Stress Testing Gainesville's Main Street Water Reclamation Facility to Meet Paynes Prairie Total Maximum Daily Load

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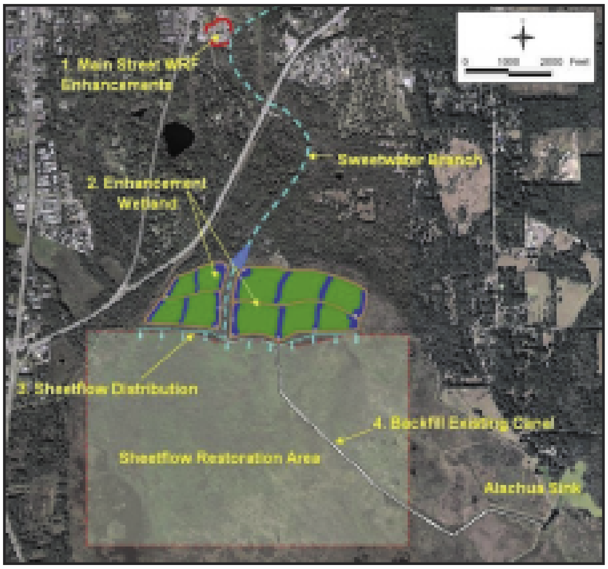
The Paynes Prairie Preserve State Park is a 21,000-acre natural and historical landmark situated in Alachua County at the southern tip of Gainesville. The quality of the park's wetlands has been impacted by urban surface water runoff and treated effluent from the city's Main Street Water Reclamation Facility via the Sweetwater Branch. Also, a manmade canal short-circuits the Sweetwater Branch flow to Alachua Sink, an active sink feature with a direct hydraulic connection to the Floridan Aquifer.



An aerial view of the proposed Paynes Prairie Sheetflow Restoration Project area near Gainesville. *Photo courtesy CH2M Hill*

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The proposed Paynes Prairie Sheetflow Restoration Project would provide a unique opportunity to rectify these problems and multiple additional benefits. This project will restore over 1,300 acres of formerly impacted wetlands, achieve regulatory total maximum daily load (TMDL) requirements for the city of Gainesville, protect the Floridan Aquifer, and offer outstanding wildlife habitat and opportunities for public recreation and wildlife viewing.

In order to achieve the TMDL and avoid adverse impacts on the restored wetland, process improvements at the Main Street Water Reclamation Facility to optimize total nitrogen and total phosphorus removal will be required to meet the proposed nitrogen and phosphorus limits of 8.0 and 0.3 milligrams per liter (mg/L), respectively.

The facility is a 7.5-million gallons per day (mgd) (annual average) conventional activated sludge plant serving the city of Gainesville. The liquid treatment processes include screening and grit removal, secondary treatment, tertiary filtration and disinfection. Solids treatment occurs in aerobic digesters; the digested solids are then thickened via two gravity belt thickeners.

Secondary treatment at the facility is separated into three trains or "plants": East, Center, and West. The East Plant consists of an aeration basin (1.6 million gallons (MG)) with three 75-horsepower (hp) mechanical surface aerators and a 100-foot diameter secondary

GRU's Main Street Water Reclamation Facility. *Photo courtesy CH2M Hill* clarifier. The East Aeration Basin is a rectangular shaped basin with a straight line flow path from one end of the basin to another.

The Center and West Plants are mirror images, each having 1.4-MG aeration basins with four two-speed 60-hp mechanical surface aerators. An 85-foot diameter secondary clarifier follows each of the two plants. The Center and West Aeration Basins are square shaped with a u-shaped flow pattern.

All three plants have a dedicated return activated sludge (RAS)/waste activated sludge (WAS) pump station. The effluent from the three plants combines in a wet well, where it is pumped to Dynasand filters (Parkson). The filtered effluent flows through a parshall flume and into the contact basin for disinfection via hypochlorite. The effluent is then dechlorinated prior to discharge to the Sweetwater Branch.

The stress test was broken into four phases in order to gather plant data under different operating conditions and loadings. The plant was stressed by taking one plant out of service with the goal of simulating design flows and loads for the remaining plants.

The order of the phasing was designed to best match the operation and maintenance schedules of the Main Street Facility. The four phases are:

- ***Phase 1 – Stressed conditions with one basin (West) out of service.*** The lead aerator in Center Aeration Basin was cycled (on five minutes per hour). This is the preferred method of operation at the Main Street Facility in order to optimize energy consumption and nitrogen removal. The East Aeration Basin was operated as usual by Main Street Facility staff; therefore, any East Plant data collected is not shown here. Data from the East Plant was used, however, in model calibration and was important in predicting overall Main Street Facility performance.
- ***Phase 2 – Stressed conditions with one basin (Center) out of service.*** The lead aerator in West Aeration Basin was run continuously. This method of operation was tested to simulate design conditions where all aerators would be needed. The East Aeration Basin was operated as usual by Main Street Facility staff.
- ***Phase 3 – Non-stressed conditions with all plants in service.*** The primary objective was to characterize existing operation. Phase 3 data was useful in understanding existing nutrient removal at the Main Street Facility and in process model development and calibration. Phase 3 data is not discussed further, since it was not integral in this article's objectives.
- ***Phase 4 – Chemical removal of phosphorus via coagulant addition prior to secondary clarifiers.*** Jar tests were performed to determine optimum coagulant and dose.

