Nutrient Removal Enhancement Using Process Automation at Holly Hill

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The City of Holly Hill, located on the Atlantic Coast just north of Daytona Beach, provides wastewater service to residential and commercial customers within the City's service area. The City operates one wastewater treatment plant that utilizes biological nutrient removal via two parallel disc aeration basins. The existing basins were constructed in 1991 and had a rated capacity of 2.4 mgd. Most of the major equipment was in need of renewal and/or replacement. Additionally, an increase in capacity was required to accommodate future flows.

The project to install a process control system was initiated by the City and engineered by Quentin L. Hampton Associates of Port Orange. The purpose of the project was to stabilize effluent nutrient levels caused by manual control of the equipment in the disc aeration basins. The control system, provided by Siemens Industry Inc., has a secondary benefit of lower energy consumption in the nutrient removal process. Hampton completed design documents during 2007 and the project was bid in early 2008.

Project construction began in the spring of 2008. The scope of the project included replacing or refurbishing most of the major equipment and increasing the permitted capacity to 3.0 mgd. The increase in capacity was achieved by re-rating the existing disc aeration basins by optimizing biological nutrient removal with automated process controls, a third clarifier, and additional filtration. The process optimization was so extensive that the existing plant supervisory control and data acquisition (SCADA) system was completely rebuilt. Variable frequency drives (VFDs) were installed on all aerators and process pumps to allow for adjustability.

The wastewater treatment plant includes tertiary treatment and high level disinfection to produce public access reclaimed water. This project has allowed the City to continue producing high quality water while stabilizing the biological process. Plant effluent data shows that nutrient levels have stabilized, which can be attributed to the automatic adjustment provided by the new plant automation.

Existing Plant: Theory of Design

The original biological process was designed for 2.4 mgd. It consisted of two separate three-channel disc aeration basins designed with a capacity of 960,000 gallons each. The outer channel of each three-channel basin contains 50 percent of the volume of the basin, but because of the out-to-in flow pattern, receives 100 percent of the oxygen demand. Therefore, the zone is deficient in oxygen and has 0 mg/l dissolved oxygen (DO). The original design required one-third of the standard oxygen transfer efficiency (SOTE) to be provided by two 20 Hp disc aerators located in the outer channel. This means that an oxygen deficit of two-thirds was automatically built into the outer channel of the system. The inner two channels hold the other 50 percent of basin volume. Four more disc aerators are provided in the interior channels producing enough SOTE to meet the final two-thirds of design oxygen demand, while bringing the DO up to maintain a minimum of 2.0 mg/l DO in the inner channel.

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Throughout the process, ammonia is biologically converted to nitrates by nitrifiers. The outer channel of each disc aeration basin is an aerated anoxic zone. Oxygen provided into this environment by the disc aerators is ravenously competed for by both heterotrophic biochemical oxygen demand (BOD) consumers and autotrophic ammonia oxidizers. If an autotroph is successful in this competition and in this zone, it will convert an ammonia ion into a nitrite ion (NO_2) to gain energy for metabolism. A nitrite ion released into the anoxic environment of the outer channel of a disc aeration basin will be sought by heterotrophic bacteria eager to use this oxygen source to metabolize readily available organic carbon. This process is called "simultaneous nitrification/denitrification" and is a distinct design enhancement of the process used in the basins.

The O_2 deficit that exists in the outer channel of the basin creates a large denitrification zone that typically encompasses 50 percent of the basin volume. Therefore, 50 percent of the basin volume and 50 percent of the design hydraulic retention time (HRT) exists as an aerated anoxic zone. This is why aerated anoxic technology is different from "oxidation ditch" technology and why shorter design HRT can be used. Internal recycle pumps are located in each basin to recycle nitrified mixed liquor suspended solids (MLSS) from the inner channel to the outer channel for denitrification. Each set of pumps is designed to recycle 400 percent of the influent flow to obtain maximum efficiency of denitrification, allowing the plant to meet its 3 mg/l effluent total nitrogen (TN) requirement.

