

Protecting Our Water Environment



Metropolitan Water Reclamation District of Greater Chicago

***MONITORING AND RESEARCH
DEPARTMENT***

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STICKNEY PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 6

***EVALUATION OF ORTHO-PHOSPHATE RELEASE USING
WASSTRIP® AT THE STICKNEY WATER RECLAMATION PLANT***

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Metropolitan Water Reclamation District of Greater Chicago
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**EVALUATION OF ORTHO-PHOSPHATE RELEASE USING WASSTRIP® AT THE
STICKNEY WATER RECLAMATION PLANT**

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FORWARD

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) recognizes the value of phosphorus as a non-renewable resource. In an effort to optimize the sustainable removal of phosphorus from its wastewater influents and the subsequent recovery of phosphorus in various forms suitable for use as an agronomic fertilizer, the MWRD initiated a Phosphorus Removal and Recovery Task Force in 2012. The Task Force initiated a study phase at several of the MWRD's Water Reclamation Plants (WRPs) to evaluate the feasibility of implementing enhanced biological phosphorus removal and to develop operational guidelines for optimizing its effectiveness. The Task Force has created WRP specific study workgroups that are focused on each of the WRPs that have been identified to participate in this initiative. As the workgroups complete various phases of their studies and evaluations they are documenting their findings and recommendations in technical memoranda. These memoranda are written by the WRP specific workgroups and vetted by the Task Force before being published. Their purpose is to capture the state of knowledge and study findings and to make recommendations for implementation of enhanced biological phosphorus removal as they are understood at the time the memoranda are published.

DISCLAIMER

The contents of this technical memorandum constitute the state of knowledge and recommendations developed by the MWRD's Phosphorus Task Force at the time of publication, and are subject to change as additional studies are completed and experience is attained, and as the full context of the MWRD's operating environment is considered.

Technical Memorandum 6

Date: October 15, 2014

To: Phosphorus Task Force & Advisory Committee

From: Kamlesh Patel
Mwende Lefler

Subject: Evaluation of Ortho-Phosphate Release Using WASSTRIP[®] at the Stickney Water Reclamation Plant

INTRODUCTION

The Metropolitan Water Reclamation District of Greater Chicago (District) has selected the Ostara technology to reduce, remove, and recover phosphorus (P) content from the post-centrate stream at its Stickney Water Reclamation Plant (SWRP). The Ostara technology suggests a concentration of 75 mg/L of ortho-phosphate (ortho-P) as a benchmark minimum to make the P recovery economically viable. Previous centrate monitoring studies conducted from July 30, 2008 to July 29, 2009, and October to November 2011, concluded that the Ostara process would not easily receive the benchmark minimum ortho-P concentrations from the post-centrate stream unless the enhanced biological P removal (EBPR) process was implemented. For this reason and to meet the upcoming NPDES permit limitation for total P (TP) at the plant, the EBPR process was retrofitted to the existing activated sludge process (ASP) in one aeration battery during 2012 and in all batteries in 2013, to treat and thereby concentrate P content in the activated sludge and subsequently in the post-centrate stream upon anaerobic digestion. As the performance of the EBPR operations at SWRP continue to improve, the waste activated sludge (WAS) from the batteries may continue to increase TP concentration up to an average 3–4% TP in the wasted solids mass. This presents an opportunity to extract the increased concentrations of TP and possibly magnesium (Mg) from the WAS stream using the Waste Activated Sludge Stripping to Remove Internal Phosphorus (WASSTRIP[®]) process and then recover the extracted P and Mg in the Ostara reactor through struvite precipitation. Thus, the WASSTRIP[®] process has the potential to enhance the P recovery at SWRP.

The WASSTRIP[®] process efficiency can be increased if carbon is introduced in the WASSTRIP[®] reactor. Using carbon from either the cell decay via endogenous respiration (endogenous carbon), internal plant sources (such as thickened, unthickened, or fermented primary sludge, or digester draw), or external sources (such as sodium acetate, QLF - Quality Liquid Feeds, a molasses-based commercial carbon source), ortho-P and soluble magnesium (Sol-Mg) can see maximum release up to 50% and 75% of the initial TP and Mg concentrations from the WAS, respectively (ostara.com). An advantage with WASSTRIP[®] is that the released Mg can be used to supplement the required equimolar Mg concentration needed for struvite precipitation, thereby decreasing the amount of costly magnesium chloride (MgCl₂) that would need to be added to the Ostara P-recovery reactor. Additionally, the extraction from the WAS stream will reduce ortho-P

and Mg concentrations in the digester feed sludge lessening the odds of forming struvite in the digesters. However, the inclusion of WASSTRIP[®] as an integral part of the Ostara process would necessitate the construction of WASSTRIP[®] reactors and increase the size of the P-recovery system due to increased loads. As such, it is necessary to understand the true potential of WASSTRIP[®] at SWRP, with and without carbon sources, to weigh against the potential capital and operational costs. The engineering economic evaluation of the P-recovery system with the WASSTRIP[®] process would rest upon critical information such as the type of and amount of carbon source needed and the subsequent released concentrations of ortho-P and Mg and respective release rates.

BACKGROUND

WASSTRIP[®] Technology

WASSTRIP[®] technology was developed as a complementary step to enhance the performance of the Ostara P-recovery system. This technology promotes the ortho-P release from the WAS stream and conveys the ortho-P enriched supernatant stream to the Ostara reactor for increased P recovery. The process is based on holding WAS quiescently under anaerobic conditions and skimming off nutrient rich supernatant stream prior to thickening and digestion. Readily biodegradable carbon is needed to promote the P release. This can often be present in the WAS itself or added. WASSTRIP[®] is commonly used in plants with EBPR treatment as EBPR WAS contains higher TP and Mg that can be more readily extracted in the process. This technology has been implemented at several full-scale WRP facilities such as Saskatoon, Saskatchewan in Canada; Tigard, Oregon; and Madison, Wisconsin (ostara.com).

Typical final ortho-P concentrations from a WASSTRIP[®] reactor are dependent upon the initial TP concentration in WAS, the type and amount of carbon source, and residence time; typical release of ortho-P ranges from 30 to 50% of the initial TP concentration depending upon these dependent factors (ostara.com). Generally, higher initial TP and Mg concentrations in the WAS stream improves the efficiency of ortho-P and Mg releases. The Mg release is based upon the moles of P released. On average, the Sol-Mg is in a 0.3:1 molar ratio with the ortho-P released.

Compared to a WAS stream, a thickened WAS (TWAS) stream would allow for a much smaller WASSTRIP[®] tank volume. The hydraulic residence times (HRTs) may vary from 24 to 48 hours to achieve the expected ortho-P release with endogenous carbon. Using endogenous carbon would increase the residence time, and hence the reactor size, over ortho-P release achieved using the external carbon sources. When a non-endogenous carbon-rich stream is added, the ortho-P release is accelerated and hence, HRTs could be reduced to approximately 6 hours, but HRTs as low as 2 hours could also achieve substantial release. Typical plant based internal carbon sources may include unthickened or thickened primary sludge, primary sludge fermentate, or digester draw.

For the WAS held under 24 hours, there is expected to be insignificant increase in concentrations of ammonia nitrogen (NH₃-N). However, as the time extends, especially over 72 hours, NH₃-N concentrations increase with the transformation from TKN as early fermentation and acido-

genesis begins with solubilization of substrates followed by digestion of the proteins/cellular material and complex carbohydrates and lipids.

Finally, plants that employ EBPR often observe deterioration in sludge dewaterability. The divalent cation bridging theory suggests this is due to low divalent to monovalent cationic (D:M) ratios in the EBPR sludge. Although outside the scope of this study, it is important to understand how WASSTRIP[®] affects the D:M ratios of the residual streams.

The SWRP Operations

SWRP has four aeration batteries - A, B, C, and D. [Table 1](#) contains the daily average flows from 2013 Battery D operations, as this battery was converted first to retrofit the EBPR process. The average Battery D WAS flow was 2.6 MGD, and average TP concentration in the WAS was 169 mg/L. This represented a daily average TP of 3,665 lbs (1.83 tpd) in Battery D WAS alone. This TP mass corresponded to 2.2% mass of the total suspended solids wasted. At these loadings, the Ostara reactor would see 0.54 tons of ortho-P per day from Battery D WAS alone if 30% of the initial TP concentration could be released as ortho-P as observed in other installations. Based on this data, it can be estimated that approximately 2 tons of ortho-P loading per day may be introduced from all four batteries to the Ostara P-recovery system, assuming similar EBPR performance in all the batteries and these expected release rates.

Currently, WAS is airlifted from the final clarifiers, combined with the primary sludge from the South West preliminary tanks and a mixture of WAS and primary sludge from the O'Brien plant, and sent to the gravity concentration tanks for thickening. In the future all of these streams will be separated before thickening. The WAS will be pumped to the pre-digestion centrifuges through a wet well and pumping station while the primary sludge will feed gravity concentration tanks before it is sent to the digesters. Finally, the O'Brien sludge will be thickened through dedicated pre-digestion centrifuges before feeding the digesters. Because of the separation of the sludge streams, minimal additional infrastructure will be needed if the WASSTRIP[®] process is implemented.

Presently, the pre-digestion centrifuges thicken the combined gravity concentrated sludge solids to approximately 5 to 6% before the stream is transported to the digesters. Digester draw from the digesters is pumped to the post-digestion centrifuges or the LASMA lagoons for dewatering. Carbon dioxide (CO₂) is injected into the digested sludge to lower the pH if digester draw is pumped to the post-digestion centrifuges to alleviate struvite formation in pipes, pumps, and centrifuge machines. Additionally in the post-digester centrifuge operations, dilution water is used in significant quantities within the centrifuges themselves and centrate drains to mitigate struvite formation and/or deposition. Because the P-recovery reactors are designed on a loading basis, it would be beneficial to reduce the use of dilution water.

It is unknown whether struvite is a problem in WAS conduits at SWRP; however, the implementation of the WASSTRIP[®] process may alleviate or eliminate struvite formation in WAS conduits and the digesters as well as in the pre- and post-digester conduits, pumps, and appurtenances as a significant quantity of ortho-P and Sol-Mg would be removed ahead of the digestion process.

Figure 1 depicts a hypothetical WASSTRIP[®] process flow diagram if incorporated into SWRP operations. Available gravity thickening tanks or secondary clarifiers may be used to thicken WAS to 15,000 – 20,000 mg/L total solids (TS) ahead of the WASSTRIP[®] process. The TWAS would then be pumped to the WASSTRIP[®] tanks where an internal or external carbon-rich stream would also be added. After an appropriate residence time for ortho-P release, the supernatant from the WASSTRIP[®] tanks would be separated, combined with post-digester centrate, and fed directly to the Ostara reactors for P recovery. The TWAS solids from the tanks would then be returned to the WAS process stream for additional thickening before feeding to the digesters.

OBJECTIVES

The overall goal of the study was to help develop the design parameters for the WASSTRIP[®] process for enhancing P recovery at SWRP. The specific objectives were to:

1. Evaluate the potential maximum released ortho-P concentration and its release rate from the WAS or TWAS stream with internal and external carbon sources.
2. Evaluate the potential NH₃-N concentration increase during the WASSTRIP[®] process.
3. Generate information on capillary suction time (CST) as an indicator of dewaterability of the WAS or TWAS after the WASSTRIP[®] process.

MATERIALS AND METHODS

The Ostara supplied test procedure (Appendix I) was used as a backbone to develop the District work plan (Appendix I) to conduct the WASSTRIP[®] bench-scale tests. These tests included the WAS and TWAS streams with the endogenous internal plant and external carbon sources. WAS with endogenous carbon, and WAS with an internal or external carbon source, TWAS with endogenous carbon, and TWAS with an internal or external carbon source were evaluated. Internal plant carbon sources included unthickened primary sludge, thickened primary sludge, fermented primary sludge supernatant (fermentate), and gravity concentration tank (GCT) overflow; external carbon sources included sodium acetate and QLF. The sodium acetate, thickened primary sludge, and primary sludge fermentate additions were done with WAS while the remaining carbon additions were only done with TWAS. A summary of these treatments is presented in Table 2.

Battery D was initially chosen for the WAS samples for the experiments. However, given the poor biological P-removal performance observed in November and December, 2013 for Battery D, Battery B WAS was used for the endogenous carbon with TWAS treatments.

