Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 16-18

STICKNEY PHOSPHORUS TASK FORCE

TECHNICAL MEMORANDUM NO. 10

RECYCLE STREAM STUDY DATA SUMMARY AT THE STICKNEY WASTEWATER RECLAMATION PLANT

April 2016

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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 recovery of phosphorus in various forms suitable for use as an agronomic fertilizer, the MWRD initiated a Phosphorus Removal and Recovery Task Force (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.

Recycle Stream Study Data Summary at the Stickney Wastewater Reclamation Plant

Technical Memorandum 10

Date: April 1st, 2016

To: Phosphorus Task Force & Advisory Committee

From: Phosphorus Study Team

Subject: Recycle Stream Study Data Summary – Technical Memorandum 10

The Stickney Water Reclamation Plant (WRP) in Cicero, Illinois, is currently targeting a monthly average of 1 mg/L total phosphorus (TP) in its effluent through an anoxic/anaerobic/aerobic (AAnO) scheme. The Stickney WRP was originally designed as a single-stage nitrification activated sludge plant which treats domestic and industrial sewage from a combined sewer system that had a 2014 average flow of 728 million gallons per day (MGD) and has an average design flow of 1,200 MGD. The plant has two influent pumping stations, West Side and Southwest Side, and two primary treatment systems. The West Side receives primarily domestic sewage while the Southwest Side generally receives the flows from plant recycles and Tunnel and Reservoir Plan (TARP) pumpback in addition to domestic and industrial sewage. The Terrence J. O'Brien (O'Brien) WRP pumps its combined primary sludge and waste activated sludge (WAS) to the Stickney WRP for solids treatment. The combined O'Brien sludge and Stickney Southwest Side preliminary sludge and WAS are treated in Stickney WRP's solids train through thickening, anaerobic digestion and dewatering either via centrifugation or lagooning; Imhoff solids from the West Side are added directly to the digester prior to dewatering.

As stated above, these recycle streams are, in most cases, recycled to the head of the Southwest Side treatment plant and combined with influent raw sewage. In some cases the preliminary sludge occasionally is sent to the West Side train. The AAnO process, similar to other biological nutrient removal processes, prefers stability. From a previous recycle stream study completed in winter 2014, the recycle streams have the ability to change the dynamics of the system in terms of the nutrient loading. Due to the fluctuations in the streams, direction was given at a Stickney Phosphorus Task Force Executive Team meeting (April 20, 2015) for the study team to conduct a characterization of the recycle streams via intensive sampling.

The objectives of this study are to identify the nutrient and carbon (C) loadings from Stickney's recycle streams and to address the concerns associated with recycle streams as related to the AAnO process. These recycle streams represent a significant nutrient (nitrogen [N] and phosphorus [P]) load on the Stickney WRP's nutrient removal process, and may need to be managed better to assure compliance with effluent quality goals and improve treatment efficiency.

Methods

Recycle Streams Sampling and Analysis

Five recycle streams at the Stickney WRP were identified for monitoring: supernatant overflows from the gravity concentration tanks (GCT) and new gravity thickening building (GTB) tanks; centrate from the pre- and post-digestion centrifuge facilities; and overflow from the facultative lagoons, i.e. Lawndale Avenue Solids Management Area (LASMA). The Maintenance and Operations (M&O) Department routinely monitors Southwest raw, a sample point which contains all the above mentioned recycle streams and TARP pumpback in addition to domestic and industrial sewage.

Stickney WAS was thickened in the GCTs, and the overflow supernatant was sent back to the head of plant at time of study; the GCT tanks were abandoned in late 2015, and Stickney WAS has been directly sent to pre-centrifuges since then. An autosampler for GCT overflow was set up by a wet well in the GCT building at the time of study. When the P recovery processes, Ostara® and Waste Activated Sludge Stripping to Remove Internal Phosphorus®, come online in 2016 and 2017, respectively, Stickney WAS will be thickened in four GCT tanks, combined with primary sludge fermentate, and held under anaerobic conditions in four GCT tanks. The treated WAS will then be sent to pre-digestion centrifuges. The pre-centrate and post-centrate will then be sent to the Ostara® struvite reactors for P recovery.

The combined O'Brien sludge and Stickney preliminary sludge is sent to the new GTB tanks, and its overflow supernatant is sent back to the head of the plant. An autosampler for GTB overflow was set up in the overflow pipeline.

The underflow from the GCTs is centrifuged in the pre-digestion centrifuges. The pre-digestion centrate, along with any dilution water used in the process, was collected as a composite sample through an autosampler which was connected to the pre-centrate pipeline.

The cake from the pre-digestion centrifuge machines, the thickened Stickney preliminary and O'Brien sludge, and Imhoff solids are digested in digesters and dewatered in the post-digestion centrifuges or lagooned. The post-centrate was collected with two autosamplers, one at the centrate line exiting the building to the south (centrifuges 1–12) and one existing the building to the west (centrifuges 13–24). The reason for having two sampling points was to ensure that post-centrate samples could be collected in case one side was shut down, which happens occasionally. The samples collected from the two autosamplers were equally combined into one post-centrate sample. The sample contained the centrate as well as dilution water and any flow through polymer preparation and building roof drains.

LASMA is used for additional digestion and dewatering or when the plant does not have the ability to dewater digester draw in its post-digestion centrifuges. The runoff from LASMA is collected at a desilting pond before returning to the Stickney WRP. This sample was collected at the overflow point with an autosampler.

The Southwest influent samples, which contain all of the recycle streams, TARP and Southwest Side raw sewage (STRAW), were collected with an autosampler downstream of the aerated grit tanks.

All the autosamplers were set up to collect a 50-mL aliquot every 15 minutes; these aliquots were composited prior to analysis to reflect a 24-hour period for diurnal discretionary sampling except where noted below.

For each daily composite sample, suspended solids (SS) and volatile SS (VSS), TP, orthophosphate (ortho-P), ammonia N (NH_3-N), soluble chemical oxygen demand (solCOD) and volatile fatty acids (VFAs) were analyzed; if there was not enough sample volume to conduct all analyses, SS, VSS, solCOD, and VFA were omitted. The study period was from May 6, 2015, to June 26, 2015.

Discrete samples for the five recycle streams and STRAW were analyzed for three days (July 8 through 10, 2015) in an effort to capture diurnal effects. Discrete samples were collected every four hours (six samples per day). Samples were analyzed for TP, ortho-P, NH_3-N, SS_VSS, solCOD, and VFAs.

Flow Measurement of Recycle Streams. Post-centrate flows would ideally be estimated based by adding feed flow to the post-centrifuges, estimated dilution water, and diluted polymer flow and then subtracting solids capture, as shown in the second column of Table 1. The feed flows for post-centrates were measured and recorded in M&O log sheets. The post-centrate contained centrate as well as dilution water and any flow through diluted polymer and building roof drains. Estimating flows at the sample point using a mass balance approach was not successful; about 30 percent of the time, the calculated centrate flow was negative based on the samples and data collected. Therefore, the reported post-centrate flow values were doubled as the feed flow in order to calculate the load; this approach was used in previous studies by Kamlesh Patel in 2012 and Black & Veatch in 2014.

Pre-centrate flows would ideally be estimated based by adding feed flow to the pre-centrifuges, estimated dilution water, and diluted polymer flow and then subtracting solids capture. The feed flows for pre-centrates were measured and recorded in M&O log sheets. The pre-centrate flow also contains some dilution water and diluted polymer, but the two dilution flows are negligible compared to pre-centrate flow, according to discussions with M&O Department operating engineers. More refined flows considering solids capture in pre-centrate process were also calculated, but the calculation of mass between feed, centrate, and cake produced was not balanced; about 30 percent of the time, the calculated centrate flow was negative based on the samples collected, making the pre-centrifuge feed flow a more reliable measure. Therefore, the pre-centrate flow was estimated to be equal to the feed flow as recorded in the M&O Department's daily log sheets.

TABLE 1: FLOW MEASUREMENTS AND ESTIMATIONS

Recycle streams	Initial Equation	Measurements	Estimation/Assumptions	Final Equation
Post-Centrate	Feed+dilution flow+diluted polymer -solids capture	Feed: recorded as running time and capacity (gpm)	Dilution water+ diluted polymer: estimated the same as feed. Solids capture: not always balanced, therefore not considered.	2*Feed
Pre-centrate	Feed+dilution flow+diluted polymer -solids capture	Feed: recorded as running time and capacity (gpm)	Dilution water+ diluted polymer: negligible. Solids capture: not always balanced, therefore not considered	Feed
GCT over flow	WAS flow–predigestion feed flow	WAS flow readings from flow meter Feed: recorded as running time and capacity (gpm)		WAS flow – predigestion feed flow
GTB overflow	O'Brien sludge flow + preliminary sludge flow	Both readings from flow meter	Underflow: considered insignificant	O'Brien sludge flow + preliminary sludge flow
LASMA	Desilting pond pump operating hours*pump capacity	Pump hours	Ignoring rain water	Desilting pond pump operating hours*pump capacity

GCT overflow flow was calculated as the Stickney WAS flow minus pre-digestion feed. The WAS flow was measured by meter, and the pre-digestion feed flow was recorded by M&O operating staff as shown in Table 1. GTB overflow was calculated as O'Brien sludge flow plus Stickney preliminary sludge flow; both flows were measured by meters LASMA flow was calculated from desilting pond pump operating hours and multiplied by the pump capacity from May 15, 2015, through June 26, 2015; for days prior to May 15, 2015, we estimated the average flow as the difference between 3 MGD (the average value of post-centrate feed and LASMA overflow from the 10-day recycle stream study conducted in early 2014 by Black & Veatch) and the post-centrate feed flow.

Data Summary

Recycle Stream Flows

The STRAW flow varied from 213 MGD to 872 MGD, with an average flow of 484 MGD during the study period. The total flow from all five identified recycle streams varied from

5.6 MGD to 33.6 MGD, with an average recycle flow of 20 MGD. The percent recycle flow in the Southwest raw flow varied from 1.4 percent to 9.2 percent, with an average of 4.7 percent during the study period.

Figure 1 shows the flows from all recycle streams and the Southwest raw during the study period. The high standard deviation (195 MGD) indicates that the Southwest raw flow fluctuated significantly due to the fact that the Stickney WRP receives a combined sewer flow. The recycle stream flows were as variable as plant influent (STRAW) as shown in Figure 1, which had a coefficient of variation (CV) of 40 percent as shown in Table 2.