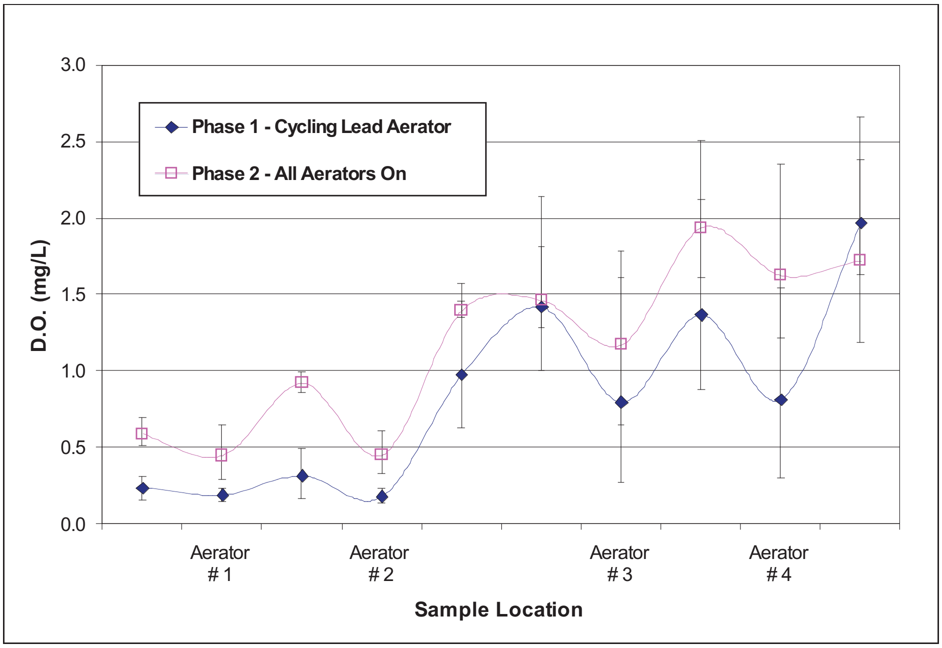

Figure 1: Dissolved Oxygen during Phases 1 and 2 in Center/West Plant

Aluminum sulfate (alum) was selected as the coagulant based on phosphorus removal, affect of pH, and ease of storage and application. Alum was added continuously at the effluent of the West Aeration Basin for approximately three weeks.

Methodology

In all, 42 different locations in the plant were sampled for various parameters, including dissolved oxygen, ammonia, nitrite, nitrate, total phosphorus, ortho-phosphorus, alkalinity, and total suspended solids. Typically, samples were taken at 8:30 a.m. and 1:15 p.m. each day. All liquid samples were collected from the upper three feet of the water column.

Samples for total Kjeldahl nitrogen (TKN) and total phosphorus were preserved for transport to the Kanapaha Water Reclamation Facility Lab (another GRU facility) for analysis. To preserve, hydrochloric acid was added to these samples until their pH was less than 2. Immediately after adding hydrochloric acid, the samples were placed in the refrigerator and cooled to less than 4° Celsius until transport.

Parameters tested include: chemical oxygen demand (COD), nitrate, nitrite, ammonia and ortho-phosphorus. Tests for ortho-phosphorus, TKN, nitrate, nitrite, ammonia and COD required the sample to be filtered. Samples were filtered immediately after collection and tested for nitrate as soon as possible. Once the nitrate samples were completed, any ammonia and nitrite tests were completed.

A Hach DR 2800 VIS Spectrophotometer, with a wavelength range of 340 to 900 nanometers, and compatible Hach test kits were used for all nitrate, nitrite, ammonia, ortho-phosphorus, and COD tests conducted.

An HQ40d Dual-Input Multi Parameter Digital Meter attached to a LDO101 IntelliCAL Rugged Dissolved Oxygen Probe was used to measure the dissolved oxygen (DO) at multiple locations and depths throughout the aeration basins and secondary clarifiers. The DO probe cable was marked at one, four, seven, and 10 feet from the probe end to indicate the depths. Measurements were taken at one, four, and seven feet below the water surface in all three aeration basins.

In addition, measurements were taken at 10 feet below water surface in the East Aeration Basin. The Center and West Aeration Basin walkways were elevated, which precluded measurements at 10 feet below water surface. DO measurements in the secondary clarifiers were taken at four and seven feet below the water surface.

