Rochester Water Reclamation Plant

2019 Facilities Plan

Technical Memorandum 5: Final Clarifier Computational Fluid Dynamics Modeling

TM 5 of 13 | J4325

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Technical Memorandum

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List of Abbreviations

ABC	Aeration Basin Complex
BC	Brown and Caldwell
BNR	biological nutrient removal
CFD	computational fluid dynamics
City	City of Rochester
d	day(s)
DSS	dispersed suspended solids
EDI	energy-dissipating inlet
ESS	effluent suspended solids
F	fraction(s)
FEDWA	Flocculating Energy Dissipating Well Arrangement
ft	foot/feet
ft^2	square foot/feet
g	gram(s)
gal	gallon(s)
gpd	gallon(s) per day
HPOAS	high-purity oxygen activated sludge
hr	hour(s)
IC2	Intermediate Clarifier 2
IC4	Intermediate Clarifier 4
L	liter(s)
lb	pound(s)
m	meter(s)
mg	milligram(s)
mgd	million gallons per day
mL	milliliter(s)
MLSS	mixed liquor suspended solids
RAS	return activated sludge
rpm	revolution(s) per minute
s	second(s)
SBD	sludge blanket depth
SLR	solids loading rate
SOR	surface overflow rate
SPA	state point analysis
SSV30	settled sludge volume
SVI	sludge volume index
SVISN	sludge volume index—2-liter settleometer unstirred
TM	technical memorandum
TSS	total suspended solids
V	velocity
WRP	water reclamation plant

Executive Summary

This technical memorandum (TM) summarizes the City of Rochester (City) Water Reclamation Plant (WRP) final clarifier field testing program and capacity analysis. The program and analysis were conducted to establish the basis of existing final clarifier capacity under current and future operations and recommend improvements to further increase capacity and/or improve performance.

The WRP consists of two parallel activated sludge systems: The Aeration Basin Complex (ABC) air-activated sludge system and a two-stage high-purity oxygen activated sludge (HPOAS) train. A key to the WRP capacity is the hydraulic and solids loading rate (SLR) capacity of the final clarifiers in each treatment train. To define the final clarifier capacity under current operations and potential capacity with system improvements, clarifier computational fluid dynamics (CFD) modeling using the 2Dc clarifier model was conducted. This section summarizes the results of the ABC and second stage HPOAS final clarifier analysis. The first stage HPOAS intermediate clarifiers (IC) were not evaluated using the 2Dc clarifier model; however, stress testing was conducted to compare the field-measured and theoretical state point analysis (SPA) capacities.

The ABC facility has one 120-foot-diameter final clarifier with a 17-foot side water depth (Final Clarifier 5), and the second stage HPOAS train has four 120-foot-diameter final clarifiers with 14-foot side water depths (Final Clarifiers 1 through 4).

Methodology

Field testing was conducted on September 12, 2017 (Final Clarifier 5) and December 13, 2017 (Final Clarifier 3) to collect data to calibrate both clarifier 2Dc models. Final Clarifier 3 was selected to be representative of Final Clarifiers 1–4. Field testing included stress testing the clarifier over a range of loading conditions to elicit responses in effluent suspended solids (ESS), return activated sludge (RAS) total suspended solids (TSS), and sludge blanket depths (SBDs) and bench-scale tests to define flocculation and settling parameters.

Each clarifier 2Dc model was successfully calibrated to the stress test data and subsequently used in the capacity and performance-enhancing evaluations. Final clarifier capacity is defined when either the predicted ESS exceeded 25 milligrams per liter (mg/L) or the SBD exceeded half the clarifier side water depth at peak loading conditions. This work does not address hydraulic capacity, such as flow over weirs or through clarifier inlet piping, which is the focus of other modeling work in the planning effort.

Final Clarifier 5 (ABC Facility)

The Final Clarifier 5 capacity analysis assumes that the ABC facility continues operation with an anaerobic selector yielding the historical 90th percentile design sludge volume index (SVISN) of 130 mL/g. Table ES-1 shows Final Clarifier 5 has an SLR capacity of 39 pounds per square foot-day (lb/ft2-d) under the current configuration and can be increased to 43 lb/ft2-d by increasing the flocculation well depth from 4.0 feet to 8.5 feet. Increasing the flocculation well depth also maintains predicted ESS at roughly 7 mg/L at all flows analyzed while the existing configuration saw a steady increase in predicted ESS from 7 mg/L to 25 mg/L as the SOR was increased. Additional analysis showed increasing the clarifier RAS flow rate and/or increasing the diameter of the flocculation well had little to no benefit on clarifier capacity or performance.

The City should also consider installing a dual-suction sludge collector to replace the existing collector to promote rapid sludge removal when the collector reaches the end of its useful life to minimize fluctuations in SBD levels.

Final Clarifiers 1–4 Existing HPOAS Operations

Table ES-1 shows that Final Clarifiers 1 through 4 have an SLR capacity of 24 lb/ft^2-d under current operations that can be increased to 31 and 38 lb/ft^2-d by increasing the RAS pumping rate per clarifier to 3.6 and 5.3 million gallons per day (mgd), respectively. Modeling showed negligible improvement in clarifier capacity/performance by increasing the flocculation baffle diameter from 15 percent to more typical values of 20 to 35 percent of the clarifier diameter. The existing flocculation baffle is one-half the existing side water depth, (i.e., BC's recommended depth) so no modifications to the flocculation baffle depth are recommended. No other clarifier modifications were evaluated or recommended.

Final Clarifiers 1–4 BNR Operations with an Anaerobic Selector

Table ES-1 shows Final Clarifiers 1–4 capacity under BNR operations with an anaerobic selector is the same as that with the existing HPOAS operation. When comparing the clarifier capacity under current operations with an SVISN of 90 mL/g to BNR operations with an anaerobic selector (SVISN of 130 mL/g) a common thought is the clarifier capacity should increase due to a more favorable SVI. However, when considering sludge quality, one must consider how the sludge flocculates, settles, and compacts. In this case, solids compaction under current operations is better than the ABC BNR solids (i.e. 1/SVI equals the maximum solids compaction/return solids concentration), however this is offset by poorer solids flocculation and settling characteristics. The combination of these three sludge quality factors results in the same clarifier SLR capacity for both current HPOAS and BNR operations with an anaerobic selector; however, predicted effluent TSS is roughly one-half with BNR operations.

Like HPOAS operations, clarifier capacity can be increased by increasing RAS capacity to 3.6 mgd/clarifier (31 lb/ft^2-d) and 5.3 mgd/clarifier (38 lb/ft^2-d). Enlarging the flocculation well had a negligible impact on capacity at a target MLSS of 3,500 mg/L or higher.

Table ES-1. Rochester Final Clarifier Capacity Analysis Results

Condition	Unit	Final Clarifier 5		Final Clarifiers 1–4			
Process configuration	--	BNR with anaerobic selector		Existing 2-stage HPOAS		BNR with anaerobic selector	
Clarifier condition	--	Existing	Deepened flocculation well	Existing	Increased RAS	Existing	Increased RAS
Sludge volume index[b]	mL/g	130	130	90	90	130	130
RAS flow/clarifier	mgd	6.0	6.0	2.5	3.6/5.3	2.5	3.6/5.3
Solids loading rate	lb/ft^2-d	39	43	24	31/38	24	31/38
Peak hour flow/clarifier [a]							
at MLSS = 3,000 mg/L	mgd	11.5	12.8	8.3	10.4/12.0	8.3	10.5/12.6
at MLSS = 3,500 mg/L	mgd	9.1	10.3	6.8	8.4/9.5	6.8	8.5/10.0
at MLSS = 4,000 mg/L	mgd	7.2	8.2	5.6	6.9/7.7	5.6	7.0/8.1
at MLSS = 4,500 mg/L	mgd	5.8	6.7	4.7	5.7/6.2	4.7	5.8/6.6

a. Assumes no hydraulic limitations.

b. 2 L non-stirred settleometer.

HPOAS Intermediate Clarifiers

The City performed two days of clarifier stress testing on the HPOAS ICs on February 15 and 16, 2018, to define the maximum loading condition at which either the ESS exceeded 25 mg/L or SBD remained stable (i.e., not rising). This loading condition was then compared to the theoretical SPA loading condition for the same SVI, RAS flow, and MLSS to determine a “de-rating” factor for use with other SPAs when defining IC capacity. Stress testing showed that Intermediate Clarifiers 1 and 2 (IC1/IC2) could achieve an SLR of roughly 65 percent of the SPA theoretical maximum allowable SLR and Clarifiers 3 and 4 (IC3/IC4) could achieve 70 percent of the theoretical SLR. On both days of testing, the clarifier SBD was the limiting factor. Testing also showed IC1 and IC2 capacities may be less than 65 percent of the theoretical maximum allowable SLR when SORs exceed 1,000 gal/ft^2-d.

Table ES-2 summarizes IC capacity at the historical 90th percentile SVI of 260 mL/g and a potential design SVI of 150 mL/g assuming a well-settling sludge in the first-stage HPOAS system. At an SVI of 260 mL/g, the peak de-rated SLR is 11.5 lb/ft^2-d (i.e., 65 percent of the theoretical SPA maximum allowable SLR). SPA shows that increasing the clarifier RAS flow to 2.5 mgd/clarifier can increase the SLR capacity to 13 lb/ft^2-d.

At a design SVI of 150 mL/g, the peak loading capacity increases to 17 lb/ft^2-d and 20 lb/ft^2-d if the RAS flow is increased to 2.5 mgd/clarifier. The IC peak SLR should not be associated with the peak hour flow because the second-stage HPOAS will dampen and accommodate high ESS surges out of the clarifiers. BC proposes that the IC maximum SLR/flow be defined as the 1-day maximum day condition rather than peak hour flow. At MLSS concentrations of 1,200 to 1,500 mg/L, BC assumed that clarifier performance is hydraulically limited at 1,200 gal/ft^2-d. Further testing could be conducted to verify the peak SOR capacity.

Table ES-2. Rochester HPOAS Intermediate Clarifier Capacity Analysis Results

Condition	Units	SVI[c] = 260 mL/g		SVI[c] = 150 mL/g	
Clarifier condition		Existing	Increased RAS	Existing	Increased RAS
Return sludge flow/clarifier	mgd	2.0	2.5	2.0	2.5
Solids loading rate	lb/ft^2-d	11.5	13.0	17.0	20.0
Flow/clarifier					
at MLSS = 1,200 mg/L	mgd	5.3	5.7	7.7 [a]	7.7 [a]
at MLSS = 1,500 mg/L	mgd	3.8	4.1	6.7	7.7
at MLSS = 2,000 mg/L	mgd	2.4	2.5	4.5	5.2

a. Assumes maximum SOR of 1,200 gal/ft^2-d.

b. Based upon 65% of SPA theoretical maximum allowable SLR.

c. 2 L non-stirred settleometer.

Recommendations

Based on modeling results, BC recommends Final Clarifier 5’s flocculation well depth be increased from 4 to 8.5 feet and Final Clarifier 1-4 RAS pumping capacity be increased from 2.5 to 5.25 mgd/clarifier. Both modifications will increase clarifier capacity and treatment performance. Additionally, City staff noted that some Final Clarifier 1-4 collector organ pipes may be plugged. Additionally, City staff has since noted that 2 of the 10 organ pipes on each Final Clarifier 1-4 collector were purposely plugged. The City should confirm that all organ pipes are operable and unplug the organ pipes to maximize capacity of the collectors/ clarifiers.

Finally, BC proposes that the IC SLR capacity be limited to the 65 percent of the SPA theoretical maximum allowable SLR and be defined as the 1-day maximum loading condition rather than peak hour loading condition.

Section 1: Scope of Work

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 identify current and future WRP facility requirements. This TM summarizes the WRP final clarifier field testing program and capacity analysis which will be used to establish the basis for final clarifier capacity and recommend improvements to further increase capacity and/or improve performance.

Three clarifiers representing critical points of treatment at the WRP were field-tested to calibrate clarifier-specific computational fluid dynamics (CFD) models. Primary influent flow is split between the air-activated sludge Aeration Basin Complex (ABC) and high-purity oxygen activated sludge (HPOAS) facility—both of which include final clarifiers. The third modeled clarifier was Primary Clarifier 2, which services the HPOAS train but is not discussed in this TM. The final clarifiers in test chronological order are:

- Final Clarifier 5 (ABC facility)
- Final Clarifier 3 (HPOAS facility)

The clarifier CFD model used for this analysis, 2Dc, was developed by a research team led by Professor J. Alex McCorquodale at the University of New Orleans. The model accounts for hydrodynamics, sludge settling, turbulence, sludge rheology, flocculation, clarifier geometry, and varying hydraulic and sludge withdrawal loadings. Discrete particle settling, flocculation-induced settling, hindered settling, and compression settling also are described by the model. Model inputs include mixed liquor settling and flocculating characteristics, discrete settling fractions, final clarifier geometry, surface overflow rate (SOR), temperature, mixed liquor suspended solids (MLSS) concentration, collector mechanism type, and return activated sludge (RAS) flow rate. The mixed liquor characteristics are determined on site using field and laboratory methods. Using these inputs, the model predicts effluent suspended solids (ESS) and RAS total suspended solids (TSS). In addition, the model output can also predict 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 models were calibrated a capacity analysis and performance investigations for each clarifier type were completed including modifying clarifier internal baffling and sludge withdrawal rates.

This technical memorandum (TM) summarizes the WRP final clarifier field testing program and capacity analysis. The TM is organized into two major sections representing each final clarifier evaluated followed by a recommendations section. Each clarifier section includes a brief overview, discussion on field testing results, model calibration and existing capacity analysis, followed by a final section on performance-enhancing improvements. Intermediate clarifier testing conducted by the City is summarized in Attachment D.

Section 2: Final Clarifier 5 (ABC Facility) Analysis

The WRP routes a portion of primary influent flow to the ABC facility for treatment. Figure 2-1 identifies the treatment processes in the ABC facility, which consists of a primary clarifier followed by two aeration basins and a final clarifier (Final Clarifier 5).

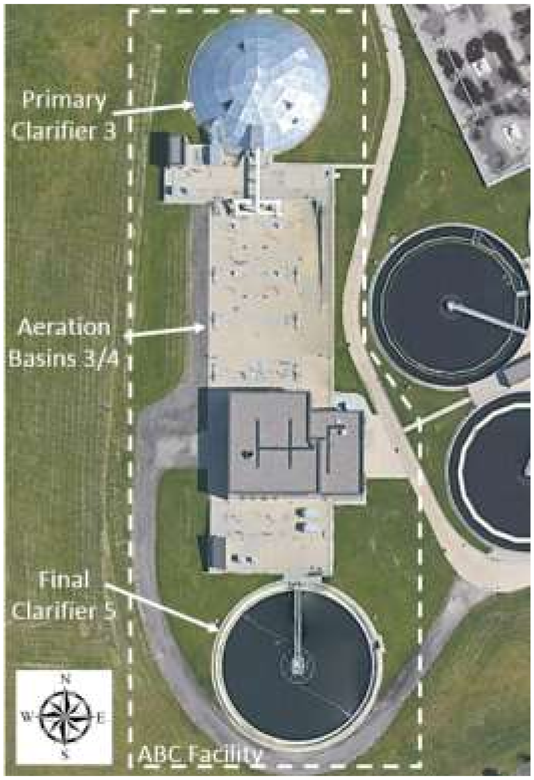

Figure 2-1. ABC treatment processes

Image source: Google Earth.

2.1 Final Clarifier 5 Overview

Final Clarifier 5 is a circular clarifier located within the ABC facility. Mixed liquor from the two upstream aeration basins combines into a common pipe that feeds the clarifier. Flow enters the clarifier from a center column with vertical slots at the water surface. A Flocculating Energy Dissipating Well Arrangement (FEDWA) energy-dissipating inlet (EDI) implements baffles to decrease the kinetic energy in the flow before entering a second baffle zone, typically called a flocculation well.

Forward flow ultimately advances to the tank periphery to overflow a weir into the collection launder, which discharges on the eastern side of the clarifier. Solids that settle in the clarifier are removed by a rotating hydraulic suction collector. The collector mechanism has two arms: one arm is a perforated suction collector arm that hydraulically removes the settled solids for transport to the RAS pumps, the opposing arm is equipped with multiple plow blades intended to turn the sludge over and facilitate thickening. A dual-armed skimmer also removes scum from the clarifier surface by directing it into a scum beach/trough for removal. Figure 2-2 shows the clarifier arrangement; Table 2-1 summarizes the size and features of Final Clarifier 5.

Figure 2-2. Final Clarifier 5 arrangement

Table 2-1. Rochester Final Clarifier 5 Design Details		
Item	Unit	Value
Final Clarifier 5		
Number of clarifiers	--	1
Diameter	ft	120.0
Side water depth	ft	17.0
Inlet column diameter	ft	3.5
FEDWA inner baffle diameter	ft	8.0
FEDWA outer baffle diameter	ft	13.0
FEDWA depth	ft	3.0
Flocculation well diameter	ft	24.5
Flocculation well depth	ft	4.0
Launder type	--	Peripheral
Launder width	ft	4
Sludge collector type	--	One-arm suction One-arm scraper
Sludge collector capacity	mgd	6.0 [a]
Scum baffle radius	ft	55.30
Scum baffle depth	ft	1.75
RAS Pumps		
Number	--	2
Unit flow capacity	mgd	6.0
Unit head capacity	ft	25
Unit power	HP	60

a. *Source: USFilter 2005.*

2.2 Final Clarifier 5 Field Testing

BC's field testing program was designed to develop information necessary to calibrate the clarifier CFD model. For this application, the 2Dc version of the CFD model was used because the clarifier is circular. In general, the protocols used follow those in *WERF/CRTC Protocols for Evaluating Secondary Clarifier Performance* (Wahlberg 2001). The field and laboratory data collection program was conducted on September 12, 2017. During this site visit, the following five different types of tests were performed:

- Flocculation testing
- Column settling testing
- Dispersed suspended solids (DSS) testing
- Discrete particle testing
- Final Clarifier 5 stress testing

This section describes the tests and testing results from the first four bullets above, and Final Clarifier 5 stress testing is summarized in Section 2.3. Attachment A contains the *Final Clarifier Field Testing Plan*, and Attachment B contains the field testing data.

2.2.1 Flocculation Testing

Mixed liquor flocculation characteristics describe the propensity of the floc to both aggregate and break apart. his 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 in the aeration basins and clarifier flocculation zones while minimal particles exit the clarifier.

To determine the flocculation characteristics of the mixed liquor, jar test experiments were performed on site. A six-paddle Phipps and Bird stirrer was used to flocculate the mixed liquor samples. Flocculation was induced mechanically by stirring the sample. Square, 2-lilter (L) jars were used for the flocculation tests. The flocculation beakers were filled with 2.0 L of mixed liquor. 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 beaker and analyzed for TSS. The flocculation characteristics were determined by fitting Equation 1 (Wahlberg et al. 1994) to the experimental data. The flocculation characteristics used in the CFD 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), grams per liter (g/L)
n_o = initial number of particles, g/L
G = root-mean square velocity gradient, s^{-1}
X = mixed liquor concentration, g/L
K_A = floc aggregation rate coefficient, L/g
K_B = floc breakup rate coefficient, seconds (s)
t = time, s

2.2.2 Column Settling Testing

Batch settling tests were performed on mixed liquor and return sludge thickened or diluted with non-chlorinated second-stage effluent to various concentrations to determine the settling characteristics for use in the 2Dc model. 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.

$$V_S = V_o e^{-kX} \tag{2}$$

where:

V_S = interface settling velocity, m/hr

X = solids concentration, g TSS/L

Vo = solids-specific settling parameter, m/hr

k = solids-specific settling parameter, L/g TSS

2.2.3 Dispersed Suspended Solids Testing

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

2.2.4 Discrete Particle Settling Testing

The 2Dc model characterizes mixed liquor particles/solids into three fractions: (1) large, (2) medium, and (3) small settling velocity. BC performed six discrete particle settling tests, to define the large and medium particle size distributions (Ramalingam et al. 2011). BC calculated the small particle velocity distribution using the DSS test results.

2.2.5 Testing Results

Table 2-2 summarizes the mixed liquor characteristics measured during the sampling program and the final value used in model calibration. Several modifications to the measured data or typical values were required to calibrate the model as noted in Table 2-2. Section 2.3 discusses the modifications in detail.

Table 2-2. Rochester Final Clarifier 5 Mixed Liquor Characteristics (September 12, 2017)

Parameter	Test Results	Model Calibration Value	Comments
Plant recorded SVI (SVISN)	105	105	
Hindered settling constants	V_o = 13.0 m/hr k = 0. 51 L/g	V_o = 13.0 m/hr k = 0. 51 L/g	
Compression zone settling constants	V_c = 30.8 m/hr k_c= 0.98 L/g	V_c = 6.5 m/hr k_c= 0.25 L/g	Typical values of roughly 1/2 V_o and k
Floc aggregation rate coefficient (K_A)	2.3×10^{-5} L/g	2.3×10^{-5} L/g	
Floc breakup rate coefficient (K_B)	1.9×10^{-9} L/g	1.9×10^{-9} L/g	
Discrete particle fractions (F)			
F_{large}	50.70%	77.00%	Adjusted to match ESS
F_{medium}	49.09%	22.79%	Adjusted to match ESS
F_{small}	0.21%	0.21%	

Table 2-2. Rochester Final Clarifier 5 Mixed Liquor Characteristics (September 12, 2017)

Parameter	Test Results	Model Calibration Value	Comments
Discrete particle velocity (V)			
V_{large}	V_o	V_o	
V_{medium}	$0.5V_o$	$0.7V_o$	Adjusted to match ESS
V_{small}	$0.1V_o$	$0.1V_o$	
Dispersed suspended solids	3.8–6.8 mg/L	5.0 mg/L	

2.3 Final Clarifier 5 Model Calibration

BC performed stress testing on Final Clarifier 5 to gather additional data required to calibrate the 2Dc model. The influent flow to Final Clarifier 5 was increased every 60 to 90 minutes, while the RAS flow rate was held constant throughout the entire test. The SBD, MLSS, and RAS TSS were recorded/collected every 30 minutes, and SBD was measured at both the mid-radius and launder locations (32.5 and 6.5 feet [ft] from the clarifier end wall, respectively). An equal volume of mixed liquor was also taken from each aeration basin and mixed for sludge quality testing. MLSS samples were pulled from the aeration basin effluent header in the tunnels. BC collected ESS samples every 15 minutes from the launder discharge structure. Figure 2-3 shows stress test sampling locations,

Figure 2-3. Final Clarifier 5 stress test sample locations

Image source: Google Earth.

Figure 2-4 shows solids loading rates (SLRs) and SORs during the stress test. The test SOR rate varied from approximately 280 to 1,000 gallons per square foot-day (gal/ft^2-d) with corresponding SLRs of 7 to 23 pounds per square foot-day (lb/ft^2-d).

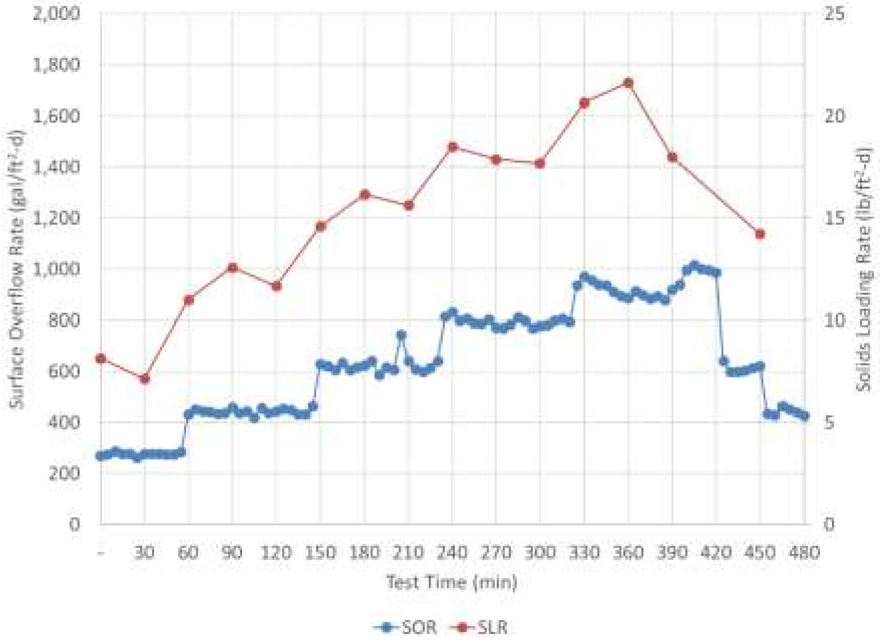

Figure 2-4. Final Clarifier 5 stress test solids loading rate and surface overflow rate

During the stress test denitrification began occurring in the sludge blanket. Denitrification was originally observed in a test column and then in Final Clarifier 5 as indicated by the floating sludge mats visible in Figure 2-5. The stress test flow rate was not increased as planned immediately after observing the floating sludge. For calibration purposes, the measured data were considered up to roughly 360 minutes from the start of the test. This time cutoff was selected based on the measured jump in ESS as shown in Figure 2-6.

Figure 2-5. Final Clarifier 5 stress test denitrifying sludge blanket

Figures 2-6 through 2-9 show the measured and model-predicted ESS, RAS TSS, and SBDs (1,200 milligrams per liter [mg/L]) at the mid-radius and launder locations. The calibrated model conservatively, but closely—matched the measured data and predicted the ESS, RAS TSS, and SBDs at the higher operating conditions.

The ESS prediction closely matches the field-measured data up to the calibration cutoff at test time of 360 minutes. As the loading on the clarifier increased the predicted ESS became slightly more conservative than the field-measured data, but the difference is considered negligible.

The predicted RAS TSS correlated with the field-measured data. While the predicted values do not exactly match the up and down trend of the field data, the prediction falls within the field-measured range and increasing TSS pattern. This level of accuracy is good for planning efforts.

Field-measured SBDs showed significant variation from one measurement to another. For example, SBD changed from 1.5 feet at test time = 0 minutes to roughly 4 feet at test time =15 minutes. These large changes in SBD are directly related to the location of the collector arm. At low SBDs, the collector suction header had just passed the SBD measuring point, while the opposite was generally true for higher SBDs. The model-predicted SBDs trend well with the measured average values through test time of 210 minutes. After 210 minutes, the model conservatively over-predicts the SBDs by 1 to 2 feet.