According to the approved work plan, the tests for all the treatments were conducted as summarized below:

- Volume of WAS collected in the morning hours of the experiment from Battery D or B was 8 gallons for WAS experiments and 15 gallons for TWAS experiments; for TWAS experiments, the 15 gallons volume of WAS was reduced to an approximate 5 gallons settled volume before use. All these samples were stored in covered bucket(s) at room temperature throughout the duration of the test. Sample amounts, types, and amount and sources of carbon used during the experiments are detailed in Table 3 with estimated resulting COD dosages.
- For endogenous carbon with WAS experiments, two WAS samples were collected at time, $T = 0$, from the bucket for two separate sets of analyses, except for CST, as shown in Table 4, to ensure the accuracy of the initial concentrations of all analytes, as the efficiency of the process would be evaluated with respect to the initial concentrations.
- For TWAS experiments, one pre-settled WAS sample (from 15 gallons raw sample) was collected for suspended solids (SS) and volatile suspended solids (VSS) analyses to determine how much SS and VSS settled in 5 gallons settled volume. Upon pre-settled sample collection, the WAS buckets were allowed to sit unperturbed for 1 hour. At the end of the hour, the liquid portion was decanted and disposed. The remaining TWAS from multiple buckets was combined into one container in order to have enough volume for testing and used for the experiment. For endogenous carbon with TWAS experiments, $T = 0$ samples were taken after the settled portions of the WAS from different buckets were combined with each other. A TWAS sample was analyzed for SS, VSS, and TP.
- For supplemental carbon experiments (Table 5), $T = 0$ samples were taken as soon as the carbon source was added and well-mixed with WAS or TWAS. The parameters analyzed on carbon sources are listed in Table 5. Sodium acetate (30 g) was added as a powder for each sodium acetate treatment to approximately 5 gallons of TWAS volume; other sources of carbon were added similarly to approximately 5 gallons of WAS or TWAS.
- Additional samples were taken during testing for analyses at the pre-determined time intervals, as indicated in Tables 4 and 5. The WAS or TWAS sample from a bucket with or without carbon addition was thoroughly mixed by hand avoiding aeration before collection of the sample.
- For analyses that required soluble samples, an aliquot from the sludge sample was coarse filtered followed by vacuum filtration through 0.45 μm filter paper.
- All samples were refrigerated (with or without preservatives depending on the parameter) until analyzed per the guidelines of the Stickney Analytical Laboratory (SAL).
- The CST tests were performed on unfiltered aliquots of the samples following a Standard Methods procedure at the beginning and end of the experiments to evaluate

the impact of WASSTRIP® on WAS dewaterability. No polymers or other dewatering aids were used.

The ortho-P release rate was calculated for each time interval; the percent release at a given time interval was based on calculating a ratio of ortho-P concentration in relation to initial TP. This value was multiplied by 100 to obtain percent release and expressed with the unit of %. This percent release value was then divided by the number of hours elapsed to obtain an hourly release rate, which was expressed with the units of %/hr. The percent TP in the WAS or TWAS samples were calculated based on the basis of the SS in the sample.

RESULTS AND DISCUSSION

The initial SS, VSS and TP concentrations for all WAS and TWAS samples used in tests are presented in [Table 6](#).

The plant WAS SS concentrations varied from significantly through the duration of the experiment from 2,780 mg/L to 12,070 mg/L; WAS used in experiments had relatively less variation in SS concentrations from 9,405 to 12,070 mg/L. These differences could be due to the variations in operation and performance of the batteries and final clarifiers. Aside from the last two weeks, the VSS to SS ratios, however, were quite similar.

The TWAS SS concentrations varied from 12,400 mg/L to 17,470 mg/L despite each of the WAS samples were allowed to thicken consistently as described in the Materials and Methods section for TWAS treatments. For TWAS treatments, the ratios of VSS to SS did not change much upon WAS thickening, but SS concentrations increased by a minimum of 1.2 to a maximum of 5.5 times; VSS concentrations increased by a minimum of 1.2 to a maximum of 5.3 times; and TP concentrations increased by a minimum of 1.5 to a maximum of 2.9 times. The highest and lowest TWAS SS concentrations were observed in week Nos. 4 and 5, respectively; the highest and lowest TWAS VSS concentrations were observed in week Nos. 6 and 5, respectively; and the highest and lowest TWAS TP concentrations were observed in week Nos. 5 and 7, respectively.

Percent TP in WAS samples for all experiments ranged from 1.38 to 6.87%; the WAS experiments during weeks Nos. 1 through 3 had a range of 1.38% (week No. 3) to 3.57% (week No. 1), and the TWAS experiments during weeks Nos. 4 through 7 had a range of 1.83% (week No. 7) to 6.87% (week No. 5). Upon thickening, percent TP in TWAS SS ranged from 2.02% (week No. 4) to 3.82% (week No. 5). This indicates that WASSTRIP® process performance with TWAS will have less variation and better process control than if using WAS.

The results of different forms of internal and external carbon sources tested with WAS and TWAS are presented below.

Effect of Internal and External Carbon Supplementation with WAS

Endogenous Carbon (Week Nos. 1 and 2)

The results of two experiments performed on WAS from Battery D are summarized in Table 7. The ortho-P concentrations after 54 and 52 hours of endogenous respiration were 72.00 and 53.41 mg/L, respectively, during the week Nos. 1 and 2 experiments. These released ortho-P concentrations varied significantly as did the initial TP concentrations of the WAS. However, the percent release varied in a narrow range between 20 and 23%. In both tests, the ortho-P concentrations continued to increase over the experimental period of 54 hours indicating that there was a continual release, despite a slower rate, throughout the duration of the experiment.

Both the released ortho-P concentrations and percent release were less than typically reported WASSTRIP[®] results from other installations; typical WASSTRIP[®] released ortho-P concentration is reported at 120 mg/L and a minimum percent release of 30%. The performance of Battery D on the testing days is also presented in Table 7. There was poor P removal in the battery for those days. The released ortho-P concentrations in these experiments were examined relative to the EBPR performance for that day; that is, it was hypothesized that if there is low P uptake in the battery, there would be low release in the WASSTRIP experiments, because TP concentration in WAS would not be high enough. As seen in later experiments, however, direct correlations between battery performance and WASSTRIP results were not seen. Additionally, percent TP in the WAS was not necessarily higher if battery EBPR performance was better according to the operation data collected so far.

The concentrations of released NH₃-N were monitored and these results are also included in Table 7. Maximum concentrations observed were 18.33 and 22.07 mg/L after 48 and 52 hours of endogenous respiration, respectively, during the weeks No. 1 and 2 experiments. The percentage increase in NH₃-N concentration with respect to initial TKN concentration varied from 2.79 to 7.05% with the highest percentage increase of 7.05% in week No. 2, which is considered insignificant from treatment aspects.

Carbon Sources (Unthickened Primary Sludge (Week Nos. 1 and 3), GCT Overflow (Week Nos. 2 and 3), and QLF (Week No. 3))

The results of assorted internal carbon treatments comprising of unthickened primary sludge and GCT overflow experiments were similar at the end of experiments (Table 8) compared to the endogenous carbon treatment experiments (Table 7). The released ortho-P concentrations after 24 hours were 44.93 and 82.90 mg/L, respectively during the week Nos. 1 and 3 experiments for unthickened primary sludge added, with an average 34.15 percent release. The 50.37% release with the unthickened primary sludge addition during the week No. 3 experiment was uncharacteristically high, especially ortho-P release between 4 and 24 hours. This could perhaps be due to the concentration of usable carbon available in primary sludge; week No. 3 could have had more complex carbon that took a bit longer to break down into a usable form.

With the GCT overflow addition, the released ortho-P concentrations after 24 hours were 55.46 and 29.34 mg/L, respectively, during the week Nos. 2 and 3 experiments while the average percent release was 19.18%. This result is quite similar to the results seen from the endogenous carbon treatment experiments.

The addition of QLF showed a more unique trend in that the ortho-P concentrations increased drastically within the first hour, decreased, and then increased to peak concentrations by 6 hours. Although not shown, the amount of carbon added from QLF was quite high as measured by sol-COD (7,200 mg/L); initial carbon concentrations from primary sludge and GCT overflow in week No. 3 were much lower and both around 25 mg/L measured as sol-COD. This higher sol-COD is one factor that could have substantially accelerated the release in the QLF tests. However, given that these are results from only one experiment, the ortho-P release pattern and initial carbon concentration effect could not be ascertained.

Figure 2 depicts the maximum ortho-P percent release for WAS with internal and external carbon supplementation. In all of these carbon supplementation experiments, except for week No. 3 where endogenous carbon was not tested, similar peak percent releases were observed when compared to endogenous carbon treatment. The unusually high Ortho P release in Week 3 due to the addition of unthickened PS would need replication to verify these results; it should also be noted that the addition of PS could result in an increase in the TP mass in the system, which may not have been accounted for due to the lack of information.

The releases with non-endogenous carbon supplement occurred in a shorter time period; the peak ortho-P concentrations were achieved within 6 to 24 hours with carbon supplementation as opposed to 48 hours for endogenous carbon treatments. This suggests that maximum ortho-P concentrations can be achieved either by using carbon augmentation to the WASSTRIP[®] process, or by holding WAS longer if using the endogenous carbon.

Effect of Internal and External Carbon Supplementation with TWAS

Endogenous Carbon (Week Nos. 5, 6, and 7)

The results of three experiments are presented in Table 9. The end of experiment released ortho-P concentrations varied between 35.75 and 99.91 mg/L with a maximum ortho-P concentration of 125.70 mg/L observed in week No. 5; this was attributed to the highest initial percent TP in the TWAS (3.82%). The lowest ortho-P release was observed in week No. 7 during which TWAS had the second lowest initial percent TP (2.21%). This observation signifies that higher ortho-P release depends upon higher initial percent TP in WAS.

As anticipated, the ortho-P concentrations slowly increased in all three experiments. However, the ortho-P concentrations decreased during two experiments after reaching the peak concentrations; the ortho-P concentrations increased to a peak concentration of 125.70 mg/L during week No. 5 after 48 hours of endogenous respiration and then decreased to 99.91 mg/L at 54 hours; likewise, after reaching a peak concentration of 83.72 mg/L during week No. 6 after 24 hours of endogenous respiration, it decreased to 80.42 mg/L and 47.35 mg/L after 30 and 48 hours, respectively. This is not a commonly observed trend during the WASSTRIP[®] process as the ortho-P release generally follows a first-order reaction, meaning a continual increase over the course of the experiment followed by an asymptotic maximum. These experimental results indicate that the optimal WASSTRIP[®] detention time would likely be between 24 to 48 hours for TWAS with endogenous carbon. The percent releases ranged from 13% to 27%. However, ortho-P release in week No. 7 was uncharacteristically low; this week also had the lowest initial SS concentration,

lowest initial TP concentration (285 mg/L), and lowest initial %TP in TWAS as mentioned in the above paragraph.

With TWAS, the ortho-P concentrations and percent releases observed during the experiments were much less than those from typical WASSTRIP[®] process. The Battery B effluent TP concentrations and percent TP removals during each of the testing days are presented in Table 9. The TP removal ranged from 86 to 95% in the battery. While these removal rates are indicative of good EBPR, the ortho-P release from WAS did not correspond to EBPR performance.

Initial TKN concentrations were relatively constant for these three experiments, ranging from 1,091 to 1,249 mg/L. The percentage increase in NH₃-N concentration with respect to initial TKN concentration varied from 2.84 to 3.90% with the highest percentage increase of 3.9% in week No. 7.

Sodium Acetate (Week Nos. 4, 5, 6 and 7)

The sodium acetate carbon supplementation to TWAS results are presented in Table 10. Sodium acetate (30 g) was added as a powder for each treatment to approximately 5 gallons of TWAS. Although sodium acetate will not likely be added in a full-scale installation at SWRP due to very high operational costs, it was used in the experiments, because it provides an ideal carbon source for the experiment to induce ortho-P release, and the results can be related to other carbon sources. It is more likely that internal carbon sources, such as unthickened or thickened primary sludge or primary sludge fermentate, will be preferred carbon sources for full-scale implementation at SWRP if the WASSTRIP[®] process is implemented and these sources can provide the needed carbon.

The observed maximum ortho-P concentrations were between 35.10 and 87.93 mg/L, and maximum percent releases were between 12 and 27% for all sodium acetate experiments with the TWAS (Table 10). It should be noted that week No. 7 had the lowest release (ortho-P concentration of 35.10 mg/L after 24 hours corresponding to approximately 12% release) out of the four experiments. This provides further evidence that initial percent TP or concentration affects ortho-P released concentrations the most. The average maximum ortho-P concentration was 69.96 mg/L, and the corresponding maximum average percent release was 20% for all four TWAS experiments with acetate added.

