# Extractive Nutrient Recovery is a Mature Option for Managing Phosphorus in Sidestreams

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Extractive nutrient recovery represents a complementary approach to traditional nutrient removal options. In this approach, nutrients are intentionally recovered as chemical nutrient products from wastestreams versus being removed. These recovered products can be reused within a secondary market that typically targets the agricultural sector.

In addition to allowing facilities to produce a chemical nutrient product with resale value, extractive nutrient recovery can allow plants to decrease costs by reducing aeration and supplemental carbon requirements, as well as minimizing operations and maintenance (O&M) costs associated with chemical scaling at water resource recovery facilities (WRRFs).

For extractive nutrient recovery to become a viable strategy, it must maintain the ability to meet stringent water quality standards and be cost-competitive with existing nutrient control strategies. Some WRRFs are already evaluating this option and applying technologies focused on extractive phosphorus (P) recovery.

## Basics of Phosphorus Removal and Recovery

Phosphorus removal from wastewaters can be accomplished using biological or chemical means. For biological treatment, phosphorus-accumulating bacteria are used to remove up to 90 percent of soluble phosphorus from the liquid stream. For chemical P removal, metal salts are used to precipitate phosphorus from the liquid stream. Typically the solids produced from biological and/or chemical P removal will undergo thickening, stabilization, and/or dewatering, resulting in the generation of a sidestream flow.

In scenarios where the solids are biologically stabilized, the sidestream can represent up to 30 percent of the overall phosphorus load. In many cases, the sidestream load is also intermittent due to dewatering operating. This combination of high concentration and intermittent flows can negatively impact the mainstream process nutrient removal treatment performance.

In the case of extractive phosphorus recovery, this high-strength sidestream is intercepted and phosphorus chemical precipitants that have reuse value are intentionally recovered (Table 1). In the most commonly applied technology, phosphorus is recovered from sidestream flows as struvite ($NH_4MgPO_4\cdot6H_2O$). These reactions occur in designated reactors where precipitation potential is controlled by sodium hydroxide addition while limiting the reagent—typically magnesium—added to the sidestream. During this crystallization process, between 80 and 90 percent of the soluble phosphorus and 20 and 30 percent of the nitrogen from the sidestream can be recovered. The effluent from this process can then be recycled within the recovery process or be returned to the mainstream process, while the struvite can be reused as a slow-release fertilizer (struvite).

In some cases, nuisance precipitation of struvite, hydroxyapetite, or vivianite ($Fe_3(PO_4)_2\cdot8H_2O$) can occur during thickening, stabilization, or dewatering steps. To help eliminate this problem, selective release of phosphorus before anaerobic digestion can be employed. One patented option for doing this is called the WASSTRIP™ process in which waste activated sludge is combined with a

| Principle Behind Recovery | Recovered Element(s) | Reuse Potential |
|---|---|---|
| A concentration step (e.g., enhanced biological phosphorus removal or adsorption onto selective media) acts to remove phosphorus from the mainstream flow. The phosphorus is then released into a smaller stream via aerobic or anaerobic digestion, volatile fatty acid-stripping, or media regeneration. This stream is then subjected to chemical precipitation and crystallization. | P, N, Mg / P, Ca | fertilizer / fertilizer |
| Acid addition to digested sludge redissolves nutrients. The sludge is then dewatered to generate a nutrient-rich stream, which is subjected to chemical precipitation at alkaline pH. | P, N, Mg | fertilizer |
| Acid addition to sludge ash redissolves nutrients. Selective precipitation of phosphate complexes is performed at pH 3.5. | P, Ca, Al | fertilizer; coagulant |
| Potassium or magnesium chlorides are added to the ash. This mixture is then heated to greater than 1000°C to remove heavy metals chlorides. Potassium and magnesium phosphates can then be recovered directly from the residue. | P, K, Mg | fertilizer |

P = phosphorus  N = nitrogen  Mg = magnesium
Ca = calcium  Al = aluminum  K = potassium

source of volatile fatty acids, such as primary sludge fermentate or acetic acid, to "strip" the internal phosphorus and minimize subsequent chemical scaling.

Four case studies of WRRFs performing extractive phosphorus recovery are reviewed here. Each study represents a utility at a different point in the process of implementation, and the case studies are ordered with the longest history of operation presented first.

