Improving Performance of Large Rectangular Secondary Clarifiers

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Abstract: Several modifications with different construction costs were proposed to enhance the performance in the large rectangular secondary clarifiers. A 3-Dimensional fully mass conservative clarifier model, based on modern computational fluid dynamics theory, was applied to evaluate proposed tank modifications and to estimate the maximum capacity of the existing and modified clarifiers. The comparison of model predicted results with the field data collected in tanks before and after modifications shows very good agreement.
Keywords: Clarifier, Numerical Model, Sedimentation, Sludge, Wastewater, Solids

1. Introduction

Albertson (1995) used field data collected during the last 5 years to analyze the tank behavior and to enhance the performance of the secondary clarifiers at the Passaic Valley Sewerage Commission Wastewater Treatment Plant (PVSC) in Newark. Also, an extensive dye test was completed by Crosby in 1988. Several tank modifications including flocculation baffle, energy dissipation baffles, perforated baffles and relocated effluent launders, were recommend based on their field investigation. However, it is not impossible that some tank configuration changes may give no substantial effect (or even adverse impact) on tank performance. The engineers were wondering if the undesirable tank performance could be exaggerated under certain operational conditions.

In this study, a recently developed 3-dimensional clarifier model was applied to evaluate the proposed design modifications of the PVSC secondary clarifiers. The model contains a set of conservation equations for momentum and solids transport. The double exponential formula (Takacs et al. 1991) is applied to determine the settling velocity. The constant K1 is determined by using the Daigger formula (1993). The eddy viscosity is determined by k-ε turbulence model. The model can accurately calculate the mass draw-off from RAS flow and sludge inventory in the tank due to the fully mass conservative feature of the model.

2. Configuration of Existing PVSC Secondary Clarifier and Test Loading

There are 12 large rectangular clarifiers at the PVSC Wastewater Treatment Plant. The length of clarifier = 360 ft (110 m); the tank width = 120 ft (36.6 m) and the depth of the tank = 13.5 ft (4.12 m). The surface area of each tank = 43200 ft2 (4026 m2). The clarifiers are divided into three sequential square bays defined as A, B and C. The bays are separated by an 18-inch knee wall and have sloped concrete fillets in all four corners of each bay. The tank influent flow is introduced across the in front wall at A bay through ten inlet slots. A center-mounted circular sludge removal mechanism with corner sweeps, which is often called as a rapid withdrawal facility, is used in each bay. The RAS withdrawal facility has two structural arms with five 8-inch sludge tubes per arm. According to the field data from 1988 to 1995, the rotation speed of the rake arm is in range of 1/30 to 1/60 r.p.m. The hydraulic loading, influent MLSS, RAS flow rate and settling characteristics are given in Table 1 for the stress tests.

3. Proposed Tank Modifications

The proposed modifications include: energy dissipation baffles, a flocculation zone, perforated and non-perforated baffles, modifications to the launders and modifications of sludge withdrawal facility. In the original project, total 11 of proposed modifications and combinations of them were tested. The following major modifications adopted in final tank construction are presented as:

- **Modification 1** Inlet flocculation baffle, the distance from tank influent to the baffle = 6.6 m (21.6 ft) and the baffle depth = 2.4 m (the space under the baffle lip = 41% of the flow cross section area);
- **Modification 2** A perforated baffle between bay A and B with slot space of 52% of flow cross section area;
- **Modification 3** A perforated baffle between bay B and C with slot space of 65% of flow cross section area;
- **Modification 4** A conventional baffle between bay A and B with baffle depth of 1.73 m

