METRO WASTEWATER RECLAMATION DISTRICT

MEMORANDUM

TO: Jim McQuarrie, Operations Officer **DATE:** September 29, 2014

FROM: Edyta Stec-Uddin, O&M Engineer IV

SUBJ: Primary Clarifier Evaluation

1. BACKGROUND

Primary clarification performance is important as it determines the loading to secondary treatment. Understanding the means to improve primary clarification and control loading on secondary processes is valuable. Developing guidelines for taking primary clarifiers offline and understanding the optimal operating parameters is critical to performance.

This document will focus on developing an approach to optimize primary clarification. This includes taking clarifiers offline or placing additional clarifiers online, and how this affects overall performance and the use of chemical addition (Enhanced Primary Clarification) to enhance primary clarification.

This memorandum will first provide an overview of primary treatment at the RWHTF including the physical facilities and their current performance, and primary treatment mass balance. The key operational parameters for optimizing primary treatment will then be discussed, followed by a discussion of the impact EPC can have in further enhancing primary clarification and phosphorus removal. Tools have been developed to assist Treatment in optimizing primary treatment and these tools will be briefly described. Finally, recommendations will be provided for future optimization of primary treatment.

2. PRIMARY TREATMENT OVERVIEW

Primary treatment of wastewater involves the separation and removal of suspended solids and floatables by physical-chemical methods. The most common form of primary treatment is sedimentation with skimming, and collection and removal of settled primary solids and skimmed floatables. Enhanced sedimentation methods are also used to provide relief during high seasonal loading variations, limited hydraulic capacity, or to decrease downstream loading. The most common method of enhanced sedimentation is chemically enhanced primary treatment. Conventional primary clarifiers remove 50 to 70% TSS and 25 to 40% of the COD or BOD.

Implementation of Enhanced Primary Clarification (EPC) increases BOD removal from 25 to 40% to 40 to 70%.

Table 2.1 provides typical removal rates for TSS, COD or BOD and phosphorus (MOP 8).

Table 2.1 – Typical Primary Treatment Removal Rates.

Primary treatment process	TSS removal (%)	COD or BOD_5 removal (%)	Phosphorus removal (%)	Bacteria removal (%)	Reference
Conventional primary clarifier	50–70	25–40	5–10	50–60	Metcalf and Eddy, 2003; Steel, 1979; U.S. EPA, 1987
Chemically enhanced primary treatment (CEPT)	60–90	40–70	70–90	80–90	Metcalf and Eddy, 2003; Oedegaarde, 2005
CEPT with polishing filters	60–90	40–70	80–90		Metcalf and Eddy, 2003; Jiminez et al., 1999
High-rate clarification	30–95	35–70	70–95		Metcalf and Eddy, 2003; Stevenson et al., 2008
Fine screens or sieves	25–40	25–50			Metcalf and Eddy, 2003

Note: TSS = total suspended solids; COD = chemical oxygen demand; BOD5 = five-day biochemical oxygen demand.

Primary treatment at the Robert W. Hite Treatment Facility (RWHTF) is included in both the North and South treatment trains. The North primary treatment process consists of ten primary clarifiers in three areas: area 1 (NPRI1) with three clarifiers, area 2 (NPRI2) with three clarifiers, area 3 (NPRI3) with four clarifiers. The South primary area (SPRI) includes four clarifiers. Primary sludge is pumped to four gravity thickeners (GVTs). Thin sludge pumping is implemented with the goal to of 1.5% TS. Table 2.2 illustrates the design parameters for each area.

Table 2.2 – Primary Clarifier Design Parameters.

	North Primary Area 1 & 2	**North Primary Area 3**	**South Primary**	**GVTs**
Number of Clarifiers	6	4	4	4
Diameter, ft	158	106	150	60
Volume, MG (per unit)	1.58	0.69	1.64	0.258
Max Month Flow, MGD (per unit)	21	11.9	23.5	2.94
HRT, hr	1.85	1.39	1.66	2.1
SOR, gpd/ft2	1,070	1,350	1,340	1.040

Figures 2.1 and 2.2 illustrate TSS removal rates achieved in the North, the South and overall (including GVT performance) at the RWHTF between June 1, 2012 and April 30, 2014. The North Primary efficiency varied between 54.8 and 79.6%, with a median value of 65.7% throughout this period. The South Primary performance varied significantly, mostly due to the limited mixing at the South Secondary influent sampler. The sampler location has been changed over the years but the results are still not ideal. This problem should be eliminated in 2014 when the new South Secondary complex is on-line and the associated new sampling location is in place. The South Primary efficiency between June 1, 2012 and April 30, 2014 varied between 24.2 and 81.3%, with the median value of 68.2%. Higher removal efficiency achieved between

March and August 2013 and between January 17 and April 28, 2014 was related to the fact EPC was in place.

The combined South and North efficiency varied between 47.2 and 75.0%, with a median value of 66.0%, but steadily improved to around 70% as emphasis was placed on primary treatment optimization.

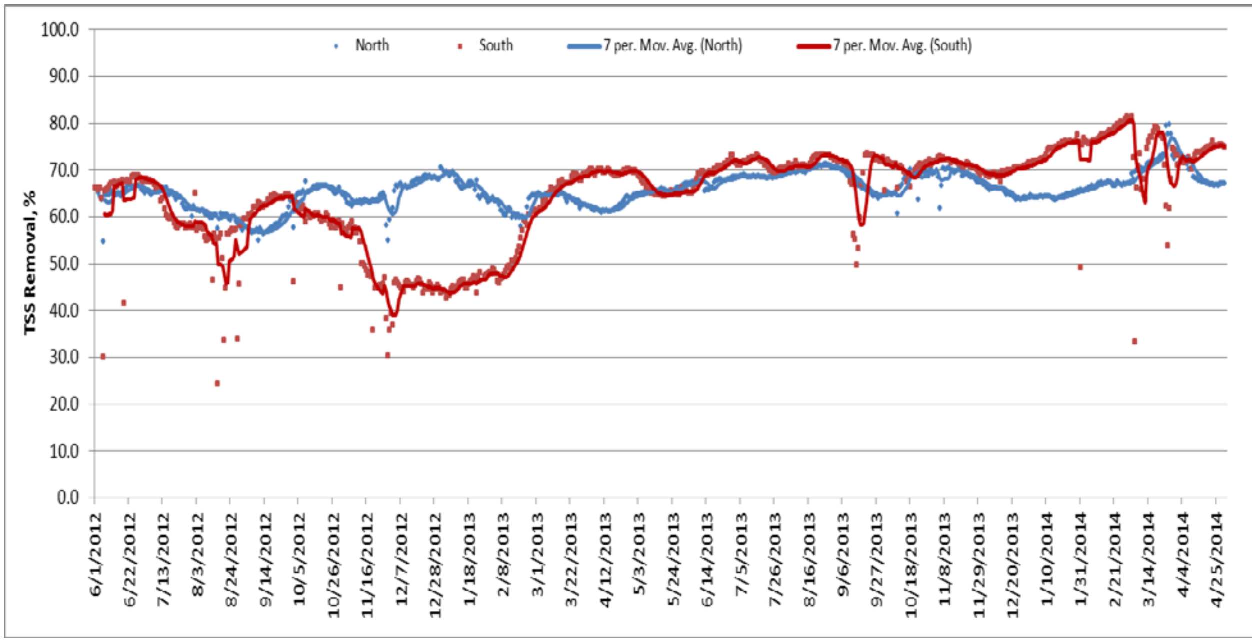


Figure 2.1 – North and South Primary removal efficiency (TSS).

