Successful Clarifier Rehabilitation: Using Computational Fluid Dynamics Modeling, Performance Specifications, and Compliance to Save Money

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The South Central Regional Wastewater Treatment and Disposal Board (Board), located in Delray Beach, comprises two secondary treatment trains called Plant A and Plant B, which provide the current permitted treatment capacity of 24 mgd annual average daily flow (AADF). Each plant is operated as an independent, complete-mix, activated sludge process, utilizing fine bubble diffused aeration and secondary clarification.

The Board is the first large publicly owned treatment works (POTW) in southeast Florida to provide reclaimed water quality to 100 percent of the effluent. Both Plants A and B are similar, and each is provided with three circular center-feed secondary clarifiers (SCs). The SCs are 105 ft in diameter and have 13.83 ft of side water depth. At the end of 2010, the internal mechanism and inset effluent launder of the Plant A SCs were deteriorated and in need of replacement. A particular feature of the existing clarifiers was a very large influent center well that was 52.5 ft in diameter. Retrofitting with a similarly large center well was costly, and the Board decided to explore additional options for modifications.

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Hazen and Sawyer and the Board designed a comprehensive rehabilitation plan that included: (A) Evaluation of historical data, computational fluid dynamics (CFD) and cost analysis modeling, to determine the most cost-effective clarifier modification; (B) Performance specifications as a means of verification of the proposed design, and to engage the manufacturers with a performance guarantee requirement; and (C) Performance testing after construction in order to verify the compliance with the contract documents. These steps are discussed.

Evaluation of Historical Data, Computational Fluid Dynamics, and Cost Analysis Modeling

The Board has a long history of compliance and achieving its treatment goals, and modifying the existing internal clarifier mechanism with a "like for like" mechanism would have been an easy but more costly solution. In order to define modifications that would not have detrimental impacts to the clarifier performance, while reducing the need for a bulky and expensive new center well, a CFD model of the existing clarifiers was calibrated and validated with actual stress testing data, then applied to propose modifications. The CFD model used in the analysis is known as 2Dc, which has the capability to evaluate internal modifications to the clarifier, while predicting variations in the effluent quality.

Clarifier field testing started on Sept. 8, 2009, with two secondary clarifiers (Clarifier 1 and Clarifier 3) in service (Clarifier 2 was out of service), and continued with two clarifiers in operation until Sept. 10, 2009, at 8:50 a.m., when Clarifier 3 was taken out of service. The stress testing with one clarifier in operation continued until approximately 6 p.m. on Sept 10. Figure 1 shows the secondary clarifier effluent total suspended solids (TSS) versus the surface overflow rate (SOR) for the field testing period; Figure 2 shows the sludge blanket depths. The average SORs with two clarifiers and one clarifier in operation were approximately 540 and 1,100 gpd/ft^2, respectively.

In general, the following observations could be obtained from the field testing:

- Clarifiers performed well during field testing at both average and peak flow conditions. Table 1 summarizes the average loading and performance data during the normal and stress testing conditions.
- Effluent TSS (ESS) was lower during stress testing compared to normal conditions, but mixed liquor suspended solids (MLSS) concentration was lower too.

