Rochester Water Reclamation Plant

2019 Facilities Plan

Technical Memorandum 4: Primary Clarifier Computational Fluid Dynamics Modeling

TM 4 of 13 | J4325

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Brown AND Caldwell

Brown AND Caldwell

30 East 7th Street, Suite 2500
Saint Paul, MN 55101

T: 651.298.0710

Technical Memorandum

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Subject: Primary Clarifier Computational Fluid Dynamics Modeling

Date: September 16, 2019

To: Matt Baker, PE, Project Manager

From: Harold Voth, PE, Project Manager

Prepared by: ______________________
Mark Miller, P.E. *

____
Lloyd Winchell, P.E.

____
Dan Gilbert, P.E.*

Reviewed by: ______________________
Donavan Esping, P.E.

____
Dan Davis, P.E.

* Licensed in Specific States

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Signature: ______________________

Name: Donavan Esping

Date: September 16, 2019 License No. 22972

Limitations:

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List of Abbreviations

3D	three-dimensional
ABC	Aeration Basin Complex
BC	Brown and Caldwell
BNR	biological nutrient removal
CFD	computational fluid dynamics
City	City of Rochester
COD	chemical oxygen demand
d	day(s)
DSS	dispersed suspended solids
F	fraction
ft	foot/feet
ft^2	square foot/feet
G	velocity gradient
gal	gallon(s)
gpm	gallon(s) per minute
HPO	high-purity oxygen
hr	hour(s)
ISS	influent suspended solids
k	solids settling parameter
K_A	floc aggregation rate coefficient
K_B	floc break-up rate coefficient
L	liter(s)
lb	lb(s)
m	meter(s)
mg	milligram(s)
mgd	million gallons per day
min	minute
n_o	initial number of particles
n_t	number of particles at time t
PE	primary effluent
PHWWF	peak hour wet weather flow
PS	primary sludge
rpm	revolution(s) per minute
s	second(s)
SBD	sludge blanket depth
SOR	surface overflow rate
t	time
TM	technical memorandum
TSS	total suspended solids
µm	micro-meter
V	velocity
V_o	initial settling velocity
V_s	settling velocity
WRP	water reclamation plant
X	particle concentration

Executive Summary

The City of Rochester (City) owns and operates the Water Reclamation Plant (WRP) that treats the City's wastewater. The City contracted Brown and Caldwell (BC) to prepare a facilities plan to evaluate and identify the facilities needed to meet current and future needs. This technical memorandum (TM) summarizes the WRP Primary Clarifier 1 and 2 field testing program and performance analysis. The program and analysis were conducted to identify possible Primary Clarifier 1 and 2 performance improvements and to establish the basis of performance without ferric chloride addition.

2Dr Clarifier Modeling

A rectangular clarifier computational fluid dynamics (CFD) model, 2Dr, was used to analyze the performance of the existing Primary Clarifiers 1 and 2 in the high-purity oxygen (HPO) train at the WRP. The evaluation effort included field testing to collect data to calibrate the 2Dr model. BC field tested Primary Clarifier 2 on December 14, 2017 without ferric chloride addition. Field testing includes operating the clarifier over a range of loading conditions to illicit responses in primary effluent total suspended solids (PE TSS), sludge blanket depths (SBDs), and primary sludge TSS concentrations plus the following bench scale tests:

1. Flocculation Testing
2. Column Settling Testing
3. Dispersed Suspended Solids Testing
4. Discrete Particle Testing

The 2Dr model was successfully calibrated to the stress test data and subsequently used to investigate potential modifications to improve clarifier performance. The clarifiers were evaluated at two conditions representing the range of conditions anticipated under future operations:

- "Maximum month" conditions with a surface overflow rate (SOR) of 475 gallons per square foot-day (gal/ft^2-d) with year 2045 maximum month primary influent TSS loadings or 340 milligrams per liter (mg/L)
- "Peak" conditions of 1,660 gal/ft^2-d with year 2045 maximum week influent TSS loadings or 175 mg/L.

This 2Dr based optimization analysis provides a relative comparison of PE TSS removal and not exact TSS removal since the model assumes equal flow distribution across the clarifier inlet. Several clarifier enhancements were investigated with 2Dr including increasing the primary sludge pumping rate, replacing the existing traveling bridge sludge collector with chain-and-flight type, adding finger launders to extend the effluent launders into the tank, and/or adding internal baffle walls. Of these improvements, adding finger launders or full-height baffle wall with 50 percent open space showed potential to improve performance per Figure ES-1.

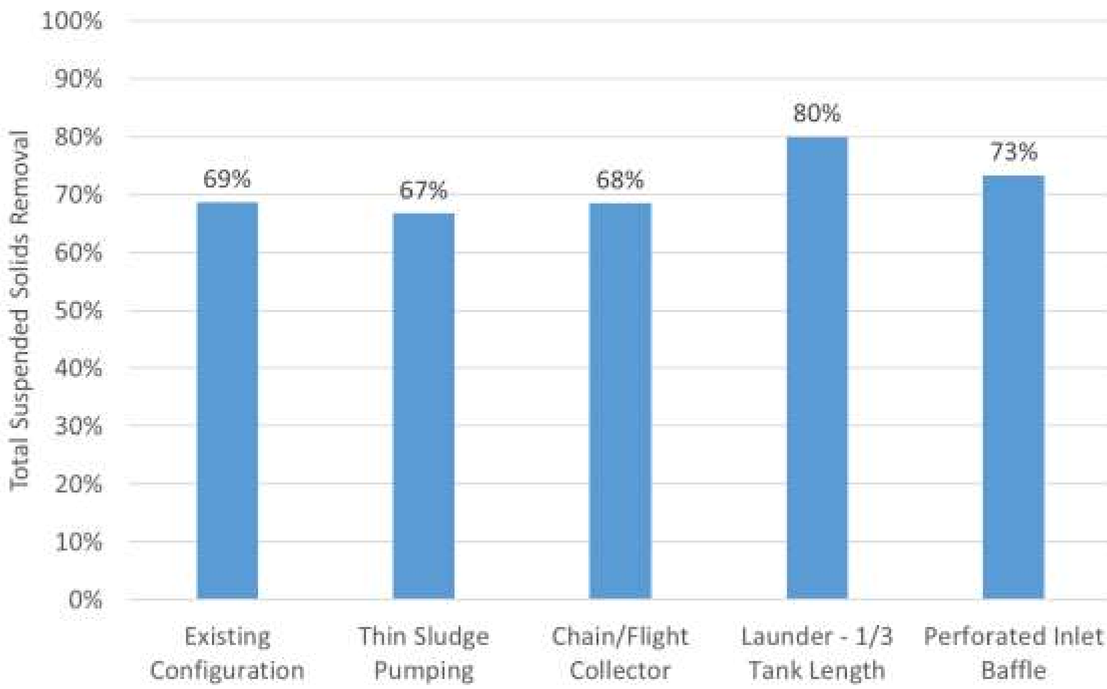

Figure ES-1. Predicted TSS removal for various performance enhancement configurations

(SOR = 475 gal/ft²-d, ISS = 338 mg/L)

Based on the initial modeling showing benefits of a full-height inlet baffle subsequent analyses showed replacing the existing inlet diffuser plates with a 33 percent porosity, or open space, full-height baffle wall improved TSS removal at peak conditions the most of several porosities investigated and by roughly 30 percentage points over the existing configuration. Also, extending the effluent launders into the tank by one-fourth or one-half of the tank length did not significantly change TSS reduction from the one-third length configuration.

Figure ES-2 provides a relative comparison of the TSS removal for the two enhancements alone and combined versus the existing configuration at maximum month and peak conditions. Predicted performance at maximum conditions was essentially the same from a modeling perspective, ranging from 69 to 80 percent TSS removal. At peak conditions, simulations including a full-height baffle almost doubled the TSS removal compared to the existing configuration or launder extensions alone. Either of the launder or full-height baffle enhancements alone or in combination would require replacing the existing traveling bridge collector with chain-and-flight collectors plus significant modification to accommodate sludge removal with a finger baffle arrangement.

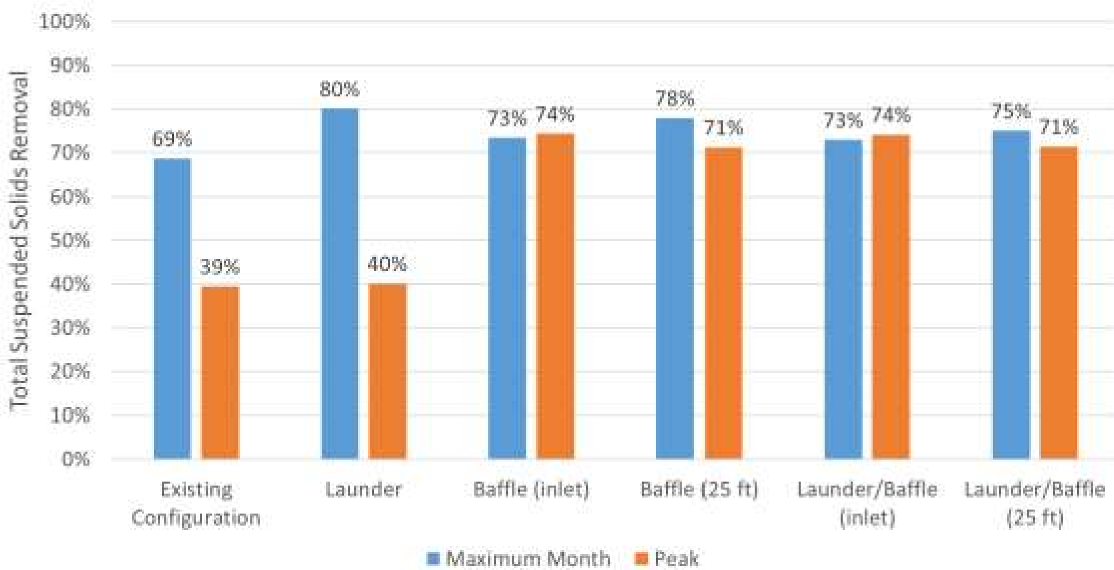

Figure ES-2. Relative comparison of predicted primary clarifier TSS removal for combined enhancements or alone

("Launder" = ½ length of tank, "Baffle" = 33 percent porosity baffle at noted distance from inlet wall)

Given the City staff's preference to stay with the travelling bridge collectors another baffle option was considered. This baffle, or diffuser baffle, would replace the existing diffuser plates on the vertical face of the inlet channel. The diffuser baffle would extend from just below the surface to about the bottom of the inlet channel which allows the existing collector to convey sludge to the sludge hopper. Figure ES-3 shows the predicted TSS removal for the diffuser baffle at different porosities and at maximum month and peak conditions. The model predicts the highest TSS removal with the 50 percent porosity baffle arrangement.

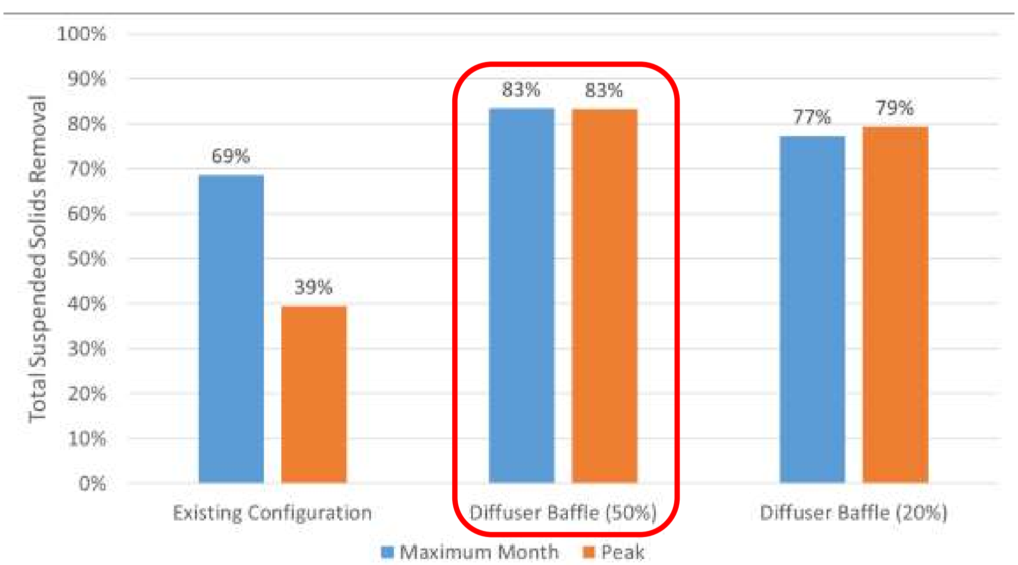

Figure ES-3. Predicted TSS removal for various diffuser baffle porosities at maximum month and peak conditions

3D Clarifier Modeling

During the primary clarifier stress testing, a "swirling" action was observed in the test clarifier at SORs greater than 2,000 gal/ft^2-d which resulted in (1) higher flows to the "south" side of the clarifier short-circuiting the clarifier and (2) uneven SBD across the clarifier with lower SBDs on the "south" side and higher blankets on the "North" side in the front half of the tank. Figure ES-4 shows the results of three-dimensional (3D) CFD FLUENT modeling at the design peak SOR which corroborates the field observed swirling pattern.

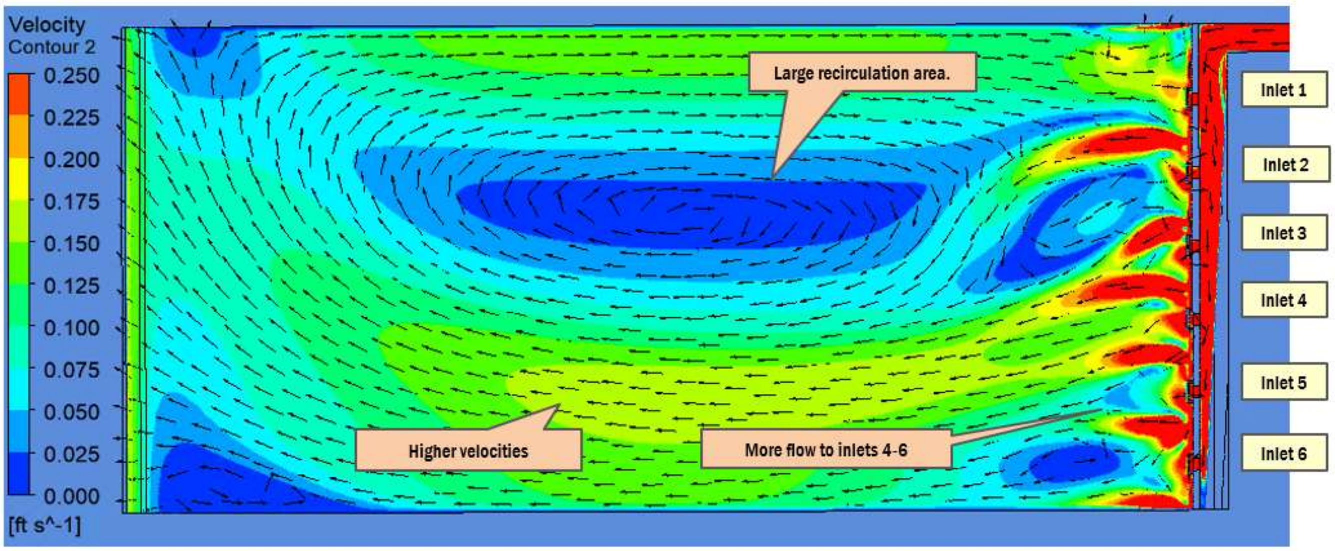

Figure ES-4. Primary Clarifier 2 swirling action during peak flow conditions (SOR = 1,660 gal/ft^2-d)

This evaluation then used the 3D CFD model to evaluate several optimization modifications to prevent upwelling at the end of tank with a Crosby type baffle, evenly distribute flow across the front of the tank, and observe the impact of replacing the existing inlet diffuser plate with the diffuser baffle described previously. 3D modeling showed no benefit from the Crosby baffle. A diffuser baffle at the inlet of the tank, analogous to that modelled with 2Dr, resulted in predicted circulatory currents within the tank similar to the existing configuration and was thus not further considered. However, replacing the existing diffuser plate with the arrangement shown in Figure ES-5 and adding stub baffles to the inlet channel shown in Figure ES-6 resulted in significant flow distribution improvement across the front of the tank and reduced the circulating currents predicted by the 3D CFD model. Figure ES-7 shows the 3D CFD model predicted stream lines with these two modifications in place, resulting in the elimination of the large circulatory patterns observed with the existing configuration. BC recommends further consideration of these modifications including a head loss analysis to determine the impacts on the hydraulic grade line at peak flow.

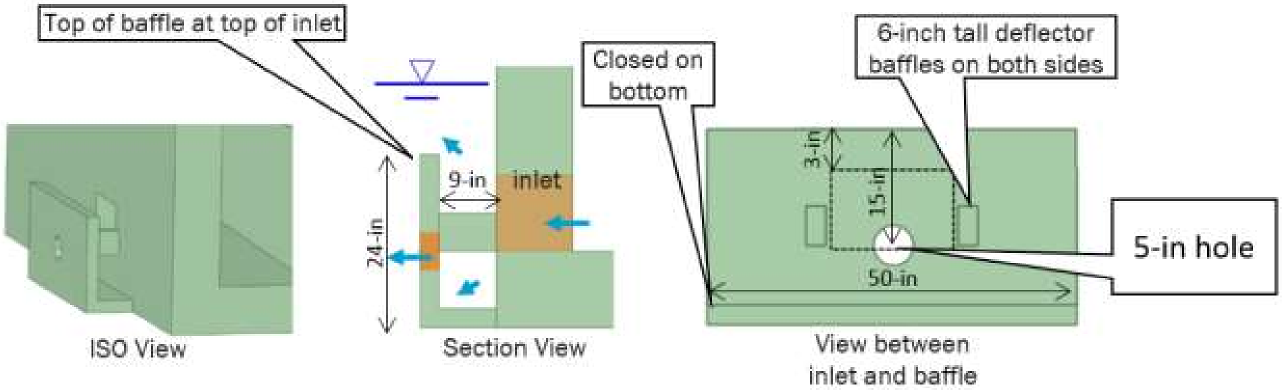

Figure ES-5. Recommended diffuser plate configuration

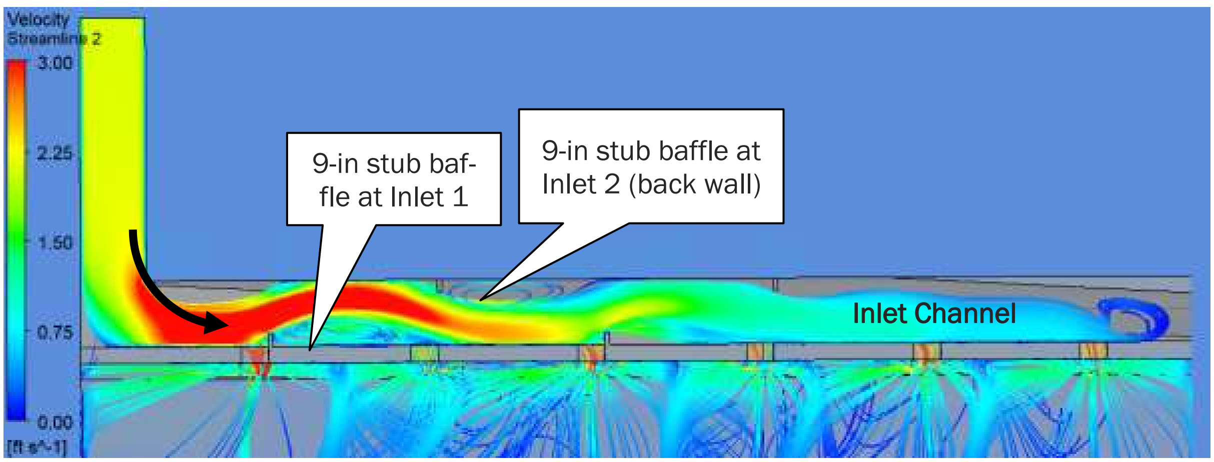

Figure ES-6. Primary Clarifier 2 recommended inlet channel stub baffle configuration

(SOR = 1,660 gal/ft²-d)

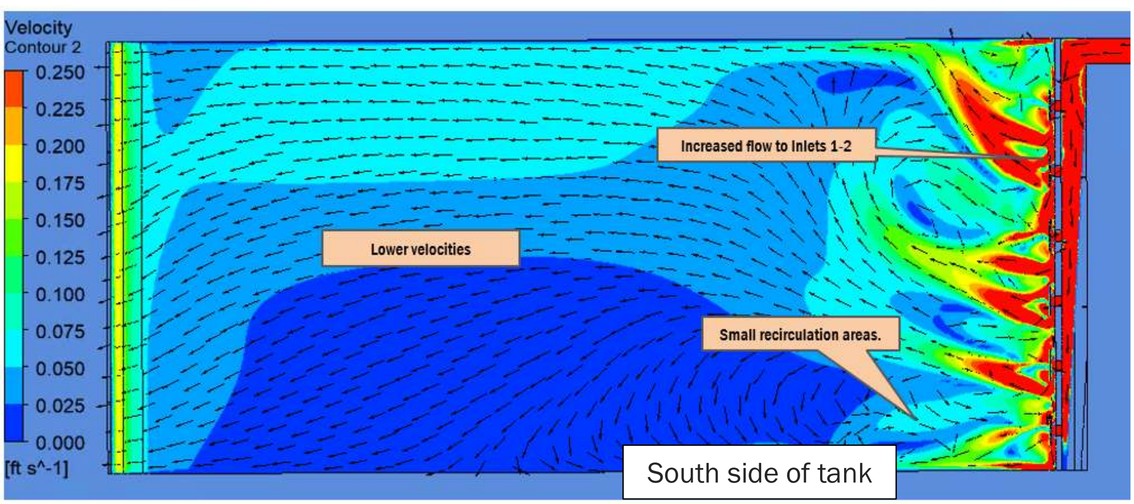

Figure ES-7. Primary Clarifier 2 diffuser plate Alternative 2 stream lines – plan view (includes inlet stub baffles)

(SOR = 1,660 gal/ft2-d)

Chemical Oxygen Demand Field Measurements

During the field test BC also collected influent and effluent samples from Primary Clarifier 2 for chemical oxygen demand (COD) analyses. The total COD capture across the clarifier during design type SORs of 500 gal/ft^2-daveraged 18 percent with an associated 59 percent TSS capture. The liquid stream alternatives evaluation Primary Clarifier 1 and 2 COD removals assumed 25 percent removal based on the wastewater characterization work and selected 55 percent TSS removal. The difference between the modeled and measured values is not significant for the liquid stream alternatives evaluation.

Recommendations

If a gravity thickener is added, it is recommended to increase the primary sludge pumping rate and overall capacity to provide the capabilities to pump thinner sludge. Increasing the pumping rate will minimize the potential for solids carryover at high SORs, minimize sulfide generation in the primary clarifiers, and minimize sulfide levels in the primary effluent or sludge with or without ferric chloride addition. Extended launders and baffles offer benefit at higher SORs, however replacement of the existing traveling bridge to accommodate these enhancements is required and locating perimeter launders on the tank walls may not see the same benefit as modeled. Based on the City staff's preference to stay with the traveling bridge collectors and the significant capital cost to replace the collectors and install the enhancements, this analysis does not recommend extending the launders or adding a full-height baffle.

2Dr modeling showed adding a diffuser baffle to the internal vertical face of the inlet channel could significantly increase TSS removal provided the influent flow could be evenly distributed across the tank. Detailed 3D CFD modeling of the promising diffuser baffle showed undesirable circulating currents in the tank and was therefore removed from consideration. Additional investigations with the 3D CFD model showed adding stub walls in the inlet channel and replacing the existing inlet diffuser plate with a modified diffuser plate predicted significant reductions in the circulatory flow patterns in the tank and better distribution amongst the six inlet ports. BC recommends including temporary stub walls in the inlet channel to observe the flow distribution and measuring solids blanket distribution in the clarifiers prior to implementing full scale improvements. If successful, fully evaluate the hydraulic impacts of adding the baffles/proposed inlet structures.

Long term plans eliminate ferric chloride addition to Primary Clarifiers 1 and 2 during normal conditions. Ferric chloride addition increases the TSS capture rate of the clarifiers but will not be required on a typical basis. Nevertheless, BC recommends keeping the ferric chloride addition capacity to the primary clarifiers for upset conditions.

Section 1: Scope of Work

The City of Rochester owns and operates the Water Reclamation Plant (WRP) that treats the City's wastewater. The City contracted Brown and Caldwell (BC) to prepare a facilities plan identifying the current and future WRP requirements. This technical memorandum (TM) summarizes the WRP Primary Clarifier 1 and 2 field testing program, model calibration, and capacity analysis without ferric chloride addition. The program and analysis established the basis of existing primary clarifier capacity under current and future operations. The analysis also recommended improvements to further increase capacity and/or improve performance.

In total three clarifiers, representing critical points of treatment at the WRP, were field tested to calibrate CFD models for the facility planning. Two of the clarifiers field tested serve in the secondary treatment processes at the WRP and the related analyses are described elsewhere (BC, 2018c). This analysis covers Primary Clarifier 2 which resides in the high-purity oxygen (HPO) train.

The CFD model used for predicting clarifier TSS removal was developed by a research team led by Professor J. Alex McCorquodale at the University of New Orleans. The CFD model accounts for hydrodynamics, sludge settling, turbulence, sludge rheology, flocculation, clarifier geometry, and varying hydraulic and sludge withdraw loadings. Discrete particle settling, flocculation-induced settling, hindered settling, and compression settling also are described by the model. Model inputs include: solids settling and flocculating characteristics, discrete settling fractions, clarifier geometry, surface overflow rate (SOR), temperature, influent total suspended solids (TSS) concentration, collector mechanism type, and clarifier underflow flow rate. The solids characteristics were determined on-site using field and laboratory methods. Using these inputs, the model predicts primary effluent (PE) TSS and primary sludge solids. In addition, the model output predicts flow velocity vectors and solids concentrations throughout a two-dimensional, vertical slice of the clarifier. Sludge blanket depth (SBD) can also be determined from the solids concentration profile.

Once the model was calibrated a capacity analysis and performance enhancing evaluation were completed. The enhancements looked at internal baffling, sludge withdrawal rates, and launder configuration. Promising enhancements were further vetted with the commercially available three-dimensional (3D) hydraulic CFD model FLUENT. The 3D model can model the physical aspects of the modifications in greater detail for hydraulic analysis.

The TM is organized in three major sections covering the field supported calibration followed by the capacity analyses and then the 3D modeling analyses. The TM includes a final section summarizing the recommendations based on the work.