The design of each original disc aeration basin was intended to be manually operated to meet tight effluent TN and Total Phosphorus (TP) requirements. Since Holly Hill's wastewater is considered weak, conditions in the basin channels are variable. The worst conditions are at night, when the flow and loading on the plant drop off. To compensate for this, the original design included flow equalization to maintain more constant conditions. However, the plant still experienced periods of time in the evening when the equalization basins would empty and the basins became underloaded. Variability in effluent quality was the norm and the operators struggled to make operational adjustments as needed to maintain their average effluent quality below their limits. Plant personnel soon found that they could produce the best effluent by removing some discs on the outer channel, making it a deeper anoxic zone during light loading conditions. However, this also resulted in lowering the plant's treatment capacity as some of the SOTE capability was removed.

New Automated Plant Design

The basic design strategy for this project was to increase the stability of the plant effluent quality by incorporating the process control system. Doing so would allow the operators to return the disc aerators in the outer channel to full SOTE capacity. Increased effluent stability would also allow the plant to be re-rated to a higher capacity. Hampton and Siemens ran several design simulations at higher capacity and found that by increasing the stabilization of the process using automation, the design capacity of the system could be increased to 3.0 mgd. The new design would then be rated at 13.7 lbs/ 1000 ft^3 with a 15.3 hour HRT.

To automate oxygen delivery, the disc aerators would be returned to full disc capacity and VFDs would be replacing each motor starter. The process control system would consist of a control panel containing a programmable logic controller (PLC), operator interface screen, relays, and internal wiring components located in the motor control center (MCC). Ethernet communication was used to relay operation control instructions to the VFDs mounted on the motor starter buckets of the existing MCC. The PLC was programmed to output signals to the VFD of each disc aerator. The disc aerators would be turned on or off, or were required to change speed to control the condition of the channels according to operator controllable set-points for DO and oxidation reduction potential (ORP).

The heart of the process control system is the probes mounted in the channels of the disc aeration basins. Siemens monitors the anoxic condition in the outer channel with an ORP probe. There is no DO to be monitored in the outer channel as any oxygen is consumed too quickly; it has both a negative and positive scale, indicating if the environment is oxidative (+) or reductive (-). An anoxic condition is a reductive condition and negative readings in the outer channel are good. Generally, the more negative a reading, the better for denitrification. Set-points for control of the outer channel aerators are established in the process control system at about -200 for denitrification. The control programming turns on or changes the speed of the disc aerators as needed to control the anoxic condition in the outer channel at its set point.

The aerators of the middle and inner channels are coupled together and control of their operation and speed is based on a DO set-point for the inner channel. Usually, a 2.0 mg/l DO set-point is used for the middle channel to assure complete nitrification in the process. The on/off status and speed of the aerators in the inner two channels are controlled to meet the DO requirement in the inner channel. Both ORP and DO are monitored in the middle channel and both probes are used as backup control for the main control probes. The middle channel is used as the transition channel allowing the system to naturally adjust from the low ORP (no DO) outer channel condition to the high DO (+ORP) condition in the inner channel

A dissolved oxygen sensor and ORP probes are used to measure DO in the system, which is based on the measurement of the light produced from a luminescent material when it is exposed to oxygen; the more oxygen present, the more light produced. Reliability of DO probes are high and maintenance is low. Typically, normal maintenance involves the replacement of a removable cap about once a year. The ORP probes are salt bridge probes that are standard to the industry. Once the salt bridge is consumed, indicated by slow response, the probe salt bridge needs to be replaced. Holly Hill experienced trouble during this project with numerous salt bridge breakages. It should be noted that protective caps must be provided for all ORP probes application in wastewater. Once the protective caps were installed, the breakage problems were eliminated.

Because the existing SCADA computer was more than halfway through its useful life, a new computer was supplied with a new ver-

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sion of software and updated screens were created that more closely match the layout and functionality of the plant. Since plant operation could not be suspended during the upgrade, the new SCADA computer was installed next to the existing system without any loss of control during the upgrade process. This also required that the new system be configured to communicate with the existing PLCs and the new PLCs prior to commissioning the new equipment.

