Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 17-10

STICKNEY PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 7

SETTLING TEST RESULTS TO ASSIST IN DESIGN OF WASSTRIP© FOR THE STICKNEY WATER RECLAMATION PLANT (SWRP)

May 2017

Metropolitan Water Reclamation District of Greater Chicago

100 East Erie Street Chicago, Illinois 60611-2803 312-751-5600

STICKNEY PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 7

SETTLING TEST RESULTS TO ASSIST IN DESIGN OF WASSTRIP© FOR THE STICKNEY WATER RECLAMATION PLANT (SWRP)

By

Joseph Kozak
Supervising Environmental Research Scientist

Cindy Qin
Associate Environmental Research Scientist

Yvonne Lefler
Senior Civil Engineer

Joseph Cummings
Principal Engineer

Brett Garelli
Deputy Director of Maintenance and Operations

Glen Rohloff
Managing Civil Engineer

Monitoring and Research Department
Thomas C. Granato, Director

May 2017

FOREWORD

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 recover 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 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 WRP's 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 recovery as they are understood at the time the memoranda are published.

DISCLAIMER

The contents of this technical memoranda 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.

Settling Test Results to Assist in Design of WASSTRIP® for the Stickney Water Reclamation Plant (SWRP)

Technical Memorandum 7

Date: July 13, 2015

To: Phosphorus Task Force & Advisory Committee

From: Phosphorus Study/Planning Team

Subject: Settling Test Results for WASSTRIP® Design

1.0 Purpose

The process to use waste activated sludge (WAS) to release additional ortho-phosphate (orthoP) for recovery has been marketed as the Waste Activated Sludge Stripping to Remove Internal Phosphorus® (WASSTRIP ®) process and has been implemented in several full-scale wastewater treatment plants. Per Ostara recommendations and previous WASSTRIP® testing, WASSTRIP® includes thickening of the WAS to a TSS concentration between 15,000 and 20,000 mg/L prior to delivery of the thickened WAS (TWAS) to a WASSTRIP® reactor tank. This reduces the necessary volumes in the WASSTRIP® tanks to achieve the hydraulic residence times (HRTs) needed for the process. As shown from the first round of laboratory WASSTRIP® testing completed at SWRP, the potential orthoP release is largely driven by the total phosphorus (TP) and TSS concentrations in the WAS at the start of the process. As such, the time necessary for satisfactory thickening of the WAS was investigated herein to support the design HRT for WAS thickening.

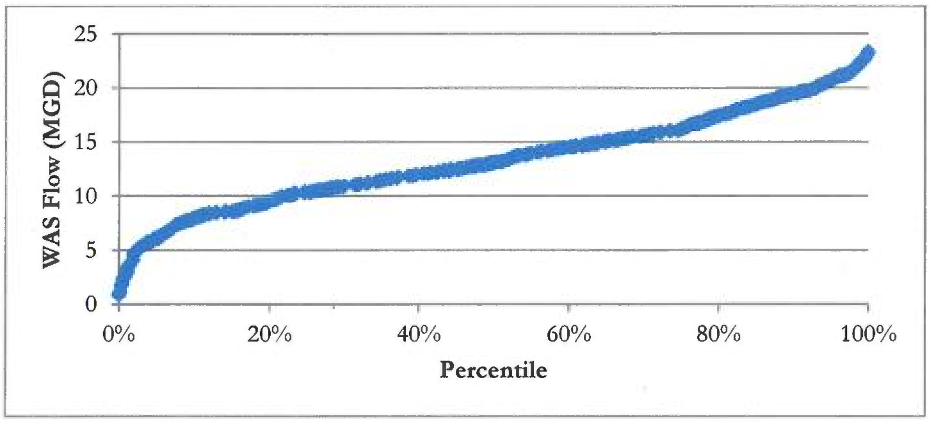
At SWRP, there are 10 existing gravity concentration tanks (GCTs) that will be used for WAS thickening, fermentation of primary sludge, and the WASSTRIP® reactors. The amount of settling that can be achieved within the existing GCTs will drive the TWAS flow and TSS concentration to the WASSTRIP® reactors; the optimal use for each tank can be guided by laboratory testing. This technical memorandum summarizes the results of the settling tests performed using SWRP WAS. At the time of this memo, four of the existing GCTs are planned for WAS thickening, but using only two GCTs is also a possibility, which would allow for a longer HRT in the WASSTRIP® reactor tanks as more tanks could be dedicated to that process.

2.0 Background

WAS Flows

2011 – 2013 SWRP WAS flows are shown in Figure 1 by percentile. The average, 90^{th} percentile, 10^{th} percentile, and standard deviation for WAS flows were 13.4 MGD, 19.5 MGD, 8.0 MGD, and 4.4 MGD, respectively. In addition, the average SWRP WAS TSS and VSS concentrations for 2013 were 7,959 mg/L and 4,757 mg/L, respectively. The VSS:TSS ratio averaged 0.62 with a standard deviation of 0.061.

Figure 1: Distribution of WAS Flows at SWRP



Dimensions of Tanks

Each of the available existing GCTs has length, width, and water depth dimensions of 70 ft, 46 ft and 9 in, and 14 ft, respectively. This corresponds to a volume of 45,815 ft^3, or 0.34 million gallons.

Existing GCT Mass Flux

Historically, the existing GCTs have been used for concentration of a combination of Stickney WAS, Stickney primary sludge (PS), and O'Brien WAS and PS. This makes direct comparisons to how the GCTs will operate with only Stickney WAS difficult as WAS will settle differently than the combination of WAS and PS. However, Table 1 presents existing data from 2011 – 2013 for the combined sludge, in order to gauge the solids loading and capture rates for the tanks. As seen, the average capture rate is 52% with an average of 11 tanks in-service at the average solids loading at solids loading rates listed. As the solids loading and solids loading rates increase, the capture rates correspondingly decrease.