Section 2: Primary Clarifier 2 Model Calibration

Figure 2-1 identifies the treatment processes in the existing HPO facility, which consist of (1) two primary clarifiers, (2) two first stage HPO aeration basins with intermediate clarifiers for carbon removal and (3) three second stage HPO basins with four final clarifiers. The City currently adds ferric chloride to the Primary Clarifiers 1 and 2 influent for phosphorus removal which also enhances TSS removal. As part of the liquids stream facilities planning effort, several alternatives could eliminate the HPO activated sludge systems and replace them with a conventional biological nutrient removal (BNR) system in which ferric chloride is not added to the primary influent. This section describes the field testing and Primary Clarifier 2 2Dr model calibration for operations without ferric chloride addition.

Figure 2-1. HPO treatment processes

Image source: Google Earth.

2.1 Primary Clarifier 2 Overview

The HPO facility includes two rectangular primary clarifiers. Primary influent enters the primary clarifier building through two pipes (36-inch) that is a mixture of single pipe (36-inch) and dual pipes (30-inch and 36-inch) between the grit collection system and Primary Clarifiers 1 and 2. The influent then flows to each primary clarifier in a tapered influent channel that distributes the flow along the width of each clarifier. Flow from the influent channels enters the primary clarifiers through six submerged, rectangular inlet ports. Steel diffuser plates are located at the inlet port locations to decrease the kinetic energy in the flow and prevent jetting into the clarifiers. Flow proceeds to the end of each clarifier and overflows a full-width weir into the collection channel. Solids that settle in the clarifier are moved to the sludge hopper, located at the influent end, by a traveling bridge scraper. The traveling bridge also moves surface scum to the scum collector located at the effluent end of the tank. Figure 2-2 is a plan view of the primary clarifiers and Figure 2-3 is a section view of Primary Clarifier 1 (identical to Primary Clarifier 2). Table 2-1 summarizes the features of Primary Clarifier 2.

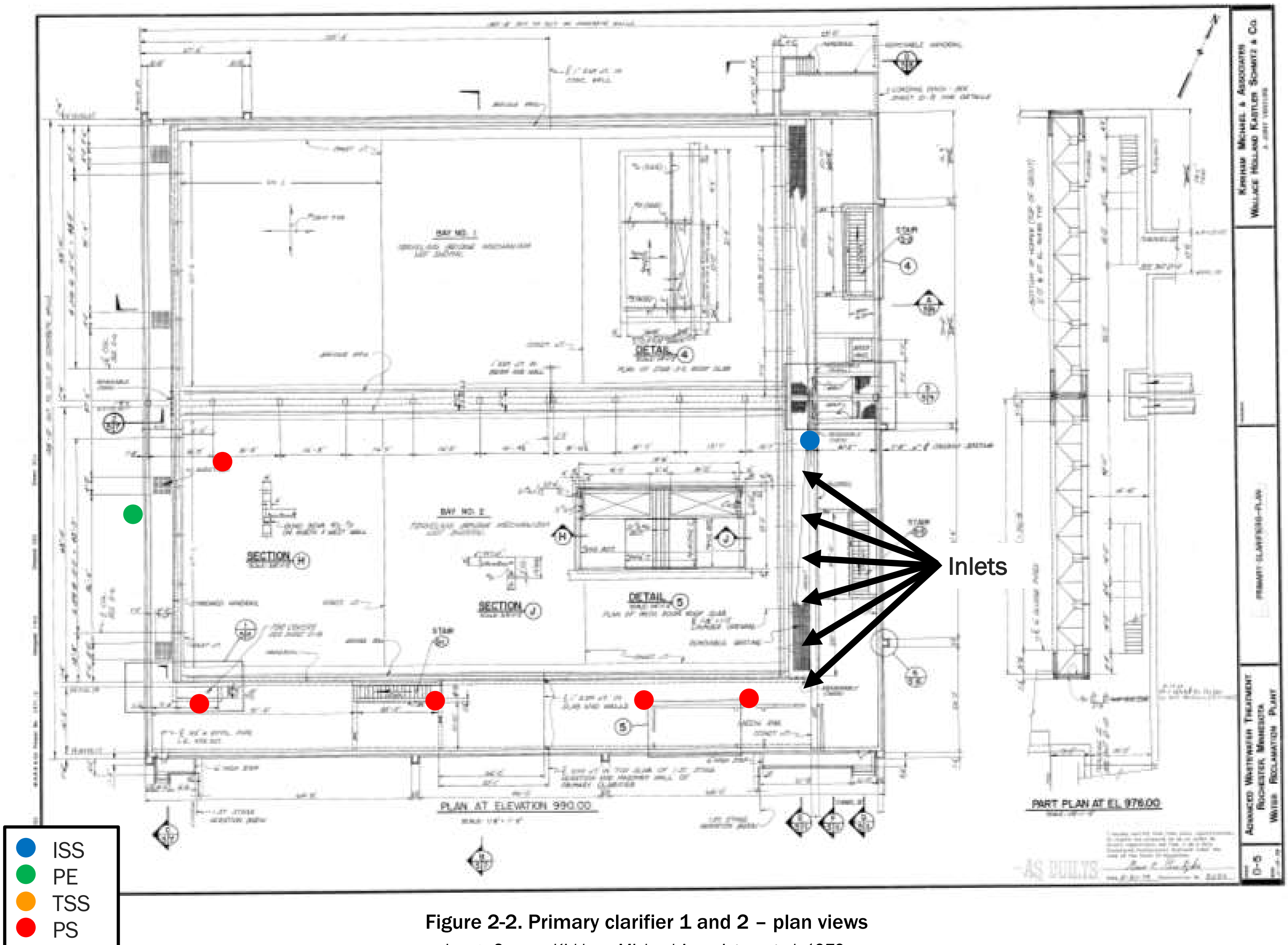

Figure 2-2. Primary clarifier 1 and 2 – plan views

Image Source: Kirkham Michael Associates, et al, 1979.

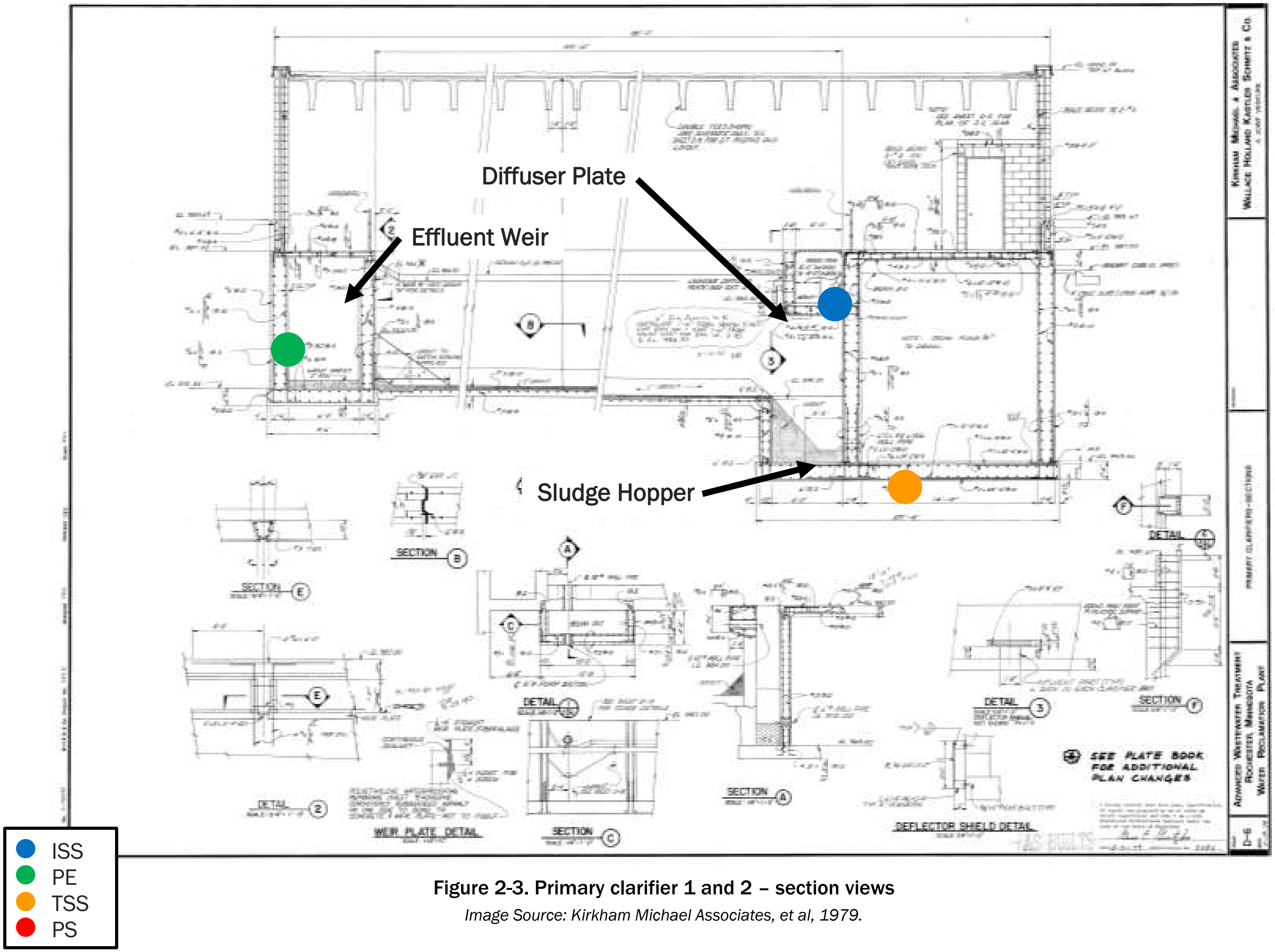

Figure 2-3. Primary clarifier 1 and 2 – section views

Image Source: Kirkham Michael Associates, et al, 1979.

Table 2-1. Rochester Primary Clarifier Design Details		
Item	Units	Value
Primary Clarifier		
No.	--	2
Length	ft	153.83
Width	ft	68
Side Water Depth	ft	10
No. of Inlet Ports	--	6
Inlet Width	ft	1.67
Inlet Height	ft	1
Diffuser Plate Width	ft	3
Diffuser Plate Height	ft	2
Diffuser Plate Wall Clearance	ft	0.5
Slope	%	0
Effluent Launder Type	--	Outboard
Effluent Launder Width	ft	68
Sludge Scraper Type	--	Traveling Bridge
Scraper Height	ft	1.25
Scum Baffle Depth	ft	1.75

2.2 Field Testing

The field-testing program was designed to develop information necessary for the CFD model calibration. For this application, the 2Dr version of the CFD model was used since the primary clarifiers are rectangular. In general, the protocols used follow those in the "WERF/CRTC Protocols for Evaluating Secondary Clarifier Performance" (Wahlberg, 2001). The field and laboratory data collection programs were conducted on December 14, 2017. During this site visit, five different types of tests were performed:

1. Flocculation Testing
2. Column Settling Testing
3. Dispersed Suspended Solids Testing
4. Discrete Particle Testing
5. Primary Clarifier 2 Stress Testing

This section describes the testing and results from items 1 through 4 above. Primary Clarifier 2 stress testing is summarized in Section 2.3. Attachment A contains the Primary Clarifier Field Testing Plan and Attachment B contains the field testing data.

2.2.1 Flocculation Testing

The flocculation characteristics of the influent solids provide information relating the propensity of the flocs to both aggregate and break apart. This is a measurement of floc strength. Ideally, flocs have a high rate of aggregation and low rate of breakup so that strong flocs are formed while minimal particles exit the clarifier. To determine the flocculation characteristics of the influent solids, jar test experiments were performed on site. A six-paddle stirrer (Phipps and Bird Stirrer) was used to flocculate the influent samples. Flocculation was induced mechanically by stirring the sample. Square beakers (2 L) were used for the flocculation tests. The beakers were filled with 2 L of primary influent. Each beaker was randomly assigned a flocculation time (0, 2, 5, 10, 15, or 30 minutes). After the prescribed flocculation time had elapsed, the stirrer was removed carefully from the beaker. After an additional 30 minutes of settling, supernatant samples were withdrawn from the beakers and analyzed for TSS. The flocculation characteristics were determined by fitting Equation 1 (Wahlberg, 1994) to the experimental data. The flocculation characteristics used for the model are defined by K_A and K_B from Equation 1.

$$n_t = \frac{K_B G}{K_A} + \left(n_o - \frac{K_B G}{K_A} \right) e^{-K_A X G t} \qquad (1)$$

where:

n_t	=	number of particles at time *t*, gram per liter (g/L)
n_o	=	initial number of particles, g/L
G	=	root-mean square velocity gradient, per second (s^{-1})
X	=	particle concentration, g/L
K_A	=	floc aggregation rate coefficient, L/g
K_B	=	floc break-up rate coefficient, s
t	=	time, s

2.2.2 Column Settling Testing

Batch settling tests were performed on thickened and diluted primary sludge (PS) to determine the compression zone settling characteristics for use in the 2Dr model. Primary sludge was diluted using primary effluent. Hindered settling characteristics used in secondary clarifier analysis were not developed for this application since influent TSS concentrations are low and typical of discrete particle settling. The experiments were performed using settling columns. Each column was equipped with a slow-speed rake turning at 1 revolution per minute (rpm) to minimize wall effects. The Vesilind equation was used to determine the solids settling properties during the settling tests and is described by Equation 2.

$$V_S = V_o e^{-kX} \qquad (2)$$

where:

V_S	=	interface settling velocity, meter per hour (m/hr)
X	=	solids concentration, g TSS/L
V_o	=	initial settling velocity, m/hr
k	=	solids-specific settling parameter, L/g TSS

2.2.3 Dispersed Suspended Solids (DSS) Testing

To supplement the settling and flocculation data, DSS was collected three times at the effluent launder during different loading conditions. The DSS is defined as the supernatant suspended solids concentration after 30 minutes of settling in a Kemmerer sampler and represents the effluent quality under ideal settling conditions.

2.2.4 Discrete Particle Settling Testing

The 2Dr model characterizes influent particles/solids into three settling fractions: large, medium, and small. Six discrete particle settling tests were performed as defined by Ramalingam et al (2011). The large and medium particle size distributions were measured during the discrete particle tests. The small particle velocity distribution was calculated using the DSS test results.

2.3 Primary Clarifier 2 Stress Test and Model Calibration

Stress testing was performed on Primary Clarifier 2 to provide the data required for calibrating the 2Dr model. The sample locations for influent suspended solids (ISS), PE TSS, and primary sludge (PS) TSS, are shown on Figures 2-2 and 2-3. The SBD measurement locations are provided in Figure 2-2.

Influent flow was increased to Primary Clarifier 2 every 60 to 90 minutes while the sludge pumping rate of 30 gallons per minute (gpm) was held constant during testing. The speed of the traveling bridge mechanism during the stress test was such that it would travel the length of the clarifier and back every 30 minutes or approximately 5 feet per minute (ft/min). Figure 2-4 shows the total HPO primary influent flow rate and the SOR of Primary Clarifier 2 during the stress test. The test SOR rate varied from approximately 400 to 2,100 gal/ft^2-d. Figure 2-4 also shows the measured ISS during the stress test. The ISS concentration trend generally followed the flow/SOR trend with roughly coinciding peaks within the last hour and a half of the stress test followed by reducing values.

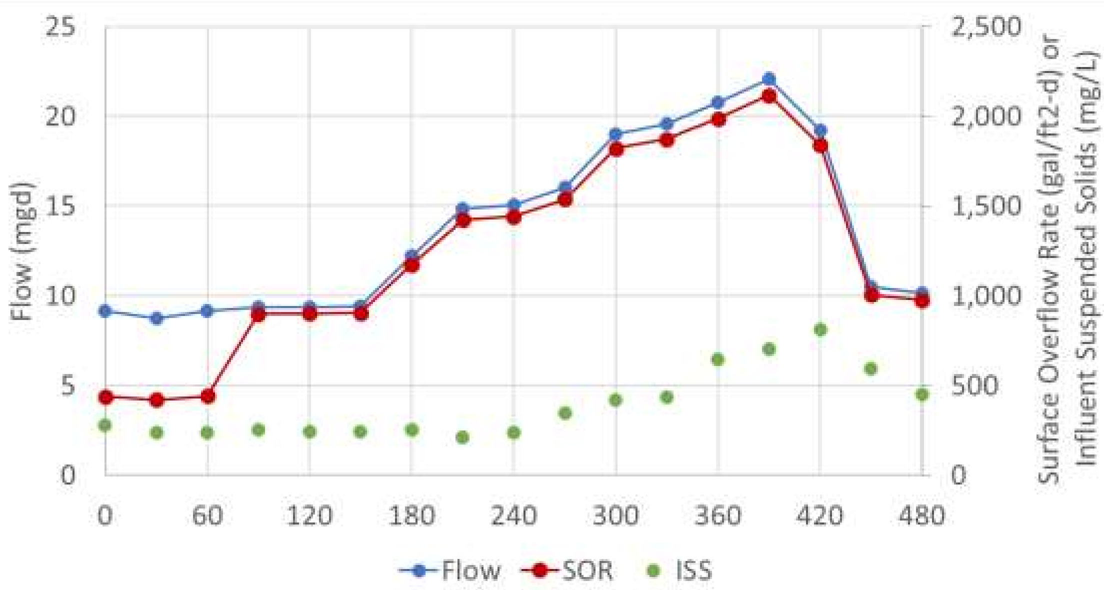

Figure 2-4. Primary Clarifier 2 stress test surface overflow rate and influent solids

The SBD at the inlet, two middle locations (Mid-1 and Mid-2), and the outlet were recorded every 30 minutes. Samples for ISS and PS TSS were also collected every 30 minutes. Samples for PE TSS were collected every 15 minutes from the effluent launder channel. Figures 2-5 through 2-11 show the model predicted and measured PE TSS, PS TSS, and SBD (predicted values calculated at the depth coinciding with 1,000 milligrams per liter [mg/L] TSS) at the four sampling locations. Figure 2-5 shows the measured and model predicted PE TSS concentrations. The model matched the measured and predicted values through test time of 180 minutes (t=180 minutes), After t=180 minutes, the PE TSS predicted values displayed a similar trend to the measured values but were offset by roughly 90 minutes through t=300 minutes and 60 minutes through t=330 minutes. This pattern suggests short-circuiting may have occurred as test SORs/flows increased. The overall correlation between measured and predicted PE TSS values shown in Figure 2-6 without the data “offset” was imprecise but the data did range on either side of the ideal one-to-one relationship. The PS TSS predicted and measured data (Figure 2-7) closely correlated for all but three points from t=300 minutes to t=390 minutes. This was likely caused by the inlet diffuser plates directing the influent flow into the sludge blanket and sweeping the solids downstream. Figure 2-8 shows the model predicted SBD was roughly 1-foot lower than measured at SOR of 1,200 gal/ft^2-d (t=180 minutes) during the beginning of the test and equal to or higher than measured values for the remainder of the test. Figures 2-9 through 2-10 show the measured SBD correlate well the measured values for the remaining locations monitored. Figure 2-12 shows the intense turbulence at the tank inlet during high flows. Overall, the model predicted values tracked well with measured values indicating the calibrated model will reliably predict the clarifier responses to performance enhancing modifications.