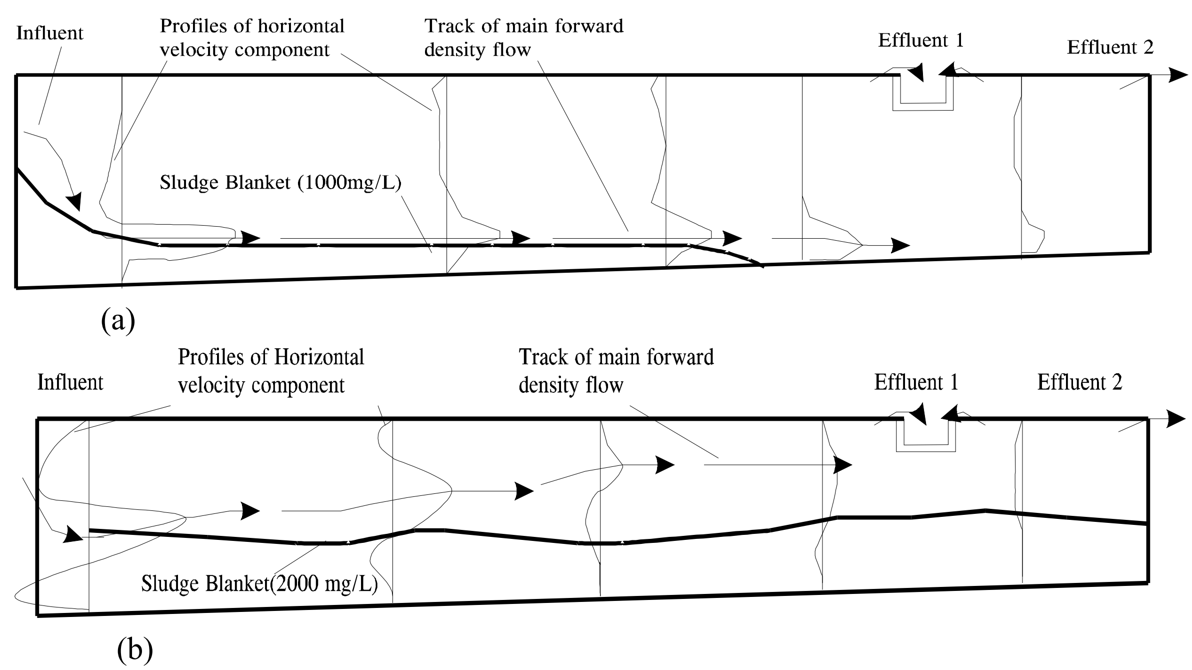


Fig. 1 Field measurement of velocity fields and Sludge blanket level in secondary clarifier at Treatment Plant Altenrhein (Bretscher et al 1992)

below the surface (the space under the baffle lip = 58% of the flow cross section area).

- **Modification 5** A conventional baffle between bay B and C with baffle depth of 1.39 m below the surface (the space under the baffle lip = 66% of the flow cross section area).
- **Modification 6** Removing existing surrounding effluent launders and adding 4 new launders in the bay C. All effluent launders are aligned with the tank longitudinal direction. The launders extend from the end wall to the perforated baffle between B and C. The total length of launders = 960 ft [8x120] which is 33.3% longer than that of the existing launders.

4. Simulations of Existing Tank and Model Verification

Figures 1(a) and 1(b) show the measurement of flow pattern and sludge blanket in a prototype rectangular tank (Bretscher et al 1992). In Fig. 1(a), the flow pattern consists of a surface reverse flow and the bottom density current in the tank with a normal sludge blanket. The distinct bottom density current and a well-developed re-circulation pattern was first observed in 1946 by Anderson and described later by many other researchers, based on their own field observations [see Parker, (1983) Chapman (1983) and Wahlberg et al (1993)]. In Fig. 1(b), the upward buoyant flow occurs in the tank with deep sludge blanket and a short circuiting flow appears near the water surface. The completely different paths of the main forward density flow in Fig. 1(a) and (b) indicate that the flow regime is strongly affected by the sludge blanket in the tank.