Table 2 shows that the highest average recycle flow was from GCT overflow, followed by GTB overflow, pre-centrate, LASMA, and then post-centrate; the low post-centrate flows were because Stickney plant operations reduced the number of post-centrifuges in service due to the high cost of polymer. To test for the equality of flows of five recycle streams, parametric analysis of variance (ANOVA) and multiple comparison tests were performed on the mean flows of five recycle streams. Results indicate that GCT overflow, GTB overflow, and pre-centrate flows are significantly different from each other. The flows of LASMA and post-centrate are statistically identical.

FIGURE 1: RECYCLE STREAM FLOWS AND SOUTHWEST RAW FLOW DURING THE STUDY PERIOD

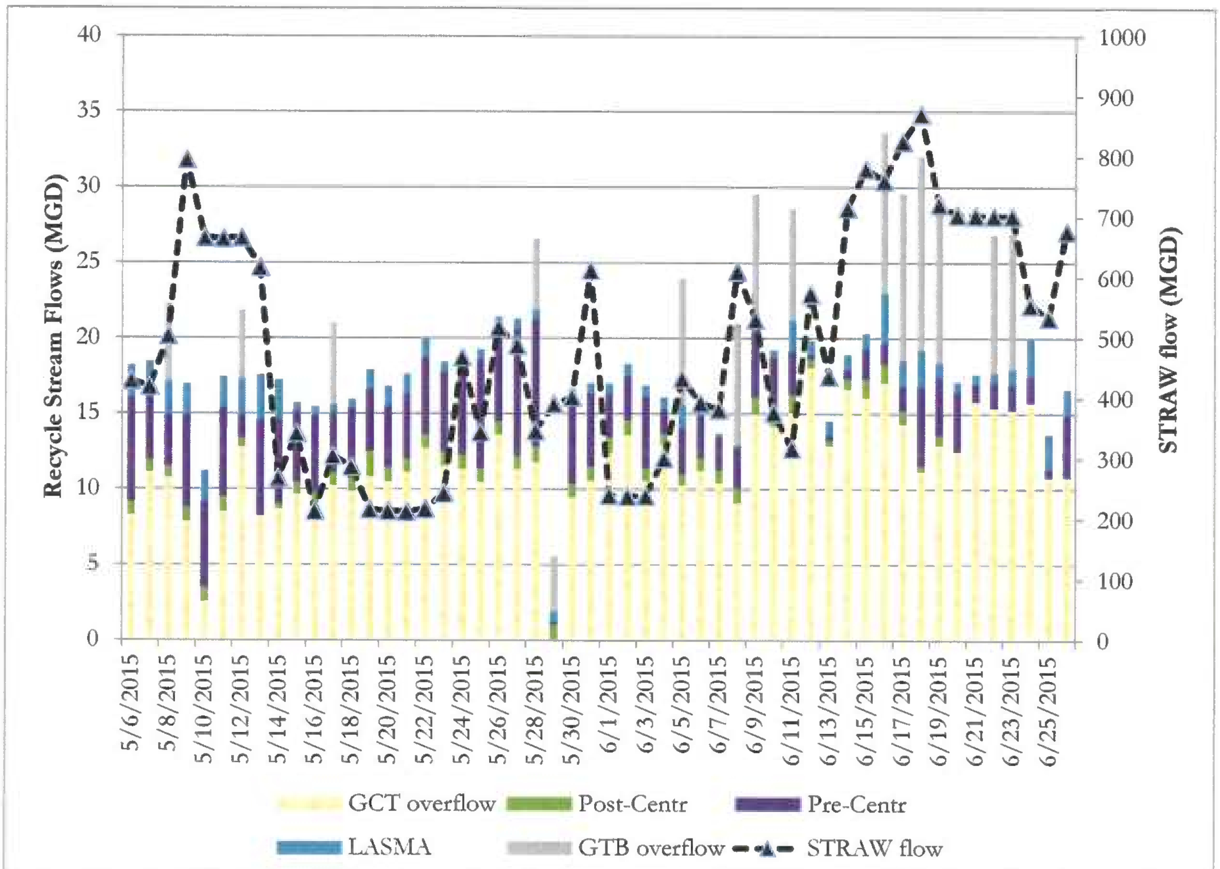


TABLE 2: STATISTICAL DATA OF FLOW FROM EACH RECYCLE STREAM AND SOUTHWEST RAW DURING THE STUDY PERIOD

	Flow, MGD					
	Southwest Raw	GTB Overflow	GCT Overflow	Post-Centrate	LASMA	Pre-Centrate
Sampling Days	44	15	48	37	44	43
Average	484	7.85	11.82	1.70	1.28	3.79
Minimum	213	3.65	2.54	0.09	0.25	0.19
Maximum	872	12.79	18.06	3.35	3.36	8.42
Standard Deviation	195	2.74	2.85	0.53	0.78	2.08
Coefficient of Variation	40%	35%	24%	31%	61%	55%

Orthophosphate Load and Concentrations. Figure 2 shows the ortho-P mass loads from all recycle streams and in STRAW during the study period. It can be seen that ortho-P loads in both Southwest influent and recycle streams fluctuated on a daily basis. Some daily recycle stream ortho-P loads are missing in the graph because samples could not be collected due to a power outage, clogged autosampler sample lines, or low flow in sample line; the last of these is the main reason why GTB samples were missed most of the time.

FIGURE 2: ORTHOPHOSPHATE LOAD FROM EACH RECYCLE STREAM AND IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

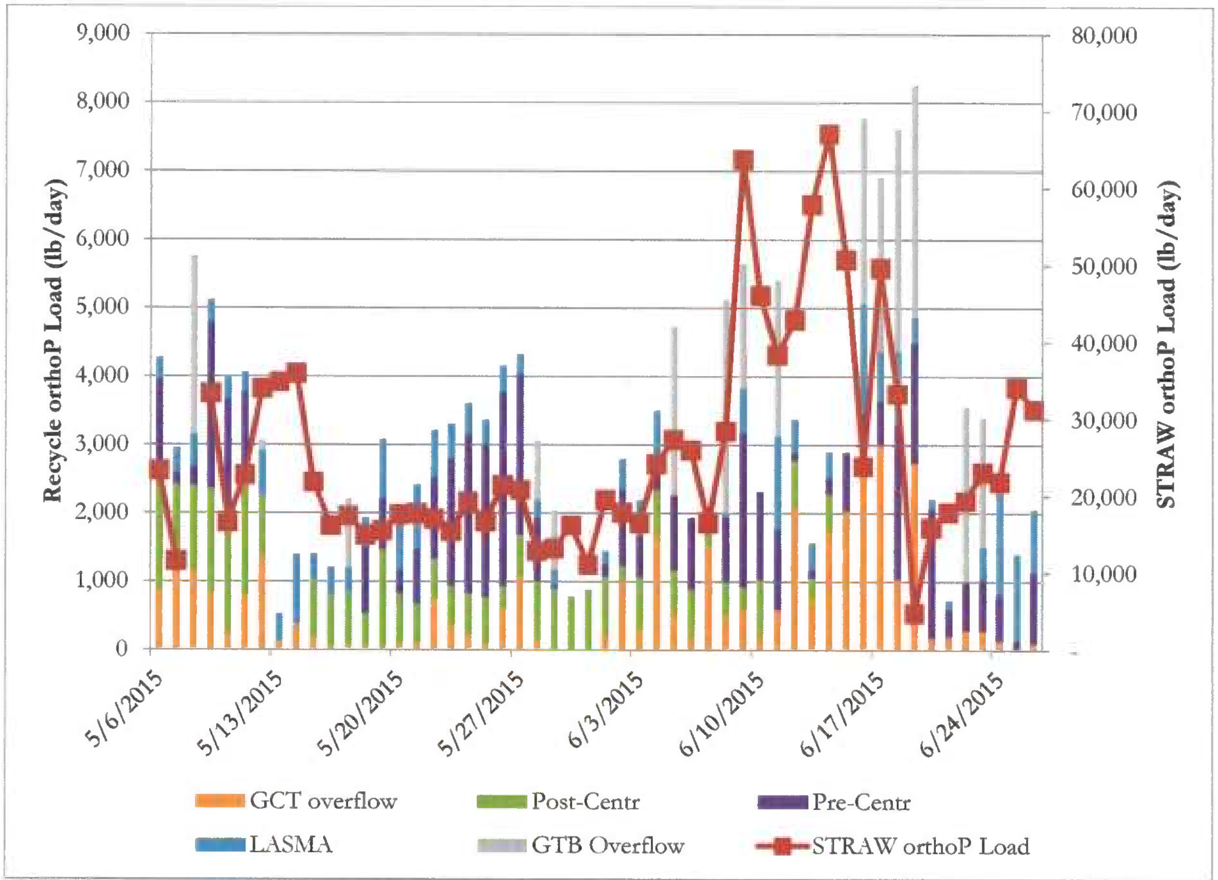


Table 3 shows the statistical data for ortho-P loads in the recycle streams. It can be seen that post-centrate had the lowest average ortho-P load of all five recycle streams during the study period. However, it should be noted that there were only three to five post-centrifuges in service during most of the study period. Due to autosampler set-up problems, only 15 samples were collected from the GTB overflow during the study period. From the average ortho-P load of 15 days' data, GTB overflow was the biggest ortho-P load contributor to the STRAW, followed by pre-centrate, GCT overflow, LASMA, and then post-centrate. However, the loads from each recycle stream varied significantly, with standard deviations of 200 lbs/d and greater. The CV of ortho-P load in the recycle streams varied from 47 percent to 103 percent. The ortho-P load of GCT overflow had the highest relative variation with a CV of 103 percent, and GTB overflow had the lowest relative variation with a CV of 47 percent as shown in Table 2. The ANOVA and multiple comparison tests show that ortho-P load from GTB is statistically higher than all other streams; ortho-P loads from pre-centrate and GCT overflow are statistically similar, and ortho-P loads from LASMA and post-centrate are statistically similar.