Table 1: Influent, Thickened Sludge, and Overflow Flow, Solids Loading, and Solids Loading Rates to the Existing GCTs from 2011 – 2013 Data

	Average[1]	90th Percentile	10th Percentile
Influent Flow (MGD)	24.2	30.7	17.7
Influent Solids Loading (ton/day)	872	1,281	530
Influent Solids Loading Rate (lb/day-ft^2)	45	67	27
Thickened Sludge Flow (MGD)	6.6	9.0	4.3
Thickened Sludge Mass Flux (ton/day)	421	671	188
Overflow Flow (MGD)	17.6	23.4	11.3
Overflow Mass Flux (ton/day)	232	500	25
Capture Rate (%)	52	83	22

[1]: Concentration data collected from M&O grab samples. It is noted that the mass flux from the overflow and the thickened sludge does not add to the influent loading; detailed analysis was not performed on these loadings.

Hydraulic Residence Times, Overflow Rates, and Solids Flux based on Repurposed GCTS and Historic WAS data

Table 2 presents the average, 10th percentile, and 90th percentile WAS flows and the solids loading data for the 2011 – 2013 time period. The corresponding HRTs and solids loading rates if 2 or 4 GCTs are to be used are also included. At each of these flows and number of tanks, overflow rates, with units of gal/day-ft^2, are also determined. Overflow rates give a representation of the ability for particles to settle in a tank based on the flow and geometry of the basin. If a gravity concentration tank were to be constructed, the surface area of the tank would be designed such that the overflow rate would be less than 1,200 gal/day-ft^2 (Ten State Standards). From this piece of design criteria, the average flow could only be accommodated using 4 GCTs as the overflow rate using 2 GCTs is considerably higher under average conditions. Additionally, the overflow rate using 2 GCTs would only be within the appropriate range when the WAS flow is in the bottom tenth percentile.

The solids loading rates can also be determined based on using 2 or 4 GCTs for thickening using the average, 90th percentile, and 10th percentile solids loading. With 2 GCTs for thickening, the average solids loading rate would be approximately 135 lb/day-ft^2. This value is approximately three times the average influent solids loading rate for the operation of the existing GCTs, meaning the capture rate would be expected to be significantly reduced. The average solids loading rate using 4 GCTs, 67 lb/day-ft^2, is equal to the 90th percentile solids loading rate of the existing GCTs in Table 1. If the WAS were to settle similar to the WAS and PS combination and 4 GCTs were used, the corresponding capture rate based on existing GCT data would be approximately 40%. However, as stated before, WAS will settle differently than the WAS and PS combination.

Table 2: Calculation of HRTs, Overflow Rates, and Solids Loadings Based on 2011 – 2013 WAS Flows Utilizing 2 or 4 GCTs

	Average	90th Percentile	10th Percentile
WAS Flow (MGD)	13.4	19.5	8.0
Solids Loading (ton/day)	443	702	231
TP Concentration (mg/L)[1]	171	261	80
Using 2 GCTs			
HRT (min)	73	52	119
Overflow Rate (gal/day-ft^2)	2,047	2,872	1,253
Solids Loading Rate (lb/day-ft^2)	135	214	70
Using 4 GCTs			
HRT (min)	146	104	238
Overflow Rate (gal/day-ft^2)	1,024	1,436	626
Solids Loading Rate (lb/day-ft^2)	67	107	35

[1]: TP concentrations are based on data from 1/2014 – 4/2015 as this time frame better represents the concentrations the plant will be experience with full-scale EBPR.

For the remainder of this memo, the average flow of 13.4 MGD will be used for further calculations and process design, along with the corresponding HRTs. The times of 60 and 120 minutes are used as comparisons to the 73 and 146 minute HRTs that the use of 2 or 4 GCTs would allow.

3.0 Methods and Data Summary

The workplan used in obtaining the data within this report is attached as Appendix I. Two different settling columns were used to determine the WAS settling capabilities. The first was the large settling column in the WTPR pilot plant lab and the second was a bench top settling column, both equipped with mixers which were run through the duration of the trials.

With the large column, seven trials were completed. The first four trials measured the height of the sludge blanket/water interface and WAS TSS concentrations at the beginning and end of the test for sludge taken from the middle of the sludge blanket; these trials followed Part A of the workplan, as written. In addition to the blanket height measurements, the last three trials deviated from the initial workplan as they also included sample collection from the bottom port of the settling column every 5 to 10 minutes during settling for TWAS TSS concentration analysis.

The small settling column tests were run with differing initial TSS concentrations for the same WAS. This was accomplished by collecting a sample of WAS and creating three different concentrations of TSS; one test was run using WAS as collected from field, one through allowing the WAS to settle and then decanting the liquid portion from the top for a thicker WAS, and one through combining the WAS from field with the decanted liquid from the second trial for a thinner WAS. Although the workplan specified WAS collected from field, WAS settled for 15 minutes and decanted, and half WAS plus half final clarifier effluent for Trials 1 through 3, respectively, there was some variance in terms of initial dilutions; however, TSS concentrations were measured at the beginning of each trial to quantify the differences. There were 4 separate trials of the smaller settling column tests.

Determination of Settling Velocities, Solids Concentrations and Limiting Flux

The large settling column was first used to determine the concentration of solids in the thickened portion of the WAS and the settling velocities. Based on these velocities, the solids capture over time can be calculated through use of a flux curve. Traditionally, this approach is not used for determining the thickening of WAS. However, in order to balance the overflow and underflow rates, it is necessary to use an approach that includes the approximation of both concurrently.

Figure 2 shows the raw settling data in terms of the height of the sludge blanket over time. As can be seen, there is a period of a constant settling rate at the beginning of the settling tests. This settling rate decreases over time as more of the solids have settled out and compression settling begins.