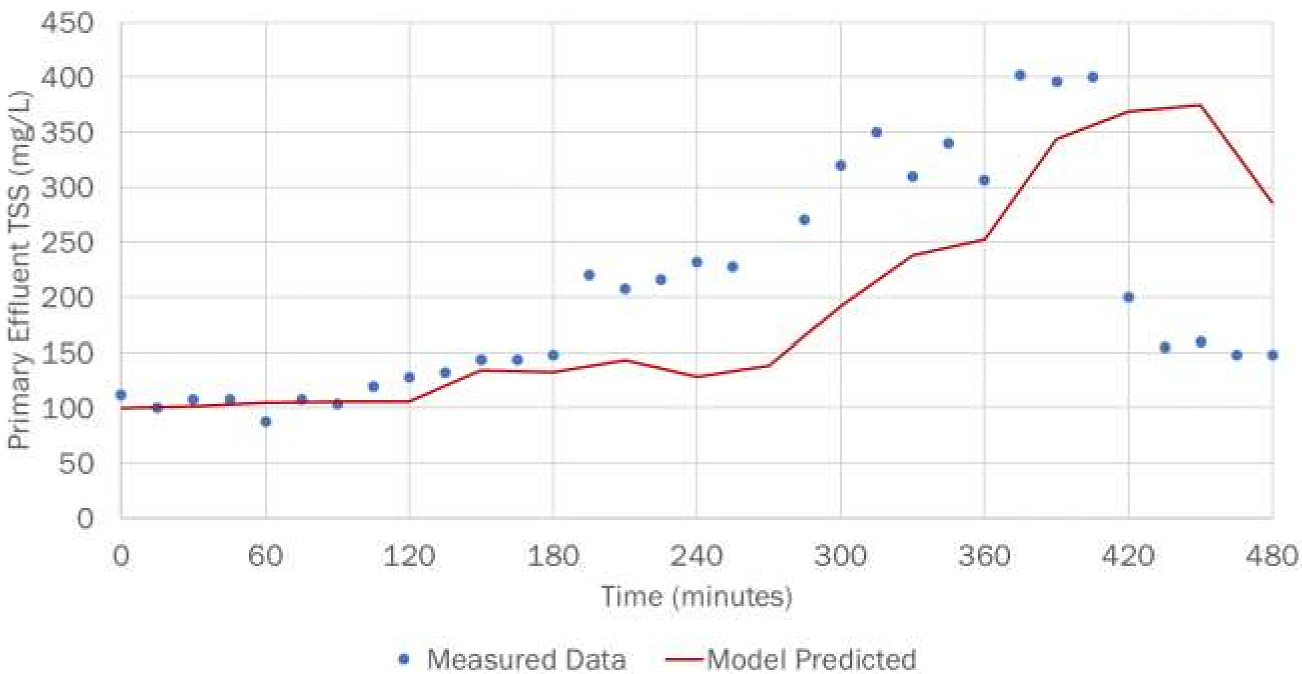

Figure 2-5. Primary Clarifier 2 measured and predicted PE TSS

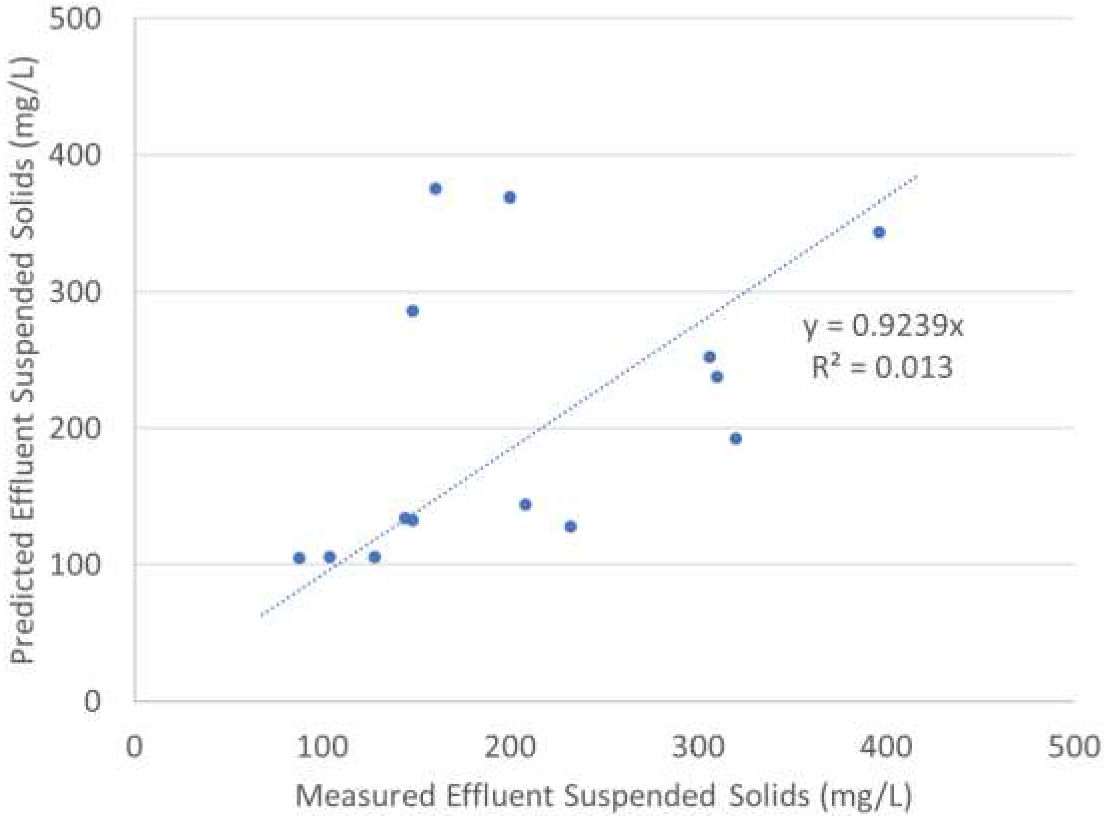

Figure 2-6. Primary Clarifier 2 measured and predicted PE TSS correlation

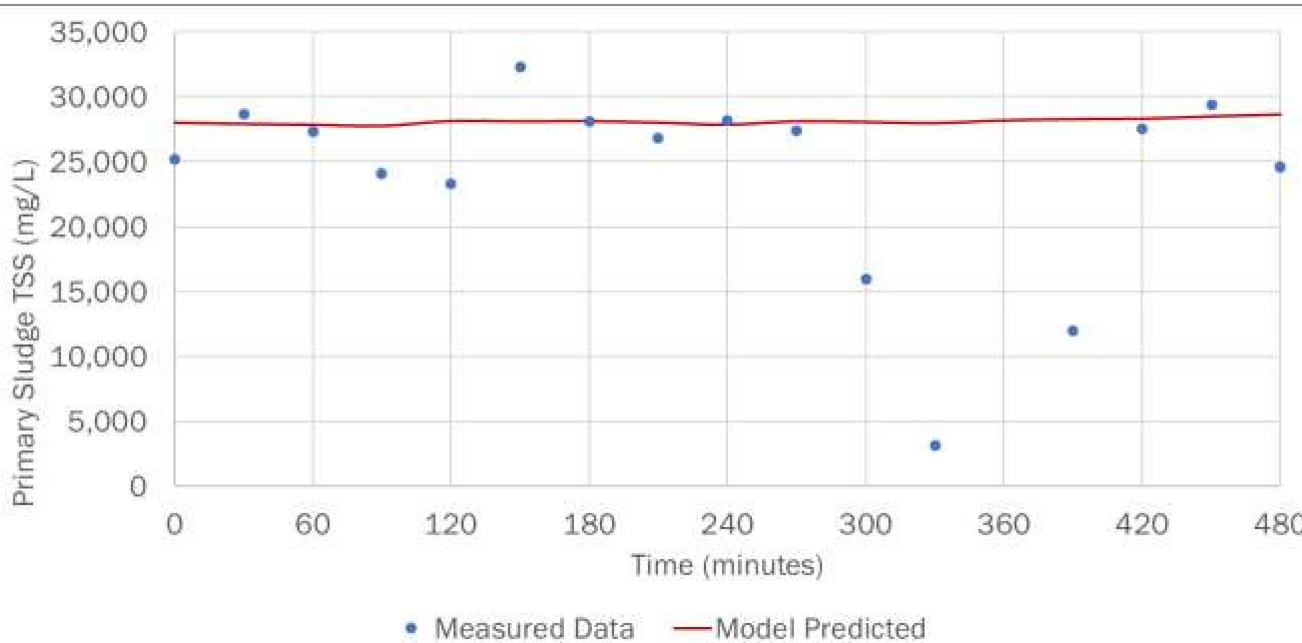

Figure 2-7. Primary Clarifier 2 measured and predicted primary sludge TSS

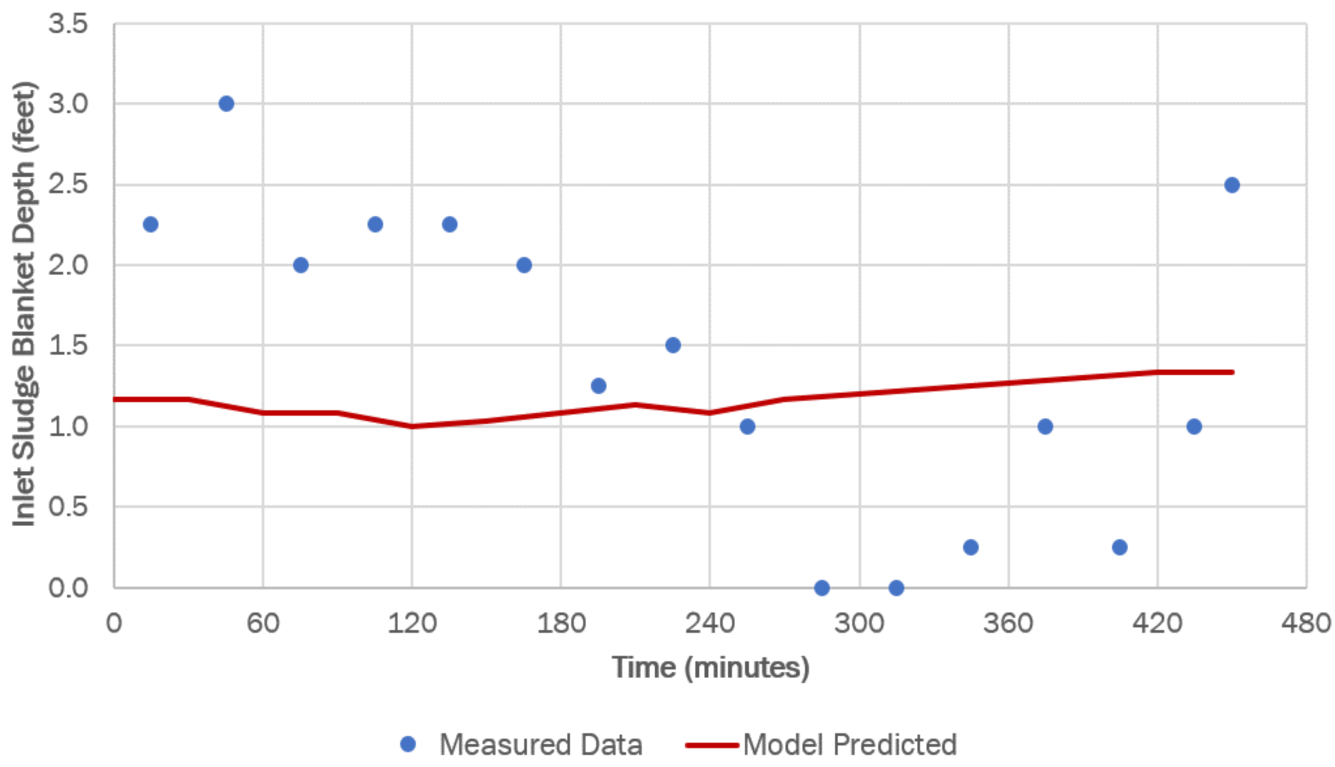

Figure 2-8. Primary Clarifier 2 measured and predicted SBD at inlet end

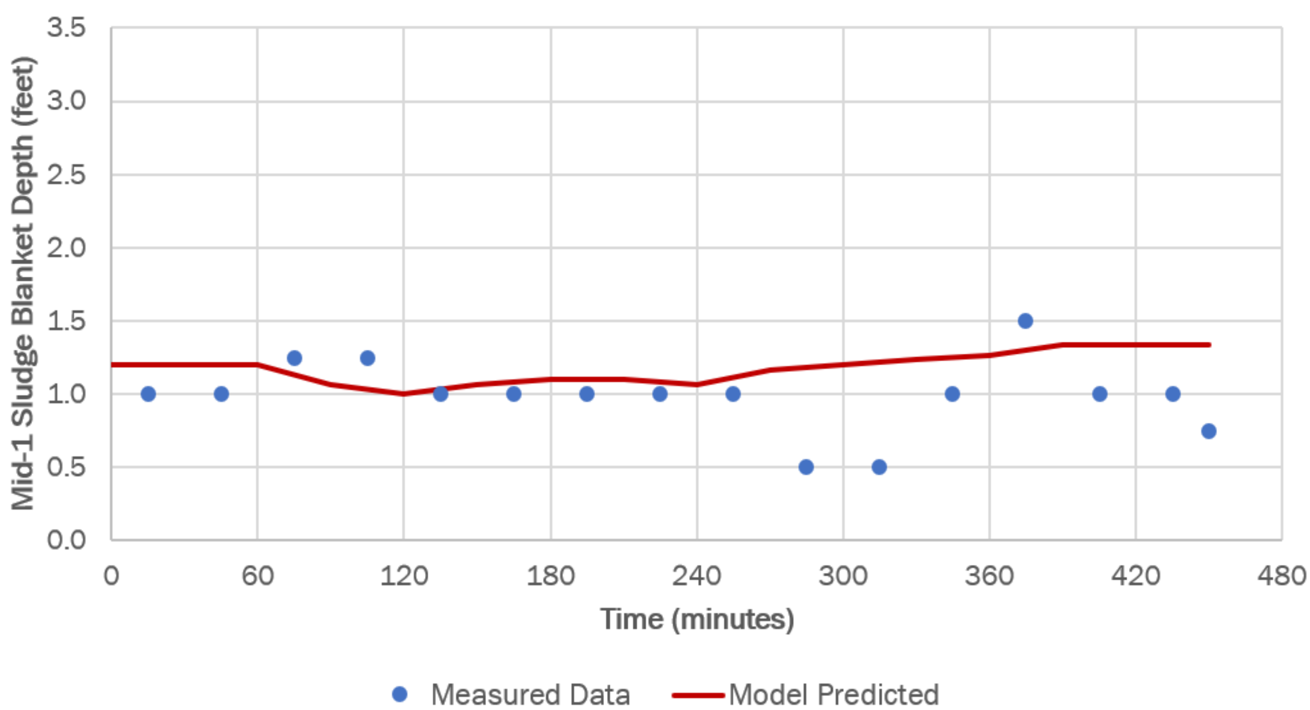

Figure 2-9. Primary Clarifier 2 measured and predicted SBD at Middle-1 location

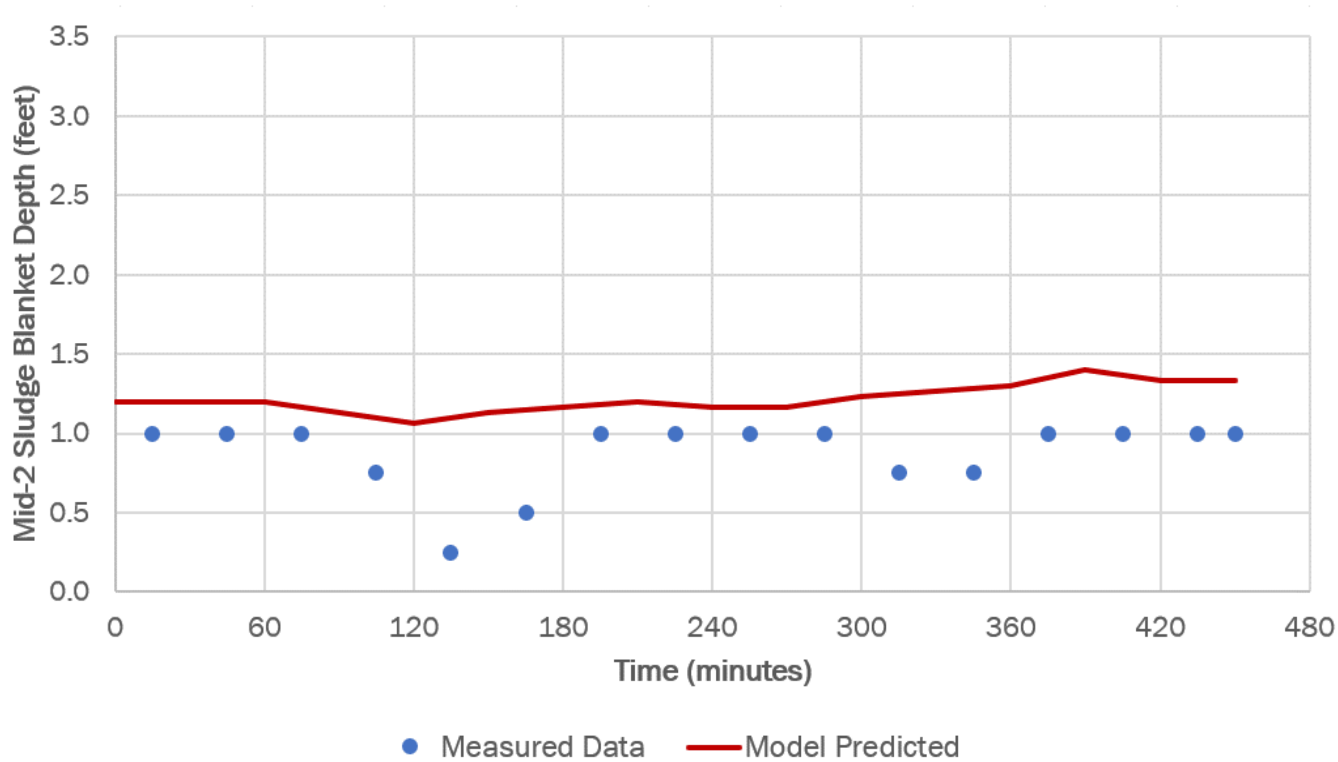

Figure 2-10. Primary Clarifier 2 measured and predicted SBD at Middle-2 location

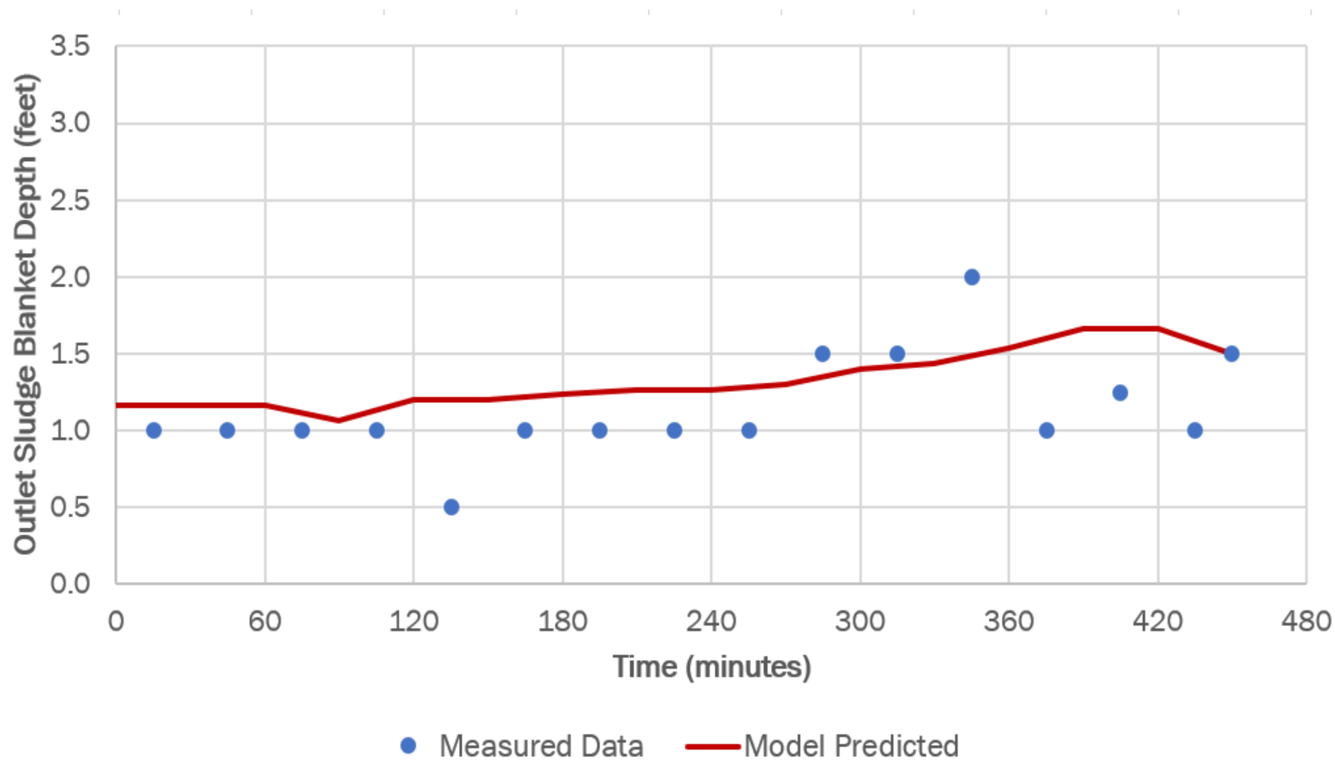

Figure 2-11. Primary Clarifier 2 measured and predicted SBD at outlet end

Figure 2-12. Inlets during high flows of stress test

Figure 2-13 shows the graphical output of the 2Dr model and represents a length-wise slice through the clarifier. The initial (t = 0 minutes) and peak SOR (t = 360 minutes) test times are shown. Key elements and dimensions are also identified including the clarifier length, side water depth, and inlet channel and diffuser plate. Suspended solids concentrations are indicated by color and vectors represent fluid velocity (vector length is relative to the magnitude of velocity at the point corresponding to the tail end of the vector arrow). The vector scale is exaggerated so that differences in low velocities can be distinguished. As a result, the highest velocities, which are at the inlet and outlet (upper corners of graphics), are confined to a relatively small volume. Examination of tank velocity profiles should be focused on the following issues:

- Good mixing at the tank inlet for optimal flocculation.
- Avoidance of high velocities along the top of the blanket.
- Avoidance of sludge blanket re-suspension or "fluffing" the blanket.
- Avoidance of large circulatory currents within the tank, typically referred to as "density currents."

PE TSS values cannot be accurately discerned from graphics such as Figure 2-13 since the logarithmic color scale is adjusted to favor the higher concentrations typical of the sludge blanket zone and to distinguish between thickening rather than clarification failure. To examine PE TSS predictions, plotted representation of the output is more useful. Examination of solids profiles should be focused on the depth of the sludge blanket, end wall effects, and solids removal or conveyance efficiency.

Figure 2-13 shows good energy dissipation during low SORs with a density current directing solids to the sludge blanket. However, at peak SORs, this density current reverses and high velocities near the surface appear to result in short circuiting. The density current also appears to disturb the sludge blanket after it recirculates toward the head of the tank near the outlet wall. Clarifier performance could be improved by adding a perforated baffle wall to prevent/minimize the density current at high flows (Section 3).

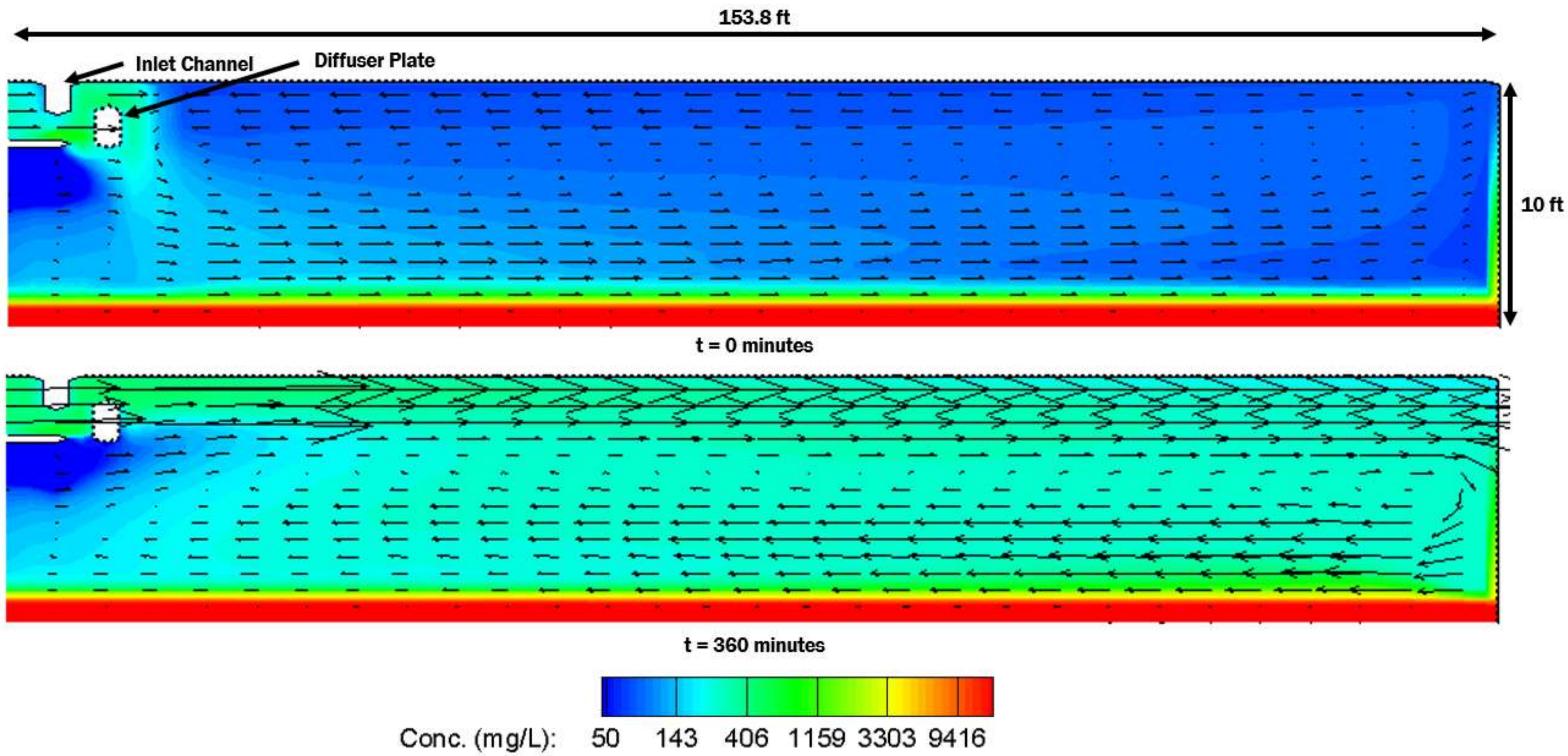

Figure 2-13. Primary clarifier 2 calibration at test time 0 and 360 minutes

To achieve the calibration represented in Figures 2-5 through 2-11 several modifications to the measured data or values typically used were required. The following discusses the specific modifications.

Sludge Compression Constants – the sludge blanket diffusion factor (sludge compaction factor) was set to match the PS TSS concentration. As measured, the predicted PE TSS was lower than measured. To adjust for the lower PE TSS, the measured compression zone settling constants V_c and k_c were decreased to increase the predicted PE TSS.

Particle Fractions – the solids particle fractions were assumed based on previous experience as measuring particle distribution with primary sludge is difficult and discrete settling tests did not provide satisfactory results. The assumed large, medium, and small particle fractions were set to 20, 15, and 20 percent, respectively, to match the measured PE TSS and PS TSS. An initial non-settleable fraction was also used based on the FSS test results of 33 percent. This fraction was adjusted to 45 percent to match the measured PE TSS values.

Particle Fraction Settling Velocities – the particle fraction settling velocities are based on previous experience and were set to 6, 3, and 1.5 m/hr for the large, medium, and small particle fractions, respectively. A settling velocity of zero was used for the non-settleable fraction.

Table 2-2 summarizes the influent solids characteristics measured during the sampling program and final values used in the model calibration.

Table 2-2. Rochester Primary Clarifier 2 Solids Characteristics (December 14, 2017)

Parameter	Test Results	Model Calibration Value	Comments
Hindered Settling Constants	--	V_o = 10.0 m/hr k = 0. 55 L/g	Assumed
Compression Zone Settling Constants	V_c = 3.43 m/hr k_c= 0.217 L/g	V_c = 5 m/hr k_c= 0.1 L/g	Modified with sludge blanket diffusion factor to match primary sludge TSS and PE TSS concentrations
Floc Aggregation Rate Coefficient (K_A)	1.57 x 10^{-4} L/g	1.57 x 10^{-4} L/g	
Floc Breakup Rate Coefficient (K_B)	3.00 x 10^{-7} L/g	3.00 x 10^{-7} L/g	
Discrete Particle Fractions (F)			
F_{large}	--	20%	
F_{medium}	--	15%	
F_{small}	--	20%	
$F_{non\text{-}settleable}$	33%	45%	Adjusted to match PE TSS
Discrete Particle Velocity (V)			
V_{large}	--	6 m/hr	Assumed
V_{medium}	--	3 m/hr	Assumed
V_{small}	--	1.5 m/hr	Assumed
$V_{non\text{-}settleable}$	0 m/hr	0 m/hr	
Dispersed Suspended Solids	76 to 140 mg/L	101 mg/L	Used average FSS results with 30-minutes of flocculation

Section 3: Clarifier Performance Optimization

The analysis used the calibrated 2Dr clarifier model to consider several clarifier enhancements to optimize performance. The following presents the basis of analysis and enhancement investigated using the 2Dr model.

3.1 Basis of Analysis

The clarifier optimization investigations used the following flow and load conditions based upon the projected year 2045 influent flows and loadings (BC, 2018a).

- Maximum month plant influent flow – 23.8 million gallons per day (mgd)
- Peak hour wet weather flow (PHWWF) – 51 mgd
- Maximum month plant influent TSS – 58,400 pounds per day (lb/d)
- Maximum week plant influent TSS – 64,900 lb/d
- Recycle TSS – 15 percent increase of influent TSS load
- Flow split to HPO facility – 40 percent (maximum month) or 65 percent (peak conditions)
- Equal flow split between Primary Clarifier 1 and 2
- Primary Clarifier 1 and 2 are both in service

Using these flows and loadings, two conditions were evaluated to define whether a potential modification could improve primary clarifier performance.

- "Maximum month" conditions with a SOR of 475 gal/ft^2-d and primary influent TSS of 340 mg/L
- "Peak" conditions with a SOR of 1,660 gal/ft^2-d and primary influent TSS of 175 mg/L

3.2 Clarifier Optimization Investigation

The calibrated 2Dr model was used to evaluate the following enhancements to improve primary clarifier performance.

- Thin sludge pumping – remove primary sludge at roughly 5,000 mg/L to minimize solids blankets and potential solids/organics carryover in effluent. This approach also reduces the potential of anaerobic conditions creating additional hydrogen sulfide and solubilizing particulate chemical oxygen demand (COD) that would exert an aeration demand in the downstream secondary treatment processes.
- Chain and flight collector – alternative sludge/scum collection technology common in industry for rectangular tanks. These collectors provide a more continuous sweeping of the sludge compared to the existing traveling bridge mechanisms which may improve performance and may be needed for thin sludge pumping.
- Extended launders – instead of the existing effluent weir configuration that spans the width of the tank at the outlet, consider "finger" launders that extend into the tank longitudinally. This modification can reduce the upward velocity to the launder minimizing solids re-suspension and scouring of the sludge blanket. Fingers launders can also be configured to mitigate end wall effects (i.e. flow hits end wall and redirects upward to launder which may pull solids from the sludge blanket as well). Alternatively, the extended launders could be isolated to the tank end and side walls to minimize impacts on the existing collector.
- Inlet baffle – add a full-depth baffle near the tank inlet spanning the entire width. Due to 2Dr limitations the closest the baffle can be simulated at inlet is 13-ft from the tank head wall (eastern wall of tank). The porosity, or percent of openness, of the baffle allows flow through but causes

even flow distribution that limits short circuiting currents that often entrain solids. Adding a baffle at the inlet or downstream requires switching collectors to a chain and flight type. The existing traveling bridge requires absolute clearance throughout the tank to operate.

Figure 3-1 illustrates the potential clarifier enhancements.

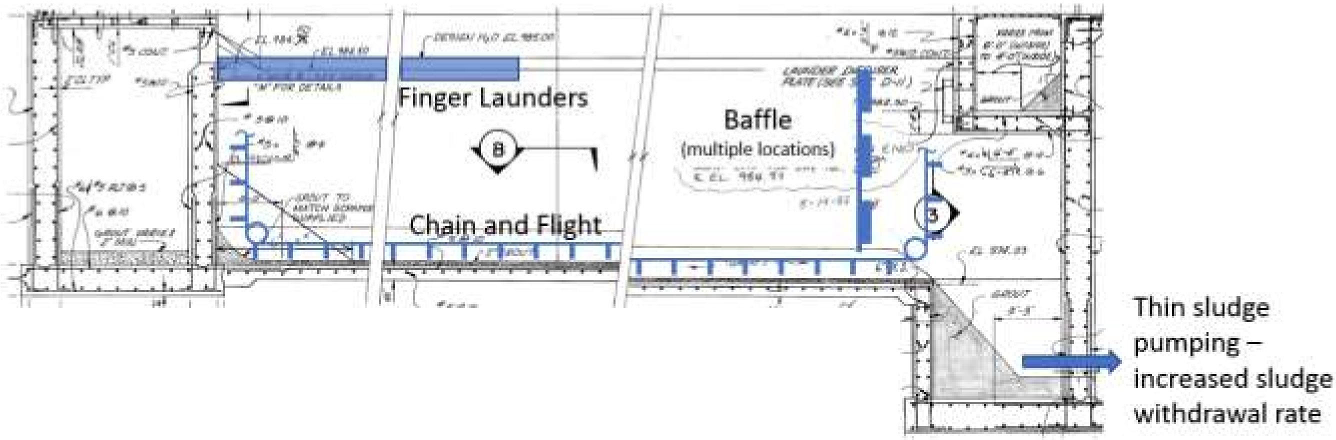

Figure 3-1. Primary Clarifier 1 and 2 potential enhancements to improve performance

Image Source: Kirkham Michael Associates, et al, 1979.