TABLE 3: STATISTICAL DATA OF ORTHOPHOSPHATE LOAD FROM EACH RECYCLE STREAM IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

	Ortho-P Load, lbs/d				
	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	43	37	48	15	44
Average	1,077	804	745	2,096	572
Minimum	46	216	55	136	73
Maximum	2,840	1,828	2,994	3,384	1,615
Standard Deviation	753	400	771	979	373
Coefficient of Variation	70%	50%	103%	47%	66%

FIGURE 3: PERCENT ORTHOPHOSPHATE MASS IN SOUTHWEST SIDE RAW SEWAGE OF EACH RECYCLE STREAM

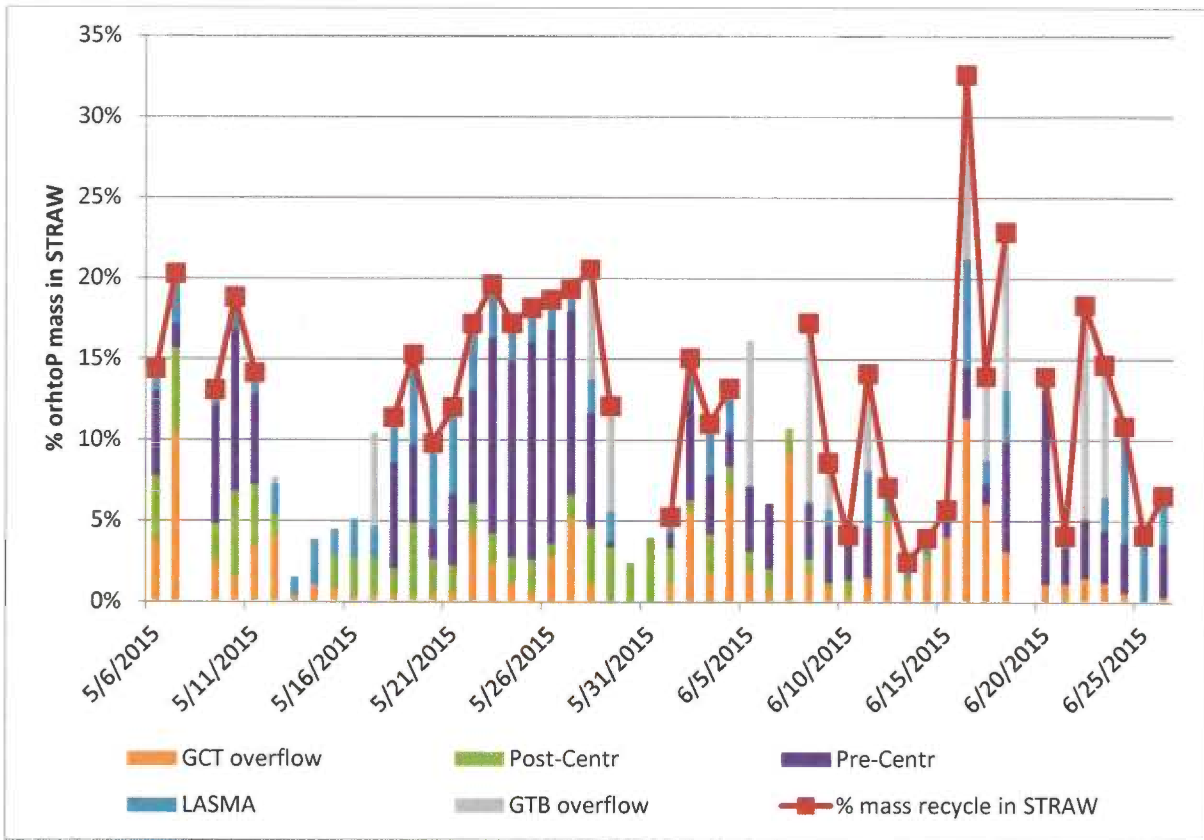


Figure 3 shows that the combined recycle streams contributed 5–33 percent of the total load in the Southwest raw influent, with an average of 13 percent during the study period. The broken lines in STRAW are because some recycle samples were not collected every day as discussed above. Like the ortho-P load, the percent ortho-P mass in STRAW has similar CV values for each stream, e.g. GCT overflow had the highest relative variation and GTB overflow had the lowest relative variation of all five recycle streams. In order to identify the reasons for these variations, the ortho-P concentrations distributions were plotted for all the recycle streams with respect to plant outfall as shown in Figure 4. The ortho-P concentrations in LASMA and post-centrate are the highest of all the recycle streams. Figure 4 shows there was no direct correlation of outfall ortho-P spikes with the recycle stream ortho-P concentrations during the study period. Recycle stream flows are relatively stable except flows from LASMA, which depends on dry or wet weather conditions (Figure 1) and LASMA had the highest standard deviation and CV compared to other streams (Table 2). The statistical data of ortho-P concentrations in all recycle streams are summarized in Table 4. As shown, LASMA and post-centrate had the highest ortho-P concentrations and similar in an average of ~55 mg/L, followed by pre-centrate at 38 mg/L ortho-P, GTB overflow at 31 mg/L, and GCT overflow at only 7 mg/L during the study period. The post-centrate ortho-P concentrations are lower than expected, because of the high amount of dilution and drainage water contributing to the sample point. Only raw centrate will be fed into the Ostara reactors. The ANOVA and multiple comparison tests show that ortho-P concentrations from post-centrate and LASMA are identical and statistically similar and higher than the other streams; ortho-P concentrations from pre-centrate and GTB overflow are statistically similar, and ortho-P concentration from GCT overflow is statistically lower than other streams.

TABLE 4: STATISTICAL DATA OF ORTHOPHOSPHATE CONCENTRATIONS IN ALL RECYCLE STREAMS DURING THE STUDY PERIOD

	Ortho-P Concentration, mg/L				
	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	43	33	45	15	40
Average	38	55	7	31	54
Minimum	5	13	1	4	16
Maximum	65	124	25	61	93
Standard Deviation	16	26	7	13	23
Coefficient of Variation	42%	46%	90%	40%	42%

FIGURE 4: RECYCLE STREAM AND PLANT OUTFALL ORTHOPHOSPHATE CONCENTRATIONS DURING THE STUDY PERIOD

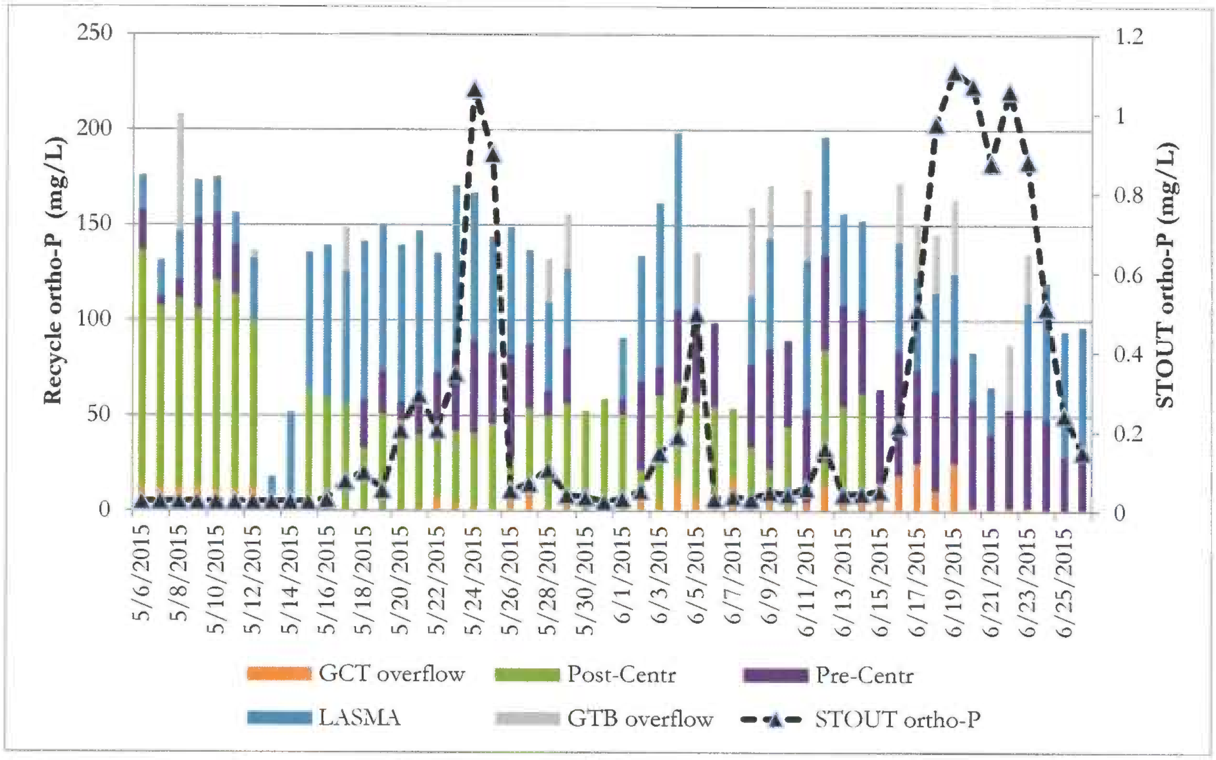


FIGURE 5: CORRELATION OF OUTFALL ORTHOPHOSPHATE CONCENTRATIONS WITH THE PERCENT RECYCLE STREAM MASS IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

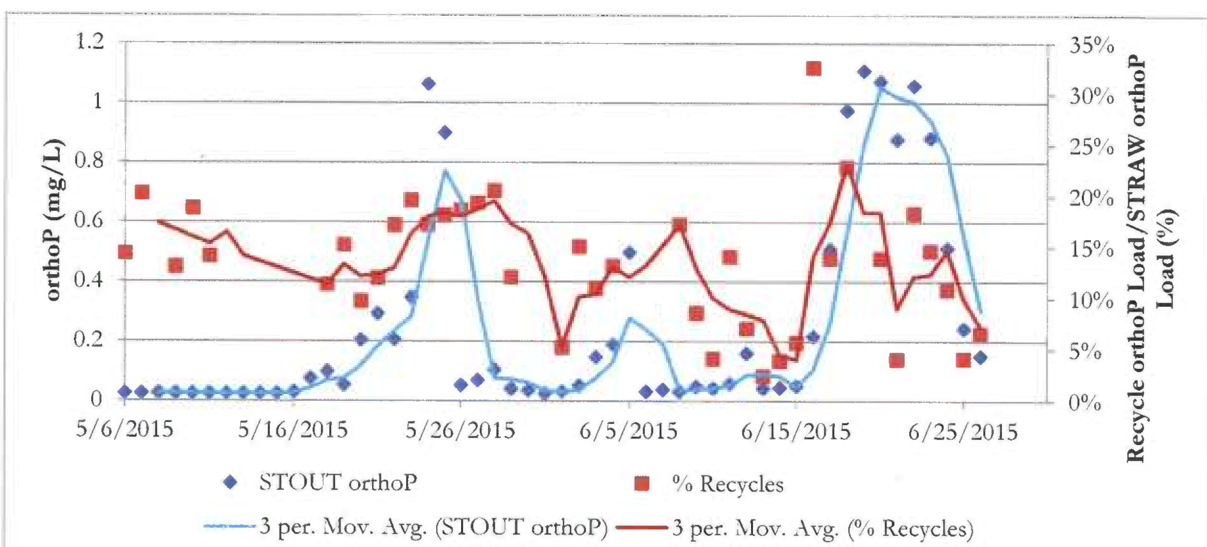


Figure 5 shows the trend between the plant outfall ortho-P concentrations and the percent ortho-P load in STRAW from the recycle streams; an increase in contribution from the recycle stream ortho-P load in the plant's Southwest influent could have the potential to cause elevated ortho-P concentrations in the plant outfall. Statistical analysis through the autoregressive regression model shows that the outfall ortho-P concentrations depends significantly on both the percent recycled ortho-P load in STRAW and the previous outfall ortho-P concentration with very high fitted criterion R-square of 0.79 during the study period. This means the outfall ortho-P concentrations were positively affected by the outfall ortho-P from the previous day as well as the percent ortho-P load from recycles in STRAW.