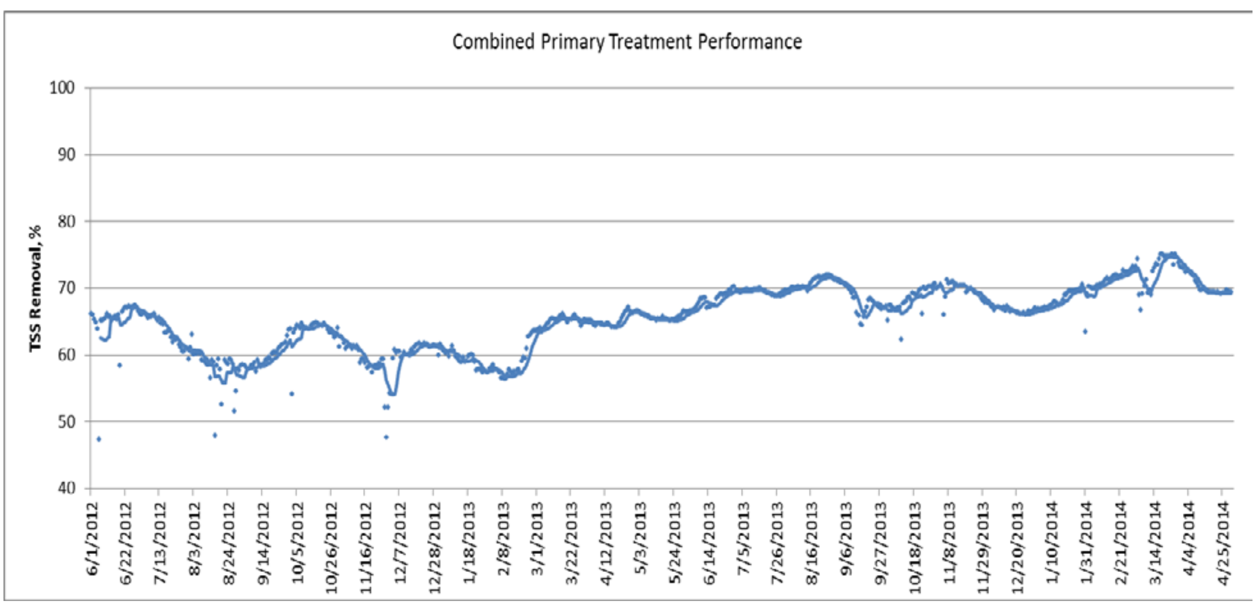


Figure 2.2 – Overall Primary removal efficiency (TSS).

Figure 2.3 illustrates BOD removal rates between July 1 and November 30, 2013 when the optimization efforts were in place. The individual plant BOD removal values varied: the South (high purity oxygen) achieved removal between 7.5 and 50.5%, with the median removal value of 43.3%.

The North Plant's BOD removal varied between 5.4 and 35.9%, with the median value of 24.3%.

The decrease in BOD removal in September 2013 was caused by the process shutdown to accommodate construction activities.

Overall combined BOD removal, during the time when optimization was implemented, varied between 27 and 37%, with the median value of 32%. Overall combined BOD removal values are presented in a figure 2.4.

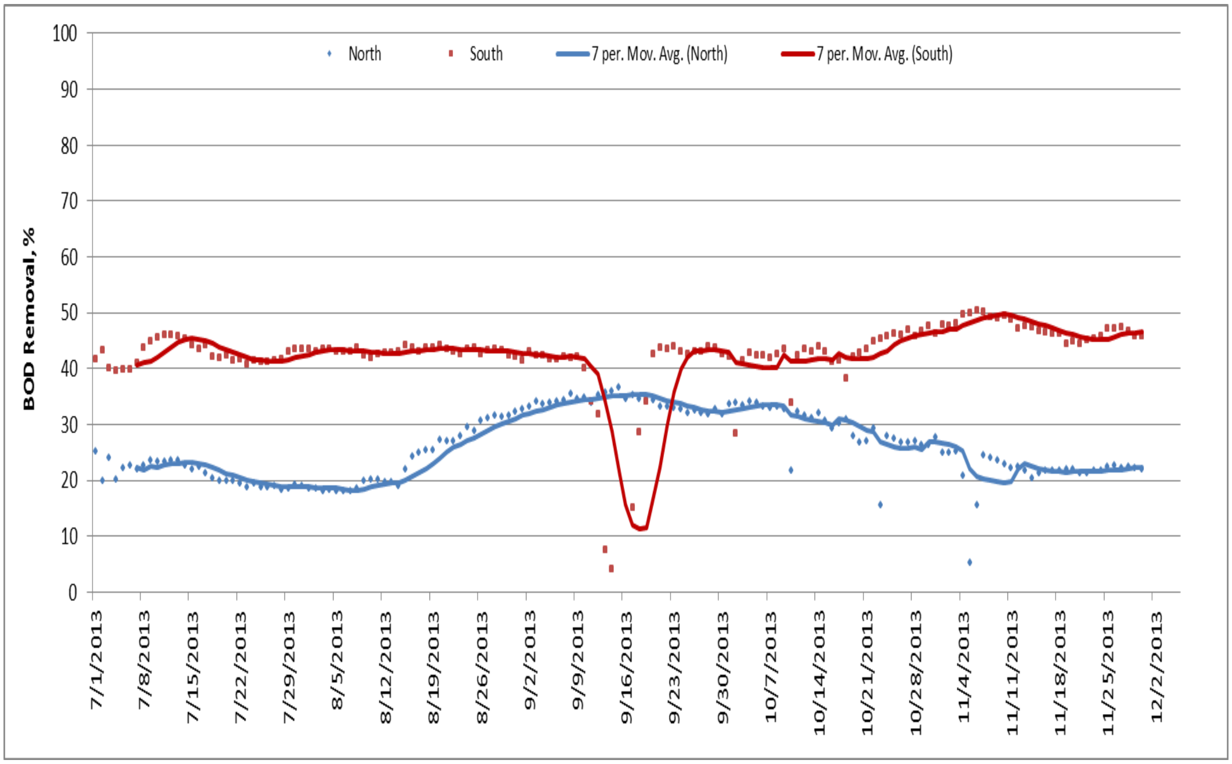


Figure 2.3 – North and South Primary removal efficiency (BOD).

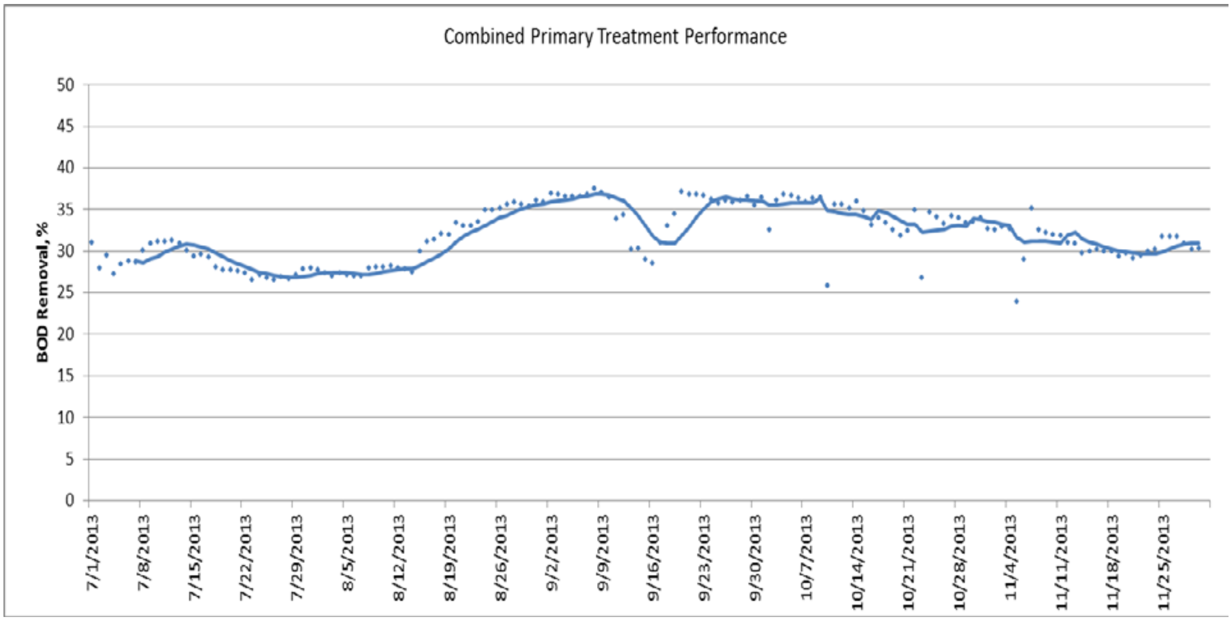


Figure 2.4 – Overall Primary removal efficiency (BOD).

3. OPTIMIZATION OF PRIMARY TREATMENT

There are two ways to improve primary clarifier performance: optimizing clarifier operational parameters, and the addition of chemicals to help with settling (EPC).