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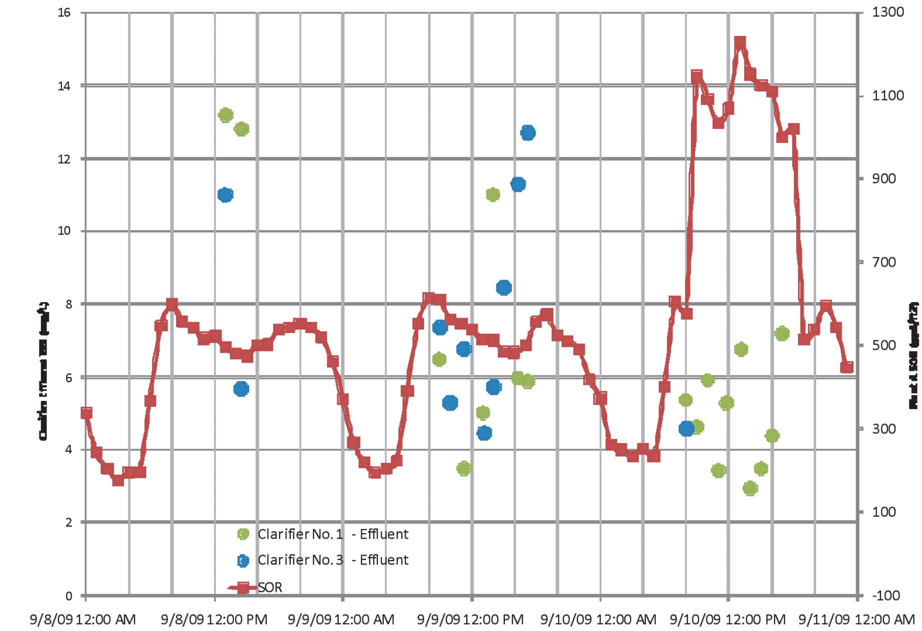

Figure 1. Effluent Total Suspended Solids During Field Testing Period and Clarifier Surface Overflow Rate

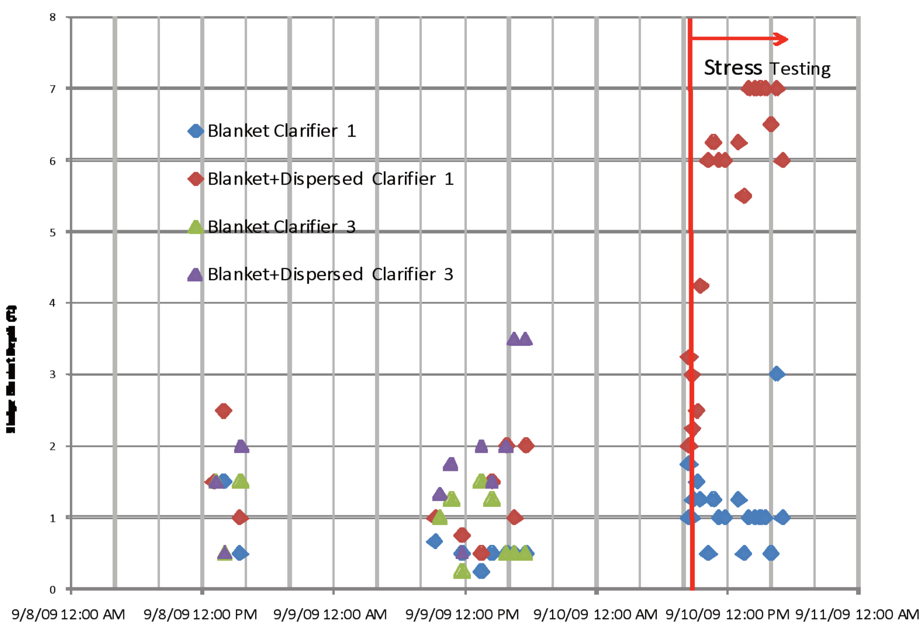

Figure 2. Secondary Clarifier Sludge Blanket Depth During Field Testing

Table 1. Loading and Performance Data During Field Testing – Averages

9/8/2009 & 9/9/2009 (8 am to 6 pm)				9/10/2009 (9 am to 6 pm)			
MLSS	**SOR**	**ESS**	**RAS TSS**	**MLSS**	**SOR**	**ESS**	**RAS TSS**
1,920	540	8	4,400	1,650	1,100	5	4440