Nitrate Nitrogen Load and Concentrations.

FIGURE 6: AMMONIA NITROGEN LOAD OF EACH RECYCLE STREAM AND THE SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

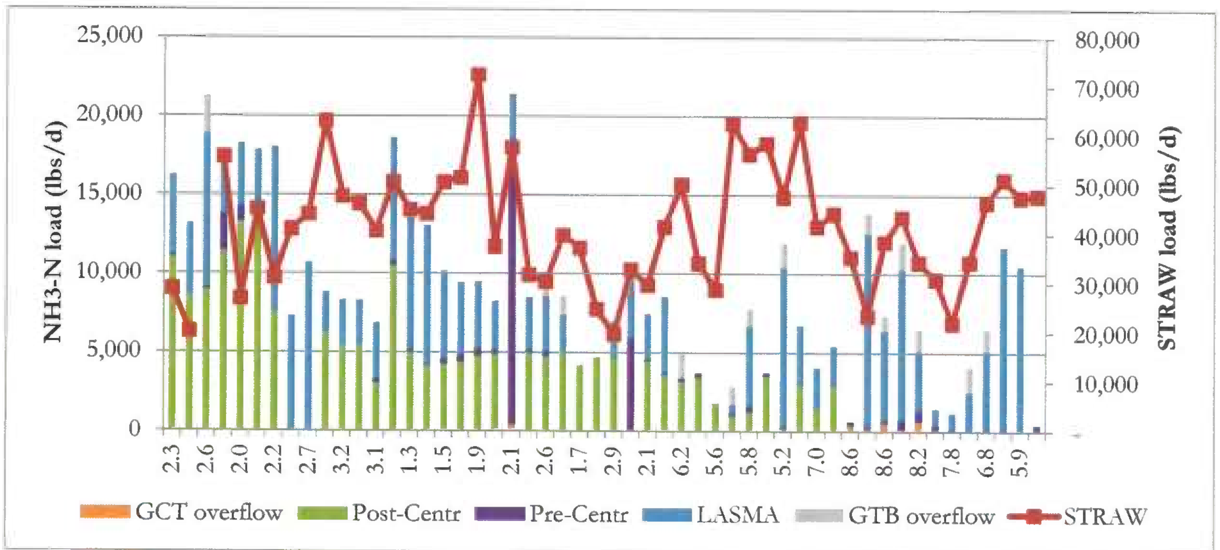


Figure 6 shows the NH_3-N mass load from each recycle stream and STRAW during the study period. Table 5 shows the NH_3-N load contribution from the recycle streams to plant influent from highest to lowest are LASMA, post-centrate, GTB overflow, pre-centrate, and GCT overflow, respectively. The standard deviations of the NH_3-N loads in the recycle streams are very high relative to the ortho-P loads. The CV of the STRAW load is 29 percent, much lower than the recycle stream NH_3-N loads, especially the pre-centrate and GTB overflow. The ANOVA and multiple comparison tests show that the NH_3-N load from LASMA is statistically higher than all other streams; NH_3-N loads from post-centrate and GTB overflow are statistically identical, and the NH_3-N load from GCT overflow is statistically lower than other recycle streams. The NH_3-N load from pre-centrate is statistically different from LASMA but similar to post-centrate, GTB overflow, and GCT overflow.

TABLE 5: STATISTICAL DATA OF AMMONIA NITROGEN LOAD FROM EACH RECYCLE STREAMS DURING THE STUDY PERIOD

	NH_3-N, lbs/d				
	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	42	37	49	14	44
Average	844	5,111	76	1,272	5,199
Minimum	8	31	8	26	577
Maximum	17,483	13,587	625	2,363	12,351
Standard Deviation	2,795	3,389	132	504	3,143
Coefficient of Variation	331%	66%	174%	40%	60%

FIGURE 7: PERCENT AMMONIA NITROGEN LOAD IN SOUTHWEST SIDE RAW SEWAGE OF EACH RECYCLE STREAM

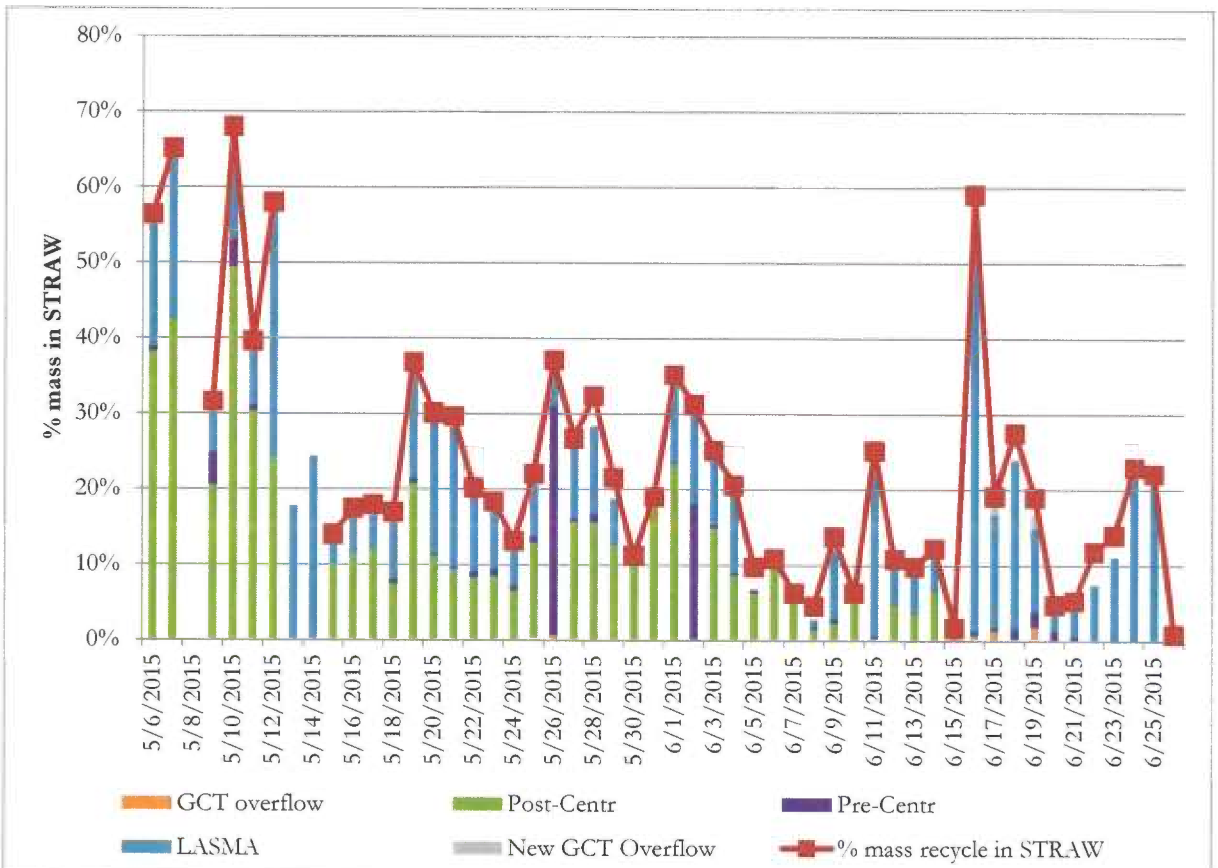
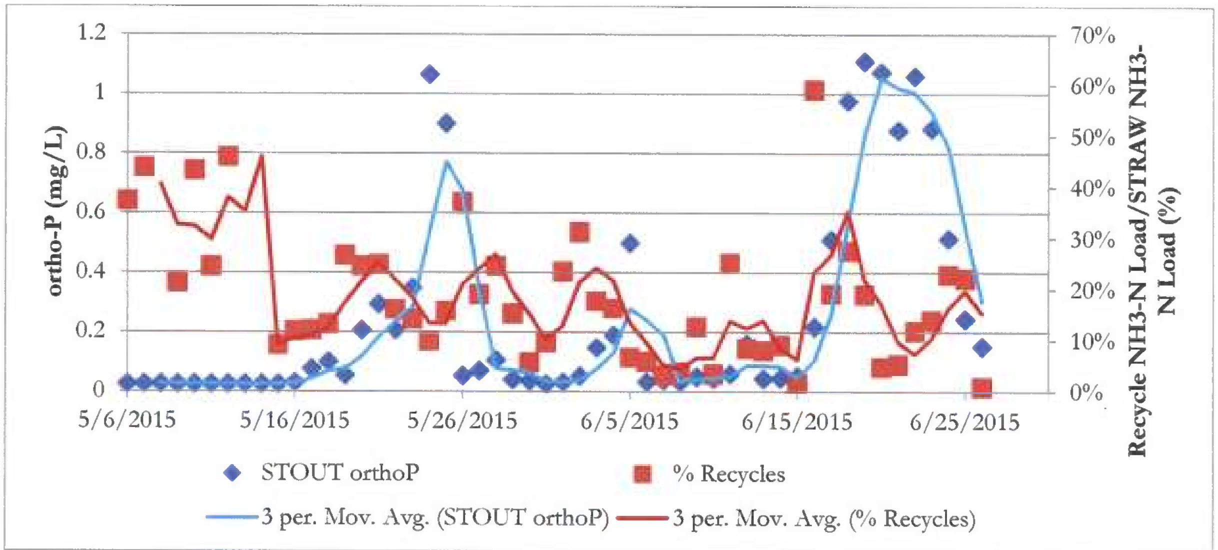


Figure 7 shows that the recycle streams contributed to the plant Southwest influent in a wide range of 2–68 percent NH_3-N load. The average NH_3-N load from the recycle streams in STRAW was 18 percent during the study period. Due to autosampler problems, LASMA samples were not collected on 6 out of 49 sampling days. The average LASMA percent NH_3-N load in STRAW was 13 percent on 43 sampling days. The average post-centrate percent NH_3-N load in STRAW was 12 percent on 37 sampling days; post-digest centrifuges were shut down for contractual work in the last 12 days of study. It can be seen that LASMA and post-centrate were the two biggest NH_3-N load contributors to the plant influent of all recycle streams during the study period. Please note that Stickney operations also reduced post-digestion centrifuge operation due to polymer cost and sent more sludge to lagoons during the study period.