Operating data including output frequency, motor speed, motor current, motor torque percent, motor power percent, and motor voltage from the variable speed drive controlling each mechanical surface aerator was recorded prior to sampling. Additional data such as mixed liquor suspended solids (MLSS), flow rates, and sludge blanket tests were conducted by Main Street Facility operators and gathered from the facility reports.

The treatment processes at the Main Street Facility were modeled using CH2M Hill's proprietary wastewater process modeling software, Pro2D™, an Excel-based spreadsheet model developed by the company to assess complete wastewater performance by

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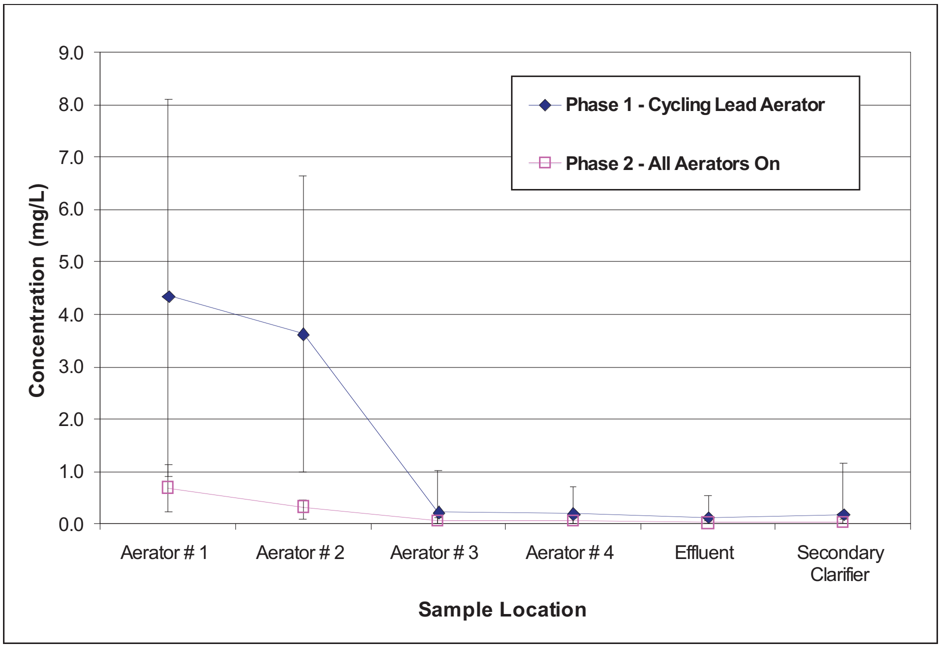

Figure 2: Ammonia during Phases 1 and 2 in Center/West Plant

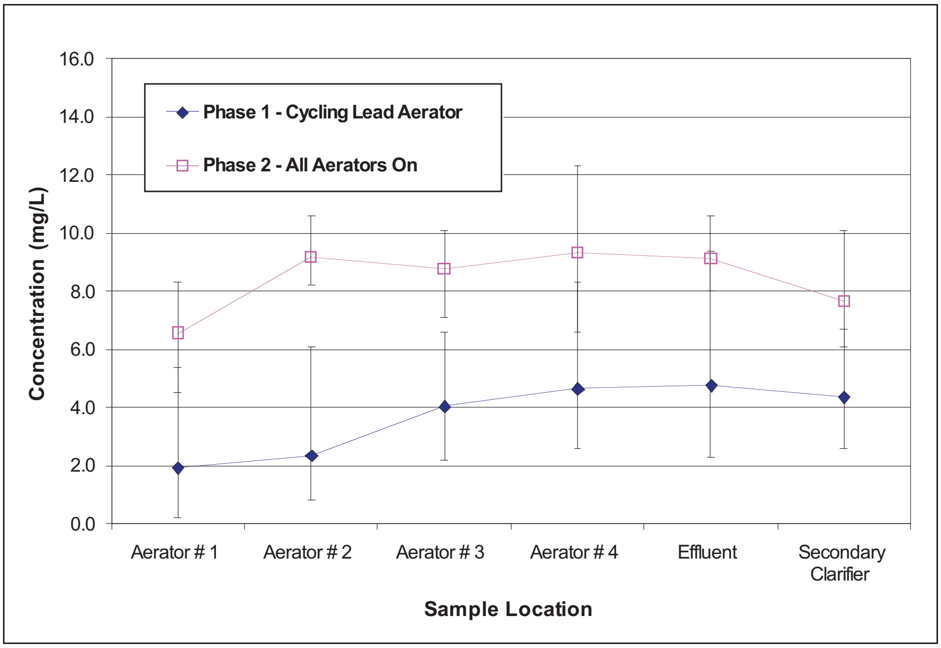

Figure 3: Nitrate during Phases 1 and 2 in Center/West Plant

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calculating a mass balance for the entire process. The suspended bacterial growth substrate conversion modeling in Pro2D is based on the International Water Association Activated Sludge Model 2 (ASM 2).