Table 2. Summary of Observed and Predicted Results During Model Validation

Validation	9/9/2009 (8 a.m. to 6 p.m.)				9/10/2009 (9 a.m. to 6 p.m.)			
	MLSS	SOR	ESS	RAS TSS	MLSS	SOR	ESS	RAS TSS
Observed	1900	540	7	4450	1650	1100	5	4440
Predicted	1900	540	7	6155	1650	1100	6	5325

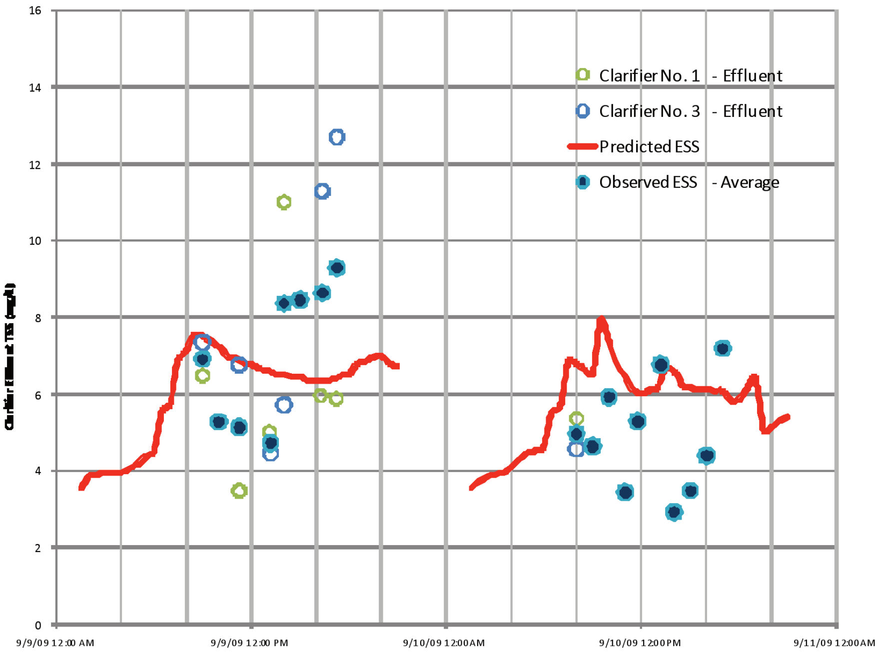

Figure 3. Observed and Predicted Effluent Total Suspended Solids During Model Calibration and Validation

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- Sludge blanket depth was low and well controlled during normal and stress testing conditions.
- Dispersed sludge zone was high during stress testing.

The CFD model was calibrated to match the field data observed during the average flow conditions obtained during days one and two (i.e., Sept. 8 and 9, 2009) and was validated running dynamic analyses for the observed time series on Sept. 9 and 10, 2009. Figure 3 shows the comparison between the observed and predicted effluent TSS (during Sept. 9 and 10, 2009) and Table 2 summarizes the observed and predicted average values during the validation of the model. As can be seen in Table 2 and Figure 3, observed and predicted values were in agreement.

The internal features that were evaluated included: the influent center well diameter and depth, the location of the effluent launder, the addition of internal baffles, the addition of energy dissipating inlets (EDIs), and modifications to the sludge withdrawal mechanisms. It was determined that the most cost-effective modification was to retrofit the SCs with a smaller center well, 30 ft in diameter, and increasing the end wall clearance of the inset effluent launder from approximately 2 ft to 10 ft. The itemized construction cost for the modification of the three clarifiers was approximately $1.3 million. Compared to retrofitting with a "like for like" mechanism, the proposed modifications resulted in improved performance and total savings of approximately $0.4 million. Figures 4 and 5 show the CFD modeling outputs for different sizes of the center well and for different locations of the effluent launder, respectively. Figure 6 shows pictures of the original and retrofitted effluent launder, and Figure 7 shows the original and retrofitted influent center well.