FIGURE 8: CORRELATION OF OUTFALL ORTHOPHOSPHATE CONCENTRATIONS WITH THE PERCENT RECYCLE STREAM AMMONIA NITROGEN LOAD IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD



As shown in Figure 8, it does not seem that the portion of NH_3-N load from recycle streams in STRAW directly correlated to outfall ortho-P concentrations during the study period. However, in historical Stickney operations data, there is an indication that higher effluent TP concentrations might be correlated with higher effluent nitrate concentrations, especially when influent C was not sufficient. The return of ammonia load from the recycle streams could affect the sustainability of the enhanced biological phosphorus removal (EBPR) process. Higher ammonia concentrations in STRAW due to the increased portion of the NH_3-N loads from the recycle streams could result in higher nitrate in the plant effluent. The higher nitrate in the effluent can subsequently result in higher nitrate in the return activated sludge, which compromises the EBPR process due to the C demand for denitrification. When influent C was not sufficient, the denitrification C demand could imbalance the EBPR process. Therefore, managing the NH_3-N load in recycle streams is considered very important to maintaining a healthy EBPR process.

Suspended Solids, Soluble Chemical Oxygen Demand, and Volatile Fatty Acids Load. Table 6 shows the statistical data for the SS loads in the recycle streams. It can be seen that post-centrate and LASMA had low average SS loads compared to the other three recycle streams monitored during the study period. As mentioned above, it should be noted that there were only three to five post-centrifuges in service during most of the study period. Due to autosampler set-up problems, only 11 samples were collected from the GTB overflow during the study period. From the average SS load of 11 days' data, GTB overflow was the biggest SS load contributor to the STRAW, followed by GCT overflow, pre-centrate, LASMA, and then post-centrate. However, the loads from each recycle streams varied significantly, with standard deviations 2,336 lbs/d and greater. The CV of SS load in the recycle streams varied from 56 percent to 186 percent. The SS load from the post-centrate had the highest relative variation with a CV of 186 percent; however, it was low SS load contributor. GTB overflow had the lowest relative variation, with a CV of 56 percent; it had the highest SS load to the plant influent as shown in Table 5.

TABLE 6: STATISTICAL DATA OF SUSPENDED SOLIDS LOAD FROM EACH RECYCLE STREAMS IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

	SS, lbs/d				
	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	38	36	40	11	37
Average	86,994	7,008	213,541	589,970	3,718
Minimum	2,101	561	5,320	142,677	1,153
Maximum	507,644	69,188	971,757	1,081,068	10,713
Standard Deviation	89,846	13,150	271,971	334,860	2,336
Coefficient of Variation	103%	186%	127%	56%	63%

TABLE 7: STATISTICAL DATA OF SOLUBLE CHEMICAL OXYGEN DEMAND LOAD FROM EACH RECYCLE STREAMS IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

	COD, lbs/d				
	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	38	37	39	10	39
Average	2,913	1,970	4,106	26,134	4,177
Minimum	51	594	2,127	1,014	406
Maximum	11,057	5,192	34,297	79,733	13,705
Standard Deviation	2,245	1,290	5,042	26,911	3,277
Coefficient of Variation	77%	55%	123%	103%	78%

Table 7 shows the statistical data for solCOD loads in the recycle streams. It can be seen that GTB overflow had the highest average solCOD load to the plant influent during the study period, followed by LASMA, GCT overflow, pre-centrate, and then post-centrate. However, the loads from each recycle streams varied significantly, with standard deviations of 545 lbs/d and greater. The CVs of solCOD load in the recycle streams varied from 55 percent to 123 percent. The ANOVA and multiple comparison tests show that the solCOD load from GTB overflow is statistically the highest of all recycle streams; solCOD loads from post-centrate, pre-centrate, LASMA, and GCT overflow are statistically identical. Therefore, GTB tanks can be managed and operated as a partial solution for providing C for sustainable EBPR at the Stickney WRP. An in-house engineering contract was generated to convert two GTB tanks into fermentors for supplying additional C for this purpose.

TABLE 8: STATISTICAL DATA OF VOLATILE FATTY ACIDS LOAD FROM EACH RECYCLE STREAMS IN SOUTHWEST SIDE RAW SEWAGE DURING THE STUDY PERIOD

	VFAs, lbs/d					
	STRAW	Pre-Centrate	Post-Centrate	GCT Overflow	GTB Overflow	LASMA
Sample Counts	32	28	34	26	11	30
Average	52,673	444	144	1,311	16,062	156
Minimum	10,019	8	62	378	187	13
Maximum	227,806	1,784	334	21,678	43,938	608
Standard Deviation	48,750	434	50	4,155	13,298	127
Coefficient of Variation	93%	98%	51%	317%	78%	81%

Table 8 shows the statistical data for VFA loads in the recycle streams. From the average VFA load, GTB overflow was the highest VFA load contributor to the STRAW, followed by GCT overflow, pre-centrate, LASMA, and then post-centrate. The standard deviations for the recycle stream VFA loads were very high, especially for GTB overflow and GCT overflow. The CVs of VFA loads in the recycle streams varied from 51 percent to 317 percent, in which GCT overflow had the highest fluctuation of load. The ANOVA and multiple comparison tests show that the VFA load from GTB overflow is statistically the highest of all recycle streams; VFA loads from post-centrate, pre-centrate, LASMA, and GCT overflow are statistically identical. As mentioned above, the VFA load from GTB can be managed to provide C for sustainable EBPR.

Historic Data Comparison. Table 9 shows the Stickney recycle stream load data comparison from three separate studies: 2009, 2014, and 2015. It should be noted that sampling points, length of study, and type of sampling were not the same during each study. Additionally, the GTB overflow is a new stream at the Stickney WRP, not existing in 2009 and 2014. Based on the available data, it can be seen that post-centrate was lower in all loads in 2015 study due to a reduction in number of machines operated. LASMA was higher in loads in 2014 study due to higher flow and higher concentrations observed during the 2014 study period. The average NH_3-

N and ortho-P concentrations for LASMA were 70 percent higher and 100 percent higher in 2014, respectively. Due to sludge separation, GCT overflow ortho-P and NH_3-N loads were lower in 2015, as shown in Table 9. The solCOD loads from all recycle streams in 2009 study were much higher than in 2015.

TABLE 9: COMPARISON OF 2009, 2014, AND 2015 STICKNEY WATER RECLAMATION PLANT RECYCLE STREAM WATER QUALITY DATA

Source	Year	SS (lbs/d)	ortho-P (lbs/d)	NH_3-N (lbs/d)	solCOD (lbs/d)	VFAs (lbs/d)
GCT Overflow	2009	79,309	943	1,604	14,300	ND
	2014	346,776	1,578	4,177	ND	ND
	2015	213,541	745	76	4,106	1,311
Pre-Centrate	2009	84,488	2,099	1,836	30,198	ND
	2014	112,218	897	8,323	ND	ND
	2015	86,994	1,077	844	2,913	444
Post-Centrate	2009	9,200	747	9,037	5,081	ND
	2014	19,506	752	6,495	ND	ND
	2015	7,008	804	5,111	1,970	144
LASMA	2009	ND	ND	ND	ND	ND
	2014	8,818	1,950	29,479	ND	ND
	2015	3,718	572	5,199	4,177	156

ND: No data available.

Discrete Sample Data Summary.

FIGURE 9: THE SOUTHWEST SIDE RAW SHIFT FLOW FROM JUNE 8, 2015, THROUGH JUNE 10, 2015

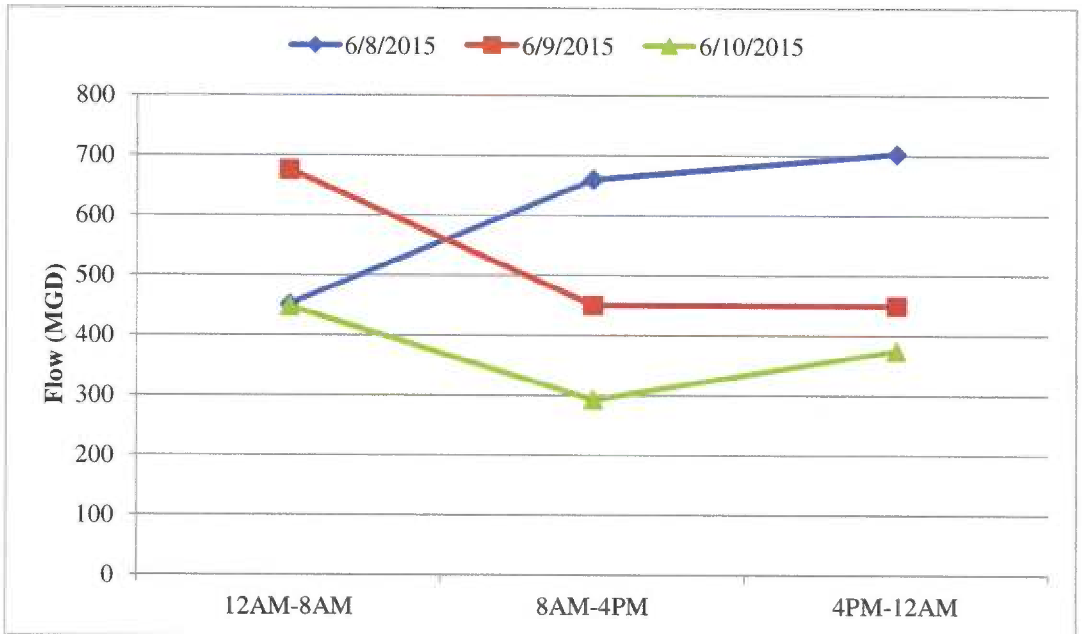
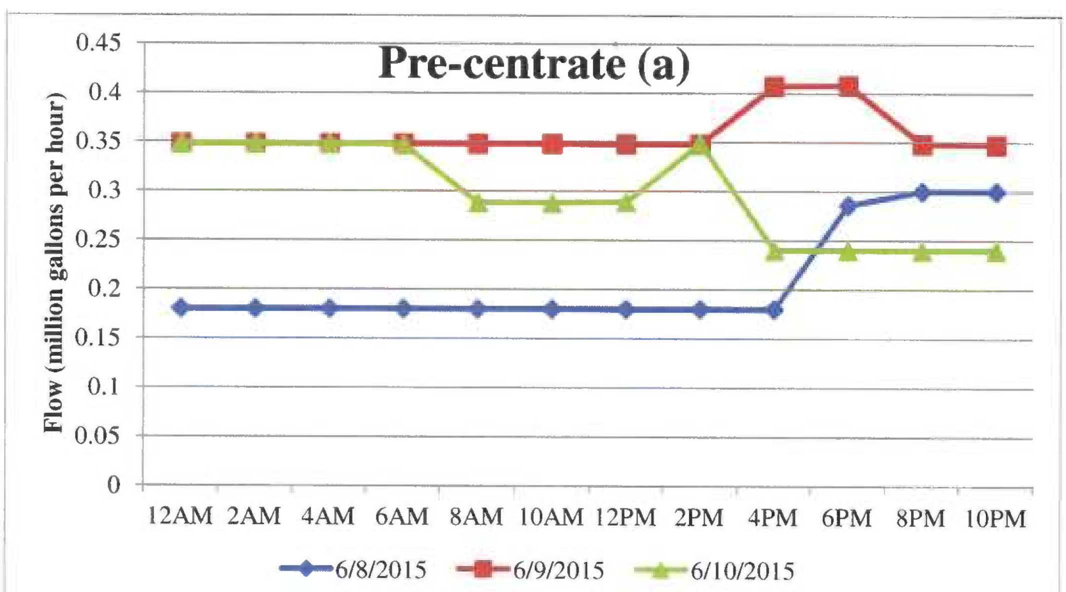