Similar to the sodium acetate experiment, the lowest ortho-P release observations were made with endogenous carbon addition to TWAS in a week No. 7 test (Table 9). In both sodium acetate and endogenous carbon addition to TWAS experiments, the lowest TWAS SS concentration was observed in week No. 7 tests compared to results from other weeks among like test groups (Tables 9 and 10); this lower SS concentration would project to lower biological activity of PAOs during the testing. Lower TWAS SS and higher left over carbon concentrations suggest that PAOs need to be increased to either expedite or continue further ortho-P release. This is corroborated by the fact that the lowest initial percent TP in TWAS and WAS was observed in week No. 7 which affected the ortho-P release similarly regardless of carbon type or treatment examined.

Like the week No. 5 endogenous carbon experiments, the maximum released ortho-P concentration of 70.23 mg/L after 4 hours reduced to 54.58 mg/L after 24 hours during the week No. 4 sodium acetate experiment, and the maximum released ortho-P concentration of 87.93 mg/L after 6 hours reduced to 65.74 mg/L after 24 hours during the week No. 5 sodium acetate experiment. Due to a lack of information on carbon concentrations for endogenous treatments, the role of carbon in week No. 5 experiments between both groups cannot be commented upon.

Generally, the ortho-P release rates were markedly higher than endogenous treatments during the initial hours in each of the carbon-supplemented experiments; these rates sharply declined as time progressed as anticipated. The pattern observed with both the endogenous carbon with TWAS and carbon supplemented TWAS experiments in which the ortho-P release peaked and then decreased over time is unexpected, and the reasoning for it is unclear. However, it appears that the optimum time for the complete release may be shorter than the experiment durations. It is also possible that, through shaking of the sample and sampling technique, the anaerobic integrity of the sample may have been compromised, and ortho-P could have been uptaken under aerobic conditions.

The NH₃-N concentrations during the experiments indicate that NH₃-N concentrations increased approximately 0.2 to 2% of the initial TKN concentrations.

The initial VFA concentrations for the acetate experiments varied (Table 10) from 291 to 1,202 mg/L. However, the VFA concentrations after 24 hours were in a narrower range from 1,306 to 1,624 mg/L. The initial concentrations may be indicative of improper mixing of sodium acetate in the TWAS. Additionally, the variation in initial VFA concentrations could also be in part due to the approximate TWAS volume used in all experiments causing different initial carbon concentrations; the amount of sodium acetate addition was exactly 30 g, but the TWAS volume was only approximately 5 gallons. All higher VFA concentrations after 24 hours seemed to indicate that additional VFA was produced during the experiments. The initial and 24 hours concentrations of sol-COD (as a surrogate parameter to VFA) corroborate improper mixing and possible carbon solubilization during the WASSTRIP[®] process.

Over the course of each of these experiments, the carbon concentrations increased as measured by Sol-COD and VFA (Table 10); the VFA and Sol-COD concentrations at 2 hours were 1.6 and 1.5 times higher than the initial concentrations, respectively. The lowest and highest VFA concentrations at 24 hours were 1.2 and 5.6 times higher than the initial concentrations. The highest carbon concentrations corresponded to the peak ortho-P concentrations and percent release per hour. However, there is no clear correlation between initial VFA concentrations and peak ortho-P concentrations or ortho-P percent release rate perhaps due to improper sodium acetate mixing at the beginning of the experiments. This may indicate that the ortho-P percent release rate may not be driven by the concentration of carbon when it is present in excess of what is necessary. At this time this work may be insufficient to shed light on the required initial carbon concentration.

Thickened Primary Sludge (Week Nos. 4, 5 and 7), and Primary Sludge Fermentate (Week Nos. 4)

The results for the thickened primary sludge carbon supplementation to TWAS are presented in [Table 11](#). Maximum percent release from the initial TP concentrations were between 11 and 23%. These results were more typical in terms of the expected release pattern – the ortho-P was released over the entire time span of the experiment with a sharper increase in the beginning with tapering off towards the end. Similar to the TWAS with endogenous and sodium acetate carbon supplemented experiments from week No. 7, the results for this treatment in a week No. 7 (11%) indicated lowest ortho-P release. For all three separate tests of the thickened primary sludge addition treatment, the average maximum ortho-P concentration was 63 mg/L, and the average maximum percent release was 18%.

The initial sol-COD, VFA, and TP concentrations for the primary sludge addition experiments varied considerably with changing characteristics of the primary sludge due to variances in the process treatment efficiencies and thickened primary sludge characteristics ([Table 12](#)). However, on a given experimental day, the sol-COD concentrations in the thickened primary sludge addition experiments remained steady for the first 6 hours and then increased between 6 and 24 hours. In the thickened primary sludge experiments, the one-hour thickening time did not greatly increase the SS concentrations; weeks Nos. 4 and 5, respectively had pre-thickened SS concentrations of 1.6 and 2.9% and were 1.6 and 3.2% after thickening. The third thickened experiment in week No. 7 had a thickened SS concentration of 1.7%.

The thickened primary sludge experiments had sol-COD concentrations ranging from 311 to 1,468 mg/L and averaging 800 mg/L, with the higher sol-COD concentrations corresponding to the higher initial primary sludge SS concentrations. Unthickened primary sludge experiments had an average 211 mg/L sol-COD. Ratios of VFA to sol-COD in primary sludge alone averaged 60% across all of the primary sludge experiments. After WAS or TWAS was combined with primary sludge, the sol-COD concentrations at the beginning of the experiment did show a correlation to percent release.

The results for the primary sludge fermentate addition as a carbon source to TWAS experiments conducted in a week No. 4 are presented in [Table 13](#). The observed maximum ortho-P concentration was 63.3 mg/L, and maximum percent release was 21% at 24 hours. Very similar results were observed for this treatment compared to the sodium acetate and thickened primary sludge experiments results.

Comparisons of Thickened and Unthickened WAS Treatments.

Except for one outlier during the WAS experiments in Week 6, the TWAS experiments had higher initial TP concentrations compared to the WAS experiments due largely to the higher SS concentrations. The initial TP percentage ranged from 2.0 to 3.8 for TWAS and 1.4 to 6.9 for WAS used in the treatments. However, for a given treatment on two separate experimental days, the initial percent TP could be different enough to cause variations in the results. The average peak concentration of ortho-P for the endogenous TWAS experiments was 81.72 mg/L; this is substantially higher than the endogenous WAS average peak concentration of 62.71 mg/L. However, average percent release was similar and peaked for both at 22 and 21% at 54 hours for endogenous WAS and TWAS treatments, respectively.

The correlations between maximum released ortho-P concentrations and initial SS and initial TP concentrations in WAS and TWAS experiments were similar. When using data from both WAS and TWAS experiments, initial TP concentrations were much more highly correlated to maximum released ortho-P concentrations than initial SS concentrations, with an r^2 -value of 0.41 for initial TP concentrations and 0.03 for initial SS concentrations. An r^2 -value of 0.34 was obtained (Figure 7) when initial TP concentrations were normalized with initial corresponding WAS SS concentrations and examined in relation to maximum released ortho-P concentrations. These correlations suggest that initial SS concentration does not drive ortho-P release as much as initial TP concentration does.

Figure 3 depicts the average ortho-P percent released over time for WAS with endogenous and other carbon additions. The release occurred over the entirety of the trial in each case. The primary sludge addition resulted in the highest ortho-P release followed by GCT overflow and endogenous carbon additions.

Figure 4 depicts the average ortho-P percent released over time for TWAS with endogenous and other carbon additions. The peak releases occurred at different times for different treatments.

As seen in Figure 5, the same trends were apparent with ortho-P release for TWAS, with endogenous and other carbon supplementation, as compared to WAS trends seen in Figure 3. In all of these experiments, the percent releases were less than 30%. Although the initial carbon concentrations were much greater with the sodium acetate and primary sludge addition experiments, the ortho-P percent release was about the same for carbon additions to WAS and TWAS. This, too, would suggest that the supplemental carbon does not induce greater release overall, but it does release ortho-P much quicker, thus shortening the process time and allowing for smaller reactor sizes.

Figure 6 depicts the average hourly ortho-P percent release rates during experimental durations. As seen, with carbon supplementation, the releases largely occurred within the first 6 hours, with release rates dropping rapidly after the initial 2 hours. The fastest release rates were observed with supplemental sodium acetate experiments.

Figure 7 depicts the correlation between initial percent TP and maximum released ortho-P concentrations observed in each of these experiments. The maximum ortho-P concentrations observed in the experiments corresponded to the higher initial percent TP as opposed to effluent TP concentrations in the battery. This suggests that the ability of EBPR to concentrate P in the WAS will be a significant driver for the success of the WASSTRIP[®] process.

Impact on Dewatering Characteristics

For WAS and TWAS treatments with endogenous or other forms of carbon additions, limited CST data were collected at the beginning and end of the experiments. Average CST data are presented in Table 14. For WAS endogenous carbon treatments, average CST increased from 17.1 to 41.2 seconds (141%) on 11/12/13 and from 20.5 to 29.0 seconds (42%) on 11/19/13. Similarly, for TWAS endogenous carbon treatments, average CST increased from 24.5 to 58.1

seconds (137%) on 12/17/13; from 54.5 to 56.1 seconds (3%) on 1/8/14; and from 39.1 to 87.3 seconds (123%) on 1/14/14.

With carbon additions, for WAS with unthickened primary sludge treatment on 11/12/13, average CST increased from 30.3 to 51.0 seconds (68%). For WAS with GCT overflow treatment on 11/19/13, average CST increased from 18.8 to 26.3 seconds (40%). For TWAS with thickened primary sludge treatment on 12/17/13, average CST increased from 35.2 to 43.0 seconds (22%). For TWAS with sodium acetate treatment on 1/8/14, average CST increased from 77.5 to 92.0 seconds (19%).

Regardless of treatments, increased CSTs suggest that the WASSTRIP[®] process deteriorated dewatering characteristics.

CONCLUSIONS

Based on the bench-scale experimental study results, the following conclusions are drawn:

- The WASSTRIP[®] experiments, regardless of different treatments, could not reliably and consistently achieve the overall released ortho-P concentrations to meet the minimum bench mark concentration of 75 mg/L. Percent release obtained in the tests was less than 30% for all treatments, which is much lower than observed from the WASSTRIP[®] experiments at other plants.
- The EBPR performance in the batteries did not seem to have an effect on the final released ortho-P concentrations in the WASSTRIP[®] tests as varied performance in the batteries was observed. In other words, better EBPR performance did not lead to higher ortho-P concentrations or release rates, but the ability of EBPR to concentrate TP in the WAS did matter as higher initial concentration and percent of TP in the WAS or TWAS led to higher ortho-P release. Maximum ortho-P concentrations compared to the maximum hourly ortho-P release rates correlated well with the initial TP concentrations and %TP both for WAS and TWAS, with and without carbon supplementation. Thus, the percent and concentration of initial TP in WAS or TWAS will be a significant driver for the success of the WASSTRIP[®] process.
- The peak ortho-P concentrations occurred at different times for different treatments and varied significantly at the end of the treatments, both for WAS and TWAS, with and without carbon supplementation. Generally, higher maximum released ortho-P concentrations were observed with TWAS treatments compared to WAS treatments.
- The optimum HRT for the WAS endogenous treatments was approximately 52 hours and for the TWAS endogenous treatments was between 24 and 48 hours. For the WAS with assorted carbon addition treatments, the optimum HRT was approximately 24 hours. With TWAS and sodium acetate and primary sludge treatments, the optimum HRT ranged from 4 to 24 hours.

- Supplementation of initial carbon concentrations did not increase the maximum ortho-P concentration, but increased the rate of ortho-P release, which would result in expeditious process completion time. At this time, the amount of carbon needed is unknown.
- The percent increase in $\text{NH}_3\text{-N}$ with respect to initial TKN concentrations was insignificant and similar for both WAS and TWAS treatments, with endogenous and other forms of carbon additions. The increase was less, however, for all other forms of carbon supplementation treatments.
- The WASSTRIP[®] process deteriorated dewatering characteristics with respect to CST increase, but the degree of deterioration could not be established.

RECOMMENDATIONS

Based on the study results, the following are suggested to address the unanswered questions:

- Based on the rate of ortho-P released in numerous treatments, the preferred carbon source would be sodium acetate followed by thickened primary sludge combined with TWAS. However, considering the higher operational costs associated with sodium acetate, additional tests are recommended using thickened primary sludge and its fermentate.
- Additional tests with the lower initial carbon concentrations may shed some light on optimum carbon concentrations.
- A Sol-Mg and Sol-K release study may be added to additional WASSTRIP[®] testing to understand the dynamics of these cation concentrations during the tests.
- A future study is being planned to examine the effects of EBPR on sludge dewatering. WASSTRIP[®] will be considered in this work.

