Full-Scale Nutrient Reduction Pilot—Important First Step to Comply with Florida's 2008 Ocean Outfalls Elimination Rule

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The North Regional Wastewater Treatment Plant in Broward County is one of six publicly owned treatment works (POTWs) in Southeast Florida discharging secondary treated effluent through open outfalls into the Atlantic Ocean. Debate among regulatory agencies, environmental groups, utilities, and the public at large started in the mid-1980s with concerns about the receiving environment.

For the past 20 years compliance had focused on appropriate effluent limits, but on July 1, 2008, the state of Florida introduced a new dimension into this debate by placing into effect new rules requiring elimination of open-ocean outfalls as primary effluent management methods by 2025.

Between 2008 and 2025, the POTWs are required to implement advanced wastewater treatment and/or management practices that will reduce nutrient mass loadings to the ocean. The rules require upgrading these POTWs to comply with effluent total suspended solids (TSS), five-day biochemical oxygen demand (BOD_5), total nitrogen (TN) and total phosphorus (TP) limits of 5, 5, 3, and 1 milligrams per liter (mg/L), respectively by 2018 or implementation of alternative treatment and management practices resulting in an equivalent mass loading reduction.

POTWs could avoid building costly advanced treatment facilities by implementing nutrient reduction strategies starting in 2009, which would result in an equivalent cumulative mass loading between 2009 and 2025. The average effluent TN and TP from the North Regional Treatment Plant for the period of record between April 2003 and December 2007 are approximately 23 mg/L and 1.5 mg/L, respectively.

The 100-million-gallons-per-day (mgd) annual average daily flow (AADF) North Regional Plant currently is permitted to discharge up to 66 mgd AADF to its ocean outfall. Effluent flow that is not discharged to the outfall is pumped to six deep injection wells.

Secondary treatment takes place in five 20-mgd AADF activated sludge modules operating in parallel (Modules A through E). Two of the treatment modules are equipped with fine-bubble diffusers and three are operating with the original surface aerators. The plant currently is required to provide carbonaceous removal to comply with effluent TSS and five-day carbonaceous BOD ($CBOD_5$) of 30 and 25 mg/L, respectively, only on a monthly average basis to discharge to the open-ocean outfall. A schematic layout of the plant is shown in Figure 1.

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Module C BNR Pilot Program

In anticipation of the required nutrient reduction, Broward County undertook a demonstration program to evaluate the ability of the North Regional Plant to operate in a nitrification/denitrification mode. The goal of the program was to assess cost-effective process modifications that would achieve the necessary reduction in nutrient loadings.

The pilot program consisted of a full-scale study in one of the 20-mgd AADF fine-bubble aeration modules (Module C), which consists of four parallel basins composed of three stages each. The stages are not isolated from each other physically, but each has its own bank of fine-bubble diffusers.

The process modifications included operating the first stage of two of the basins with the diffusers off in order to create anoxic con-