3.1 PRIMARY CLARIFIER OPERATIONAL OPTIMIZATION EVALUATION

Primary clarification operational optimization evaluation efforts took place in 2013. The main purpose of this work was to establish optimal clarifier loading criteria and improve understanding and influence of operational set points around primary treatment in order to improve optimum TSS removal performance. Factors considered were SOR, underflow (U/F) rate, and wastewater temperature. Additional efforts included operational control strategy changes: keeping underflow solids density from the primary clarifiers constant, with 1.5% TS targeted. GVTs were used to temporarily store solids; GVT underflow rate was constant with the upper control being blanket level. The underflow rate was based on the influent flow.

The evaluation was focused on the North Primary Treatment complex because the South sampling location will be changed when PAR 1085 (South Secondary Improvements) is complete. The evaluation period was from January 1, 2012 through August 31, 2013. The following parameters were evaluated:

- Influent and effluent TSS,
- Overall % TSS removal,
- Maximum removal rate,
- Surface Overflow Rate (SOR).

The initial overall performance evaluation was based on influent and effluent TSS values. Figures 3.1, 3.2, and 3.3 illustrate influent and effluent TSS values for all three North Primary areas. The effluent values (~100 mg/l) were fairly constant throughout the evaluation period for all three North primary areas. Influent TSS values varied slightly based on the area possibly due to the sampler location and limited mixing at the NPRI3. For the remainder of this document, all three North primary areas will be evaluated together as one unit.

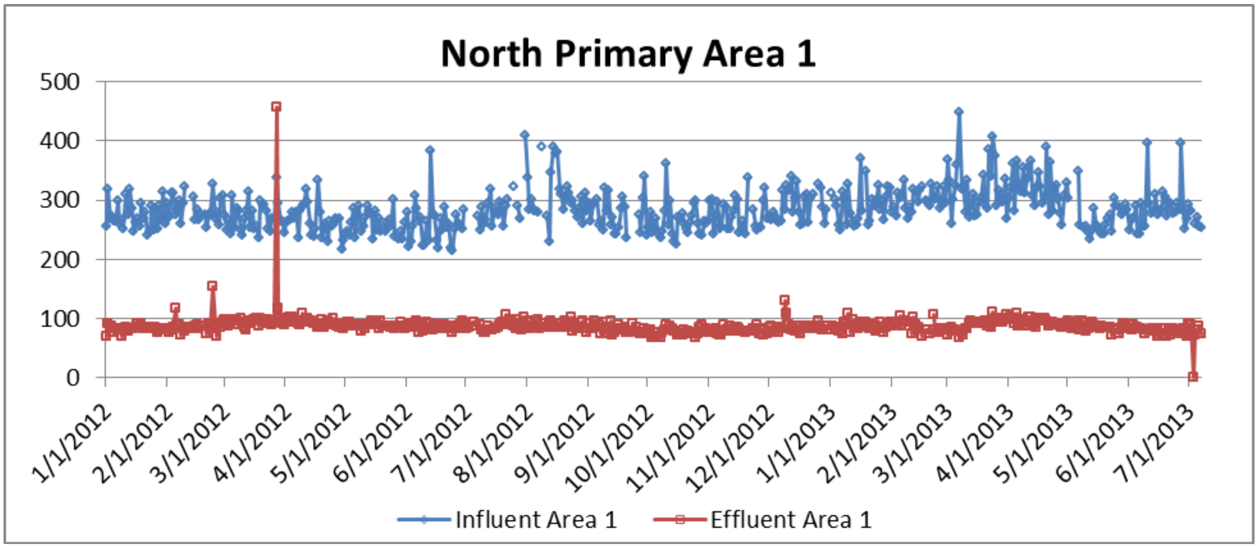


Figure 3.1 – North Primary Area 1 Influent and Effluent TSS values.

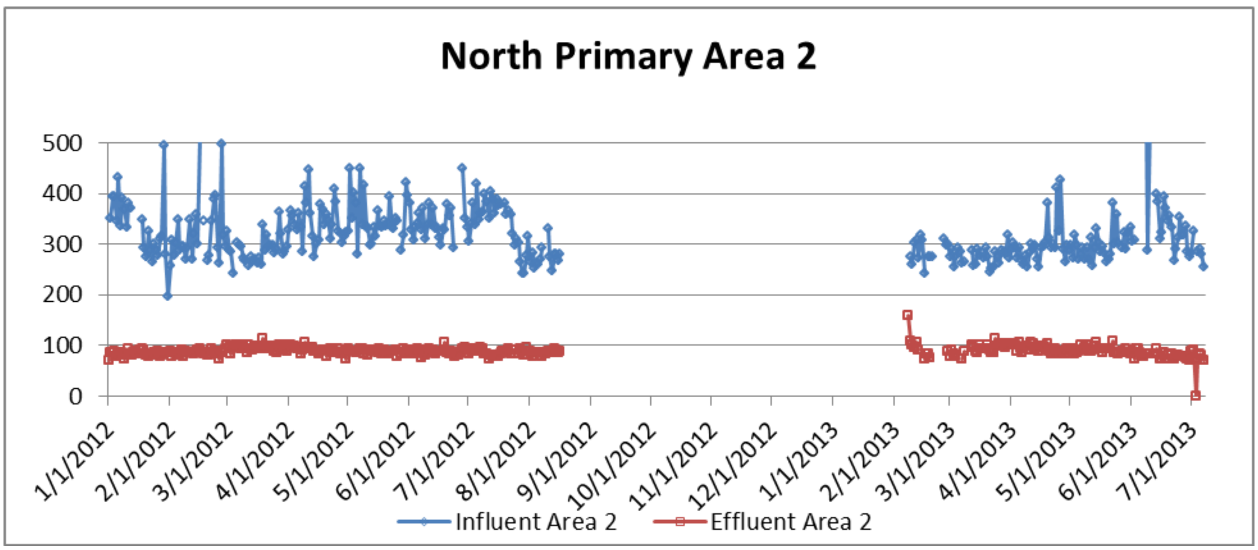


Figure 3.2 – North Primary Area 2 Influent and Effluent TSS values.

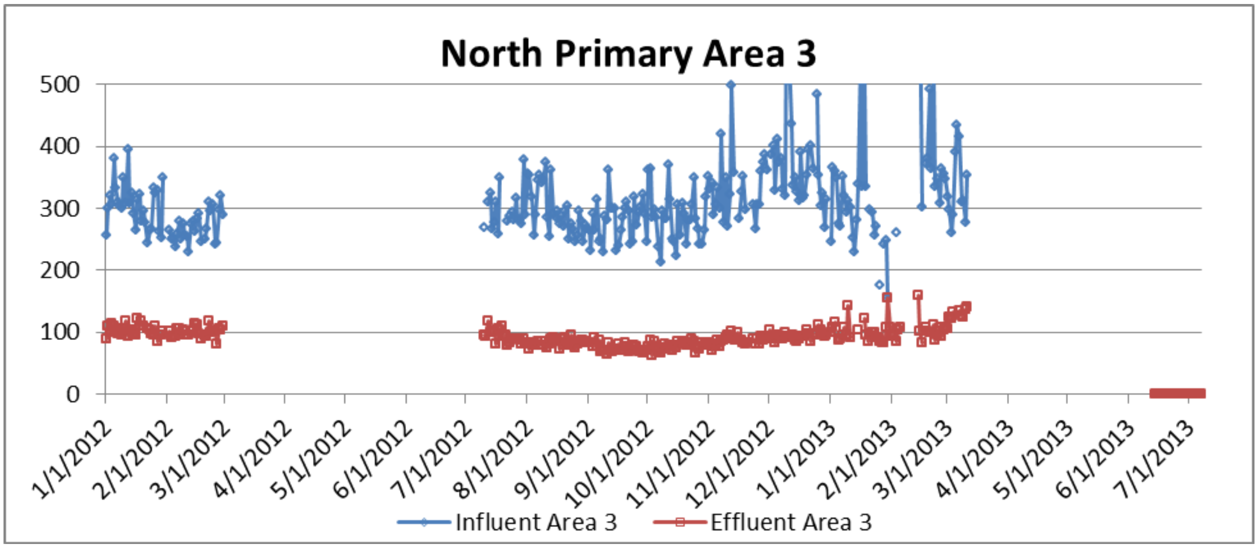
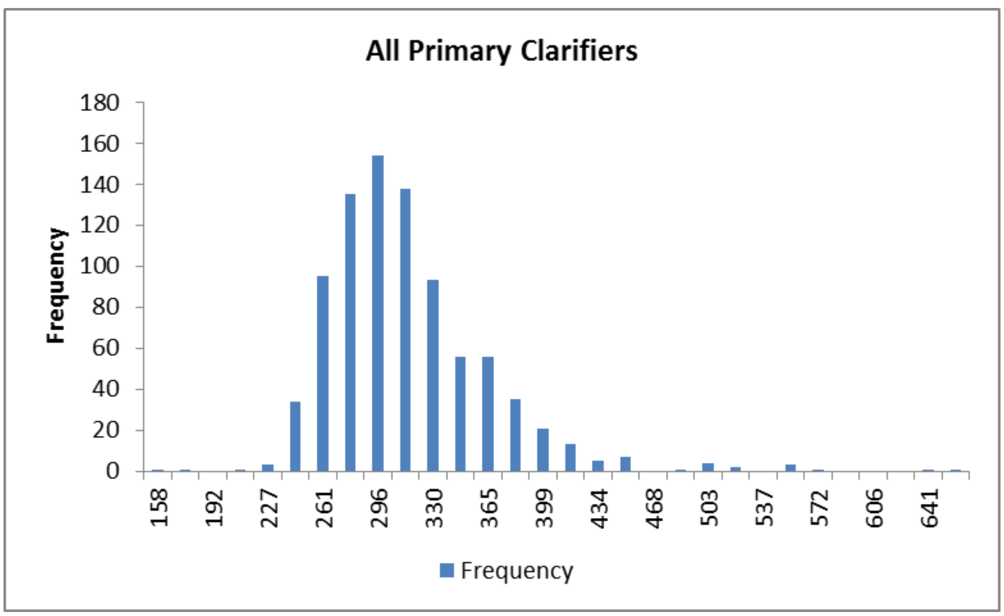