TABLE 1: 2013 WAS DATA FOR BATTERY D

	WAS (MGD)	WAS [SS] (mg/L)	WAS [TP] (mg/L)
Average	2.6	7,585	169
Min	0	1,500	48
Max	6.1	27,263	331
75 th %	3.7	9,170	196

**TABLE 2: A SUMMARY OF WASSTRIP® EXPERIMENTS PERFORMED
NOVEMBER 11, 2013, THROUGH JANUARY 15, 2014**

Week No.	Experiment Date	WAS Source Battery	WAS	Source of Carbon
1	11/12/2013	D	<ul style="list-style-type: none"> • Unthickened • Unthickened 	<ul style="list-style-type: none"> • Endogenous • Unthickened Primary Sludge
2	11/19/2013	D	<ul style="list-style-type: none"> • Unthickened • Unthickened 	<ul style="list-style-type: none"> • Endogenous • GCT Overflow
3	12/3/2013	D	<ul style="list-style-type: none"> • Unthickened • Unthickened • Unthickened 	<ul style="list-style-type: none"> • GCT Overflow • Unthickened Primary Sludge • QLF
4	12/10/2013 – 12/11/2013	D	<ul style="list-style-type: none"> • Thickened • Thickened • Thickened 	<ul style="list-style-type: none"> • Thickened Primary Sludge • Sodium Acetate • Primary Sludge Fermentate
5	12/17/2013 – 12/18/2013	B	<ul style="list-style-type: none"> • Thickened • Thickened • Thickened 	<ul style="list-style-type: none"> • Endogenous • Thickened Primary Sludge • Sodium Acetate
6	1/8/2014	B	<ul style="list-style-type: none"> • Thickened • Thickened 	Endogenous Sodium Acetate
7	1/14/2014 – 1/15/2014	B	<ul style="list-style-type: none"> • Thickened • Thickened • Thickened 	Endogenous Sodium Acetate Thickened Primary Sludge

TABLE 3: AMOUNTS AND TYPES OF DIFFERENT CARBON SOURCES USED WITH ESTIMATED CHEMICAL OXYGEN DEMAND DOSAGES

Carbon Source	Unthickened WAS with Supplemental Carbon	Thickened WAS with Supplemental Carbon
Sodium acetate	30 g in 8 gal WAS (average 750 mg Sol-COD/L)	30 g in 5 gal WAS (1,210 mg Sol-COD /L)
Primary Sludge	2,000 mL in 7 gal & 3,400 mL in 8 gal WAS (26 & 36 mg Sol-COD/L, respectively, for 7 gal and 8 gal)	1,000 mL in 5 gal WAS (177 mg Sol-COD/L)
GCT Overflow	3,400 mL in 8 gal WAS (34 mg Sol-COD/L)	--
QLF	200 mL in 6 gal WAS (7,200 mg Sol-COD/L)	--
Thickened Primary Sludge	--	1,000 mL in 5 gal WAS (30 mg Sol-COD/L)
Primary Sludge Fermentate	--	1,000 mL in 5 gal WAS (65 mg Sol-COD/L)

Note: The 5- or 8-gallon WAS volumes were approximate, but these volume approximations were not considered while calculating the estimated Sol-COD dosages; the Sol-COD values were from analytical results.

TABLE 4: SAMPLE TIMES AND ANALYSES PERFORMED FOR WAS AND TWAS ENDOGENOUS CARBON WASSTRIP[®] EXPERIMENTS

Sample Time (hours)	Analytes	CST Testing
0	SS, VSS, TP, Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, conductivity, alkalinity	X
1	PO ₄ -P	
4	PO ₄ -P	
6	PO ₄ -P	
24	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P	
30	PO ₄ -P	
48	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P	
54	PO ₄ -P	
72	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, conductivity, alkalinity	X
80	PO ₄ -P	

**TABLE 5: SAMPLE TIMES AND ANALYSES PERFORMED FOR WAS AND TWAS
WASSTRIP[®] CARBON ADDITION EXPERIMENTS**

Sample Time (hours)	Analytes	CST Testing
C source	SS, VSS, TP, Mg, Ca, K, Na, Al, Fe, VFA, Sol-COD	
0 – after combination with C source	SS, VSS, TP, Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, conductivity, alkalinity, VFA, Sol-COD	X
0.5	PO ₄ -P	
1	PO ₄ -P	
1.5	PO ₄ -P	
2	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, VFA, Sol-COD	
3	PO ₄ -P	
4	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, VFA, Sol-COD	
6	PO ₄ -P	
24	Mg, Ca, K, Na, Al, Fe, NH ₃ -N, PO ₄ -P, conductivity, alkalinity, VFA, Sol-COD	X

TABLE 6: SS, VSS AND TP RESULTS FOR ALL WAS SAMPLES BEFORE AND AFTER THICKENING

	WAS				TWAS			
	[SS] (mg/L)	[VSS] (mg/L)	[TP]* (mg/L)	[VSS]/[SS]	[SS] (mg/L)	[VSS] (mg/L)	[TP] (mg/L)	[VSS]/[SS]
Week 1	9,405	5,950	264	0.63	--	--	--	--
Week 2	12,070	7,535	313	0.62	--	--	--	--
Week 3	9,500	6,540	131	0.69	--	--	--	--
Week 4	5,620	3,680	123	0.65	17,470	11,250	353	0.64
Week 5	5,200	3,600	165	0.69	12,400	8,680	474	0.70
Week 6	2,780	2,220	191	0.80	15,330	11,800	354	0.77
Week 7	10,740	8,080	197	0.75	12,920	9,660	285	0.75

Weeks Nos. 1 through 3 used WAS and 4 through 7 used TWAS.

* TP values were not analyzed prior to thickening. The TP values presented in this table are from the RAS grab samples collected by M&O as a surrogate for WAS.

TABLE 7: WASSTRIP[®] TEST RESULTS FOR THE WAS ENDOGENOUS CARBON TREATMENT

Week No. 1 (11/12/2013)							
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L
0 (average)	313	2.09	0.67	--	14,080	658	<0.1
1	--	3.52	1.12	1.12	--	--	--
4	--	15.72	5.03	1.26	--	--	--
6	--	18.65	5.96	0.99	--	--	--
24	--	42.82	13.69	0.57	15,138	--	5.17
30	--	54.80	17.52	0.59	--	--	--
48	--	67.74	21.66	0.45	14,182	--	18.33
54	--	72.00	23.02	0.43	--	--	--

Note: Battery D Effluent TP, 1.26 mg/L

Battery D TP Removal, 56%

TABLE 7 (Continued): WASSTRIP® TEST RESULTS FOR THE WAS ENDOGENOUS CARBON TREATMENT

Week No. 2 (11/19/2013)							
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L
0 (average)	267	0.90	0.34	--	13,280	313	<0.1
1	--	1.60	0.60	0.61	--	--	--
4	--	10.41	3.90	0.99	--	--	--
6	--	15.67	5.87	0.99	--	--	--
24	--	36.58	13.71	0.58	13,384	--	6.43
28	--	38.64	14.48	0.52	--	--	8.07
48	--	50.58	18.96	0.40	13,502	--	18.31
52	--	53.41	20.02	0.39	--	--	22.07

Note: Battery D Effluent TP, 1.51 mg/L

Battery D TP Removal, 72%

TABLE 8: WASSTRIP® TEST RESULTS FOR WAS WITH THE ADDITION OF UNTHICKENED PRIMARY SLUDGE, GCT OVERFLOW, AND QLF

Elapsed Time, hr	Unthickened Primary Sludge			GCT Overflow			QLF	
	Week No. 1 (11/12/13)	Week No. 3 (12/3/13)	Week No. 2 (11/19/13)	Week No. 3 (12/3/13)	Week No. 2 (11/19/13)	Week No. 3 (12/3/13)	Week No. 3 (12/3/13)	Week No. 3 (12/3/13)
TP at T = 0 (mg/L)	275	165	260	179	131			
0 (average)	Ortho-P, mg/L: 6.43 % Ortho-P Release: 2.57	Ortho-P, mg/L: 2.34 % Ortho-P Release: 1.42	Ortho-P, mg/L: 4.84 % Ortho-P Release: 1.81	Ortho-P, mg/L: 2.50 % Ortho-P Release: 1.50	Ortho-P, mg/L: 4.36 % Ortho-P Release: 1.63	Ortho-P, mg/L: 2.54 % Ortho-P Release: 1.52	Ortho-P, mg/L: 17.8 % Ortho-P Release: 21.63	Ortho-P, mg/L: 2.6 % Ortho-P Release: 3.16
0.5	Ortho-P, mg/L: 11.32 % Ortho-P Release: 4.52	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 4.19 % Ortho-P Release: 1.57	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 4.36 % Ortho-P Release: 1.63	Ortho-P, mg/L: 2.54 % Ortho-P Release: 1.52	Ortho-P, mg/L: 29.2 % Ortho-P Release: 35.48	Ortho-P, mg/L: 29.2 % Ortho-P Release: 35.48
1	Ortho-P, mg/L: 13.51 % Ortho-P Release: 5.39	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 4.36 % Ortho-P Release: 1.63	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 4.36 % Ortho-P Release: 1.63	Ortho-P, mg/L: 2.54 % Ortho-P Release: 1.52	Ortho-P, mg/L: 33.2 % Ortho-P Release: 40.34	Ortho-P, mg/L: 33.2 % Ortho-P Release: 40.34
1.5	Ortho-P, mg/L: 15.46 % Ortho-P Release: 6.17	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 6.12 % Ortho-P Release: 2.29	Ortho-P, mg/L: 2.54 % Ortho-P Release: 1.52	Ortho-P, mg/L: 6.12 % Ortho-P Release: 2.29	Ortho-P, mg/L: 2.54 % Ortho-P Release: 1.52	Ortho-P, mg/L: 17.8 % Ortho-P Release: 21.63	Ortho-P, mg/L: 17.8 % Ortho-P Release: 21.63
2	Ortho-P, mg/L: 11.77 % Ortho-P Release: 4.70	Ortho-P, mg/L: 2.94 % Ortho-P Release: 1.79	Ortho-P, mg/L: 7.63 % Ortho-P Release: 2.86	Ortho-P, mg/L: 3.63 % Ortho-P Release: 2.18	Ortho-P, mg/L: 7.63 % Ortho-P Release: 2.86	Ortho-P, mg/L: 3.63 % Ortho-P Release: 2.18	Ortho-P, mg/L: 2.7 % Ortho-P Release: 3.28	Ortho-P, mg/L: 2.7 % Ortho-P Release: 3.28
3	Ortho-P, mg/L: 19.88 % Ortho-P Release: 7.93	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 10.26 % Ortho-P Release: 3.85	Ortho-P, mg/L: 4.36 % Ortho-P Release: 2.61	Ortho-P, mg/L: 10.26 % Ortho-P Release: 3.85	Ortho-P, mg/L: 4.36 % Ortho-P Release: 2.61	Ortho-P, mg/L: 2.9 % Ortho-P Release: 3.52	Ortho-P, mg/L: 2.9 % Ortho-P Release: 3.52
4	Ortho-P, mg/L: 28.53 % Ortho-P Release: 11.39	Ortho-P, mg/L: 8.46 % Ortho-P Release: 5.14	Ortho-P, mg/L: 13.60 % Ortho-P Release: 5.10	Ortho-P, mg/L: 9.58 % Ortho-P Release: 5.74	Ortho-P, mg/L: 13.60 % Ortho-P Release: 5.10	Ortho-P, mg/L: 9.58 % Ortho-P Release: 5.74	Ortho-P, mg/L: 27.3 % Ortho-P Release: 33.17	Ortho-P, mg/L: 27.3 % Ortho-P Release: 33.17
6	Ortho-P, mg/L: 33.04 % Ortho-P Release: 13.19	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: 20.78 % Ortho-P Release: 7.79	Ortho-P, mg/L: 14.29 % Ortho-P Release: 8.56	Ortho-P, mg/L: 20.78 % Ortho-P Release: 7.79	Ortho-P, mg/L: 14.29 % Ortho-P Release: 8.56	Ortho-P, mg/L: 32.1 % Ortho-P Release: 39	Ortho-P, mg/L: 32.1 % Ortho-P Release: 39
24	Ortho-P, mg/L: 44.93 % Ortho-P Release: 17.93	Ortho-P, mg/L: 82.90 % Ortho-P Release: 50.37	Ortho-P, mg/L: 55.46 % Ortho-P Release: 20.79	Ortho-P, mg/L: 29.34 % Ortho-P Release: 17.57	Ortho-P, mg/L: 55.46 % Ortho-P Release: 20.79	Ortho-P, mg/L: 29.34 % Ortho-P Release: 17.57	Ortho-P, mg/L: -- % Ortho-P Release: --	Ortho-P, mg/L: -- % Ortho-P Release: --