For this study, the influent and effluent data collected was used to calibrate Pro2D to model the biological processes of the Main Street Facility. Once a model is created that effectively captures the processes, other parameters can be adjusted to predict the facility's performance in other conditions. For example, a calibrated Pro2D model can predict the facility's ability to remove nitrogen in a range of temperatures, in addition to the summer temperatures experienced during field testing.

Results & Discussion

Dissolved oxygen measurements were taken at 10 locations in each of the Center and West Aeration Basins. Figure 1 shows the average DO values at the 10 locations throughout the basins for Phases 1 and 2 (Note, the error bars shown here and in other figures indicate the maximum and minimum value recorded).

The initial sample locations had low DO values (<1 mg/L) in both phases. Cycling the lead aerator during Phase 1 did result in lower DO values compared to Phase 2, particularly in the first half of the basin. The DO measurements at the effluent of the basin, however, were similar, indicating that the remaining three aerators were sufficient to aerate the basin when the lead aerator is not operated.

Samples for ammonia and nitrate were collected at six locations in the Center and West Plants: four samples in the aeration basin, another in the effluent box, and another at the effluent from the secondary clarifier. Figure 2 shows the average ammonia concentration at the six sample locations during Phases 1 and 2.

As expected from the DO data, the average ammonia concentrations are higher in the first half of the basins in Phase 1, compared to Phase 2. Although the DO is less than 1 mg/L in Phase 2, most of the ammonia is oxidized by the first sample location. In Phase 1, however, higher average ammonia concentrations remain until the second half of the basin. The remaining sample locations show very low ammonia levels, similar to Phase 2.

This data indicates that sufficient retention time and aeration capacity is available to nitrify the ammonia present in the aeration basin, even while cycling the lead aerator, at these conditions. It is important to note that the wastewater temperature during the testing ranged from 25 to 28°C (77 to 82.4°F). In winter months, the nitrification rate is significantly lower; therefore, these operating and loading conditions were modeled under minimum wastewater temperatures to determine if the same level of treatment could be achieved.

Figure 3 shows the nitrate levels at the six locations in the Center and West Plants for Phases 1 and 2. The nitrate concentrations in Phase 2 are approximately twice those measured in Phase 1. This data indicates that cycling the lead aerator in Phase 1 created anoxic conditions in the aeration basin, which enabled denitrification to occur.

The ammonia data in Figure 2 showed that nitrification was also occurring in Phase 1; therefore, cycling the lead aerator created conditions conducive to simultaneous nitrification/denitrification and resulted in average nitrate concentrations of less than 5 mg/L leaving the Center and West Plants in Phase 1.

In Phase 2, the higher DO levels lead to a more rapid nitrification of the influent ammonia, but less denitrification. In Phase 2, the average nitrate concentration in the Center and West Plant effluents was near 8 mg/L. This amount of nitrate in the effluent would lead to a total nitrogen concentration of approximately 10 mg/L, including organic nitrogen

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remaining after treatment. The Phase 2 data indicates that the Main Street Facility would have difficultly meeting the 8 mg/L total nitrogen requirement if it needed to operate the lead aerator continuously at design loadings.

Once all the data from Phases 1 through 3 was analyzed, a model was created which included all of the processes, with the respective volumes, at the Main Street Facility. The data collected in the field study then was used to calibrate the process model. In order to optimize the calibration, it was determined that data from individual days within in each phase should be used.

Selecting a daily data set to use within each phase was based on several factors, including facility operation consistent with phase objectives, influent loading approximating design loadings for facilities in service, and availability of operational data. Influent data from the two days used in the calibrations is shown in Table 1.

Table 1

Phase	Date	Flow		CBOD5		TSS	
1	July 7th	4.27 mgd	(85%[1])	6,054 lb/d	(132%)	8,191 lb/d	(106%)
2	August 6th	4.31 mgd	(86%)	5,392 lb/d	(88%)	5,751 lb/d	(74%)

Note: 1. Indicates percentage of annual average design value for MSWRF with one basin out of service.