Figure 2: Sludge Blanket Height over Time

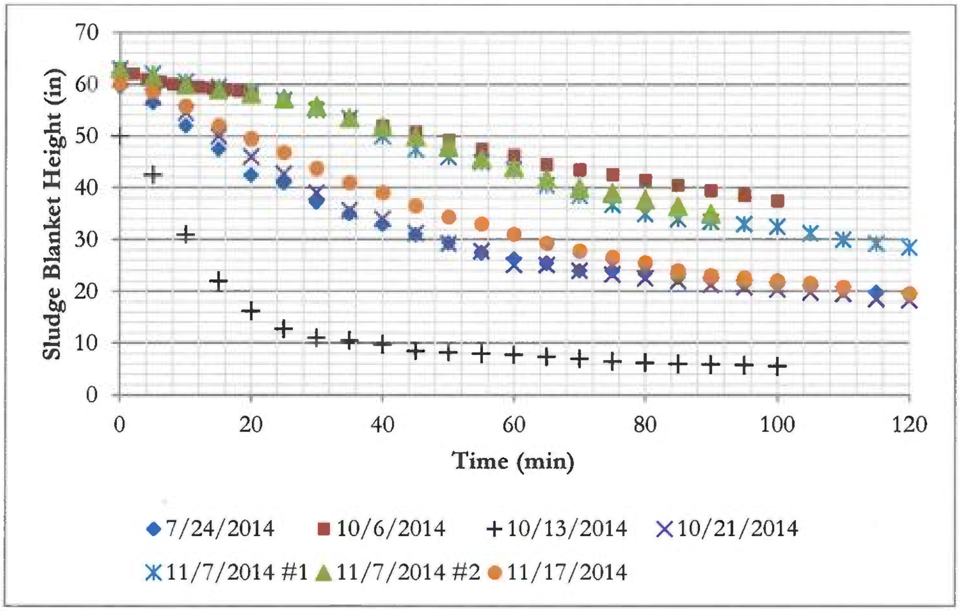


Table 3 compiles the pertinent initial data from all of the large column trials and includes a calculation of the initial settling velocity. The initial settling velocity is determined by finding the slope of the period of constant settling seen in each of the trials.

Table 3: Initial Data from Each Trial

Trial Date	v_0 (ft/hr)	TSS_0 (mg/L)	VSS_0 (mg/L)	VSS_0/TSS_0
7/24/14	4.67	8,790	4,950	0.56
10/6/14	0.80	11,680	7,180	0.61
10/13/14	10.25	3,710	2,440	0.66
10/21/14	2.95	7,120	4,460	0.63
11/7/14 #1	2.38	6,300	3,920	0.62
11/7/14 #2	1.89	9,100	5,600	0.62
11/17/14	2.50	9,090	5,310	0.58
AVG	**3.63**	**7,970**	**4,837**	**0.61**

The solids flux due to settling can be plotted versus SS. This settling flux, G_S in units of lbs/ft^2-day, is calculated using Equation 1, where 0.001497 is a unit conversion, V_S is the zone settling velocity due to gravitational forces in ft/hr, and X is the SS concentration in mg/L. V_S is calculated from Equation 2, where V_0 and k are the Vesilind parameters, which were found by fitting a curve to the graph of the settling velocities from the settling trials in Table 3 versus initial solids concentrations.

$$G_s = 0.001497 \times V_s \times X \qquad \text{(Equation 1)}$$

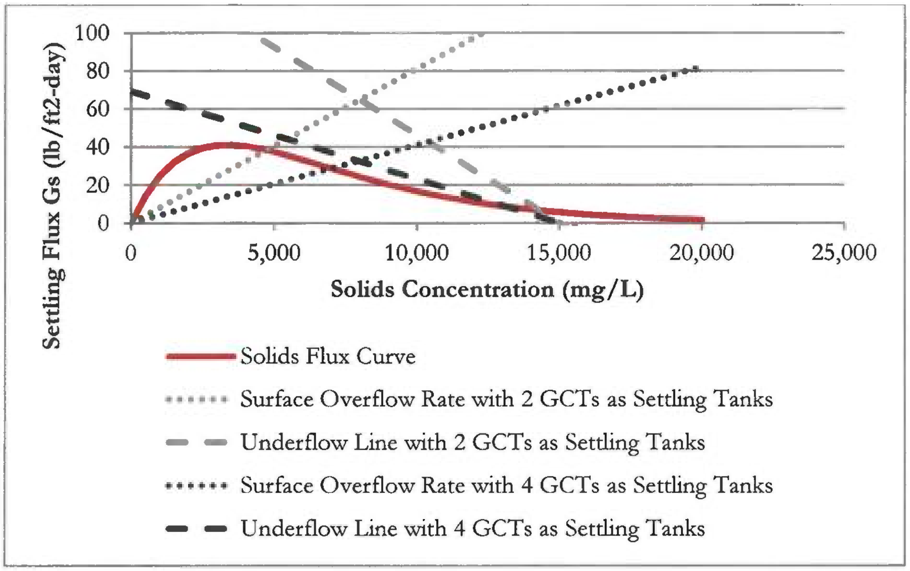
$$V_s = V_0 e^{-kX} \qquad \text{(Equation 2)}$$

$V_0 = 22.2$ (based on curve from trials)
$k = 0.0003$ (based on curve from trials)