TABLE 9: WASSTRIP[®] TEST RESULTS FOR THE TWAS ENDOGENOUS CARBON TREATMENT

Week No.5 (12/17/2013)							
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L
0 (average)	474	0.42	0.09	--	11,448	1,249	<0.2
1	--	3.87	0.82	0.82	--	--	--
4	--	14.32	3.02	0.76	--	--	--
6	--	31.20	6.59	1.10	--	--	--
24	--	98.66	20.82	0.87	11,703	--	9.89
30	--	84.58	17.85	0.60	--	--	--
48	--	125.70	26.53	0.56	11,503	--	35.42
54	--	99.91	21.09	0.39	--	--	--

Note: Initial SS, 5,200 mg/L

Thickened SS, 14,060 mg/L

Thickened SS/Initial SS was 2.7

Battery B Effluent TP, 0.33 mg/L

Battery B TP Removal, 95%

TABLE 9 (Continued): WASSTRIP® TEST RESULTS FOR THE TWAS ENDOGENOUS CARBON TREATMENT

Week No. 6 (1/8/2014)							
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L
0 (average)	354	9.72	2.75	--	9,267	1,238	4.86
1	--	15.49	4.38	4.44	--	--	--
4	--	46.14	13.03	3.31	--	--	--
6	--	54.96	15.53	2.63	--	--	
24	--	83.72	23.65	1.00	9,420	--	29.65
30	--	80.42	22.72	0.77	--	--	--
48	--	47.35	13.38	0.28	8,190	--	4.22

Note: Initial SS, 2,780 mg/L

Thickened SS, 15,330 mg/L

Thickened SS/Initial SS was 5.5

Battery B Effluent TP, 0.69 mg/L

Battery B TP Removal, 86%

TABLE 9 (Continued): WASSTRIP® TEST RESULTS FOR THE TWAS ENDOGENOUS CARBON TREATMENT

Week No. 7 (1/14/2014)							
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L
0 (average)	285	1.75	0.62	--	10,715	1,091	3.24
1	--	1.89	0.66	0.67	--	--	--
4	--	6.72	2.36	0.60	--	--	--
6	--	11.06	3.89	0.66	--	--	--
24	--	30.76	10.81	0.46	10,673	--	14.47
30	--	32.87	11.55	0.39	--	--	--
48	--	35.75	12.57	0.26	11,670	--	42.56

Note: Initial SS, 10,740 mg/L

Thickened SS, 12,920 mg/L

Thickened SS/Initial SS was 1.2

Battery B Effluent TP, 0.24 mg/L

Battery B TP Removal, 94%

TABLE 10: WASSTRIP® TEST RESULTS FOR TWAS WITH SODIUM ACETATE ADDITION

Week No. 4 (12/11/2013)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD mg/L	
0 (average)	353	11.24	3.42	--	12,101	1,365	0.19	1,202	1,313	
0.5	--	21.56	6.55	13.11	--	--	--	--	--	
1	--	31.52	9.58	9.58	--	--	--	--	--	
1.5	--	40.81	12.41	8.27	--	--	--	--	--	
2	--	45.5	13.83	6.92	11,142	--	5.63	1,914	1,913	
3	--	64	19.46	6.49	--	--	--	--	--	
4	--	70.23	21.35	5.34	11,129	--	3.48	2,043	1,848	
6	--	67.3	20.46	3.41	--	--	--	--	--	
24	--	54.58	16.59	0.69	--	--	3.6	1,476	--	

Note: Initial SS, 5,620 mg/L

Thickened SS, 17,470 mg/L

Thickened SS/Initial SS was 3.1

Battery B Effluent TP, <0.2 mg/L

Battery B TP Removal, >96.6%

TABLE 10: WASSTRIP® TEST RESULTS FOR TWAS WITH SODIUM ACETATE ADDITION

Week No. 4 (12/11/2013)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD mg/L	
0 (average)	353	11.24	3.42	--	12,101	1,365	0.19	1,202	1,313	
0.5	--	21.56	6.55	13.11	--	--	--	--	--	
1	--	31.52	9.58	9.58	--	--	--	--	--	
1.5	--	40.81	12.41	8.27	--	--	--	--	--	
2	--	45.5	13.83	6.92	11,142	--	5.63	1,914	1,913	
3	--	64	19.46	6.49	--	--	--	--	--	
4	--	70.23	21.35	5.34	11,129	--	3.48	2,043	1,848	
6	--	67.3	20.46	3.41	--	--	--	--	--	
24	--	54.58	16.59	0.69	--	--	3.6	1,476	--	

Note: Initial SS, 5,620 mg/L

Thickened SS, 17,470 mg/L

Thickened SS/Initial SS was 3.1

Battery B Effluent TP, <0.2 mg/L

Battery B % TP Removal, >96.6%

TABLE 10 (Continued): WASSTRIP® TEST RESULTS FOR TWAS WITH SODIUM ACETATE ADDITION

Week No. 6 (1/8/2014)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD, mg/L	
0 (average)	318	13.04	4.10	--	9,355	1,072	3.71	419	484	
0.5	--	23.46	7.38	14.57	--	--	--	--	--	
1	--	34.02	10.70	10.56	--	--	--	--	--	
1.5	--	42.26	13.29	8.74	--	--	--	--	--	
2	--	47.35	14.89	7.35	8,190	--	4.22	1,530	1,871	
3	--	52.84	16.62	5.47	--	--	--	--	--	
4	--	56.84	17.88	4.41	8,314	--	6.21	1,423	1,936	
6	--	51.96	16.34	2.69	--	--	--	--	--	
24	--	86.58	27.23	1.12	8,723	--	38.31	1,823	2,741	

Note: Initial SS, 2,780 mg/L

Thickened SS, 14,140 mg/L

Thickened SS/Initial SS was 5.5

Battery B Effluent TP, 0.69 mg/L

Battery B TP Removal, 86%

TABLE 10 (Continued): WASSTRIP® TEST RESULTS FOR TWAS WITH SODIUM ACETATE ADDITION

Week No. 7 (1/14/2014)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD, mg/L	
0 (average)	295	7.56	2.57	--	10,618	1,098	1.73	720	749	
0.5	--	14.40	4.89	9.89	--	--	--	--	--	
1	--	18.59	6.31	6.38	--	--	--	--	--	
1.5	--	22.37	7.59	5.12	--	--	--	--	--	
2	--	23.62	8.01	4.06	9,580	--	2.18	1,460	1,412	
3	--	25.22	8.56	2.89	--	--	--	-----	--	
4	--	26.13	8.86	2.24	9,623	--	2.89	1,285	1,273	
6	--	21.82	7.40	1.25	--	--	--	-----	--	
24	--	35.10	11.91	0.50	9,709	--	23	1,306	1,433	

Note: Initial SS, 8,420 mg/L

Thickened SS, 13,310 mg/L

Thickened SS/Initial SS was 1.6

Battery B Effluent TP, 0.24 mg/L

Battery B TP Removal, 94%

TABLE 11: WASSTRIP® TEST RESULTS FOR TWAS WITH THICKENED PRIMARY SLUDGE ADDITION

Week No. 4 (12/10/2013)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD, mg/L	
0 (average)	302	2.10	0.70	--	12,658	794	<0.1	<5	29.5	
0.5	--	2.54	0.84	1.69	--	--	--	--	--	
1	--	3.74	1.24	1.24	--	--	--	--	--	
1.5	--	5.61	1.86	1.24	--	--	--	--	--	
2	--	8.51	2.82	1.41	12,671	--	0.4	<5	32	
3	--	13.11	4.35	1.45	--	--	--	--	--	
4	--	19.06	6.32	1.58	12,755	--	0.81	<5	36	
6	--	29.69	9.84	1.64	--	--	--	--	--	
24	--	70.22	23.28	0.97	13,054	--	10.24	50	155	

Note: Initial SS, 5,620 mg/L

Thickened SS, 14,150 mg/L

Thickened SS/Initial SS was 2.5

Battery B Effluent TP, <0.2 mg/L

Battery B TP Removal, >96.6%

TABLE 11 (Continued): WASSTRIP® TEST RESULTS FOR TWAS WITH THICKENED PRIMARY SLUDGE ADDITION

Week No. 5 (12/17/2013)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD, mg/L	
0 (average)	445	7.15	1.60	--	11,595	1,205	2.52	68	177	
0.5	--	17.34	3.89	7.78	--	--	--	--	--	
1	--	24.54	5.50	5.50	--	--	--	--	--	
1.5	--	28.41	6.37	4.25	--	--	--	--	--	
2	--	46.22	10.37	5.18	11,532	--	3.36	10	131	
3	--	55.24	12.39	4.13	--	--	--	--	--	
4	--	64.37	14.44	3.61	11,417	--	4.13	<5	139	
6	--	76.76	17.22	2.87	--	--	--	--	--	
24	--	85.76	19.24	0.80	11,433	--	16.02	136	450	

Note: Initial SS, 5,200 mg/L

Thickened SS, 12,400 mg/L

Thickened SS/Initial SS was 2.4

Battery B Effluent TP was not available

Battery B % TP Removal could not be determined, because Battery B Effluent was not available

TABLE 11 (Continued): WASSTRIP® TEST RESULTS FOR TWAS WITH THICKENED PRIMARY SLUDGE ADDITION

Week No. 7 (1/15/2014)										
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD, mg/L	
0 (average)	308	--	--	--	10,029	1,149	6.41	<5	55	
0.5	--	7.61	2.55	5.10	--	--	--	--	--	
1	--	11.96	4.01	4.01	--	--	--	--	--	
1.5	--	13.42	4.50	3.00	--	--	--	--	--	
2	--	15.83	5.31	2.65	11,298	--	3.36	<5	52	
3	--	22.59	7.57	2.52	--	--	--	--	--	
4	--	21.92	7.35	1.84	11,066	--	4.11	11	62	
6	--	23.17	7.77	1.29	--	--	--	--	--	
24	--	32.87	11.02	0.46	11,327	--	28.43	291	599	

Note: Initial SS, 8,420 mg/L

Thickened SS, 13,310 mg/L

Thickened SS/Initial SS was 1.6

Battery B Effluent TP, <0.2 mg/L

Battery B TP Removal, >94%

TABLE 12: SS, VSS, AND TP CONCENTRATIONS FOR ALL UNTHICKENED AND THICKENED PRIMARY SLUDGE SAMPLES AT THE BEGINNING OF WASSTRIP® TESTS

	Pre-Thickening			After Thickening		
	[SS] (mg/L)	[VSS] (mg/L)	[TP] (mg/L)	[SS] (mg/L)	[VSS] (mg/L)	[TP] (mg/L)
Week 1	14,720	7,570	114	--	--	--
Week 3	18,600	11,640	263	--	--	--
Week 4	16,220	10,700	--	16,080	10,540	256
Week 5	29,240	20,060	--	32,020	22,120	695
Week 7	--	--	--	17,000	12,280	257

Weeks Nos. 1 and 3 used unthickened primary sludge addition to WAS, and Weeks Nos. 4, 5, and 7 used thickened primary sludge addition to TWAS.