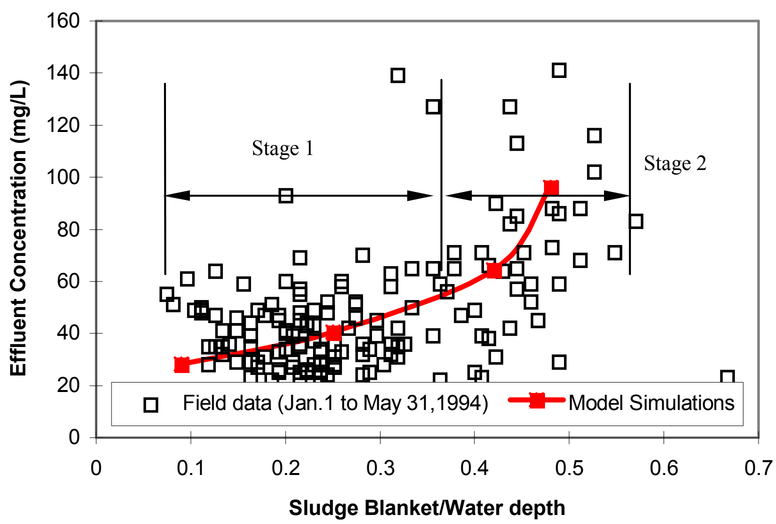
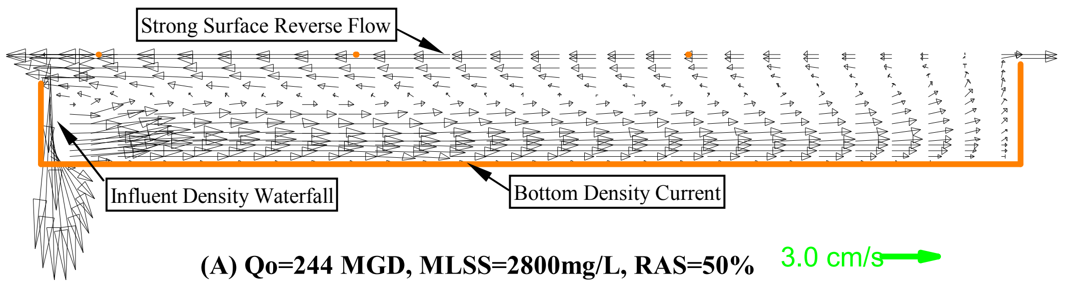
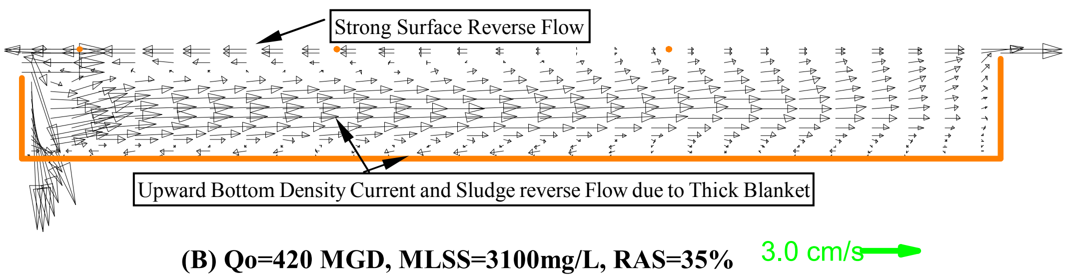


Fig. 2 Hydraulics Behavior in Existing Tank

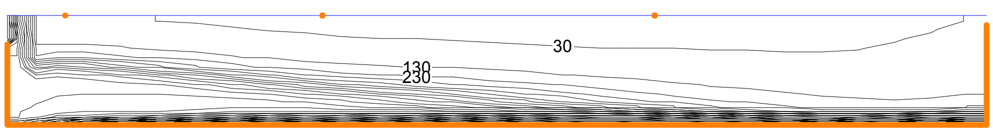
The relationship between effluent concentration and sludge blanket in the PVSC tanks is presented in Figure 2. Both model predictions and field data in Fig. 2 show that the hydraulic behavior in the existing tank can be divided into two stages. At stage 1 while the sludge blanket level is below 40% of the water depth, the slow increase in effluent concentration with an increase sludge blanket indicates that the tank performance is primarily controlled by tank hydraulic efficiency. At stage 2 the sludge blanket is in range of 45% to 65% of the water depth. The steep trend of the profile suggests that the tank performance be controlled by sludge blanket.