This optimization analysis provides a relative comparison of PE TSS removal and not exact TSS removal since the model assumes equal flow distribution across the clarifier inlet.

Figure 3-2 compares the predicted TSS removal for the existing configuration versus the initial enhancement configurations under maximum month conditions. Thin sludge pumping, achieved in the model by increasing sludge removal rate from 30 gpm to about 140 gpm, did not improve clarifier TSS removal performance. At peak conditions with thin sludge pumping the predicted TSS removal was the same 39 percent as the existing configuration. Combining thin sludge pumping with a chain and flight collector also did not improve TSS removal. Based on these findings thin sludge pumping was not considered further for enhancing clarifier performance though it may be warranted because of other treatment benefits (e.g. reduced sulfide generation observed in primary clarifiers and carbon solubilization in the sludge blanket which would bleed into the secondary treatment process and require additional aeration). Replacing the existing traveling bridge collector with a chain and flight collector mechanism resulted in the same predicted TSS removal and therefore was removed from consideration as a standalone improvement. Extending the effluent launder into the tank to a position equal to one-third of the tank length or adding a 33 percent perforated baffle wall showed the most promise for reducing the PE TSS compared to the existing configuration though from a modeling accuracy standpoint the results were not significantly different. Both enhancements would interfere with the traveling bridge collector and were thus simulated with a chain-and-flight type.

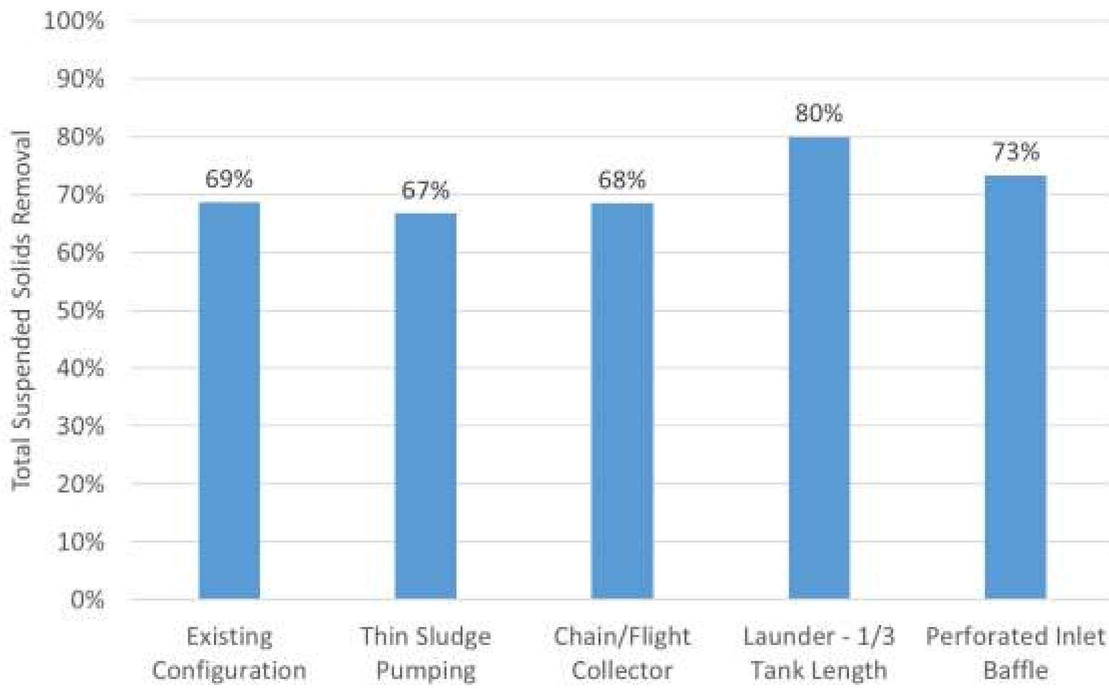

Figure 3-2. Predicted TSS removal for various performance enhancement configurations

(SOR = 475 gal/ft^2-d, ISS = 338 mg/L)

3.2.1 Extended Launder Length

The analysis further explored the extended launder enhancement at different launder lengths. Figure 3-3 compares the predicted TSS removal for extending the launder from one-fourth to one-half of the tank length. At the maximum month conditions, the extended launder provides similar TSS reduction for all lengths investigated compared to the existing configuration. The slight improvement in predicted TSS removal with the launder extensions is marginal considering the collector modifications required to accommodate the revised configuration.

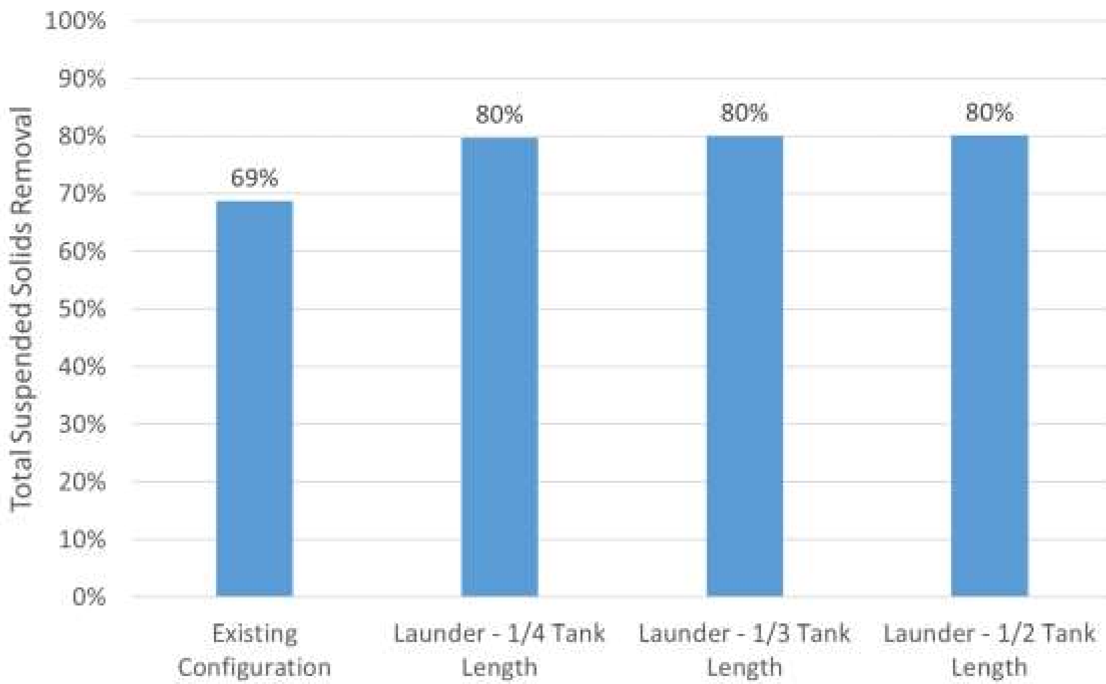

Figure 3-3. Predicted TSS removal for various launder extension lengths

(SOR = 475 gal/ft²-d, ISS = 338 mg/L)

3.2.2 Perforated Baffle Wall

Several additional perforated baffle arrangements were investigated to see if primary clarifier performance could be further improved. Figure 3-4 compares the predicted TSS removal when varying the porosity of the baffle wall over a range from 17 to 50 percent. The analysis identified the optimal porosity between 25 and 33 percent which would improve the predicted TSS removal from 69 to 73 percent at maximum month conditions. In general, the predicted TSS removal for all baffle porosities was not significantly different from a modeling perspective.

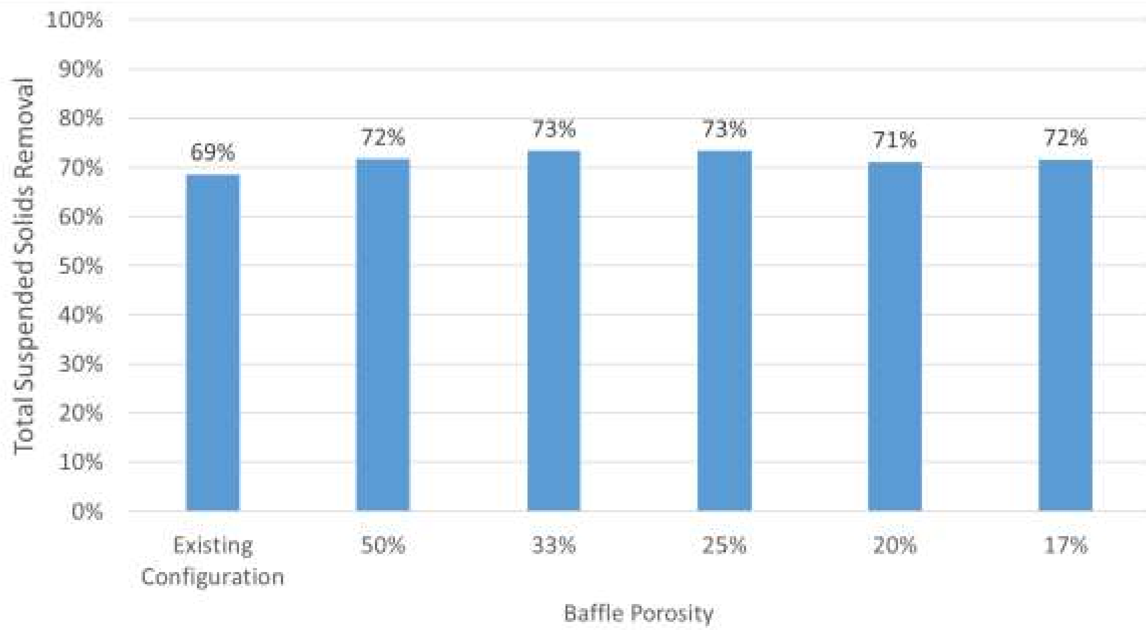

Figure 3-4. Predicted TSS removal for various inlet baffle porosity

(SOR = 475 gal/ft²-d, influent TSS = 338 mg/L)

In addition, the baffle wall location was evaluated to determine if moving the wall further into the tank could improve performance. Figure 3-5 compares the predicted TSS removal results with a 33 percent porosity baffle located over the range of 13 (inlet) to 48 feet (4 to 15 meters) from the eastern tank wall. The analysis identified the optimal baffle location at about 25 feet from the eastern tank wall. The full-height baffle requires switching to a chain-and-flight collector since the existing traveling bridge requires a completely open tank. The predicted increase in TSS removal is marginal when considering the required modifications to the collector mechanism.

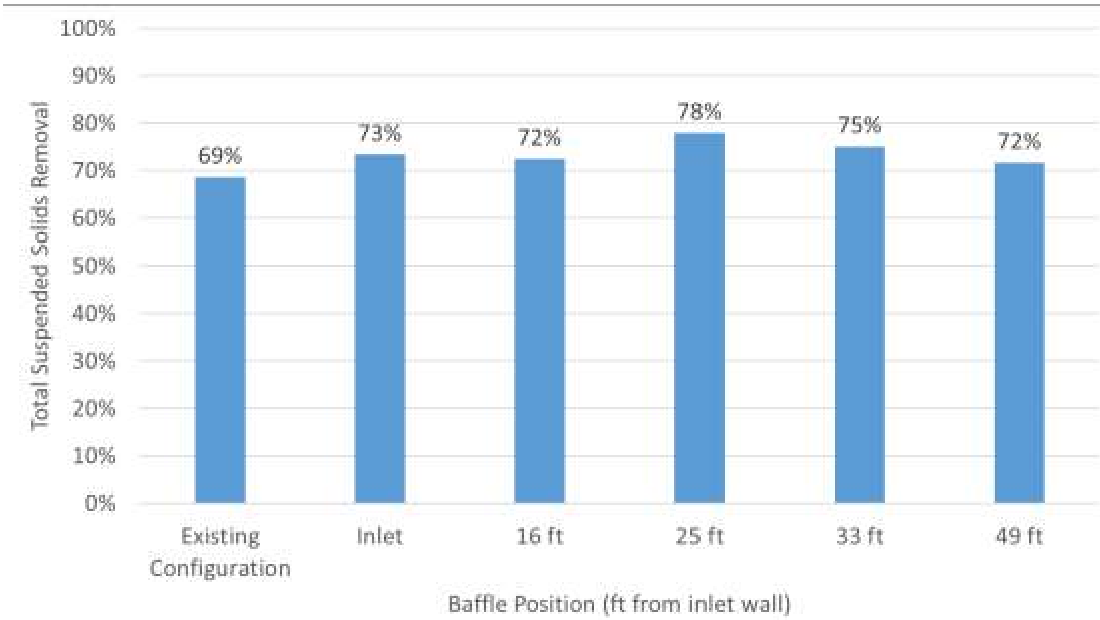

Figure 3-5. Predicted TSS removal for various baffle locations

(33 percent baffle porosity, SOR = 475 gal/ft²-d, influent TSS = 338 mg/L)

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3.2.3 Enhancement Combinations

Once the analysis identified the optimal configurations of the launder extension and baffle enhancements, combinations of the two were modeled. Figure 3-6 shows that when combined the predicted PE TSS removal remains the same or drops compared to the individual enhancements alone at maximum month conditions.

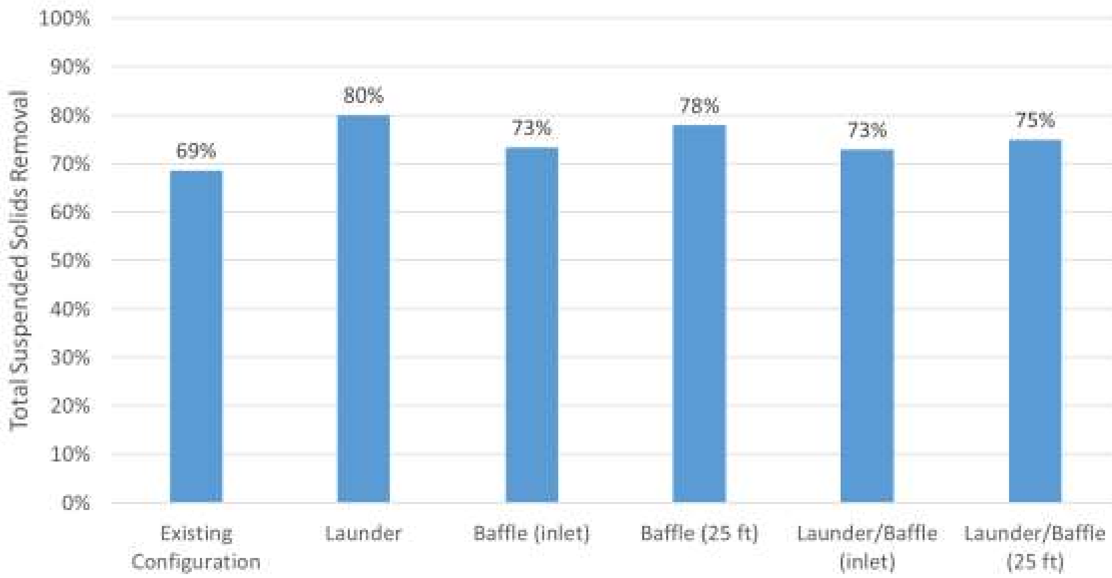

Figure 3-6. Predicted TSS removal for combined enhancements or alone

("Launder" = ½ length of tank, "Baffle" = 33 percent porosity baffle with distance from inlet wall noted, SOR = 475 gal/ft^2-d, influent TSS = 338 mg/L)

The analysis also looked at the primary clarifier TSS removal performance of extending the launder to half the tank length and full-height perforated baffles at peak loadings conditions as shown in Figure 3-7. The launder enhancement predicted TSS removal is the same as the existing configuration due to high flow sweeping solids to the launder. The baffle simulations perform better though, almost the same regardless of location or whether the launder modification is included. So, the baffle alone at the inlet will provide the greatest benefit over the range of conditions considered and a launder extension is not recommended.

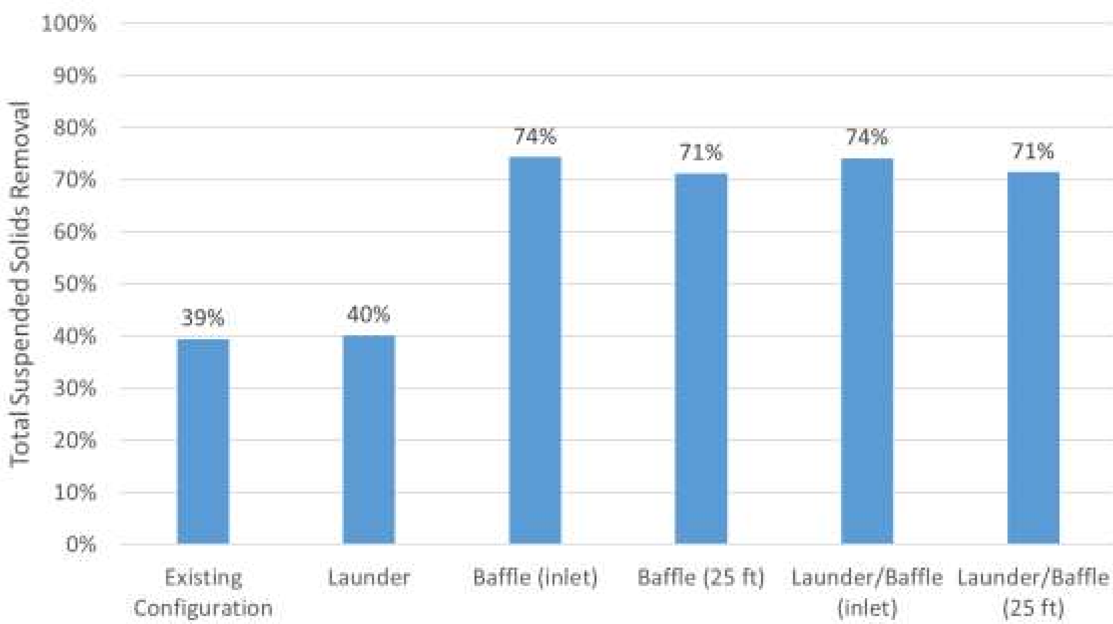

Figure 3-7. Predicted TSS removal for combined enhancements or alone

("Launder" = ½ length of tank, "Baffle" = 33 percent porosity baffle with distance from inlet wall noted, SOR = 1,660 gal/ft²-d, influent TSS = 175 mg/L)

3.2.4 Diffuser Baffle

Based on City staff's comments regarding their preference to not install chain-and-flight sludge collectors another small diffuser baffle was investigated that would work with the existing travelling bridge collector. The diffuser baffle would replace the existing diffuser plates with a perforated baffle but only extending to the bottom of the inlet channel. The diffuser baffle would be porous to mitigate flow from streaming to the surface or to the sludge blanket at the bottom. Figure 3-8 illustrates the conceptual diffuser baffle arrangement. Figure 3-9 shows the predicted TSS removal rates for various porosity diffuser baffles. All baffle porosities provided an improvement over the existing configuration at maximum month and peak conditions. The 50 percent porosity baffle model predicted the highest and most consistent TSS removal rates.

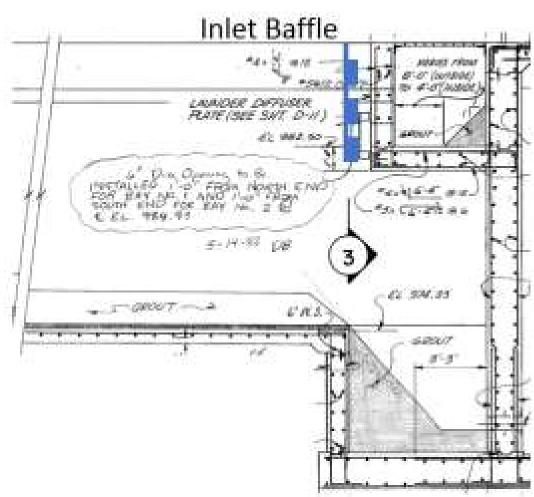

Figure 3-8. Primary Clarifier 1 and 2 diffuser baffle

Image Source: Kirkham Michael Associates, et al, 1979.

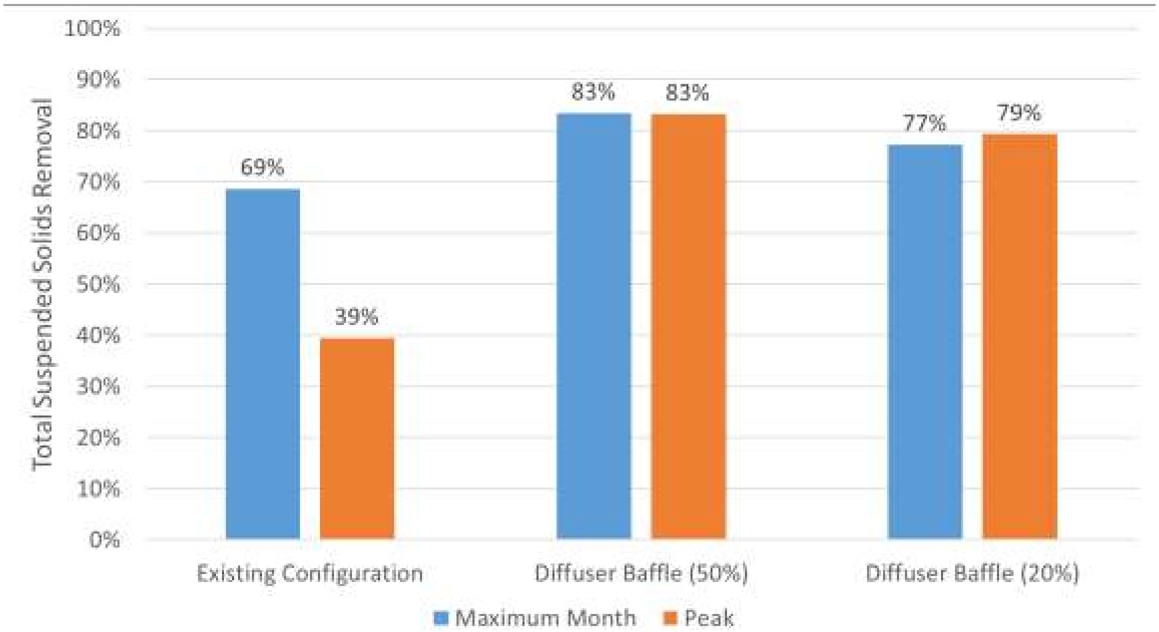

Figure 3-9. Predicted TSS removal for various diffuser baffle porosities at maximum month and peak conditions

(Maximum Month: SOR = 475 gal/ft²-d, influent TSS = 338 mg/L – Peak: SOR = 1,660 gal/ft²-d, influent TSS = 175 mg/L)

Section 4: Three-Dimensional Hydraulic Evaluation

As noted in Section 2 above, BC observed uneven flow and solids distribution during the clarifier stress test at higher SORs. To evaluate existing flow patterns in the primary clarifier influent channels and clarifier, how to evenly distribute flow across the primary clarifier, and the practicality of the diffuser baffle described in Section 3.2.4, the 3D hydraulic CFD modeling software (FLUENT) from ANSYS was used. The 3D CFD model is limited to hydraulic considerations as the sludge settling characteristics are not accounted for in the simulation.

4.1 Existing Conditions

During the field test BC observed a swirling pattern on the tank surface at peak flow conditions and uneven solids blanket distribution as noted above. Circulatory currents in primary clarifiers are undesirable as they may resuspend settled solids or effectively create dead zones which in turn result in higher velocities or short circuiting in the forward flowing portions of the tank. Figure 4-1 represents the graphical output of the 3D model simulated with peak flow conditions (i.e. 16.6 mgd per clarifier). The large predicted recirculation zone closely matches what was observed in the field.

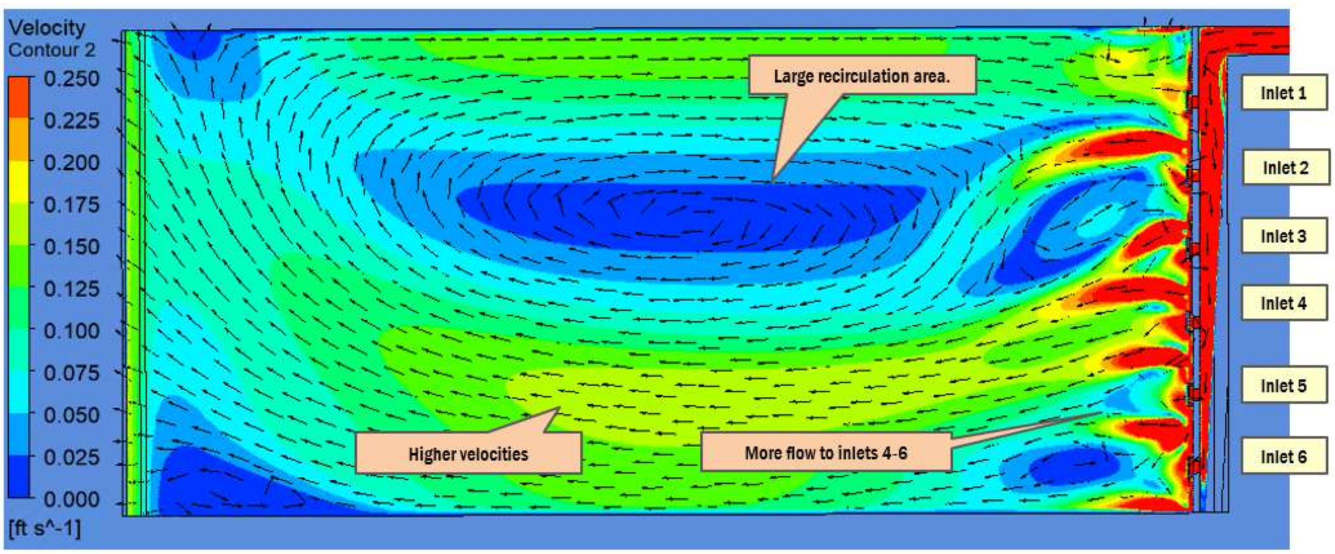

Figure 4-1. Primary Clarifier 2 predicted swirling action during peak flow conditions

(SOR = 1,660 gal/ft²-d)

Further analysis suggested the large recirculation zone results from poor flow distribution into the tank as well as momentum of flow as it enters the tank. The inlet channel on the east end of the tank conveys flow across the tank width. Along the channel six 1-ft tall by 1.7-ft wide rectangular ports allow a portion of the flow to enter the tank. The 3D CFD model predicts flow imbalances amongst the six inlet ports with the majority entering the tank at the furthest downstream ports (Inlets 5 and 6). Figure 4-2 summarizes the relative flow balance of each inlet port with a negative value representing the percentage under the equal flow split level.