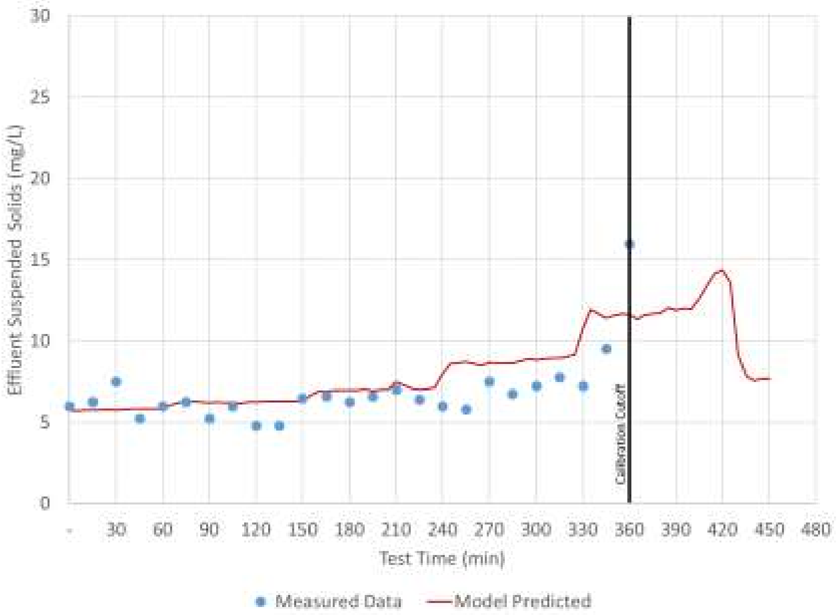

Figure 2-6. Final Clarifier 5 measured and predicted ESS

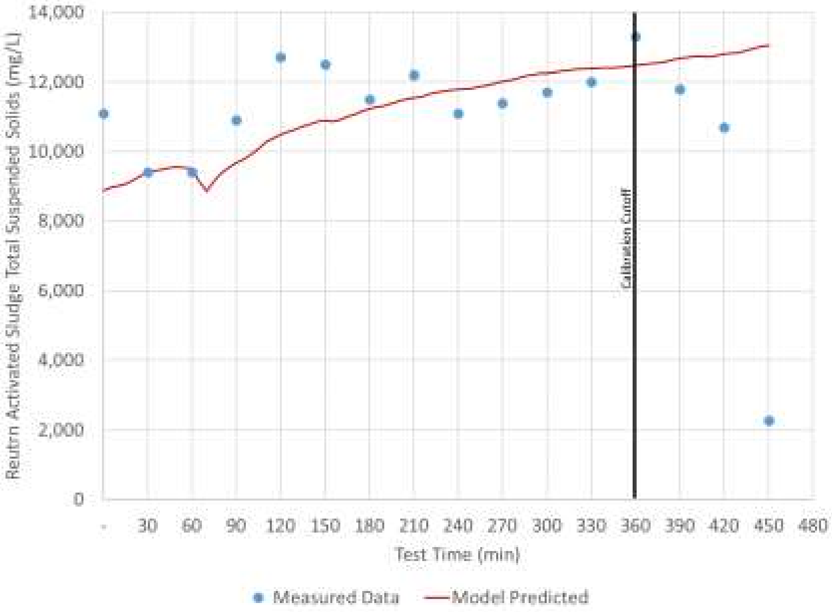

Figure 2-7. Final Clarifier 5 measured and predicted RAS TSS

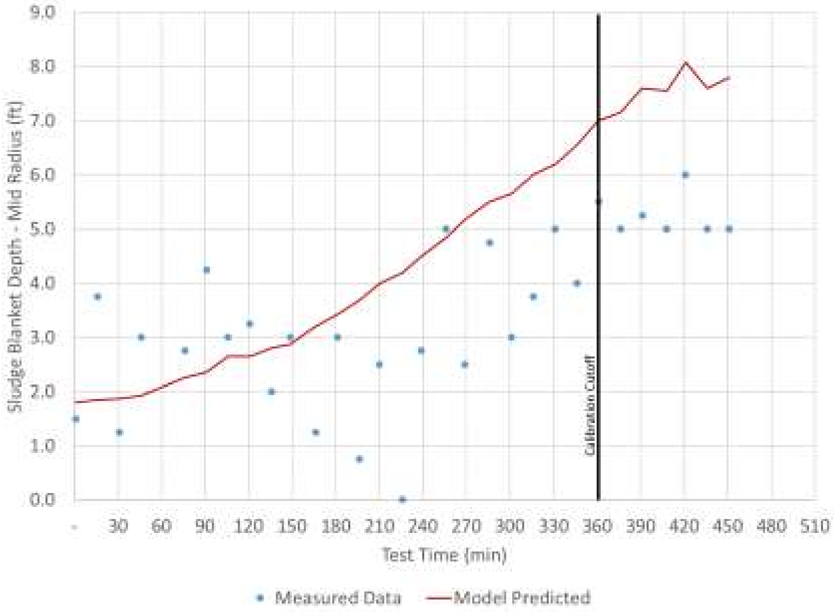

Figure 2-8. Final Clarifier 5 measured and predicted SBD at mid-radius

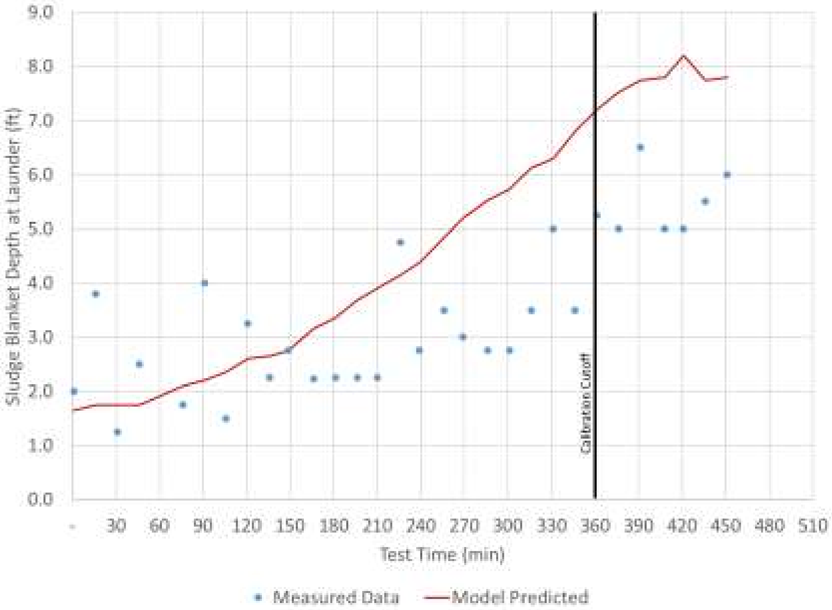

Figure 2-9. Final Clarifier 5 measured and predicted SBD at launder

Figure 2-10 shows the graphical output of the 2Dc model that represents a radial slice through half of the clarifier. The initial (i.e., test time = 0 minutes) and calibration final (i.e., test time = 360 minutes) test times are shown to bookend the calibration simulation. Key elements and dimensions are also identified including the FEDWA, flocculation well, scum baffle, radius, and side water depth. 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 end of the vector arrow tail).

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 (upper left corner of graphics), are confined to a relatively small volume. They appear large, but the inlet energy is rapidly dissipated—so it should not necessarily be inferred that these velocities will dominate fluid motion within the tank. Any examination of tank velocity profiles should instead 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”

ESS values cannot be accurately discerned from graphics (e.g., Figure 2-10) because the logarithmic color scale is adjusted to favor higher TSS concentrations (typical of the sludge blanket zone) and distinguish between thickening and clarification failure. It is more effective to examine plotted output representation than to examine ESS predictions. Examining solids profiles should be focused on the SBD, end wall effects, and solids removal or conveyance efficiency.

Figure 2-10 shows good mixing within the FEDWA at both test times. The model predicts that a significant density current forms as observed by the circular flow pattern beneath the flocculation well. Clarified liquid from the upper clarifier flows back toward the head of the tank, forming the current. This density current appears to slightly increase with increasing SOR but was not sufficient to stir up the blanket and cause significant effluent solids carryover as the density current flows up the clarifier end wall. Clarifier performance can potentially be improved by adding a deeper flocculation well to prevent/minimize the density current.

Figure 2-10 also shows the sludge blanket response as it increases from the low to higher SLR (i.e., rise of the yellow/orange interface from test time 0 to 360 minutes).

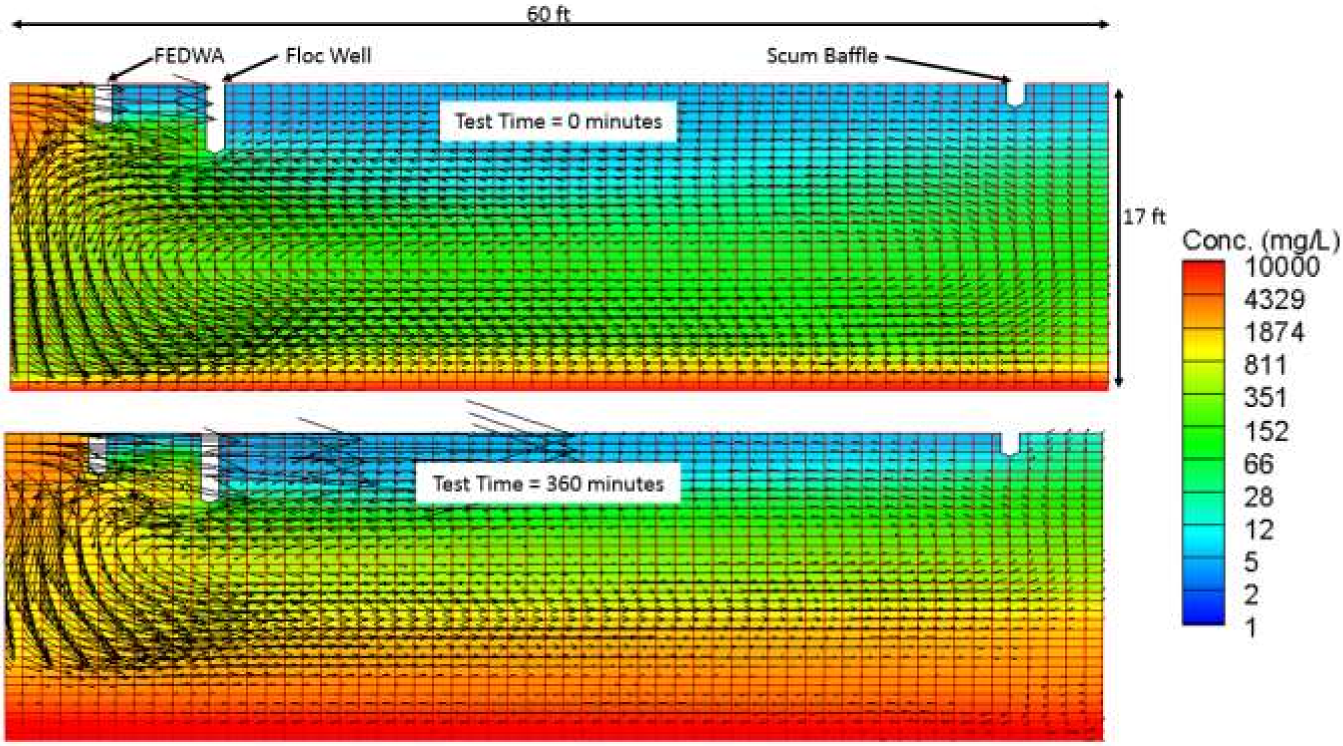

Figure 2-10. Final Clarifier 5 calibration at test time 0 and 360 minutes

To achieve the calibration represented in Figures 2-6 through 2-10 several modifications to the measured data or values typically used were required. The following discusses the specific modifications.

Sludge Compression Constants. The sludge compression settling constants calculated using the field data were unusually high compared to similar tests where the compression factors are roughly one-half the hindered settling factor values. During the 2Dc model calibration, BC adjusted the compression settling factors to more typical values of half of the hindered settling factors (V_o, k) to better match measured results.

Particle Fractions. The fractions of large and medium particles measured were roughly 1:1. This ratio is low relative to the large fraction compared to similar activated sludge systems. A large particle fraction of 0.77 was selected based on several other facilities, which improved the calibration to the measured ESS. The resulting medium particle fraction was then 0.2279.

Medium Particle Fraction Velocity. A final adjustment to the medium particle fraction velocity was required to achieve the final calibration ESS. Typically, the medium particle fraction velocity is set to one-half of V_o, but this predicted an elevated ESS compared to measured data. BC performed a sensitivity analysis on the medium particle fraction velocity, and the final value of 70 percent of V_o proved slightly conservative from an ESS standpoint at the higher loading conditions near the end of the simulation.

2.4 Final Clarifier 5 Capacity Analyses

This section summarizes the Final Clarifier 5 capacity analysis. The basis of this capacity analysis, existing clarifier capacity, clarifier performance enhancements, and capacity curves are presented in this section.

2.4.1 Capacity Analysis Failure Criteria

This analysis uses two failure criteria at peak hour flow conditions. If either criterion below is exceeded, the simulated clarifier operating condition is considered to have failed:

- Predicted ESS greater than 25 mg/L
- Predicted SBD greater than one-half the clarifier side water depth (SBD greater than 8.5 feet)

2.4.2 Sludge Quality

The WRP uses the 2-L unstirred settleometer SVI (SVISN) test to measure sludge quality. Figure 2-11 shows the ABC historical SVISN values from January 2, 2012, through September 27, 2017. BC typically uses the 90th percentile SVI value of a historical data set as the design condition for sludge quality/settling characteristics. The 90th percentile SVISN for Final Clarifier 5 is 130 milliliters per gram (mL/g) for the provided historical data. This SVISN and the 105 mL/g value measured during the stress test are used to adjust the calibration model Vesilind settling characteristics (Wahlberg et al. 1995) for the design SVISN conditions. Table 2-3 summarizes the model calibration and design Vesilind settling characteristic adjustment.

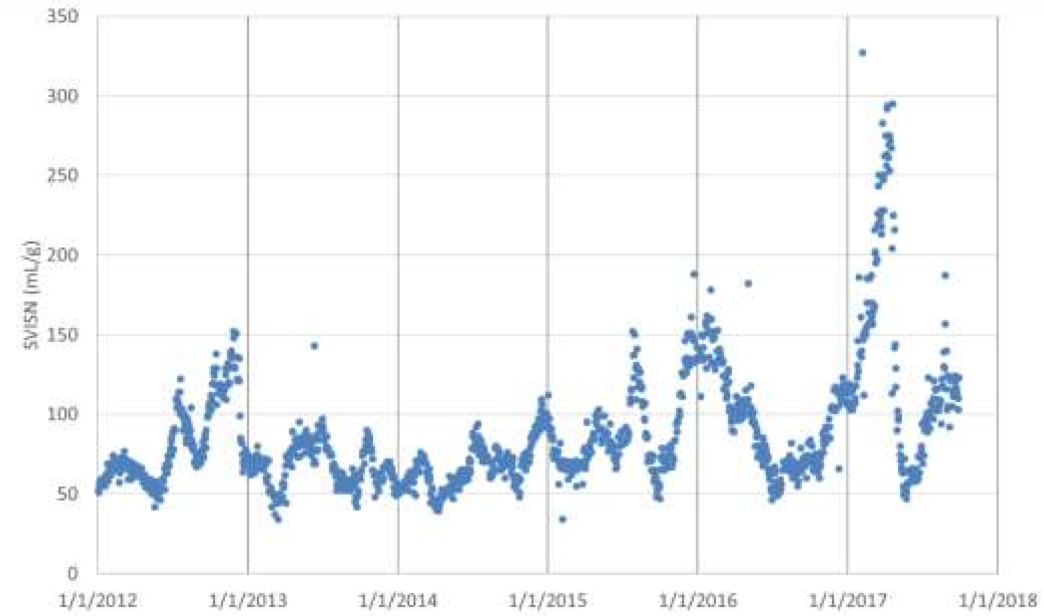

Figure 2-11. ABC historical SVISN

Table 2-3. Rochester Final Clarifier 5 Design Sludge Settling Characteristics		
Parameter	**Model Calibration Value**	**Design Value**
SVISN	105 mL/g	130 mL/g
Hindered settling constants	V_o = 13.0 m/hr k = 0. 51 L/g	V_o = 12.0 m/hr k = 0. 56 L/g
Compression zone settling constants	V_c = 6.5 m/hr k_c= 0.25 L/g	V_c = 6.0 m/hr k_c= 0.28 L/g

2.4.3 Existing Clarifier Capacity

The initial existing-capacity analysis used the documented RAS flow capacity of 6.0 million gallons per day (mgd), an MLSS of 3,500 mg/L, and the design settling characteristics presented in Table 2-3. The analysis varied influent flow until either the ESS or SBD reached the failure criteria described above. Table 2-4 summarizes the results as influent flow varies from 7.0 to 10.0 mgd. An influent flow of 9.0 mgd corresponding to an SLR of 39 lb/ft^2-d met the SBD limit of 8.5 feet, while lower influent flow predicted lower SBD, and higher influent flow exceeded the SBD limit. ESS was easily met for all runs.

Table 2-4. Rochester Final Clarifier 5 Existing Capacity Analysis Results
(MLSS = 3,500 mg/L, SVI = 130 mL/g)

Run	Influent Flow (mgd)	RAS Flow (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
6	7.0	6.0	34	600	8	4.5	5.5
7	8.0	6.0	36	700	9	6.0	7.0
1	9.0	6.0	39	800	11	7.5	8.5
8	10.0	6.0	41	900	16	10.0	10.5

Red text indicates failure mode.

Figure 2-12 shows the graphical output of the 2Dc model at the established capacity of 39 lb/ft^2-d and SOR of 800 gallons per day per square foot (gal/ft^2-d). A significant density current is predicted, as indicated by the superimposed red arrow, that is sweeping the sludge blanket to the end wall. In Figure 2-13 the increased SBD at the end wall from the density current is more pronounced when changing the graphic color gradient to show the SBD interface (green represents TSS less than 1,200 mg/L, and red represents TSS higher than 1,200 mg/L).

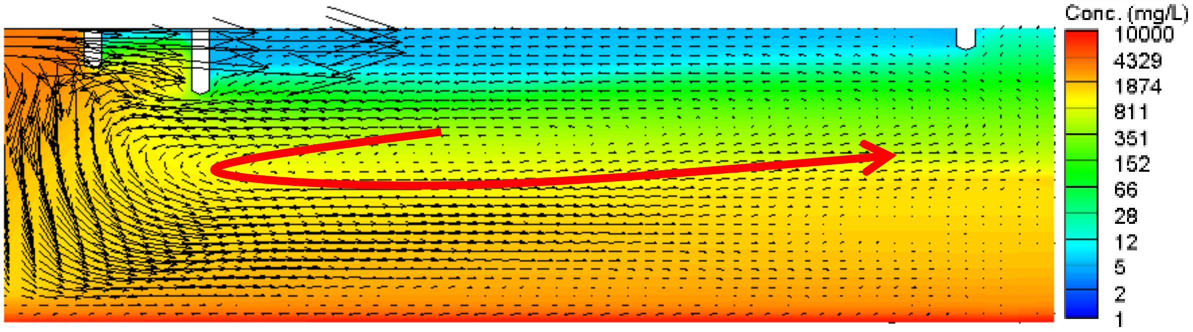

Figure 2-12. Final Clarifier 5 capacity simulation graphical output
(flow = 9.0 mgd, RAS flow = 6.0 mgd, MLSS = 3,500 mg/L)

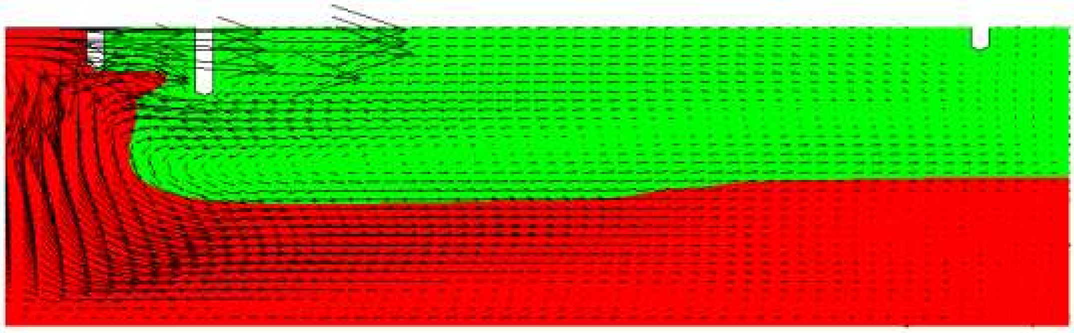

Figure 2-13. Final Clarifier 5 capacity simulation SBD graphical output
(flow = 9.0 mgd, RAS flow = 6.0 mgd, MLSS = 3,500 mg/L, SBD interface in red =1,200 mg/L)

2.4.4 Clarifier Performance Enhancements

Based on the initial capacity analysis BC considered three performance-enhancing modifications to Final Clarifier 5:

1. Increase the flocculation well depth equal to one-half the clarifier side water depth,
2. Increase the flocculation well diameter (the existing well diameter is roughly 20 percent of the clarifier diameter, while diameters greater than 30 percent have proven optimal for other facilities),
3. Consider different RAS flow rates.

Table 2-5 summarizes simulations completed to determine the impact of RAS flow rate, flocculation well depth, and flocculation well diameter on Final Clarifier 5 capacity and performance. Runs 1 and 2 show decreasing the RAS flow rate from 6.0 mgd (current RAS capacity) to 3.0 mgd, increases ESS slightly but greatly increases the SBD to failure at approximately 12 feet. Increasing the RAS flow rate above the 6.0 mgd capacity (Run 4 and 5) resulted in nearly the same ESS perspective as the existing configuration (Run 1) but the SBD increased above the failure point. The higher SLR associated with the higher RAS flow rates returning to the clarifier influent in Runs 4 and 5 overwhelms any benefit of the increased RAS bottom withdrawal flow rate. This analysis indicates that the current RAS pumps are adequate, and no changes are required.

Table 2-5 also shows increasing the flocculation well depth, reduces the ESS and SBD by 5 mg/L and 1.0 to 1.5 feet respectively (see Runs 1 and 8). Increasing the flocculation well diameter to 25 and 35 percent of clarifier diameter with the existing floc well depth (Run 9 and 10, respectively) provided no performance benefit. Run 11 represents a combination of the deeper flocculation well extended to 25 percent of the clarifier diameter. The only change from Run 8 was a 0.5-foot decrease in SBD measured at the launder, which is considered insignificant.

Based on the results, the most attractive capacity and performance enhancement is increase the existing flocculation well depth from 4 to 8.5 feet.

Table 2-5. Rochester Final Clarifier 5 Flocculation Well Analysis Results (MLSS = 3,500 mg/L, SVI = 130 mL/g)

Configuration	Run	Influent Flow (mgd)	RAS Flow (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	Flocculation Well Depth (ft)	Flocculation Well Diameter (ft)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
Existing	1	9.0	6.0	39	800	4.0	24.5	11	7.5	8.5
RAS flow variation	2	9.0	3.0	31	800	4.0	24.5	15	12.0	12.0
	3	9.0	5.0	36	800	4.0	24.5	12	7.5	8.5
	4	9.0	7.0	41	800	4.0	24.5	11	8.0	9.0
	5	9.0	8.0	44	800	4.0	24.5	12	8.5	9.5
Flocculation well variation	8	9.0	6.0	39	800	8.5	24.5	6	6.5	7.0
	9	9.0	6.0	39	800	4.0	30.0	11	7.5	8.5
	10	9.0	6.0	39	800	4.0	42.0	11	7.5	9.0
	11	9.0	6.0	39	800	8.5	30.0	6	6.5	6.5

Red text indicates failure mode.

Figure 2-14 graphically shows the improved configuration compared to current WRP setup; a marked reduction in the density current is identified. The increased flocculation well depth configuration provides significant ESS reduction, and the improved ESS performance becomes critical at higher SORs, discussed below.

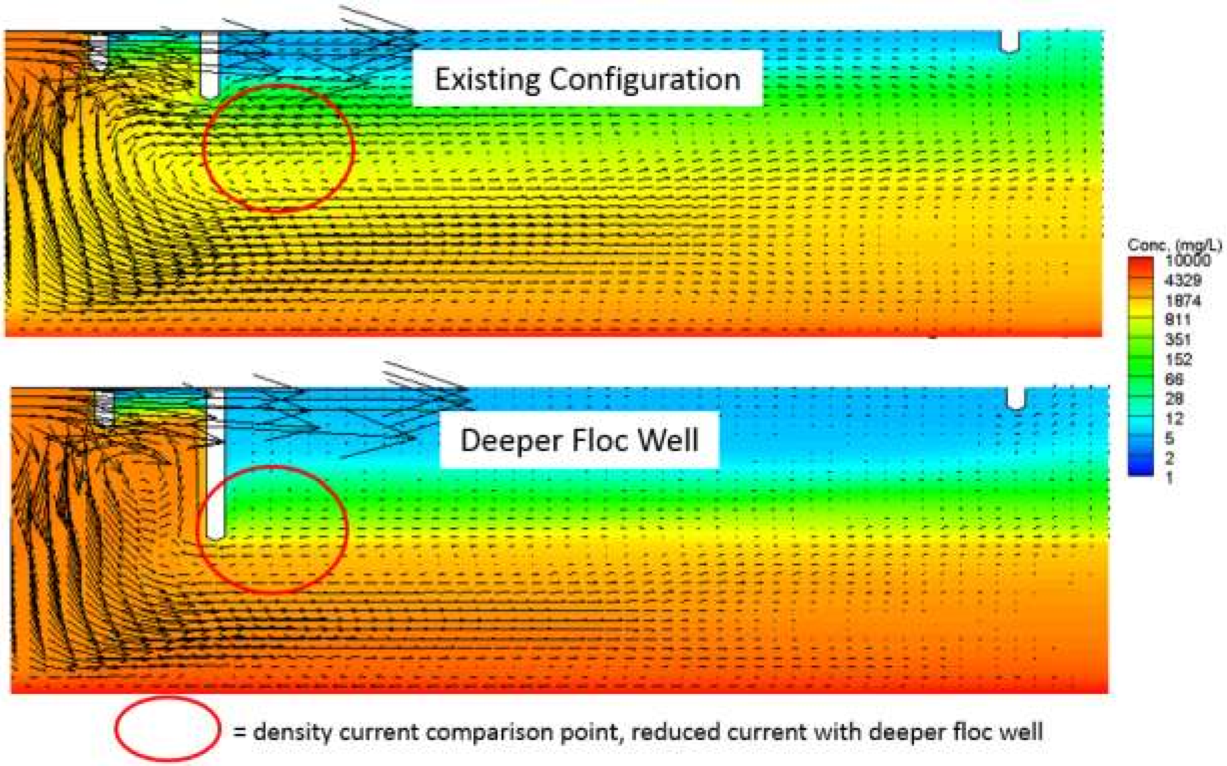

Figure 2-14. Final Clarifier 5 capacity comparison with increased flocculation well depth (flow = 9.0 mgd, RAS flow = 6.0 mgd, MLSS = 3,500 mg/L)

2.4.5 Capacity Curves

After completing the initial clarifier analysis with both existing and enhanced configurations (flocculation well deepened) at an MLSS of 3,500 mg/L, BC evaluated the clarifier capacity over a range of MLSS and influent flows for the existing clarifier and a clarifier with an 8.5-foot deep flocculation well. Table 2-6 summarizes the results of this analysis, which are presented graphically in Figure 2-15.

For the existing clarifier, Table 2-6 shows the predicted ESS increases with flow, which leads to ESS and SBD limiting SLR capacity at SORs greater than 1,350 gal/ft^2-d. With a deepened flocculation well, clarifier capacity increases from 39 to 42 lb/ ft^2-d and predicted ESS performance remains below 10 mg/L at SORs up to 1,800 gal/ ft^2-d. Increasing the flocculation well diameter did not significantly reduce SBD, thus no modifications are recommended.

The City should consider installing a dual-suction collector when it replaces the existing collector to promote rapid sludge removal and minimize fluctuations in the SBD levels observed with the single suction collector.

Table 2-6. Rochester Final Clarifier 5 Capacity Curve Development (SVI = 130 mL/g, RAS flow = 6.0 mgd)

Configuration	MLSS (mg/L)	Flow (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	ESS (mg/L)	SBD (ft)
Existing	2,000	18.0	35[a]	1,550	25	8.5
	2,500	15.0	39	1,350	25	8.4
	3,000	12.0	39	1,050	16	8.4
	3,500	9.0	39	800	11	8.4
	4,500	6.0	39	500	7	8.4
8.5 ft deep flocculation well	2,200	20.0	42	1,800	11	8.5
	2,500	17.0	42	1,450	8	8.5
	3,000	13.0	42	1,200	6	8.5
	3,500	10.0	42	950	6	8.5
	4,500	7.0	42	600	6	8.5

Red text indicates failure mode.

a. Reduced SLR to maintain ESS < 25 mg/L.