Performance Specifications

The performance of secondary clarifiers is a function of several variables, and writing a set of

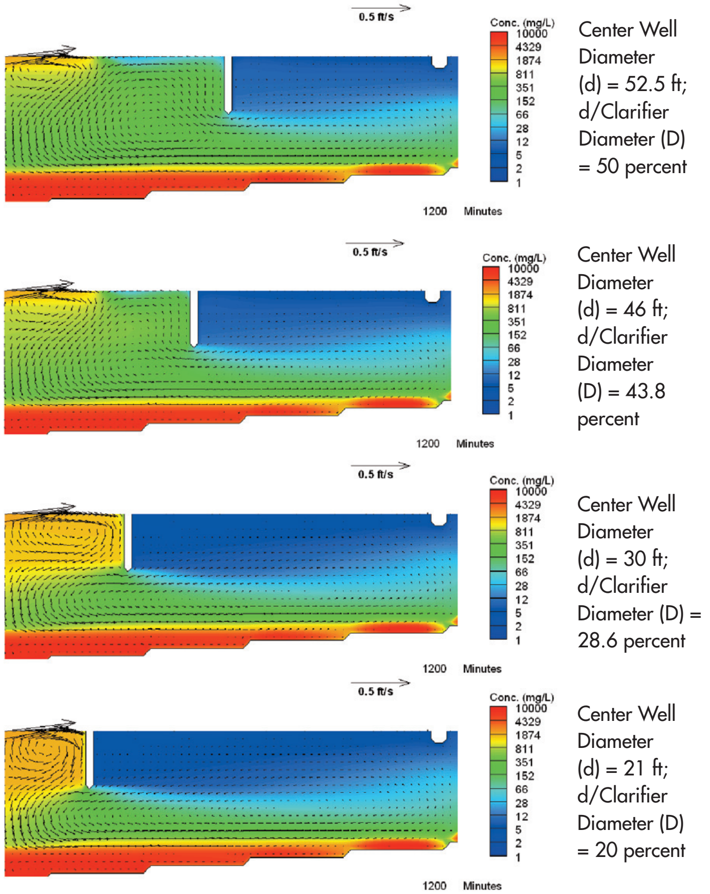

Figure 4. Board Computational Fluid Dynamics Modeling Results: Suspended Solids Contours and Velocity Vectors for Different Center Well Diameters, Average Surface Overflow Rate = 540 gpd/ft²