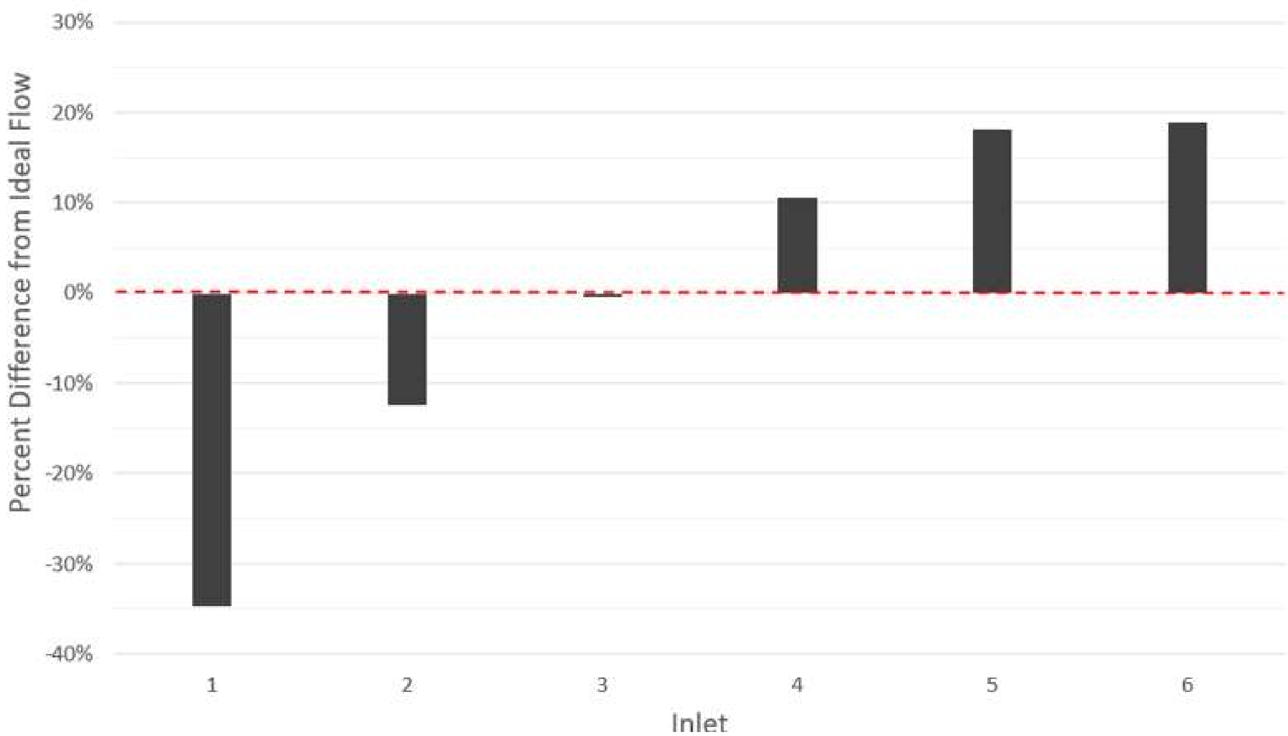

Figure 4-2. Primary Clarifier 2 predicted inlet port flow distribution

(SOR = 1,660 gal/ft²-d)

4.2 Inlet Channel Evaluation

Using the existing configuration as a baseline, additional 3D CFD modeling looked at different modifications to promote better flow distribution into the clarifier. The evaluation considered two modifications. The first looked at various arrangements of stub baffles placed in the inlet channel flush with the downstream inlet port opening wall that would disrupt the flow pattern and affect a more equal distribution. Figure 4-3 shows an example of stub baffles in the inlet channel. The second modification constricted the inlet port opening at the downstream end of the inlet channel to force more flow through the upstream ports. Table 4-1 summarizes the modification configurations investigated.

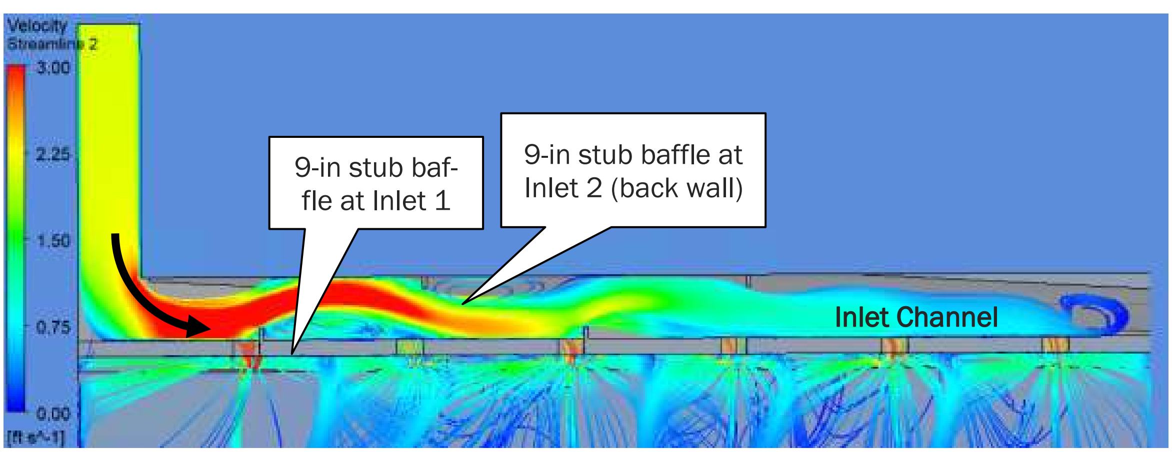

Figure 4-3. Primary Clarifier 2 inlet channel stub baffle configuration – Scenario 4

(SOR = 1,660 gal/ft²-d)

Table 4-1. Rochester Primary Clarifier Influent Channel Modifications Evaluated							
Scenario	Description	Inlet 1	Inlet 2	Inlet 3	Inlet 4	Inlet 5	Inlet 6
1	Stub baffles on inlet side of channel (first three inlets only)	0.75 ft	1 ft	1.25 ft	none	none	none
2	Stub baffles staggered in channel (first three inlets only)	1.25 ft (inlet side)	1.5 ft (opposite side)	1.25 ft (inlet side)	none	none	none
3	Partially closed inlets	Open	Open	20 percent closed	20 percent closed	30 percent closed	30 percent closed
4	Stub baffles staggered (entire length of channel)	0.75 ft stub (inlet side)	0.75 ft stub (opposite side)	0.75 ft stub (inlet side)	0.75 ft stub (opposite side)	none	none

Scenario 4 provides the best flow balance as shown in Figure 4-4. The CFD model for Scenario 4 predicts influent flow balance within 7 percent of a perfect flow distribution. Scenario 4 includes four 0.75-ft stub baffles staggered along the channel as shown in Figure 4-3. The stub baffles are located along the influent channel just on the downstream side of the inlets and are staggered from the inlet side to the opposite side. The stub baffles disrupt the flow stream and prevent the preferential discharge through the last two inlets like the existing, or baseline, configuration at peak conditions. This evaluation did not look at the head loss added by the stub baffles which must be analyzed prior to installation.

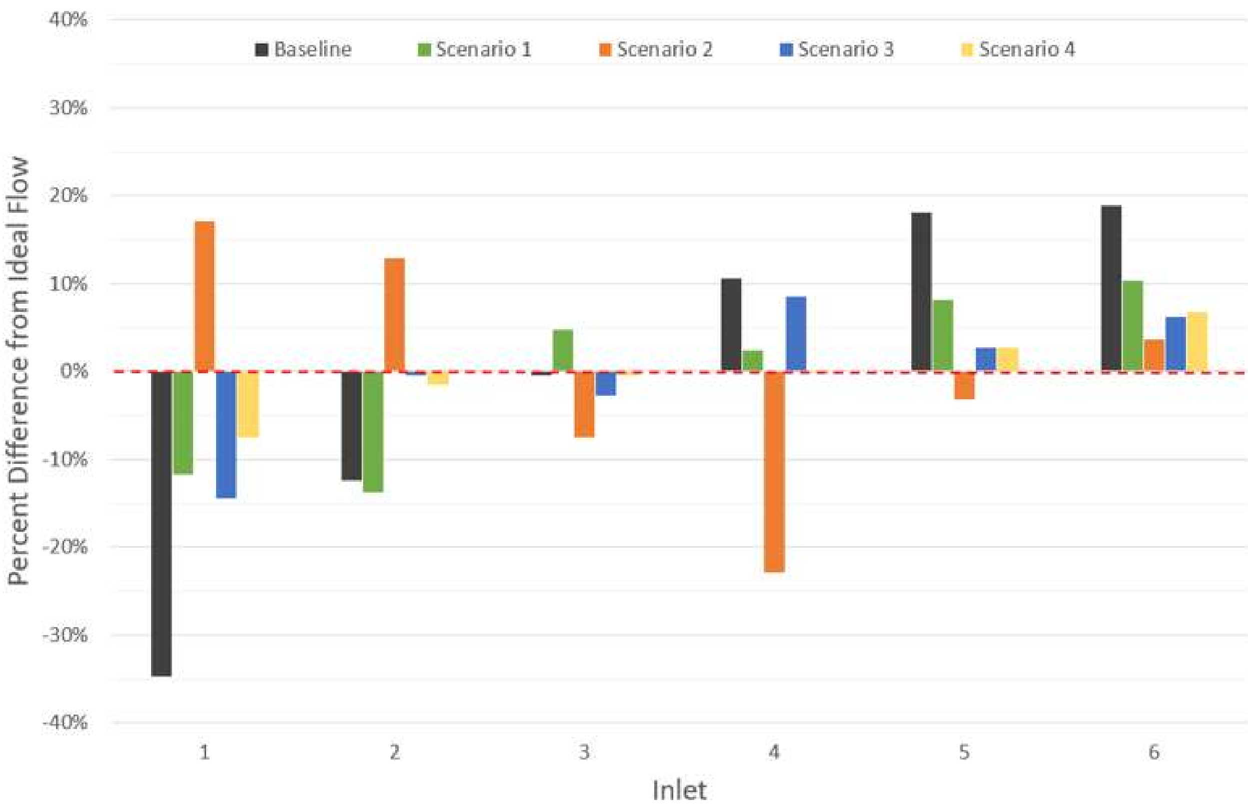

Figure 4-4. Primary Clarifier 2 predicted inlet channel flow distribution

(SOR = 1,660 gal/ft^2-d)

4.3 Diffuser Baffle Evaluation

Based on the 2Dr work in Section 3, this evaluation used the 3D CFD model to evaluate a diffuser baffle near the inlet channel spanning the entire width of the tank. To accommodate the traveling bridge sludge collector travel extents the inlet baffle would be located within about 1-ft of the inlet channel wall face. Also, the baffle would not extend below the inlet channel as the sludge collector structure extends under this area when transporting sludge to the sludge hopper.

BC experience with other tank inlet structures warranted the addition of bottom plates underneath the inlet to prevent downward jets and maintaining a plate in front of the inlet to avoid jetting into the tank. Figure 4-5 shows the inlet configuration used in the 3D CFD model with a 40 percent open area. The 40 percent open area was used in lieu of the 50 percent investigated with 2Dr as a caution in case the structural rigidity of the baffle with the higher openness was an issue. Note that2Dr can only model specified baffle porosities (i.e. 25, 33, 50, etc. percent).

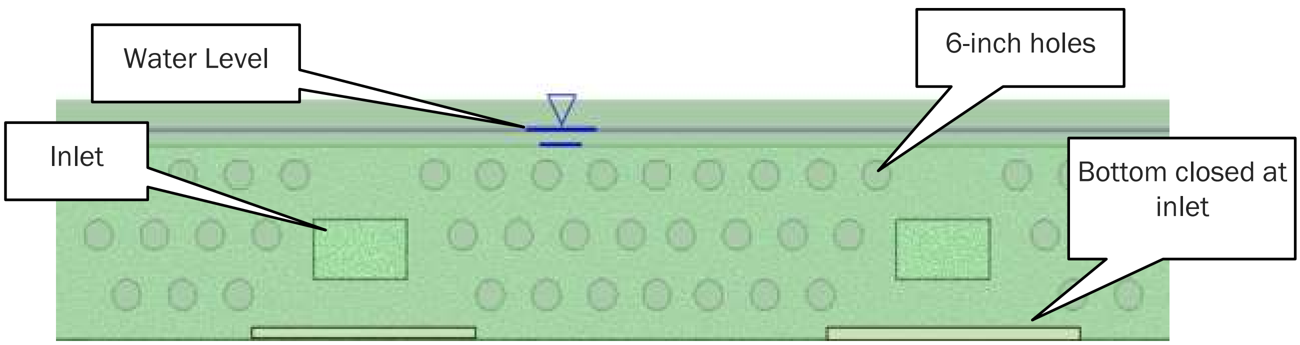

Figure 4-5. Inlet baffle configuration used in 3D CFD model

Including the inlet channel stub baffles and proposed diffuser baffle improvements in Figures 4-3 and 4-5 respectively, the model predicted undesirable recirculation zones in the tank at peak conditions as shown in Figure 4-6. Significant downward jets were also predicted from the inlets despite the bottom plates as shown in Figure 4-7. The flow also still favors the south side of tank as indicated by the concentration of stream lines on the tank's south side in Figure 4-6. The collection of flow on the south side appears to result from downward jets from the inlets pushing flow to the south, see red plumes between inlet bottom plates in Figure 4-7.

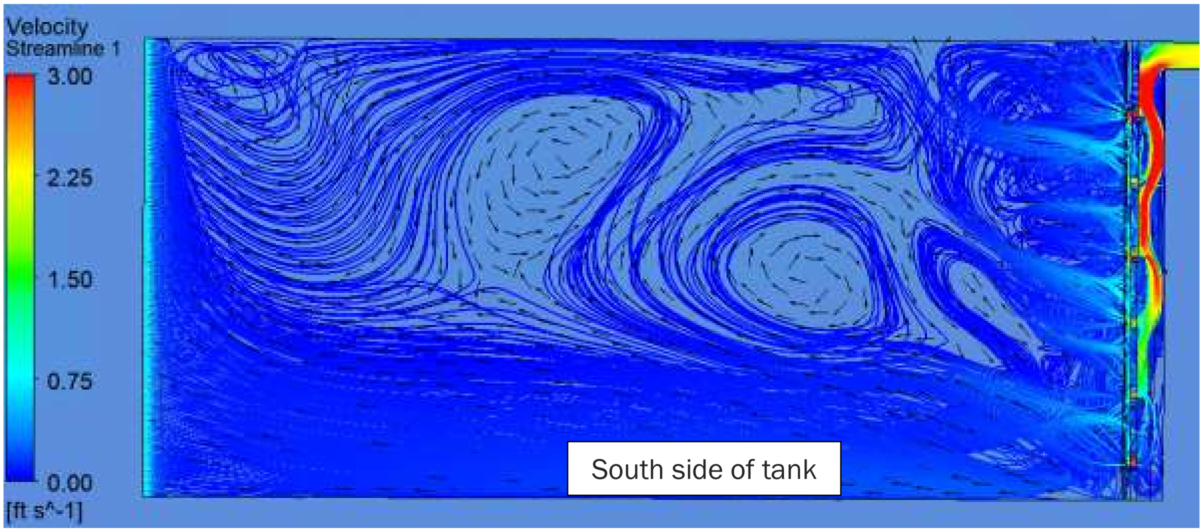

Figure 4-6. Primary Clarifier 2 inlet baffle model predicted stream lines – plan view

(SOR = 1,660 gal/ft²-d)

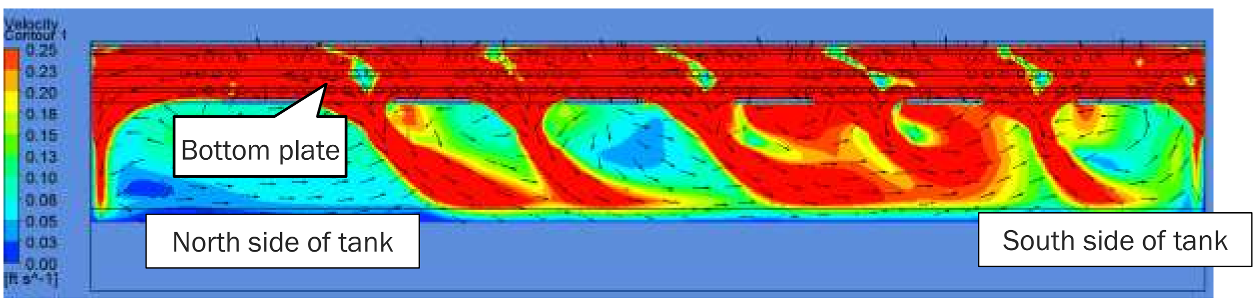

Figure 4-7. Primary Clarifier 2 inlet baffle model predicted stream lines – section view

(SOR = 1,660 gal/ft²-d)

The full width diffuser baffle did not provide significant flow distribution improvements. However, since the 2Dr analysis showed improvements with baffling this evaluation looked at alternative configurations of the existing diffuser plate.

4.4 Diffuser Plate Evaluation

The existing configuration includes a diffuser plate on the tank side of the inlet channel wall at each inlet port. Figures 4-8 and 4-9 shows the existing diffuser plates. The objective of the diffuser plate is to prevent flow from jetting into the tank and straight to the effluent weir. The open sides of the diffuser plates do cause jetting to the surface (Figure 2-12) and bottom which may stir up the sludge blanket which was predicted by the model too as shown in Figure 4-10. Since 2Dr predicted improved performance with a porous baffle this evaluation looked at modifying the diffuser plates.

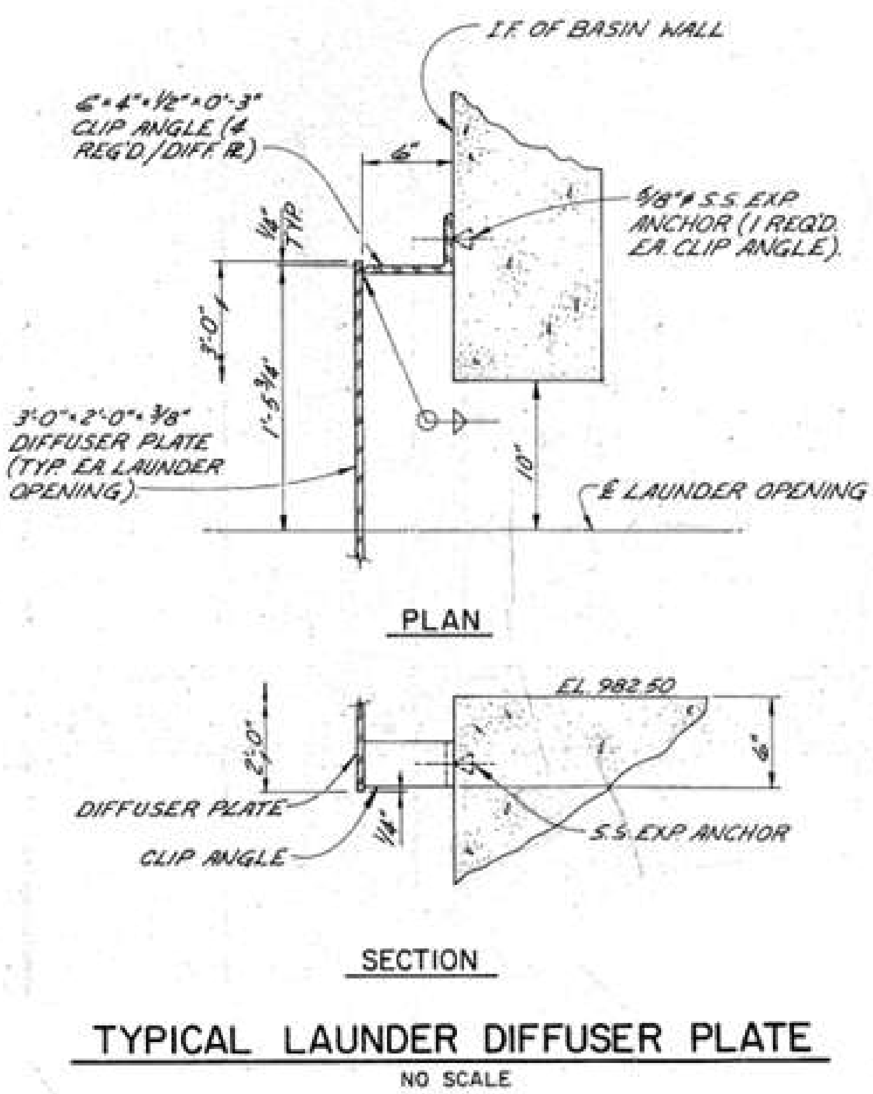

Figure 4-8. Existing diffuser plate details

Image Source: Kirkham Michael Associates, et al, 1979.

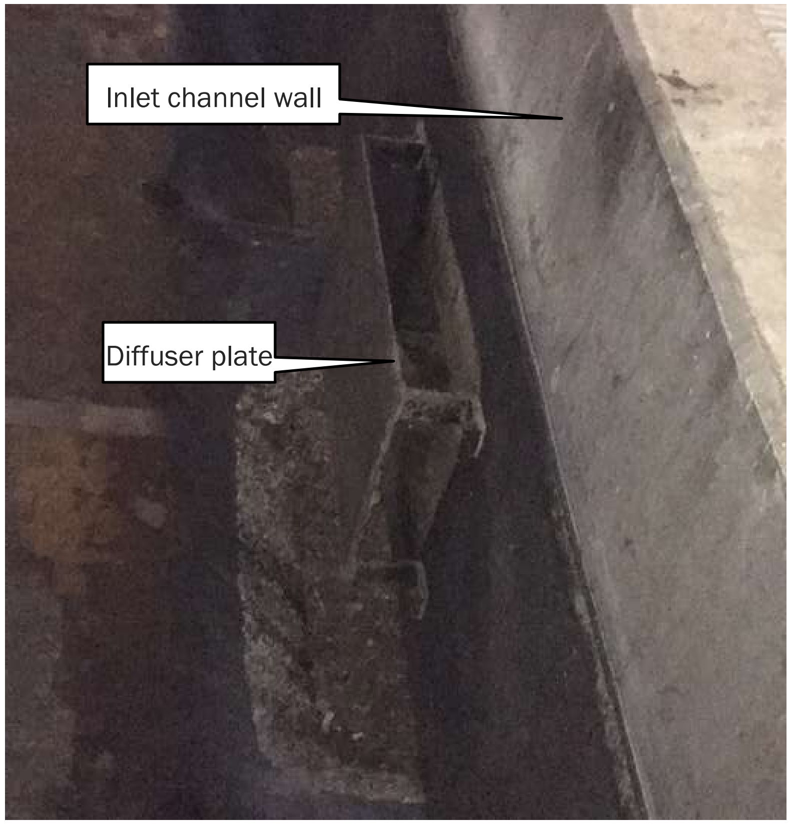

Figure 4-9. Existing diffuser plate photograph

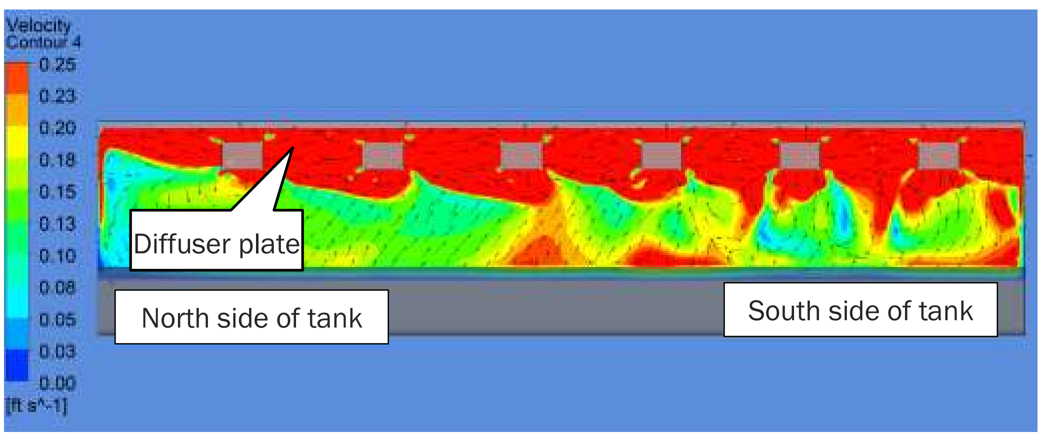

Figure 4-10. Primary Clarifier 2 existing diffuser plates – section view

(SOR = 1,660 gal/ft^2-d)

This evaluation looked at two alternative diffuser plate modifications. Alternative 1 closes off the sides of the diffuser plate to eliminate side jetting that forced flow to the south side of the tank. Two openings were also added to the diffuser plate face to allow some restricted flow forward, see Figure 4-11.

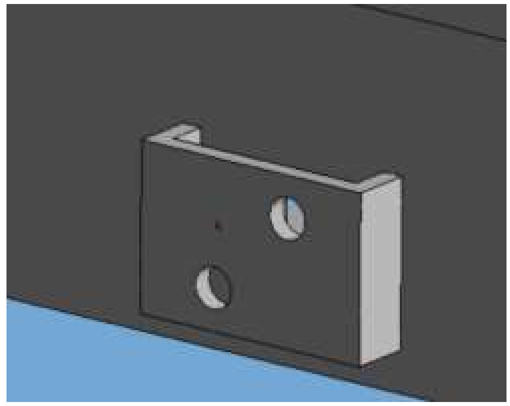

Figure 4-11. Alternative 1 diffuser plate configuration

When simulated in the 3D CFD model at peak conditions, Alternative 1 predicted flow patterns pushed flow to the bottom of the tank near the sludge hopper. See Figure 4-12 for the model graphical output of the stream lines.