Figure 3.3 – North Primary Area 3 Influent and Effluent TSS values.

3.1.1 INFLUENT TSS FREQUENCY EVALUATION

Throughout the testing period, primary influent TSS values varied between 150 mg/L to 400 mg/L, with values occasionally exceeding 400 mg/L. Figure 3.4 illustrates the statistical influent TSS frequency, indicating the majority of values are between 250 to 350 mg/L, with 300 mg/L being the most frequent value.



3.4 – Primary Influent TSS Frequency.

3.1.2 TSS REMOVAL EVALUATION

Initial efforts were made to determine whether there is a correlation between primary influent TSS and observed removal rate. Figure 3.5 below is a graphical representation of the observed % removal as a function of influent TSS. The theoretical removal rate trendline was added to compare with the actual data. For the most frequent influent TSS value of 300 mg/L, the removal rates varied between 60 and 80%.

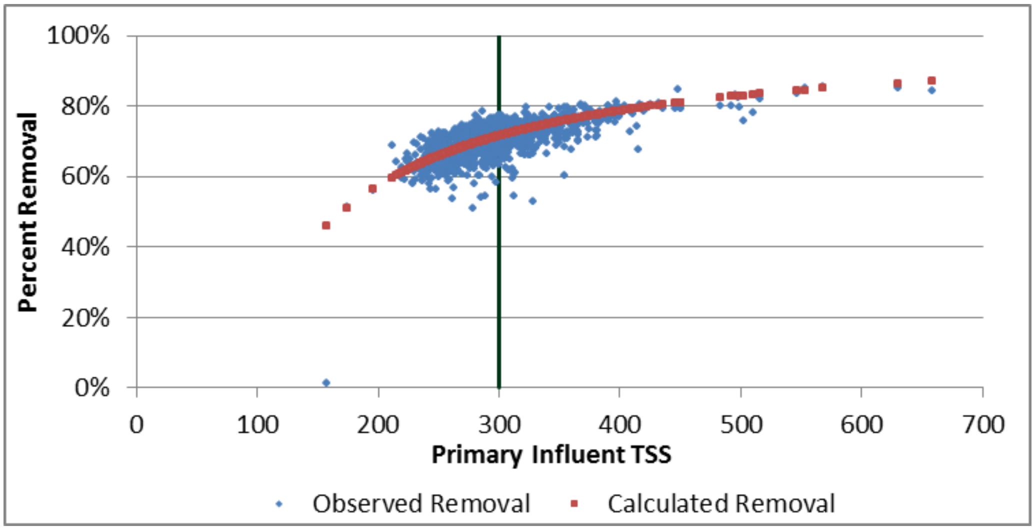


Figure 3.5 – Removal Rates and Influent TSS.

Further evaluation was based on a 2006 WERF report called "Determine the Effect of Individual Wastewater Characteristics and Variances on Primary Clarifier Performance". The report indicated TSS removal efficiency in primary clarifiers is a function of the surface overflow rate (SOR), the influent TSS concentration (TSS_i), the settling parameter (λ), and non-settleable TSS concentration (TSS_{non}).

The ideal primary clarifier effluent concentration will be equal to only the non-settleable TSS in the influent. Primary effluent TSS above the TSS_{non} suggests there is an opportunity to further optimize primary treatment performance. The maximum TSS removal efficiency occurs when the primary effluent TSS is equal to the influent non-settleable TSS. The difference between non-settleable TSS and effluent TSS indicates primary clarifier inefficiency.

The following parameters were calculated to evaluate primary clarifier efficiency at the RWHTF and to establish the optimal operating range:

- Non-settleable TSS,
- Specific settling parameter (λ),
- Maximum theoretical TSS removal rates,
- Effects of SOR on the percent removal for various removal rates,
- Effects of SOR on the percent removal for various λ.

Based on the results, performance sensitivity to SOR can be predicted.

3.1.3 NON-SETTLEABLE TSS AND SPECIFIC SETTLING PARAMETER

It is established that the non-settleable TSS fraction is assumed to be constant for a given wastewater to conduct the analysis. The first step to establish the optimal operating range is determining the non-settleable TSS value. Data from January 2012 to August 2013 was used to obtain the non-settleable TSS value. This value was obtained by using the least squares method of the curve fitting available from Excel, primary influent (TSS_{pi}), and primary effluent (TSS_{eff}) TSS values. The non-setteable TSS (TSS_{non}) value of 82 mg/L was established.

The second step included the settling parameter (λ) calculation. The value of λ is specific to the solids and raw wastewater characteristics and is measured in gpd/ft^2. λ characterizes wastewater settling. The λ value was estimated using the least square method curve fitting and resulted in a λ value of 3,230 gpd/ft^2. This value was used for the remainder of this evaluation.

3.1.3 MAXIMUM TSS REMOVAL

Using the non-settleable TSS and λ values described above, the maximum TSS removal rate (E_{TSSmax}) was calculated using Equation 3.1.

(Eq. 3.1) $E_{TSSmax} = 1 - (TSS_{non}/TSS_{pi})$

Estimated effluent TSS removal concentrations (E_{TSS}) as a function of SOR were then calculated using Equation 3.2.

(Eq. 3.2) $E_{TSS} = E_{TSSmax} * (1 - e^{(-\lambda/SOR)})$

Based on 300 mg/L (the most frequent influent TSS value), the maximum TSS removal rate is 72.6%. The estimated removal based on the maximum removal value and SOR values ranging between 700 and 1,000 gpd/ft^2 are presented in Table 3.1.

Based on these results, removal rates around 70% should be expected. Otherwise, the Plant Operator should review operating targets against actual conditions and make an assessment that all primary treatment equipment is functioning properly.

Table 3.1 – Estimated TSS Removal Rates.

	SOR, gpd/ft^2	% TSS Removal
1	700	73.3
2	800	71.3
3	900	70.6
4	1,000	69.7

3.1.4 SENSITIVITY ANALYSIS

Additional sensitivity analyses were performed to evaluate how different λ values effect % removal based on different SORs. For this evaluation, the maximum removal rate of 70% was used. Figure 3.6 shows the % TSS removal for λ values of 2,500, 3,500 and 4,500 gpd/ft^2. Based on these curves, operating clarifiers at SOR values 700 gpd/ft2 and below in general does not add value, while operating at 1,000 gpd/ft^2 or above will cause significant performance decrease.