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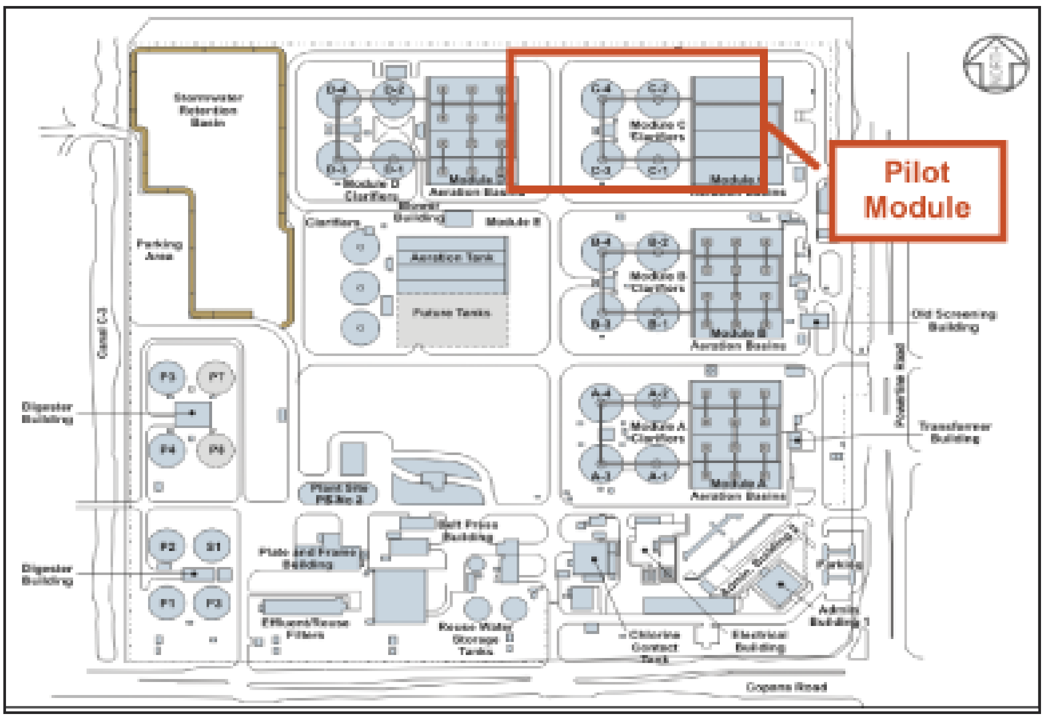


Figure 1: Broward County North Regional Wastewater Treatment Plant Site Plan

Figure 2: Influent and Effluent TN Obtained during the Pilot Program

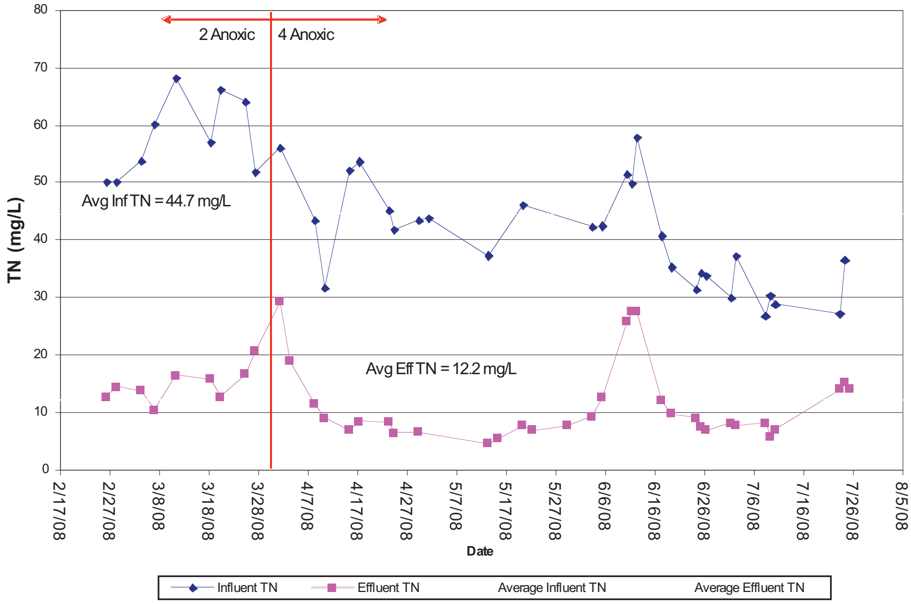
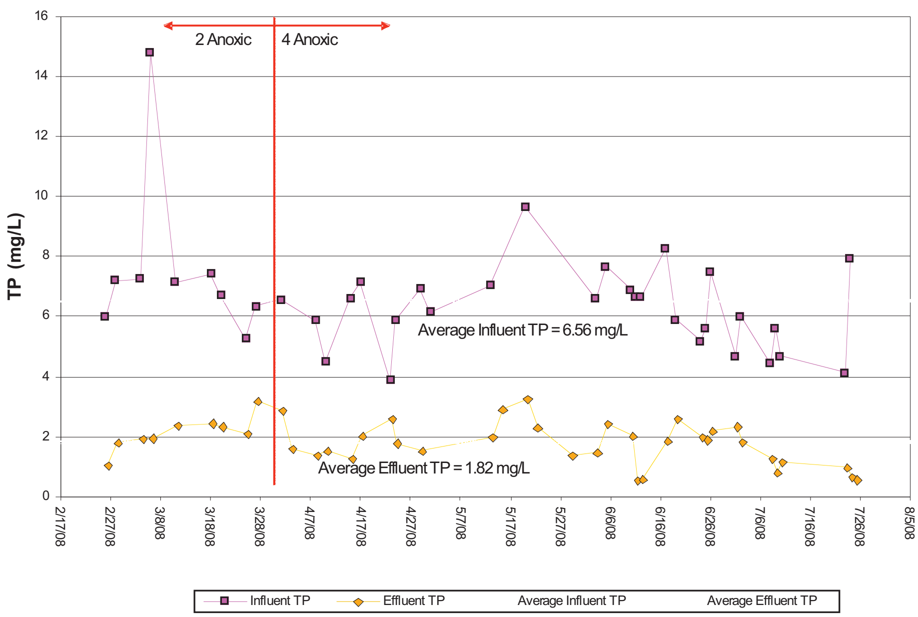