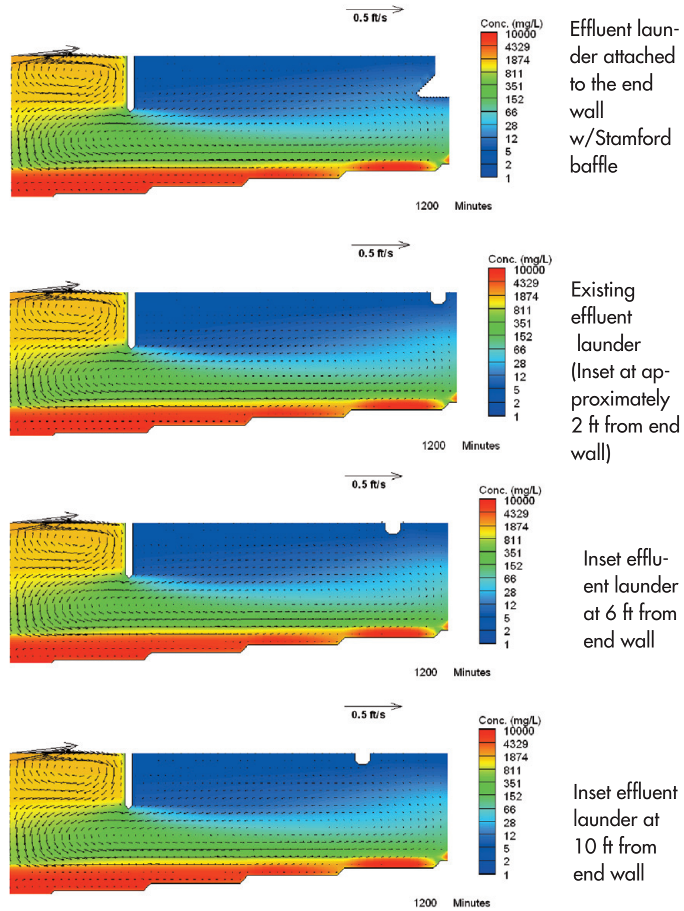

Figure 5. Board Computational Fluid Dynamics Modeling Results: Suspended Solids Contours and Velocity Vectors for Different Locations of the Effluent Launder, Average Surface Overflow Rate = 540 gpd/ft²

performance specifications is particularly challenging. It is critical to include in the description certain ranges for the most important variables so that the manufacturers are compelled to participate in the bid without increasing their cost. In other words, it is important to define a set of realistic expectations. As shown in Table 3, for the Board's secondary clarifiers, maximum effluent TSS and return activated sludge (RAS) total solids (TS) concentrations were defined as performance requirements for different flow conditions. For each compliance scenario, a set of maximum values or ranges were defined for some key parameters. These parameters are also presented in Table 3. The values for the performance requirements and associated compliance parameters were defined, taking into account the historical data, the CFD modeling results, and the permit requirements. The manufacturers were provided with the proposed dimensions and given the option to propose an alternative design should the SCs not meet the performance requirements. All the bidding manufactures agreed with the proposed modifications.

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Figure 6. Original (left) and Retrofitted (right) Effluent Launder

Figure 7. Original (left) and Retrofitted (right) Influent Center Well

Table 3. Secondary Clarifiers Design Criteria and Performance Requirements

Parameter	Average Day	Maximum Day
Max Flow, mgd	4.0	5.8
Max RAS flow, mgd	4.0	4.0
Max MLSS, mg/L	2500	2500
SVI, mL/g	100 - 200	100 – 200
Max Surface Overflow Rate, gpd/SF	470	670
Max Solids Loading Rate, lbs/d/SF	19.3	23.6
Max Sludge Blanket Depth (ft)[(2)]	4.0	6.0
Max Weir Loading Rate, gpd/ft	6700	14100
Required Performance at Design Flow Condition		
Max Effluent TSS, mg/L	20	30
RAS Concentration, percent	0.3 - 1.2	0.3 - 1.2

Table 4. Secondary Clarifier No. 2 Performance Testing – Comparison with Secondary Clarifier No. 3

Parameter	New SC No. 2	Existing SC No. 3
Avg. Day Flow (mgd)	3.5	
SOR (gpd/sf)	402	
MLSS (mg/L)	1,850	
Sludge Volume Index (SVI) (mL/g)	100	
Blanket Level (ft)	1.75	1.25
Avg. RAS (mg/L)	4,450	5,120
Effluent TSS (mg/L)	1.5	3.2

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Performance Testing Results

The technical specifications included a testing protocol so compliance and success could be measured. Following rehabilitation with the new mechanism and effluent launder, Plant A, SC No. 2, was performance tested in July 2011 and compared to the performance of SC No. 3, which was operated with the original mechanism. Tests were conducted at annual average, maximum day, and peak hourly flow conditions. The field data indicated that newly rehabilitated SC No. 2 was in compliance with the contract documents, but also that it outperformed existing SC No. 3. Comparison testing data are presented in Table 4.

The SC No. 1 was performance tested in October 2011, and the test demonstrated that it was functioning as designed and in accordance with the specifications. The SC No. 3 was scheduled to be performance tested in March 2012, but emergency conditions with poor sludge settleability and high flows required that this clarifier be placed in service before the testing. The three retrofitted clarifiers performed well during this emergency condition. Based on this experience, and the successful performance test results for identical SCs No. 1 and No. 2, the owner and engineer decided to waive the performance testing for SC No. 3.