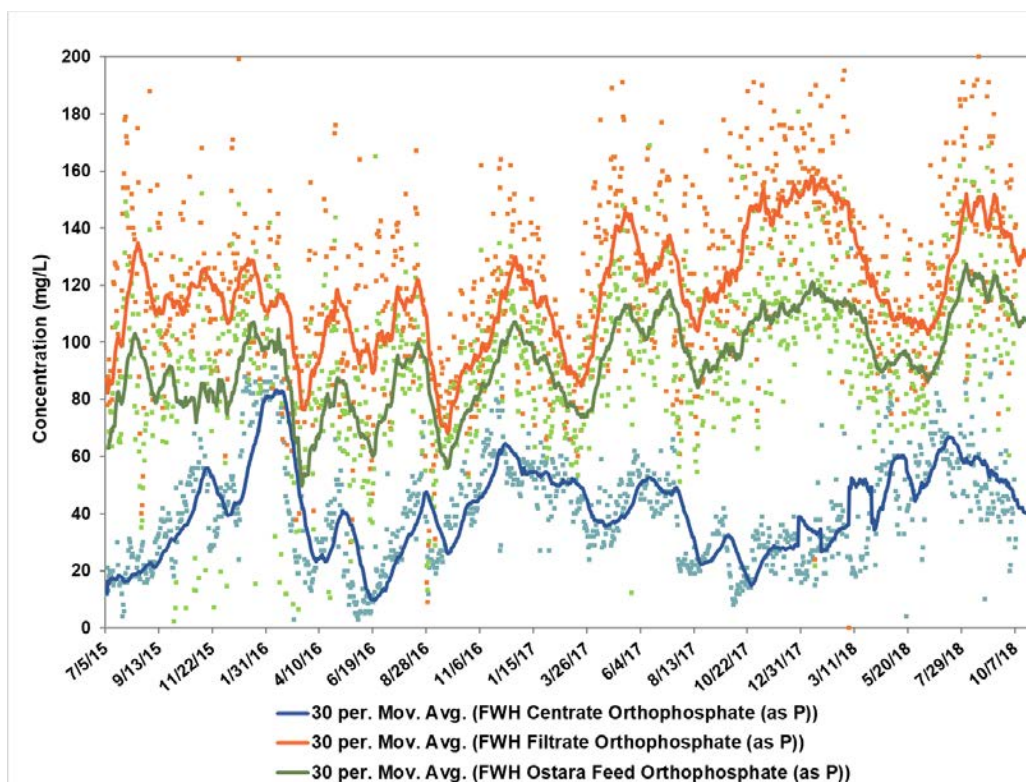


Figure 8: FWHWRC Ostara Pearl® Feed  $PO_4$ -P Concentrations

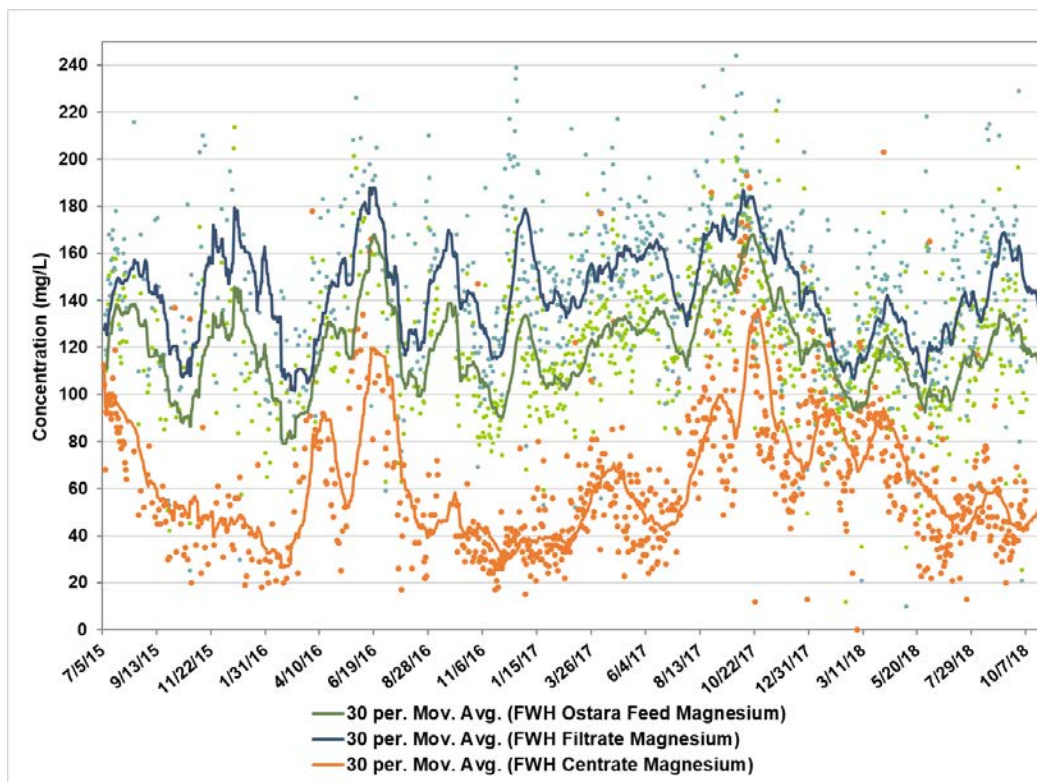


Figure 9: FWHWRC Ostara Pearl® Feed Mg Concentrations

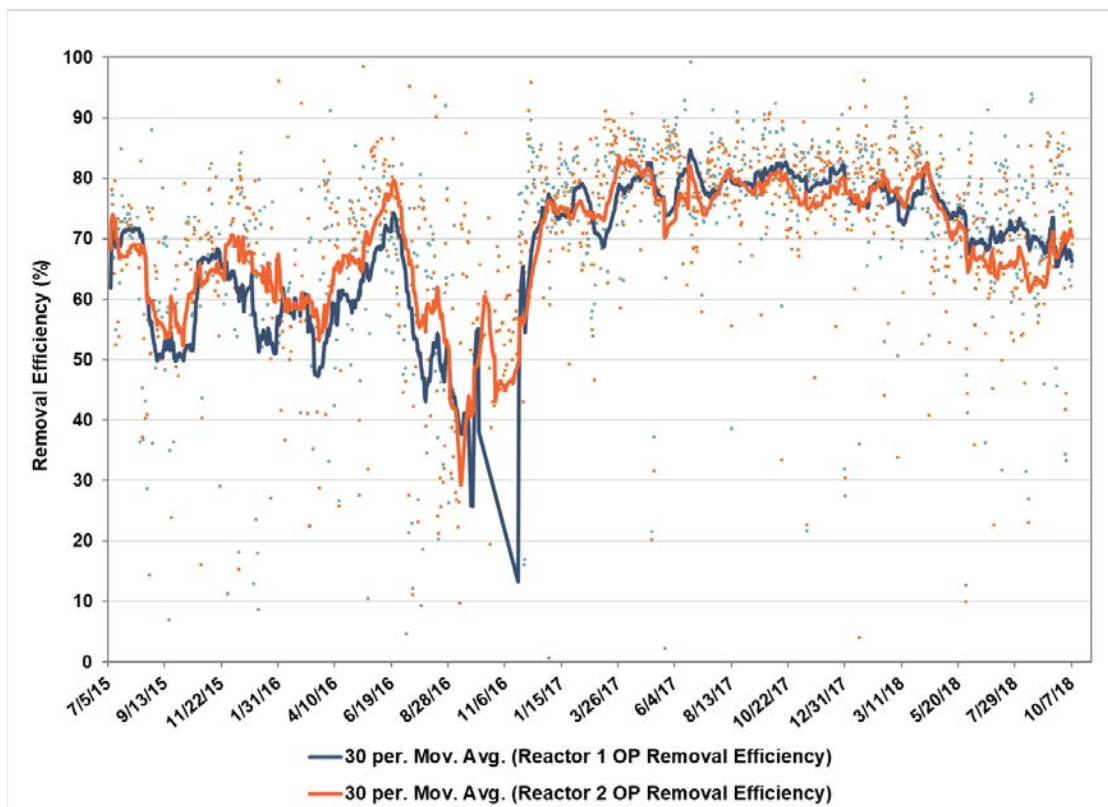


Figure 10: FWHWRC Ostara Pearl® Performance Data –  $PO_4\text{-P}$  Removal Efficiency

Additional benefits observed since startup include:

- Alum addition to achieve the 0.08 mg/L TP limit has also decreased, with alum usage in the biological system decreased from an average of 40 mg/L to 5 mg/L.
- Dewatering solids from the centrifuges has increased from 22.2% to 23.7%.
- Dewatering polymer addition has decreased from 38 to 31 active pounds per dry ton.
- The dewatering cake solids has increased approximately 1.5% since startup. Additionally, nuisance struvite formation has decreased as the centrate pipes have not required pressure jetting since startup.

#### 4 CONCLUSIONS

In conclusion, these projects and others demonstrate that nutrient recovery is a viable treatment alternative that offers many operational and financial benefits including:

- Minimizing nuisance scaling
- Reducing chemical demand
- Reducing impact of sidestream nutrient loading on the mainstream process
- Regaining lost volume and pumping/treatment capacity
- Reducing sludge volume and associated hauling costs
- Potentially offsetting costs with product sales

Therefore, implementing phosphorus recovery can help utilities realize their mission of recovering valuable resources while simultaneously increasing treatment efficiency to ensure long-term sustainability.



## 5 REFERENCES

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