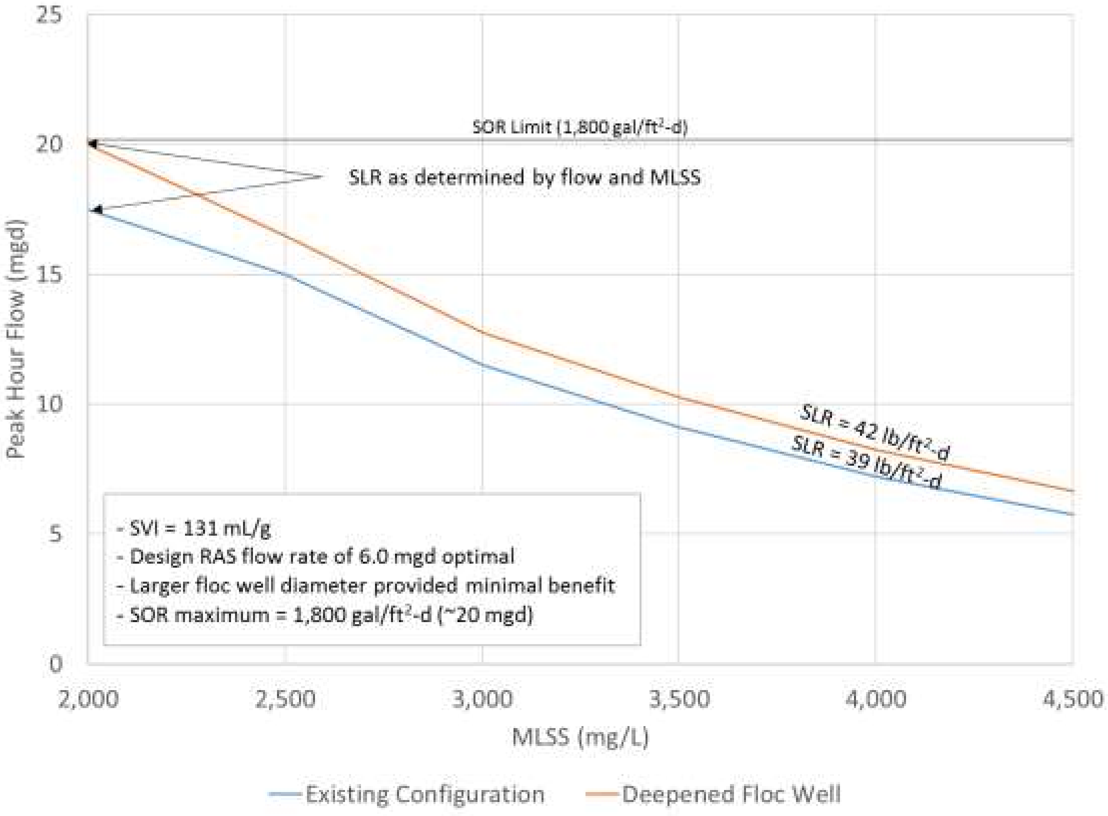

Figure 2-15. Final Clarifier 5 capacity curves

Section 3: Final Clarifiers 1–4 (HPOAS Facility) Analysis

The majority of WRP primary influent flow is currently routed to the HPOAS train for treatment. Figure 3-1 identifies the treatment processes in the HPOAS facility, which consists of two primary clarifiers followed by two first-stage HPOAS reactors and intermediate clarifiers (ICs). IC effluent is nitrified in three second-stage HPOAS basins with solids separation in Final Clarifiers 1 through 4.

Figure 3-1. HPOAS treatment processes

Image source: Google Earth.

3.1 Final Clarifiers 1–4 Overview

The HPOAS facility has four circular final clarifiers, Final Clarifiers 1–4. Mixed liquor from the three upstream second-stage basins combines into a common 60-inch-diameter pipe that feeds the final clarifier influent splitter box. After passive hydraulic splitting in the splitter box, flow enters each clarifier from a center column with vertical slots at the water surface. A type of EDI (called a Clariflow® Well by the original manufacturer, Walker Process) implements baffles to decrease the kinetic energy in the flow before entering a second baffle zone, typically called a flocculation well.

Figure 3-2 shows the EDI and flocculation well. Forward flow finally travels to the effluent weirs and launders located roughly 10 feet inboard of the outer clarifier wall (see Figure 3-3). An organ pipe sludge collector removes solids that settle in the clarifier. Each clarifier has two dedicated RAS pumps to pump return sludge flows. Figure 3-4 shows a similar organ pipe collector mechanism located at a different facility. Scum is also collected from the surface of the clarifier with a single skimmer arm that directs the scum into a collection hopper for removal. Table 3-1 summarizes the size and features of Final Clarifiers 1 through 4.

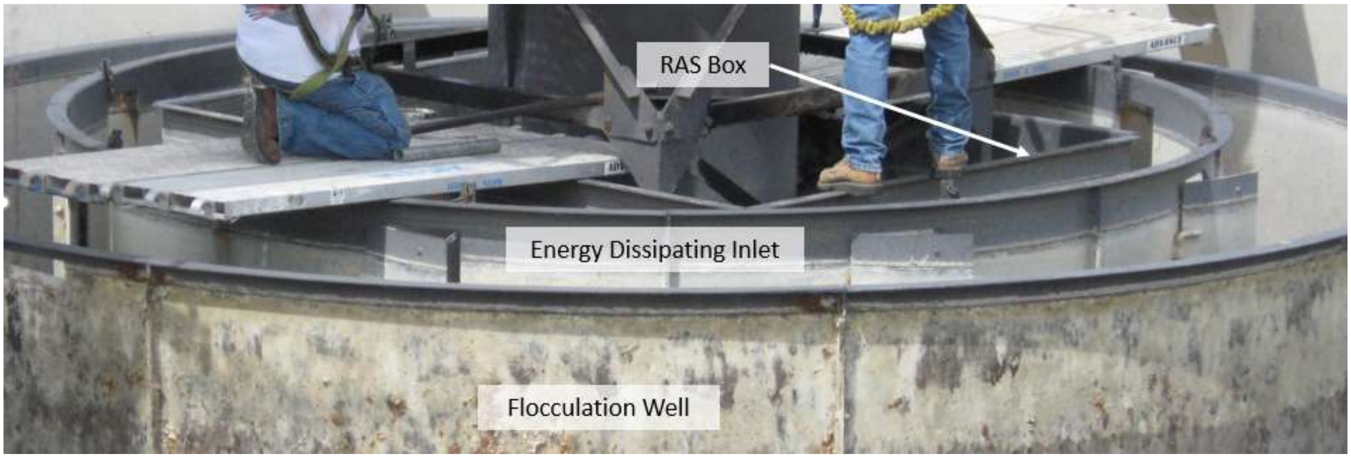

Figure 3-2. Final Clarifiers 1–4 inlet details

Figure 3-3. Final Clarifiers 1–4 configuration

Image source: Google Earth.

Figure 3-4. Final Clarifier 1-4 organ pipe sludge collector

Table 3-1. Rochester Final Clarifiers 1–4 Design Details		
Item	**Units**	**Value**
Final Clarifiers 1–4		
Number of clarifiers	--	4
Diameter	ft	120
Side water depth	ft	14
Inlet column diameter	ft	3.5
EDI diameter	ft	13
EDI depth	ft	5.5
Flocculation well diameter	ft	18
Flocculation well depth	ft	7.5
Launder type	--	Inboard
Launder width	ft	3.5
Sludge collector type	--	Dual-arm organ pipe
Sludge collector capacity	mgd	5.3 [a]
Scum baffle radius	ft	48.5
Scum baffle depth	ft	0.8
RAS Pumps		
Number	--	8
Unit flow capacity	mgd/clarifier	2.5/3.6 [b]
Unit head capacity	ft	8/18 [b]
Unit power	horsepower	15

a. *Source: USFilter 2005.*

b. *Plant staff reported that capacity at 100% speed is 1.7–2.1 mgd at 8 ft of head; a maximum of 2.5 mgd was recorded on the temporary flow meter installed for the stress test. The system was originally designed for 3.6 mgd at 18 ft with 4 pumps operating.*

3.2 Final Clarifier 3 Field Testing

The field testing for Final Clarifier 3 was the same as Final Clarifier 5 except for the approach to characterize discrete particle settling velocities and fractions. Instead of estimating particle settling velocity distributions by observing particles settle, the modified test measured the solids mass distribution settling at velocities of 2, 4, 6, 8, 10, and 12 m/hr. While this required more field tests and sample analyses, the broader velocity range provided a better representation of particle velocity distribution.

On December 13, 2017, BC conducted the Clarifier 3 field testing program and completed the same tests as described for Final Clarifier 5. (Final Clarifier 3 stress testing is summarized in Section 3.3.) Attachment A contains the *Final Clarifier Field Testing Plan* and Attachment C contains the Clarifier 3 field testing data.

Table 3-2 summarizes the mixed liquor characteristics measured during the sampling program and final value used for model calibration. Adjustments to the field measured compression zone settling constant (k_c) and discrete particle fractions were required to calibrate the model (see Table 3-2). Section 3.3 discusses these modifications in detail.

The most notable finding was the medium particle fraction of 60 percent which is unusually high. Most activated sludge systems with similar solids retention times will have 70 to 80 percent of the discrete particles in the large particle fraction. BC speculates that the high medium particle fraction is the result of low influent carbon to the second-stage HPOAS, which can lead to microbial population with less desirable settling characteristics (e.g., pin floc). Shearing by the oxygen mixers may be another possible explanation for the high fractions.

Table 3-2. Rochester Final Clarifier 3 Mixed Liquor Characteristics (December 13, 2017)

Parameter	Test Results	Model Calibration Value	Comments
Plant recorded SVI (SVISN)	120	120	
Hindered settling constants	V_o = 9.1 m/hr k = 0. 56 L/g	V_o = 9.1 m/hr k = 0. 55 L/g	
Compression zone settling constants	V_c = 3.6 m/hr k_c= 0.39 L/g	V_c = 3.6 m/hr k_c= 0.28 L/g	Reduction of k_c required to better match SBD
Floc aggregation rate coefficient (K_A)	2.1 x 10^{-5} L/g	2.1 x 10^{-5} L/g	
Floc breakup rate coefficient (K_B)	3.0 x 10^{-9} L/g	3.0 x 10^{-9} L/g	
Discrete particle fractions (F)			
F_{large}	39.24%	36.84%	Decreased to match ESS
F_{medium}	60.16%	60.16%	
F_{small}	0.60%	3.00%	Increased to match ESS
Discrete particle velocity (V)			
V_{large}	V_o	V_o	
V_{medium}	$0.5V_o$	$0.5V_o$	
V_{small}	$0.1V_o$	$0.1V_o$	
Dispersed suspended solids	9.8–14.4 mg/L	7 mg/L	

3.3 Final Clarifier 3 Model Calibration

BC performed stress testing on Final Clarifier 3 to gather the data required to calibrate the 2Dc model. The influent flow to Final Clarifier 3 was increased every 60 to 90 minutes while the RAS flow rate was held constant during testing. The SBD, MLSS, and RAS TSS were recorded/collected every 30 minutes. SBDs were measured at the mid-point between the flocculation well and launder and at launder (34 and 7 feet from the clarifier end wall, respectively). A few SBD measurements were taken at the end wall, but results matched the coinciding launder measurement (see Attachment C). BC collected mixed liquor from the influent splitter box for sludge quality testing and ESS samples every 15 minutes from the launder discharge structure. RAS TSS samples were collected from the Final Clarifier 3 RAS pump discharge piping. Figure 3-5 shows stress test sampling locations.

Figure 3-5. Final Clarifier 3 stress test sample locations

Image source: Google Earth.

Figure 3-6 shows SLRs and SORs during the stress test. The test SOR varied from approximately 400 to 1,300 gal/ft^2-d with corresponding SLRs of 12 to 22 lb/ft^2-d. The test SOR rates are based on adjusting the reported flow at the head of the WRP after the grit tank by the amount of time it takes for the flow to reach Final Clarifier 3. This adjustment used visual observations of the splitter box level trends to delay the flow to Final Clarifier 3. Figure 3-7 shows the data used and selected time delay to arrive at the Final Clarifier 3 flow rate. The blue line/dot series represents the HPOAS flow measured in the headworks while the red line/dots represent the final clarifier splitter box level.

After test time = 150 minutes, all flow was directed to Final Clarifier 3. A consistent relationship between the flow and splitter box was difficult to discern from the data. Nevertheless, during the peak HPOAS flow condition at test time = 360 minutes the splitter box level peaked roughly 30 minutes later, at test time = 420 minutes. The 30-minute lag is also what WRP staff estimate based on their operating experience and was thus used for the calibration. The purple line/dots represent the delayed Final Clarifier 3 influent flow.

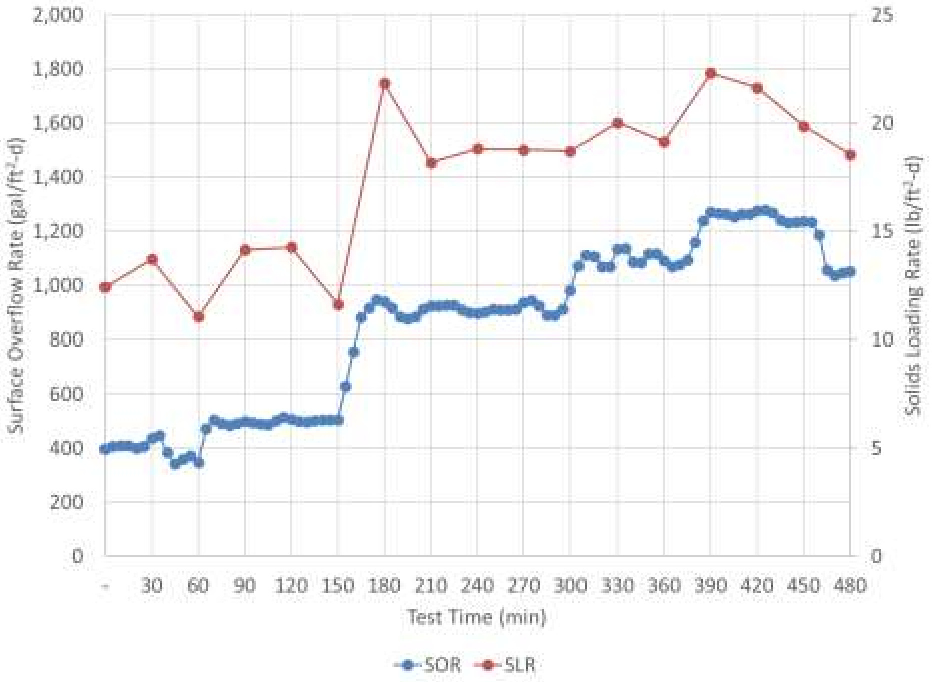

Figure 3-6. Final Clarifier 3 stress test solids loading rate and surface overflow rate

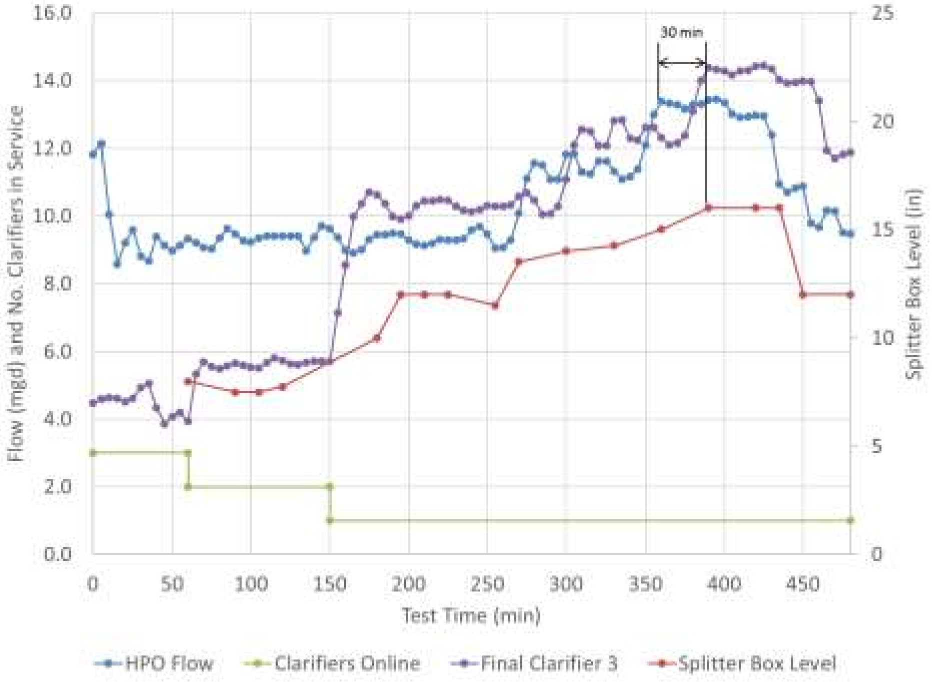

Figure 3-7. Final Clarifier 3 stress test flow determination

Figures 3-8 through 3-11 show the measured and predicted ESS, RAS TSS, and SBDs at the mid-radius and launder locations. The calibrated model closely matches the measured ESS and RAS TSS data under all loading conditions. A non-settleable TSS concentration of 7 mg/L was required to match the first 90 minutes of the test during stable operation. The SBDs were conservatively predicted higher at lower loading conditions, but more closely matched measured values at peak loading. Because the main area of interest revolves around peak loading, this calibration is suitable for the capacity analysis discussed later.

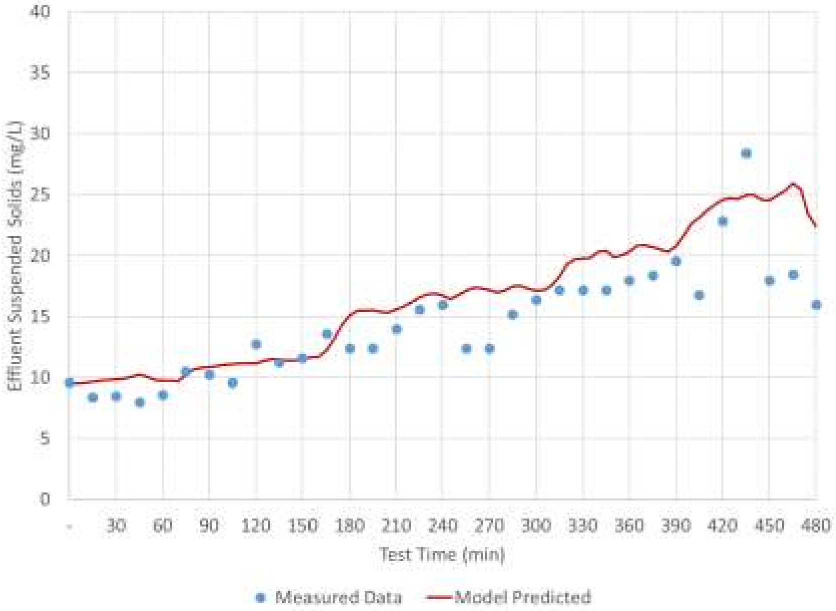

Figure 3-8. Final Clarifier 3 measured and predicted ESS

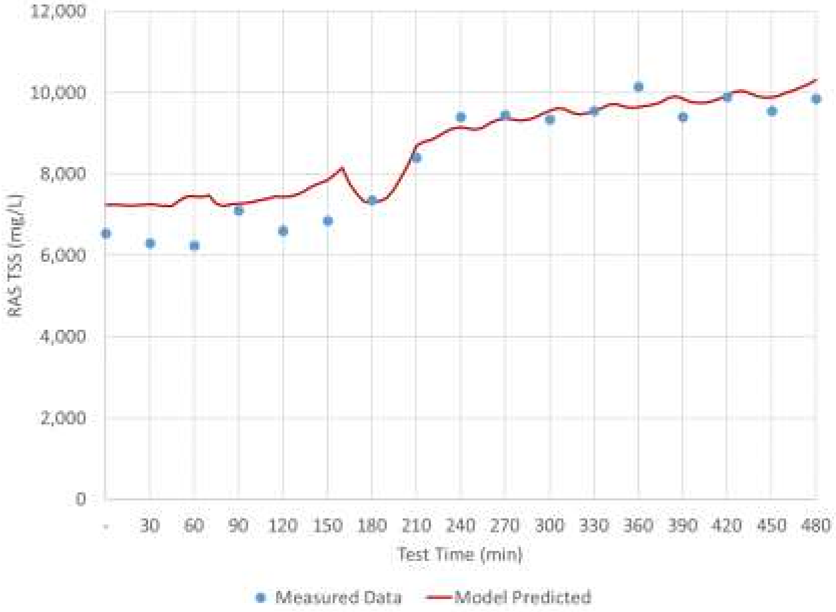

Figure 3-9. Final Clarifier 3 measured and predicted RAS TSS

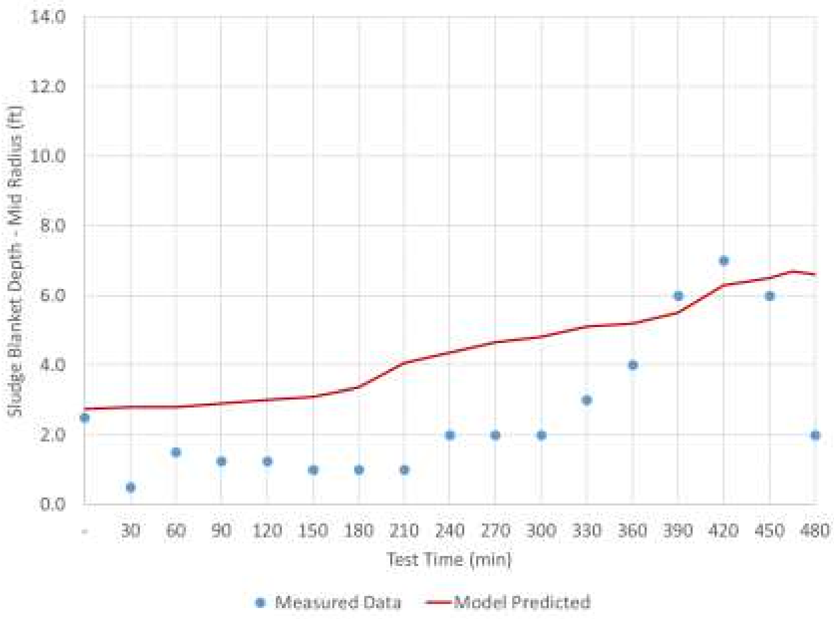

Figure 3-10. Final Clarifier 3 measured and predicted SBD at mid-radius

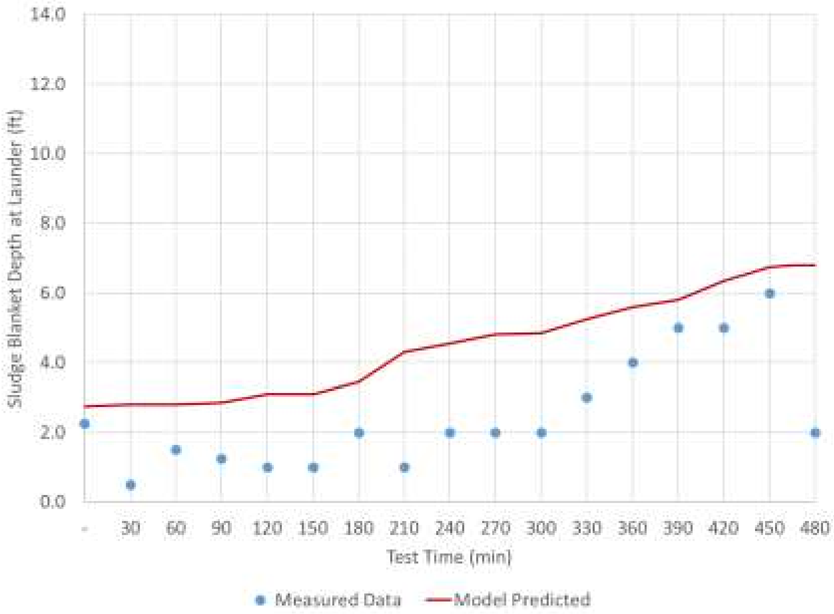

Figure 3-11. Final Clarifier 3 measured and predicted SBD at launder

Figure 3-12 shows the graphical output of the 2Dc model and represents a radial slice through half of the clarifier. The initial (test time = 0 minutes) and peak loading condition (test time = 420 minutes) times are shown to bookend the measured loading conditions. Key elements and dimensions are also identified including the flocculation well, scum baffle, radius, and side water depth. The EDI was not modeled in the final calibration run based upon BC experience for this type of EDI.

The suspended solids concentrations are indicated by color, and vectors represent fluid velocity (the vector length is relative to the magnitude of velocity at the point corresponding to the end of the tail of the vector arrow). The vector scale is exaggerated so that differences in low velocities can be distinguished, and the large arrows stemming from the inlet are confined to a small space at the inlet. Examining tank velocity profiles should instead be focused on the following issues:

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

Figure 3-12 shows good mixing within the flocculation well at the beginning and end of the test. A small density current is formed at the beginning of the test, as observed by the circular flow pattern under the flocculation well as clarified liquid from the upper clarifier flows back toward the head of the tank but is overcome by the higher flow at the end of the test. This density current was not sufficient to stir up of the blanket or cause significant effluent solids carryover as the density current flows up the clarifier end wall.

Figure 3-12 also shows the sludge blanket response as it increases from the low to higher SLR (i.e., rise of the yellow/orange interface from test time 0 to 420 minutes).

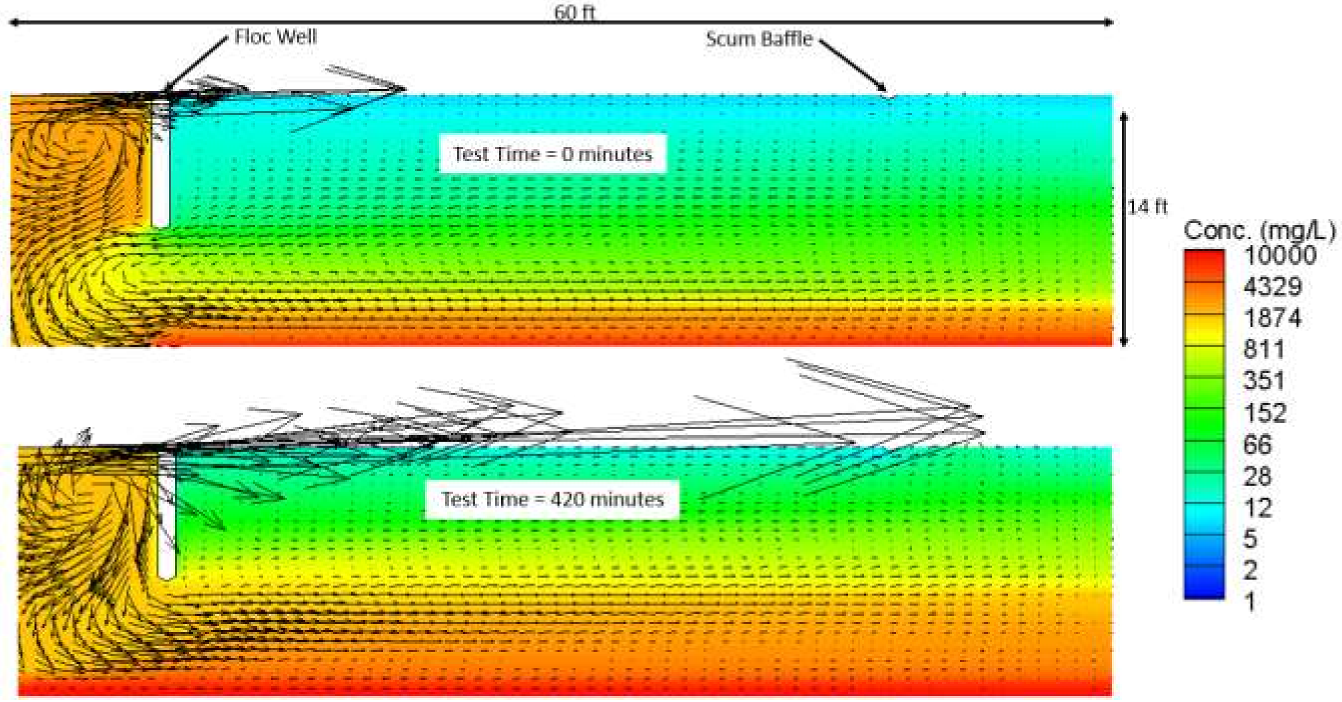

Figure 3-12. Final Clarifier 3 calibration at test time 0 and 420 minutes

To achieve the calibration represented in Figures 3-8 through 3-12 two adjustments to the measured data or typical values were required:

- **Sludge compression constant:** Field-measured sludge compression constants predicted higher-than-measured SBDs. The k_c constant was reduced by 30 percent to achieve the calibration results identified above.
- **Particle fractions:** After adjusting the sludge compression constant, the predicted ESS was lower than measured. BC increased the F3 fraction (i.e., smallest settleable fraction) to 3 percent and balanced the total particle balance by subtracting from the F1 fraction, or large particles.