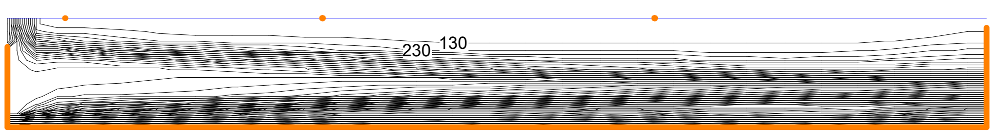
(A) Qo=244 MGD, MLSS=2800mg/L, RAS=50%



(B) Qo=420 MGD, MLSS=3100mg/L, RAS=35%



(C) Qo=244 MGD, MLSS=2800mg/L, RAS=50%



(D) Qo=420 MGD, MLSS=3100mg/L, RAS=35%

Figure 3 Flow Pattern and Sludge Blanket (in a vertical section along tank central axis) in Existing Tank

For the cases with Qo=224 and 420 MGD in the PVSC tank, Figures 3(a) to (d) present the simulated flow and solids fields in a vertical section (along the central axis). In the existing secondary settling tank, which was equipped by 3 rotating sludge rake arms and a surrounding effluent launder system in the end bay, the predicted hydraulic regime typically consists of the influent density waterfall, a bottom density current and a strong surface reverse flow due to the absence of proper baffling. For the case of a thick sludge blanket, the simulation shows that the bottom density current deflects upward. The predicted results are consistent with the field data of Bretscher et. al. (1992).

The top view of solids fields is presented in Figures 4(a) and 4(b) for two different loading conditions. The results demonstrate the effect of the existing effluent draw-off system on the effluent quality. The tank effluent with the highest solids concentration occurs at the two downstream corners of bay C where the upward current, which is focused from both directions is much stronger than elsewhere. This interesting phenomenon also was observed by the clarifier operator at PVSC and they describe is as "*Sludge blows out*".

Two major issues in the PVSC clarifier modifications, based on the simulations of the existing tank, are to improve the hydraulic performance and removal efficiency; and to control sludge blanket.