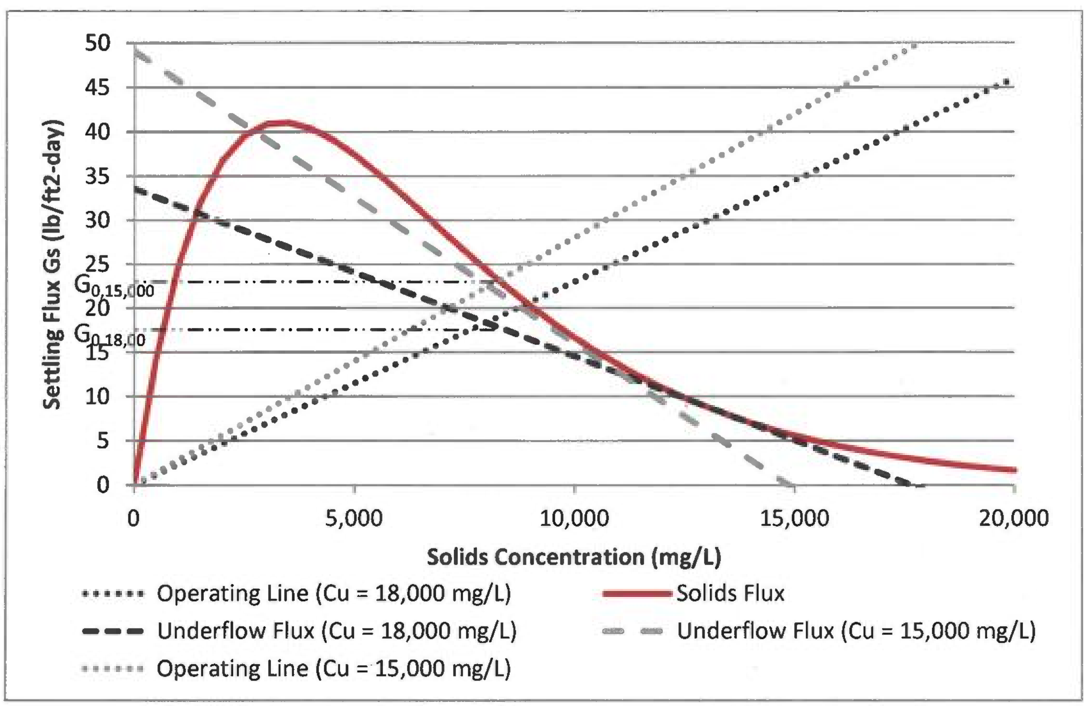
Figures 3a and 3b show the flux curves from Equation 1 based upon various initial solids concentrations. The underflow and overflow operating lines are also plotted on both graphs. Figure 3a shows the underflow and overflow lines as developed for the average flow (13.4 MGD) and average incoming solids concentration (7,970 mg/L) conditions with either 2 or 4 GCTs operating as settling tanks; these average conditions define the slopes of the lines. The intersection of the two lines is referred to as the state point. As seen in both scenarios, the underflow rate operating line is above the descending portion of the solids flux curve meaning that the tank is overloaded with respect to thickening, resulting in the accumulation of sludge in the tank in an unsteady way.

Figure 3b shows the underflow and overflow lines if the GCTs are forced to operate within the flux curve, making the GCTs operational. The underflow lines use the target underflow concentrations of 15,000 mg/L and 18,000 mg/L while remaining tangent to the underside of the flux curve, which is developed based on the data from the settling tests. In addition, the overflow line is plotted from the origin to a point on the underflow operating line defined by the initial feed concentration, or 7,970 mg/L for this set of trials. The operating flux based on the average influent solids concentrations can then be found, labeled on the graph as $G_{0,15,000}$ and $G_{0,18,000}$; from the settling tank data, this value is approximately 22.6 lb/day-ft^2 and 18.3 lb/day-ft2 when the designed underflow solids concentration is 15,000 mg SS/L and 18,000 mg SS/L, respectively. For a TWAS of 15,000 mg SS/L, the underflow would be approximately 1.3 MGD/tank while a TWAS of 18,000 mg SS/L would lead to an underflow of approximately 0.9 MGD/tank. The influent to the tanks under these conditions would be would be 2.4 MGD/tank and 1.6 MGD/tank with the target TWAS of 15,000 and 18,000 mg SS/L, respectively. The influent values of 2.4 MGD/tank and 1.6 MGD/tank would lead to overflow rates of 733 gal/day-ft^2 and 489 gal/day-ft^2 for nearly 100% capture of solids, respectively, both of which are below the standard design maximum.

Figure 3: Flux Curve from Settling Data with Underflow and Operating Lines



(a) Underflow and overflow lines developed based on average WAS SS concentration and flow.



(b) Underflow and overflow lines developed by limiting the influent WAS flow to force lines under the flux curve.

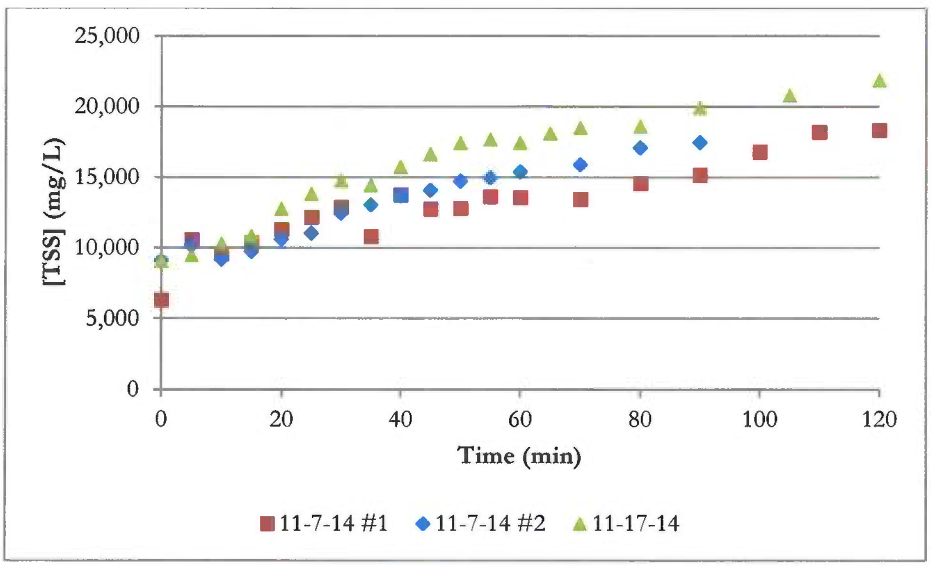
In addition to the height record, three of the trials were also performed with sampling from the bottom port of the large settling column throughout the duration of the trial. Table 4 shows the concentration of the settled solids at selected times while Figure 4 shows this increase in solids concentration over time graphically. From this data, the average TSS concentrations at 60 and 120 minutes are 15,470 and 20,509 mg/L, respectively. Average TP concentrations are 353 and 453 mg/L, respectively.