3.4 Final Clarifiers 1–4 Capacity Analysis

This section summarizes BC's capacity analysis of Final Clarifiers 1 through 4. The basis of evaluation, existing clarifier capacity under current and potential future biological nutrient removal (BNR) operations, clarifier performance enhancements, and capacity curves are presented. Final Clarifier 3 calibrated model was used to predict the capacity of Final Clarifiers 1–4.

3.4.1 Basis of Capacity Analysis

The basis of capacity analysis comprised analyzing failure criteria and sludge quality.

3.4.1.1 Capacity Analysis Failure Criteria

This failure criteria analysis uses the same two failure criteria at peak hour flow conditions (as described under Final Clarifier 5). If either criterion below is exceeded, the simulated clarifier operating condition is considered to have failed:

- Predicted ESS greater than 25 mg/L
- Predicted SBD greater than one-half the side water depth of the clarifier (SBD greater than 7 feet)

3.4.1.2 Sludge Quality

Figure 3-13 shows the Second stage HPOAS reported SVISN values from January 1, 2014, through September 27, 2017. The 90th percentile SVISN is 92 mL/g and will be used to define the capacity of Final Clarifiers 1 through 4 for the current operations flow scheme.

For potential future BNR operations with an anaerobic selector, a design SVISN of 130 mL/g will be used to match the ABC 90th percentile design SVI and associated mixed liquor characteristics including particle fractions, particle velocity, dispersed solids, and flocculation kinetics.

Table 3-3 summarizes the design sludge settling characteristics for current HPOAS and potential future BNR operations.

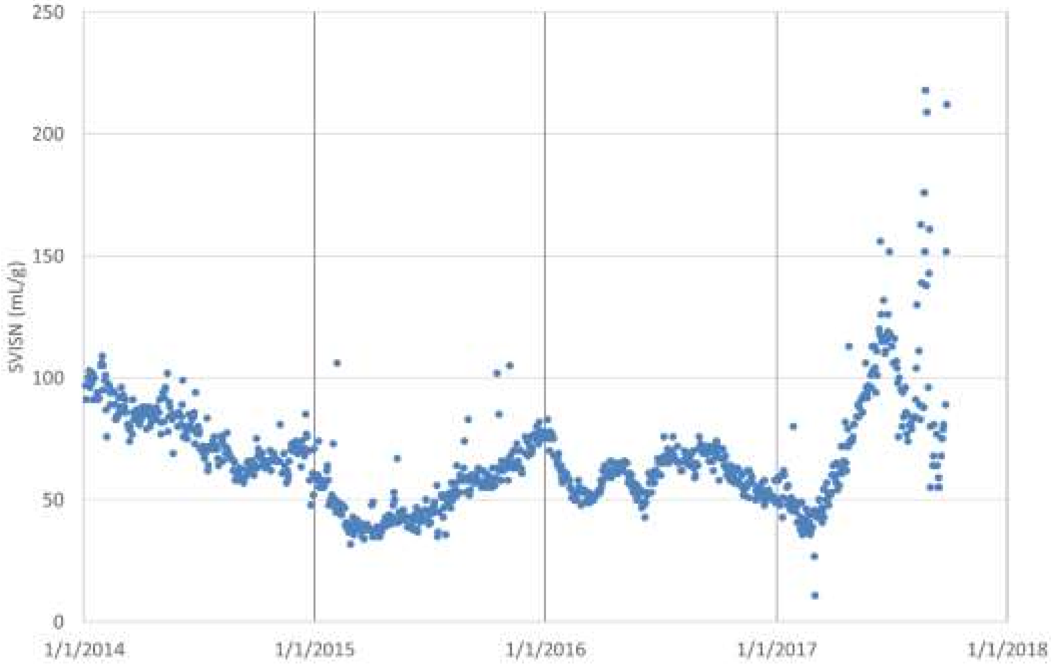

Figure 3-13. Second Stage HPOAS historical SVISN

Table 3-3. Rochester Final Clarifiers 1–4 Design Sludge Settling Characteristics

Parameter	Model Calibration Value	HPOAS Design Value	BNR Design Value [a]
SVISN	120	92	130
Hindered settling constants	V_o = 9.1 m/hr k = 0. 56 L/g	V_o = 10.2 m/hr k = 0. 50 L/g	V_o = 12.0 m/hr k = 0. 56 L/g
Compression zone settling constants	V_c = 3.6 m/hr k_c= 0.28 L/g	V_c = 5.1 m/hr k_c= 0.25 L/g	V_c = 6.0 m/hr k_c= 0.28 L/g
Discrete particle fractions (F)			
F_{large}	36.84%		77.00%
F_{medium}	60.16%		22.79%
F_{small}	3.00%		0.21%
Discrete particle velocity (V)			
V_{large}	V_o		V_o
V_{medium}	$0.5V_o$		$0.7V_o$
V_{small}	$0.1V_o$		$0.1V_o$

a. Assumes operation with an anaerobic selector.

3.4.2 Existing Clarifier Capacity: HPOAS Operation

The existing capacity analysis used the maximum RAS flow of 2.5 mgd recorded during the stress test (temporary flow meter) with one RAS pump per clarifier in operation. This initial investigation assumes an MLSS of 3,500 mg/L. The analysis varied influent flow until either the ESS exceeded 25 mg/L or SBD exceeded 7-feet. Table 3-4 shows the existing clarifiers have a SLR capacity of 24 lb/ft^2-d as simulations with SLRs of 27 and 30 lb/ft^2-d resulted in SBDs greater than 7-feet (Runs 7-HPO and 8-HPO). The predicted ESS was less than 25 mg/L for all runs.

Table 3-4. Rochester Final Clarifiers 1–4 Capacity Analysis Results: Existing HPOAS Operation

(MLSS = 3,500 mg/L, SVISN = 92 mL/g)

Run	Influent Flow/ Clarifier (mgd)	RAS Flow/ Clarifier (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
1-HPO	7.0	2.5	24	625	12	7.0	7.0
7-HPO	8.0	2.5	27	700	13	9.2	8.9
8-HPO	9.0	2.5	30	800	15	10.7	10.6

Red text indicates failure mode.

3.4.3 Existing Clarifier Capacity: Potential Future BNR Operation

Table 3-5 summarizes the Final Clarifiers 1–4 existing clarifier capacity analysis under potential future BNR operations. Modeling shows that the Final Clarifiers 1-4 SLR capacity with BNR is the same as that for HPOAS operations at a RAS flow of 2.5 mgd (24 lb/ft^2-d). Like the HPOAS operation, Final Clarifier 1-4 capacity is limited by SBD, however, predicted ESS under BNR operations decreased by about 50 percent. The reduced ESS can be attributed to the reduced non-settleable and higher fraction of larger fast settling solids of the BNR sludge while the SBD reacted the same regardless.

Figure 3-14 shows the graphical output of the 2Dc model at the established capacity of 24 lb/ft^2-d and SOR of 625 gal/ft^2-d. The predicted velocity profiles look good with significant mixing in the flocculation well, minimal density current, and low velocities at the sludge blanket surface (yellow color).

Table 3-5. Rochester Final Clarifier 1-4 Capacity Analysis Results: Potential Future BNR Operation

(MLSS = 3,500 mg/L, SVISN = 130 mL/g)

Run	Influent Flow/Clarifier (mgd)	RAS Flow/Clarifier(mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
1-BNR	7.0	2.5	24	625	6	7.0	7.0
7-BNR	8.0	2.5	27	700	6	9.0	8.9
8-BNR	9.0	2.5	30	800	7	10.8	10.7

Red text indicates failure mode.

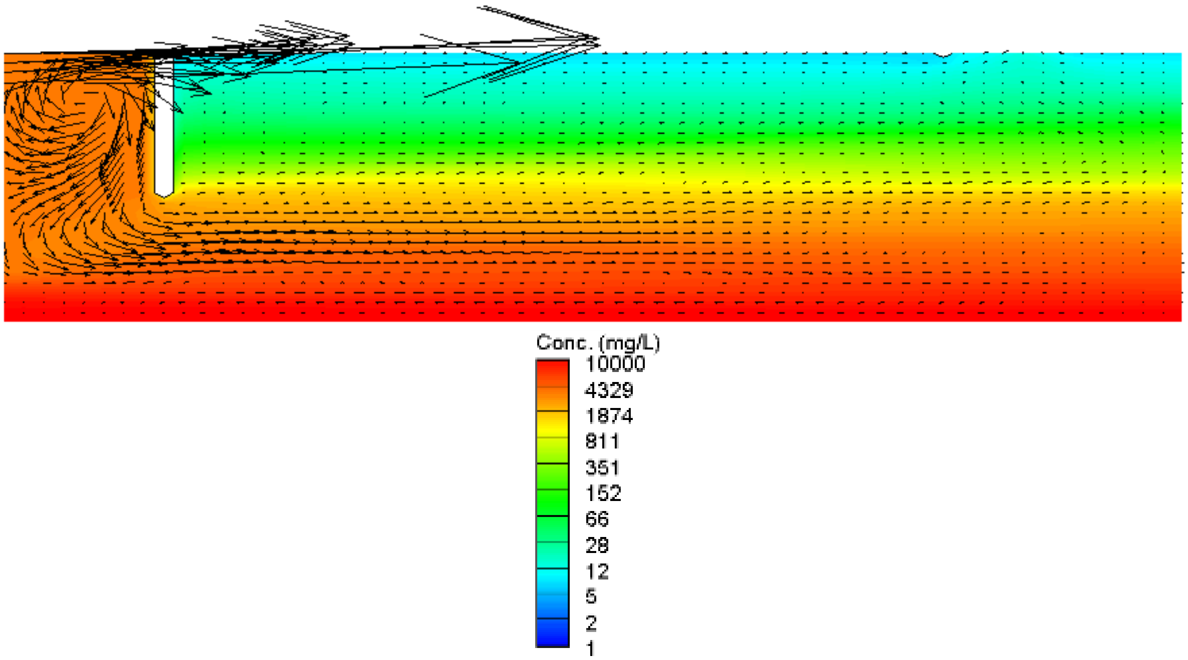

Figure 3-14. Final Clarifiers 1–4 capacity run
(Flow = 7.0 mgd/clarifier, RAS flow = 2.5 mgd/clarifier, MLSS = 3,500 mg/L, SVISN = 130 mL/g)

3.4.4 Clarifier Performance Enhancements

Based on the existing-configuration capacity analysis in Section 3.4.3, two performance-enhancing modifications to Final Clarifiers 14 were considered. The first modification considered increasing the RAS flow rate from 2.5 mgd/clarifier to 3.6 mgd/clarifier (two RAS pumps operating per clarifier) and 5.3 mgd/clarifier (stated capacity of collector mechanism). The approach of operating two RAS pumps per clarifier during peak flow conditions without having a standby RAS pumps has been used at numerous facilities and is BC recommended design standard as it provides excellent turn-down and peak pumping capacity when needed.

Table 3-6 summarizes the predicted clarifier SLR capacities for both either HPOAS and BNR operations. For either operation, increasing RAS capacity to 3.6 mgd/clarifier increases the SLR capacity by 30 percent to 31 lb/ft^2-d (Runs 5-HPO and 5-BNR) which equates to a 20 percent increase in flow capacity. Increasing the RAS capacity further to 5.3 mgd/clarifier nearly achieves a 60 percent increase in SLR capacity (Runs 6-HPO and 6-BNR) or 35 to 40 percent increase in flow capacity. The predicted ESS under BNR operations are roughly half the predicted HPOAS operation ESS for nearly all RAS flow rates.

Table 3-6. Rochester Final Clarifiers 1–4: RAS Capacity Impacts (MLSS = 3,500 mg/L)

Operation	Run	Influent Flow/Clarifier (mgd)	RAS Flow/Clarifier (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
HPOAS (SVISN = 92 mL/g)	1-HPO	7.0	2.5	24	625	12	7.0	7.0
	5-HPO	8.5	3.6	31	750	12	7.0	7.0
	6-HPO	9.5	5.3	38	850	14	7.0	6.8
BNR (SVISN = 130 mL/g)	1-BNR	7.0	2.5	24	625	6	7.0	7.0
	5-BNR	8.5	3.6	31	750	6	7.0	7.0
	6-BNR	10.0	5.3	39	900	6	7.0	6.9

Red text indicates failure mode.

The second modification investigated was increasing the flocculation well diameter. As shown in the 2Dc graphical outputs the existing flocculation well diameter is 15 percent of the clarifier diameter. Flocculation well diameters have increased over time, but most range from 20 to 35 percent of the clarifier diameter (Ekama et al. 2006).

Table 3-7 summarizes simulations conducted to determine the impact of flocculation well diameter changes on Final Clarifiers 1–4 capacity and performance under current HPOAS operations. Compared to the existing configuration (see Run 1-HPO) increasing the flocculation well diameter, resulted in negligible improvements to predicted ESS and SBD; results were similar for the BNR operation. These results do not support changing the existing flocculation well diameter. Modifications to the flocculation well depth were not evaluated because the current depth is already at one-half the side water depth.

Table 3-7. Rochester Final Clarifiers 1–4 Flocculation well Diameter Impact: HPOAS Operations (RAS = 2.5 mgd/clarifier, MLSS = 3,500 mg/L, SVISN = 92 mL/g)

Configuration	Run	Influent Flow/Clarifier (mgd)	SLR (lb/ft^2-d)	Flocculation Well Diameter (ft)	ESS (mg/L)	Mid-Radius SBD (ft)	Launder SBD (ft)
Existing	1-HPO	7.0	24	18	12	7.0	7.0
Flocculation well diameter (25%)	9-HPO	7.0	24	30	11	6.8	6.8
Flocculation well diameter (33%)	10-HPO	7.0	24	40	11	6.5	6.3
Flocculation well diameter (33%)	11-HPO	7.5	25	40	11	7.0	7.0

3.4.5 Capacity Curves

After establishing the initial clarifier capacity analysis for both current and enhanced configuration (increased RAS flows) at an MLSS of 3500 mg/L, the capacity of the existing clarifier over a range of MLSS and influent flows was conducted under current HPOAS and potential future BNR operations at RAS flows of 2.5, 3.6 and 5.3 mgd/clarifier. The results of this analysis are summarized in Table 3-8 and presented graphically in Figures 3-15 and 3-16.

In several cases the SLR is less than 24, 31, or 38/39 lb/ft^2-d because the predicted SBD exceeded the 7-foot failure criterion. Under these cases the influent flow (SLR) was reduced until an acceptable SBD was achieved. The HPOAS and BNR operations generally achieve the same SLR capacity with BNR-operation-predicted ESS at roughly one-half the HPOAS-operation-predicted ESS.

Table 3-8. Rochester Final Clarifier 1-4 Capacity Analysis

Operation	MLSS (mg/L)	Flow/Clarifier (mgd)	RAS Flow/Clarifier (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	MLSS (mg/L)	ESS (mg/L)	SBD (ft)
HPOAS (SVI = 92 mL/g)	2,000	14.0	2.5	24	1,200	2,000	20	7.0
	2,500	11.0	2.5	24	950	2,500	15	7.0
	3,000	8.0	2.5	24	750	3,000	12	7.0
	3,500	7.0	2.5	24	600	3,500	12	7.0
	4,500	5.0	2.5	24	400	4,500	10	7.0
	2,000	16.0	3.6	27[b]	1,400	2,000	24	7.0
	2,500	13.0	3.6	31	1,150	2,500	18	7.0
	3,000	10.0	3.6	31	900	3,000	14	7.0
	3,500	8.0	3.6	31	750	3,500	12	7.0
	4,500	6.0	3.6	31	500	4,500	10	6.9
	2,000	17.0	5.3	36[b]	1,500	2,000	24	7.0
	2,500	15.0	5.3	36[b]	1,300	2,500	21	7.0
	3,000	12.0	5.3	38	1,050	3,000	15	7.0
	3,500	10.0	5.3	38	850	3,500	14	7.0
	4,500	6.0	5.3	38	550	4,500	10	6.5
BNR (SVI = 130 mL/g)[a]	2,000	14.0	2.5	24	1,200	2,000	7	6.9
	2,500	11.0	2.5	24	950	2,500	6	6.4
	3,000	8.0	2.5	24	750	3,000	6	6.0
	3,500	7.0	2.5	24	600	3,500	6	7.1
	4,500	5.0	2.5	24	400	4,500	6	6.2
	2,000	16.0	3.6	30[b]	1,400	2,000	8	7.0
	2,500	13.0	3.6	31	1,150	2,500	6	7.0
	3,000	10.0	3.6	31	900	3,000	6	7.0
	3,500	8.0	3.6	31	750	3,500	6	7.0
	4,500	6.0	3.6	31	500	4,500	6	7.0
	2,000	17.0	5.3	33[c]	1,500	2,000	7	5.5

Table 3-8. Rochester Final Clarifier 1-4 Capacity Analysis

Operation	MLSS (mg/L)	Flow/Clarifier (mgd)	RAS Flow/Clarifier (mgd)	SLR (lb/ft^2-d)	SOR (gal/ft^2-d)	MLSS (mg/L)	ESS (mg/L)	SBD (ft)
	2,500	15.0	5.3	37[b]	1,300	2,500	7	7.0
	3,000	12.0	5.3	39	1,050	3,000	6	7.0
	3,500	10.0	5.3	39	850	3,500	6	7.0
	4,500	7.0	5.3	39	600	4,500	6	5.7

Red text indicates failure mode.

a. NPR sludge characteristics based on ABC sludge observations.

b. Reduced SLR to stay within SBD limit of 7.0 ft.

c. Reduced SLR to stay with SOR limit of 1,500 gal/ft^2-d.

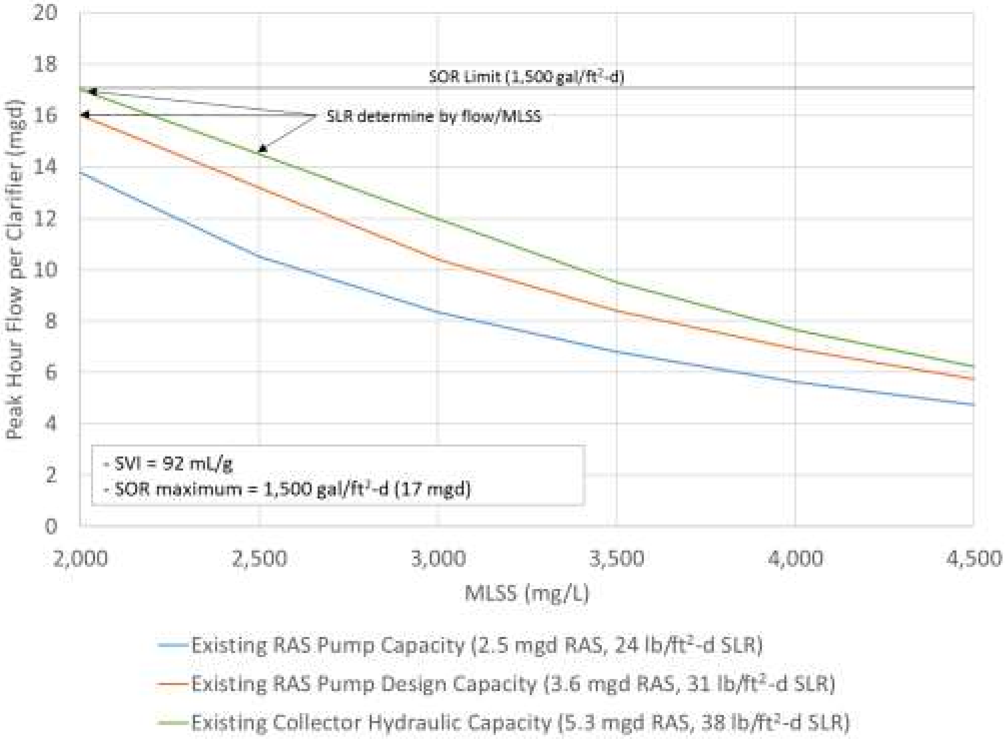

Figure 3-15. Final Clarifiers 1–4 capacity curves: HPOAS operation

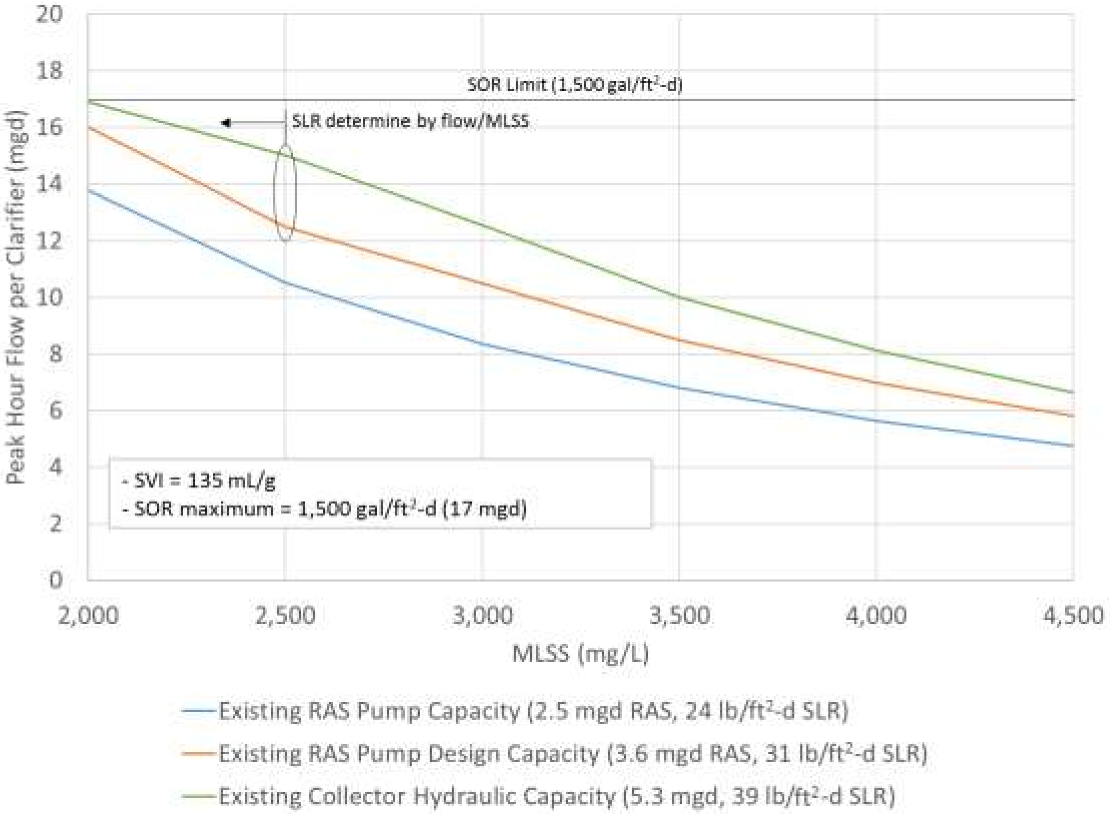

Figure 3-16. Final Clarifiers 1–4 capacity curves: BNR operation

A brief investigation was completed on whether a larger-diameter flocculation well could improve capacity at lower MLSS concentrations. The SBDs could be reduced by roughly 1 foot in the HPOAS operation with 25 percent of clarifier diameter flocculation well and 2 to 3 mg/L ESS reduction. This level of reduction would shift only the “plateau for the 3.6 mgd RAS capacity to start at 2,500 instead of 3,000 mg/L MLSS while the other curves remained the same. Based on the improved ESS performance under the BNR operation a 25 percent of clarifier diameter flocculation well would eliminate all “plateaus” in Figure 3-16 because of SBD reduction. Whether a larger-diameter flocculation well provides benefit depends on the overall process treatment configuration and design MLSS, which will be defined in a subsequent effort.

Section 4: Recommendations

Final Clarifiers 3 and 5 were field-tested with acquired data used to successfully calibrate the 2Dc clarifier models. Subsequent capacity analyses with the calibrated models shows the clarifier modifications below can increase performance and capacity.

- **Final Clarifier 5**: Increasing the flocculation well depth from 4.0 to 8.5 feet (i.e., one-half the side water depth) will increase the SLR capacity from 39 to 42 lb/ft^2-d (or roughly 8 percent) and significantly reduce ESS during high flow/loading conditions by 50 percent or more.
- **Final Clarifiers 1 through 4**: Increasing the RAS flow per clarifier from 2.5 to 3.6 mgd by operating both RAS pumps during peak loading conditions will increase the SLR capacity from 24 to 31 lb/ft^2-d under either HPOAS or BNR operations. An additional 25 percent increase in SLR capacity (39 lb/ft^2-d) can be achieved by increasing the RAS flow to the suction collector design capacity of 5.3 mgd per clarifier but will require an upgraded pumping system. The need for additional capacity will be determined during the alternatives analysis; however, the existing RAS pumps are beyond an expected 20-year equipment life, and replacement should consider a capacity increase. WRP staff also noted that the RAS flow metering data are not trustworthy and improvements to hardware and (possibly) installation locations are warranted for better process control.

Section 5: References

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Attachment A: Rochester WRP Final Clarifier Test Plan

Secondary Clarifier Field Testing Workplan

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Prepared for:	City of Rochester Water Reclamation Plant
Project Title:	WRP Facilities Plan
Project No.:	150811
Subject:	Secondary 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 secondary clarifier capacity. This test plan provides an overview of the testing procedures and assistance required from the City.

The City currently operates five types of clarifiers at the WRP's parallel high purity oxygen activated sludge (HPOAS) and conventional activated sludge (ABC) system. The WRP achieves primary clarification with rectangular units in the HPOAS system and a single circular unit in the ABC system. The HPOAS train includes four 90-foot diameter intermediate clarifiers for the first stage HPOAS system and four 120-foot secondary clarifiers with 14-foot side water depths (SWD) for the second stage HPOAS system. The ABC system consists of one 120-foot diameter secondary clarifier with 18-foot SWD. Figure 1-1 identifies the clarifiers on the WRP site.