## Nansemond Wastewater Treatment Plant

The Nansemond Treatment Plant in Suffolk, Va., is a 30-mgd facility that uses a five-stage biological nutrient removal (BNR) process with supplemental carbon addition to meet 8 mg/L total nitrogen (TN) and 1 mg/L total phosphorus (TP) discharge limits. The facility's influent contains high nitrogen (44 mg/L) and phosphorus (8 mg/L) concentrations due to industrial contributions.

Solids handling at this facility consists of anaerobic digestion of co-thickened primary and waste activated sludge, followed by centrifuge dewatering. Previously, dewatering centrate contributed up to 30 percent of total P load at this facility, which resulted in frequent upsets of the biological phosphorus removal process.

### Options

A calibrated whole-plant process model was used to determine the benefits of implementing sidestream treatment to reduce the sidestream P load. Ferric chloride precipitation and proprietary crystallization of struvite from the centrate were considered for controlling phosphorus recycle loads.

### Findings

Both ferric addition and struvite crystallization were effective options for controlling the sidestream P load. In order to distinguish between the two options, a net present-cost evaluation was performed. For the ferric alternative, it was assumed that the precipitate would be processed through centrifuges and disposed of through incineration. Two different scenarios were evaluated for struvite crystallization. In the first option, crystallizer equipment would be purchased and the operation and maintenance would be the responsibility of the utility (capital option). In the second option, the utility would pay a monthly fee for the equipment vendor to provide the facility and equipment (fee option). In both options, recovered product would be purchased by the vendor at a price that offsets the operating costs borne by the utility (e.g., electricity, chemicals, etc.).
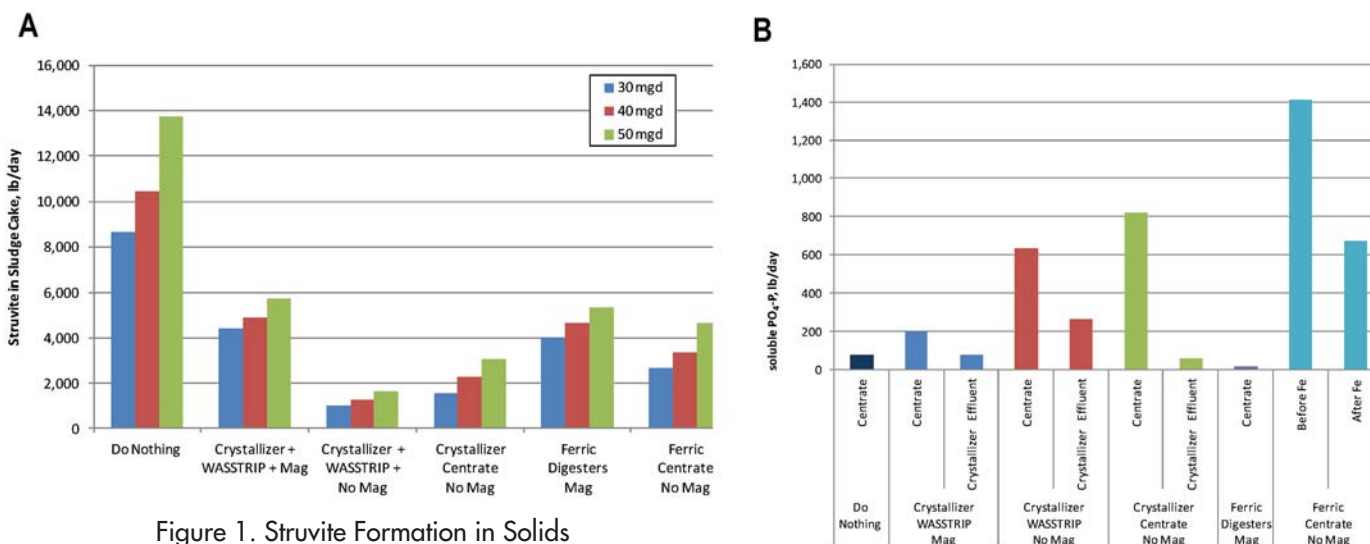
Figure 1. Struvite Formation in Solids
for Each Alternative Scenario

The present-worth analysis indicated that both phosphorus recovery options would cost less than using ferric. A comparison between capital and fee options indicated that the capital purchase option had a faster payback and was more advantageous for the owner. The utility constructed the OSTARA crystallizer facility using this option. Based on earlier pilot tests, it was expected to remove about 400 lb/d of orthophosphate from the centrate. Full-scale operation began in September 2012, and approximately 327 US tons of Crystal Green® product (specialty fertilizer) have been produced to date.