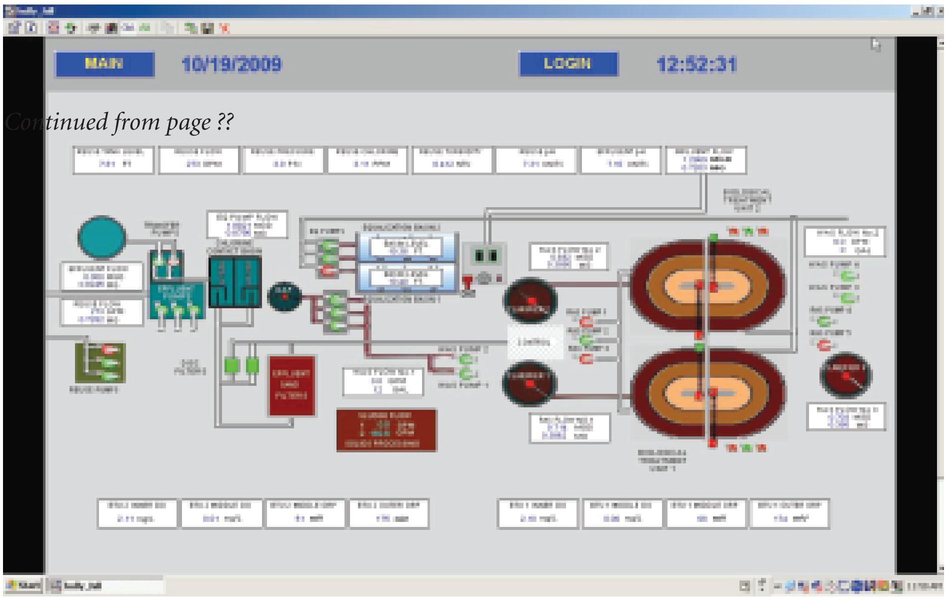
An additional level of control redundancy was established by providing a touch screen to be included on the new control panel. In the event that the SCADA computer system fails, control of the aeration system will still be available with the screen.

A flexible communication option was provided by utilizing a central processing unit (CPU) with Ethernet I/O capability as the selection for the PLC. This also ensures future upgrade compatibility with industrial communication networks. There are a variety of options for the networks, remote input/output (I/O), and other instruments available in the market.

Maintaining full operation of the plant during this switchover was a must; to do this properly, an existing PLC panel was specified to be decommissioned one input/output at a time. The design included adding an I/O terminal strip to the existing panel to facilitate the connections to the new PLC panel.

Since the PLC has industrial communication network capability, the addition of ancillary equipment via I/O over the existing fiber optic network was very simple. The design includes a remote panel with I/O and a communication interface installed in the effluent control building where the existing PLC was no longer functioning. The three effluent pumps were connected to this new I/O and now are controlled automatically via the SCADA system, rather than manually as had been done in recent years.

The project was also designed to minimize field wiring and its associated cost. All new VFDs were specified with an interface. This included a new local network for communication between the process control system PLC, the aeration disc VFDs, the return activated sludge (RAS), and waste activated sludge (WAS) pump VFDs. A managed network switch was installed to control network traffic. Since the Ethernet protocol was not specified for the VFDs, protocol conversion was required for the PLC and VFDs.



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Project Implementation

A few issues were encountered during the construction and startup of this project and it took the combined effort by all parties to overcome them. In particular, the operators of the Holly Hill Wastewater Treatment Plant must be recognized for their diligence and determination to effectively and efficiently operate the plant throughout the construction period while avoiding major process upsets. They were required many times to operate the system manually while electrical work was ongoing and equipment was not available for service. Additionally, the project engineer and contractor collaborated to solve both major and minor differences in the field, avoiding costly change orders. Some of the challenges experienced during process startup and operation included:

- Maintaining process quality while the process controls were moved from the old SCADA system to the new. This was encountered by operational staff as each piece of equipment was individually converted to the new control system. Several times two PLCs were required to control an individual piece of equipment simultaneously.
- Communication issues between the new PLC and new and existing electrical equipment was a challenge throughout construction. Typically, the problem was resolved quickly, but some issues required time extensions for additional programming.
- Because of the way the walkways of the existing basins were constructed, they proved to be poor choices for mounting locations

of the new DO and ORP probes. The walkway on this basin was approximately 5 ft above the water level, so mounting probes on the handrail was challenging. Also, the ORP probe location was near the influent cascade, which entrains air into the water at the end of the anoxic zone and adds oxygen to the system. To resolve this problem, the ORP setpoint was adjusted to an offset value in the control programming to provide a value that the system could successfully control.