Table 4: TSS and TP Concentrations from Sampling at Bottom of Sludge Blanket

Trial Date	TSS_0 (mg/L)	TP_0 (mg/L)	TSS_{60} (mg/L)	TP_{60} (mg/L)	TSS/TSS_0 @ 60	TSS_{120} (mg/L)	TP_{120} (mg/L)	TSS/TSS_0 @ 120
11/7/14 #1	6,300	231	13,560	306	2.15	18,320	420	2.91
11/7/14 #2[1]	9,100	136	15,400	337	1.69	21,316	469	2.34
11/17/14	9,090	246	17,440	417	1.92	21,890	471	2.41
AVG	**8,160**	**204**	**15,470**	**353**	**1.92**	**20,509**	**453**	**2.55**

[1]: 11/7/14 Trial #2 ended at 90 minutes; data listed here for 120 minutes are projections based on the data to that point.

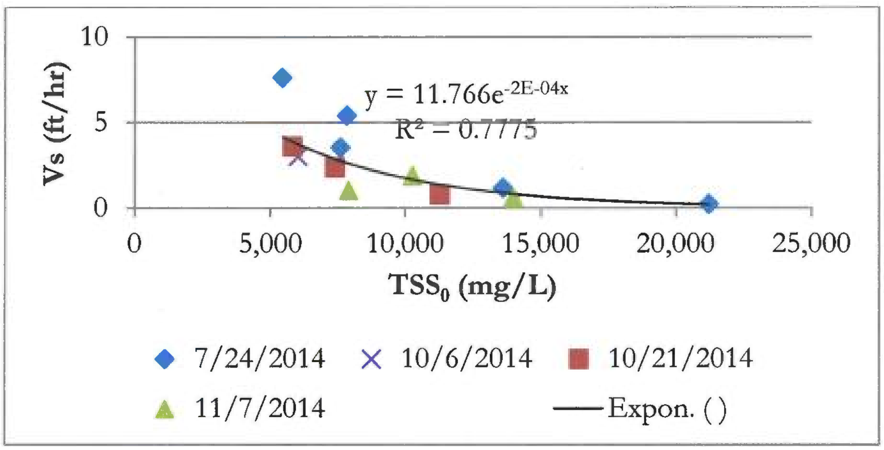
Figure 4: TSS Concentrations from Settling Blanket Taken at 5-Minute Intervals



Effect of Initial TSS Concentration on Settling

The smaller settling column tested the effects of different initial WAS TSS concentrations on settling. Similar to the large settling column, the sludge water interface height divided by time was used to find the velocity for each of the trials. The compilation of the velocity data relative to the initial WAS TSS concentration is shown in Figure 5. The curve created can be used to predict settling velocities for various influent WAS concentrations to the settling tanks. The velocity data here is lower than that of the large settling column average data; the settling velocity calculated from the Figure 5 equation is approximately 2.39 ft/hr at an initial TSS concentration of 7,970 mg/L compared to the average 3.63 ft/hr from the large column. The peak of the flux curve developed from the small settling column data is also lower than the flux curve from the large settling column, with a peak of approximately 33.5 lb/day-ft^2 compared to 41 lb/day-ft^2 from the large settling column flux curve. Should the average initial WAS TSS concentrations vary in the future, the curve could be used to determine the corresponding settling velocity.

Figure 5: Effects of Initial TSS Concentration on Settling Velocity – Small Settling Column Results



4.0 Implications for WASSTRIP® Process

Using the settling data developed throughout this report, Table 5 shows the results of various combinations of influent characteristic data and the number of GCTs in service. The average flow, TSS concentration, and TP concentration data are taken from Table 2, leading to an average WAS mass flux of 443 ton SS/day, or 886,000 lb SS/day, and 19,110 lb TP/day. From Table 4, TP concentrations when TWAS is thickened to SS concentrations of 15,000 mg SS/L and 18,000 mg SS/L can be estimated through existing data ratios to be 342 mg TP/L and 405 mg TP/L, respectively. Through the use of the flux curve and the limiting flux, the allowable flow of WAS at average solids concentrations to the GCTs can be found, as well as the TWAS flow at the targeted TWAS SS concentrations. Ultimately, these results can be used to estimate the HRTs in the WASSTRIP® reactors and for selection of an ideal usage of tanks available. In addition, the concentration of the combination of the treated and untreated WAS can be estimated by assuming 15 mg orthoP/L in the untreated WAS centrate; if all of the untreated and treated WAS is sent to the P recovery system, this is the concentration the system will experience. From past discussions with Ostara, the system is most economical when concentrations are above 75 mg/L.