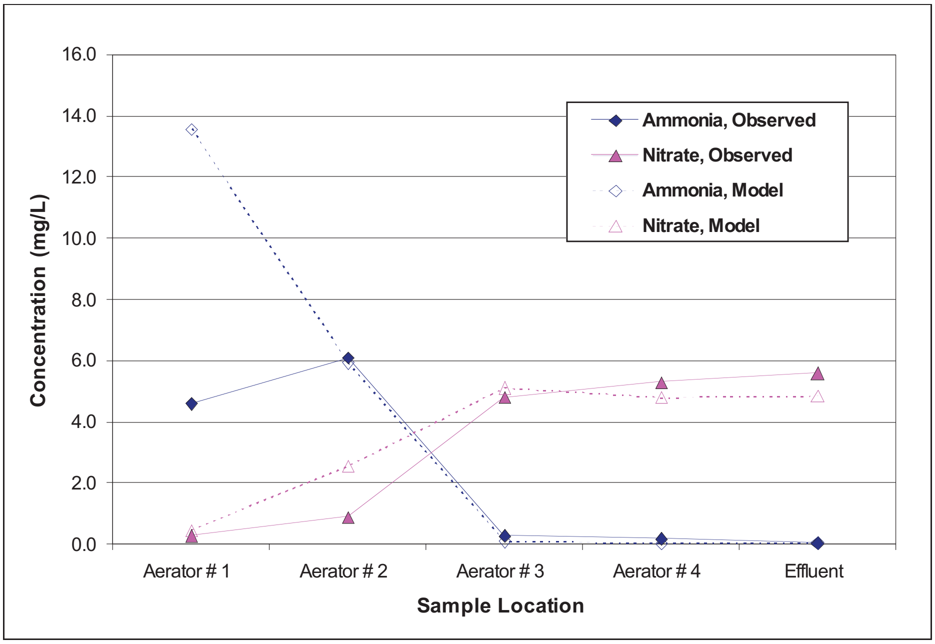

Figure 4: Phase 1 Modeled versus Actual Values for Center/West Plant

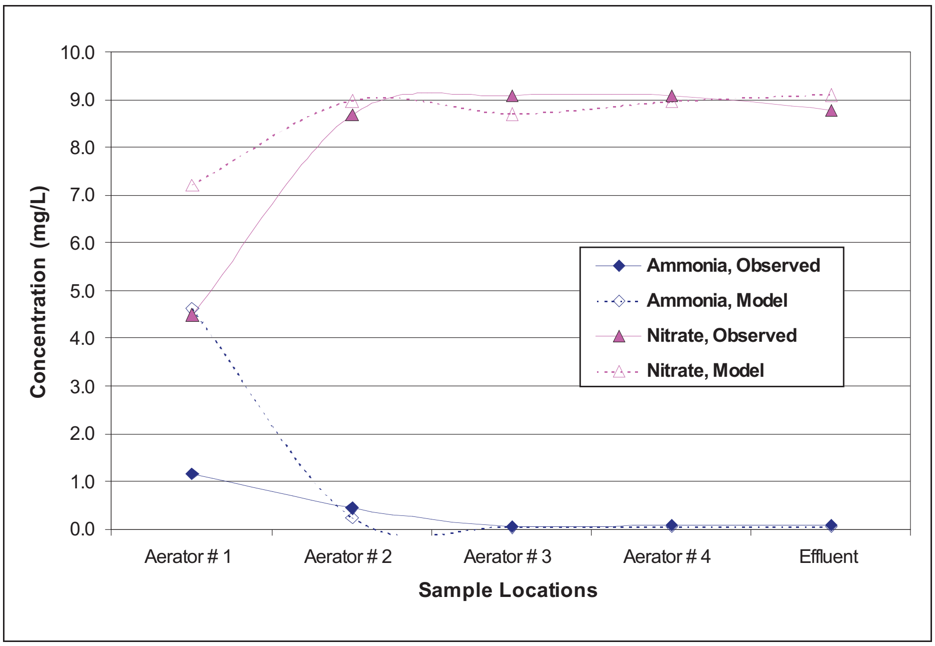

Figure 5: Phase 2 Modeled versus Actual Values for Center/West Plant

The influent data (flows, loads, temperature, etc.) was input into the model, along with operational data (for example, RAS rates) for each plant. Next, each aeration basin was segmented into zones, corresponding to the DO sample locations. The Center and West Basins each had 10 zones and the East Basin had seven. The DO values recorded in the field were input into each zone, then the model was run using a solids retention time that matched the actual operational observations.

Comparing the initial model results and the field data indicated that some denitrification was occurring in the secondary clarifiers. The Main Street Facility operated with a RAS/WAS concentration near 2 percent solids, higher than many similar facilities, which may explain the denitrification. In order to mimic this phenomenon in the model, a separate zone was created in the model to simulate RAS denitrification. The DO for these basins was set to 0.1 mg/L.

This modification allowed the model to predict the amount of denitrification occurring in the secondary clarifiers, which otherwise would not be captured in the aeration basin model.

The additional basins allowed the model to capture denitrification occurring in the secondary clarifiers; however, the field data also indicated the simultaneous nitrification/denitrification was occurring in the aeration basins. The initial model runs were not adequately capturing this, and were overestimating the nitrate in the effluent.

The final adjustment in calibrating the process model was to the DO values in the first three zones (approximately 30 percent by volume) in the Center/West basin. The model was able to better capture the simultaneous nitrification/denitrification occurring when the DO values in the first three zones were lowered by 0.1 mg/L, 0.1 mg/L, and 0.2 mg/L respectively. This adjustment was made on both the Phase 1 and Phase 2 DO values. The results of the model for ammonia and nitrate in the Center/West Plant, compared to the field data in Phase 1, are shown in Figure 4.