Results and Discussion

Holly Hill operators controlled the process in a similar manner as before by utilizing settleometers and sludge blanket depth to control wasting rates and manage solids residence time. Process control system automation controls and aerator speeds were based on DO and ORP probes. This adjustment allows the oxic and anoxic portions of the basin to increase or decrease in size, as required. Process automation also controls internal recycle (IR) and RAS flow rates in accordance with the influent flow rate. Operators can input a multiplier of influent flow for the IR and RAS controls to match, allowing the pumps to turn down during low flows when denitrification occurs with less recycle saving energy.

This project was successful in reaching the objectives of stabilizing the effluent quality while at the same time conserving energy. To show this success, two years of operation were selected: one before the project was implemented in 2007, and one year of successful operation after the project was implemented in 2010. Table 1 compares the influent flow that was realized during each of the selected years. The data indicates that the average flow for each year (minus the extreme peak realized during severe wet weather at the end of September in 2007) were very near each other. In 2010, higher influent flows occurred during the first half of the year, while conversely, in 2007, higher influent flows were realized during the later half of the year. Therefore, the years selected are appropriate for this comparison.

Reduction of nutrients is a key focus of the City's National Pollutant Discharge Elimination System (NPDES) permit and is tightly monitored by the Florida Department of Environmental Protection (FDEP). The City's effluent is discharged into the intracoastal waterway and its discharge limit is 3 mg/l TN. Table 2 shows the most recent results of effluent TN species making up the TN discharge from this plant during 2010, after the process control system was installed and made operational. What can be noted in the graphic is the