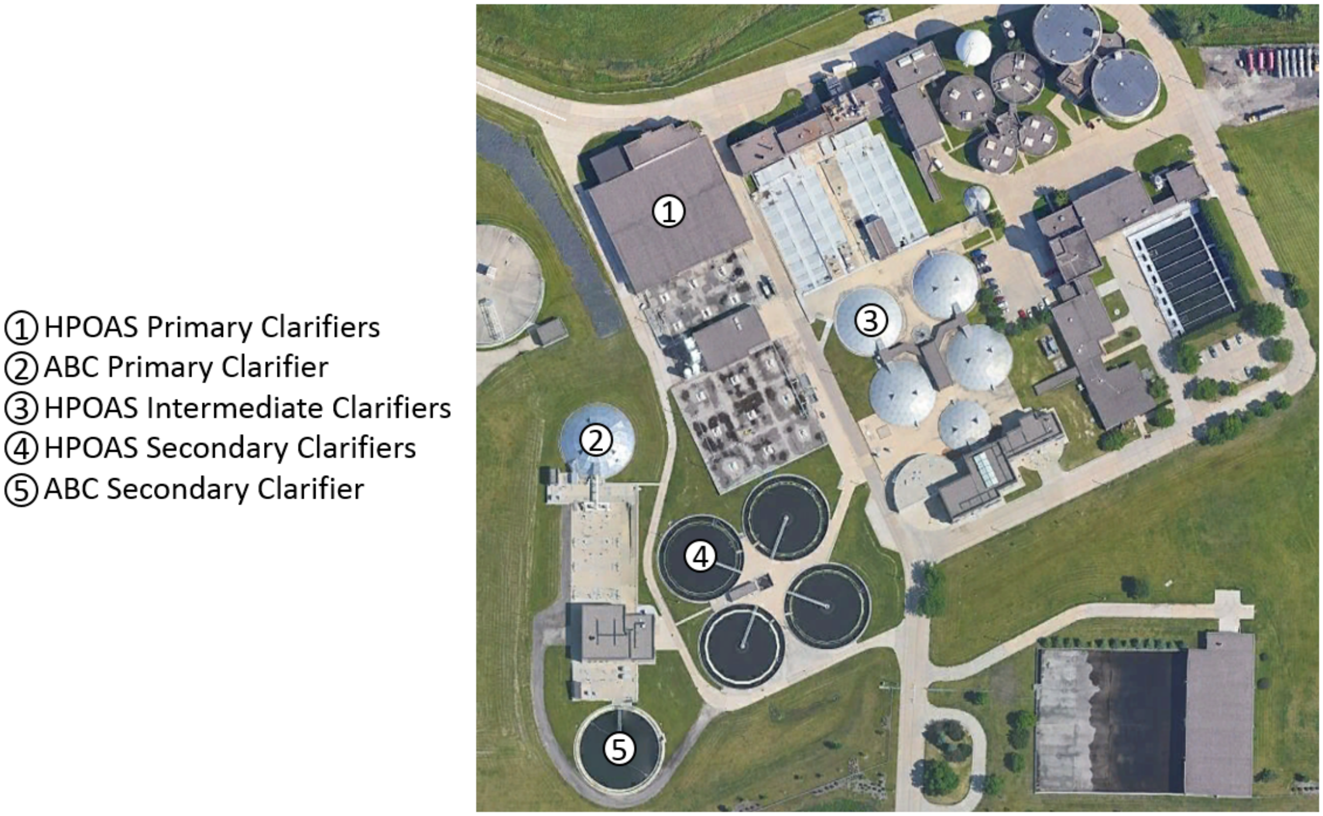


Figure 1-1. Rochester WRP Aerial View

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 and ABC secondary clarifier. A separate workplan addresses the HPOAS primary clarifier testing.

The clarifier field testing will be used to calibrate and validate a CFD clarifier model, 2Dc, which considers hydrodynamic, flocculation, and sedimentation effects on performance. Brown and Caldwell (BC) will use the calibrated 2Dc models to determine clarifier capacity and identify features to possibly increase capacity. 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 describes the planned field testing in limited detail. Exact test dates, sampling locations, etc. need to be coordinated with the City prior to the testing.

2.1 Test Schedule

Field testing both secondary clarifiers (SCs) shall be accomplished in one site visit. This approach minimizes impacts on City staff and increases project resource efficiency. The testing shall require 2.5 days on site for mobilizing, testing, and de-mobilizing. Figure 2-1 depicts the timeline identifying the proposed testing milestones.

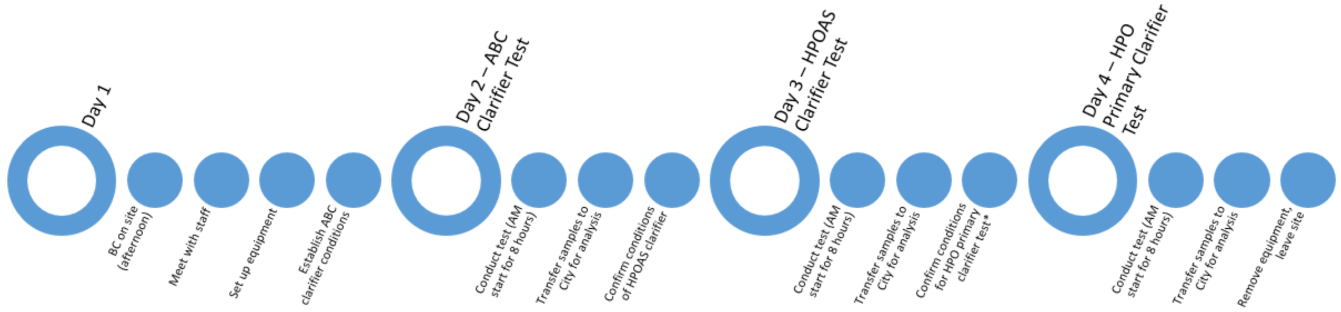


Figure 2-1. Secondary Clarifier Testing Timeline

BC proposes to test the ABC SC first followed by the HPOAS SC. This sequence will depend on facility operations, equipment status, and City preference. The City shall also identify the specific HPOAS test clarifier prior to BC arriving on site. The clarifier selected requires adequate flow monitoring equipment on both the influent and return activated sludge (RAS) system, 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. The first day of testing set up ideally occurs on a Tuesday which allows the use of the facility operating data from Monday for setting the baseline test conditions.

Testing is subject to wet weather. If flows reach high levels such that the test clarifiers 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 six different types of tests on each day of clarifier testing. The discussion below provides additional details on these tests.

- Stress Tests
- Sludge Volume Index (SVI) 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 indoors near the secondary clarifiers with nearby floor drain in case of spills, electrical outlet, and lighting. A potable or non-potable water for rinsing equipment is requested at the end of each stress test.

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

Each stress test will last approximately 8 hours. BC staff will be on site up to 2 hours 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 SCs 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 RAS concentration). The general SOR itinerary starts at a baseline condition depending on the facility's operation from the previous day (flow, SVI, and mixed liquor suspended solids). BC requests three weeks of operating data from the City three days prior to the test. The operating data will determine the final SOR itinerary and RAS flow setting for the stress test. BC will direct the City to adjust the RAS flow the day prior to testing. The City shall adjust the RAS flow and hold the RAS flow constant for at least 12 hours prior to the start of the stress test. Depending on plant staffing, setting the test SC conditions may be advisable by the end of the plant manager's normal work day.

The SOR itinerary consists of up to six operating conditions during the test duration delineated by changes in SOR. The RAS flow on the test clarifier shall remain constant during the test. 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 is increased to a maximum value and then for the last hour the SOR is reduced to the SOR set point prior to the maximum (WRP staff will need to help adjust the flows/SOR). This itinerary design intends to achieve variations in performance that provide targets for calibrating the model against.

Achieving the SOR targets differs between the ABC and HPOAS facilities. The following describes the general process for achieving the SOR itinerary in each facility.

2.2.1.1 HPOAS Secondary Clarifier

The HPOAS second stage system consists of four SCs. Based on a typical flow split of 25% to the ABC facility and I influent flow of 12 mgd with all SCs in service, the HPOAS SCs operate at an SOR of roughly 200 gal/sf-d. Flow and SOR variation for the HPOAS stress test will rely on shutting off flow to non-test HPOAS SCs and the ABC facility, plus additional flow may be required by storing some volume in the equalization basin and returning the EQ flow during period of high SORs. Table 2-1 summarizes a preliminary test itinerary for the HPOAS SC test assuming the WRP influent flow is consistent with the typical 12 mgd historical value. City staff will need to aid in turning off the non-test HOPAS SCs, adjusting the ABC flow split, and opening EQ discharge/increasing influent pump output. High flow conditions may dictate that a flow increase to the ABC facility to achieve the desired HPOAS test clarifier 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.

During HPOAS train clarifier testing, the heat recovery system on the test clarifier (if applicable) shall not be operating.

Table 2-1. Rochester WRP HPOAS Secondary Clarifier Preliminary Stress Test SOR Itinerary[1]

Condition	Condition Duration (hours)	Target Surface Overflow Rate (gal/sf-d)	No. HPOAS SCs in Service	Flow Split to ABC	HPOAS Flow (mgd)
1	1	200	4	25%	9
2	1.5	400	2	25%	9
3	1.5	800	1	25%	9
4	1.5	1,060	1	0%	12
5	1.5	1,500	1	0%	17[2]
6	1	1,060	1	0%	12

[1] *Preliminary testing itinerary based upon a total influent flow of 12 mgd.*

[2] *The additional 5 mgd of flow required can be supplied with approximately 300,000 gallons of stored EQ volume or by RAS flow from non-test clarifiers.*

2.2.1.2 ABC Secondary Clarifier

Based on average influent flow to the WRP (12 mgd) and the typical split to the ABC plant (25%) the SOR of the ABC SC typically operates at an SOR of approximately 200 gal/sf-d. Table 2-2 summarizes a preliminary test itinerary for the ABC SC assuming the WRP influent flow is consistent with the typical 12 mgd. City staff will adjust the flow split to the ABC system to achieve the target SOR. Note that to achieve the desired flow to the ABC facility requires significant reduction in flow the HPOAS system under typical influent flow conditions. High influent flow conditions may dictate a flow reduction to ABC facility and subsequent increase to the HPOAS system. 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 2-2. Rochester WRP ABC Secondary Clarifier Preliminary Stress Test SOR Itinerary

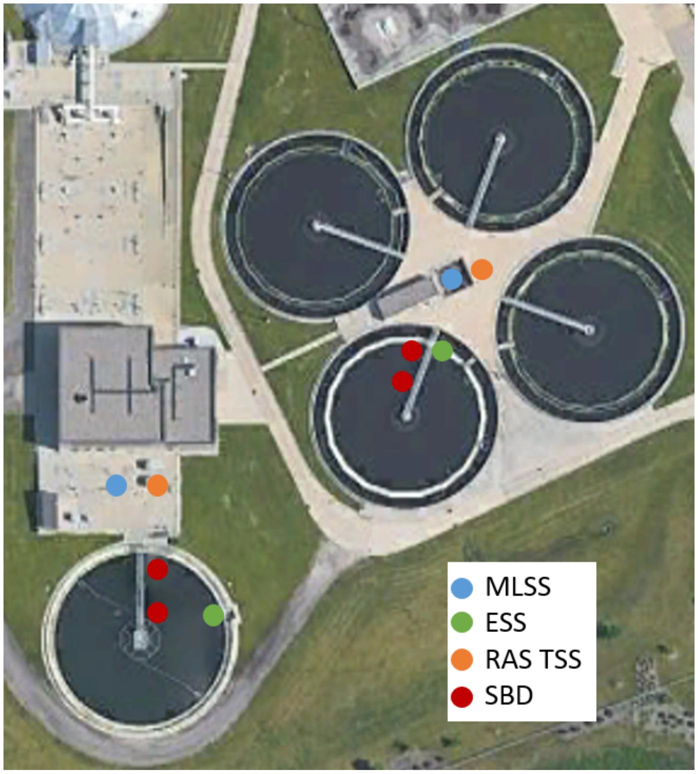
Condition	Condition Duration (hours)	Target Surface Overflow Rate (gal/sf-d)	Flow Split to ABC	Flow Diverted to ABC (mgd)
1	1	270	25%	3.0
2	1.5	420	40%	4.8
3	1.5	580	55%	6.6
4	1.5	740	70%	8.4
5	1.5	850	80%	9.6
6	1	740	70%	8.4

Preliminary testing itinerary based upon a total influent flow of 12 mgd and a maximum flow to the ABC facility of 9.6 mgd..

During both stress tests BC staff will collect a significant number of samples and measurements for effluent suspended solids (ESS), mixed liquor suspended solids (MLSS), RAS total suspended solids (RSS), sludge blanket depth (SBD), and temperature. 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 remove launder covers and or clean launders of algae, install sample taps of RAS 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. Secondary Clarifier Stress Test Sampling and Measurements

Item	Sampling / Measurement Frequency per test FST	Sample Collection and Measurement Performed by
MLSS	1 every 30 minutes	BC
ESS	1 every 15 minutes	BC
MLSS Supernatant TSS after 30 minutes settling	1 every hour	BC
RSS	1 every 30 minutes	BC
SC RAS flow rates	5-minute flow intervals starting 24-hours prior to testing	City SCADA
Sludge blanket depths at 1/3 radius and launder	1 every 30 minutes	BC
Mixed liquor and SC temperature	1 every 60 minutes	BC
Mixed liquor or HPOAS/ABC influent flow rate	5-minute flow intervals starting 24-hours prior to testing	City SCADA
SVI	daily value	City and BC



Note: location subject to access point identification.

2.2.2 Sludge Volume Index (SVI) and Supernatant Tests

BC will conduct SVI tests every 60 minutes during the stress test. These values help confirm the sludge conditions over the course of the day and serves as a check on the City's daily reported value. The City shall inform BC as to the type of SVI test conducted at the WRP (e.g. 1 or 2 L and stirred or unstirred).

At the completion of the SVI test a supernatant sample will be collected for TSS analysis. The results of these analyses are used to check the results of other tests described below.

2.2.3 Column Settling Test

Column settling tests to determine sludge settling characteristics will be completed. The settling tests will be performed using a settling column provided by BC. Approximately eight different MLSS concentrations will be tested to determine discrete, clarification, and sludge compression zone settling constants, V_o and k, in Equation 1 (Vesilind, 1968).

$$V = V_o e^{-kX} \tag{1}$$

where:

V = interface settling velocity, m/hr

X = solids concentration, g TSS/L

V_o = sludge-specific settling parameter, m/hr

k = sludge-specific settling parameter, L/g TSS

Determination of the V_o and k values along with SVI allows comparison of the settling characteristics with WRP historical SVI database such that the SC design parameters (90th percentile SVI, V_o, k) can be adjusted if sludge quality differs. In addition, the V_o and k values will be used to perform modeling of the full-scale SCs using the 2Dc 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 SC 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

2.2.4 Flocculation Test

Flocculation tests to define flocculation characteristics of the mixed liquor will be completed using a 6-paddle gang stirrer. The flocculation testing provides information describing the propensity of the mixed liquor floc to aggregate and break apart. This is a measurement of floc strength. Ideally, the flocs will have high rates of aggregation and low rates of breakup to form strong flocs in the aeration basins and SC flocculation center wells which results in minimal individual particles exiting the SC. 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 and the potential ESS concentration if mixed liquor is optimally flocculated and with ideal hydraulic conditions in the SC. Figure 2-3 shows the experimental setup for determining flocculation characteristics.

Figure 2-3. Flocculation Jar Test Apparatus

2.2.5 DSS Test

To supplement the settling and flocculation data, dispersed suspended solids (DSS) will be determined near the effluent launder three times during each test. 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 biological 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

2.2.6 Discrete Particle Test

Discrete particle tests to determine the mixed liquor settling distribution will be completed. 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 2Dc 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 two-days of secondary clarifier testing. Each test requires 121 total suspended solids (TSS) analysis for a combined total of 242 TSS samples. The City shall provide the 500 and 1,000 mL sample bottles, sample bottle labels, and analyze all samples collected during testing.

Table 3-1. WRP Secondary Clarifier Testing TSS Analytical Requirements

Item	Sample Bottle Size (mL)	HPOAS Secondary Clarifiers	ABC Clarifier
Mixed Liquor Suspended Solids	500	17	17
Effluent Suspended Solids	1,000	33	33
RAS TSS	500	17	17
Supernatant TSS	1,000	9	9
Flocculation Test	1,000	21	21
Column Settling Test	500	9	9
DSS Test	1,000	3	3
Discrete Particle Test	1,000	12	12
TSS samples per clarifier test	**–**	**121**	**121**

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.

Table 4-1. City Responsibilities for Secondary 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 HPOAS test clarifier	
• Confirm existing instrumentation (e.g. flow meters) installed and calibrated	
• Identify available sampling points for MLSS, RAS, and effluent	
• Provide access to sampling points which may require launder cover removal, sample tap installation, etc.	
• Clean algae from test clarifier effluent launder to prevent skewing ESS results	
• Identify temporary set up location for BC bench scale testing – preferable indoors (utilities required include water, electric, lighting and floor drain if indoors)	
• Identify type of SVI test conducted (1 or 2 L and stirred or unstirred)	
• Recent operating data	Arrival at site for test
• Provide sample bottles, labels, chain of custody forms, and portable storage coolers	
• Supply working sludge judge	
• Operate at baseline conditions (RAS 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: Final Clarifier 5 Field Test Data

Test Time (min)	Primary 3 Influent	RAS (mgd)	SOR (gpd/sf)
0	3.1	1.0	271
5	3.1	1.0	275
10	3.3	0.9	289
15	3.1	1.0	277
20	3.1	1.0	278
25	3.0	1.0	263
30	3.1	1.0	277
35	3.1	1.0	277
40	3.1	1.0	278
45	3.1	1.0	275
50	3.1	1.0	275
55	3.2	1.0	284
60	4.9	1.0	433
65	5.1	1.0	453
70	5.0	1.0	445
75	5.0	1.0	442
80	4.9	1.0	436
85	5.0	1.0	438
90	5.2	1.0	459
95	4.9	1.0	437
100	5.0	1.0	446
105	4.8	1.0	421
110	5.2	1.0	457
115	5.0	1.0	438
120	5.0	1.0	446
125	5.1	1.0	455
130	5.1	1.0	449
135	4.9	1.0	433
140	4.9	1.0	433
145	5.3	1.0	466
150	7.1	1.0	628
155	7.0	1.0	623
160	6.9	1.0	606
165	7.2	1.0	633
170	6.9	1.0	606
175	7.0	1.0	617
180	7.0	1.0	623
185	7.3	1.0	642
190	6.6	1.1	587
195	7.0	1.0	617
200	6.9	1.0	606
205	8.4	1.0	745
210	7.3	1.0	642
215	6.9	1.0	610
220	6.8	1.0	599
225	6.9	1.0	614
230	7.3	1.0	642
235	9.2	1.0	815
235	9.2	1.0	815
240	9.4	1.0	832
245	9.0	1.0	800
250	9.1	1.0	806
255	8.9	1.0	790
260	8.9	1.0	787
265	9.1	1.0	804
270	8.7	1.0	772
275	8.7	1.0	769
280	8.9	1.0	785
285	9.2	1.0	812
290	9.0	1.0	800
295	8.7	1.0	769
300	8.8	1.0	776
305	8.8	1.0	781
310	9.0	1.0	799
315	9.1	1.0	806
320	9.0	1.0	793
325	10.6	1.0	936
330	11.0	1.0	972
335	10.8	1.0	955
340	10.6	1.0	940
345	10.6	1.0	938
350	10.3	1.0	913
355	10.1	1.0	894
360	10.0	1.0	887
365	10.3	1.0	914
370	10.2	1.0	899
375	10.0	1.0	885
380	10.1	1.0	894
385	9.9	1.0	878
390	10.4	1.0	919
395	10.6	1.0	939
400	11.3	1.0	997
405	11.5	1.0	1016
410	11.3	1.0	1000
415	11.3	1.0	997
420	11.2	1.0	987
425	7.3	1.0	642
430	6.8	1.0	598
435	6.8	1.0	598
440	6.8	1.0	604
445	6.9	1.0	614
450	7.0	2.1	621
455	4.9	4.6	434
460	4.9	4.8	429
465	5.3	4.8	465
470	5.1	5.0	451
475	5.0	4.9	440
480	4.8	5.0	428

Collector Speeds		
Clarifier	Units	Speed
Final 5	rpm	0.029

ESS				
Test Time (min)	Sample Time	Sampler Initials	Sample Name	TSS (mg/L)
0	~7:30	SB	ESS-ABC-0	6
15	7:50	SB	ESS-ABC-15	6.25
30	8:00	SB	ESS-ABC-30	7.5
45	8:15	SB	ESS-ABC-45	5.25
60	8:28	SB	ESS-ABC-60	6
75	8:43	SB	ESS-ABC-75	6.25
90	8:56	SB	ESS-ABC-90	5.25
105	9:13	SB	ESS-ABC-105	6
120	9:29	SB	ESS-ABC-120	4.8
135	9:45	SB	ESS-ABC-135	4.8
150	9:58	SB	ESS-ABC-150	6.5
165	10:14	SB	ESS-ABC-165	6.6
180	10:28	SB	ESS-ABC-180	6.25
195	10:43	SB	ESS-ABC-195	6.6
210	11:02	SB	ESS-ABC-210	7
225	11:14	SB	ESS-ABC-225	6.4
240	11:32	SB	ESS-ABC-240	6
255	11:44	SB	ESS-ABC-255	5.8
270	12:02	SB	ESS-ABC-270	7.5
285	12:14	SB	ESS-ABC-285	6.75
300	12:32	SB	ESS-ABC-300	7.25
315	12:44	SB	ESS-ABC-315	7.75
330	1:00	SB	ESS-ABC-330	7.25
345	1:17	SB	ESS-ABC-345	9.5
360	1:30	DPE	ESS-ABC-360	16
375	1:45	DPE	ESS-ABC-375	37.0
390	2:03	DPE	ESS-ABC-390	45.6
405	2:17	DPE	ESS-ABC-405	97
420	2:32	DPE	ESS-ABC-420	96
435	2:47	DPE	ESS-ABC-435	114
450	~3:02	DPE	ESS-ABC-450	136
465	--	--	ESS-ABC-465	
480	--	--	ESS-ABC-480	

MLSS				
Test Time (min)	Sample Time	Sampler Initials	Sample Name	TSS (mg/L)
0	~7:30	SB	MLSS-ABC-0	2740.0
30	8:09	SB	MLSS-ABC-30	2360.0
60	8:35	SB	MLSS-ABC-60	2540.0
90	9:08	SB	MLSS-ABC-90	2760.0
120	9:35	SB	MLSS-ABC-120	2620.0
150	10:05	SB	MLSS-ABC-150	2440.0
180	10:38	SB	MLSS-ABC-180	2720.0
210	11:08	SB	MLSS-ABC-210	2580.0
240	11:38	SB	MLSS-ABC-240	2420.0
270	12:08	SB	MLSS-ABC-270	2500.0
300	12:38	SB	MLSS-ABC-300	2460.0
330	1:05	SB	MLSS-ABC-330	2340.0
360	1:35	DPE	MLSS-ABC-360	2660.0
390	2:05	DPE	MLSS-ABC-390	2140.0
420	~2:35	DPE	MLSS-ABC-420	
450	~3:00	DPE	MLSS-ABC-450	2120.0
480	--	--	MLSS-ABC-480	

RAS				
Test Time (min)	Sample Time	Sampler Initials	Sample Name	TSS (mg/L)
0	~7:30	SB	RAS-ABC-0	11,100
30	8:06	SB	RAS-ABC-30	9,400
60	8:38	SB	RAS-ABC-60	9,400
90	9:06	SB	RAS-ABC-90	10,900
120	9:37	SB	RAS-ABC-120	12,700
150	10:07	SB	RAS-ABC-150	12,500
180	10:34	SB	RAS-ABC-180	11,500
210	11:05	SB	RAS-ABC-210	12,200
240	11:35	SB	RAS-ABC-240	11,100
270	12:05	SB	RAS-ABC-270	11,400
300	12:35	SB	RAS-ABC-300	11,700
330	1:03	SB	RAS-ABC-330	12,000
360	1:35	DPE	RAS-ABC-360	13,300
390	2:05	DPE	RAS-ABC-390	11,800
420	~2:30	DPE	RAS-ABC-420	10,700
450	~3:00	DPE	RAS-ABC-450	2,280
480	--	--	RAS-ABC-480	

Start Time		End Time			Sludge Blanket Depth, feet		
Hour	Min	Hour	Min	Test Time (min)	Mid Radius	Launder	Collector Arm Position (degrees)*
7	30	7	32	1	1.5	2	0
7	45	7	47	16	3.75	3.8	270
8	-	8	2	31	1.25	1.25	270
8	15	8	17	46	3	2.5	270
8	45	8	47	76	2.75	1.75	200
9	-	9	2	91	4.25	4	350
9	15	9	17	106	3	1.5	360
9	30	9	32	121	3.25	3.25	280
9	45	9	47	136	2	2.25	300
9	58	10	-	149	3	2.75	260
10	15	10	17	166	1.25	2.225	260/270
10	30	10	32	181	3	2.25	210
10	45	10	47	196	0.75	2.25	200
10	59	11	1	210	2.5	2.25	Mid just before arm, launder after
11	15	11	17	226	0	4.75	Mid just afer arm, launder before
11	28	11	30	239	2.75	2.75	310
11	45	11	47	256	5	3.5	300
11	58	12	-	269	2.5	3	270
12	15	12	17	286	4.75	2.75	250
12	30	12	32	301	3	2.75	200
12	45	12	47	316	3.75	3.5	190
13	-	13	2	331	5	5	330
13	15	13	17	346	4	3.5	340
13	30	13	32	361	5.5	5.25	345
13	45	13	47	376	5	5	270
14	-	14	2	391	5.25	6.5	270
14	17	14	19	408	5	5	270
14	30	14	32	421	6	5	45
14	45	14	47	436	5	5.5	5
15	-	15	2	451	5	6	170

*Position relative to mechanism bridge and counting clockwise.