The dashed lines in Figure 4 show the ammonia and nitrate values as predicted by

Table 2: Model Results for MSWRF at AAD Flows and Loads Minimum and Maximum Temperatures

	AAD Flows & Loads at Minimum Temperature	AAD Flows & Loads at Maximum Temperature
Influent Parameters		
Flow	7.5 mgd	
$CBOD_5$	8,950 lb/d (143 mg/L)	
TSS	13,581 lb/d (217 mg/L)	
TKN	1,940 lb/d (31 mg/L)	
Ammonia	1,552 lb/d (25 mg/L)	
Temperature	17°C (62.6°F)	28°C (82.4°F)
Effluent Concentrations		
Ammonia (as N)	0.03	0.05
Refractory Nitrogen (as N)	0.71	0.69
Nitrate (as N)	9.10	4.93
Total Nitrogen	9.84	5.67

the model, while the solids lines show the values measured in the field. The model and measured values did not agree well for ammonia at the initial data point. The model was unable to predict the rate of nitrification observed at those conditions; therefore, the model over-predicts the ammonia concentration at the first point. With the exception of the first data point, however, the model was able to predict the ammonia and nitrate concentrations accurately in the rest of the basin and in the plant effluent.

The same comparison for the Phase 2 data and the model predictions are shown in Figure 5. Similar to Phase 1, the model did not match well with the field data for the first sample location, but the ammonia and nitrate values did match well throughout the rest of the basin.

The calibrated model was then used to predict Main Street Facility performance at other loading conditions and temperatures. The operating conditions were assumed to follow those observed in Phase 1, with the lead aerator cycling. Cycling the lead aerator created more favorable conditions for simultaneous nitrification/denitrification that is necessary for nitrogen removal.

The first two conditions modeled were the design annual average daily (AAD) flow and historical AAD loads at the minimum and maximum temperatures experienced at the Main Street Facility. Key influent parameters and effluent concentrations used in this analysis are shown in Table 2.

The model results indicate at design AAD flow and loads that the facility can continue normal operation (cycling the lead aerator) and comfortably meet the future total nitrogen effluent limit of 8 mg/L at the maximum temperature. At the same flows and loads but at the minimum temperature, the predicted concentration of total nitrogen in the effluent is 9.84 mg/L, indicating that the facility will not meet the required effluent limit for total nitrogen on a daily basis; however, the future total nitrogen limit is expected to be permitted on a rolling 12-month annual average basis, so it was also important to determine how the facility would perform over the course of an entire year.

A simulated design year for the Main Street Facility was created by applying peaking factors to the influent AAD flows, loads, and temperature for each month of the year. The peaking factors were calculated based on the past three years of historical data.

January was determined to be the coldest month, and one of the highest in influent loadings. To ensure the simulated year captured the worst possible conditions, the January flows and loads were set to the design maximum month flows and loads (based on previously determined peaking factors) and the minimum design temperature.

The simulated AAD design year data was input by month into the calibrated model. The output was a monthly average for total nitrogen based on the loadings and temperature. The results are shown in Figure 6.

The data set labeled "Current Operations" shows the predicted total nitrogen effluent using current facilities and operations at the facility. The average of these monthly values results in an annual total nitrogen concentration of 7.6 mg/L. This is below the target value of 8 mg/L but gives little room for plant upsets or extended peaks, so two upgrade scenarios were identified:

1. ***Convert the first zone of the Center and West Aeration Basins to a dedicated anoxic zone.*** Construct baffle walls in the existing basins, and add submersible mixers to blend the raw influent with the nitrified recycle. Pumps and piping would be added to recycle twice the influent flowrate from the effluent of the aeration basin to the new anoxic zone (nitrified recycle). The second aerator in each basin would be upgraded from 60 hp to 100 hp to make up for the aeration capacity lost in the conversion to an anoxic basin. No upgrades were assumed to the East Plant. The hydraulics and geometry of the East Plant are not conducive to these upgrades. The Center/West Plants each have four-aerator arrangements and a flow pattern that makes these recom-