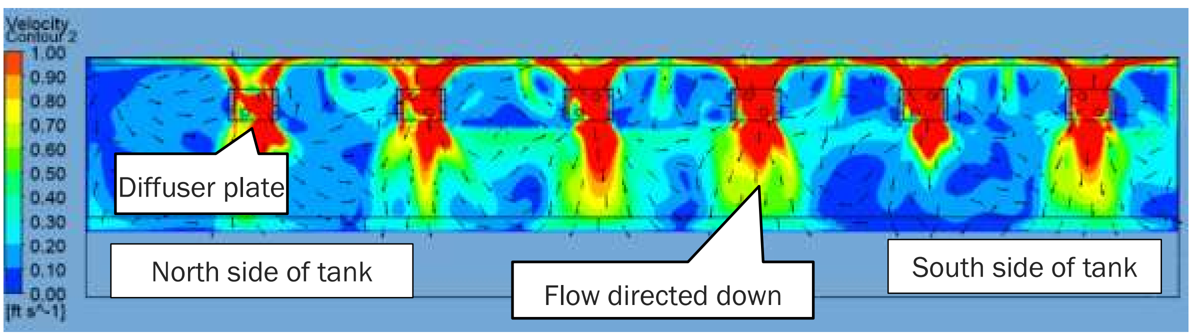

Figure 4-12. Primary Clarifier 2 diffuser plate Alternative 1 stream lines – section view

(SOR = 1,660 gal/ft2-d)

Alternative 2 shifts the diffuser plate down and incorporates a single opening in the face with a fully closed bottom and partially closed sides as shown in Figure 4-13. This configuration is intended to spread the flow out in several directions and dissipate energy.

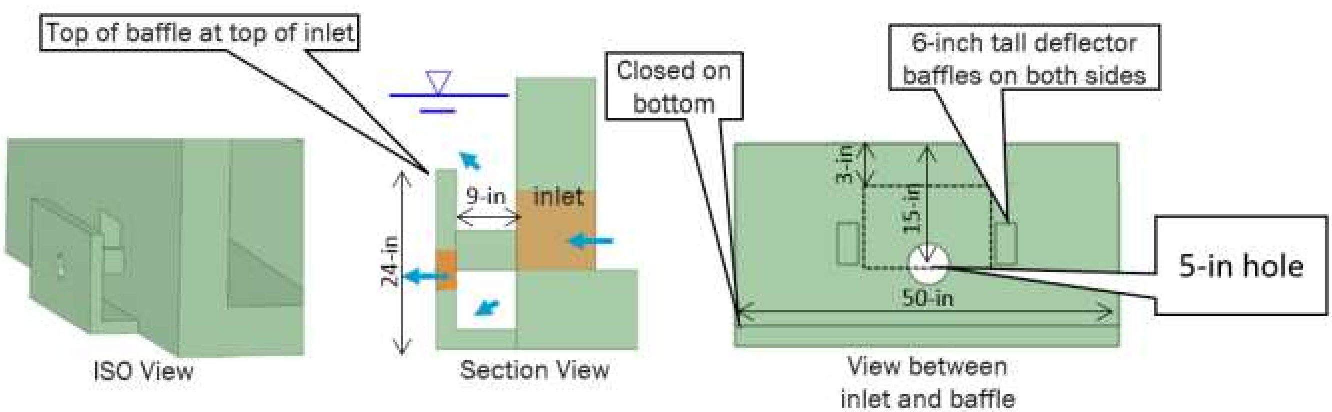

Figure 4-13. Alternative 2 diffuser plate configuration

When combined with the proposed inlet stub baffles, Alternative 2 resulted in the greatest recirculation current reduction in the tank as shown in Figure 4-14. The closed bottom of the diffuser plates also eliminated downward jetting as shown in Figure 4-15.

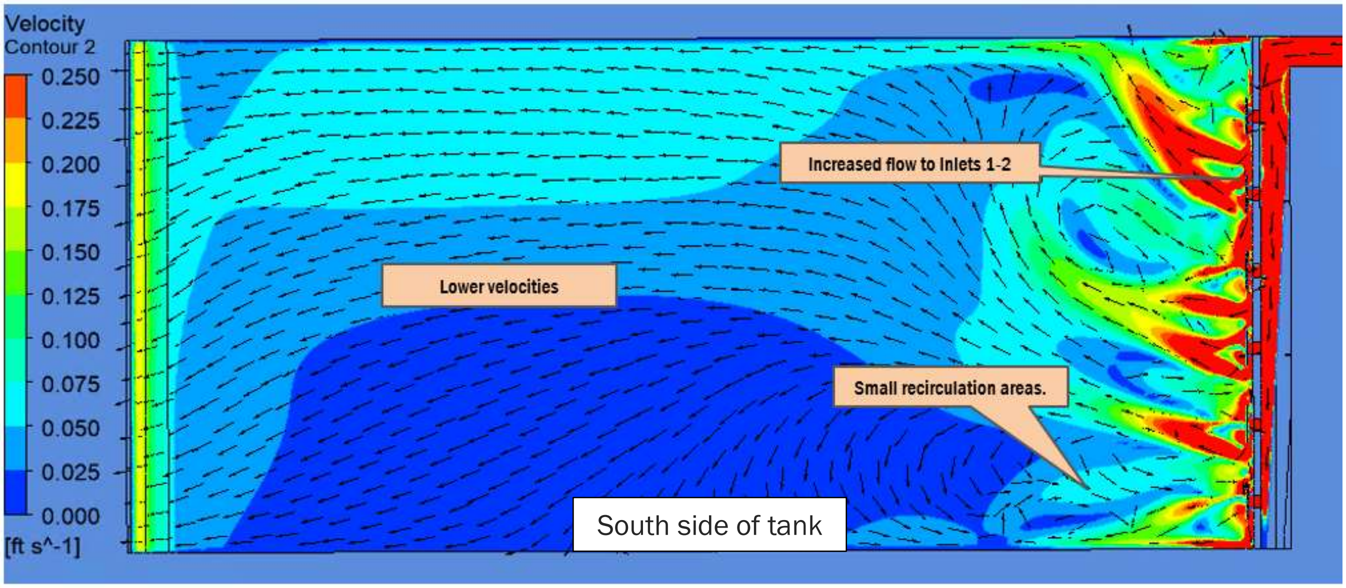

Figure 4-14. Primary Clarifier 2 diffuser plate Alternative 2 stream lines – plan view (includes inlet stub baffles)

(SOR = 1,660 gal/ft2-d)

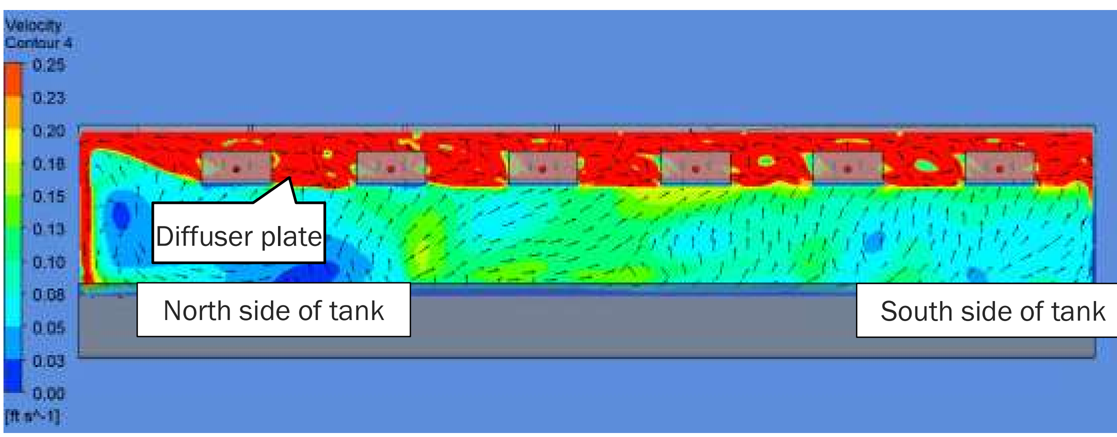

Figure 4-15. Primary Clarifier 2 diffuser plate Alternative 2 stream lines – section view (includes inlet stub baffles)

(SOR = 1,660 gal/ft^2-d)

The Alternative 2 diffuser plate 3D CFD simulation predicts significant improvements in tank hydraulics and BC recommends it for further consideration. The diffuser plate modified configuration may impose additional head loss and needs to be analyzed.

4.5 End Wall Baffle Evaluation

BC conducted an additional evaluation of a Crosby type baffle at the end wall of the tank using the 3D CFD model. A Crosby type baffle projects into the tank off the end wall at a downward 45-degree angle with the intention of stopping current flowing up the end wall and bringing solids from the sludge blanket to the effluent weir. Figure 4-16 shows the velocity contours of the existing configuration at the end wall. A red shaded area indicates a higher velocity than blues or greens. The 3D CFD model does not predict a significant end wall current while the highest velocities are at the effluent weir.

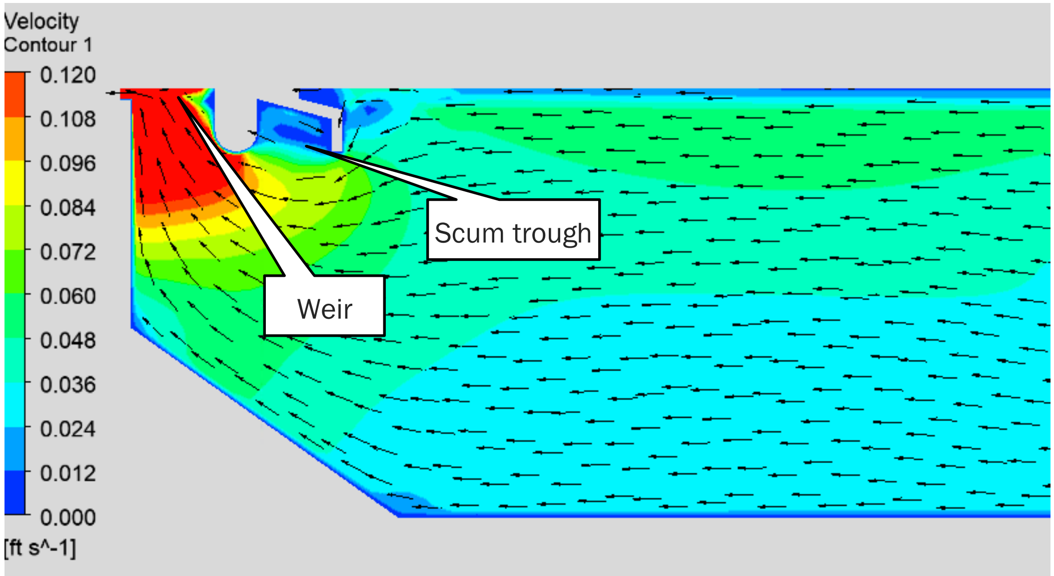

Figure 4-16. Primary Clarifier 2 existing end wall configuration velocity profile – section view

(SOR = 1,660 gal/ft²-d)

As shown in Figure 4-17 the model did not predict an improved velocity profile when including the Crosby type baffle. The red velocity region indicates the effluent weir still has relatively high velocities. The Crosby type baffle was not further considered.

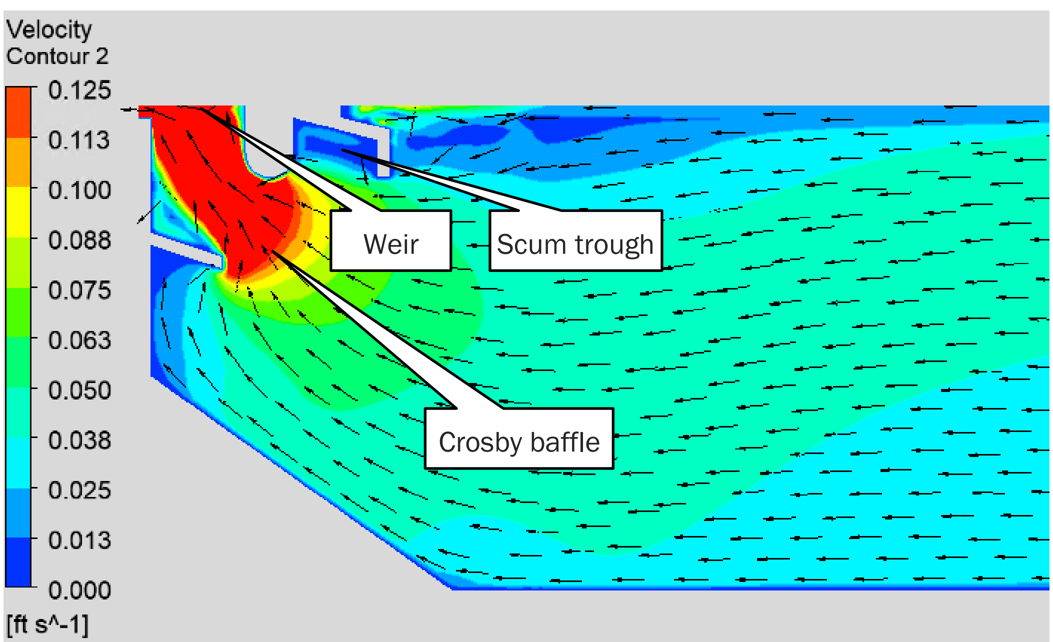

Figure 4-17. Primary Clarifier 2 end wall with Crosby type baffle velocity profile – section view

(SOR = 1,660 gal/ft²-d)

Section 5: Chemical Oxygen Demand Investigation

During the stress testing of Primary Clarifier 2 BC collected influent and effluent samples every 30 minutes for COD analysis. BC split each sample for total and filtered COD analyses and field filtered samples for filtered (soluble) COD analysis. The filtered samples were passed through a 1.5 micro-meter (µm) glass fiber filter to remove particulate material. Figure 5-1 and 5-2 show the results of the COD sampling during the stress test. The influent total COD concentration followed the rise and fall of the SOR (see Figure 2-4). This trend suggests that the influent sewers were scoured when emptied to provide adequate flow to the clarifier for stress testing purposes. The influent filtered COD followed a similar trend though not as concisely. The effluent total COD analyses showed some removal across the primary clarifier but varied from no removal to about 50 percent. Effluent filtered COD analyses showed no consistent loss or gain across the primary clarifier.

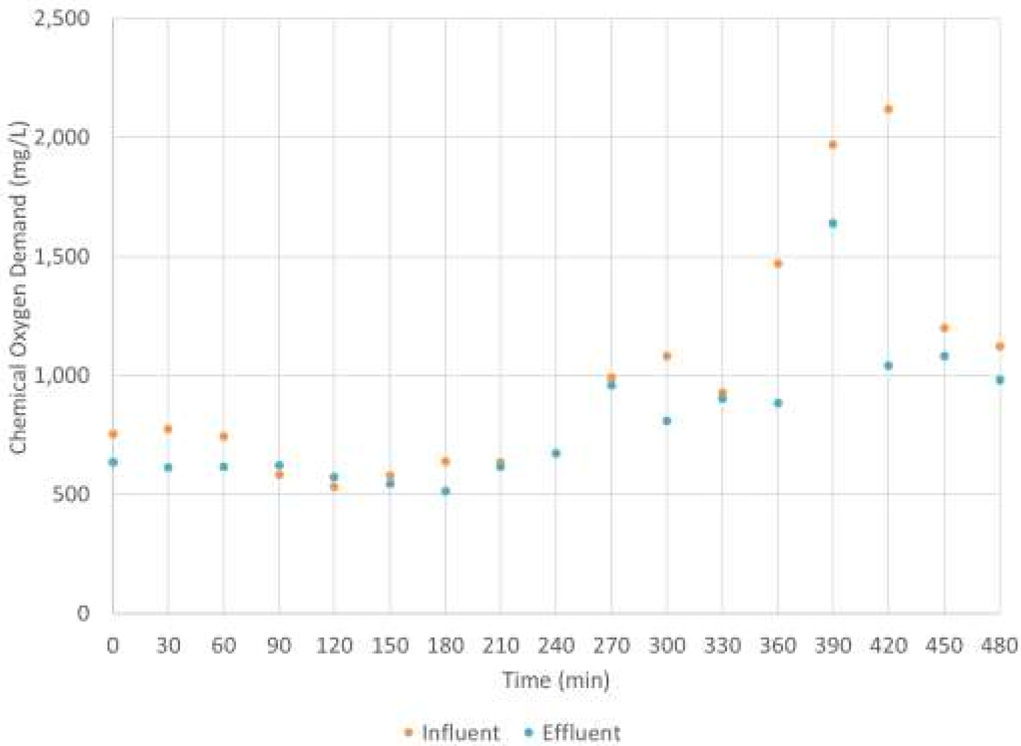

Figure 5-1. Stress test Primary Clarifier 2 influent and effluent total COD

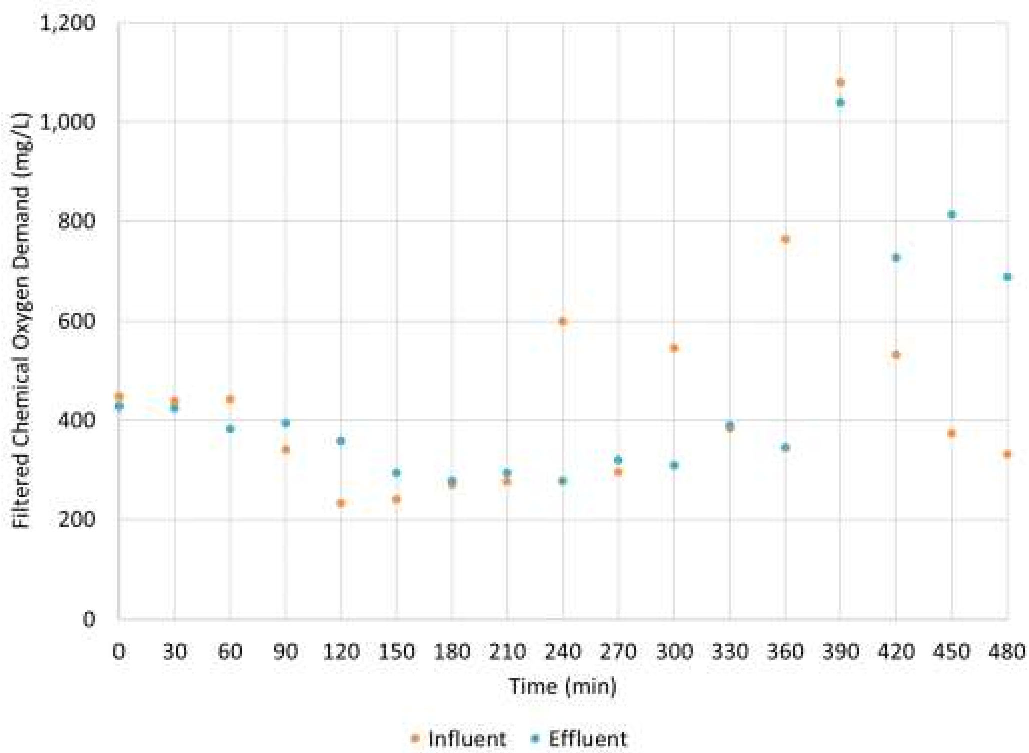

Figure 5-2. Stress test Primary Clarifier 2 influent and effluent filtered COD

Table 5-1 shows the average total COD removal during the first 60 minutes of the stress test when the test SOR was around the 475 gal/ft^2-d maximum month design SOR. During this initial period the total COD and TSS removals average 18 and 59 percent, respectively, as shown in Table 5-1.

Table 5-1. Rochester Primary Clarifier COD and TSS Removal Results without Ferric Chloride Addition

Sample Time (min)	Total COD			TSS		
	Influent (mg/L)	Effluent (mg/L)	Capture (%)	Influent (mg/L)	Effluent (mg/L)	Capture (%)
0	752	636	15	280	112	60
30	776	614	21	240	108	55
60	743	616	17	236	88	63
Average	757	622	18	252	103	59

This COD investigation was conducted without ferric chloride addition to establish a baseline performance in case future operations ceased adding ferric chloride to the primary clarifiers. Without ferric chloride addition TSS and COD removal will decrease. As a point of comparison, the 2017 Rochester WRP BioWin™ model calibration with ferric chloride addition used an average TSS removal of 67 percent with a resulting COD removal of 45 percent (BC 2018b). The significant difference in COD removal is dominated by the additional colloidal COD removal with ferric addition and to a lesser extent the increased TSS/particulate removal. The reduced COD and TSS captures measured here will be considered for liquid treatment alternative evaluations not utilizing ferric chloride addition to Primary Clarifiers 1 and 2.

Section 6: Recommendations

If a gravity thickener is added, BC recommends increasing the primary sludge pumping rate and overall capacity to provide the capabilities to pump thinner sludge despite the 2Dr model not predicting a TSS removal increase. Increasing the pumping rate will minimize the potential for solids carryover at high SORs, minimize sulfide generation in the primary clarifiers, and minimize sulfide levels in the primary clarifiers with or without ferric chloride addition. Extended launders and full-height baffles offer benefit at higher SORs however replacement of the existing traveling bridge to accommodate these enhancements is required and locating perimeter launders on the tank walls may not result in the same benefit as modeled. Based on the City staff's preference to stay with the traveling bridge collectors and the significant capital cost to replace the collectors and install the enhancements, this analysis does not recommend extending the launders or adding a full-height baffle.

2Dr modeling showed adding a diffuser baffle to the internal vertical face of the inlet channel could increase TSS removal provided the influent flow could be evenly distributed across the tank. Detailed 3D CFD modeling of the recommended diffuser baffle showed undesirable circulating currents in the tank and was therefore removed from consideration. Additional investigations with the 3D CFD model shows coupling stub walls in the inlet channel and a modified diffuser plate significantly reduces circulatory flow patterns in the tank and better distributes flow amongst the six inlet ports. BC recommends adding temporary stub walls to the inlet channel to observe the flow distribution and measured solids blanket distribution in the clarifiers prior to implementing full scale improvements and if successful fully evaluate the hydraulic impacts of adding the baffles/proposed inlet structure.

Long term plans eliminate ferric chloride addition to Primary Clarifiers 1 and 2 during normal conditions. Ferric chloride addition increases the TSS capture rate of the clarifiers but will not be required on a typical basis. Nevertheless, BC recommends keeping the ferric chloride addition capacity to the primary clarifiers for upset conditions.

Section 7: References

Brown and Caldwell (BC). 2018a. *Water Reclamation Plant Facilities Plan Influent Flows and Loadings.* July 3, 2018.

BC. 2018b. *Water Reclamation Plant Facilities Plan Wastewater Characterization and BioWin Calibration Technical Memorandum.* September 7, 2018.

BC. 2018c. *Water Reclamation Plant Facilities Plan Final Clarifier Computational Fluid Dynamics Modeling.* September 20, 2018.

Google Earth. 2018. Various aerial photographs/maps (accessed online September 2018).

Kirkham Michael & Associates, Wallace Holland Kestler Schmitz & Company. 1979. Advanced Wastewater Treatment Rochester, Minnesota Water Reclamation Plant. November 19.

Attachment A: Rochester WRP Primary Clarifier Test Plan

30 East 7th Street, Suite 2500
Saint Paul, MN 55101
T: 651.298.0710

Primary Clarifier Field Testing Workplan

Prepared for:	City of Rochester Water Reclamation Plant
Project Title:	WRP Facilities Plan
Project No.:	150811
Subject:	Primary Clarifier Field Testing Workplan
Date:	June 26, 2017
To:	Matt Baker, P.E. Project Manager
From:	Harold Voth, P.E. Project Manager
Prepared by:	Lloyd Winchell, P.E, Process Engineer
	Don Esping, P.E., Senior Process Engineer
Reviewed by:	Jose Jimenez, Ph.D, Senior Process Engineer

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Section 1: Introduction

The City of Rochester (City) is currently planning to evaluate different biological nutrient removal (BNR) scenarios as part of its facilities planning efforts at the Water Reclamation Plant (WRP). A key to defining the BNR facility improvements is to define the primary clarifier performance. This test plan provides an overview of the testing procedures and assistance required from the City for field testing one of the high purity oxygen activated sludge (HPOAS) train primary clarifiers (Primary Clarifier 1 or Primary Clarifier 2).

The WRP HPOAS train provides primary clarification with two 147 feet long by 68-feet wide rectangular clarifiers with 10 -foot side water depths. Sludge from the primary clarifiers (PC) is removed by traveling bridge collector/scraper mechanisms which move sludge to a withdrawal hopper at the inlet of the tank. Figure 1-1 identifies the primary clarifier location on the WRP site.

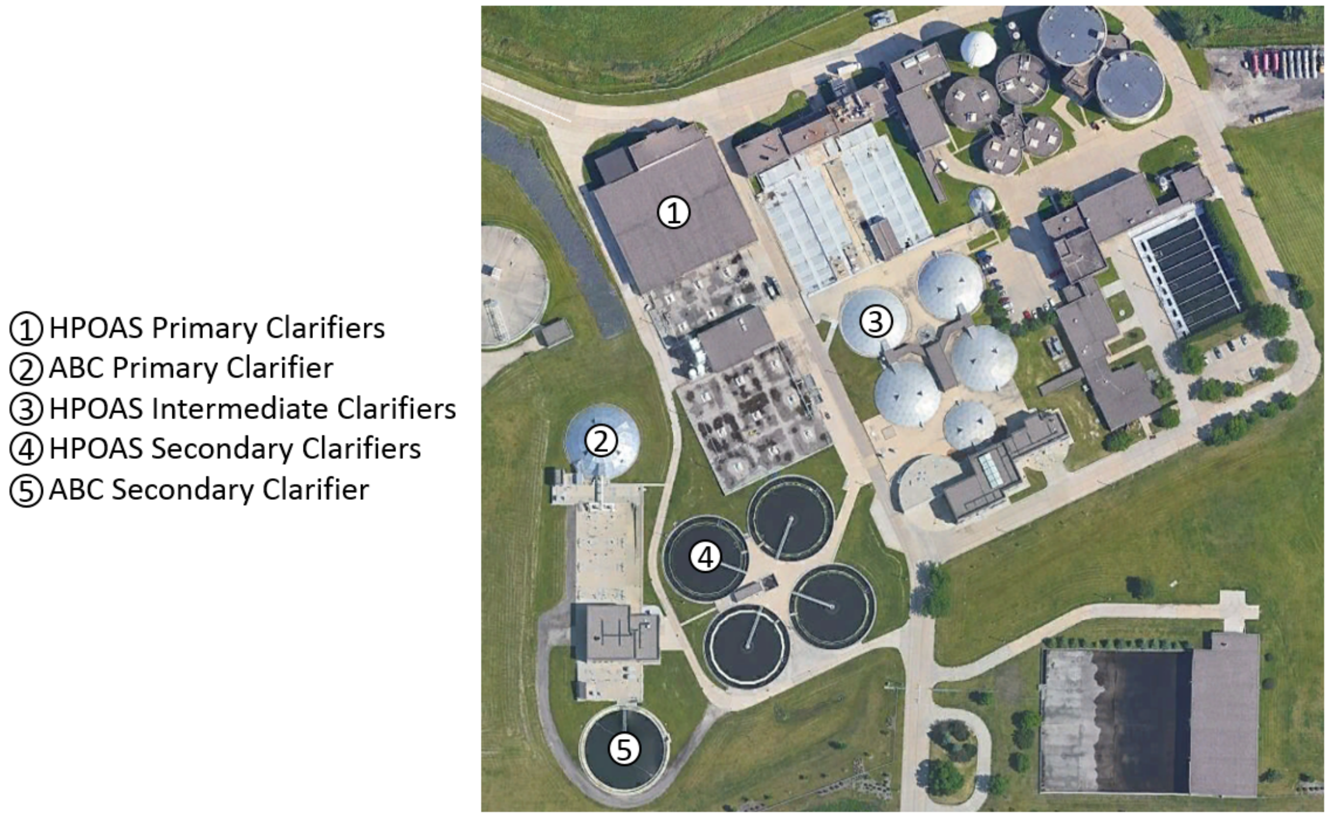


Figure 1-1. Rochester WRP Aerial View.