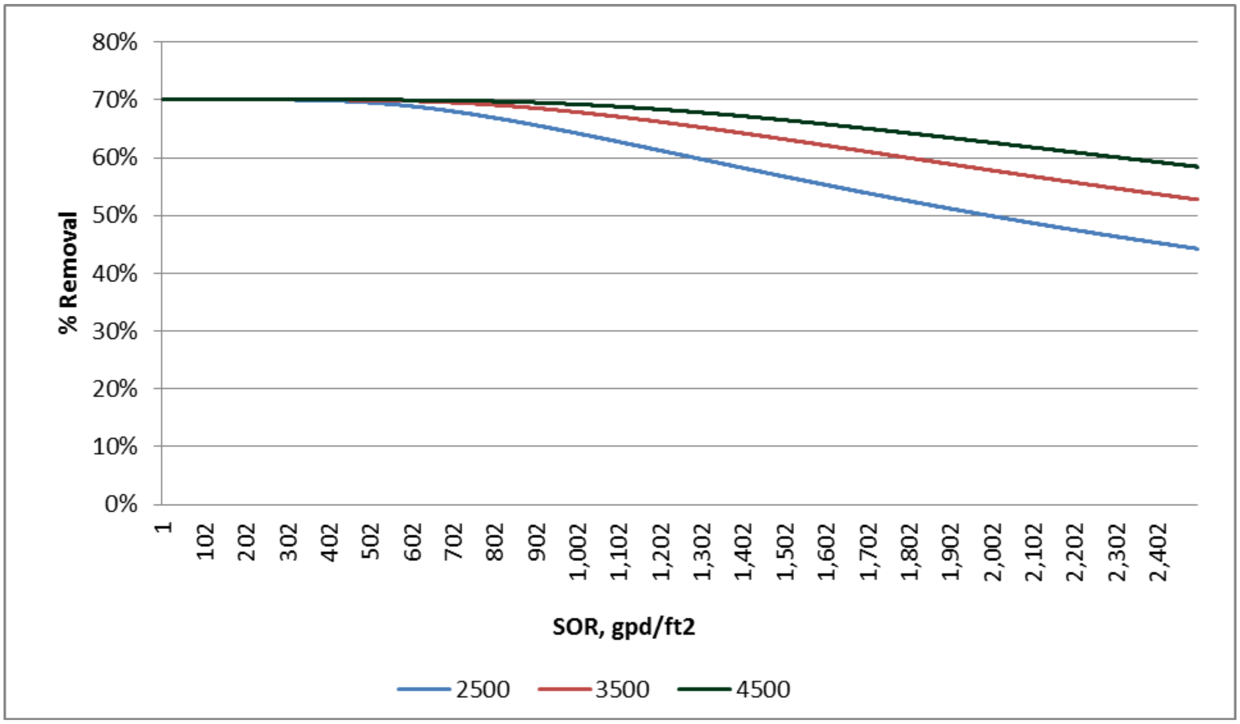


Figure 3.6 - Removal Rate as a Function of SOR for Various λ Values.

Figure 3.7 illustrates performance sensitivity curves for three maximum removal values: 60, 70, and 80%. Based on these values, the optimal SOR operating range is between 700 and 1,000 gpd/ft^2. Operating primary clarifiers at SOR values below 700 gpd/ft2 does not provide any additional performance improvements, while on the other end, operating above 1,000 gpd/ft2 will cause the removal rate to decrease at a high rate.

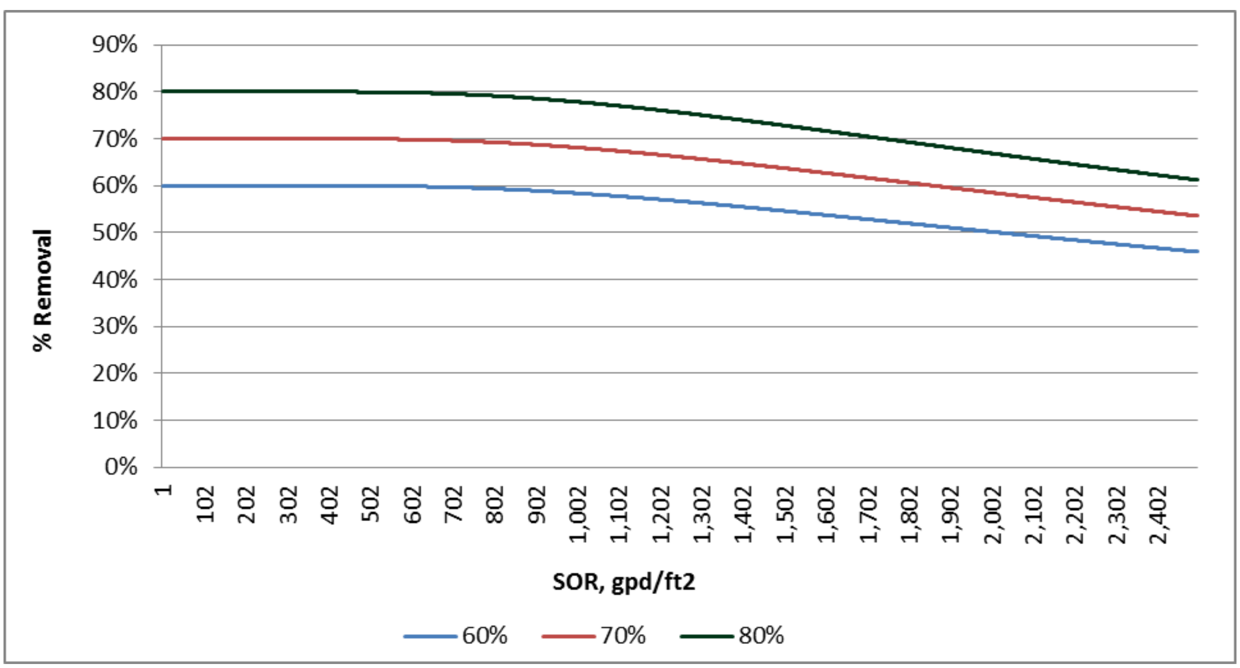


Figure 3.7 – Removal Rate as a Function of SOR for Various Maximum Removal Rates.

Both sensitivity analyses concur that the recommended SOR values should be between 700 and 1,000 gpd/ft^2. This conclusion, however, disregards the influence of temperature. The hypothesis can be communicated by suggesting that higher SOR values (1,000 gpd/ft^2) might want to be targeted during the warm water temperature months when the impact of viscosity on particle settling velocity is less pronounced and rate of hydrolysis on particulate matter is higher. Conversely, lower SOR (700 gpd/ft^2) may be more appropriate during cold temperature months when particle settling velocities are slowed by viscosity.

3.1.5 TEMPERATURE

Temperature plays a major role in primary treatment: higher temperature can cause digestion and possibly odors, while lower temperature may lead to slower settling velocities. Effect of the temperature on settling velocities at typical temperature ranges are illustrated in table 3.2. One can infer from Table 3.2 that a discrete particle settles at a rate 20 percent slower during winter (15° C) than it would during summer (23°C).

Table 3.2 – Temperature Effect on Settling Velocity.

Temperature	Viscosity	Settling velocity
^{0}C	cPoise	ft/hr
10	-1.3070	0.49320
15	-1.1404	0.56520
18	-1.0540	0.61200
20	-1.0050	0.64080
25	-0.8937	0.72000

Figure 3.8 illustrates annual variations of the wastewater temperatures for 2009 through 2013. Temperature varied between 14 and 23°C. Based on these values, two periods can be assumed: the warm weather season generally between end of May and December, and the cold weather season between December and May. To help assure maximum performance and referring back to Figure 3.6, perhaps SORs between 500 and 700 gal/day/ft^2 should be targeted during the cold weather season and SORs between 700 and 1,000 gal/day/ft^2 targeted during the warm weather season.