Table 5: Results of Tank Usage Scenarios

Scenario	Condition	Allowable WAS Influent Flow to GCTs (MGD)	Untreated WAS Flow (MGD)	Untreated TP Load (lb/day)	TWAS Underflow (MGD)	TWAS TP Load (lb/day)	orthoP Load with Ideal 25% Release Achieved (lb/day)	orthoP Concentration to P Recovery with Treated & Untreated Flow (mg/L)
1	Maximum WAS Flow Treated Based on Limits of 2 GCTs as Thickeners & 15,000 mg SS/L in Underflow	4.75	8.9	12,690	2.6	7,420	1,860	31
2	Maximum WAS Flow Treated Based on Limits of 4 GCTs as Thickeners & 15,000 mg SS/L in Underflow	9.5	3.9	5,560	5.1	14,550	3,640	55
3	Maximum WAS Flow Treated Based on Limits of 4 GCTs as Thickeners & 18,000 mg SS/L in Underflow	6.5	6.9	9,840	3.6	12,160	3,040	46
4	Use of 6 GCTs as Thickeners & 15,000 mg SS/L in Underflow	13.4	0	0	7.2	19,110	4,780	86
Other Alterna-tives	Based on Operation of Existing GCTs a. All Flow Sent to 4 GCTs as Thickeners & 15,000 mg SS/L in Underflow[1]	13.4	10.8	12,040	2.6	7,420	1,860	86
	Theoretical b. 4 GCTs as Thickeners, Polymer Addition, & 20,000 mg SS/L underflow[2]	13.4	0	0	5.3	19,110	4,780	86

[1]: Untreated WAS flow and TP load for Other Alternatives (a) is the overflow rate and overflow TP load from forcing all flow through GCTs. This is based on an assumed capture rate of 37%, which is the average capture rate of the existing GCTs when the solids loading rate is 65 – 70 lb/day-ft^2. In this scenario, orthoP concentration to P recovery is able to maintain 86 mg/L because the untreated WAS is overflow from the tank back to the head of the plant.

[2]: The TWAS flow from this scenario is speculative; it is based on assuming polymer added is capable of capturing all solids to a concentration of 20,000 mg SS/L in the underflow and calculated through a mass balance between the influent and underflow.

5.0 Findings

The findings presented are largely based on settling column data; it should be noted that full-scale implementation will show variations from the lab-scale study. Based on the concentrations at the bottom of the settling column, underflow solids concentrations are capable of reaching 1.5%, the solids concentration that is desirable for the WASSTRIP® process, after 60 minutes, or the HRT allowed by using only two of the existing GCTs; concentrations are capable of reaching 2.0% after 120 minutes. However, the flux curve derived based on lab settling tests shows that the GCTs would be overloaded when treating the average flow of 13.4 MGD using either 2 or 4 GCTs, ultimately limiting their ability to settle. This is also seen through the performance of the existing GCTs treating both PS and WAS. The predicted average WAS loading rate of 67 lb/day-ft^2 with 4 GCTs as thickening tanks is the same as the 90th percentile of the existing loading the GCTs currently experience; at this loading, about 37% of solids from a combination of PS and WAS are captured. As the system would be quite overloaded with 4 GCTs as thickening tanks, the use of 2 GCTs for thickening does not seem to be a viable option.

Operating the WASSTRIP® thickeners in an overloaded state is not recommended as this will cause significant solids overflow and could potentially have detrimental effects on the EBPR process; this is shown in Table 5, under Other Alternatives (a) to gauge the effect. If only 37% of the solids are captured, an average of 12,040 lb TP/day would be returned to the head of the treatment plant; this represents 11% of the average TP loading to the plant in 2014.

In evaluating the other options from Table 5, having 2 GCTs as thickening tanks significantly limits the orthoP load to the P recovery system; therefore, Option 1 is not considered further. Also, there seems to be little benefit in thickening the TWAS past 15,000 mg SS/L (Option 3). This leaves Option 2, Option 4, and Other Alternatives (b) as choices for further development. In order to adequately capture the solids sent to the GCTs, the flow to the 4 GCTs would need to be limited, the number of tanks used as dedicated thickening tanks would need to be increased, or polymer would need to be added to the 4 GCTs. There are advantages and disadvantages to each alternative that would need further evaluation in order to optimize the process.

In terms of limiting the flow, the design and installation of a system to send only a portion of the WAS flow to the GCTs for WASSTRIP® treatment is feasible. However, current infrastructure from the pre-digestion centrifuges would take a combination of all centrate from all centrifuges to the P recovery system, thus re-combining both untreated and treated centrate. To effectively split this flow, dedicated centrifuges for treated and untreated flow would need to be specified, separate centrate lines installed, and the untreated centrate line rerouted to the head of the plant. On the other hand, if the flow is limited, the TWAS flow is reduced, and the HRT in the WASSTRIP® reactor tanks would be increased (with a TWAS flow of 5.1 MGD, the HRT would be approximately 6.4 hours accounting only for TWAS flow, but not including the carbon flow necessary to induce release; this is close to the 6 hours recommended for WASSTRIP® with a carbon addition). Disadvantages of a split flow without separating lines is that the combination of the treated and untreated centrate significantly lowers the orthoP concentration in the centrate (from approximately 86 mg/L to 66 mg/L) sent to the P recovery process, thus threatening the economic viability of the process. In addition, with treating only a limited flow, there is approximately 5,560 lb TP/day that would be sent to anaerobic digesters if no release of P occurs during centrifuge thickening.

If the average WAS flow of 13.4 MGD is to be treated, 6 tanks would be optimal for settling without the use of polymer; 8 tanks would be necessary to treat the 90^{th} percentile flow of 19.5 MGD at an average SS concentration. This would potentially allow for 4,780 lb orthoP/day to flow to the P recovery system and no TP left as unrecovered. The estimated orthoP concentration would also be above the recommended 75 mg orthoP/L threshold. However, based solely on the TWAS flow, the HRT in 4 WASSTRIP® reactors would be reduced to 4.8 hours. This would also account for all 10 tanks and the fermentation of the carbon source would need additional tankage at a separate location.

The option of installing a polymer system to expedite thickening needs further investigation. The amount of polymer added would need to effectively double the peak of the flux curve to allow for the underflow. The addition of polymer could limit the tankage necessary while allowing for sufficient capture. The operating cost of polymer addition and the capital cost of a polymer system and the savings of avoiding rerouting of the untreated centrate stream to achieve WASSTRIP® for 100% of the WAS would need to be weighed against the potential incremental benefit of 1,100 lb orthoP released/day and a higher orthoP concentration in the centrate stream.