The Facilities Plan work scope calls for clarifier testing with subsequent computational fluid dynamics (CFD) modeling for the following clarifiers.

1. HPOAS primary clarifier
2. HPOAS secondary clarifier
3. ABC secondary clarifier

This workplan discusses testing procedures for the HPOAS train primary clarifier. A separate test plan addresses the HPOAS and ABC secondary clarifier testing.

The clarifier field testing will be used to calibrate and validate a CFD clarifier model, 2Dr, which considers hydrodynamic and sedimentation effects on performance. Brown and Caldwell (BC) will use the calibrated

2Dr model to determine clarifier performance and identify features to possibly increase performance. Note that this effort does not address hydraulic capacity, which is the focus of other work in the Facilities Plan project.

Section 2: Field Testing

The following section describes key planned field testing. Exact test dates, sampling locations, etc. will be coordinated with the City prior to the testing. Note that this testing will be completed during the same week as the secondary clarifier testing.

2.1 Test Schedule

Primary clarifier field testing will be conducted in one site visit, which will coincide with the secondary clarifier testing. The testing shall require 1 day of on-site testing as shown in Figure 2-1.

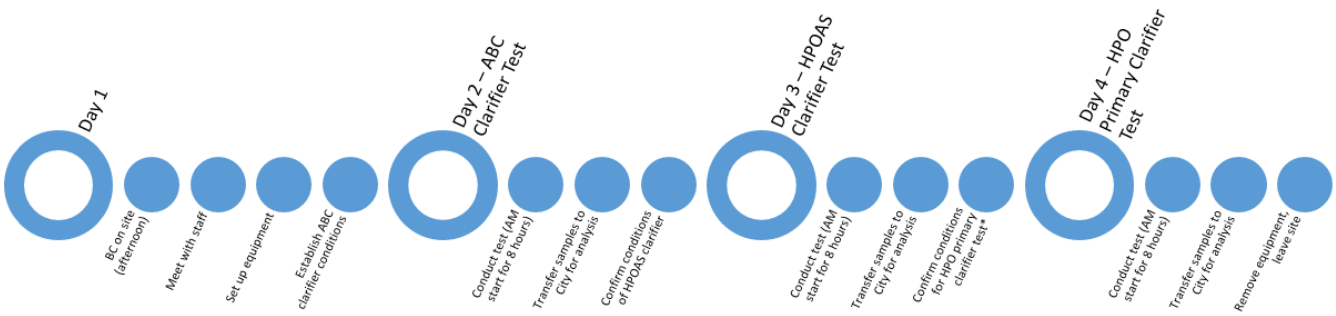


Figure 2-1. Clarifier Testing Timeline

The City shall identify the specific PC clarifier to be tested prior to BC arriving on site. The clarifier selected requires adequate flow monitoring equipment on both the influent and primary sludge (PS) flows, properly operating collector equipment, and accessibility for sampling.

Testing shall be conducted as soon as possible, ideally in July or early August. The City shall inform BC of possible test dates.

Testing is subject to wet weather. If flows reach high levels such that the test clarifier cannot be ramped up/down then testing will be delayed. BC will exert every effort to coordinate the testing with the weather to avoid days on site.

2.2 Test Details

BC will perform the five different types of tests on each day of clarifier testing. The discussion below provides additional details on these tests.

- Stress Tests
- Column Settling Tests
- Flocculation Tests
- Dispersed Suspended Solids (DSS) Tests
- Discrete Particle Tests

BC staff will require a dedicated space, at least 100 ft^2, for conducting the bench top tests. Preferably the space will be located inside the Primary Clarifier Building in an area with an electrical outlet, lighting, and potable or non-potable water for rinsing equipment

BC staff also will need security clearance to the facility for entry during all times of the day around the stress test for setup, tear down, and assessing conditions immediately prior to test initiation. Likewise, the City shall alert BC to any safety training requirements adequately ahead of the testing to ensure compliance.

2.2.1 Stress Tests

The stress test will last approximately 8 hours. BC staff will be on site up to 1 hour prior to test initiation to finalize the setup and assess the current operating state of the facility. During the stress tests, flows to the test PC will be varied to increase or decrease the surface overflow rate (SOR) that should illicit changes in performance (i.e. effluent suspended solids, sludge blanket depth (SBD), and sludge concentration). The general SOR itinerary starts at a baseline condition depending on the facility's operation from the previous day. BC will request three weeks of operating data from the City one week prior to testing. The operating data will determine the final SOR itinerary. The City shall adjust operations to achieve the baseline conditions and maintain operations for a minimum of 12 hours prior to the start of the stress test. Depending on plant staffing, setting the test PC conditions may be advisable by the end of the plant manager's normal work day.

The ferric chloride feed to the test PC must also be turned off, preferably 36 hours prior to testing. Without ferric chloride, the testing will measure the baseline settling characteristics of the influent solids. Subsequent testing could consider the enhanced settling with ferric chloride addition if deemed necessary. (Note: The subject of whether to feed ferric chloride to the primary clarifiers will be further discussed with City staff)

The SOR testing itinerary consists of up to six operating conditions delineated by changes in SOR. The primary sludge flow on the test clarifier shall remain constant during the test and will be set by plant staff to match current operations. The first hour of the test establishes the baseline conditions and continues the operating conditions established the day prior. In 1.5 hour increments the SOR increases to a maximum value and then for the last hour the SOR is reduced to the SOR set point prior to the maximum SOR (WRP staff will need to help adjust the flows/SOR). This itinerary design intends to achieve variations in performance that provide targets for calibrating and validating the 2Dr clarifier model.

Based on a typical influent flow of 12 mgd with 25 percent of the flow routed to the ABC train, HPOAS PCs operate at an SOR of approximately 450 gpd/sf with both units in service. Flow and SOR variation for the PC stress test will rely on shutting off flow to the non-test HPOAS PC and the ABC facility, plus additional flow will likely be required by storing some volume of plant influent or diverting plant effluent into the equalization basin for introduction into the flow stream at high SOR conditions. Table 2-1 summarizes a preliminary test itinerary for the HPOAS train. Table 2-1 assumes the WRP influent flow is constant and will need to be adjusted based upon diurnal flow patterns. With these assumptions, the test would require over 2.1 MG of influent stored in the EQ basin.

City staff will need to aid in turning off the non-test HPOAS train PC, adjusting the ABC flow split, and opening EQ discharge/increasing influent pump output. High influent flow conditions may dictate a flow increase to the ABC facility to achieve the desired HPOAS train PC SOR. BC will prepare and provide the City with a revised SOR itinerary the day prior to stress testing based on the provided operating data.

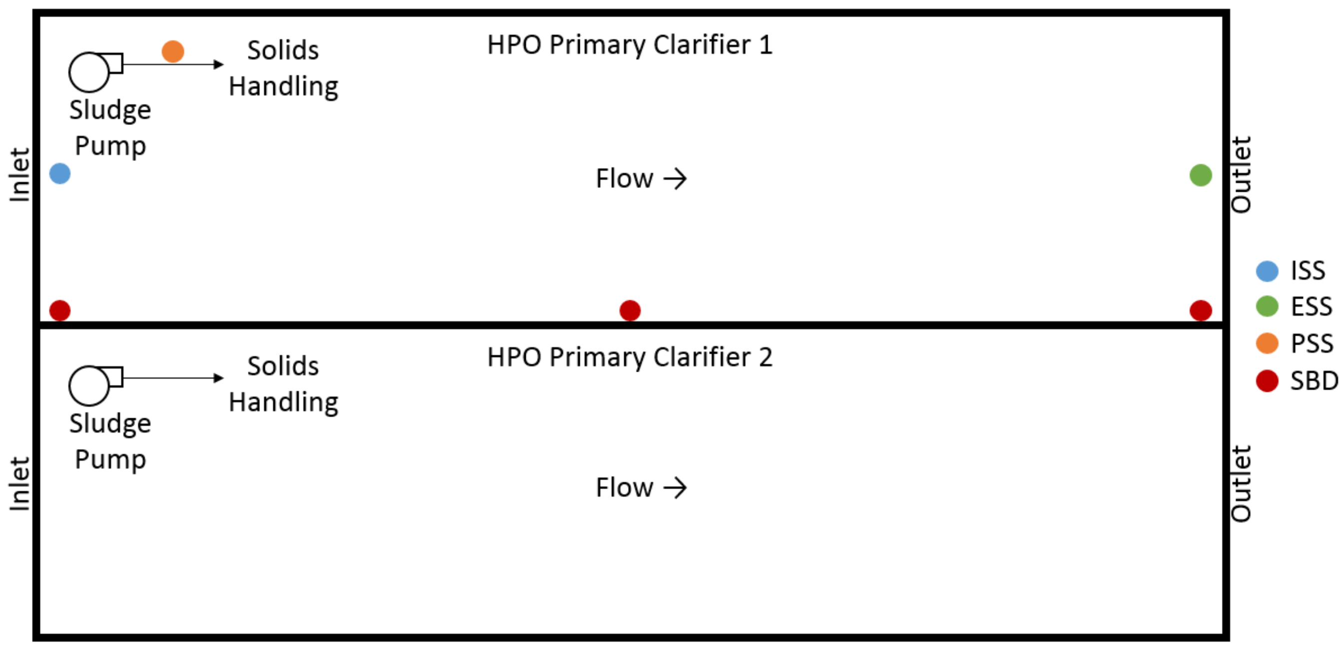
Table 2-1. Rochester WRP HPOAS Primary Clarifier Preliminary Stress Test SOR Itinerary[1]						
Condition	Condition Duration (hours)	Target Surface Overflow Rate (gal/sf-d)	No. HPO PCs in Service	Flow Split to ABC	HPO Flow (mgd)	EQ Volume Required (MG)
1	1	450	2	25%	9	0
2	1.5	900	1	25%	9	0
3	1.5	1,500	1	0%	1.5	0.2
4	1.5	2,000	1	0%	20	0.5
5	1.5	3,000	1	0%	30	1.1
6	1	2,000	1	0%	20	0.3

[1]Preliminary itinerary based upon an influent flow of 12 mgd.

During the stress test BC staff will collect samples and measurements for primary influent suspended solids (ISS), primary effluent suspended solids (ESS), primary sludge total solids (PSS), sludge blanket depth (SBD), temperature, primary influent total and filtered (1.5 um) COD, and primary effluent total and filtered (1.5 um) COD. The City will concurrently collect flow measurements using existing instrumentation, assumed already installed and operating with data logging by SCADA type system, that shall be provided to BC in Microsoft Excel format and at the data interval requested. City shall verify existing meters are calibrated and operating and notify BC as soon as possible if the meters cannot provide the required data. Table 2-3 summarizes the sample and measurement needs.

Access to the representative sampling points is key. This may require the City to install sample taps on primary sludge lines, open hatches, etc. prior to test. The City shall coordinate with BC prior to test dates to confirm the sample locations.

Table 2-3. Primary Clarifier Stress Test Sampling and Measurements		
Item	**Sampling / Measurement Frequency per test FST**	**Sample Collection and Measurement Performed by**
ISS, Primary Influent COD, Primary Influent filtered COD	1 every 30 minutes	BC
ESS	1 every 15 minutes	BC
Primary Effluent COD, Primary Effluent Filtered COD	1 every 30 minutes	BC
PSS	1 every 30 minutes	BC
Test PC primary sludge flow rate	5-minute flow intervals starting 24-hours prior to testing	City SCADA
SBD at front, middle, and end of tank	1 every 30 minutes	BC
Influent temperature	1 every 60 minutes	BC
PC influent flow rate	5-minute flow intervals starting 24-hours prior to testing	City SCADA



Note: location subject to access point identification.

2.2.2 Column Settling Test

Column settling tests to determine primary sludge settling/compaction characteristics will be completed. The settling compaction tests will be performed using a settling column provided by BC. Approximately six different

PSS concentrations will be tested to determine sludge compression zone settling constants, V_c and k, in Equation 1 (Vesilind, 1968).

(1) $$V = V_c e^{-kX}$$

where:

V	=	settling velocity, m/hr
X	=	solids concentration, g TS/L
V_c	=	sludge-specific settling/compaction parameter, m/hr
k	=	sludge-specific compaction parameter, L/g TSS

The V_c and k values will be used to perform modeling of the full-scale PCs using the 2Dr clarifier model as described by McCorquodale et al. (2005).

The settling testing apparatus shown in Figure 2-2 includes three settling columns clustered within a larger column that serves as a temperature-controlled water bath through which plant effluent is pumped. The apparatus design conforms to WERF protocols. In addition, each column will be equipped with a slow-speed rake turning at 1 rpm to minimize wall effects.

Figure 2-2. Settling Column Used for Batch Settling Tests

2.2.3 Flocculation Test

Flocculation tests to define flocculation characteristics of the primary influent solids will be completed using a 6-paddle gang stirrer. The flocculation testing provides information describing the propensity of the influent solids to aggregate and break apart and settleable and non-settleable solids. Supernatant suspended solids will be measured after different flocculation time intervals (0, 2, 5, 10, 15 and 30 minutes at approximately 50 rpm) and 30 minutes of settling. Supernatant TSS will be used to define the flocculation requirements, the potential ESS concentration if the influent is optimally flocculated and with ideal hydraulic conditions in the PC, and non-settleable solids. Figure 2-3 shows the experimental setup for the flocculation tests.

Figure 2-3. Flocculation Jar Test Apparatus

2.2.4 DSS Test

To supplement the settling and flocculation data, dispersed suspended solids (DSS) will be determined near the effluent weir. The DSS are defined as the supernatant suspended solids concentration after 30 minutes of settling in a Kemmerer sampler. This kind of sampler is used because it allows sample collection and settling to be done in the same sample container, thereby sparing the solids any aggregation or floc break-up effects resulting from sample transfer from one vessel to another. The Kemmerer sampler will be provided by BC. Figure 2-4 shows the Kemmerer sampler.

Figure 2-4. Kemmerer Sampler

2.2.5 Discrete Particle Test

Discrete particle tests will be conducted to determine the influent solids settling velocities and particle distribution. The discrete settling tests will be performed using the settling column shown in Figure 2-5 provided by the BC team. The settling velocities of multiple particles are measured and categorized as either slow, medium, or fast settling. These settling velocity hierarchies are used in the 2Dr clarifier model to delineate the fraction of particles that will settle fast, medium, and slow.

Figure 2-5. Discrete Settling Column

Section 3: Sample Analysis

Table 3-1 summarizes the samples that will be collected for analysis during the PC stress test. The City shall provide 500 mL sample bottles, sample bottle labels, and analyze all samples collected during testing.

Table 3-1. WRP Primary Clarifier Testing Analytical Requirements

Item and Location	Number of Samples
COD	
Primary Influent Total COD	17
Primary Effluent Total COD	17
Primary Influent Filtered COD	17
Primary Effluent Filtered COD	17
Overall Total COD Analyses	**68**
TSS	
Primary Influent	17
Primary Effluent	33
Primary sludge (TS)	17
Flocculation Test	21
Column Settling Test	9
DSS Test	3
Discrete Particle Test	12
Overall Total TSS Analyses	**112**

Section 4: City Responsibilities

Table 4-1 summarizes the City's responsibilities for the SC testing described herein. The table also organizes the responsibilities into whether the item requires addressing prior to testing.

Table4-1. City Responsibilities for Primary Clarifier Testing	
Item	**When to Address**
• Available dates for testing	Prior to Test
• Identify any safety training or security clearances required for BC staff	
• Identify test clarifier	
• Confirm existing instrumentation (e.g. flow meters) installed and calibrated	
• Identify available sampling points for influent, primary sludge, and effluent	
• Provide access to sampling points which may require grating removal, sample tap installation, etc.	
• Identify temporary set up location for BC bench scale testing – preferable indoors (utilities required include water, electric, lighting and floor drain if indoors)	
• Recent operating data	
• Turn off ferric chloride feed to test clarifier	
• Provide sample bottles, labels, chain of custody forms, and portable storage coolers	
• Supply working sludge judge	
• Operate at baseline conditions (primary sludge flow constant) for at least 12 hours prior to test	During test
• Adjust flows and clarifiers online to achieved target SORs	
• Accept samples at laboratory (after 4 PM)	
• Analyze samples	Post test

Section 5: References

Vesilind, P. A. (1968) Theoretical considerations: design of prototype thickeners from batch settling tests. *Water and Sewage Works*, 115, 302.

McCorquodale, A., Griborio, A. and Georgiou, I. (2005) A Public Domain Settling Tank Model. Proceedings WEFTEC, Washington DC

Attachment B: Primary Clarifier 2 Field Test Data

Test	Samples	Label	Description	TSS	TSS 2nd Run
Dispersed Suspended Solids	125	DSS-PC1	Kemmerer sample at time 1	76	
Dispersed Suspended Solids	126	DSS-PC2	Kemmerer sample at time 2	116	
Dispersed Suspended Solids	127	DSS-PC3	Kemmerer sample at time 3	140	
Floc Kinetics	128	FSS-PC-ISS1	ISS sample at time 1		
Floc Kinetics	129	FSS-PC-ISS2	ISS sample at time 2	264	
Floc Kinetics	130	FSS-PC-ISS3	ISS sample at time 3	520	
Floc Kinetics	131	FSS1-PC-0	Floc settling supernatant - 0 min flocculation -1	148	
Floc Kinetics	132	FSS1-PC-2	Floc settling supernatant - 2 min flocculation -1	140	
Floc Kinetics	133	FSS1-PC-5	Floc settling supernatant - 5 min flocculation -1	128	
Floc Kinetics	134	FSS1-PC-10	Floc settling supernatant - 10 min flocculation -1	116	
Floc Kinetics	135	FSS1-PC-15	Floc settling supernatant - 15 min flocculation -1	104	
Floc Kinetics	136	FSS1-PC-30	Floc settling supernatant - 30 min flocculation -1	100	
Floc Kinetics	137	FSS2-PC-0	Floc settling supernatant - 0 min flocculation -2	132	
Floc Kinetics	138	FSS2-PC-2	Floc settling supernatant - 2 min flocculation -2	104	
Floc Kinetics	139	FSS2-PC-5	Floc settling supernatant - 5 min flocculation -2	108	
Floc Kinetics	140	FSS2-PC-10	Floc settling supernatant - 10 min flocculation -2	92	
Floc Kinetics	141	FSS2-PC-15	Floc settling supernatant - 15 min flocculation -2	80	
Floc Kinetics	142	FSS2-PC-30	Floc settling supernatant - 30 min flocculation -2	80	
Floc Kinetics	143	FSS3-PC-0	Floc settling supernatant - 0 min flocculation -3	180	
Floc Kinetics	144	FSS3-PC-2	Floc settling supernatant - 2 min flocculation -3	148	
Floc Kinetics	145	FSS3-PC-5	Floc settling supernatant - 5 min flocculation -3	152	148
Floc Kinetics	146	FSS3-PC-10	Floc settling supernatant - 10 min flocculation -3	116	156
Floc Kinetics	147	FSS3-PC-15	Floc settling supernatant - 15 min flocculation -3	116	134
Floc Kinetics	148	FSS3-PC-30	Floc settling supernatant - 30 min flocculation -3	124	136
Zsv	149	ZSV-PC-FS	ISS sample at time collected		
Zsv	150	ZSV-PC-1	Settling column test 1	29200	
Zsv	151	ZSV-PC-2	Settling column test 2	11300	
Zsv	152	ZSV-PC-3	Settling column test 3	8600	
Zsv	153	ZSV-PC-4	Settling column test 4	5800	
Zsv	154	ZSV-PC-5	Settling column test 5	11700	
Zsv	155	ZSV-PC-6	Settling column test 6		
Zsv	156	ZSV-PC-7	Settling column test 7		
Zsv	157	ZSV-PC-8	Settling column test 8		

Discrete Settling Velocity	158	DS1-PC-V1	Discrete settling velocity 1, sample 1		
Discrete Settling Velocity	159	DS2-PC-V1	Discrete settling velocity 1, sample 2		
Discrete Settling Velocity	160	DS3-PC-V1	Discrete settling velocity 1, sample 3	872	
Discrete Settling Velocity	161	DS1-PC-V2	Discrete settling velocity 2, sample 1		
Discrete Settling Velocity	162	DS2-PC-V2	Discrete settling velocity 2, sample 2		
Discrete Settling Velocity	163	DS3-PC-V2	Discrete settling velocity 2, sample 3	590	
Discrete Settling Velocity	164	DS1-PC-V3	Discrete settling velocity 3, sample 1	28	
Discrete Settling Velocity	165	DS2-PC-V3	Discrete settling velocity 3, sample 2	24	
Discrete Settling Velocity	166	DS3-PC-V3	Discrete settling velocity 3, sample 3	2350	
Discrete Settling Velocity	167	DS1-PC-V4	Discrete settling velocity 4, sample 1	14	
Discrete Settling Velocity	168	DS2-PC-V4	Discrete settling velocity 4, sample 2	10	
Discrete Settling Velocity	169	DS3-PC-V4	Discrete settling velocity 4, sample 3	880	
Discrete Settling Velocity	170	DS1-PC-V5	Discrete settling velocity 5, sample 1	22	
Discrete Settling Velocity	171	DS2-PC-V5	Discrete settling velocity 5, sample 2	18	
Discrete Settling Velocity	172	DS3-PC-V5	Discrete settling velocity 5, sample 3	2040	
Discrete Settling Velocity	173	DS1-PC-V6	Discrete settling velocity 6, sample 1	20	
Discrete Settling Velocity	174	DS2-PC-V6	Discrete settling velocity 6, sample 2	16	
Discrete Settling Velocity	175	DS3-PC-V6	Discrete settling velocity 6, sample 3	1730	
Discrete Settling Velocity	176	DS1-PC-ISS	Sample of diluted ISS	220	
Discrete Settling Velocity	177	DS2-PC-ISS	Sample of diluted ISS	190	
Discrete Settling Velocity	178	DS3-PC-ISS	Sample of diluted ISS	510	
Discrete Settling Velocity	179	DS1-PC-ESS	Sample of filtered effluent	9.6	
Discrete Settling Velocity	180	DS2-PC-ESS	Sample of filtered effluent	10	
Discrete Settling Velocity	181	DS3-PC-ESS	Sample of filtered effluent	516	
Stess Test	182	ISS-PC-0	ISS for PC sample at time - 0 min	280	
Stess Test	183	ISS-PC-30	ISS for PC sample at time - 30 min	240	
Stess Test	184	ISS-PC-60	ISS for PC sample at time - 60 min	236	
Stess Test	185	ISS-PC-90	ISS for PC sample at time - 90 min	256	
Stess Test	186	ISS-PC-120	ISS for PC sample at time - 120 min	244	
Stess Test	187	ISS-PC-150	ISS for PC sample at time - 150 min	244	
Stess Test	188	ISS-PC-180	ISS for PC sample at time - 180 min	256	
Stess Test	189	ISS-PC-210	ISS for PC sample at time - 210 min	212	
Stess Test	190	ISS-PC-240	ISS for PC sample at time - 240 min	236	
Stess Test	191	ISS-PC-270	ISS for PC sample at time - 270 min	348	376
Stess Test	192	ISS-PC-300	ISS for PC sample at time - 300 min	872	420
Stess Test	193	ISS-PC-330	ISS for PC sample at time - 330 min	536	436
Stess Test	194	ISS-PC-360	ISS for PC sample at time - 360 min	644	530
Stess Test	195	ISS-PC-390	ISS for PC sample at time - 390 min	700	700
Stess Test	196	ISS-PC-420	ISS for PC sample at time - 420 min	810	690
Stess Test	197	ISS-PC-450	ISS for PC sample at time - 450 min	590	580
Stess Test	198	ISS-PC-480	ISS for PC sample at time - 480 min	450	360

Stess Test	199	PS-PC-0	PS PC sample at time - 0 min	25200	
Stess Test	200	PS-PC-30	PS PC sample at time - 30 min	28700	
Stess Test	201	PS-PC-60	PS PC sample at time - 60 min	27300	
Stess Test	202	PS-PC-90	PS PC sample at time - 90 min	24100	
Stess Test	203	PS-PC-120	PS PC sample at time - 120 min	23300	
Stess Test	204	PS-PC-150	PS PC sample at time - 150 min	32300	
Stess Test	205	PS-PC-180	PS PC sample at time - 180 min	28100	
Stess Test	206	PS-PC-210	PS PC sample at time - 210 min	26800	
Stess Test	207	PS-PC-240	PS PC sample at time - 240 min	28200	
Stess Test	208	PS-PC-270	PS PC sample at time - 270 min	27400	
Stess Test	209	PS-PC-300	PS PC sample at time - 300 min	16000	
Stess Test	210	PS-PC-330	PS PC sample at time - 330 min	3100	2900
Stess Test	211	PS-PC-360	PS PC sample at time - 360 min		
Stess Test	212	PS-PC-390	PS PC sample at time - 390 min	12000	
Stess Test	213	PS-PC-420	PS PC sample at time - 420 min	27500	
Stess Test	214	PS-PC-450	PS PC sample at time - 450 min	29400	
Stess Test	215	PS-PC-480	PS PC sample at time - 480 min	24600	