**TABLE 13: WASSTRIP® TEST RESULTS FOR TWAS WITH PRIMARY SLUDGE
FERMENTATE ADDITION**

Week No. 4 (12/11/2013)									
Elapsed Time, hr	TP, mg/L	Ortho-P, mg/L	% Ortho-P Release	Ortho-P Release Rate, %/hr	Mg, mg/L	TKN, mg/L	NH ₃ -N, mg/L	VFA, mg/L	Sol-COD mg/L
0 (average)	293	11.3	3.80	--	12,724	758	5.68	18	64.5
0.5	--	16.5	5.56	11.12	--	--	--	--	--
1	--	23.4	7.88	7.88	--	--	--	--	--
1.5	--	26.3	8.86	5.90	--	--	--	--	--
2	--	28.8	9.69	4.85	12,615	--	2.99	<5	47
3	--	33.2	11.15	3.72	--	--	--	--	--
4	--	37.6	12.65	3.16	13,066	--	3.42	<5	40
6	--	42.2	14.18	2.36	--	--	--	--	--
24	--	63.3	21.29	0.89	13,387	--	10.19	53	179

Note: Initial SS, 5,620 mg/L

Thickened SS, 17,470 mg/L

Thickened SS/Initial SS was 3.1

Battery D Effluent TP, 1.36 mg/L

Battery D TP Removal, 77.7%

TABLE 14: AVERAGE CST DATA OBSERVED FOR WAS AND TWAS EXPERIMENTS WITH AND WITHOUT CARBON ADDITIONS

Sample Collection Date	Endogenous Carbon				With Other Forms of Carbon Additions		
	Treatment	Sample Time (hr)	Average CST (sec)	% Increase	Treatment	Average CST (sec)	% Increase
11/12/2013	WAS	T = 0	17.1		WAS + Unthickened PS	30.3	
		T = 24				51.0	68
		T = 52	41.15	141			
11/19/2013	WAS	T = 0	20.5		WAS + GCT overflow	18.8	
		T = 24				26.3	40
		T = 52	29.0	42			
12/17/2013	TWAS	T = 0	24.5		TWAS + Thickened PS	35.2	
		T = 24	58.1	137		43.0	22
12/18/2013		T = 0			TWAS + Sodium Acetate	42.3	
1/8/2014	TWAS	T = 0	54.5		TWAS + Sodium Acetate	77.5	
		T = 24	56.1	3		92.0	19
1/14/2014	TWAS	T = 0	39.1				
		T = 24	87.3	123			
1/15/2014		T = 0			TWAS + Sodium Acetate	47.7	
1/15/2014		T = 0			TWAS + Thickened PS	56.9	