5. Behavior of Tanks with Modifications

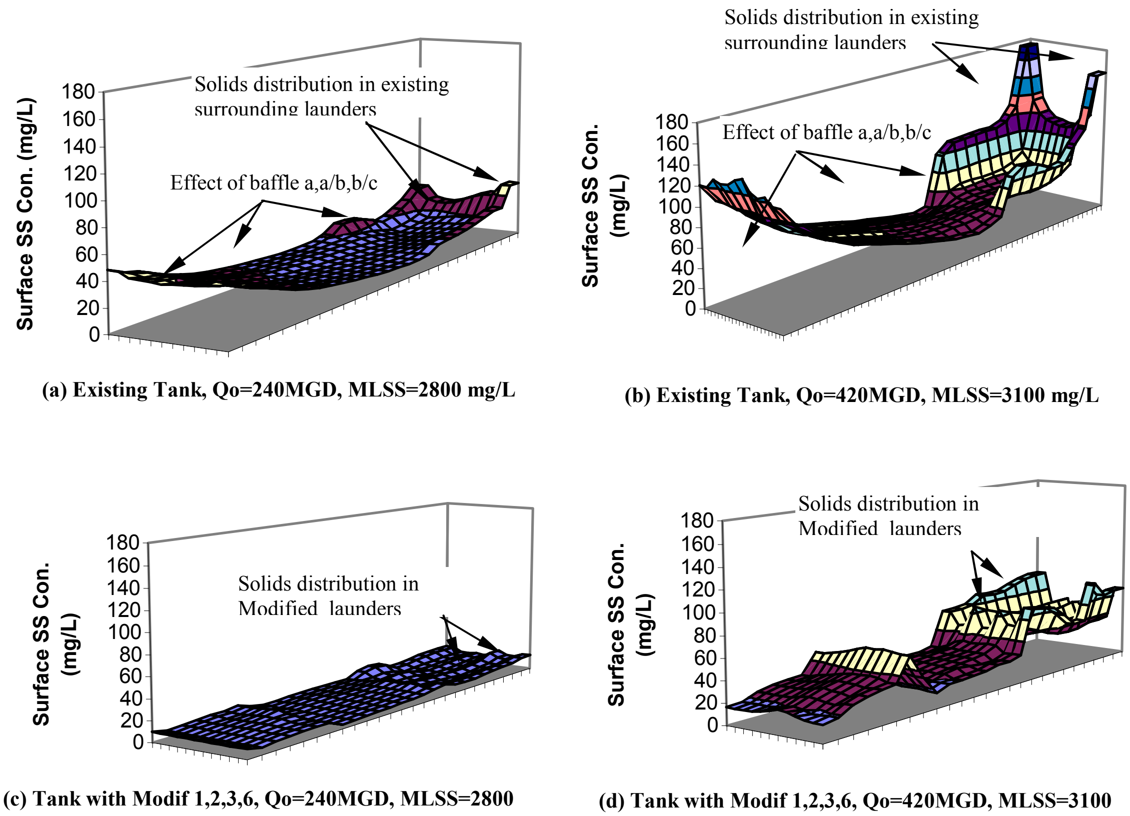
The relationship between the effluent concentration and the hydraulic loading is summarised in Table 1 for the existing tank and tanks with three different modification combinations. The predicted effluent concentration in Table 1 indicates that the average effluent concentration can be significantly reduced by improving the tank hydraulic efficiency.

The predicted flow and solids fields in the PVSC tank with modification 1,2,3 and 6 are presented in Figures 5(a) to (d) for the cases with the average (244 MGD, 2800 mg/L) and peak solids loading (420 MGD, 3100 mg/L). The flow pattern shows that influent density waterfall and surface reverse flow were significantly reduced by the 3 baffles. The flocculation baffle eliminates most of the entrainment flow from the surface clear water layers into the influent density flow thus, both the surface return flow along the entire tank surface and the bottom density current are substantially reduced [see Figs 2(a) and 5(a)].

The distribution of the sludge blanket among the 3 Bays has been significantly changed by using two perforated baffles [see Figs. 3(c) and 5(c)]. In the flocculation zone relatively minor solids compression takes place in the local sludge blanket. The highest sludge blanket occurs in Bay A due to the high resistance of the perforated baffle A/B. The lowest sludge blanket appears in Bay C. The difference of the sludge blanket level between Bay B and C is relatively small due to the lower resistance of perforated baffle B/C. The predicted flow pattern and solids field in Figures 5(a) and 5(c) show that solids,

Table 1 Summary of Loading and Effluent Concentration in Tank Stress Tests

	Hydraulic Loading Qo = 244 MGD (11 tanks in operation) Influent MLSS = 2800 mg/L RAS flow = 50% of Qo	Hydraulic Loading Qo = 314 MGD (11 tanks in operation) Influent MLSS = 2800 mg/L RAS flow = 46% of Qo	Hydraulic Loading Qo = 420 MGD (11 tanks in operation) Influent MLSS = 2800 mg/L RAS flow = 35% of Qo	Hydraulic Loading Qo = 420 MGD (11 tanks in operation) Influent MLSS = 3100 mg/L RAS flow = 35% of Qo
	Predicted Average Effluent Concentration (mg)			
Existing Tank	**28.3**	**40.5**	**64.5**	**95.6**
Modification 1, 2, 3	**13.4**	**18.5**	**33.8**	**79.6**
Modification 1,4,5	**13.8**	**18.2**	**37.0**	**160.7**
Modification 1, 2, 3, 6	**10.7**	**15.1**	**27.1**	**60.0**
For SSVI = 85 which gives SVI= 118.6 [SSVI = SVI/(1+SVI/300)]				