Stess Test	216	ESS-PC-0	ESS for PC sample at time - 0 min	112	
Stess Test	217	ESS-PC-15	ESS for PC sample at time - 15 min	100	
Stess Test	218	ESS-PC-30	ESS for PC sample at time - 30 min	108	
Stess Test	219	ESS-PC-45	ESS for PC sample at time - 45 min	108	
Stess Test	220	ESS-PC-60	ESS for PC sample at time - 60 min	88	
Stess Test	221	ESS-PC-75	ESS for PC sample at time - 75 min	108	
Stess Test	222	ESS-PC-90	ESS for PC sample at time - 90 min	104	
Stess Test	223	ESS-PC-105	ESS for PC sample at time - 105 min	120	
Stess Test	224	ESS-PC-120	ESS for PC sample at time - 120 min	128	
Stess Test	225	ESS-PC-135	ESS for PC sample at time - 135 min	132	
Stess Test	226	ESS-PC-150	ESS for PC sample at time - 150 min	144	
Stess Test	227	ESS-PC-165	ESS for PC sample at time - 165 min	144	
Stess Test	228	ESS-PC-180	ESS for PC sample at time - 180 min	148	
Stess Test	229	ESS-PC-195	ESS for PC sample at time - 195 min	220	
Stess Test	230	ESS-PC-210	ESS for PC sample at time - 210 min	208	
Stess Test	231	ESS-PC-225	ESS for PC sample at time - 225 min	216	
Stess Test	232	ESS-PC-240	ESS for PC sample at time - 240 min	232	
Stess Test	233	ESS-PC-255	ESS for PC sample at time - 255 min	228	
Stess Test	234	ESS-PC-270	ESS for PC sample at time - 270 min	492	390
Stess Test	235	ESS-PC-285	ESS for PC sample at time - 285 min	270	
Stess Test	236	ESS-PC-300	ESS for PC sample at time - 300 min	320	
Stess Test	237	ESS-PC-315	ESS for PC sample at time - 315 min	350	
Stess Test	238	ESS-PC-330	ESS for PC sample at time - 330 min	320	300
Stess Test	239	ESS-PC-345	ESS for PC sample at time - 345 min	400	280
Stess Test	240	ESS-PC-360	ESS for PC sample at time - 360 min	340	272
Stess Test	241	ESS-PC-375	ESS for PC sample at time - 375 min	400	404
Stess Test	242	ESS-PC-390	ESS for PC sample at time - 390 min	400	392
Stess Test	243	ESS-PC-405	ESS for PC sample at time - 405 min	380	420
Stess Test	244	ESS-PC-420	ESS for PC sample at time - 420 min	200	
Stess Test	245	ESS-PC-435	ESS for PC sample at time - 435 min	155	
Stess Test	246	ESS-PC-450	ESS for PC sample at time - 450 min	160	
Stess Test	247	ESS-PC-465	ESS for PC sample at time - 455 min	148	
Stess Test	248	ESS-PC-480	ESS for PC sample at time - 480 min	148	

Date	12/14/2017	Sludge Flow, gpm =		30	
	PCs in Service	**SA, sqft**	**Inf Flow, MGD**	**Eff Flow, MGD**	**SOR, gpd/sqft**
10:00:00 AM	2	20,921	9.22	9.13	441
10:30:00 AM	2	20,921	8.82	8.73	421
11:00:00 AM	2	20,921	9.24	9.16	442
11:30:00 AM	1	10,461	9.39	9.35	898
12:00:00 PM	1	10,461	9.43	9.39	902
12:30:00 PM	1	10,461	9.45	9.41	904
1:00:00 PM	1	10,461	12.30	12.25	1176
1:30:00 PM	1	10,461	14.87	14.83	1422
2:00:00 PM	1	10,461	15.08	15.03	1441
2:30:00 PM	1	10,461	16.08	16.04	1537
3:00:00 PM	1	10,461	19.06	19.01	1822
3:30:00 PM	1	10,461	19.60	19.56	1874
4:00:00 PM	1	10,461	20.80	20.76	1989
4:30:00 PM	1	10,461	22.15	22.11	2118
5:00:00 PM	1	10,461	19.25	19.20	1840
5:30:00 PM	1	10,461	10.53	10.49	1007
6:00:00 PM	1	10,461	10.21	10.17	976

	Stress Test	2nd Run	Average	Sludge Blankets			
Time (min)	ESS (mg/L)	ESS (mg/L)	ESS (mg/L)	Inlet (ft)	Mid-1 (ft)	Mid-2 (ft)	Outlet (ft)
0	112	112	112				
15	100	100	100	2.25	1	1	1
30	108	108	108				
45	108	108	108	3	1	1	1
60	88	88	88				
75	108	108	108	2	1.25	1	1
90	104	104	104				
105	120	120	120	2.25	1.25	0.75	1
120	128	128	128				
135	132	132	132	2.25	1	0.25	0.5
150	144	144	144				
165	144	144	144	2	1	0.5	1
180	148	148	148				
195	220	220	220	1.25	1	1	1
210	208	208	208				
225	216	216	216	1.5	1	1	1
240	232	232	232				
255	228	228	228	1	1	1	1
270	492	390	441				
285	270	270	270	0	0.5	1	1.5
300	320	320	320				
315	350	350	350	0	0.5	0.75	1.5
330	320	300	310				
345	400	280	340	0.25	1	0.75	2
360	340	272	306				
375	400	404	402	1	1.5	1	1
390	400	392	396				
405	380	420	400	0.25	1	1	1.25
420	200	200	200				
435	155	155	155	1	1	1	1
450	160	160	160	2.5	0.75	1	1.5
465	148	148	148				
480	148	148	148				

Flocculation Test

Flocculation Test

Test Objective:	Define floc kinetics
Test Location	Rochester, MN
Test Date	Thursday, December 14, 2017
Test Attendee	
Sample Location	PC Influent
Settling Time	30 minute

	10:05 AM	1:09 PM	2:25 PM	
	Test 1	Test 2	Test 3	
Time	Supernatant TSS	Supernatant TSS	Supernatant TSS	
0	148	132	180	
2	140	104	148	2nd Run
5	128	108	152	148
10	116	92	116	156
15	104	80	116	134
30	100	80	124	136
SS	280	264	520	
G	52	52	52	
Temp (°C)	60.5	61.4	60.5	
Paddle Speed	59	60	61	

$$n_t = \frac{K_B G}{K_A} + \left(n_o - \frac{K_B G}{K_A}\right) e^{-K_A X G t}$$

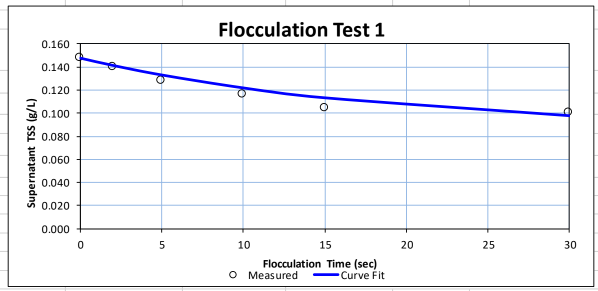
Where:

n_t	=	number of particles at time t, gTSS/L
n_o	=	initial number of particles, gTSS/L
G	=	root-mean square velocity gradient, s^{-1}
X	=	mixed liquor concentration, gTSS/L
K_A	=	floc aggregation rate coefficient, L/gTSS
K_B	=	floc break-up rate coefficient, s
t	=	time, s

Test 1 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (mg/L)	(n_t-Calc n_t)^2		
0	0.148	0.148	0.000000000	n_0 (mg/L)	0.148
2	0.140	0.142	0.000002647	G (sec^{-1})	52
5	0.128	0.133	0.000027570	X (g/L)	0.28
10	0.116	0.122	0.000035290	K_a (L/g TSS)	6.078E-05
15	0.104	0.113	0.000085890	K_B (sec)	9.906E-08
30	0.100	0.098	0.000005729		
		SSE***	0.000157125		

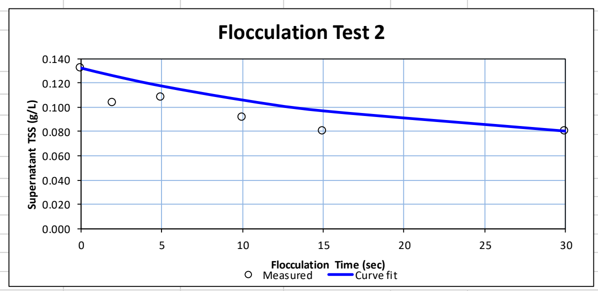
** By varying Ka and Kb to reach minimum "SSE"
*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed



Test 2 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (mg/L)	(n_t-Calc n_t)^2		
0	0.132	0.132	0.000000000	n_0 (mg/L)	0.132
2	0.104	0.126	0.000467683	G (sec^{-1})	52
5	0.108	0.117	0.000084371	X (g/L)	0.26
10	0.092	0.106	0.000186361	K_a (L/g TSS)	6.078E-05
15	0.080	0.097	0.000277946	K_B (sec)	7.610E-08
30	0.080	0.080	0.000000000		
		SSE***	0.001016361		

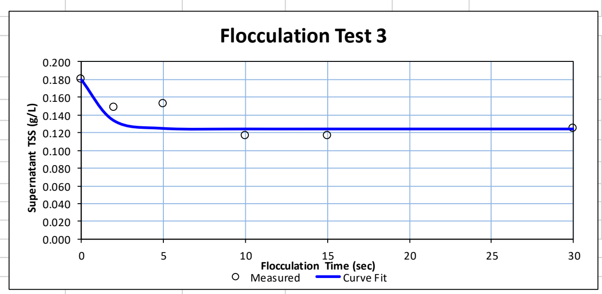
** By varying Ka and Kb to reach minimum "SSE"
*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed



Test 3 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (mg/L)	(n_t-Calc n_t)^2		
0	0.180	0.180	0.000000000	n_0 (mg/L)	0.180
2	0.148	0.133	0.000213159	G (sec^{-1})	52
5	0.152	0.125	0.000748216	X (g/L)	0.52
10	0.116	0.124	0.000064119	K_a (L/g TSS)	5.500E-04
15	0.116	0.124	0.000064001	K_B (sec)	1.312E-06
30	0.124	0.124	0.000000000		
		SSE***	0.001089497		

** By varying Ka and Kb to reach minimum "SSE"
*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed

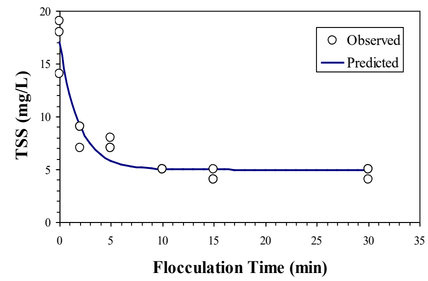


The flocculation coefficients, KA and KB, are determined by fitting the equation below to the experimental data as shown in the figures.
Use solver iterations to solve for KA and KB. See imbedded notes for each.

$$n_t = \frac{K_B G}{K_A} + \left(n_o - \frac{K_B G}{K_A}\right) e^{-K_A X G t}$$

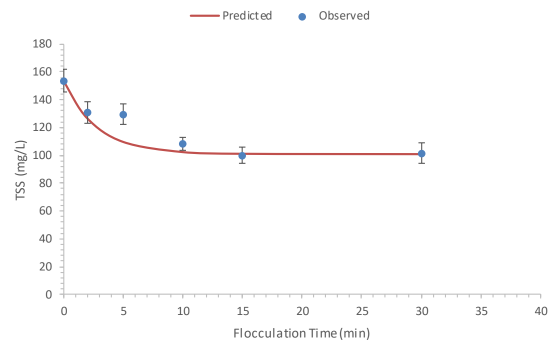
Where:

n_t	number of particles at time t, gTSS/L
n_o	initial number of particles, gTSS/L
G	root-mean square velocity gradient, s^{-1}
X	mixed liquor concentration, gTSS/L
K_A	floc aggregation rate coefficient, L/gTSS
K_B	floc break-up rate coefficient, s
t	time, s



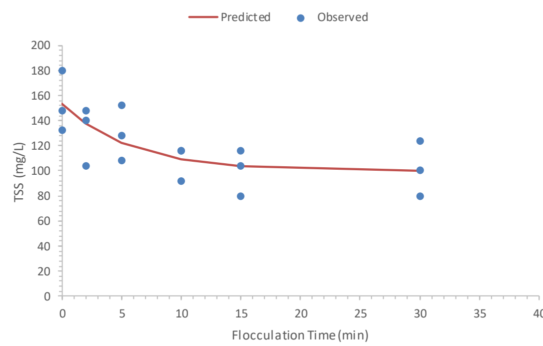
Time (s)	Time (min)	Observed TSS (mg/L)	SE	Observed n_t (g/L)	Predicted n_t (g/L)	Predicted TSS (mg/L)	Error^2
0	0	153	8.1	0.153	0.153	153.3	0.00E+00
120	2	131	7.8	0.131	0.127	126.6	1.67E-05
300	5	129	7.3	0.129	0.110	109.7	3.85E-04
600	10	108	4.6	0.108	0.102	102.4	3.12E-05
900	15	100	6.1	0.100	0.101	101.2	1.41E-06
1800	30	101	7.3	0.101	0.101	100.9	1.53E-07
						Sum Error	4.34E-04

n_o	0.153	g/L
G	52	s^{-1}
X	0.355	g/L
K_A	3.23E-04	L/g
K_B	6.27E-07	s



Time (s)	Time (min)	Observed TSS (mg/L)	SE	Observed n_t (g/L)	Predicted n_t (g/L)	Predicted TSS (mg/L)	Error^2
0	0	148		0.148	0.153	153.3	2.84E-05
0	0	132		0.132	0.153	153.3	4.55E-04
0	0	180		0.180	0.153	153.3	7.11E-04
120	2	140		0.140	0.137	137.5	6.29E-06
120	2	104		0.104	0.137	137.5	1.12E-03
120	2	148		0.148	0.137	137.5	1.10E-04
300	5	128		0.128	0.122	122.0	3.59E-05
300	5	108		0.108	0.122	122.0	1.96E-04
300	5	152		0.152	0.122	122.0	9.00E-04
600	10	116		0.116	0.109	108.9	5.10E-05
600	10	92		0.092	0.109	108.9	2.84E-04
600	10	116		0.116	0.109	108.9	5.10E-05
900	15	104		0.104	0.103	103.3	4.25E-07
900	15	80		0.080	0.103	103.3	5.45E-04
900	15	116		0.116	0.103	103.3	1.60E-04
1800	30	100		0.100	0.100	99.7	1.17E-07
1800	30	80		0.080	0.100	99.7	3.86E-04
1800	30	124		0.124	0.100	99.7	5.93E-04
			Average	0.101	0.100	Sum Error	5.64E-03

n_o	0.153
G	52
X	0.355
K_A	1.57E-04
K_B	3.00E-07



Settling Column Test

Test Date	
Test Time	
Plant SVI	mL/g

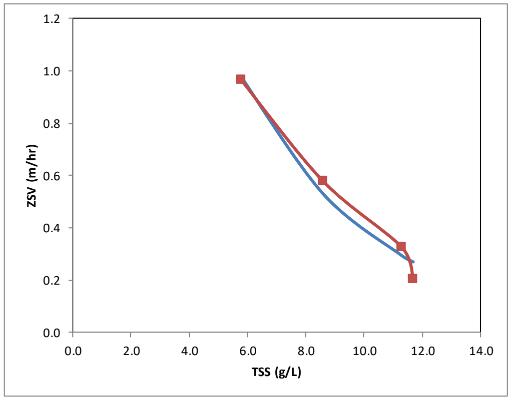
Vesilind Equation

$$ZSV = v_0 e^{k \times TSS_i}$$

Where

ZSV	=	Zone Settling Velocity, m/hr
v_0	=	Sludge settleability constant, m/hr
k	=	Sludge settleability constant, L/mg TSS
TSS	=	Initial sludge concentration, mg/L

Settling Test	ZSV m/h	Hindered g/L	Vo and k Determination: Compression g/L	Pred Comp ZSV m/h	Error^2
1					
2	0.96		5.8	0.98	0.0002
3	0.58		8.6	0.53	0.0020
4	0.33		11.3	0.30	0.0008
5	0.20		11.7	0.27	0.0050
6					
7					
8					
	V (m/hr)*		3.43		0.0081
	k (L/mg-TSS)		0.217		



Zone Settling Velocity Determination

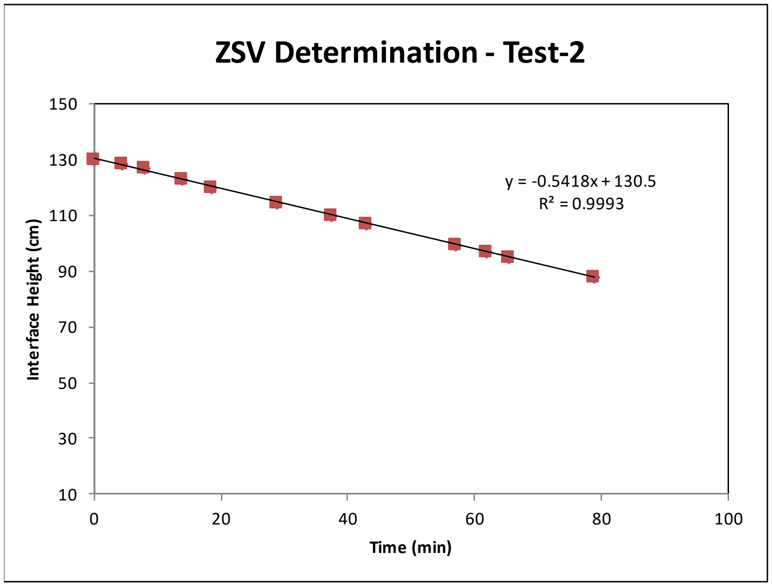
ZSV-HPOAS-1		ZSV-HPOAS-2		ZSV-HPOAS-3		ZSV-HPOAS-4		ZSV-HPOAS-5		ZSV-HPOAS-6		ZSV-HPOAS-7		ZSV-HPOAS-8	
TSS (mg/L)**	29,200	TSS (mg/L)	11,300	TSS (mg/L)	8,600	TSS (mg/L)	5,800	TSS (mg/L)	11,700	TSS (mg/L)		TSS (mg/L)		TSS (mg/L)	
Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm	Time min	Sludge Interface Height cm
		0	130	0	132	0	131	0	124						
		4.5	128.5	6	125	4	123	8.5	122						
		8	127	8.5	122.75	10	112	22	118.5						
		14	123	11.5	119.5	14	105.5	31.5	115						
		18.5	120	17	114.5	21.5	94	43.5	110						
		29	114.5	26	105	27	86	53	107						
		37.5	110	42	90.5	32.5	78.5	61	104						
		43	107	48.5	85										
		57	99.5												
		62	97												
		65.5	95												
		79	88												
Temp (F)															
ZSV (cm/min)***		ZSV (cm/min)***	0.54	ZSV (cm/min)***	0.96	ZSV (cm/min)*	1.61	ZSV (cm/min)***	0.34	ZSV (cm/min)***		ZSV (cm/min)***		ZSV (cm/min)***	
ZSV (m/hr)***	0	ZSV (m/hr)	0.33	ZSV (m/hr)	0.58	ZSV (m/hr)	0.96	ZSV (m/hr)	0.20	ZSV (m/hr)	0	ZSV (m/hr)	0	ZSV (m/hr)	0.0

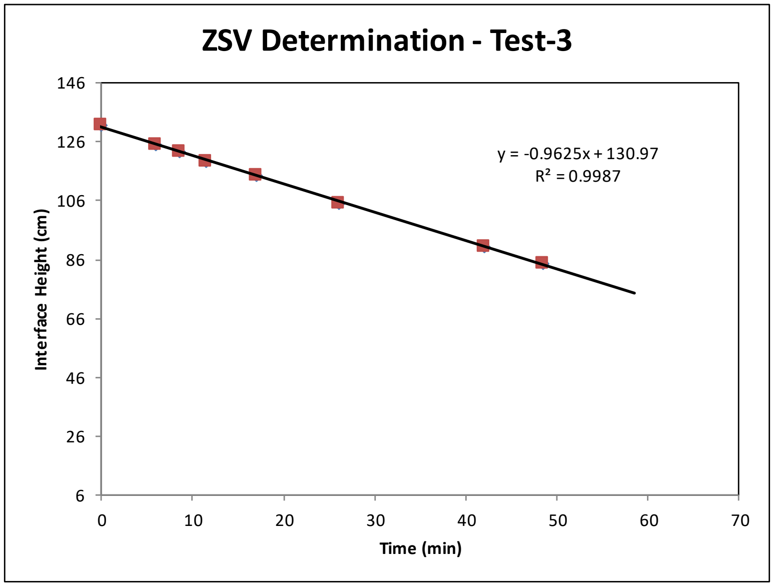
* data shown in red squares below are used to regress the linear ZSV

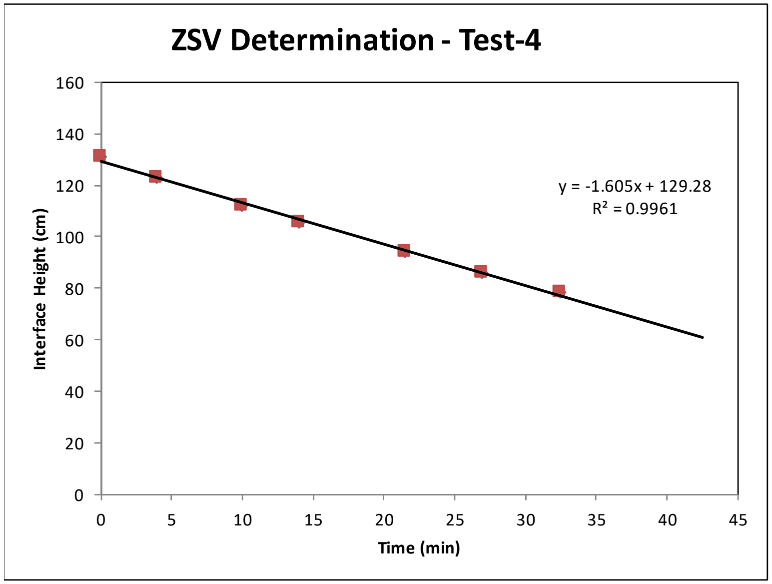
** "TSS" is sample

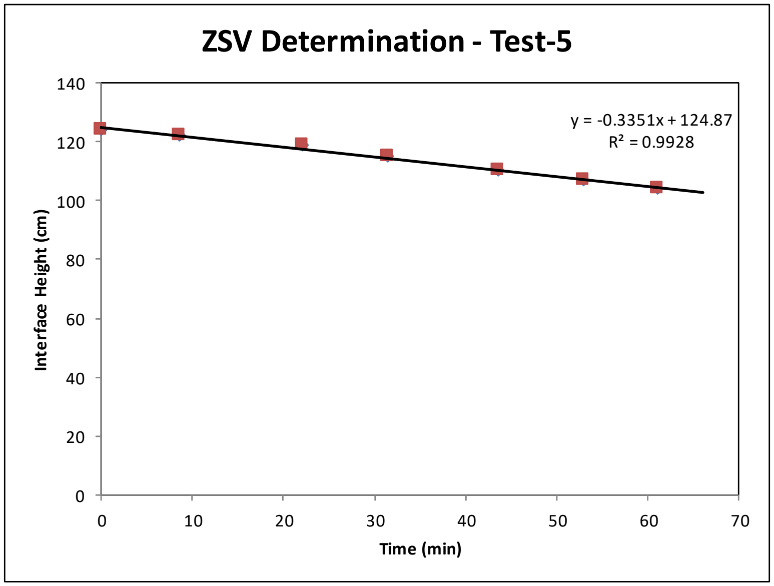
*** ZSV is determined by linear regression as shown in following Figures and then convert from cm/min to m/hr

Brown AND Caldwell


ZSV Determination - Test-2
y = -0.5418x + 130.5
R² = 0.9993
Interface Height (cm)
Time (min)
150
130
110
90
70
50
30
10
0
20
40
60
80
100


ZSV Determination - Test-3
y = -0.9625x + 130.97
R² = 0.9987
Interface Height (cm)
Time (min)
146
126
106
86
66
46
26
6
0
10
20
30
40
50
60
70


ZSV Determination - Test-4
y = -1.605x + 129.28
R² = 0.9961
Interface Height (cm)
Time (min)
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45


ZSV Determination - Test-5
y = -0.3351x + 124.87
R² = 0.9928
Interface Height (cm)
Time (min)
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70

Dispersed Suspended Solids Test		
Kemmerer DSS	**ISS, mg/L**	**DSS, mg/L**
DSS_PC1	236	76
DSS_PC2	244	116
DSS_PC3	700	140
Average	393	111

Discrete Settling Test - 1					
Floc Size	Floc Fraction	Settling Time, min	TSS, mg/L	Mass of settled solids, mg	Mass applied to column, mg
Class 1	32%	8.8	28	42	128
Class 2	-16%	13.1	14	21	128
Class 3	9%	26.3	22	33	128
Class 4	-2%	52.5	20	30	128
Non-Settle	77%			0	128

Sample	TSS
PC TSS Grab	220
Eff TSS Grab	10

	Volume, L
Sample	0.45
Column	1.57
Cone	1.49
	Height, cm
Column	87.5

Discrete Settling Test - 2					
Floc Size	Floc Fraction	Settling Time, min	TSS, mg/L	Mass of settled solids, mg	Mass applied to column, mg
Class 1	31%	8.8	24	36	116
Class 2	-18%	13.1	10	15	116
Class 3	10%	26.3	18	27	116
Class 4	-3%	52.5	16	24	116
Non-Settle	79%			0	116

Sample	TSS
PC TSS Grab	190
Eff TSS Grab	10

	Volume, L
Sample	0.45
Column	1.57
Cone	1.49
	Height, cm
Column	87.5

LOWER ENERGY // CLEAN DESIGN

DECREASED MAINTENANCE // INNOVATIVE PROCESSES

Technical Memorandum 1	Influent Flows and Loadings
Technical Memorandum 2	Wastewater Characterization and BioWin Calibration
Technical Memorandum 3	Plant Hydraulic Evaluation
Technical Memorandum 4	Primary Clarifier Computational Fluid Dynamics Modeling
Technical Memorandum 5	Final Clarifier Computational Fluid Dynamics Modeling
Technical Memorandum 6	Liquid Stream Alternative Evaluation
Technical Memorandum 7	Solids Alternative Evaluation
Technical Memorandum 8	Digester Gas Management
Technical Memorandum 9	Disinfection and Outfall Evaluation
Technical Memorandum 10	Whole Plant Evaluation
Technical Memorandum 11	Heat Recovery Loop Alternative
Technical Memorandum 12	NPDES Permitting Process
Technical Memorandum 13	Industrial Discharge Wasteloads and Practices

Discrete Settling Test - 3					
Floc Size	Floc Fraction	Settling Time, min	TSS, mg/L	Mass of settled solids, mg	Mass applied to column, mg
Class 1	83%	9.25	880	1311	1579
Class 2	195%	13.63	2040	3040	1561
Class 3	143%	26.75	1730	2578	1805
Class 4	131%	53.00	2350	3502	2668
Non-Settle				0	1561

Sample	TSS
Class 1 Initial TSS	516
Class 2 Initial TSS	510
Class 3 Initial TSS	590
Class 4 Initial TSS	872

	Volume, L
Sample	0.00
Column	1.57
Cone	1.49
	Height, cm
Column	87.5