Test Date	Tuesday, September 12, 2017	
Test Time	8 am through 1 pm	
Plant SVI	105	mL/g

Vesilind Equation

$$ZSV = v_0 e^{-k \times TSS_0}$$

Where

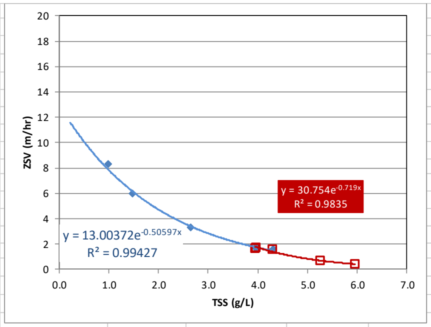
ZSV = Zone Settling Velocity, m/hr

v_0 = Sludge settleability constant, m/hr

k = Sludge settleability constant, L/mg TSS

TSS = Initial sludge concentration, mg/L

	Vo and k Determination				
Settling Test	ZSV m/hr	Hindered g/L	Compression g/L	Estimated Compression ZSV m/hr	Corrected Hindered ZSV m/hr
1	8.29	0.98			
2	6.00	1.47			6.00
3	3.33	2.64			3.33
4	1.74	3.96	3.96	2.37	1.74
5	1.60	4.30	4.30	2.17	1.60
6	1.65	3.95	3.95	2.38	1.65
7	0.42		5.95	1.43	0.42
8	0.70		5.25	1.71	0.70
	V_0 (m/hr)*		13		
	k (L/mg-TSS)		0.51		
	Vc		6.5		
	Kc		0.25		



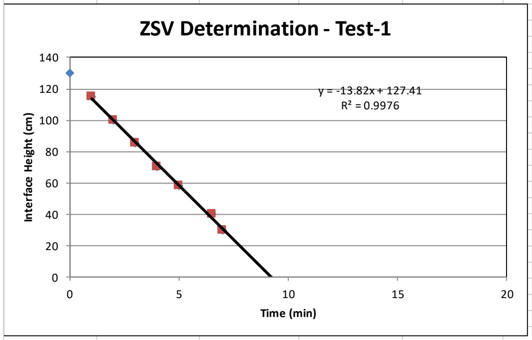
Zone Settling Velocity Determination

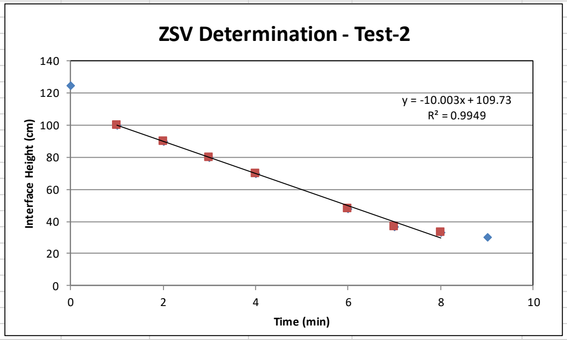
ZSV-1		ZSV-2		ZSV-3		ZSV-4		ZSV-5		ZSV-6		ZSV-7		ZSV-8	
TSS (mg/L)**	980	TSS (mg/L)	1470	TSS (mg/L)	2640	TSS (mg/L)	3960	TSS (mg/L)	4300	TSS (mg/L)	3950	TSS (mg/L)	5950	TSS (mg/L)	5250.0
Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height
min	cm	min	cm	min	cm	min	cm	min	cm	min	cm	min	cm	min	cm
0	130	0	125	0	138	0	134	0	141	0	121	0	107	0	0
1	115	1	100	1	124	1	132	1	138.5	1	120.5	2	106.5	2	0
2	100	2	90	2	118	2	129	2	135.5	2	118.5	5	105.5	5	denite in column
3	85	3	80	3	112	3	125.5	3	133	3	116.5	7	104	7	stirred column
4	70	4	70	4	106	4	122.5	4	131	4	113.5	9	102.5	9	139
5	58	6	48	5	100	5	119.5	5	128	5	112	11	101	11	139
6.5	40	7	37	6	94	6.5	115	6	125.5	6	109.5	13	100	13	134
7	30	8	33	7	89	7	114	7	124	7	107	15	column denite	15	131.5
8		9	30	8	84	8	112	8	121	8	104	17	0	17.75	129
9				9	78.5	10	105	9	118	9	100.5	19	0	19	127
10						11	102	10	115	10	98	21	0	21.5	124
11						12	100	11	112.5	11	94.5	23	0	23.5	column denite
12						13	96.5	12.5	109.5	12.5	91	25	0	25.5	0
13								13	107	13	89	27	0	27.5	0
14								14	103.5	14	87	29	0	29.5	0
15								15	100	15	84.5	31	0	31.5	0
16								17	95	17	80	0	0		
17												0	0		
18												0	0		
												0	0		
												0	0		
												0	0		
												0	0		
												0	0		
												0	0		
												0	0		
Temp (F)															
ZSV (cm/min)***	13.8	ZSV (cm/min)***	10.0	ZSV (cm/min)***	5.6	ZSV (cm/min)**	2.9	ZSV (cm/min)***	2.7	ZSV (cm/min)***	2.754	ZSV (cm/min)*	0.700	ZSV (cm/min)**	1.2
ZSV (m/hr)***	8.3	ZSV (m/hr)	6.0	ZSV (m/hr)	3.3	ZSV (m/hr)	1.7	ZSV (m/hr)	1.6	ZSV (m/hr)	1.7	ZSV (m/hr)	0.4	ZSV (m/hr)	0.7

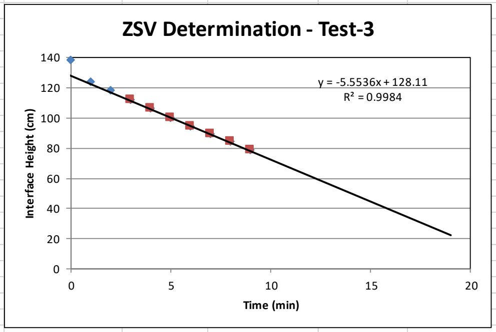
* data shown in red squares below are used to regress the linear ZSV

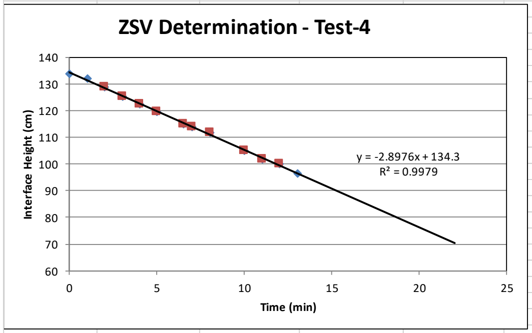
** "TSS" is sample

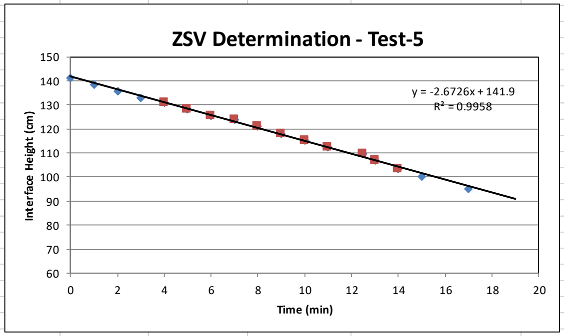
*** ZSV is determined by linear regression as shown in following Figures and then convert from cm/min to m/hr

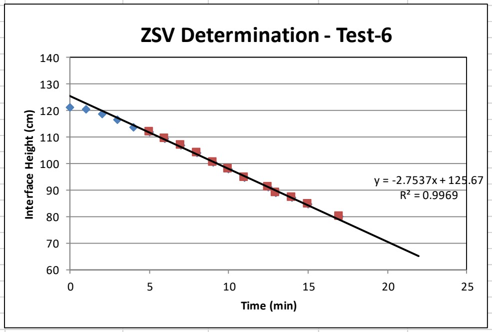

ZSV Determination - Test-1
y = -13.82x + 127.41
R² = 0.9976
Interface Height (cm)
Time (min)
0
20
40
60
80
100
120
140
0
5
10
15
20

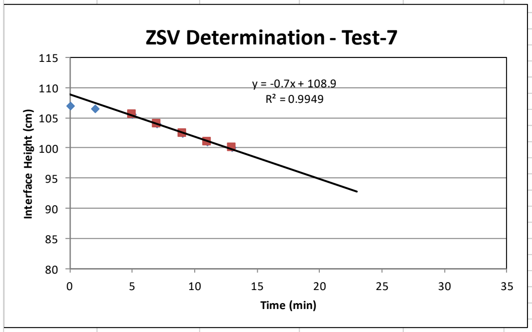

ZSV Determination - Test-2
y = -10.003x + 109.73
R² = 0.9949
Interface Height (cm)
Time (min)
0
20
40
60
80
100
120
140
0
2
4
6
8
10

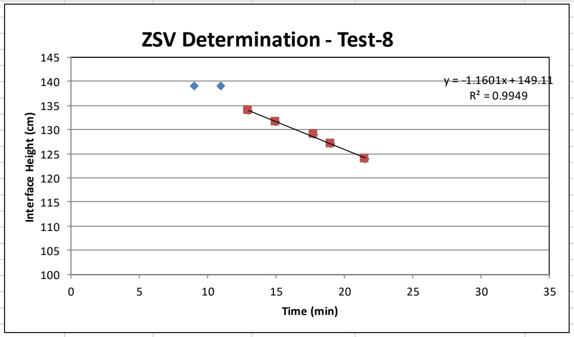

ZSV Determination - Test-3
y = -5.5536x + 128.11
R² = 0.9984
Interface Height (cm)
Time (min)
0
20
40
60
80
100
120
140
0
5
10
15
20


ZSV Determination - Test-4
y = -2.8976x + 134.3
R² = 0.9979
Interface Height (cm)
Time (min)
60
70
80
90
100
110
120
130
140
0
5
10
15
20
25


ZSV Determination - Test-5
y = -2.6726x + 141.9
R² = 0.9958
Interface Height (cm)
Time (min)
60
70
80
90
100
110
120
130
140
150
0
2
4
6
8
10
12
14
16
18
20


ZSV Determination - Test-6
y = -2.7537x + 125.67
R² = 0.9969
Interface Height (cm)
Time (min)
60
70
80
90
100
110
120
130
140
0
5
10
15
20
25


ZSV Determination - Test-7
y = -0.7x + 108.9
R² = 0.9949
Interface Height (cm)
Time (min)
80
85
90
95
100
105
110
115
0
5
10
15
20
25
30
35


ZSV Determination - Test-8
y = -1.1601x + 149.11
R² = 0.9949
Interface Height (cm)
Time (min)
100
105
110
115
120
125
130
135
140
145
0
5
10
15
20
25
30
35

Flocculation Test

Test Objective:	Define floc kinetics
Test Location	Rochester WRP
Test Date	Tuesday, September 12, 2017
Test Attendee	Sarah Brunsvold and Lloyd Winchell
Sample Location	50:50 from end of ABC basins 3 and 4
Settling Time	30 minute

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

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

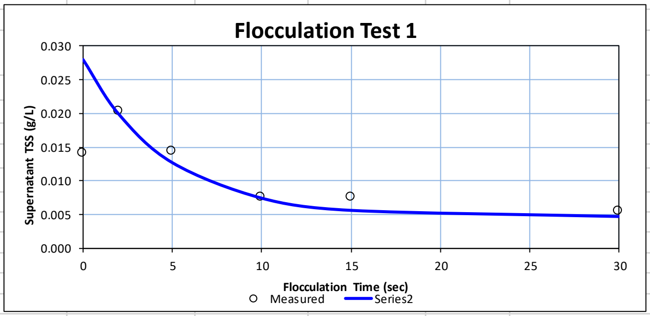
	9:00 AM	10:11 AM	1:45 AM
	Test 1	Test 2	Test 3
Time	Supernatant TSS	Supernatant TSS	Supernatant TSS
0	~~14.0~~	19.5	15.8
2	20.3	14.3	10.0
5	14.4	10.3	6.6
10	7.5	5.3	6.3
15	7.5	4.8	6.8
30	5.5	6.6	~~17.3~~
SS	2720	2680	2260
G	57	57	59
Temp (°C)	21	21	21
Paddle Speed	60	60	62

Test 1 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (g/L)	(n_t-Calc n_t)^2		
0	0.014	0.028	0.000196000	n_0 (g/L)	0.028
2	0.020	0.020	0.000000113	G (sec^{-1})	57
5	0.014	0.013	0.000002787	X (g/L)	2.72
10	0.008	0.007	0.000000001	K_a (L/g TSS)	2.294E-05
15	0.008	0.006	0.000003351	K_B (sec)	1.900E-09
30	0.006	0.005	0.000000548		
		SSE***	0.000202800		

** By varying Ka and Kb to reach minimum "SSE"

*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed

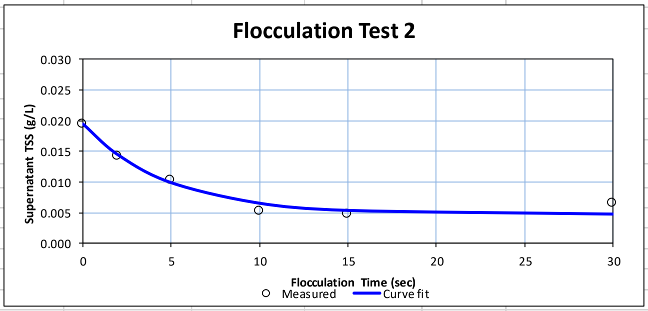

Flocculation Test 1

Test 2 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (g/L)	(n_t-Calc n_t)^2		
0	0.020	0.020	0.000000000	n_0 (g/L)	0.020
2	0.014	0.014	0.000000031	G (sec-1)	57
5	0.010	0.010	0.000000132	X (g/L)	2.68
10	0.005	0.007	0.000001629	K_a (L/g TSS)	2.294E-05
15	0.005	0.005	0.000000305	K_B (sec)	1.900E-09
30	0.007	0.005	0.000003429		
		SSE***	0.000005527		

** By varying Ka and Kb to reach minimum "SSE"

*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed

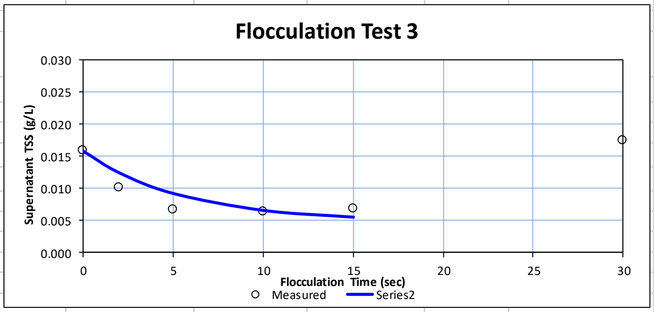

Flocculation Test 2

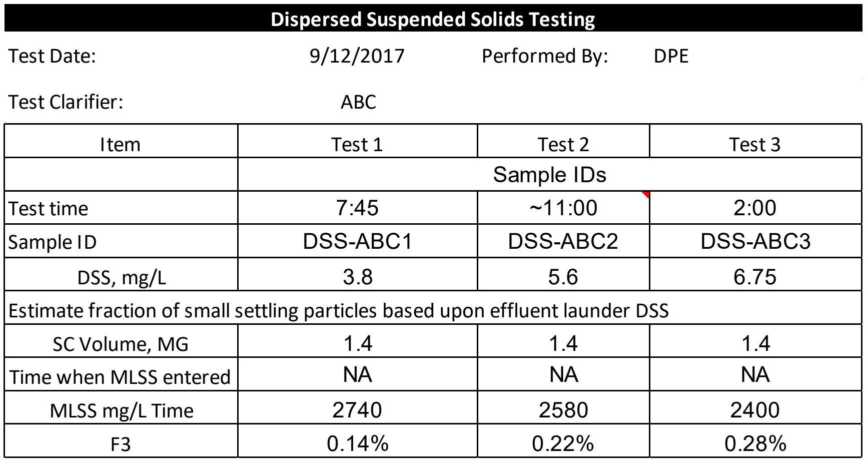
Test 3 Curve Fitting**

Flocculation time (min)	Spernatant TSS - n_t (g/L)	Calc n_t (g/L)	(n_t-Calc n_t)^2		
0	0.016	0.016	0.000000000	n_0 (g/L)	0.016
2	0.010	0.012	0.000005989	G (sec-1)	59
5	0.007	0.009	0.000007003	X (g/L)	2.26
10	0.006	0.007	0.000000143	K_a (L/g TSS)	2.294E-05
15	0.007	0.006	0.000001363	K_B (sec)	1.900E-09
30	0.017	0.005	0.000152986		
		SSE***	0.000167485		

** By varying Ka and Kb to reach minimum "SSE"

*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed


Flocculation Test 3

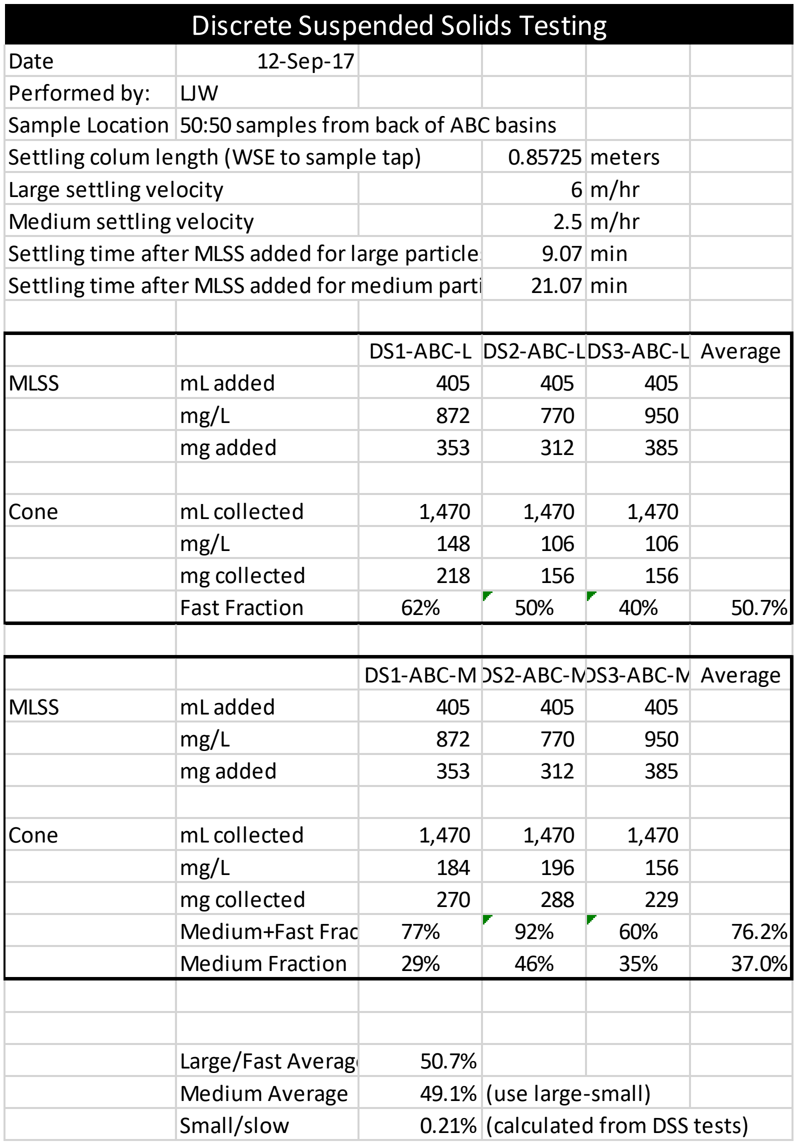


Dispersed Suspended Solids Testing

Test Date: 9/12/2017 Performed By: DPE

Test Clarifier: ABC

Item	Test 1	Test 2	Test 3
	Sample IDs		
Test time	7:45	~11:00	2:00
Sample ID	DSS-ABC1	DSS-ABC2	DSS-ABC3
DSS, mg/L	3.8	5.6	6.75
Estimate fraction of small settling particles based upon effluent launder DSS			
SC Volume, MG	1.4	1.4	1.4
Time when MLSS entered	NA	NA	NA
MLSS mg/L Time	2740	2580	2400
F3	0.14%	0.22%	0.28%



Discrete Suspended Solids Testing

Date	12-Sep-17				
Performed by:	LJW				
Sample Location	50:50 samples from back of ABC basins				
Settling colum length (WSE to sample tap)			0.85725	meters	
Large settling velocity			6	m/hr	
Medium settling velocity			2.5	m/hr	
Settling time after MLSS added for large particle			9.07	min	
Settling time after MLSS added for medium parti			21.07	min	
		DS1-ABC-L	DS2-ABC-L	DS3-ABC-L	Average
MLSS	mL added	405	405	405	
	mg/L	872	770	950	
	mg added	353	312	385	
Cone	mL collected	1,470	1,470	1,470	
	mg/L	148	106	106	
	mg collected	218	156	156	
	Fast Fraction	62%	50%	40%	50.7%
		DS1-ABC-M	DS2-ABC-M	DS3-ABC-M	Average
MLSS	mL added	405	405	405	
	mg/L	872	770	950	
	mg added	353	312	385	
Cone	mL collected	1,470	1,470	1,470	
	mg/L	184	196	156	
	mg collected	270	288	229	
	Medium+Fast Frac	77%	92%	60%	76.2%
	Medium Fraction	29%	46%	35%	37.0%
	Large/Fast Averag	50.7%			
	Medium Average	49.1%	(use large-small)		
	Small/slow	0.21%	(calculated from DSS tests)		

Attachment C: Final Clarifier 3 Field Test Data

Test Time (min)	Final Flow (mgd)	RAS (mgd)	SOR (gpd/sf)
0	4.5	2.3	396
5	4.6	2.3	406
10	4.6	2.3	411
15	4.6	2.3	409
20	4.5	2.3	400
25	4.6	2.3	408
30	4.9	2.3	437
35	5.1	2.3	447
40	4.3	2.3	384
45	3.9	2.3	341
50	4.1	2.3	360
55	4.2	2.3	371
60	3.9	2.3	348
65	5.3	2.3	471
70	5.7	2.3	504
75	5.6	2.3	492
80	5.5	2.3	485
85	5.6	2.3	492
90	5.7	2.3	501
95	5.6	2.3	495
100	5.5	2.3	489
105	5.5	2.3	488
110	5.7	2.3	502
115	5.8	2.3	514
120	5.7	2.3	507
125	5.6	2.3	498
130	5.6	2.3	496
135	5.7	2.3	501
140	5.7	2.3	504
145	5.7	2.3	505
150	5.7	2.3	505
155	7.1	2.3	630
160	8.6	2.3	756
165	10.0	2.3	882
170	10.4	2.3	917
175	10.7	2.3	947
180	10.6	2.3	939
185	10.4	2.3	916
190	10.0	2.3	883
195	9.9	2.3	877
200	10.0	2.3	885
205	10.3	2.3	911
210	10.4	2.3	924
215	10.4	2.3	923
220	10.5	2.3	927
225	10.5	2.3	925
230	10.3	2.3	910
235	10.2	2.3	898
240	10.1	2.3	896
245	10.2	2.3	901
250	10.3	2.3	911
255	10.3	2.3	910
260	10.3	2.3	909
265	10.3	2.3	912
270	10.6	2.3	937
275	10.7	2.3	945
280	10.5	2.3	925
285	10.0	2.3	888
290	10.1	2.3	890
295	10.3	2.3	910
300	11.1	2.3	981
305	12.1	2.3	1070
310	12.6	2.3	1111
315	12.5	2.3	1105
320	12.1	2.3	1069
325	12.1	2.3	1068
330	12.8	2.3	1134
335	12.9	2.3	1136
340	12.3	2.3	1087
345	12.2	2.3	1082
350	12.6	2.3	1116
355	12.6	2.3	1115
360	12.3	2.3	1090
365	12.1	2.3	1069
370	12.2	2.3	1076
375	12.4	2.3	1094
380	13.1	2.3	1158
385	14.0	2.3	1237
390	14.4	2.3	1271
395	14.3	2.3	1266
400	14.3	2.3	1263
405	14.2	2.3	1253
410	14.3	2.3	1263
415	14.3	2.3	1264
420	14.4	2.3	1275
425	14.4	2.3	1277
430	14.3	2.3	1269
435	14.0	2.3	1240
440	13.9	2.3	1230
445	13.9	2.3	1233
450	14.0	2.3	1236
455	14.0	2.3	1234
460	13.4	2.3	1185
465	11.9	2.3	1056
470	11.7	2.3	1035
475	11.8	2.3	1045
480	11.9	2.3	1051

ESS				
Test Time (min)	Sample Name	Sampler Initials	Sample Time	TSS (mg/L)
0	ESS-HPOAS-0	DPE	9:00 AM	9.6
15	ESS-HPOAS-15	DPE	8:15 AM	8.4
30	ESS-HPOAS-30	DPE	8:30 AM	8.5
45	ESS-HPOAS-45	DPE	8:45 AM	8
60	ESS-HPOAS-60	DPE	9:00 AM	8.6
75	ESS-HPOAS-75	DPE	9:15 AM	10.5
90	ESS-HPOAS-90	DPE	9:30 AM	10.25
105	ESS-HPOAS-105	DPE	9:45 AM	9.6
120	ESS-HPOAS-120	DPE	10:00 AM	12.75
135	ESS-HPOAS-135	DPE	10:15 AM	11.25
150	ESS-HPOAS-150	DPE	10:30 AM	11.6
165	ESS-HPOAS-165	DPE	10:45 AM	13.6
180	ESS-HPOAS-180	DPE	11:00 AM	12.4
195	ESS-HPOAS-195	DPE	11:15 AM	12.4
210	ESS-HPOAS-210	DPE	11:30 AM	14
225	ESS-HPOAS-225	DPE	11:45 AM	15.6
240	ESS-HPOAS-240	DPE	12:00 PM	16
255	ESS-HPOAS-255	DPE	12:15 PM	12.4
270	ESS-HPOAS-270	DPE	12:30 PM	12.4
285	ESS-HPOAS-285	DPE	12:45 PM	15.2
300	ESS-HPOAS-300	DPE	1:00 PM	16.4
315	ESS-HPOAS-315	DPE	1:15 PM	17.2
330	ESS-HPOAS-330	DPE	1:30 PM	17.2
345	ESS-HPOAS-345	DPE	1:45 PM	17.2
360	ESS-HPOAS-360	DPE	2:00 PM	18
375	ESS-HPOAS-375	DPE	2:15 PM	18.4
390	ESS-HPOAS-390	DPE	2:30 PM	19.6
405	ESS-HPOAS-405	DPE	2:45 PM	16.8
420	ESS-HPOAS-420	DPE	3:00 PM	22.8
435	ESS-HPOAS-435	DPE	3:15 PM	28.4
450	ESS-HPOAS-450	DPE	3:30 PM	18
465	ESS-HPOAS-465	DPE	3:45 PM	18.5
480	ESS-HPOAS-480	DPE	4:00 PM	16

MLSS				
Test Time (min)	Sample Name	Sampler Initials	Sample Time	TSS (mg/L)
0	MLSS-HPOAS-0	DPE	9:00 AM	2,500
30	MLSS-HPOAS-30	DPE	9:30 AM	2,580
60	MLSS-HPOAS-60	DPE	10:00 AM	2,420
90	MLSS-HPOAS-90	DPE	10:30 AM	2,420
120	MLSS-HPOAS-120	DPE	11:00 AM	2,420
150	MLSS-HPOAS-150	DPE	11:30 AM	1,980
180	MLSS-HPOAS-180	DPE	12:00 PM	2,300
210	MLSS-HPOAS-210	DPE	12:30 PM	1,940
240	MLSS-HPOAS-240	DPE	1:00 PM	2,060
270	MLSS-HPOAS-270	DPE	1:30 PM	1,980
300	MLSS-HPOAS-300	DPE	2:00 PM	1,900
330	MLSS-HPOAS-330	DPE	2:30 PM	1,800
360	MLSS-HPOAS-360	DPE	3:00 PM	1,780
390	MLSS-HPOAS-390	DPE	3:30 PM	1,820
420	MLSS-HPOAS-420	DPE	4:00 PM	1,760
450	MLSS-HPOAS-450	DPE	4:30 PM	1,660
480	MLSS-HPOAS-480	DPE	5:00 PM	1,780

RAS				
Test Time (min)	Sample Name	Sampler Initials	Sample Time	TSS (mg/L)
0	RAS-HPOAS-0	DPE	9:00 AM	6,540
30	RAS-HPOAS-30	DPE	9:30 AM	6,300
60	RAS-HPOAS-60	DPE	10:00 AM	6,250
90	RAS-HPOAS-90	DPE	10:30 AM	7,100
120	RAS-HPOAS-120	DPE	11:00 AM	6,600
150	RAS-HPOAS-150	DPE	11:30 AM	6,850
210	RAS-HPOAS-180	DPE	12:00 PM	7,350
225	RAS-HPOAS-210	DPE	12:30 PM	8,400
240	RAS-HPOAS-240	DPE	1:00 PM	9,400
270	RAS-HPOAS-270	DPE	1:30 PM	9,450
300	RAS-HPOAS-300	DPE	2:00 PM	9,350
330	RAS-HPOAS-330	DPE	2:30 PM	9,550
360	RAS-HPOAS-360	DPE	3:00 PM	10,150
390	RAS-HPOAS-390	DPE	3:30 PM	9,400
420	RAS-HPOAS-420	DPE	4:00 PM	9,900
450	RAS-HPOAS-450	DPE	4:30 PM	9,550
480	RAS-HPOAS-480	DPE	5:00 PM	9,850

Splitter Box Weir Level		
Test Time (min)	Measurer Initials	Flow Depth (in)
0	DPE	
15	DPE	
30	DPE	
45	DPE	
60	DPE	8
75	DPE	
90	DPE	7.5
105	DPE	7.5
120	DPE	7.75
135	DPE	
150	DPE	
165	DPE	
180	DPE	10
195	DPE	12
210	DPE	12
225	DPE	12
240	DPE	
255	DPE	11.5
270	DPE	13.5
285	DPE	
300	DPE	14
315	DPE	
330	DPE	14.25
345	DPE	
360	DPE	15
375	DPE	
390	DPE	16
405	DPE	
420	DPE	16
435	DPE	16
450	DPE	12
465	DPE	
480	DPE	12

Start Time		End Time			Normal Sludge Blanket Depth, feet			Fluff Sludge Blanket Depth, feet			Black Sludge Blanket Depth, feet			
Hour	Minute	Hour	Minute	Test Time (min)	Mid-Radius	Launder	End Wall	Mid-Radius	Launder	End Wall	Mid-Radius	Launder	End Wall	Collector Arm Position*
9	-	9	-	-	2.50	2.25								at bridge
9	30	9	30	30.00	0.50	0.50		1.50						180 from bridge
10	-	10	-	60.00	1.50	1.50		2.00	2.00					90 from bridge
10	30	10	30	90.00	1.25	1.25	1.25							at bridge
11	-	11	-	120.00	1.25	1.00	1	2.00						190 from bridge
11	30	11	30	150.00	1.00	1.00		2.00						90 from bridge
12	-	12	-	180.00	1.00	2.00		2.00	3.00			0.50		345 from bridge
12	30	12	30	210.00	1.00	1.00		3.00	2.00					225 from bridge
13	-	13	-	240.00	2.00	2.00		3.00	3.00					90 from bridge
13	30	13	30	270.00	2.00	2.00		3.00	3.00					at bridge
14	-	14	-	300.00	2.00	2.00		4.00	4.00					180 from bridge
14	30	14	30	330.00	3.00	3.00		5.00	4.00					75 from bridge
15	-	15	-	360.00	4.00	4.00		6.00	5.00					at bridge
15	30	15	30	390.00	6.00	5.00		7.00	7.00					270 from bridge
16	-	16	-	420.00	7.00	5.00		9.00	7.00					120 from bridge
16	30	16	30	450.00	6.00	6.00		8.00	8.00					at bridge
17	-	17	-	480.00	2.00	2.00		7.00	7.00					190 from bridge

*Use bridge as zero degrees and measure collector arm clockwise from the bridge.