Figure 3: Influent and Effluent TP Obtained during the Pilot Program



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ditions. The anoxic zone that was created consumed one third of the basin volume. Once it was demonstrated that the two basins were achieving nitrification/denitrification, the two remaining basins had their Stage 1 diffusers turned off to create an anoxic zone at the front.

Air was pulsed periodically to the first stage to keep the mixed liquor suspended solids (MLSS) in suspension. Return activated sludge (RAS) flows were supposed to be maximized to approximately 20 mgd during the course of the pilot study, but limitations in the system kept the maximum RAS flow to approximately 8.4 mgd.

Pilot testing started in February 2008 and continued for six months until July 2008. During the first testing phase when Module C had two anoxic trains, target flows were kept at 15 mgd. When all the basins were switched to have anoxic zones, the 15-mgd target flow rate was maintained for six weeks.

Significant nitrification was achieved during both test phases when aerobic solids retention time (SRT) values of four to six days were maintained. After testing at a target flow of 15 mgd, the flows were increased gradually to test the nutrient removal process during stressed conditions (the influent flow to Module C is shown in Figure 4).

Pilot study results showed that effluent TN could be reduced from a daily average of 45 mg/L to a daily average of 10 to 12 mg/L, with better results obtained during the operation of four anoxic stages. Average effluent TN with two anoxic stages was 14 mg/L, while the effluent TN improved to around 11 mg/L with the operation of four anoxic stages. Average effluent TP was approximately 2.0 mg/L during both operational modes.

Figures 2 and 3 show the influent and effluent TN and TP obtained during the course of the pilot program, respectively. The period between the two-anoxic-zone test phase and the four-anoxic-zone test phase is noted on each figure.

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Table 1. Module C Average Nitrogen Removal with Two Anoxic Zones

	Two Anoxic Zones		
Parameter	**Influent (mg/L)**	**Effluent (mg/L)**	**Removal (%)**
TKN	57.8	4.0	93.1
TN	57.9	14.3	75.3
Ammonia	26.2	1.4	
Nitrite	0.0	1.4	
Nitrate	0.0	8.8	
TP	7.6	2.1	72.0%

Period of Record = 2/19/08 – 3/31/08, Average Flow = 13.9 mgd

Table 2. Module C Average Nitrogen Removal with Four Anoxic Zones

	Four Anoxic Zones		
Parameter	**Influent (mg/L)**	**Effluent (mg/L)**	**Removal (%)**
TKN	40.4	8.3	79.6
TN	40.5	11.2	72.5
Ammonia	27.2	4.3	
Nitrite	0.0	0.3	
Nitrate	0.0	3.0	
TP	6.2	1.7	72.3%

Period of Record = 4/1/08 – 7/25/08, Average Flow = 17.4 mgd

Figure 4: Module C Influent Flows, Aerobic SRT, and Effluent Ammonia during BNR Operation