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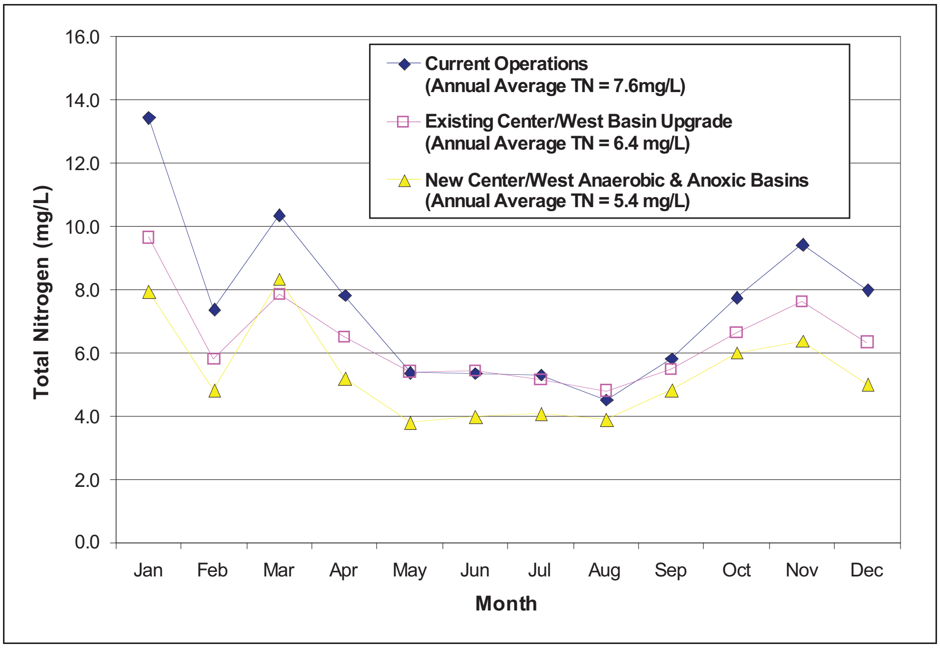

Figure 6: Monthly Averages of Effluent Total Nitrogen in Simulated Design Year for Three Alternatives

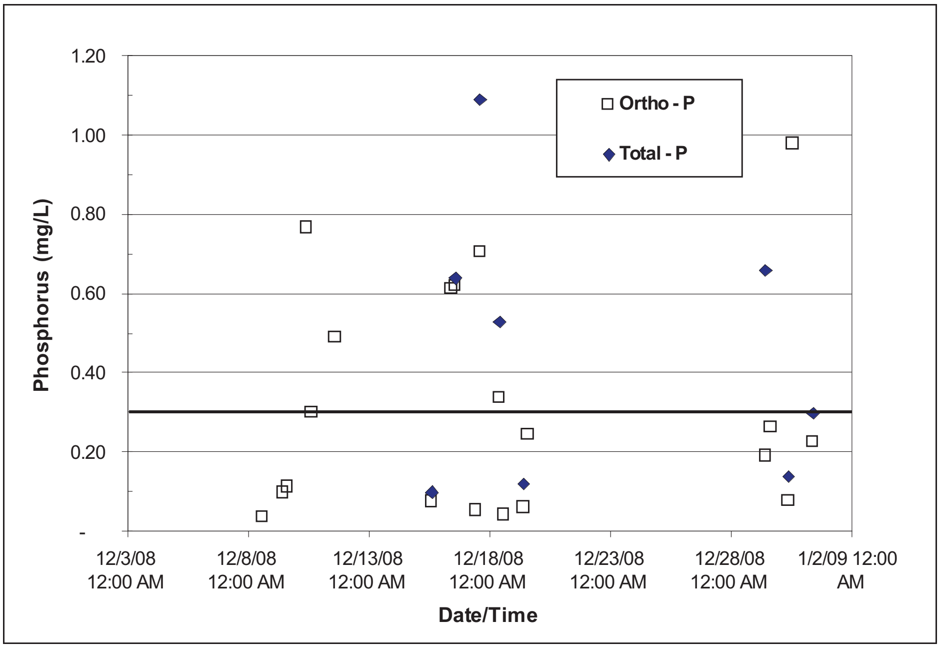

Figure 7: Phosphorus Concentrations at West Secondary Clarifier

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mended upgrades more feasible.

2. ***Construct new anaerobic and anoxic basins for the Center and West Plants.*** New dedicated basins would improve nutrient removal and would not affect existing aeration capacity. The equipment required for the new basins would be similar to the previous upgrade scenario. The upgrade would also benefit in phosphorus removal, which is discussed in the following text.

The model was altered to represent these two different upgrades, and the simulated year scenario was processed. The results from these model runs are also graphed in Figure 6 by month.

The additional dedicated anoxic basins and recycle pumping present in both upgrades were able to lower the total nitrogen in the effluent, particularly in the colder months. The annual average of the total nitrogen from the first upgrade scenario (convert existing basins) was 6.4 mg/L, and the value from the scenario using new basins was 5.4 mg/L.

In addition to Phases 1 through 3 that focused on nitrogen removal in the aeration basins, a fourth phase of testing was conducted to evaluate phosphorus removal via chemical precipitation. As stated previously, the future target concentration for total phosphorus in the effluent is 0.3 mg/L. Chemical precipitation was selected as the treatment process due to the low target level. Biological removal of phosphorus would require a more intensive facility upgrade (new anaerobic basins) and can not reliability meet 0.3 mg/L, so chemical precipitation would be required, with or without biological phosphorus removal capabilities.