**FIGURE 1: A PROPOSED FLOW DIAGRAM DEPICTING THE WASSTRIP®
PROCESS RETROFITTED TO THE EXISTING STICKNEY OPERATIONS**

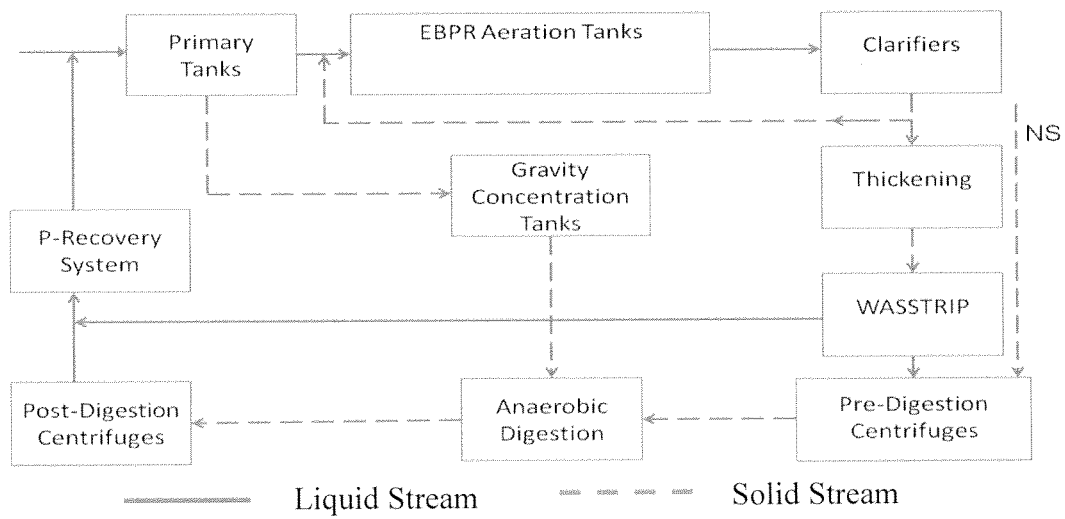


FIGURE 2: MAXIMUM ORTHO-P PERCENT RELEASE FOR WAS WITH AND WITHOUT CARBON SUPPLEMENTATION

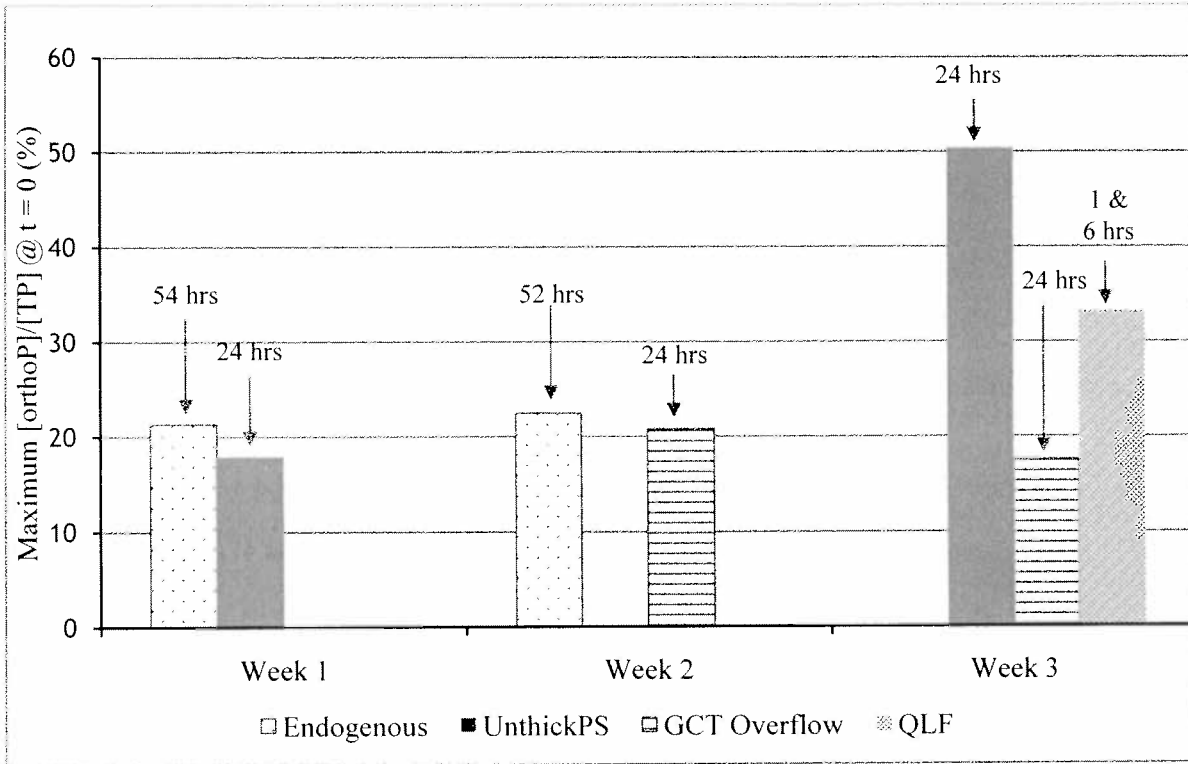


FIGURE 3: AVERAGE PERCENT RELEASE FOR WAS WITH ENDOGENOUS AND OTHER CARBON ADDITIONS

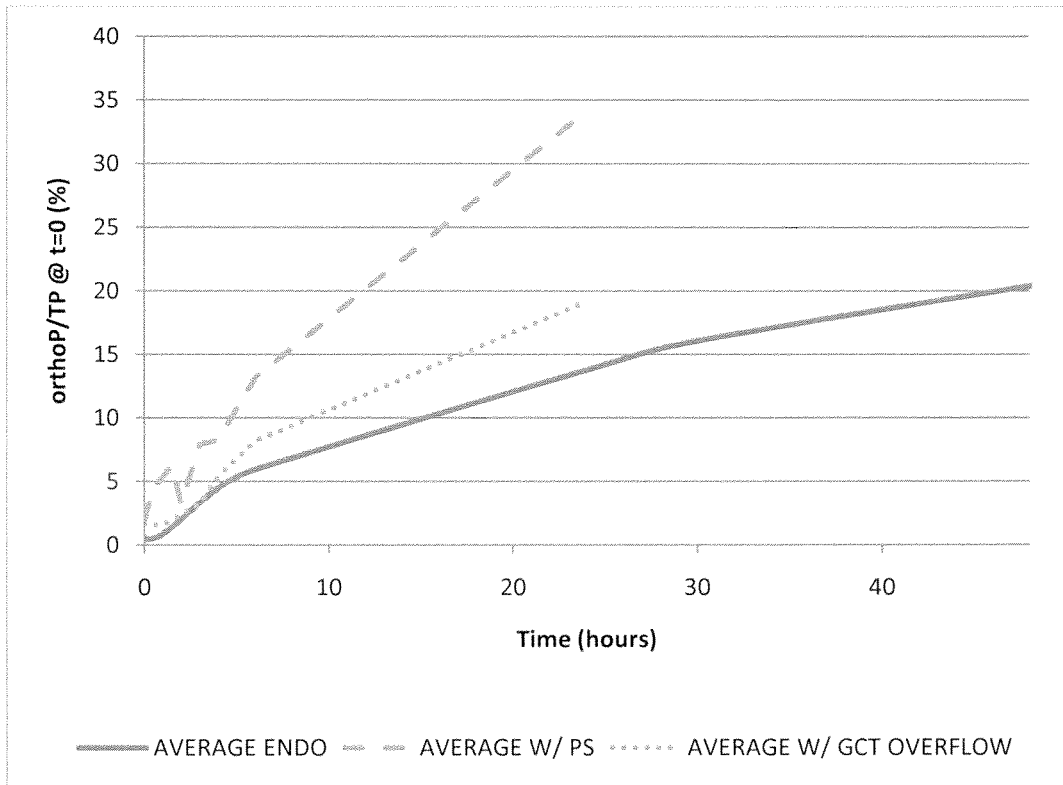


FIGURE 4: AVERAGE PERCENT ORTHO-P RELEASE FOR TWAS WITH ENDOGENOUS AND OTHER CARBON ADDITIONS

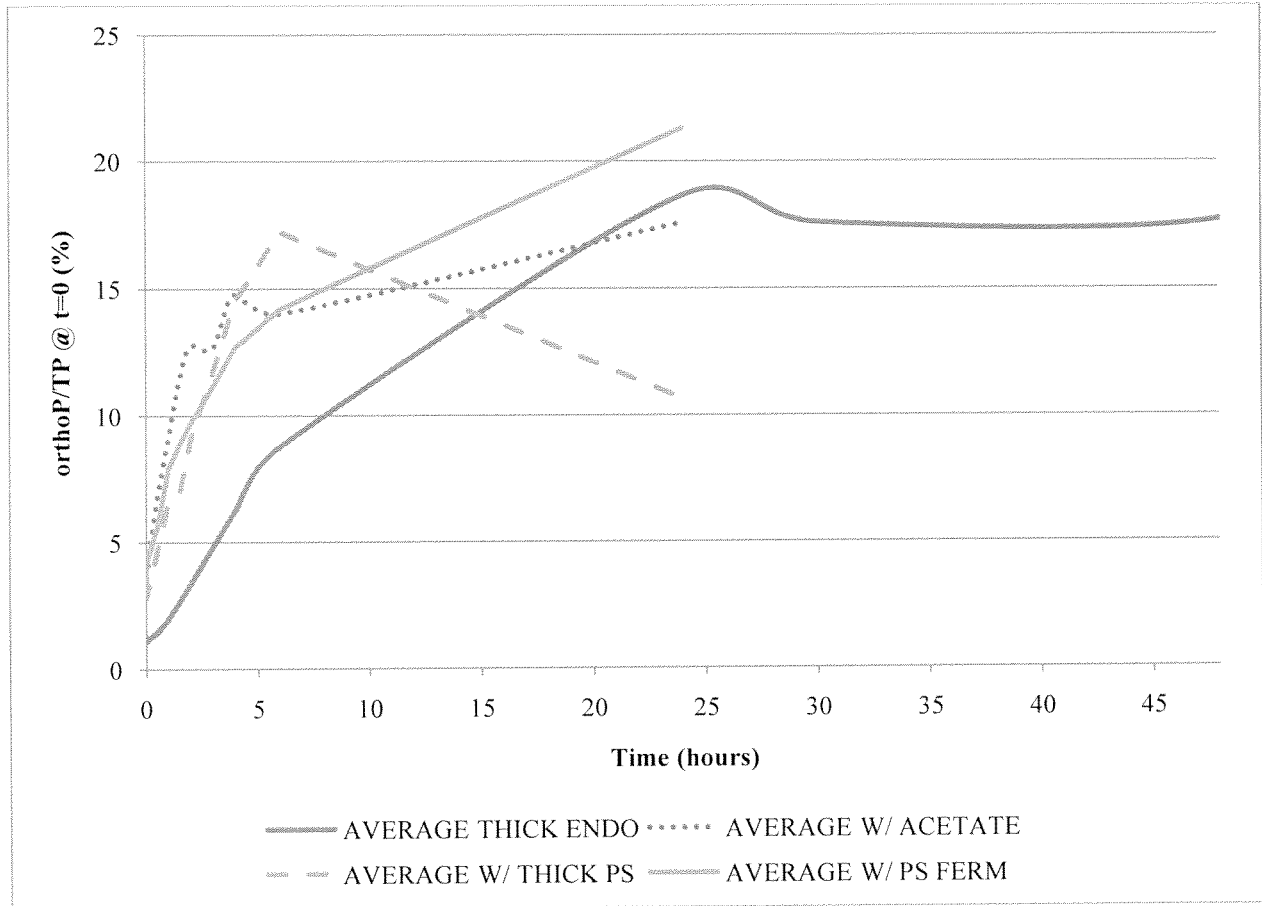


FIGURE 5: MAXIMUM ORTHO-P PERCENT RELEASE FOR TWAS WITH ENDOGENOUS AND OTHER CARBON ADDITIONS

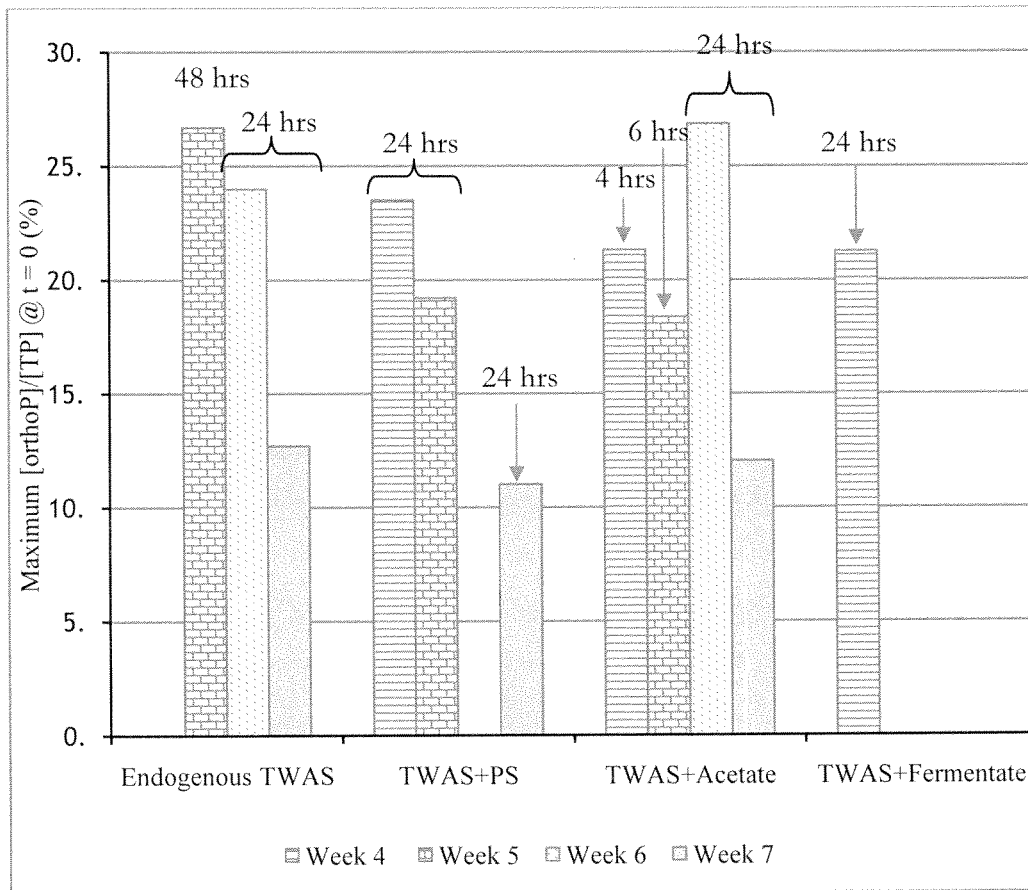


FIGURE 6: AVERAGE HOURLY PERCENT ORTHO-P RELEASE RATES FOR STUDIED WAS AND TWAS TREATMENTS

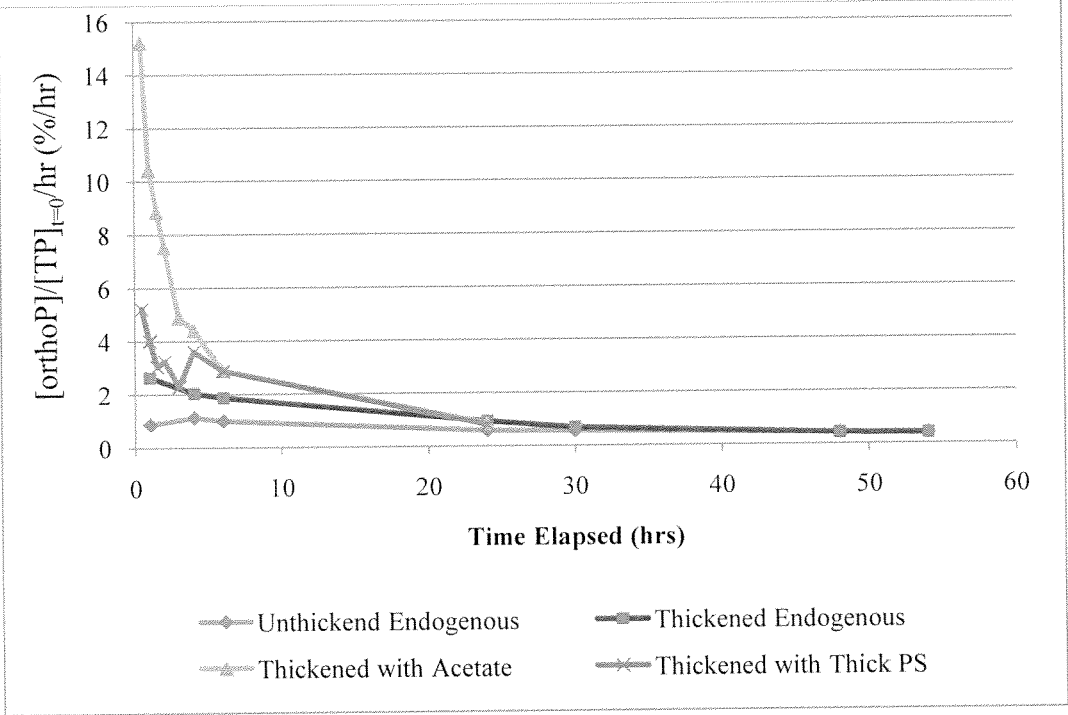
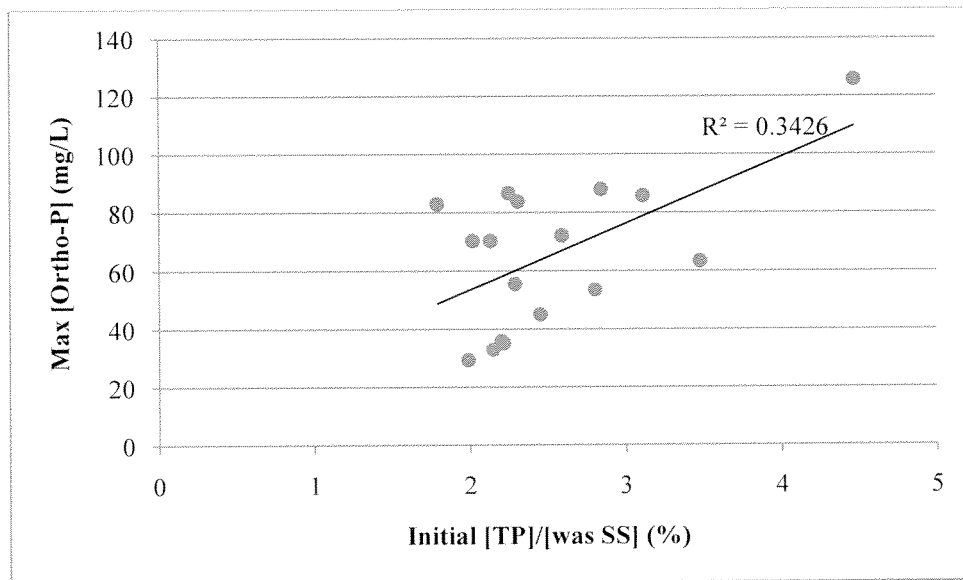


FIGURE 7: CORRELATION BETWEEN INITIAL PERCENT TP AND MAXIMUM RELEASED ORTHO-P CONCENTRATIONS OBSERVED IN ALL EXPERIMENTS



APPENDIX I

THE OSTARA SUPPLIED WASSTRIP[®] BENCH-SCALE TEST PROCEDURE
(UNEDITED VERSION)

AND

DISTRICT WORK PLAN (UNEDITED)

WAS P-release assessment sampling and test plan

Outline

The purpose of this plan is to outline a sampling and testing plan that will result in sufficient data to allow design parameters to be developed that would be required for the implementation of struvite recovery incorporating Phosphorus and Magnesium release from WAS prior to thickening. This type of process arrangement is expected to result in reduced or eliminated nuisance struvite deposits in the sludge handling system, digestion, and dewatering equipment, as well as reduced nutrient loads on the liquid train, improved biological nutrient removal process stability and reduced phosphorus levels in biosolids.

Testing required for process sizing includes:

1. Determining rate and extent of phosphate release from WAS under anaerobic conditions
2. Determining rate and extent of phosphate release from WAS mixed with primary sludge or primary sludge thickener overflow as a VFA source under anaerobic conditions
3. Determining if anaerobic treatment of WAS above is likely to impact WAS thickening on GBT through capillary suction time (CST) testing
4. Determining variability in WAS thickening and digested sludge dewatering filtrate compositions and flows over time. This will require these tests to be repeated 5-7 times over a 4-8 week period. Based on the results from the first round of testing, further testing can be carried out using only Method 1 or 2 depending on desired route.

Purpose:

To collect information required to design a struvite recovery facility treating sludge thickening and dewatering liquors, incorporating pre-release of phosphate from WAS before thickening and adequate equalization volumes to enable reliable continuous operation.

Materials:

- Fresh WAS samples
- 15 to 20 L bucket for storing WAS samples
- Large stir plate and magnetic stirrer or spoon for stirring bucket contents
- Beaker for collecting subsamples from bucket
- Centrifuge with centrifuge tubes
- Filtration apparatus with glass fiber and 0.45 um cellulose acetate filter papers
- Sample bottles for storing filtered samples.
- Personal protective equipment suitable for working with wastewater, as per local regulations. As a minimum, gloves, protective eye wear, labcoat or coveralls and closed toed shoes are recommended.

Methodology: Test #1
WAS phosphorus release – endogenous

1. Collect a 10 liter WAS sample – Record sampling date and time. It is recommended that the sample be collected in the morning (or beginning of shift) to allow for the test to be monitored more intensely over the first 8 hours. Collect an unfiltered sample for analysis of total suspended solids (TSS) total phosphorus (TP), total Mg and CST.
2. Store sample in a covered bucket at room temperature
3. Collect subsamples at the time intervals indicated in Table 1 below. Mix the bucket contents thoroughly but without aerating the sample before collecting samples. This could be done by placing the bucket on a stir plate with a magnetic stirrer on low speed to prevent vortexing, or by using a spoon/spatula to gently mix the contents.

Table 1: Sampling and Analysis Schedule

Sample Time* (hours)	Analytes (soluble)	CST Testing
0	Mg, NH ₄ -N, PO ₄ -P, pH	X
1	PO ₄ -P	
4	PO ₄ -P	
8	PO ₄ -P	
24	Mg, NH ₄ -N, PO ₄ -P, pH	
32	PO ₄ -P	
48	Mg, NH ₄ -N, PO ₄ -P, pH	
56	PO ₄ -P	
72	Mg, NH ₄ -N, PO ₄ -P, pH	X
80	PO ₄ -P,	

*Note: Sampling times have been selected for convenience to fit within an 8 hour work day (start and end of each day) in order to get as much time coverage as possible. Alternative sampling times more convenient to the person carrying out the test would be acceptable as long as there are a similar number of data points spread throughout the 80 hour period

4. Centrifuged each sample for 7 minutes at 4000 RPM, and collect the centrate from the centrifuge tubes for filtration and analysis.
5. Filter (glass microfiber followed by 0.45 um cellulose acetate) and refrigerated centrate samples.
6. Analyze the samples for the analytes listed in Table 1 using standard laboratory procedures. If possible carry out PO₄-P analysis immediately after collecting samples (using Hach apparatus or similar). Experiment can be stopped when phosphorus release has ceased, and should be extended if the phosphorus release is observed to be incomplete at the end of the planned test period.
7. Samples collected for CST (Capillary suction time) should be whole unfiltered samples drawn from the bucket after mixing.