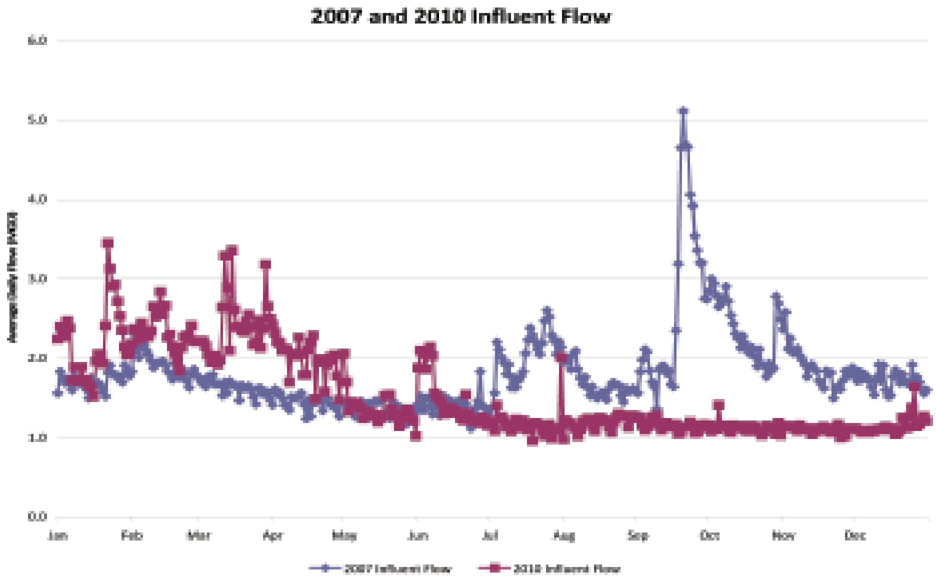

Table 1

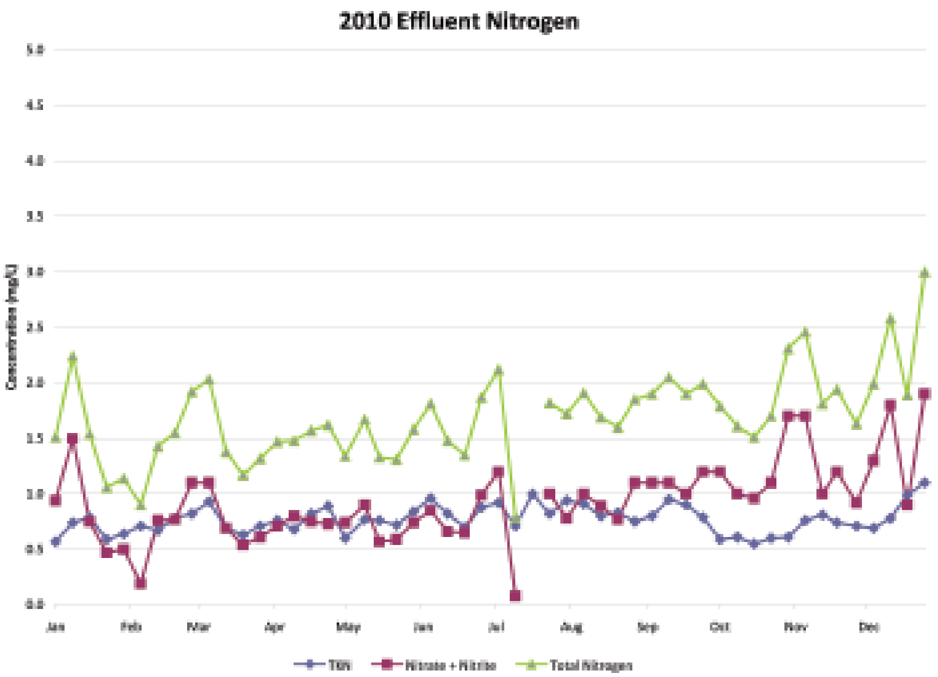

Table 2

consistency and stability of the effluent nitrogen discharges. There were no points of TN discharge found in the data above the 3.0 mg/l discharge limit. Effluent Total Kjeldahl Nitrogen (TKN) values remained steady throughout the year at less than 1.0 mg/l (averaging 0.7mg/l).

For most of the year, effluent nitrite/nitrate (NO_2/NO_3) nitrogen was maintained at or below 1.0 mg/l. A trend of increased NO_2/NO_3 to the level averaging about 1.5 mg/l is noted at the end of the year. This correlates to lower influent flows experienced during this relatively dry period and may reflect extremely low flows in the evening when recycle rates

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bring a steady stream of oxygen back to the outer channel of the basin and there is little food coming in to drive the denitrification process. Table 2 shows consistent effluent nitrogen levels with relatively low variability.

Table 3 shows a direct comparison of TN concentrations between 2007 and 2010. As shown, the TN levels for 2010 are lower than the levels achieved prior to the automation. The average effluent concentration in 2007 was 2.43 mg/l; after the project was implemented, the average effluent TN concentration was 1.70 mg/l.