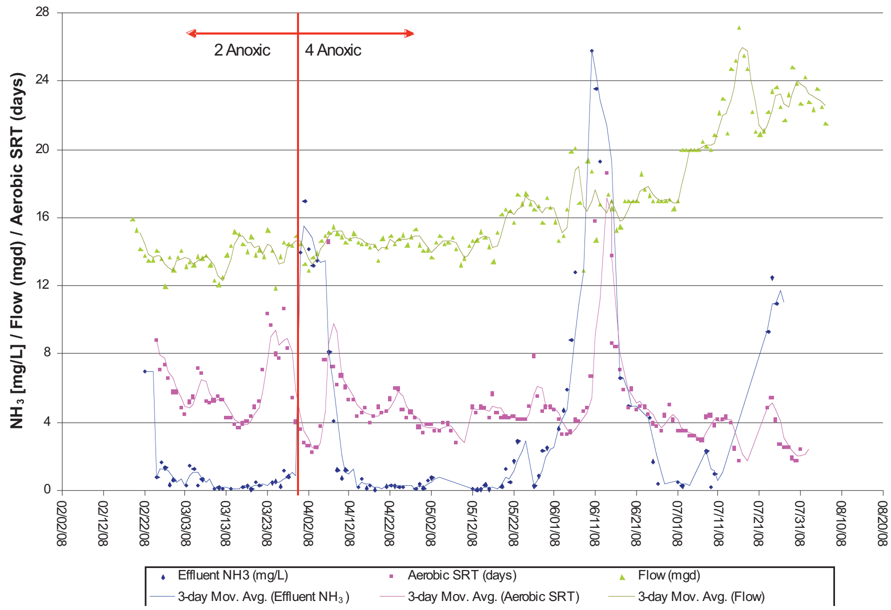

Figure 5: Module C MLSSs during BNR Operation

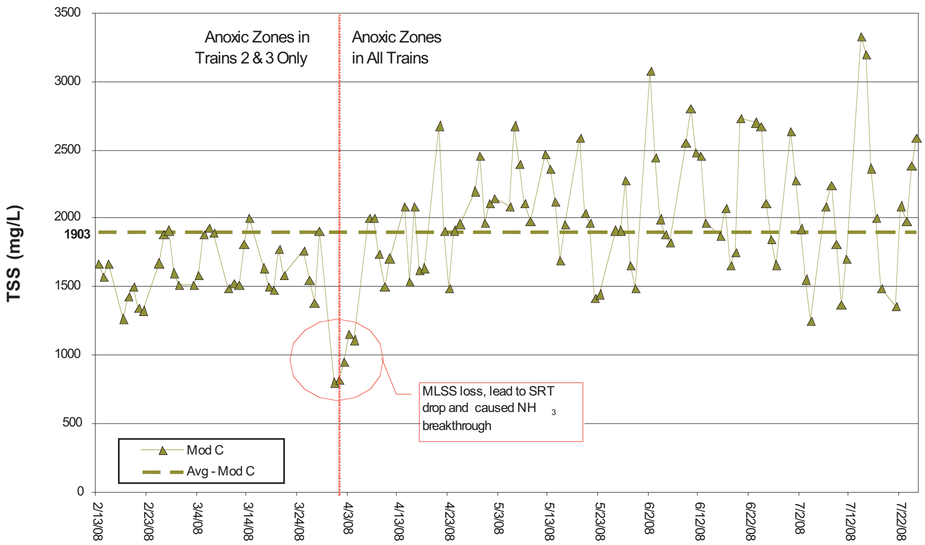

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Table 1 summarizes the influent and effluent TN and TP and their removal percentages obtained during the two-anoxic-zone test phase of the pilot study. Table 2 shows these same parameters from the four-anoxic-zone test phase. The four-anoxic-zone testing phase includes periods of higher flows.

During this study, there were two instances in which the SRT dropped close to or below two days, which resulted in ammonia breakthrough. Figure 4 shows the influent flows to Module C, along with the aerobic SRT and effluent ammonia levels over the course of the pilot study.