Test Date	Wednesday, December 13, 2017	
Test Time	9 am through 5 pm	
Plant SVI	120	mL/g

Vesilind Equation

$$ZSV = v_0 e^{-k \times TSS_0}$$

Where

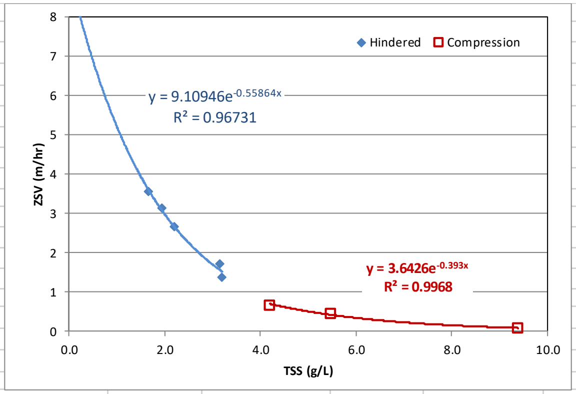
ZSV = Zone Settling Velocity, m/hr

v_0 = Sludge settleability constant, m/hr

k = Sludge settleability constant, L/mg TSS

TSS = Initial sludge concentration, mg/L

Settling Test	ZSV m/hr	Hindered g/L	Compression g/L
	Vo and k Determination		
1	2.66	2.20	
2	3.55	1.66	
3	1.38	3.20	
4	0.67		4.20
5	1.73	3.16	
6	0.45		5.48
7	3.13	1.94	
8	0.09		9.40
	V_0 (m/hr)*	9.10946	3.6426
	k (L/mg-TSS)	0.55864	0.393



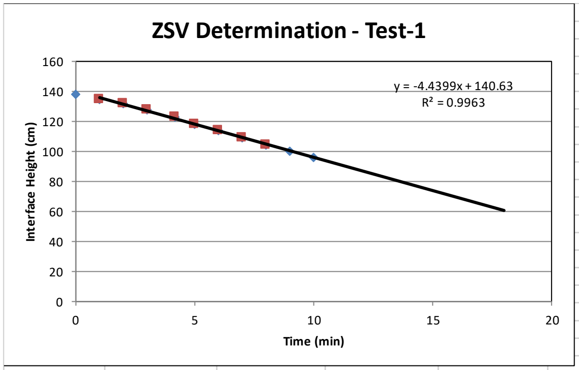
Zone Settling Velocity Determination

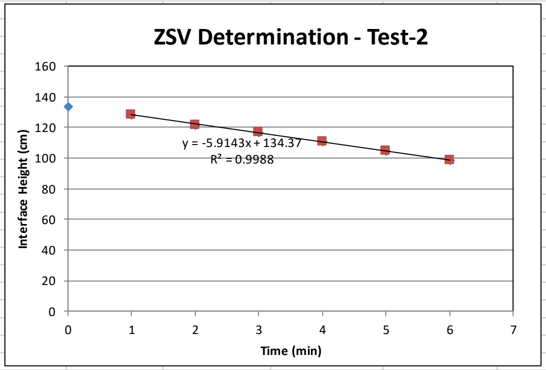
ZSV-1		ZSV-2		ZSV-3		ZSV-4		ZSV-5		ZSV-6		ZSV-7		ZSV-8	
TSS (mg/L)**	2,200	TSS (mg/L)	1660	TSS (mg/L)	3200	TSS (mg/L)	4200	TSS (mg/L)	3160	TSS (mg/L)	5480	TSS (mg/L)	1940	TSS (mg/L)	9400.0
Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height	Time	Sludge Interface Height
min	cm	min	cm	min	cm	min	cm	min	cm	min	cm	min	cm	min	cm
0	138	0	134	0	138.5	0	100	0	140.5	0	140	0	137	0	119.5
1	135	1	128.5	1	137.5	1	99.5	1	139.5	1	139.5	1	136	7	119
2	132	2	122	2	136.5	2	99	2	138	3	138.5	2.1	130	13.5	118.5
3	128	3.0	117	3.0	135.5	3.0	99	3.0	137	5.0	138	3.0	125	18	118
4.2	123	4	111	4	135	4.2	98.5	4	133	7	137	4	120	22	117.5
5	118.5	5	105	5	132.5	5.5	98	5	130.25	9	136	5.1	114	40	115
6	114	6	98.5	6	130.3	6	97.7	6	127.5	12	134.5	6.5	107	50	113
7	109.5			7	128	7.5	97	7	124.5	13.5	133.5	7	104		
8	104.5			8.416666667	125	8.5	96.5	8	121.5	15.5	132	8	99		
9	100			9	123.5	9.5	95.5	10	116	18.5	129.5	9	94		
10	96			10	121	10.5	95	12	110	23	126.25				
11						11.5	94.25	13		30	121				
12						12.5	93.25	14							
13						13.5	92.5	15							
14						14.5	91.5	16							
15						28.5	75.25	17							
16						32.5	70.25	18							
17						39	64.5								
18						45.5	59.25								
dispersed solids in supernatatnt		poor interface													
Temp (F)															
ZSV (cm/min)***	4.4	ZSV (cm/min)***	5.9	ZSV (cm/min)***	2.3	ZSV (cm/min)**	1.1	ZSV (cm/min)***	2.9	ZSV (cm/min)**	0.755	ZSV (cm/min)*	5.219	ZSV (cm/min)**	0.1
ZSV (m/hr)***	2.7	ZSV (m/hr)	3.5	ZSV (m/hr)	1.4	ZSV (m/hr)	0.7	ZSV (m/hr)	1.7	ZSV (m/hr)	0.5	ZSV (m/hr)	3.1	ZSV (m/hr)	0.1

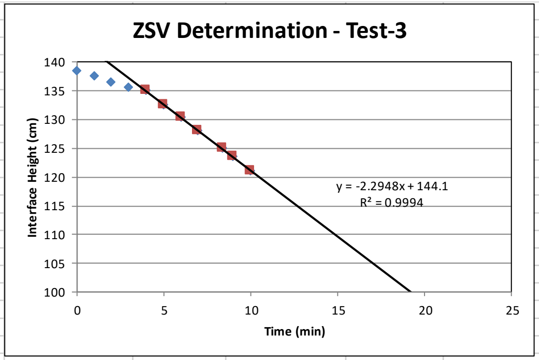
* data shown in red squares below are used to regress the linear ZSV

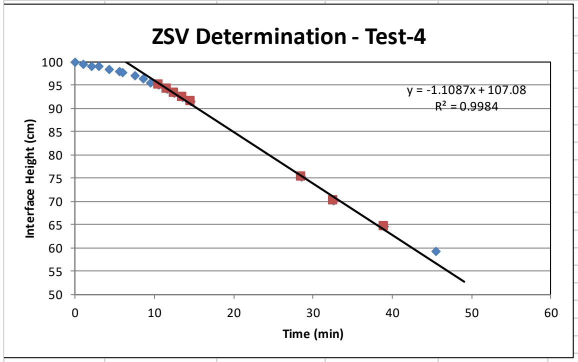
** "TSS" is sample

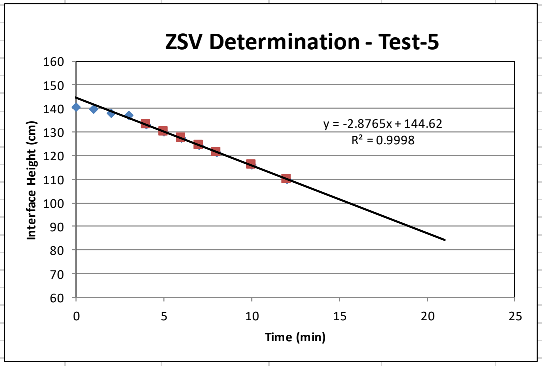
*** ZSV is determined by linear regression as shown in following Figures and then convert from cm/min to m/hr

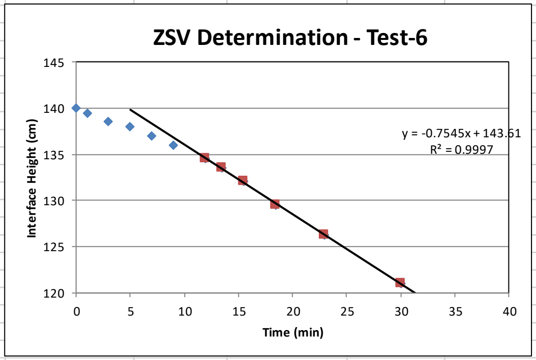

ZSV Determination - Test-1
y = -4.4399x + 140.63
R² = 0.9963
Interface Height (cm)
0
20
40
60
80
100
120
140
160
0
5
10
15
20
Time (min)

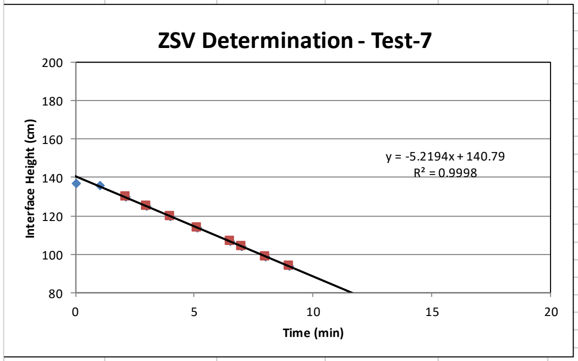

ZSV Determination - Test-2
y = -5.9143x + 134.37
R² = 0.9988
Interface Height (cm)
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
7
Time (min)

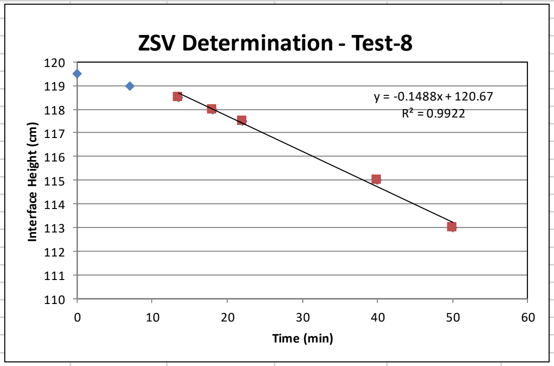

ZSV Determination - Test-3
y = -2.2948x + 144.1
R² = 0.9994
Interface Height (cm)
100
105
110
115
120
125
130
135
140
0
5
10
15
20
25
Time (min)


ZSV Determination - Test-4
y = -1.1087x + 107.08
R² = 0.9984
Interface Height (cm)
50
55
60
65
70
75
80
85
90
95
100
0
10
20
30
40
50
60
Time (min)


ZSV Determination - Test-5
y = -2.8765x + 144.62
R² = 0.9998
Interface Height (cm)
60
70
80
90
100
110
120
130
140
150
160
0
5
10
15
20
25
Time (min)


ZSV Determination - Test-6
y = -0.7545x + 143.61
R² = 0.9997
Interface Height (cm)
120
125
130
135
140
145
0
5
10
15
20
25
30
35
40
Time (min)


ZSV Determination - Test-7
y = -5.2194x + 140.79
R² = 0.9998
Interface Height (cm)
80
100
120
140
160
180
200
0
5
10
15
20
Time (min)


ZSV Determination - Test-8
y = -0.1488x + 120.67
R² = 0.9922
Interface Height (cm)
110
111
112
113
114
115
116
117
118
119
120
0
10
20
30
40
50
60
Time (min)

Flocculation Test

Test Objective:	Define floc kinetics
Test Location	Rochester WRP
Test Date	Wednesday, December 13, 2017
Test Attendee	Lloyd Winchell
Sample Location	Splitter Box
Settling Time	30 minute

	9:45 AM	11:06 AM	1:34 PM
	Test 1	Test 2	Test 3
Time	Supernatant TSS	Supernatant TSS	Supernatant TSS
0	23.0	15.2	20.0
2	12.8	12.8	14.5
5	14.8	11.5	13.0
10	10.4	10.0	10.5
15	7.0	8.0	9.5
30	6.4	8.4	8.5
SS	2340	2280	1900
G	51	51	51
Temp (°C)	17	16	16
Paddle Speed	58	59	60

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

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

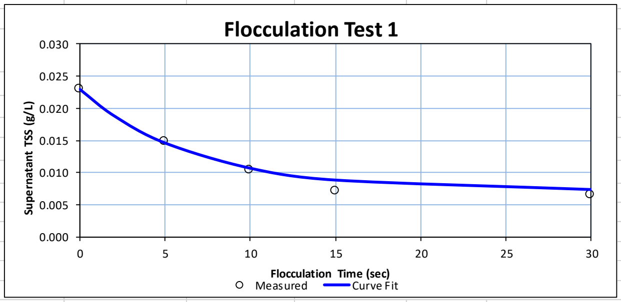
t = time, s

0.000374331

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	0.023	0.023	0.000000000	n_0 (mg/L)	0.023
2		0.019	0.000357284	G (sec^{-1})	51
5	0.015	0.015	0.000000018	X (g/L)	2.34
10	0.010	0.011	0.000000119	K_a (L/g TSS)	2.106E-05
15	0.007	0.009	0.000003615	K_B (sec)	3.000E-09
30	0.006	0.007	0.000001069		
		SSE***	0.000362105		

** By varying Ka and Kb to reach minimum "SSE"

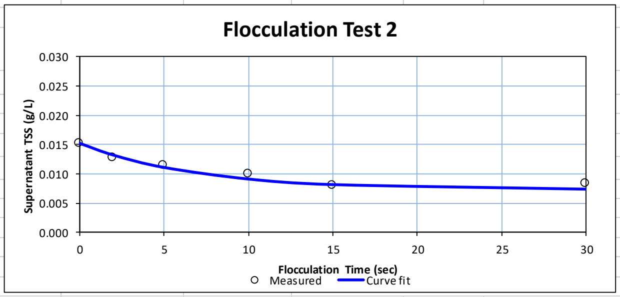
*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed



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	0.015	0.015	0.000000000	n_0 (mg/L)	0.015
2	0.013	0.013	0.000000143	G (sec-1)	51
5	0.012	0.011	0.000000185	X (g/L)	2.28
10	0.010	0.009	0.000000830	K_a (L/g TSS)	2.106E-05
15	0.008	0.008	0.000000019	K_B (sec)	3.000E-09
30	0.008	0.007	0.000001082		
		SSE***	0.000002260		

** By varying Ka and Kb to reach minimum "SSE"

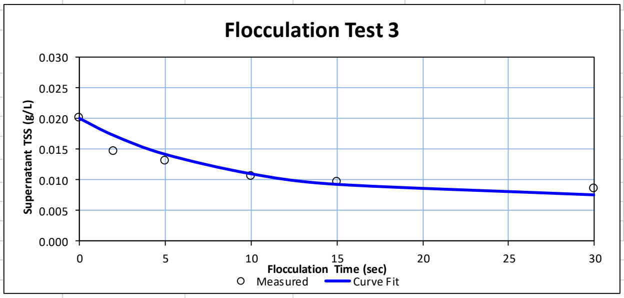
*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed



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	0.020	0.020	0.000000000	n_0 (mg/L)	0.020
2	0.015	0.017	0.000007469	G (sec-1)	51
5	0.013	0.014	0.000001363	X (g/L)	1.90
10	0.011	0.011	0.000000256	K_a (L/g TSS)	2.106E-05
15	0.010	0.009	0.000000043	K_B (sec)	3.000E-09
30	0.009	0.008	0.000000835		
		SSE***	0.000009966		

** By varying Ka and Kb to reach minimum "SSE"

*** "SSE"=Sum of Squared Errors. Error=Calculated using Ka and Kb minus observed



Dispersed Suspended Solids Testing

Test Date: 12/13/2017 Performed By: DPE

Test Clarifier: HPOAS Final 3

Item	Test 1	Test 2	Test 3
	Sample IDs		
Sample time	8:30	12:45	15:45
Sample ID	DSS-HPOAS1	DSS-HPOAS2	DSS-HPOAS3
DSS, mg/L	12.6	9.8	14.4
Estimate fraction of small settling particles based upon effluent launder DSS			
SC Volume, MG			
Time when MLSS entered			
MLSS mg/L	2500	2000	1790
F3	0.50%	0.49%	0.80%

Discrete Suspended Solids Testing

Date: 12/13/2017
Performed by: LJW
Sample Location: Splitter Box
Settling colum length (WSE to sample tap) → 0.875 meters

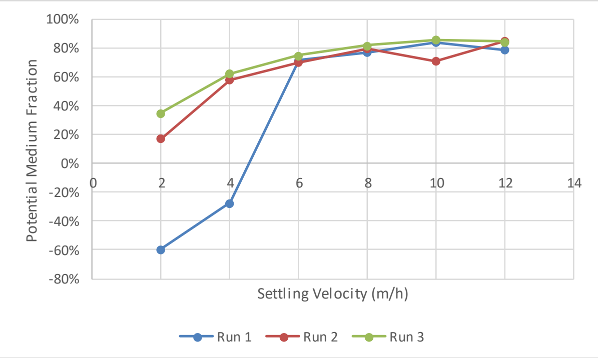
Run	Velociy (m/h)	Settling Time (min)*	Volume Added (mL)	X (mg/L)	Mass Added (mg)	Sample Volume (mL)	Sample X (mg/L)	Sample Mass (mg)	Fraction	Potential Medium Fraction
1	12	4.88	400	858	343.2	1570	45	70.65	21%	79%
	10	5.75	400	858	343.2	1570	34	53.38	16%	84%
	8	7.06	300	858	257.4	1570	37	58.09	23%	77%
	6	9.25	300	858	257.4	1570	46	72.22	28%	71%
	4	13.63	300	858	257.4	1570	208	326.56	127%	-27%
	2	26.75	300	858	257.4	1570	260	408.2	159%	-59%
2	12	4.88	300	680	204	1570	18.8	29.516	14%	85%
	10	5.75	300	680	204	1570	37	58.09	28%	71%
	8	7.06	300	680	204	1570	26	40.82	20%	79%
	6	9.25	300	680	204	1570	38.4	60.288	30%	70%
	4	13.63	300	680	204	1570	54	84.78	42%	58%
	2	26.75	300	680	204	1570	107	167.99	82%	17%
3	12	4.88	300	652	195.6	1570	18.5	29.045	15%	85%
	10	5.75	300	652	195.6	1570	17	26.69	14%	86%
	8	7.06	300	652	195.6	1570	22	34.54	18%	82%
	6	9.25	300	652	195.6	1570	30.5	47.885	24%	75%
	4	13.63	300	652	195.6	1570	46	72.22	37%	62%
	2	26.75	300	652	195.6	1570	80	125.6	64%	35%

*added 30 seconds for currents to subside when mixing MLSS

Fractions		
F1	39.24%	(by difference with F2 and F3, check versus Vo velocity if within range tested above)
F2	60.16%	(based on observed mass of 1/2 Vo from data above, need to identify Vo with Zsv tests)
F3	0.60%	(from DSS tests)

F2 selection

	Vo =	9.1	m/h, see Zsv-HPOAS.xlsx - cell I17 in "Calculations" tab.
	1/2 Vo =	4.55	m/h, assume 4 m/h test per above
	Average F2	60%	



Attachment D: Intermediate Clarifier Stress Testing

Intermediate Clarifier Stress Testing

City of Rochester (City) Water Reclamation Plant (WRP) staff performed two days of clarifier stress testing on the HPOAS Intermediate Clarifiers 2 (IC2) and 4 (IC4) on February 15 and 16, 2018. Stress testing was conducted to define the maximum solids loading rate (SLR) at which either the effluent suspended solids (ESS) exceeded 25 milligrams per liter (mg/L) or sludge blanket depths (SBDs) (measured in feet [ft] from the bottom of the clarifier) remained stable at sustained loading conditions. This maximum loading condition was then compared to the theoretical state point analysis (SPA) SLR for the same sludge volume index (SVI) using a non-stirred settlometer (SVISN), return activated sludge (RAS) flow, and influent flow to determine a de-rating factor that can be applied to SPAs for defining IC capacity.

Table D-1 presents the physical characteristics of each test clarifier.

Table D-1. Rochester Intermediate Clarifiers 2 and 4 Characteristics

Item	Units	Intermediate Clarifier 2	Intermediate Clarifier 4
Diameter	ft	90	90
Side water depth	ft	10	14
Inlet type	--	Rim fed	Center fed
Launder	--	peripheral	peripheral
Collector type	--	hydraulic suction	hydraulic suction

D.1 Testing: General

IC2 and IC4 were tested simultaneously. Each stress test lasted roughly 5 hours. During the test, the clarifier SOR was increased every 1.0 to 1.5 hours while maintaining the target SOR as best as possible. Mixed liquor flow was evenly distributed between online clarifiers, and RAS flows/clarifier were set at the same constant rate.

The reported RAS flows rates were multiplied by a factor of 0.85 because draw-down testing of the intermediate clarifiers showed the RAS flow meters measurements were roughly 15 percent higher than the draw-down test flow rate. Mixed liquor suspended solid (MLSS), ESS, SBD, and settled sludge volume (SSV30) were collected at key time intervals to capture the quasi "steady-state" loading conditions. The SSV30 values were converted into SVISN using the measured MLSS.

D.2 Day 1 Testing – February 15, 2018

Day 1 testing was completed with two clarifiers in service and RAS flow rates set at approximately 2.1 million gallons per day (mgd) after flow correction. Figure D-1 shows the test clarifier SORs. Five loading periods can be analyzed from the data collected with SORs of approximately 665, 765, 890, 960, and 1,065 gallons per square foot day (gal/ft^2-d).

Figure D-2 shows that the test SLR ranged from 18.6 to 22.6 pounds per square foot day (lb/ft^2-d). SVISNs during testing averaged 135 milliliters per gram (mL/g) and varied plus or minus 6 mL/g. Figure D-3 shows that IC2 SBD increased throughout the test with a semi-stable SBD during Period 2, when the SLR was 72 percent of the theoretical SPA SLR. Interestingly, during Period 4 and 5 IC2's SLR was roughly the same percentage of the SPA theoretical maximum SLR—but the blankets increased significantly. This could mean the SLR de-rating factor of the rim-fed clarifier changes (i.e., increases) at higher SORs. IC4 SBD increased during Periods 1 through 3 and became stable during Periods 4 and 5 when operating at 71 to 72 percent of the SPA theoretical SLR.

Figure D-4 shows IC2 maintained ESS less than 30 mg/L when blankets remained below 7 feet and sustained loadings at 70 percent of the SPA theoretical SLR ultimately resulted in loss of significant solids over the weirs. The IC4 ESS remained below 25 mg/L throughout the stress test with ESS averaging roughly 10 mg/L when SORs were below 960 gal/ft^2-d. It should be noted that 4 of the 6 IC4 ESS samples did not meet quality assurance protocol with at least 1 mg of solids retained on the filter.

Test data are summarized in Table D-2 and SPA charts are provided in Figures D-5 through D-9 at the end of this section.