Figure 9 shows the average Southwest Side influent flow from each shift during the discrete sampling period of June 8, 2015, through June 10, 2015. The average Southwest Side influent flows could vary 200 MGD between shifts.

FIGURE 10: PRE-CENTRATE BIHOURLY (A) AND POST-CENTRATE (B) HOURLY FLOWS



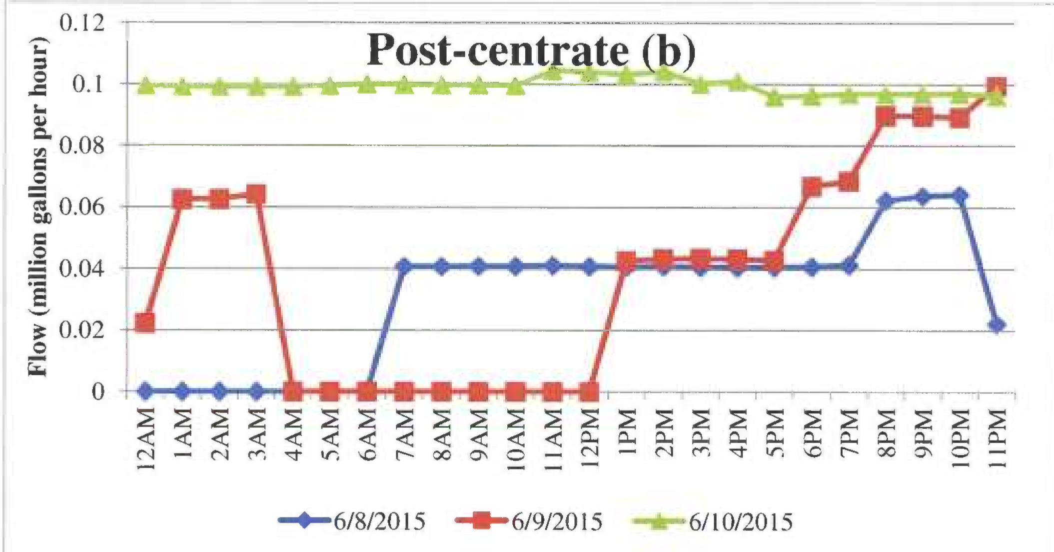


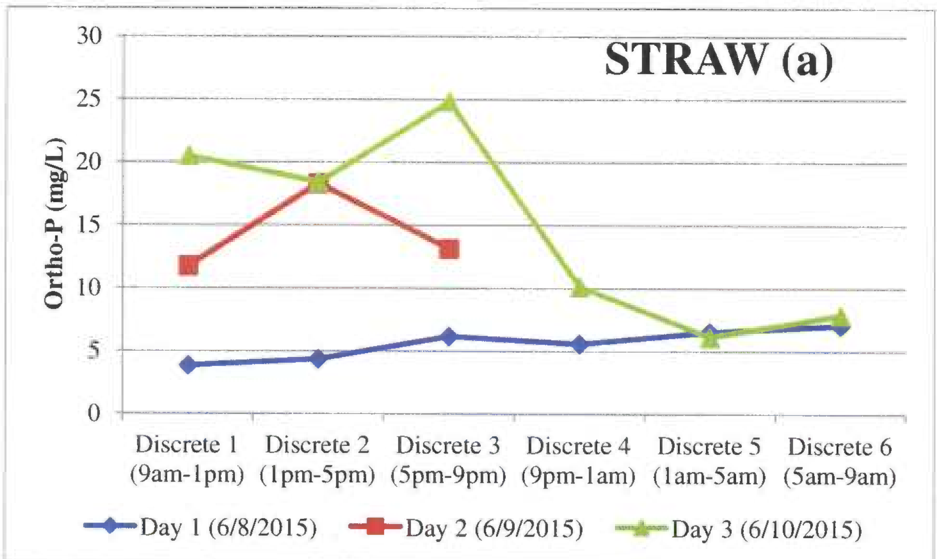
Figure 10 shows the hourly or bi-hourly flow of pre-digestion centrate (a) and post-digestion centrate (b). The other three recycle streams were only recorded on a daily basis; the daily flows from these streams are summarized in Table 10 during the discrete sampling period.

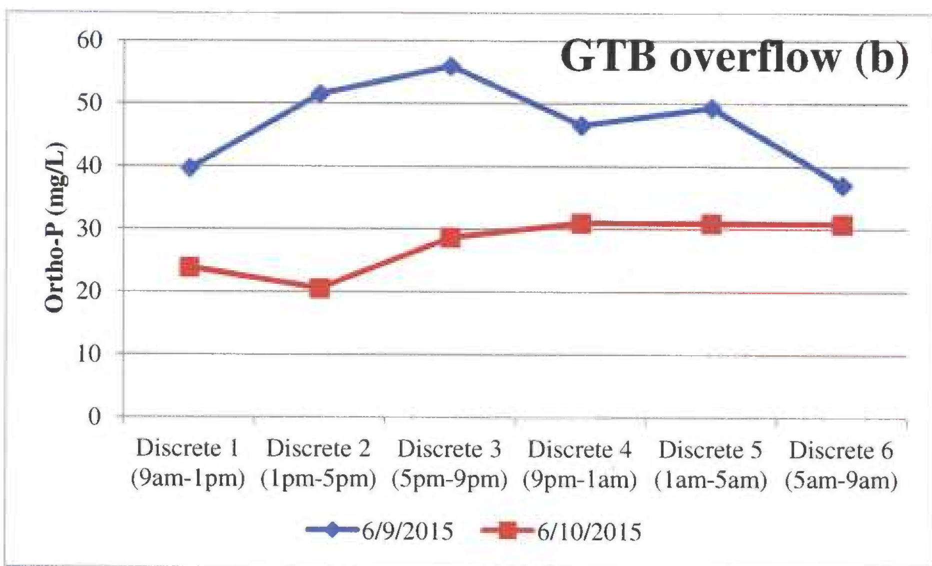
TABLE 10: FLOW DATA OF LAWNDALE AVENUE SOLIDS MANAGEMENT AREA, GRAVITY CONCENTRATION TANKS AND GRAVITY THICKENING BUILDING OVERFLOW FROM JUNE 8, 2015, THROUGH JUNE 10, 2015

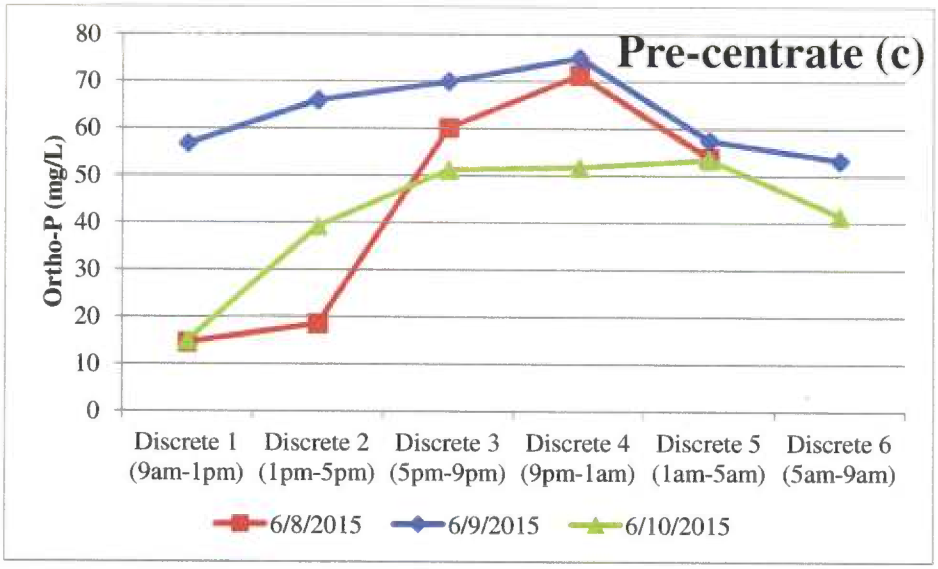
Date	Flow, MGD		
	LASMA	GTB Overflow	GCT Overflow
06/08/2015	0.2	8.0	9.1
06/09/2015	1.4	7.8	15.0
06/10/2015	0.5	NR	14.2

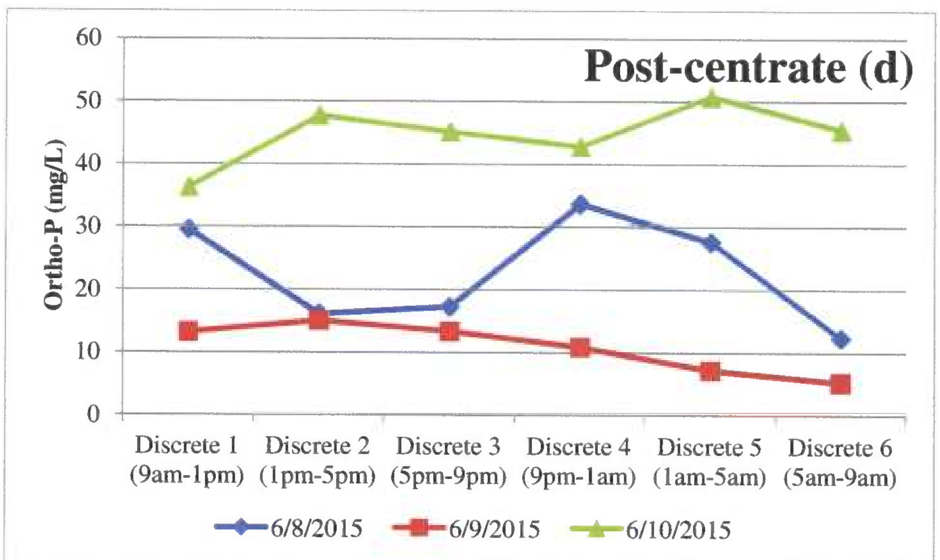
NR: Not recorded.