The first breakthrough shows a significant drop in aerobic SRT in conjunction with a steep rise in ammonia, which was brought on by a steep drop in the module's MLSS concentration (see Figure 5). The second event, which occurred during the high-flow testing, does not show as significant a drop in aerobic SRT, but the ammonia breakthrough still occurred. The wasting rate of the RAS was reduced significantly to bring the SRT up, as demonstrated by the sharp rise in SRT after the ammonia breakthrough.

BioWin Modeling

The data gathered during the pilot study were used to develop and calibrate a BioWin™ model of Module C. This model was then used to evaluate and optimize future nutrient reduction strategies, including installing a baffle to isolate the anoxic zone, increasing the RAS rate, and installing an internal nitrified recycle (NRCY) flow. A representative BioWin model showing the elements of Module C is shown in Figure 6.

Model Calibration

A dynamic simulation was used to calibrate the model. Adjusting the influent fractionation and specific kinetic parameters, the model was calibrated to predict accurately the

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Figure 6: Module C BioWin™ Model

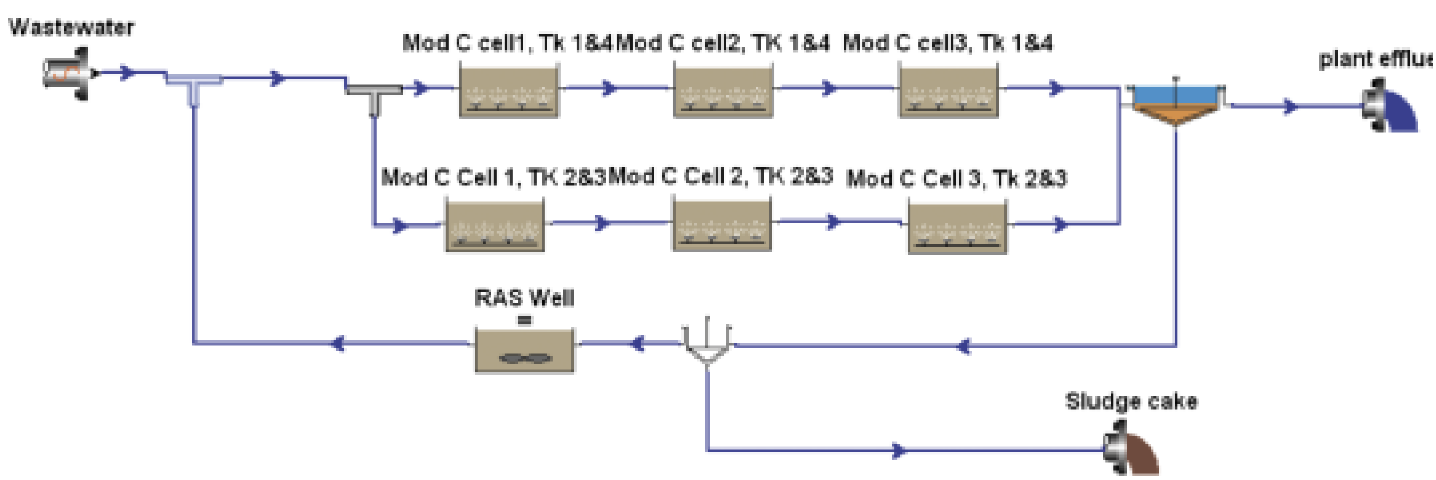


Figure 7: Solids Calibration of Module C BioWin Model

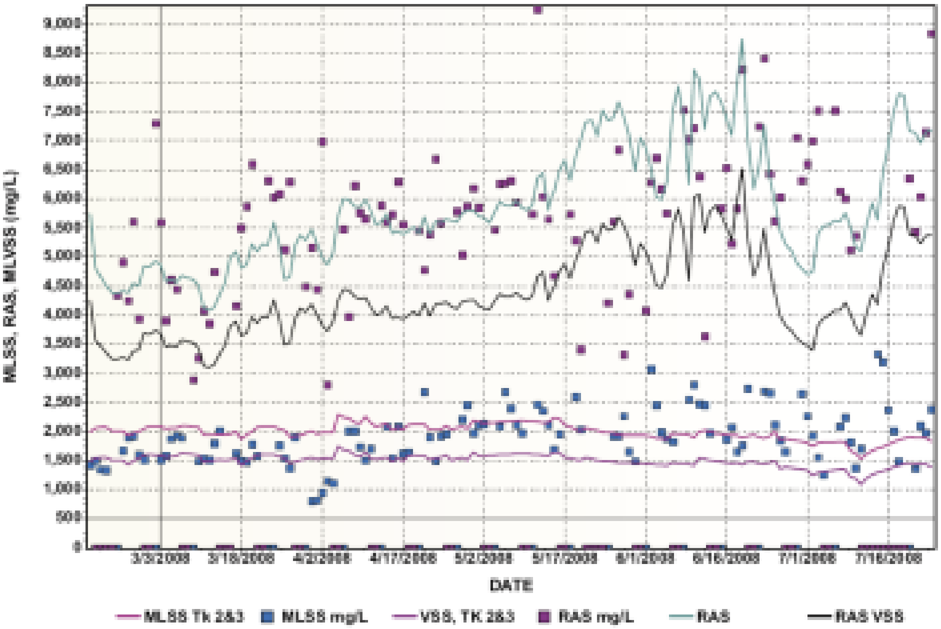
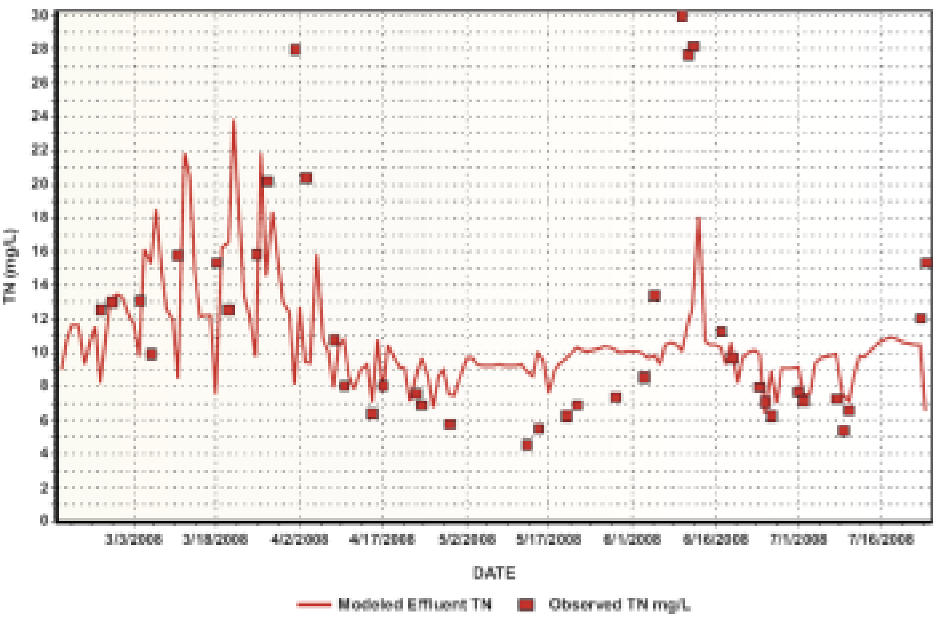


Figure 8: Observed vs. Predicted Effluent TN during Model Calibration



Scenario	Predicted Effluent TN (mg/L)	Predicted Effluent TP (mg/L)
1 - Base Case - one aerator off per basin and no modifications	11 - 13	2 - 2.5
2 - Base Case + baffled anoxic zone	12 - 15	2 - 2.5
3 - Scenario #2 + NRCY		
100% NRCY	9 - 11	2 - 2.5
200% NRCY	8 - 10	2 - 2.5
300% NRCY	7 - 10	2 - 2.5
4 - Scenario #2 + 100% RAS rate	10 - 12	2 - 2.5

Table 3 BioWin Modeling – Predicted Effluent Values for TN and TP

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North Regional Wastewater Treatment Plant solids inventory and effluent quality observed during the pilot program.