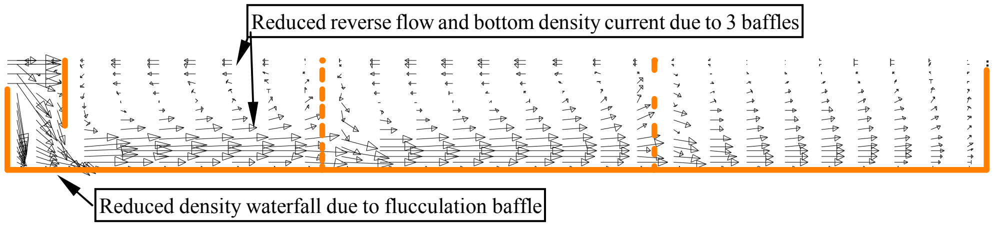
(a) Existing Tank, Qo=240MGD, MLSS=2800 mg/L

(b) Existing Tank, Qo=420MGD, MLSS=3100 mg/L

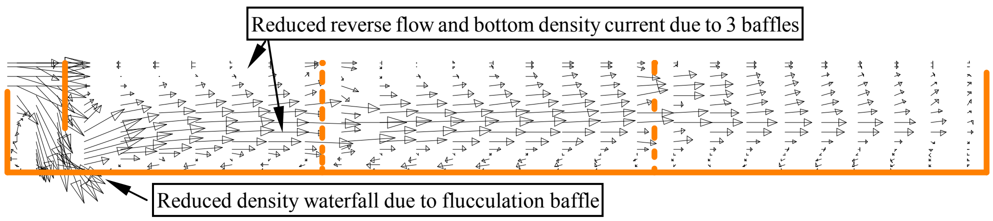
(c) Tank with Modif 1,2,3,6, Qo=240MGD, MLSS=2800

(d) Tank with Modif 1,2,3,6, Qo=420MGD, MLSS=3100

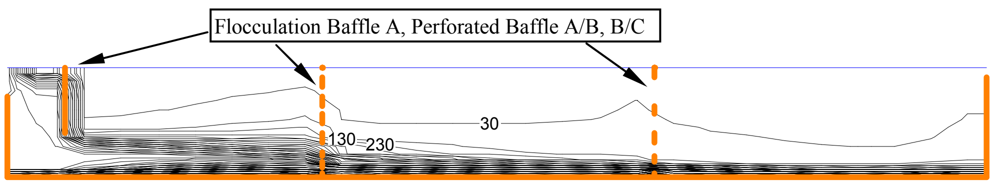
Figure 4 Comparison of Solids Distributions on Surface Layer Between Existing and Modified Tank (Modification 1,2,3,6)



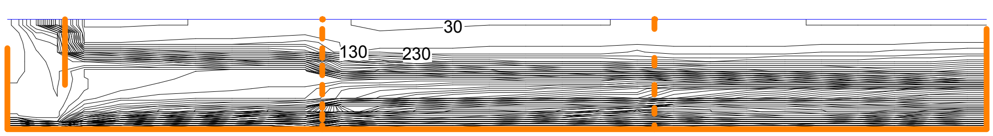
(A) Qo=244 MGD, MLSS=2800mg/L, RAS=50%



(B) Qo=420 MGD, MLSS=3100mg/L, RAS=35%



(C) Qo=244 MGD, MLSS=2800mg/L, RAS=50%



(D) Qo=420 MGD, MLSS=3100mg/L, RAS=35%

Figure 5 Flow Pattern and Sludge Blanket (in a vertical section along tank central axis) in Tank with Modification 1,2,3,4