Struvite Solubility Determination - Jar Test Procedure

Reporting

1. Report data in the following table format:

Sample Time	TP (mg/L)	Mg total (mg/L)	TSS	PO4-P (mg/L)	NH4-N (mg/L)	Mg sol (mg/L)	CST (sec)	pH

Methodology: Test #2**WAS phosphorus release – with primary sludge thickener supernatant as carbon source**

Steps 1-3 should be performed as rapidly as possible (i.e. in less than 30 minutes if possible to avoid sample degradation before the first sample is drawn.

1. Collect a 10 liter WAS sample – Record sampling date and time. It is recommended that the sample be collected in the morning (or beginning of shift) to allow for the test to be monitored more intensely over the first 8 hours. Collect an unfiltered sample for analysis of total suspended solids (TSS) total phosphorus (TP), total Mg and CST.
2. Collect a 1000 ml sample of primary sludge thickener overflow, primary sludge or thickened primary sludge. Collect an unfiltered sample for analysis of total suspended solids (TSS) total phosphorus (TP) and total Mg and volatile fatty acids (VFAs)
3. Mix WAS and primary sludge overflow (or other VFA source) samples in a bucket. A 1.5:1 molar ratio of VFA:P (or a 4:1 mass ratio as acetate:P) is believed to be ideal according to work by Liao et al at UBC, but this may prove to be excessive in terms of demand on the VFA available at the plant. For example to get 200 mg/L P release, 800 mg/L VFA as acetate would be required in the mixture.
4. Keep in a covered bucket at room temperature.
5. Collect subsamples at the time intervals indicated in Table 2 below. Mix the bucket contents thoroughly but without aerating the sample before collecting samples. This could be done by placing the bucket on a stir plate with a magnetic stirrer on low speed to prevent vortexing, or by using a spoon/spatula to gently mix the contents.

Table 2: Sampling and Analysis Schedule

Sample Time* (hours)	Analytes (soluble)	CST Testing
0	Mg, NH ₄ -N, PO ₄ -P, VFA, pH	X
0.5	PO ₄ -P	
1	PO ₄ -P	
1.5	PO ₄ -P	
2	Mg, NH ₄ -N, PO ₄ -P, VFA, pH	
3	PO ₄ -P	
4	Mg, NH ₄ -N, PO ₄ -P, VFA, pH	
8	PO ₄ -P	
24	Mg, NH ₄ -N, PO ₄ -P, VFA, pH	X
48	Mg, NH ₄ -N, PO ₄ -P, VFA, pH	

*Note: Sampling times have been selected for convenience to fit within an 8 hour work day (start and end of each day) in order to get as much time coverage as possible. Alternative sampling times more convenient to the person carrying out the test would be acceptable as long as there are a similar number of data points spread throughout the 48 hour period

Struvite Solubility Determination - Jar Test Procedure

6. Centrifuge each sample for 7 minutes at 4000 RPM, and collect the centrate from the centrifuge tubes for filtration and analysis.
7. Filter (glass microfiber followed by 0.45 um cellulose acetate) and refrigerated centrate samples.
8. Analyze the samples for the analytes listed in Table 1 using standard laboratory procedures. If possible carry out PO₄-P analysis immediately after collecting samples (using Hach apparatus or similar). Experiment can be stopped when phosphorus release has ceased, and should be extended if the phosphorus release is observed to be incomplete at the end of the planned test period.
9. Samples collected for CST (Capillary suction time) should be whole unfiltered samples drawn from the bucket after mixing.

Reporting

2. Report data in the following table format:

Sample Time	TP (mg/L)	Mg total (mg/L)	TSS	PO ₄ -P (mg/L)	NH ₄ -N (mg/L)	Mg sol (mg/L)	CST (sec)	pH

Contact Details

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Struvite Solubility Determination - Jar Test Procedure

DISTRICT WORK PLAN (UNEDITED)
ORTHO-P RELEASE FROM STICKNEY WASTE ACTIVATED SLUDGE

OBJECTIVES

1. To determine the potential implications of incorporating a waste activated sludge (WAS) phosphorus release process as part of the P-recovery system at SWRP. This series of tests will allow SWRP to give sufficient data to allow design parameters to be developed including the type of carbon to supply the process, the ortho-P load that would enter into the P-recovery system, and the rate and extent of ortho-P release.
2. To make a better informed decision with respect to expected struvite mitigation in digesters and dewatering equipment.
3. To determine variability in WAS thickening and digested sludge dewatering filtrate compositions and flows over time.
4. To potentially reduce the P content in the biosolids, which makes the biosolids more nutrient balanced.

PHASE I – WAS P RELEASE – ENDOGENOUS CARBON

1. Collect a 6 gallon sample of WAS (location TBD) in morning and store in covered bucket(s) at room temperature.
2. There should be 2 samples taken for all analytes (except for CST test sample) at the 0 hour sample time as efficiency of the process will be evaluated with respect to initial values. At the same time, collect unfiltered 600 mL WAS sample from the bucket to perform CST testing.
3. Additional samples will be taken from the WAS sample bucket for analyses at the following time intervals, as indicated in Table 1. The WAS sample bucket should be thoroughly mixed by hand avoiding aeration before collection of the sample.

TABLE 1: Sampling Frequency, Volume, and Analytes for Phase I

Sample Time (hours)	Sample Volume	Analytes	CST Testing
0	1 gallon	TSS, VSS, TP, Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , Na ⁺ , conductivity, alkalinity, Al ³⁺ , Fe ²⁺ , Fe ³⁺ , pH	X
1	300 mL	PO ₄ -P	
4	300 mL	PO ₄ -P	
6	300 mL	PO ₄ -P	
24	1 quart	Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , pH	
30	300 mL	PO ₄ -P	
48	1 quart	Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , pH	
54		PO ₄ -P	
72	1 gallon	Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , Na ⁺ , conductivity, alkalinity, Al ³⁺ , Fe ²⁺ , Fe ³⁺ , pH	X
80	300 mL	PO ₄ -P	

4. Centrifuge each sample for 7 minutes at 4000 rpm and collect the centrate from the centrifuge tubes for filtrations and analysis. (For Time 0 sample, several analytes are submitted as an unfiltered sample – these can be removed before centrifugation and filtration).
5. Filter centrate samples with 0.45-µm filter. Refrigerate samples.
6. Samples collected for CST should be whole unfiltered samples drawn from bucket after mixing.

PHASE II – WAS P RELEASE – EXTERNAL CARBON SOURCE

Steps 1 – 4 should be performed in less than 30 minutes to avoid sample degradation before first sample is drawn.

1. Collect a 6 gallon sample of WAS in the morning and store in covered bucket(s) at room temperature.

2. At the same time, collect unfiltered 600 mL WAS sample to perform CST testing.
3. Prepare the external carbon source sample. If from the field, collect samples for analyses as indicated in Table 2.
4. Mix external carbon source sample into the bucket with the WAS. There should be 2 samples taken for all analytes at the 0 hour sample time as the efficiency of the process will be evaluated with respect to initial values.
5. Additional samples will be taken from the WAS sample bucket for analyses at the following time intervals, as indicated in Table 2. The WAS sample bucket should be thoroughly mixed by hand, avoiding aeration before collection of the sample.

TABLE 2: Sampling Frequency, Volume, and Analytes for Phase II

Sample Time (hours)	Sample Volume	Analytes	CST Testing
0 – C source	7–250 mL each	TSS, VSS, TP, Mg ²⁺ , Ca ²⁺ , K ⁺ , VFA, and sol-COD	
0 – combined	1 gallon	TSS, VSS, TP, Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , Na ⁺ , conductivity, alkalinity, Al ³⁺ , Fe ²⁺ , Fe ³⁺ , pH, VFA, sol-COD	X
0.5	300 mL	PO ₄ -P	
1	300 mL	PO ₄ -P	
1.5	300 mL	PO ₄ -P	
2	1 quart	Mg ²⁺ , Ca ²⁺ , K ⁺ , NH ₄ -N ⁺ , PO ₄ -P, VFA, sol-COD, pH	
3	300 mL	PO ₄ -P	
4	1 quart	Mg ²⁺ , Ca ²⁺ , K ⁺ , NH ₄ -N ⁺ , PO ₄ -P, VFA, sol-COD, pH	
6	300 mL	PO ₄ -P	
24	1 gallon	Mg ²⁺ , NH ₄ -N ⁺ , PO ₄ -P, Ca ²⁺ , K ⁺ , Na ⁺ , conductivity, alkalinity, Al ³⁺ , Fe ²⁺ , Fe ³⁺ , pH, VFA, sol-COD	X

1. Centrifuge each sample for 7 minutes at 4000 rpm and collect the centrate from the centrifuge tubes for filtrations and analysis. (For Time 0 sample, several analytes are

submitted as an unfiltered sample – these can be removed before centrifugation and filtration).

2. Filter centrate samples with 0.45- μ m filter. Refrigerate samples.
3. Samples collected for CST should be whole unfiltered samples drawn from bucket after mixing.

PHASE III – TWAS – W/ EXTERNAL CARBON SOURCE

Phase III includes additional experiments. These can be run if time and resources permit. Trials under here include TWAS measuring P release with the most effective carbon sources as identified in Phase II. Sample procedures, sample times, and analytes shall be the same as Phase II.

SUMMARY OF TRIALS

Carbon Source	Amount Of Carbon To Add	Number Of Trials	Notes
PHASE I			
Endogenous Carbon	--	2x	
PHASE II			
GCT Overflow	2,300 mL	2x	<ul style="list-style-type: none"> • Amount suggested by Ostara. • Aiming for a 1.5:1 VFA:desired P released ratio (molar ratio). • May change carbon addition based on actual GCT concentrations after field sampling.
Primary Sludge	TBD	2x	<ul style="list-style-type: none"> • Aiming for a 1.5:1 VFA:desired P released ratio (molar ratio). • Base on average primary sludge VFA concentration of ~ 100 mg/L.
Primary Sludge Fermentate	TBD	• 2x (after 48 hr)	<ul style="list-style-type: none"> • Aiming for a 1.5:1 VFA:desired P released ratio (molar ratio). • Base on average VFA concentration of ~ 363 mg/L after 48 hrs & 450 mg/L after 72 hrs.
MicroC or QLF	TBD	2x	

Acetate	TBD	2x	• Aiming for a 4:1 mass ratio as acetate.
PHASE III			
TWAS + Best Carbon Source	TBD	3x	• Thicken WAS to about 5% before the test.

ESTIMATED MAN-HOURS

Training on Experimental Method

- Lab Techs – 8 mhrs
 - 2 techs, 4 hours
- Project Lead – 8 mhrs
 - Both Kamlesh & Mwende for training to be on same page.

Trials

- Lab Techs – 168 manhours
 - 24 mhrs/trial week
 - 1 tech, 4 hours for week before – preparation of experiment and labels, including collection of primary sludge, when needed, for fermentation.
 - 2 techs, 8 hours for first day
 - 1 tech, 4 hours for last day
- Project Lead – 70 mhrs (max – split between Kamlesh & Mwende)
 - 6 – 10 mhrs/experiment week
 - Assistance on first day of trial
 - Preparation of daily samples after first day

Data Review & Summary

- Project Lead – 3 weeks
 - Data analysis
 - Report preparation

WASSTRIP PROJECT SCHEDULE

ITEM	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11
PRE-TRIAL PREPARATION	▨ ▨ ▨ ▨	▨ ▨ ▨ ▨									
PHASE I											
1. WAS P Release Trials - Endogenous Carbon	▨ ▨ ▨ ▨	▨ ▨ ▨ ▨	▨ ▨ ▨ ▨								
PHASE II											
2. WAS P Release with GCT Over-flow			▨ ▨ ▨ ▨	▨ ▨ ▨ ▨	▨ ▨ ▨ ▨						
3. WAS P Release with Primary Sludge				▨ ▨ ▨ ▨	▨ ▨ ▨ ▨						
4. WAS P Release with Fermentate from Primary Sludge		▨ ▨ ▨ ▨	▨ ▨ ▨ ▨								
5. WAS P Release with MicroC or QLF				▨ ▨ ▨ ▨		▨ ▨ ▨ ▨	▨ ▨ ▨ ▨				
6. WAS P Release with Acetate					▨ ▨ ▨ ▨						
PHASE III											
7. Thickened WAS with Best C Source							▨ ▨ ▨ ▨	▨ ▨ ▨ ▨	▨ ▨ ▨ ▨		
DATA SUMMARY											

: Lab Tech assistance needed.
 : Project Lead involvement.