This process has stabilized the recycle load through an average 84 percent reduction in soluble phosphorus content in the centrate. Nitrogen content of the centrate also has dropped by an average of 24 percent.

## F. Wayne Hill Water Resources Center

The F. Wayne Hill Water Resources Center in Gwinnet County, Ga., is a 60-mgd facility using enhanced biological phosphorus removal and chemical precipitation to meet a stringent TP limit of 0.08 mg/L.

Solids handling consists of anaerobic digestion of primary and waste activated sludge in egg-shaped digesters. Combined primary and secondary sludge from the 22-mgd Yellow River Water Reclamation Facility is also transported to this facility through the collection system.

In 2009, Gwinnett County (GC) began adding magnesium hydroxide into the collection system to control odor and corrosion. At this point, nuisance struvite precipitation significantly decreased phosphorus recycle loads to the bioreactors, stabilizing the performance of enhanced biological phosphorus removal. However, the struvite plated out in the digester complex on piping and centrifuge surfaces, restricting flow in the centrate drain lines, reducing centrifuge dewatering capacity, and necessitating periodic pressure cleaning of the lines.

### Options

The F. Wayne Hill facility desired a solution to mitigate odor and corrosion in the collection system, reduce phosphorus and nitrogen recycle loads, and control nuisance struvite formation. To achieve these goals, Hazen and Sawyer evaluated five alternatives:
1. WASSTRIP™ and crystallizer with magnesium hydroxide addition
2. Ferric addition at digesters with magnesium hydroxide addition
3. WASSTRIP™ and crystallizer without magnesium hydroxide addition
4. Crystallizer without magnesium hydroxide addition
5. Ferric addition without magnesium hydroxide addition

Special sampling, bench, and pilot test data supported a model to simulate each of the alternatives at three flow rates representing current, and 10- and 20-year, estimated flows. A "do nothing" scenario was evaluated for comparison. The modeling results also served as the basis for a net present cost (NPC) analysis.

### Findings

Unlike most WRRFs where magnesium limits struvite formation, magnesium addition in the collection system resulted in phosphorus being the limiting reagent at the F. Wayne Hill facility. Consequently, both phosphorus recovery and ferric addition were determined to equally mitigated nuisance struvite formation. This is illustrated in Figure 1, where the difference in struvite production between the "do nothing" scenario and each treatment option represents the decrease in nuisance struvite formation.

The NPC analysis indicated that phosphorus recovery with WASSTRIP™ was the most economical option, regardless of whether magnesium continued. In either scenario, phosphorus recovery had less than an eight-year payback compared with the ferric option, and provided equivalent struvite reduction (Figure 2). The fact that this alternative provides an avenue for performing nutrient recovery also is a benefit.

Furthermore, this option offers flexibility, as the system would have the same design with or without magnesium hydroxide addition in the collection system. The only difference in the scenarios would be the need to supplement magnesium and lime for cases where magnesium addition to the collection system was discontinued.

Sensitivity analysis showed that project variations in ferric and energy costs did not change the ranking. Since the completion of this work, the F. Wayne Hill facility has initiated efforts to begin procurement of phosphorus recovery technology.

## Miami-Dade Wastewater Treatment Plant

The Miami-Dade Water and Sewer Department manages two WRRFs. The Central District Wastewater Treatment Plant treats 143 mgd and the South District Wastewater Treatment Plant treats 113 mgd. Both facilities consist of two parallel trains employing pure-oxygen activated sludge. Effluent from Central is pumped to an ocean outfall, whereas effluent from South is pumped to Class I underground injection wells. Neither facility currently has a total nitrogen or total phosphorus limit.

Solids handling at both facilities consists of anaerobic digestion of gravity-thickened waste activated sludge (WAS) followed by centrifuge dewatering. Struvite deposits have been identified in the digesters and related piping system, including valves and heat exchangers, as well as in the centrifuges.