at concentrations in range of 1000 to 2500 mg/L, spill gently over the baffle slots, at a lower velocity and potential energy head then that in the upstream Bays. Because of the kinetic energy dissipation in the bottom density current due to the perforated baffles, greater solids compression occurs in Bay B and C. The solids distributions on the surface layer in the tank with modification 1,2,3,6 are presented in Figs 4(c) and 4(d). The simulated solids distributions indicate that the relocated effluent launders can avoid the sludge blowing out at the two downstream corners. Extending launder length more evenly distributes the effluent flow.

The model results in Table 1 show that the greatest effectiveness in reducing the effluent solids using baffles alone was obtained when the tank is operated in stage 1 (the sludge blanket was lower than 40% of the water depth). For stage 2 operation since the effluent concentration was primarily controlled by the sludge blanket, the baffle's efficiency was dramatically reduced. For most cases the effluent concentration in the tanks with modifications 1,2,3 and 6 can be reduced to less than half of that in the current tank for the same loading. The results in the tanks with combinations to flocculation baffle and various inter-bay baffles are also included in Table 1. The performance of the tanks with the intermediate baffles was sensitive to the sludge blanket stage. Exceptionally good improvement in the tank performance was predicted for both solid (conventional) and perforated baffles for Stage 1 or low sludge blanket operation; for Stage 1, both perforated and solid baffles gave about 50% reduction in ESS. However, under high solids loading, i.e., Stage 2 or high blanket operation, the baffles became less effective and produced a short circuiting that in some cases degraded the effluent SS. The perforated baffle appeared to marginally better than conventional baffle in Stage 1 and significantly better in Stage 2 since the perforated baffles keep more sludge at upstream of the tank and significantly relieves the burden of the bottle neck B/C for passing through flow.

6. Cost Effectiveness Analysis

Besides the evaluation of impact of modifications on the clarifier performance, the clarifier model also help us to implement cost-effective clarifier modifications in this project. The model prediction shows that an optimized baffle design (Modif. 1,2,3), which needs about one million dollars construction cost for each tank, can give more than 80% improvement of effluent quality. A package with both baffle and effluent launder modifications (Modif. 1,2,3 and 6) offers about 20% more improvement than that of the baffle modifications. However, the construction costs were about two million dollars for each tank due to necessity of large amount steel in the new launder supporting structure. The baffle modifications show the dominate improvement of tank hydraulics behavior, especially in tanks running with normal sludge blanket level.

7. Modeling Verifications with Data Collected After Modifications

The construction work was finished by the end of 1996 in the two testing tanks (No.1 and No 3). In No.1 testing tank, both launder and baffle modification (Modif. 1,2,3,6) are