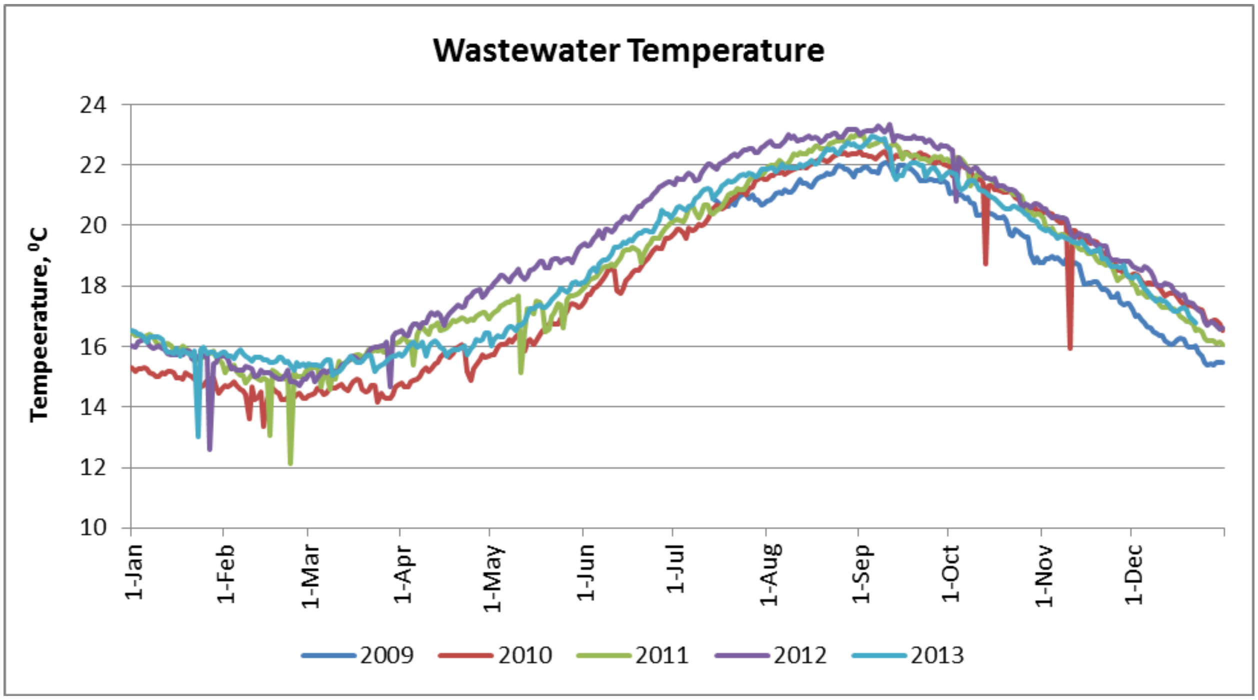


Figure 3.8 – Wastewater Temperature.

3.1.6 POST OPTIMIZATION RESULTS

Prior to the optimization efforts, TSS clarifier effluent was below 100 mg/L 90% of the time as Figure 3.9 illustrates. Post-optimization values were below 90 mg/L 90% of the time. The graph below was created using pre-optimization data size of 534 and post-optimization data size of 341.

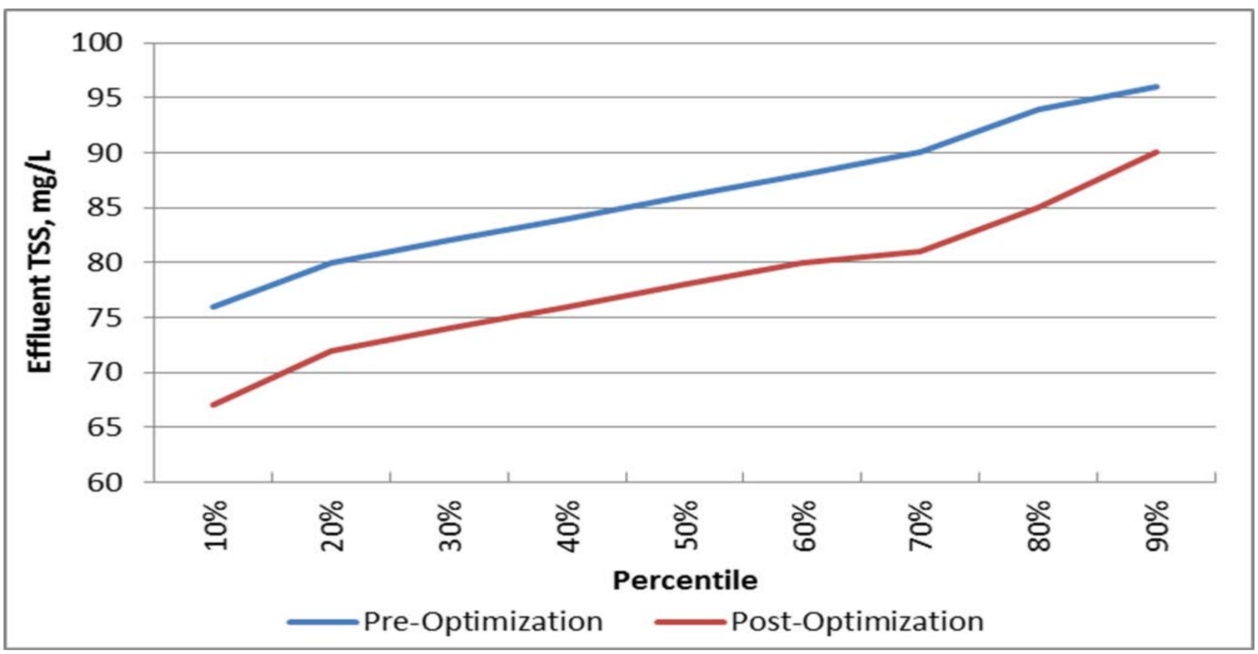


Figure 3.9 – Pre- and post- optimization clarifier effluent TSS values.

3.2 ENHANCED PRIMARY CLARIFICATION EVALUATION

Primary clarifier performance can be further improved by the use of chemicals to enhance sedimentation. The RWHTF has the capability to introduce ferric chloride and polymer to the primary influent flow to enhance primary clarification. At the end of 2012, EPC equipment testing took place. During that time, several deficiencies were discovered, including inoperable equipment and programming errors. By March 2013, these problems were resolved and EPC testing began. Initial polymer and ferric dosing was established in a laboratory. Attachment A contains details of this effort. Based on the laboratory testing, polymer dosing of 1 mg/L and 30 mg/L of ferric chloride were applied.

The main driver behind EPC testing was to prepare for the time when only half of the South Secondary process will be on-line for PAR 1085 modifications. During the 2011/2012 winter, M.Parvicella outbreaks at the North Secondary complex caused poor settling, which reduced North capacity to 68 tons of BOD per day, or 80 MGD flow. Polyaluminum Chloride (PAC) was tested in 2012 and proved to be effective in M.Parvicella elimination but was very expensive. In lieu of M.Parvicella elimination, lowering the BOD loading to the North was considered as another option. The EPC system could be applied to lower the secondary loadings. In order to evaluate whether or not EPC could be a viable option, testing took place in 2013.

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EPC testing started on March 6, 2013 and continued through June 30, 2013. During the testing, 39% strength ferric chloride and anionic polymer were added. Figure 3.8 illustrates TSS removal rates based on ferric chloride addition only between January 1, 2013 and July 1, 2013. Based on Figure 3.8, TSS removal rates increased once ferric addition was in place.

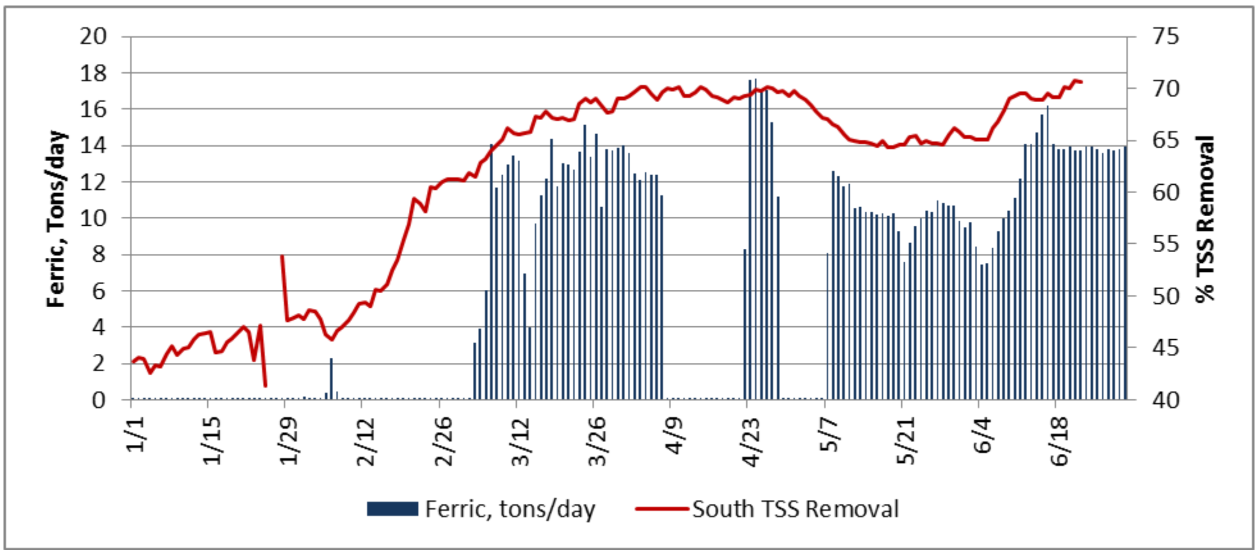


Figure 3.8 – Ferric Chloride Addition and its Effect on %TSS Removal.