Jar tests were conducted that identified alum as the preferred coagulant. A conservative target dose for the field tests was determined to be a 3:1 molar ratio of Al:P. Phase 4 field testing occurred in the West Plant. Alum was dosed at the effluent of the West Aeration Basin.

Figure 7 shows the results of the phosphorus testing of samples from the West Secondary Clarifier. Tests for ortho-phosphorus were performed at the Main Street Facility twice a day during the field tests. One sample a day was collected and tested for total phosphorus.

The total phosphorus concentration measured ranged from 0.1 mg/L to 1.1 mg/L over the course of the field study. The ortho-phosphorus measurements were within 0.1 mg/L of the total phosphorus values for the samples where the total phosphorus values were less than or equal to 0.3 mg/L. This indicates that an ortho-phosphorus test or analyzer may be used as a surrogate for total phosphorus for operational control.

Thirteen out of 20 samples tested for ortho-phosphorus were at or below 0.3 mg/L. Half (four of eight) of the total phosphorus samples were at or below 0.3 mg/L.

Analyzing all the phosphorus data at the West Secondary Clarifier measured during the field study indicates that alum addition at the aeration basin effluent is able to lower total phosphorus concentrations below 0.3 mg/L, but it is unclear if this can be done reliably. The field study testing was not able to monitor incoming flow or phosphorus concentration continuously or adjust the alum dose accordingly, as would be done in final full-scale operation; therefore, it is not known if the field scale system was sophisticated enough to properly dose the required amount of alum, or if alum dosed in this location can reliably treat to the level required.

Summary and Conclusions

Currently, the Main Street Water Reclamation Facility operates as a conventional activated sludge facility with secondary clarifiers and tertiary filtration that discharges to a surface water, the Sweetwater Branch. Although the facility does not have dedicated nutrient removal processes, historical data indicates that some removal occurs (particularly nitrogen), as part of normal operation.

A new TMDL has been proposed for the facility as part of the Paynes Prairie Sheetflow Restoration Project, which will limit effluent concentration of nitrogen to 8 mg/L. The effluent concentration of phosphorus will be limited to 0.3 mg/L for the proposed wetland operation.

The Main Street Facility meets the proposed nitrogen limit based on current operation, but it was not known whether that performance could continue at design flows and loads; therefore, the facility was stress tested at near design loadings in order to evaluate nitrogen removal. Also, full-scale testing of chemical removal of phosphorus was performed to determine the optimum coagulant and dosing locations and to see if any additional effects were caused by the process (for example, pH and solids generation).

Field testing at stressed conditions indicated that nitrogen removal occurs in two locations. First, cycling the lead aerator in the aeration basins creates conditions conducive to simultaneous nitrification/denitrification. Second, the Main Street Facility operates with a relatively shallow (one to three feet), but dense (2 percent solids) sludge blanket in the secondary clarifiers. Field testing indicated that denitrification was occurring in the sludge blankets.

The results of the field testing suggested that the facility could continue normal operation and meet the new nitrogen standard; however, the stress testing occurred during summer when wastewater temperatures were near the maximum (28°C), so the field data was used to create and calibrate a process model that was used to predict nitrogen performance at various temperatures.

In order to simulate performance over the course of a design year, the model was run with average monthly data. The results indicated that the facility could meet the nitrogen limit of 8 mg/L, but with little room to spare (annual average total nitrogen = 7.6 mg/L).

Two additional model runs were performed for the simulated design year, assuming two upgrade scenarios to Main Street Facility processes. The first was an upgrade to existing basins, while the second added new basins for nutrient removal. Both upgrade scenarios included new process equipment for mixing and recycle flows.

Based on the model predictions and the relative complexity of the two upgrade scenarios, it was recommended that the Center and West Aeration Basins be upgraded in order to meet the total nitrogen requirement reliably at buildout. Recommended upgrades include:

- Constructing baffle walls to separate the first quarter of the Center and West Aeration Basins.
- Installing submersible mixers in the area converted to an anoxic zone.
- Upgrading the second aerator in the Center and West Basins to make up for lost aeration capacity from the converted first zone.
- Adding pumps and piping to recycle up to twice the design flow from the effluent of the aeration basins to the converted anoxic zones.

Chemical precipitation was selected for removal of total phosphorus at the Main Street Facility because of the low effluent limit of 0.3 mg/L. Jar testing indicated that alum was the optimum coagulant for dosing at the aeration basin effluent.

Alum was dosed at the West Aeration Basin effluent, and field samples were collected at the West Secondary Clarifier effluent. The results indicated that alum addition was able to meet the total phosphorus limit, but not consistently. The samples that did not meet the total phosphorus limit may have been due to limitations of the temporary field testing equipment. Further testing of chemical removal of phosphorus is planned at the Main Street Facility, including dosing a coagulant upstream of the filters.