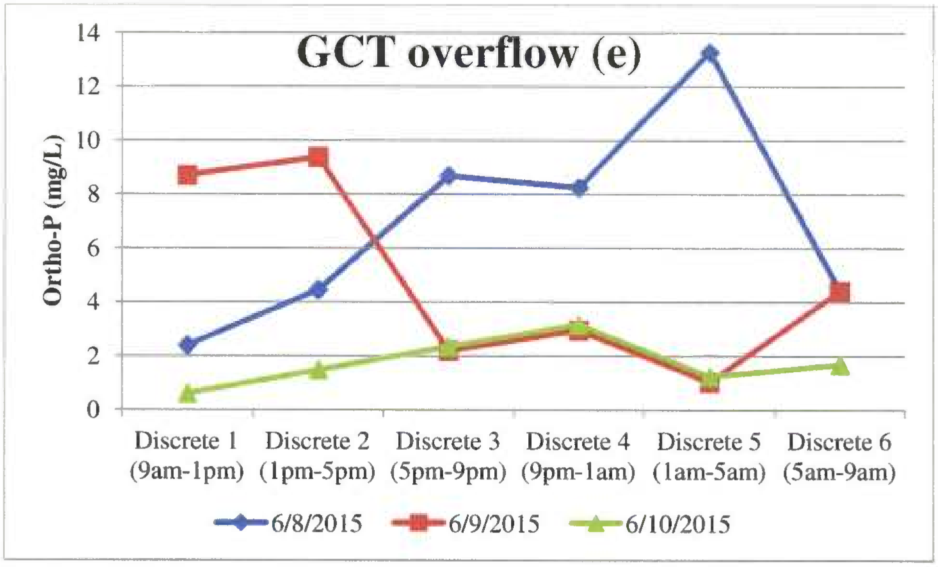
FIGURE 11: DIURNAL ORTHOPHOSPHATE CONCENTRATIONS OF SOUTHWEST SIDE RAW SEWAGE (A), GRAVITY THICKENING BUILDING OVERFLOW (B), PRE-CENTRATE (C), POST-CENTRATE (D), GRAVITY CONCENTRATION TANK OVERFLOW (E) AND LAWNDALE AVENUE SOLIDS MANAGEMENT AREA (F) FROM JUNE 8, 2015, THROUGH JUNE 10, 2015






Pre-centrate (c)
Ortho-P (mg/L)
80
70
60
50
40
30
20
10
0
Discrete 1 (9am-1pm)
Discrete 2 (1pm-5pm)
Discrete 3 (5pm-9pm)
Discrete 4 (9pm-1am)
Discrete 5 (1am-5am)
Discrete 6 (5am-9am)
6/8/2015
6/9/2015
6/10/2015


Post-centrate (d)
Ortho-P (mg/L)
60
50
40
30
20
10
0
Discrete 1 (9am-1pm)
Discrete 2 (1pm-5pm)
Discrete 3 (5pm-9pm)
Discrete 4 (9pm-1am)
Discrete 5 (1am-5am)
Discrete 6 (5am-9am)
6/8/2015
6/9/2015
6/10/2015



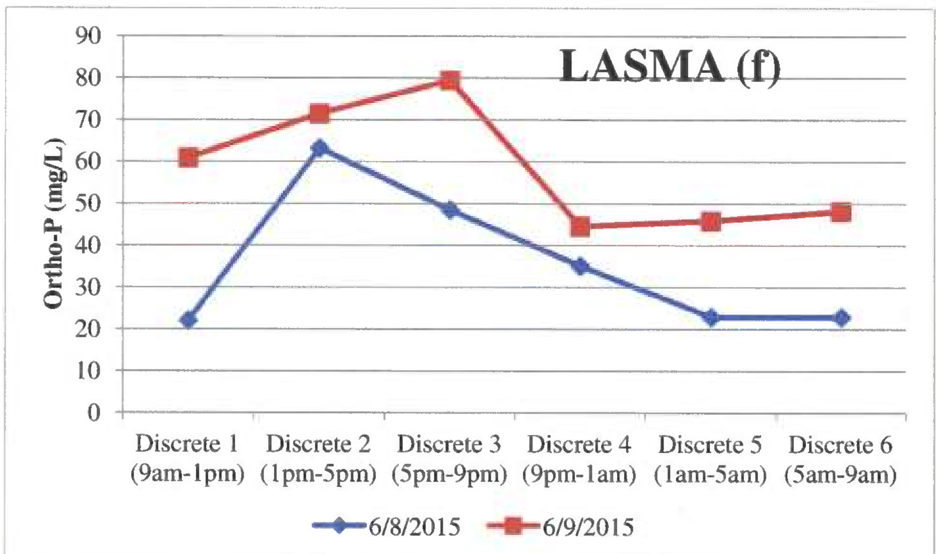
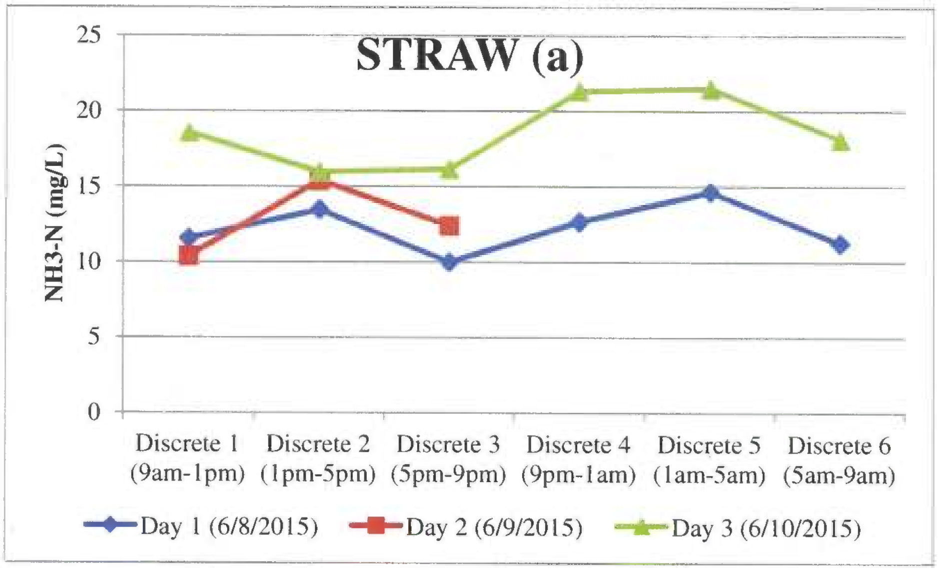
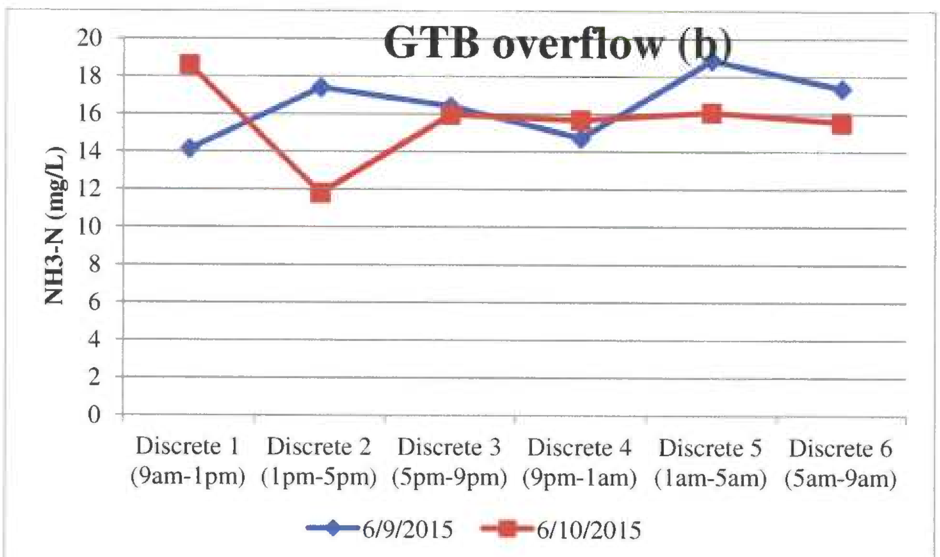
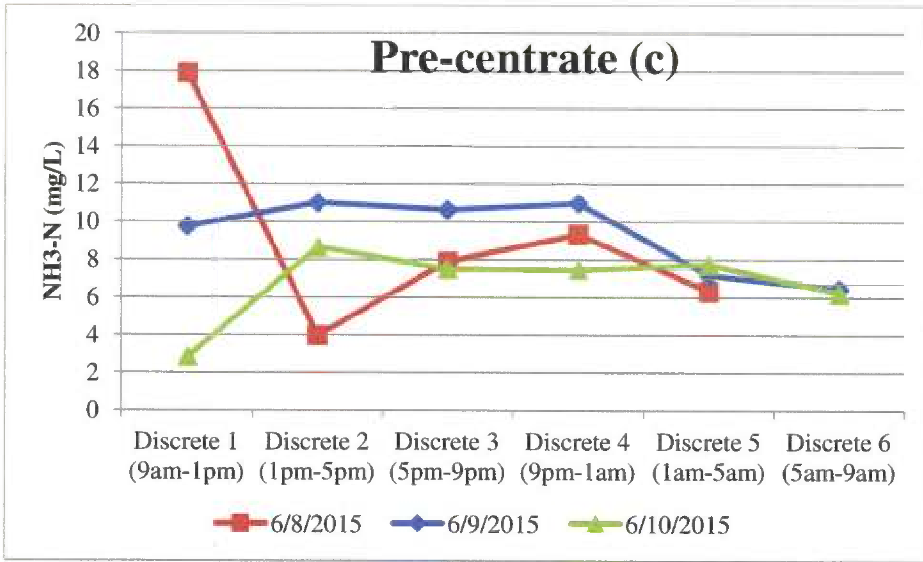