Figure D-1. Intermediate clarifier stress testing SORs - Day 1

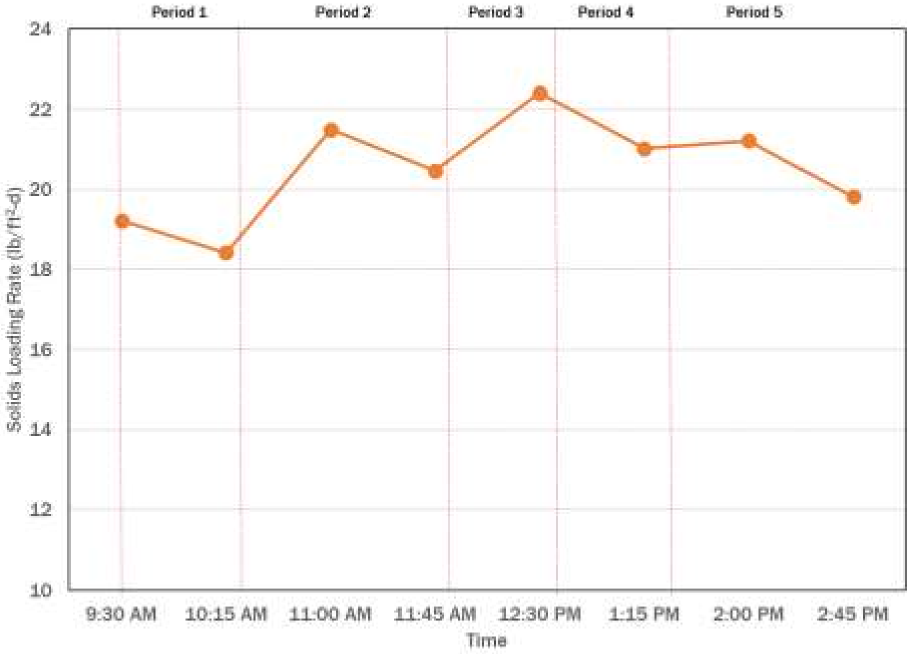


Figure D-2. Intermediate clarifier stress testing SLRs - Day 1

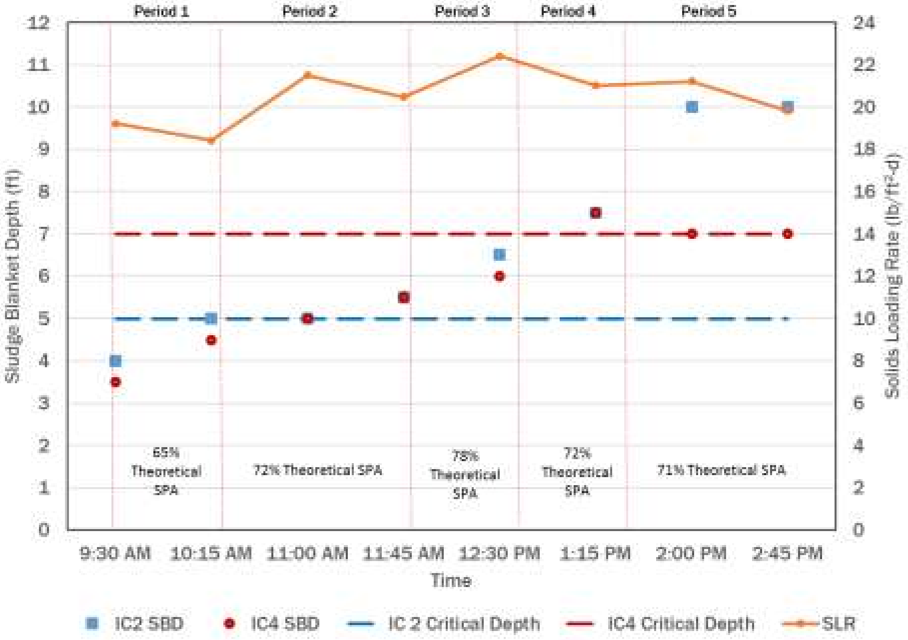


Figure D-3. Intermediate clarifier stress testing SBDs at launder - Day 1

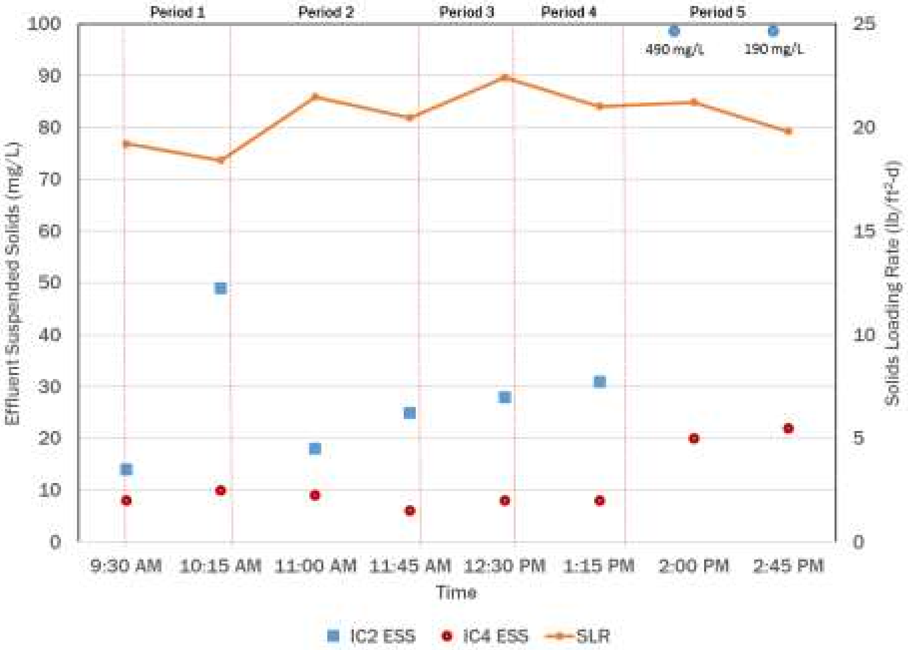


Figure D-4. Intermediate clarifier stress testing ESS - Day 1

Table D-2. Rochester Intermediate Clarifiers 2 and 4 Stress Test Data– Day 1

Time	Flow (mgd)	IC2 RAS Flow (mgd)[a]	IC4 RAS Flow (mgd)[a]	MLSS (mg/L)	SOR (gal/ft^2-d)	SLR (lb/ft^2-d)	SSV30 (mL/L)	IC2 SBD Mid Span (ft)	IC2 SBD Launder (ft)	IC4 SBD Mid Span (ft)	IC4 SBD Launder (ft)	IC2 ESS (mg/L)	IC4 ESS (mg/L)	IC2 RAS TSS (mg/L)	IC4 RAS TSS (mg/L)	Combined RAS TSS (mg/L)
9:30 AM	8.6	2.15	2.09	2,300	667	19.4	320	5.0	4.0	5.0	3.5	14	8	5,600	5,000	5,900
10:15 AM	8.6	2.15	2.10	2,200	667	18.6	310	5.5	5.0	4.5	4.5	49	10	--	--	--
11:00 AM	9.7	2.15	2.11	2,350	767	21.6	310	5.5	5.0	6.0	5.0	18	9	--	--	--
11:45 AM	9.7	2.15	2.10	2,240	767	20.6	300	6.5	5.5	5.5	5.5	25	6	5,200	5,900	5,700
12:30 PM	11.3	2.15	2.10	2,200	891	22.6	290	7.5	6.5	6.5	6.0	28	8	--	--	--
1:15 PM	12.3	2.15	2.10	1,950	963	21.1	270	7.5	7.5	6.0	7.5	31	8	--	--	--
2:00 PM	13.6	2.16	2.11	1,820	1,066	21.3	250	10	10	7.5	7.0	490	20	--	--	--
2:45 PM	13.6	2.16	2.11	1,700	1,066	19.9	220	10	10	7.0	7.0	190	22	4,900	5,900	6,100

a. Calculated flow based on 85 percent of measured flow.

Day 1 - Period 1

SVISN	135	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	3.000	g/L
Inf. flow	5.3	mgd
RAS flow	2.10	mgd
SOR	833	gal/ft^2-d
Theoretical SLR	29	lb/ft^2-d
Test SLR	19	lb/ft^2-d
% of Theoretical SLR	0.65	IC2 blanket rising
		IC4 blanket rising

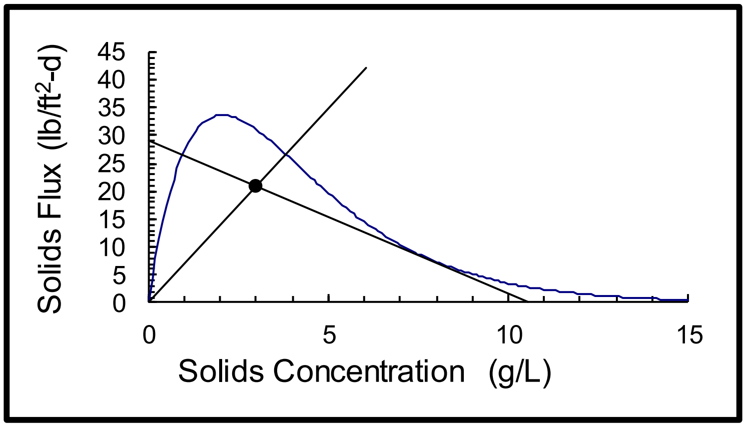


Figure D-5. Intermediate clarifier stress testing SPA analysis - Day 1:Period 1

Day 1 - Period 2

SVISN	135	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	3.200	g/L
Inf. flow	4.87	mgd
RAS flow	2.10	mgd
SOR	766	gal/ft^2-d
Theoretical SLR	29	lb/ft^2-d
Test SLR	21	lb/ft^2-d
% of Theoretical SLR	0.72	IC2 blanket steady to rising slowly
		IC4 blanket steady to rising slowly

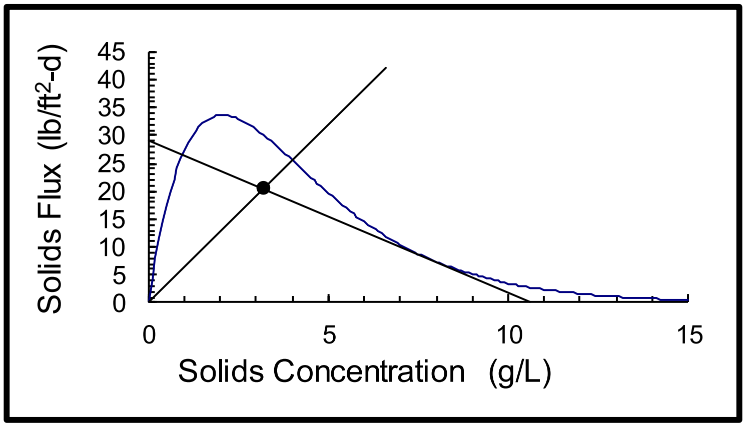


Figure D-6. Intermediate clarifier stress testing SPA analysis - Day 1:Period 2

Day 1 - Period 3

SVISN	135	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	2.850	g/L
Inf. flow	5.65	mgd
RAS flow	2.10	mgd
SOR	888	gal/ft^2-d
Theoretical SLR	29	lb/ft^2-d
Test SLR	23	lb/ft^2-d
% of Theoretical SLR	0.78	IC2 blanket rising and ESS >25 mg/L
		IC4 blanket rising

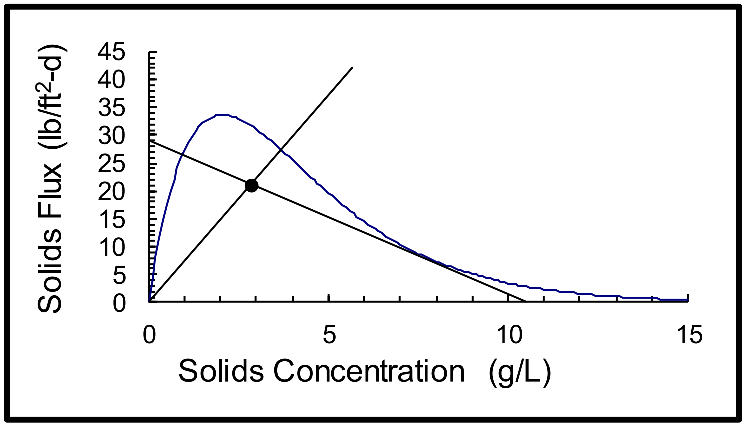


Figure D-7. Intermediate clarifier stress testing SPA analysis - Day 1:Period 3

Day 1 - Period 4

SVISN	135	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	2.700	g/L
Inf. flow	6.15	mgd
RAS flow	2.10	mgd
SOR	967	gal/ft^2-d
Theoretical SLR	29	lb/ft^2-d
Test SLR	21	lb/ft^2-d
% of Theoretical SLR	0.72	IC2 blanket rising and ESS >25 mg/L
		IC4 blanket rising

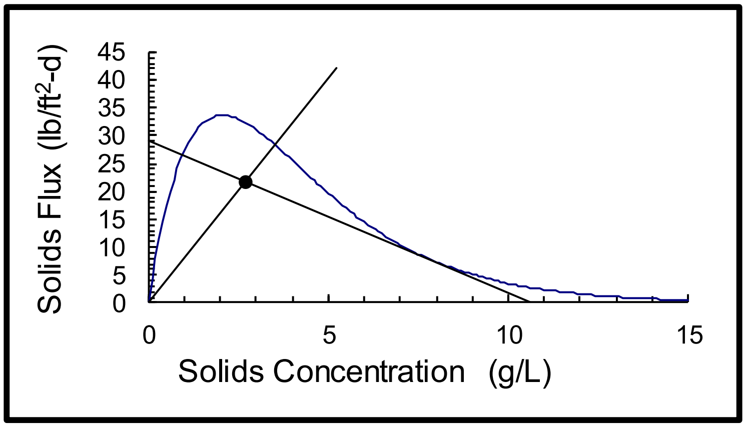


Figure D-8. Intermediate clarifier stress testing SPA analysis - Day 1:Period 4

Day 1 - Period 5

SVISN	135	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	2.500	g/L
Inf. flow	6.8	mgd
RAS flow	2.10	mgd
SOR	1069	gal/ft^2-d
Theoretical SLR	29	lb/ft^2-d
Test SLR	21	lb/ft^2-d
% of Theoretical SLR	0.71	IC2 Blanket rising and ESS >25 mg/L
		IC4 Blanket stable at critical value

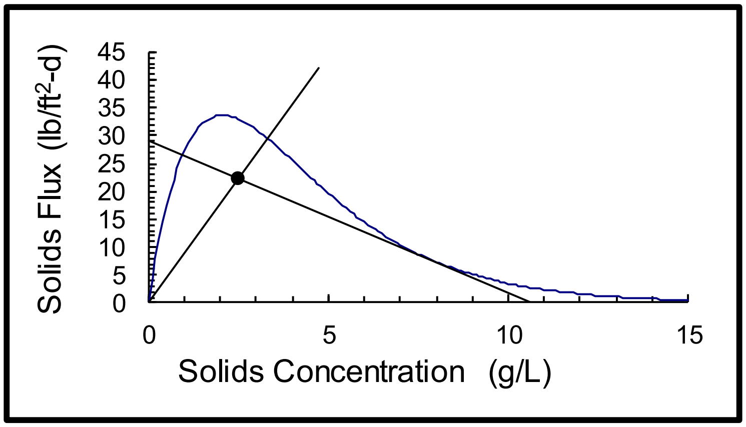


Figure D-9. Intermediate clarifier stress testing SPA analysis - Day 1:Period 5

D.3 Day 2 Testing - February 16, 2018

Day 2 testing was completed with three clarifiers in service and the RAS flow rates set at approximately 1.7 mgd after flow correction. IC2 and IC4 were used as test clarifiers on day 2. Figure D-10 shows the test clarifier SORs. Four operating periods can be analyzed from the data collected with SORs of approximately 300, 580, 800, and 1,000 gal/ft^2-d. Figure D-11 shows the clarifier SLRs ranged from 12 to 22 lb/ft^2-d during testing. SLRs after 11:00 AM decreased because of significant decreases in measured MLSS to the clarifiers.

SVISNs during the test averaged 160 mL/g with a wide range observed from a minimum of 118 mL/g to a maximum of 200 mL/g. As such, each operating period was analyzed based upon the average SVISN measured during the individual test period.

Figure D-12 shows IC2 and IC4 had stable SBDs during Period 1 (62 percent of theoretical SLR at 300 gal/ft^2-d). Both IC2 and IC4 SBD increased during Period 2 when operating at 75 percent of theoretical SLR and 580 gal/ft^2-d. IC2 SBD continued to increase during Period 3 when SLRs were 67 percent, or higher, than the SPA theoretical maximum SLR at an SOR of roughly 800 gal/ft^2-d. Conversely, IC4 SBD decreased during Period 3 when the SPA decreased to 67 percent of the theoretical value. Interestingly, both IC2 and IC4 SBDs increased during Period 4 when operating at 62 percent of the theoretical SLR and SOR of 1,000 gal/ft^2-d; however, the MLSS concentrations used in Period 4 were re-runs of original samples. If the original MLSS concentration values are used, the Period 4 SLRs are roughly 72 percent of the theoretical SLR.

Figure D-13 shows IC2 maintained ESS less than 30 mg/L for all conditions except Period 4, during which the IC2 ESS exceeded 45 mg/L on the last sample.

Test data are summarized in Table D-3 and SPA charts are provided in Figures D-14 through D-18 at the end of this section.

Figure D-10. stress testing SORs - Day 2

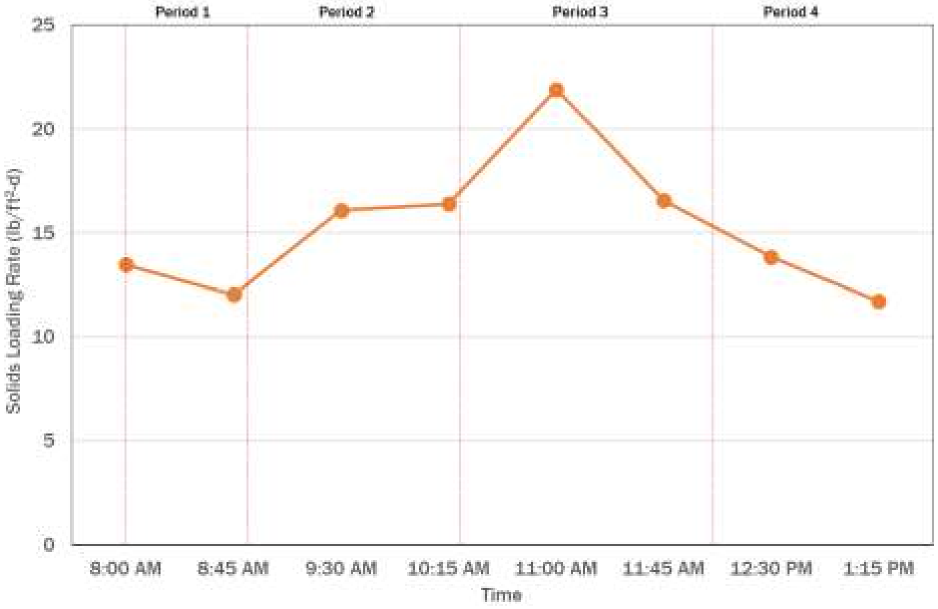


Figure D-11. Intermediate clarifier stress testing SLRs - Day 2

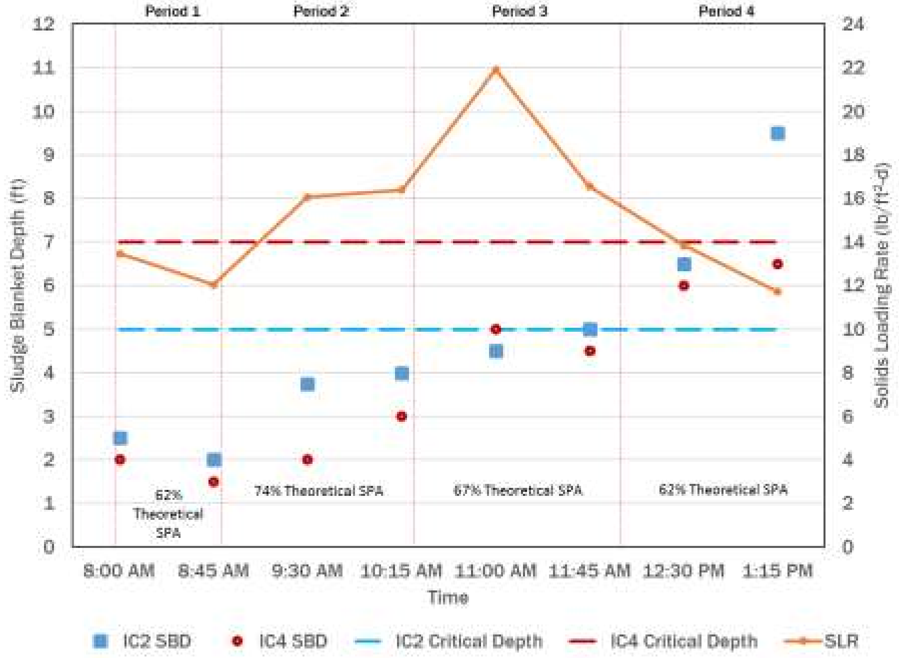


Figure D-12. Intermediate clarifier stress testing SBDs at launder - Day 2

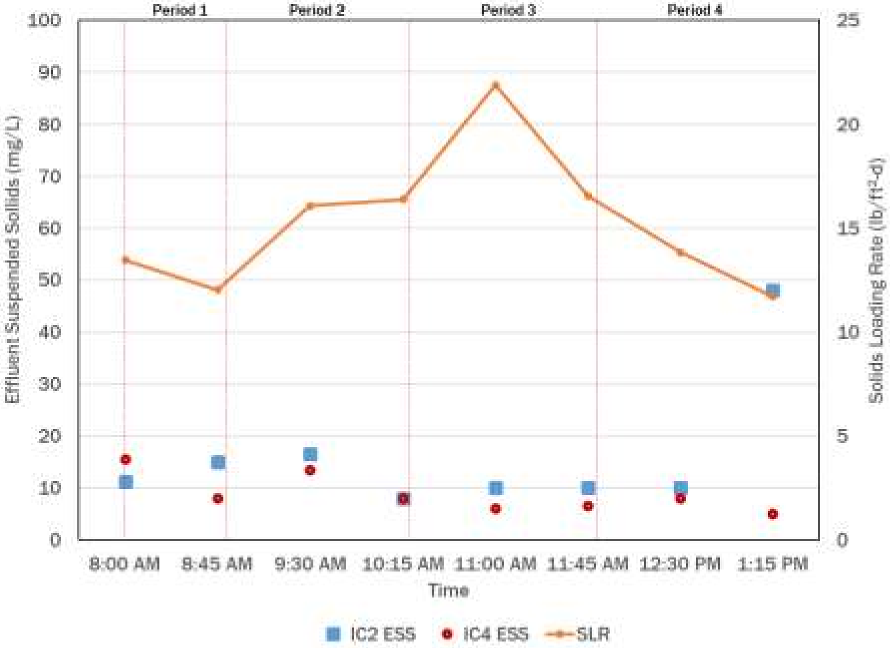


Figure D-13 – Intermediate clarifier stress testing ESS - Day 2

Table D-3. Rochester Intermediate Clarifiers 2 and 4 Stress Test Data – Day 2

Time	Flow (mgd)	IC2 RAS Flow (mgd)[a]	IC4 RAS Flow (mgd)[a]	MLSS (mg/L)	SOR (gal/ft^2-d)	SLR (lb/ft^2-d)	SSV30 (mL/L)	IC2 SBD Mid Span (ft)	IC2 SBD Launder (ft)	IC4 SBD Mid Span (ft)	IC4 SBD Launder (ft)	IC2 ESS (mg/L)	IC4 ESS (mg/L)	IC2 RAS TSS (mg/L)	IC4 RAS TSS (mg/L)	Combined RAS TSS (mg/L)
8:00 AM	5.84	1.72	1.72	2,800	306	13.5	450	2.0	2.5	2.5	2.0	11.2	15.5	4,300	5,800	4,700
8:45 AM	5.84	1.73	1.73	2,500	306	12.0	500	2.0	2.0	2.0	1.5	15.0	8.0	--	--	--
9:30 AM	11.16	1.72	1.73	2,250	585	16.1	360	3.0	3.8	3.0	2.0	16.5	13.5	--	--	--
10:15 AM	11.16	1.72	1.72	2,30	585	16.4	330	4.0	4.0	4.5	3.0	8.0	8.0	5,000	5,200	5,500
11:00 AM	15.30	1.72	1.72	2,450	802	21.9	290	5.5	4.5	5.5	5.0	10.0	6.0	--	--	--
11:45 AM	15.30	1.73	1.72	1,850	802	16.6	270	5.5	5.0	5.0	4.5	10.0	6.5	--	--	--
12:30 PM	19.20	1.72	1.72	1,300	1,006	13.8	240	8.0	6.5	6.0	6.0	10.0	8.0	--	--	--
1:15 PM	19.20	1.72	1.72	1,100	1,006	11.7	190	10.0	9.5	7.0	6.5	48.0	5.0	4,900	4,500	5,700

a. Calculated flow based on 85 percent of measured flow.

Day 2 - Period 1

SVISN	180	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	4.400	g/L
Inf. flow	1.88	mgd
RAS flow	1.70	mgd
SOR	296	gal/ft^2-d
Theoretical SLR	21	lb/ft^2-d
Test SLR	13	lb/ft^2-d
% of Theoretical SLR	0.62	Blanket at 3 ft

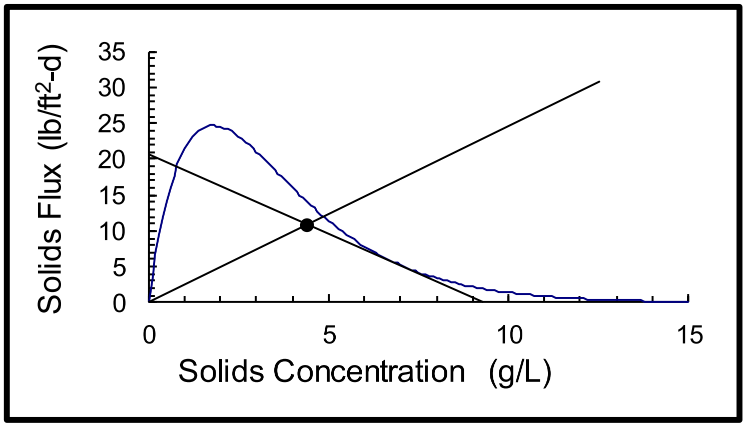


Figure D-14. Intermediate clarifier stress testing SPA analysis - Day 2:Period 1

Day 2 - Period 2

SVISN	160	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	3.100	g/L
Inf. flow	3.72	mgd
RAS flow	1.70	mgd
SOR	585	gal/ft^2-d
Theoretical SLR	22	lb/ft^2-d
Test SLR	16	lb/ft^2-d
% of Theoretical SLR	0.74	Blanket rising
		ESS ok

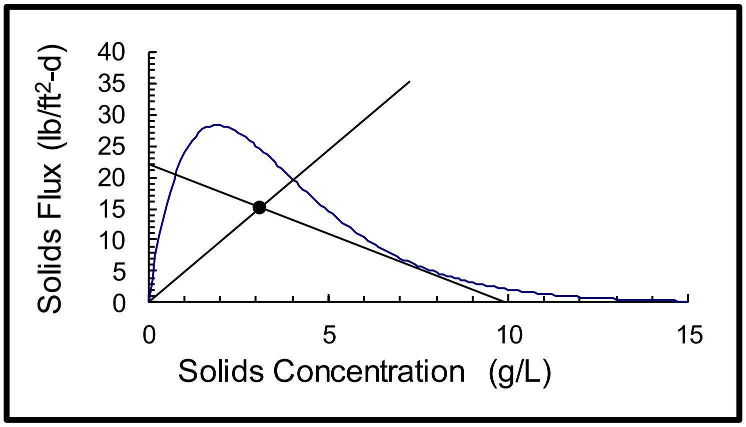


Figure D-15. Intermediate clarifier stress testing SPA analysis - Day 2:Period 2

Day 2 - Period 3

SVISN	145	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	2.700	g/L
Inf. flow	5.1	mgd
RAS flow	1.70	mgd
SOR	802	gal/ft^2-d
Theoretical SLR	24	lb/ft^2-d
Test SLR	16	lb/ft^2-d
% of Theoretical SLR	0.67	IC2 blanket rising
		IC4 blanket decreased after SLR = 22 lb/ft^2-d

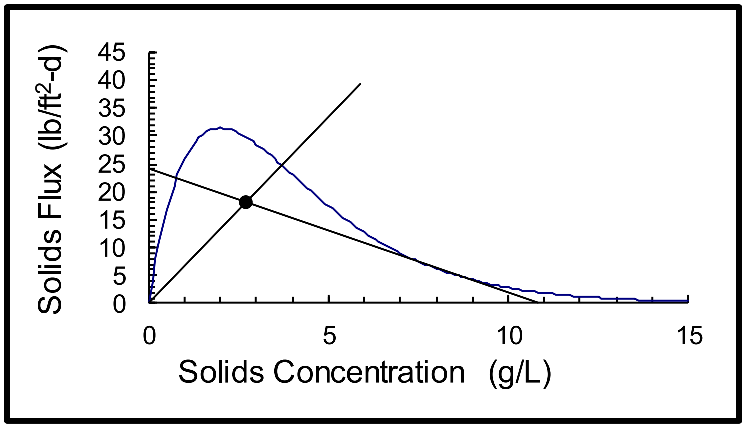


Figure D-16. Intermediate clarifier stress testing SPA analysis - Day 2:Period 3

Day 2 - Period 3

SVISN	180	mL/g
No. of clarifiers	1	
Area of each	6362	ft^2
MLSS	1.950	g/L
Inf. flow	6.4	mgd
RAS flow	1.70	mgd
SOR	1006	gal/ft^2-d
Theoretical SLR	21	lb/ft^2-d
Test SLR	13	lb/ft^2-d
% of Theoretical SLR	0.62	IC2 blanket rising

IC4 blanket decreased after SLR = 22 lb/ft^2-d

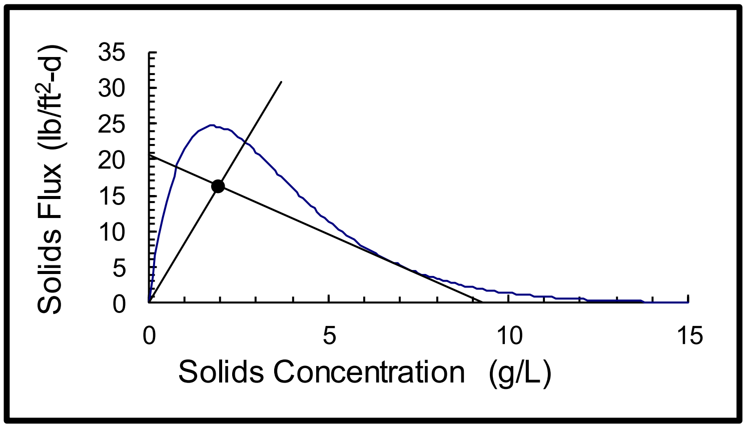


Figure D-17. Intermediate clarifier stress testing SPA analysis - Day 2:Period 4

Conclusions

Stress testing showed that IC2 and IC4 could sustain an SLR of roughly 65 and 70 percent of the SPA theoretical maximum allowable SLR, respectively. The maximum achievable SLR for IC1/2 may be lower than 65 percent at SORs greater than 1,000 gal/ft^2-d per rising blankets at this condition. On both days of testing, the clarifier SBD was the limiting factor.

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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