Central has had more severe struvite problems than South and recently had high effluent concentrations of total suspended solids (TSS), which were linked to struvite precipitation. As a short-term fix, the department fed ferric sulfate to the influent of the centrifuges.

In contrast, South has not added ferric and instead relies on weekly preventive maintenance—jetting pipe lines—to control struvite accumulation.

### Options

Three options were considered for mitigating struvite precipitation at both Central and South:
1. Ferric sulfate precipitation
2. Ferric chloride precipitation
3. Crystallizer system on centrate

A "do nothing" scenario was also considered for comparison. The evaluation included special sampling, *in-situ* scaling coupon analysis, and bench and pilot testing. Data from these studies were used to evaluate the effectiveness of full-scale chemical addition and to assess the effectiveness of the control strategies and perform a net present cost analysis.

### Findings

*In-situ* scaling coupon testing indicated that struvite accumulated primarily during and after centrifugation. Therefore, ferric addition should occur prior to dewatering if this option were selected. An optimized iron dose of approximately 300 mg/L as iron, regardless of type of iron salt, was found to be effective at both facilities.

Pilot scale testing of the crystallizer system demonstrated that this extractive phosphorus recovery option was effective in mitigating nuisance struvite formation, with soluble phosphate removal averaging 86 and 76 percent from South and Central, respectively. The present-worth analysis indicated that implementation of a centrate sidestream process similar or equal to the crystallizer nutrient recovery would be the most cost-effective solution for mitigating struvite at both facilities (Table 2).

### Durham Water Resource Recovery Facilities

The North Durham and South Durham Water Reclamation Facilities are two 76-mil
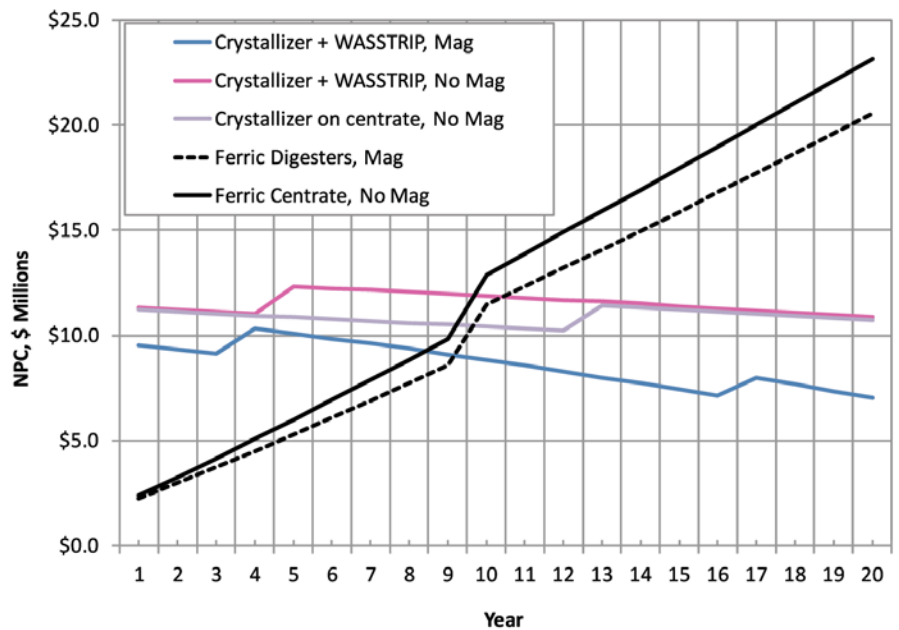
Figure 2. Net Present Cost Evaluations for Phosphorus Control Alternatives at F. Wayne Hill Water Resources Center*
* Net present worth costs are based on a 20-year period, 5 percent cost of financing, and 3 percent rate of inflation.