Figure 3.9 illustrates the effect of ferric chloride and polymer dosing on the South Primary effluent TSS values. During the times when both chemicals were applied, South Primary effluent TSS values dropped below 100 mg/L. Once polymer addition was suspended and only ferric chloride was applied, TSS values increased by 15-20 mg/L. Based on these observations, it is important to apply both chemicals together to achieve a higher degree of TSS removal.

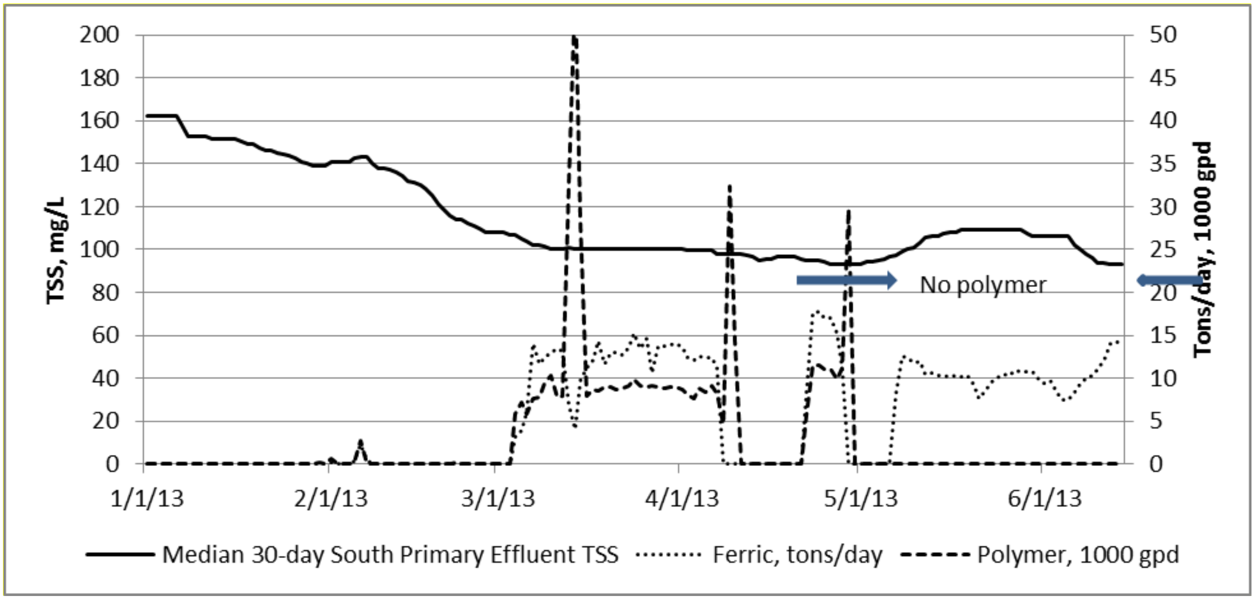


Figure 3.9 – Ferric Chloride and Polymer Dosing Effects on Primary Effluent TSS.

To evaluate additional gas production related to the extra TSS removed, Biowin model runs were performed. Results indicate up to 3% increase in methane gas production related to the additional TSS removal. Results were based on using EPC on the South Primary complex only.

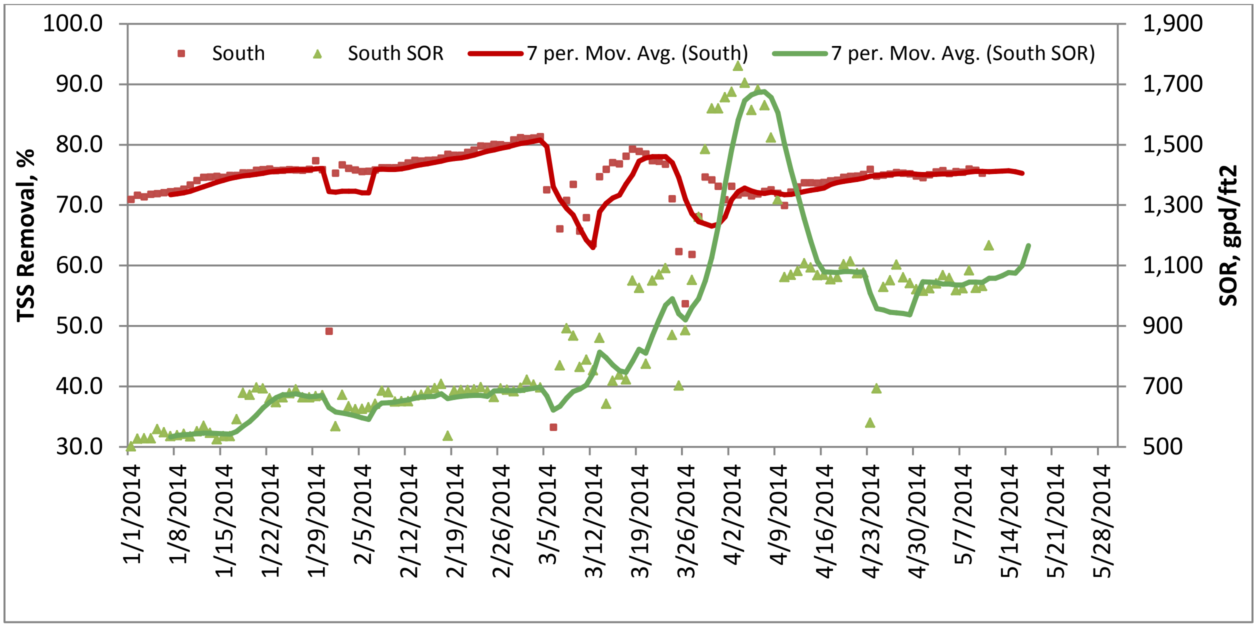
A side effect of ferric chloride addition was that higher levels of iron were detected at the South final effluent and the NPDES South influent samper. To eliminate the effect of ferric chloride dosing on the NPDES sampler, the ferric injection point was relocated downstream of the sampler. This work was finished in September 2013. A separate memo was written to further describe the higher iron levels at the effluent resulting from the ferric chloride addition, and that memo is attached.

3.3. FULL SCALE EPC IMPLEMENTATION RESULTS

3.3.1

In 2014, EPC was used to offload secondary treatment during the construction activities between January 17 and April 28. Figure 3.10 illustrates TSS reduction during the EPC testing period and associated SOR values. During the time period when higher SOR was in place, TSS removal values decreased. The first occurrence happened around March 12, when higher SOR caused dramatic performance decrease. These events happened when the North Plant was experiencing settleability problems and more flow was introduced to the South with no additional primary clarifiers available.

Overall, the performance when EPC was in place increased TSS percent removal to the high 70s. Full scale implementation proved that EPC is a viable option to decrease loading on the secondary processes and can be used on an as-needed basis.



3.10 – TSS and SOR results during EPC testing.

3.3.2 EPC AFFECT ON PHOSPHORUS REMOVAL

In 2014, EPC was used between January 17 and April 28. During that time, a decrease in TSS loading was observed, as well as lower phosphorus levels at the effluent.

Figure 3.11 illustrates total phosphorus values prior to the EPC and post-EPC. During EPC, effluent phosphorus values were generally below 1 mg/L; the excursions occurred when diversions took place on March 5 and March 26.