APPENDIX I

Work Plan Outline for WAS Settleometer Tests

PLAN OUTLINE FOR WAS SETTLEOMETER TESTS

INTRODUCTION

The Stickney Water Reclamation Plant (SWRP) has selected the Ostara technology for recovering phosphorus from its sidestreams. The post-digestion centrifuges have a phosphorus rich centrate, making it one candidate for chemical precipitation. Another option is to incorporate a waste activated sludge (WAS) phosphorus release process as part of the P-recovery system at SWRP. This process has been marketed as the Waste Activated Sludge Stripping to Remove Internal Phosphorus (WASSTRIP®) process and has been implemented in full-scale wastewater treatment plants.

Typically, WASSTRIP includes thickening of the waste activated sludge (WAS) prior to delivery of the thickened WAS to a reactor tank to reduce the volumes necessary to achieve the hydraulic residence times (HRTs) needed for the WASSTRIP® process. As such, the time necessary for satisfactory thickening of the WAS will be investigated to support the design HRT for WAS thickening.

BACKGROUND

Table 1 summarizes 2013 data on WAS solids concentrations, flow, and Sludge Volume Indices (SVIs). SVIs are included as an indication of the settleability of SWRP sludge. Historically, these are taken for the mixed liquor. Typical SVI values of 80 mL/g or less usually indicate that a mixed liquor is dense and has rapid settling characteristics; at SWRP, values are well below this threshold, but do fluctuate seasonally, with higher values in the winter.

According to the "Biosolids Technology Fact Sheet – Gravity Thickening", published by the USEPA, a reasonable detention time for primary solids thickening is 24 to 48 hours. Combinations of primary and secondary solids may be retained between 18 and 30 hours. No information could be found regarding WAS alone. At SWRP, HRTs based on the average flows from 2013 for the final clarifiers were roughly 4.5 hours.

For WASSTRIP, we would want to achieve a solids concentration of 1.5 – 2%; this is roughly double the average WAS solids concentrations from 2013. If the WAS were thickened to the design concentration, the flows to the WASSTRIP tanks would be about halved.

Settleometer tests are typically performed in order to give wastewater treatment plant operators the ability to observe and measure the rate and characteristics of the separation of solids. Here they will be used to determine an average settling velocity to make data guided decisions about the potential settling in the gravity concentration tanks (GCTs) for design purposes.

Table 1. SWRP WAS Characteristics from 2013

PARAMETER	WAS BATT A	WAS BATT B	WAS BATT C	WAS BATT D
[SS] (mg/L)				
Mean	7,816	8,445	7,511	7,677
Maximum	14,400	16,490	18,433	19,320
Std Dev	2,472	2,546	2,587	2,580
Mixed Liquor SVI (mL/g)	43	42	46	45
Flow (MGD)				
Mean	3.4	3.2	4.1	2.6
Maximum	6.4	6.1	9.1	6.1
Std Dev	1.6	1.3	1.8	1.6

OBJECTIVES

1. To determine an average initial settling velocity, Vs, for WAS.
2. To use the settling velocity and post-settling suspended solids (SS) concentrations to gauge the residence time needed for satisfactory thickening of the WAS ([SS] = 1.5 – 2%).
3. To make a determination whether the desirable WAS SS can be achieved by gravity thickening alone in under 2 hours (based on using 2 to 4 existing GCTs with an average WAS flow).
4. To determine the effect of initial WAS SS concentration on Vs and the height of sludge blanket when the settling velocity is zero ft/min.
5. To determine an average total phosphorus (TP) concentration from various concentrations of thickened WAS and orthophosphate (Ortho P) in the supernatant from the settled WAS.

MATERIALS AND METHODS

Part A – Settling Velocity Determination

1. Use a settling column in the pilot plant lab (6 feet tall, 8 inches in diameter), equipped with a 1-rpm rake.

2. Check that the test column and drainage lines are clean and all drainage and sampling valves of the column are in the closed position before a test.

3. Collect six (6) 5-gallon carboys full of WAS (1.5 gallons from each battery). Record the test date and temperature of WAS sample in the field on the Log Sheet. Use 4 carboys for the rest of Part A and 2 carboys for Part B.

4. Shake carboys before pouring to ensure sample uniformity. Pour carboys into feed drum. Thoroughly mix the drum with impeller mixer and take an initial sample for total suspended solids (TSS), volatile suspended solids (VSS), and TP analysis (Before sample). Pump 20 gallons of WAS into the test column.

5. Thoroughly mix the sample in the column using compressed air.

6. When mixing is stopped, start 1-rpm rake motor to prevent wall effects and start a stop watch. Record start height of WAS.

7. Record blanket/liquid interface height (or depth) as a function of time. Take a height reading at least every 5 minutes over the course constant settling period. Obtain at least six data points during the period of constant settling velocity.

8. Once the settling velocity approaches zero, the test can be ended. This is determined by taking three consecutive measurements, 5 minutes apart, resulting in the same height, of the sludge blanket in the column. Record each measurement, along with the time of the measurement, on the Log Sheet.

9. After settling is complete (as described in Step 8), sample the sludge from the sampling port that is approximately in the middle of the sludge blanket.

10. To sample, first open the sampling port and **discard the first 100 mL of the WAS** (about half of a boron bottle) and collect subsequent samples of WAS into boron bottles for TSS, VSS, and TP (After sample). A sample will also be collected from the middle of the supernatant zone for ortho P analysis. Mark the bottles properly and record the port numbers on the Log Sheet.

11. In the first sets of experiments, the tests should last at least 2 hours. If settling is complete before that time, height readings can be stopped; however, at 2 hours, a final height reading is to be recorded and another sample can be taken (T = 2). If SS data analysis shows no difference between time stopped and 2 hours, this step can be eliminated in future experiments.

12. Drain the column after the test is complete. Thoroughly clean the column with tap water. Leave the drainage valves open to thoroughly drain the water.