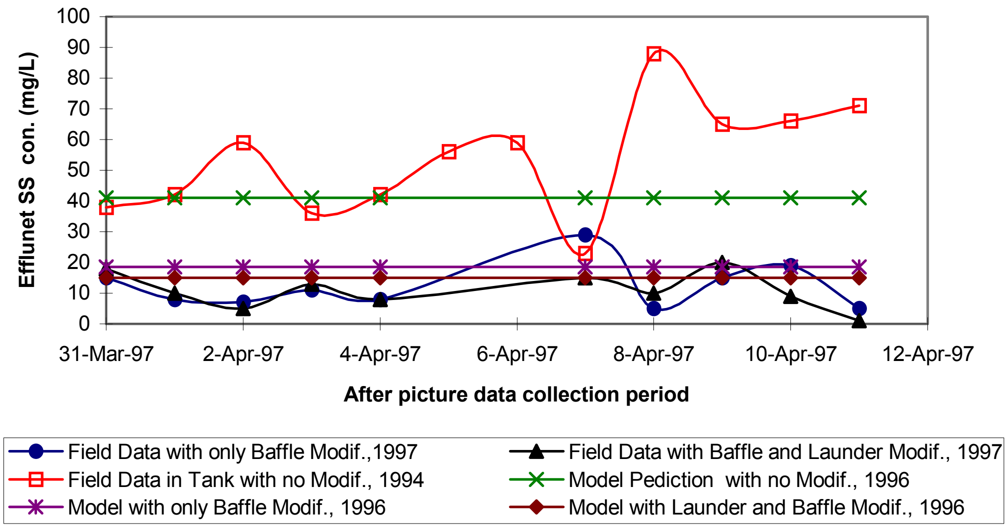


Figure 6 Effluent SS Profiles During March and April in 1994 and 1997

adopted by PVSC. The baffle modification (Modif. 1,2,3) was tested in Tank No. 3. Both inter-bay baffles (A/B and B/C) are constructed as convertible from perforated to conventional solid baffle. The field data of effluent SS concentration was collected in the both modified tanks during the period from March to April, in 1997. Figure 6 presents three daily effluent concentration profiles, which include the field data in existing tank, in 1994 and data in No. 1 and 3 testing tank in 1997, and model predicted results. The average values of effluent concentration and percentage of improvement are presented in Table 2. The clarifier operation conditions in the both data collection periods (March-April, 1994 and March-April, 1997) are very close as shown in Table 2. The comparison of model predictions with the subsequent field data indicates that among the major

Table 2 Predicted Effluent Quality and Field Data Before and After Pictures

	Operation Conditions		Effluent TSS (mg/L) and Improvement		
	Ave. MLSS (mg/L)	**Ave. Flow (mgd)**	**No Modifications**	**Baffle Modification**	**Baffle & Launder Modifications**
Field Data March~April, 94	2600	41.6	54.0	N/A	N/A
Model Predictions Jan. 1996	2800	41.7	41.0	18.5 (+54.9%)	15.1 (+63.2%)
Field Data March~April, 97	2407~2408	46.2~46.5	N/A	11.0 (+79.6%)	12.0 (+77.8%)
All field data used in this Table was offered by Hazen and Sawyer and Passaic Valley Sewerage Commission Wastewater Treatment Plant (S. Lipke, M. DeNicola and P. Sauer, in 1995 and 1997). Model Predictions was accomplished by Reid Crowther (S. Zhou and Z. Vitasovic, in period of 1995 to 1996)					

modeling results the two crucial points related to the impact of proposed modifications on the tank performance were precisely captured by the model simulations submitted one and half years ago. They are:

◊ the optimized baffle and launder modifications can reduce the effluent concentration; by more than 60%; and
◊ baffle modifications dominate the positive effect on the tank performance in tank with a normal sludge blanket.

8. Conclusions

The 3-D fully mass conservative clarifier model is applied to predict the tank performance in the existing clarifiers and the clarifiers with proposed modifications at the PVSC Wastewater Treatment Plant. The existing PVSC clarifiers suffered from the relatively poor hydraulic performance which typically occurs in a large tank without proper baffling. The unfavorable hydraulic regime includes strong turbulence, a high influent potential energy and a strong density current due to excessive flow entrainment. The baffle modifications can considerably reduce the strength of the density flow and increase the solids detention time in the tank; the effluent quality can be improved by more than 60% for any cases with a sludge blanket $\leq$40% of water depth. The effect of the baffles on the tank performance tends to be counter productive when the sludge blanket is deeper than about 60% of the water depth. Proper launder modifications can be used to improve local flow pattern near the effluent weir and to re-distribute the effluent flow along the tank longitudinal direction.

The fairly good agreement between model predictions and field data before and after pictures indicates that the present modeling has achieve a status that it can be used by design engineers to optimize the design of new clarifiers and to diagnose the performance of existing clarifiers.

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