### Table 2. Economic Evaluation for Managing Sidestream Phosphorus Concentrations Within the Miami-Dade (Fla.) Water and Sewer Department[1]

| | Central District Wastewater Treatment Plant | | | South District Wastewater Treatment Plant | | |
|---|---|---|---|---|---|---|
| | Ferric addition | Crystallizer (capital option) | Crystallizer (fee option) | Ferric addition | Crystallizer (capital option) | Crystallizer (fee option) |
| Capital cost | $1,000,000 | $4,900,000 | $1,900,000 | $900,000 | $4,900,000 | $1,900,000 |
| Annual O&M cost | $535,000 | ($2000) | $358,000 | $415,000 | ($71,000) | $289,000 |
| Net present worth | $11,700,000 | $4,860,000 | $9,060,000 | $9,200,000 | $3,480,000 | $7,680,000 |

[1] Net present worth costs are based on a 20-year period, 6 percent cost of financing, and 6 percent inflation.

### Table 3. Economic Evaluation for Managing Sidestream Phosphorus Concentrations at the North and South Durham (N.C.) Water Reclamation Facilities[1]

| | Crystallizer Option 1 | | Crystallizer Option 2 | | Alum Addition | |
|---|---|---|---|---|---|---|
| | North | South | North | South | North | South |
| Capital costs | $4,891,000 | $4,591,000 | $2,258,500 | $1,958,500 | $690, 000 | 0 |
| Operating costs | 0[1] | 0[1] | $1,077,000 | $1,037,400 | $5,444,000 | $3,023,000 |
| Present worth cost | $4,891,000 | $4,591,000 | $3,335,000 | $2,995,900 | $6,134,000 | $3,023,000 |
| Payback compared to alum addition (years) | 15 | 25 | 5 | 22 | — | — |

[1] Net present worth costs are based on a 20-year period, 5 percent cost of financing, and 3 percent inflation.

[2] These costs are zero because the dollar per ton pricing structure for the dry struvite product is equal to the operating expenses.

L/day (20-mgd) WRRFs water resource recovery facilities that employ five-stage BNR and dual-media filtration for nitrogen and phosphorus removal. Solids handling consists of gravity belt thickening, anaerobic digestion, and belt filter press dewatering.

## Options

As part of master planning efforts for future upgrades for total phosphorus removal—North will be required to meet 0.06 mg/L and South will be required to meet 0.23 mg/L—three sidestream phosphorus removal options were considered:
1. Alum addition at the digester
2. Crystallizer option 1
3. Crystallizer option 2

Nutrient mass balances and calibrated process models helped to determine the effects of reducing phosphorus in the predicted sidestream load. A cost evaluation, including data acquired from vendors, also was performed.

## Findings

Results indicated that struvite recovery processes can be cost-competitive with the use of alum for sidestream phosphorus control. These evaluations also indicated that payback periods were dependent on site-specific details (e.g., nutrient loads), as well as capital cost requirements (e.g., reactor equipment costs, new building construction, etc.).

The business model employed by the struvite crystallizer provider also played a role in the overall cost. For instance, the crystallizer option 1 process requires a dryer and classifier to provide a high quality finished product, whereas the crystallizer option 2 process does not, as it produces a less refined fertilizer. Eliminating this equipment reduced the required footprint and resulted in decreased capital cost (Table 3).

While the economics of this process are satisfactory at the North facility based on nutrient removal alone, the current regulatory environment in North Carolina does not require the removal of phosphorous from the stabilized biosolids before land application. If future regulatory changes limit phosphorus loading to Durham's land application sites, the current strategy for treating phosphorus using alum will need to be modified to recover the phosphorus from the solids.

## Extracting Answers

These projects represented unique scenarios where extractive nutrient recovery was found to be a feasible nutrient control option. For the F. Wayne Hill facility, struvite recovery was the lowest-cost, technically sound option for controlling nuisance struvite precipitation and reducing phosphorus recycle loads. Similarly at the Nansemond, Central, and South facilities in Miami, and the North Durham Water Reclamation Facility, nutrient recovery was superior to the conventional chemical (ferric or alum) precipitation approach for controlling nutrient recycle loads and nuisance formation. At the South Durham Water Reclamation Facility, struvite recovery was cost-competitive to alum; however, the payback period exceeded 20 years.

In all cases, results indicated that successful implementation of extractive recovery systems is highly dependent on the amount of nutrient that must be removed and that payback periods are shorter for more concentrated wastestreams. These payback periods also are influenced to a small degree by the extent to which infrastructure can be repurposed and to a greater extent by the business model employed by the struvite recovery technology provider. ◊