Figure 7 compares modeled and observed MLSS and RAS concentrations (the points shown on the graph show pilot data—the lines on this graph show the model's predicted values). Values for Basins 1 and 4 match those for Basins 2 and 3 and thus are not shown separately on this graph. Modeled and observed solids data match each other closely.

Figure 8 shows modeled and observed effluent TN during the BioWin model calibration. The modeled average effluent TN values for both phases of the pilot are similar to the observed data.

The calibrated BioWin model was then applied to simulate the effects that selected physical modifications and additional operational changes would have on the nutrient reduction capabilities of the plant.

Modeling Alternatives

The different alternatives that were considered to enhance nutrient reduction included:

1. Module C operates with an unbaffled anoxic zone (base case).
2. Module C operates with a baffled anoxic zone.
3. Module C operates with a baffled anoxic zone and a 100-percent NRCY flow rate.
4. Module C operates with a baffled anoxic zone and a 200-percent NRCY flow rate.
5. Module C operates with a baffled anoxic zone and a 300-percent NRCY flow rate.
6. Module C operates with a baffled anoxic zone and a 100-percent RAS recycle (20 mgd).

During the "baffled anoxic zone simulation," it was assumed that a baffle is in place at the end of Stage 1 to isolate the anoxic zone. All model scenarios were simulated at an operating MLSS of approximately 2,000 mg/L and at steady state conditions. Waste activated sludge (WAS) flows were adjusted to meet this concentration.

All the model runs were performed at the lowest observed temperature during the pilot program (26°C). Design load simulations typically are conducted at the minimum historical seven-day temperature, but no other temperature data were available. The pilot period includes data from February, and 26°C is expected to be close to the minimum seven-day temperature.

For Modeling Alternatives 1 to 5, the RAS flow was maintained at 10 mgd; it was increased to 20 mgd for Scenario 6. The model setup presented in Figure 6 was modified to incorporate the NRCY flow rate. The baffled anoxic zone was simulated in the BioWin model by utilizing a dissolved-oxygen (DO) setpoint of zero, while the field back-mixing occurring where the baffle is not present was simulated using the average DO measured for this zone (0.1 mg/L).

Table 3 shows the predicted effluent TN and TP for the different evaluated options. The 300-percent NRCY with a baffled anoxic zone is predicted to achieve the lowest effluent TN. Modeling results indicate that effluent TN can be further reduced to 7 to 10 mg/L by proceeding with this option.

Summary & Conclusions

Preliminary mass loading calculations indicate that Broward County would have to reduce its effluent TN discharge concentration to approximately 14 mg/L starting in 2009, in order to achieve the equivalent mass loading reduction without shifting any flow to the injection well system. Effluent TP must be reduced to approximately 1.2 mg/L. Field and modeling results demonstrate that the county will have multiple flexible options for achieving the required nutrient mass reductions.

Other conclusions that can be identified from the pilot study and BioWin modeling include:

- In the North Regional Wastewater Treatment Plant, denitrification can be achieved by the creation of anoxic zones, even if the RAS recycle rates are less than optimal. Nitrification still occurs despite the reduction in volume devoted to nitrification. Pilot results show that an effluent TN of approximately 12 mg/L can be achieved at an average flow of 18.7 mgd. Higher flows will have a negative impact on nitrification, resulting in higher effluent TN values.
- Stable and sustainable nitrification/denitrification will require reliable, robust process control and instrumentation to monitor the process. Good control of SRT is needed to minimize incidences of high TKN in the secondary effluent.
- BioWin modeling indicates that effluent TN quality can be further reduced to 7 to 10 mg/L by incorporating a 300-percent NRCY flow rate and a baffle to isolate the anoxic zone.
- Increasing the RAS flow from 8 to 20 mgd is expected to reduce effluent TN by approximately 1-2 mg/L over piloted results.
- Modeling and pilot results indicate that adequate Total SRT is in the range of four to six days. Lower SRT might produce ammonia breakthrough.

Acknowledgements

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