CDPHE Regulation 85 will most likely establish total phosphorus limit at 1 mg/L as an Annual Median Limit. Between January 17 and April 18, the median result for TP was 0.815 mg/L. Based on these results, ferric chloride addition at primary treatment is sufficient to remove total phosphorus to the required levels and may be used as a secondary means. It is known the amount of ferric needed for EPC is higher than for phosphorus removal; more testing is needed to accurately evaluate ferric dose for phosphorus removal. Ferric was dosed at 30 mg/L as Fe. Molar ratio of iron to total phosphorus ranged between 2.2 and 2.7; with the median value of 2.67. Theoretical molar ratio used for chemical phosphorus removal is 1:1.

3.4 COD FRACTIONATION

In 2012, efforts to evaluate COD fractionation took place. COD fractionation was performed on two sets of primary effluent: one without EPC and one with EPC. Profiling of particulate and colloidal COD was determined using the measured values (COD_T, COD_S and COD_F). Particulate COD (COD_P) was found by subtracting COD_S from the COD_T. The COD_C was found by subtracting the COD_f from the COD_S. These results are summarized in Figure 3.11.

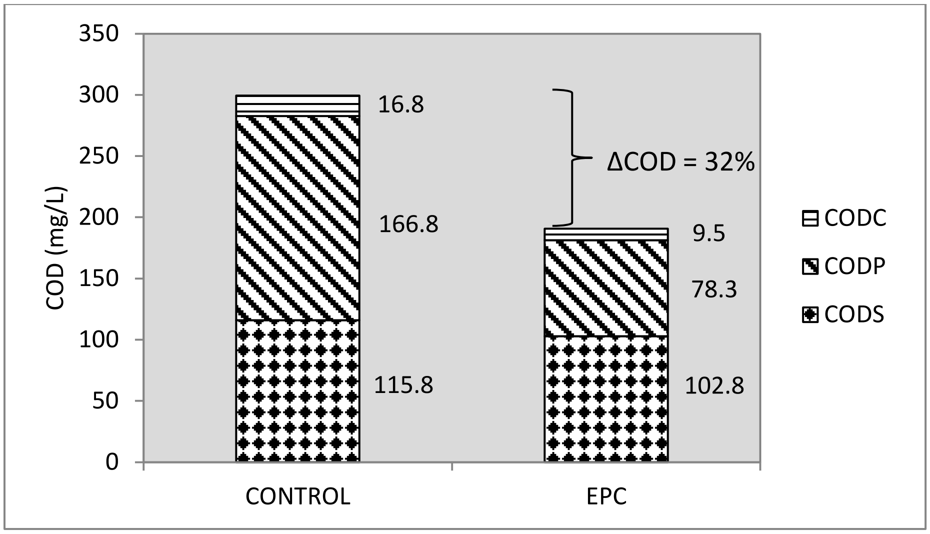


Figure – 3.11 Average COD concentrations in the control (no EPC) and EPC samples of the primary effluent.

Table 3.3 illustrates COD fractionation of the primary influent with and without EPC addition.

Testing was performed in December 2013, with the exception of the Meg's data which was performed in July 2012. The results indicate higher fraction of soluble COD when EPC is in place. Testing results concluded both plant influents have similar COD composition.

Table 3.3 – COD Fractionation Testing Results.

	South 2013		North 2013		South (Meg's) 2012	
	No EPC	EPC	No EPC	EPC	No EPC	EPC
	%	%	%	%	%	%
Colloidal	9	4	10	12	6	5
Particulate	39	31	39	25	55	41
Soluble	52	65	51	63	39	54

4. REPORTING RESULTS AND DOCUMENT LOCATIONS

Currently, an Excel document called "Primary System Removal Efficiency" (shown in Figure 2.1 and 2.2) is used to document TSS removal efficiency for the South and North primary clarification complexes as well as overall plant primary TSS removal. In October, additional SOR information was added to the Excel document. SOR information is tracked to compare to the target range of 700-1,000 gpd/ft^2. This Excel document includes an extensive instruction sheet to document data sources (flow and loading and calculations). This document is used by the Treatment Division for the Weekly Targets and Monthly Reports.

A current version of this document is located on the Treatment M drive (M:\\Treatment\Treatment Spreadsheets\Primary Treatment Mass Balance\Active). The 'Primary Treatment Mass Balance' folder contains four subfolders: Active, Archived, Superseded Versions, and Supporting Documents. The 'Active' subfolder contains the working Excel document and is updated by O&M Technical Services weekly. The ‘Archived’ subfolder contains excel documents archived on a quarterly basis.

The following flows are used to determine primary treatment efficiency:

- NPI Influent: Clear Creek (Fi-F120) + Denver Central (FI-F110) + Platte River (FI-F11) + Sand Creek North (FI-F9) – N/S Primary Diversion (FI-F130) + In Plant Waste (FI-F15)
- SPRI Influent: Sand Creek South (FI-F10) + Globeville (FI_F113) + Republic Paperboard (FI-F5) + N/S Primary Diversion (FI-F130) – Sand Creek North (FI-F9)
- NSEC Influent: Clear Creek (Fi-F120) + Denver Central (FI-F110) + Platte River (FI-F11) + Sand Creek North (FI-F9) – N/S Primary Diversion (FI-F130) + In Plant Waste (FI-F15) – NPRI Effluent Transfer (FI-F510) + GVT Overflow (FY-T710C)
- SSEC Influent: Sand Creek South (FI-F10) + Globeville (FI_F113) + Republic Paperboard (FI-F5) + N/S Primary Diversion (FI-F130) – Sand Creek North (FI-F9) + DAF Subnatant Flow (FI-A380) + NPRI Effluent Transfer (FI-F510).

An additional Excel document called ‘Primary Flows’ was created to help Treatment with decisions on taking clarifiers offline. This document allows inputting the number of primary clarifiers for each area and flows to calculate SOR and determine the impact. The calculated SOR is color coded to easily determine if the result is within limits, under-loaded, or over-loaded.

Additional information regarding the primary clarifier evaluation is located in the ‘Primary Solids Mgmt’ folder on the ‘M:\\Technical Services Group\Workgroup Drive\O&M Support\Treatment\Non-PAR Projects’ folder. This folder contains a ‘2013’ sub-folder with the supporting documentation used for evaluation including ‘Primary Clarifier Removal Efficiency 2013’ Excel document, task planning document, WERF’s study on primary clarification, and other supporting documentation.

Primary evaluation data, mostly related to EPC, performed prior to the year 2012 was consolidated and it is available on M:\\Treatment\Workgroup Drive – Operations\Enhanced Primary Clarification-EPC.

5. RECOMMENDATIONS

The current optimization efforts were based on the North Primary treatment complex performance and South Primary performance was assumed to be the same. Once PAR 1085 is complete and sufficient data is available (at least one year's worth), post evaluation of λ and overall primary treatment performance is recommended.

Maximum efficiency of 70% should be assumed as a goal for treatment when EPC is not in use. Important factors to achieve that goal are:

- SOR of 700 to 1,000 gal/ft2/day during summer months (May through October),
- SOR of 500 to 700 gal/ft2/day during winter months (November through April),
- U/F density of 1.5% total solids to eliminate unnecessary high SORs on GVTs.

When taking primary clarifiers in and out of service, U/F rate should be adjusted to avoid high SORs on GVT unit.

During periods of time when EPC is in service, the goals should 80% of TSS removal and 70% of BOD removal.

Additional EPC testing to further optimize polymer and ferric chloride dosages should be performed.

In 2011, Black & Veatch started primary mass balance efforts in order to validate loading for the upcoming facility planning. This effort should resume and overall primary treatment performance, as well as the need to add/remove sampling locations or instrumentation, should be evaluated.

Ferric chloride use as a secondary means for phosphorus removal should be considered.

REFERENCES

WEF (2010): Design of Municipal Wastewater Treatment Plants (MOP 8).

WERF (2006): Determine the Effect of Individual Wastewater Characteristics and Variances on Primary Clarifier Performance.

Cavanaugh L., Holland P. (August 2012): Secondary Capacity and Throughput Strategy for the PAR 1085 Construction Period.

ATTACHMENTS

Hollowed M. (September 2012): EPC Bench Test.

Anderson W. (November 2013): Effluent Iron Concentration Investigation.