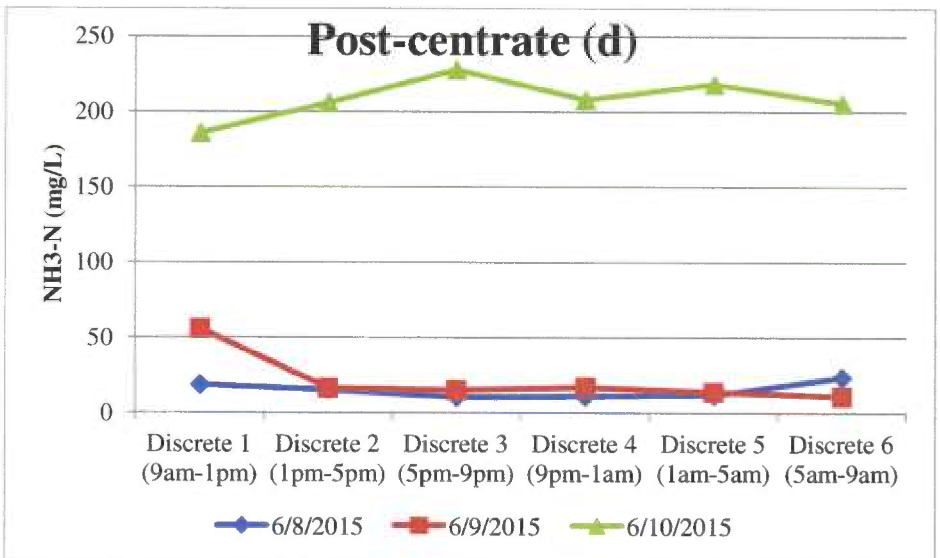
Figure 11a–f shows the ortho-P concentrations in the Southwest Side raw and each recycle stream. No clear diurnal patterns of ortho-P concentrations were found in the three-day study, except pre-centrate seemed to reach higher ortho-P concentrations between 9 p.m. and 1 a.m. In other words, the plant recycle stream flows as well as ortho-P and NH_3-N loads back to plant headwork did not fluctuate in noticeable diurnal patterns during the study period. However, theoretically the recycle streams may need more stability to avoid sudden changes from day-to-day operations.

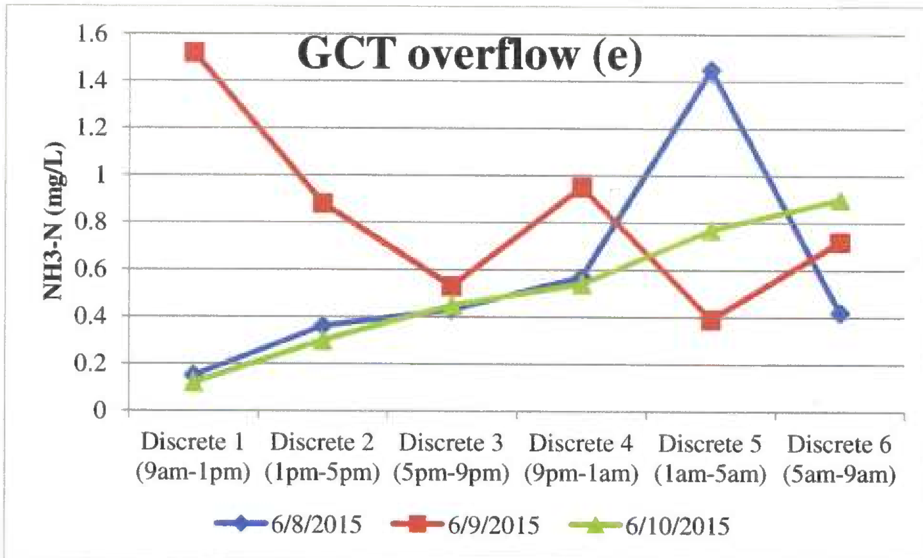
FIGURE 12: DIURNAL AMMONIA NITROGEN CONCENTRATIONS OF SOUTHWEST SIDE RAW SEWAGE (A), GRAVITY THICKENING BUILDING OVERFLOW (B), PRE-CENTRATE (C), POST-CENTRATE (D), GRAVITY CONCENTRATION TANK OVERFLOW, (E) AND LAWNDALE AVENUE SOLIDS MANAGEMENT AREA (F) FROM JUNE 8, 2015, TO JUNE 10, 2015






Pre-centrate (c)
NH3-N (mg/L)
20
18
16
14
12
10
8
6
4
2
0
Discrete 1 (9am-1pm)
Discrete 2 (1pm-5pm)
Discrete 3 (5pm-9pm)
Discrete 4 (9pm-1am)
Discrete 5 (1am-5am)
Discrete 6 (5am-9am)
6/8/2015
6/9/2015
6/10/2015


Post-centrate (d)
NH3-N (mg/L)
250
200
150
100
50
0
Discrete 1 (9am-1pm)
Discrete 2 (1pm-5pm)
Discrete 3 (5pm-9pm)
Discrete 4 (9pm-1am)
Discrete 5 (1am-5am)
Discrete 6 (5am-9am)
6/8/2015
6/9/2015
6/10/2015



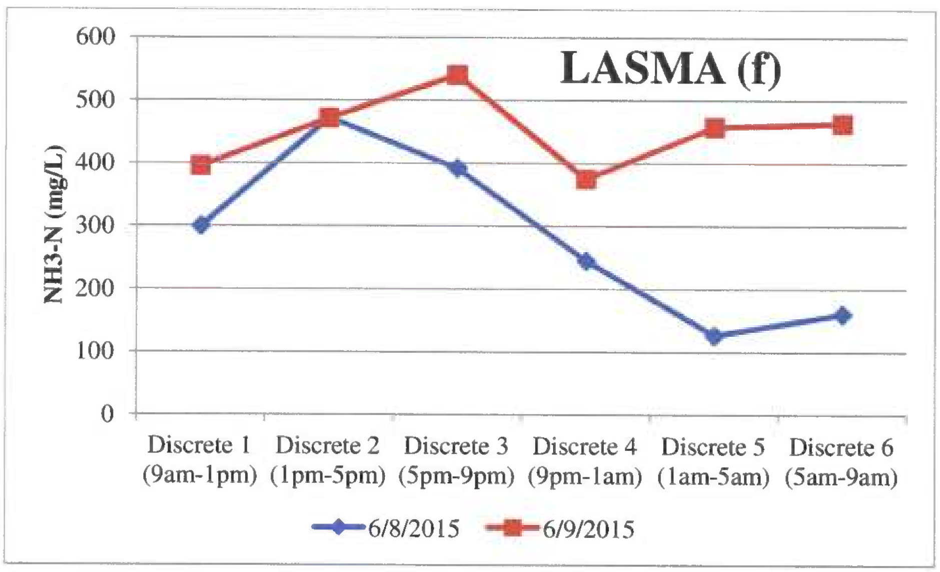


Figure 12 shows the NH_3-N concentrations in the Southwest Side raw and each recycle stream.

No diurnal patterns of NH_3-N concentration were found in the three-day study. Similarly, no diurnal patterns of SS, VFA or solCOD concentrations were found in the five recycle streams during the three-day study.

NH_3-N to ortho-P ratios in Recycle Streams.

Statistical analyses were conducted to find relations between ortho-P (Y) and NH_3-N (X) concentrations. GCT overflow and new GTB overflow streams were found not to have good relations between ortho-P and NH_3-N concentrations, with an R-square less than 50 percent. The post-centrate was found to have a relation of ortho-P = $16.517+0.111 \cdot NH_3$-N, with an R-square of 89 percent. The LASMA stream was found to have a relation of ortho-P = 0.111 · NH_3-N, with an R-square of 97 percent. The pre-centrate stream was found to have a relation of ortho-P = 23.939 · log(NH_3-N) -2.6 · log(NH_3-N) · log(NH_3-N) with an R-square of 93 percent. The results show that post-centrate and LASMA streams have a very good relationship between ortho-P and NH_3-N concentrations; therefore, one concentration can be used to predict the other non-reported concentrations.

Conclusions

Based on the study, the following conclusions can be drawn:

- From high to low, the average recycle stream flows at the Stickney WRP during the study period were GCT overflow, followed by GTB overflow, pre-centrate, LASMA, and post-centrate.

- From high to low, the average ortho-P concentrations observed in recycle streams during the study period were post-centrate, followed by LASMA, pre-centrate, GTB overflow, and GCT overflow.

- From high to low, the average ortho-P loads in recycle streams during the study period were GTB overflow, followed by pre-centrate, GCT overflow, LASMA, and post-centrate.

- From high to low, the average NH_3-N concentrations observed in recycle streams were LASMA, post-centrate, pre-centrate, GTB overflow, and GCT overflow, respectively.

- From high to low, the average NH_3-N loads in recycle streams were LASMA, post-centrate, GTB overflow, pre-centrate, and GCT overflow, respectively.

- GTB overflow was the biggest SS load contributor to the STRAW, followed by GCT overflow, pre-centrate, LASMA, and then post-centrate.

- GTB overflow was the highest VFA load contributor to the STRAW, followed by GCT overflow, pre-centrate, LASMA, and then post-centrate. Currently the VFA production in GTB overflow is unable to be further optimized due to operational limitations. However, upon conversion of two GTB tanks to fermentors, VFA production in GTB can be optimized and supplied as carbon source for sustainable EBPR at SWRP.

- No diurnal patterns were found in any recycle stream's ortho-P and NH_3-N load during three days' study. In other words, the plant recycle stream flows, as well as ortho-P and NH_3-N loads back to the plant headworks, did not fluctuate in noticeable diurnal patterns, but theoretically may need more stability to avoid sudden changes from day-to-day operations.

- Good relationships were found between ortho-P and NH_3-N concentrations in post-centrate and LASMA. Regression analysis indicated that when ortho-P increased, NH_3-N increased in both streams.

- Statistical analysis shows that the outfall ortho-P concentrations were positively affected by the outfall ortho-P from the previous day as well as the percent ortho-P load from recycles in STRAW. The outfall ortho-P follows the same trend as the ortho-P concentrations from the previous day, i.e. if ortho-P in the effluent has been increasing, the ortho-P on the following day would increase as well. When the portion ortho-P load from recycles in STRAW increased, the outfall ortho-P concentration increased.

- Higher ammonia concentrations in STRAW were correlated to an increased portion of NH_3-N concentrations from the recycle streams. Additionally, these higher NH_3-N concentrations in STRAW are associated with higher nitrate in the plant effluent, which is returned to the aeration tanks via RAS, placing an extra demand on C for denitrification and could imbalance the EBPR process.