13. Place all the sludge samples collected during the test into an environmental room with a temperature of 4°C until laboratory submission.

Part B – Effect of Initial SS Concentration on Settling Velocity

1. Start with 2 5-gallon carboys of WAS, made up of 2.5 gallons from each battery. Also collect 1 gallon of final clarifier effluent.

2. Record the test date and temperature of WAS sample in the field on the Log Sheet.

3. The test will be run at three (3) different initial solids concentrations, ranging from approximately 1,000 – 10,000 mg/L; these can be achieved using different combinations of final clarifier effluent, raw WAS, and thickened WAS, as suggested below:
    a. Trial 1: WAS as collected from field (1 gallon)
    b. Trial 2: Settle WAS for 15 minutes. Decant top of WAS (save decant for use in other trials). (1.5 gallons initial volume before settling; use 1-gallon of settled sludge for testing).
    c. Trial 3: 0.5 gallon initial WAS + 0.5 gallon final clarifier effluent.

4. Thoroughly mix each prepared sample and take an initial sample for TSS and VSS analysis (Before sample for each trial). Pour prepared WAS sample into the smaller settleometer column with rake arm attached (roughly 2.5 L). .

5. Record interface height (or depth) as a function of time as indicated in Part A. Take a height reading at least every 2 minutes over the course constant settling period. Obtain at least six data points during the period of constant settling velocity.

6. Once the settling velocity approaches zero, the test can be ended. This is determined by taking three consecutive measurements, 5 minutes apart, resulting in the same height, of the sludge blanket in the column. Record each measurement, along with the time of the measurement, on the Log Sheet.

7. After settling is complete (as described in Step 6), sample the sludge from approximately the middle of the sludge blanket through a wide-mouth pipette for TSS and VSS analysis. The mouth of the pipette will be large enough not to obstruct the entry of the larger flock particles.

8. Repeat Steps 4 – 7 for each of the trials.

9. Place all the sludge samples collected during the test into an environmental room with a temperature of 4°C until laboratory submission.

These two parts of the study will run once or twice per week and be repeated approximately 8 times in an attempt to capture varying WAS characteristics depending on tech availability.

DATA EVALUATION

Data obtained from this study and all data analyses completed will be reviewed for accuracy.

Data evaluation will focus on:

1. Interface height as a function of time.
    a. Plot the interface height (or depth) as a function of time.
    b. Visually identify the linear region of the data (the region of constant velocity).
    c. Using least squares arithmetic, determine the line of best fit through those data points corresponding to the linear region; this is defined as the initial settling velocity, Vs.
2. Evaluation of TSS and VSS concentrations before and after settling for the various trials to determine if the desired 1.5 – 2% SS concentrations can be achieved.
3. Using Vs and post-settling TSS data, the time necessary for settling WAS to 1-2% can be estimated at different initial TSS concentrations if not achieved during testing.
4. Evaluate the results with respect to the tankage available at SWRP for thickening. By using the dimensions of the existing tanks and flows, we will be able to determine the thickening that will be expected.
5. Evaluate any changes in the TP/TSS ratio that may occur over the course of the trials.
6. Evaluate the ortho P in the settled WAS supernatant.

QUALITY ASSURANCE AND QUALITY CONTROL

A QA/QC program will be employed to ensure the evaluation is representative of the test. All field samples will be collected in a manner that will ensure analysis and evaluation will provide an accurate representation of the test. These factors include preparation of sample containers (new or cleaned bottles), sample collection techniques (rinse scooper with WAS before sampling), sample preparation, sample storage and delivery in a timely manner, and laboratory analysis. A chain of custody form will be filled in and the samples stored in the cooler immediately after collection. The data quality will be evaluated as soon as possible after each study day. Extreme data values will be investigated to determine legitimacy.

TSS, VSS, TP, and orthoP will be analyzed using standard methods (2008) at ALD, and ALD will use their internal QA/QC methods. The orthoP samples will be filtered immediately. The data will be analyzed. If anomalous data is found, reruns may be requested. Outliers will be removed.

SCHEDULE

Dependent upon tech and lab availability, this could be finished in around 3.25 months.

Task	Duration
Test Preparation	Sept 22-Sept 26, 2014
Lab Testing	Sept 29-Nov 28, 2014
Data Analysis	Dec 1-Dec 12, 2014
Summary	Dec 15, 2014-Jan 9, 2015

PERSONNEL INVOLVED AND TIME COMMITMENT

The estimated man-hours required to complete this experiment are included below. The majority of the sample collection and laboratory work will be completed by Laboratory Technicians in the Wastewater Treatment Process Research Section. Data analysis, summary of data, and supervision will be completed by a collaboration between a Senior Civil Engineer and Senior Environmental Research Scientist. All others listed below will provide direction, consultation, and review of the project's deliverables.

	Person-Hours
Laboratory Technicians (1 LT)	
Prepare sample bottles	32
Sample collection (2 LTs)	32
Experimentation	48
Total Laboratory Technician Hours	**112**
SERS/CEIII	
Coordination with ALD	2
Supervision/Training for Experimentation	32
Data analysis	32
Preparation of Data Summary	40
Total AERS/CEIII Hours	**106**
Supervising Environmental Research Scientist	
Provision of direction to AERS/CEIII	2
Review of products	3
Total Supervising Environmental Research Scientist Hours	**5**
Managing Civil Engineer	
Review of products	2
Total Managing Civil Engineer Hours	**2**

	Person-Hours
Assistant Director of Monitoring and Research	
Provision of direction	2
Review of Data	2
Total Assistant Director of Monitoring and Research Hours	**4**

Signature Page

Project Leader	[signature]	**Date**	8-25-14
Supervising ERS	[signature]	**Date**	8/27/14
Managing Civil Engineer	[signature]	**Date**	8.27.14
Assistant Head of M&R	[signature]	**Date**	8/28/14