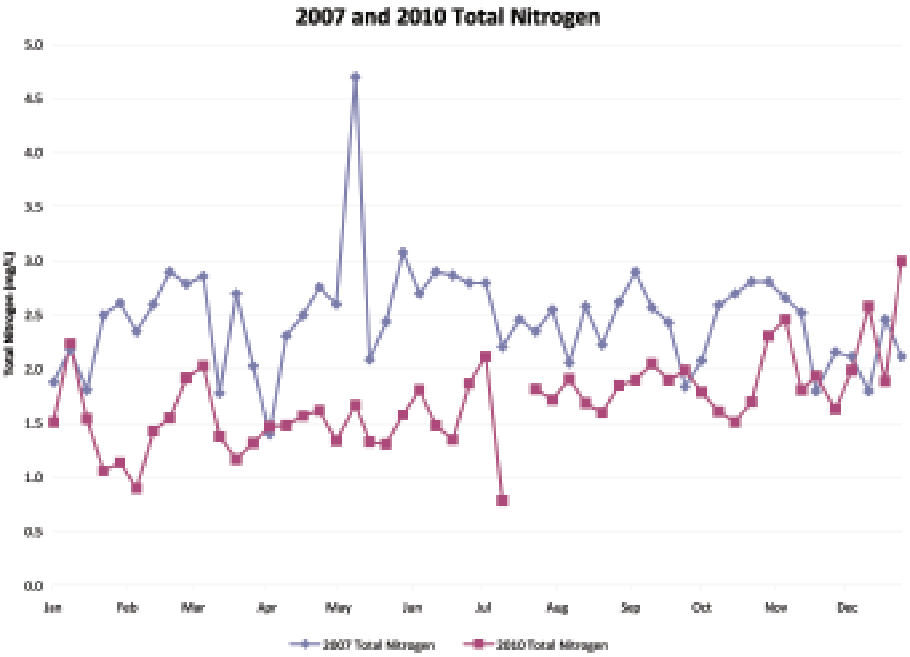

Table 3

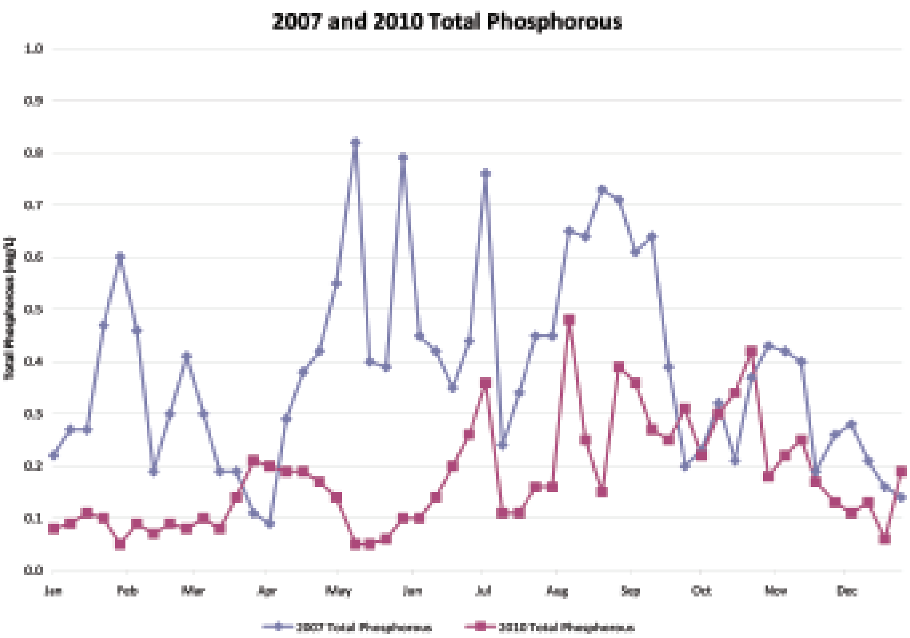

Table 4

Additionally, it appears that the 2010 concentrations are more stable than the 2007 data. This is attributed to the constant adjustments of the aerators being made based on real-time DO and ORP readings in the basin channels. The measurement of variability in any set of data is called the standard deviation, which is the average difference of the measurement variability from the mean of the data set. The mathematical formula is $[\Sigma A(R - X)]/N$, where A is the absolute value of the measurement, R is the individual measurement, X is the mean of the data set, and N is the total number of measurements in the data set. In 2007, the standard deviation of effluent TN measurements was 0.482 mg/l; the standard deviation of the 2010 data set was 0.408 mg/l. A 15.3 percent improvement in the standard deviation of results was achieved.

The process automation has also resulted in more efficient biological phosphorus removal. Table 4 shows a direct comparison of TP concentrations between 2007 and 2010. Again as shown, the TP levels for 2010 are lower than the levels achieved prior to the automation. The average effluent TP concentration in 2007 was 0.39 mg/l; after the project was implemented, the average effluent TP concentration was 0.18 mg/l, resulting in an improvement of 54 percent. This is attributed to the constant adjustments of the aerators being made based on real-time ORP readings in the outer channels. In 2007, the standard deviation of effluent TP measurements was 0.186 mg/l; the standard deviation of the 2010 data set was 0.104 mg/l, meaning a 44 percent improvement in the standard deviation of results was achieved.

Conclusions

The new process control system at Holly Hill has improved the stability of the nutrient removal process used in the basins. This is shown in the substantial improvement of the standard deviation of effluent TN and TP in data collected before the project was implemented in 2007 and post-project data collected during 2010.

This success is a reflection of the pride and professionalism of all parties concerned. All projects have a risk of failure and quite often the difference between success and failure is the character of the men and woman involved. The Holly Hill staff was successful with their old system, and now charged with successful operation of the plant after all the construction is complete, they continue to show their expertise, which is indicated by the improvement in effluent quality achieved in 2010.