City of Daytona Beach Utilizes Glycerol in a Unique Application for Enhanced Biological Phosphorus Removal

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The City of Daytona Beach owns and operates two water reclamation facilities with a combined capacity of 106,000 m^3/day (28 mgd). Both the Westside Regional Water Reclamation Facility (WRWRF), with a rated capacity of 56,782 m^3/day (15 mgd) annual average daily flow (AADF), and Bethune Point Water Reclamation Facility (BPWRF), with a rated capacity of 49,210 m^3/d (13 mgd) AADF, are five-stage Bardenpho systems and are designed to achieve advanced treatment standards for: biochemical oxygen demand (BOD_5), 5 mg/L; total suspended solids (TSS), 5 mg/L; total nitrogen (TN), 3 mg/L; and total phosphorus (TP), 1 mg/L (5/5/3/1). The reclaimed water is discharged to the Halifax River (D-001) or to the public access reuse distribution system (R-001). The WRWRF reclaimed water not sent to the reuse distribution system is conveyed to the BPWRF (R-002) and is combined with the reclaimed water from the BRWRF for discharge to the Halifax River.

The WRWRF was upgraded in 2000 to a two-process train, five-stage Bardenpho system that includes the following processes: anaerobic zone and primary anoxic zone, followed by mechanical aeration with internal nitrate recycle, second anoxic zone, reaeration, clarification, sand bed filtration, and ultraviolet light (UV) disinfection. Biosolids processing consists of three sludge holding tanks (that are not presently in service) and four two-meter belt presses. Waste activated sludge (WAS) is presently pumped to the belt presses directly for dewatering. Solids dewatering is conducted continuously, and belt press filtrate and the effluent sand filter backwash water are discharged to the flow distribution box No. 1 immediately upstream of the anaerobic zone. In addition, biosolids from the BPWRF are also discharged to the WRWRF collection system where they are treated and processed. Dewatered solids are trucked from the WRWRF to an off-site facility.

Historically, both Daytona Beach water reclamation facilities have tried to achieve biological nitrogen removal without the addition of supplemental carbon. Reclaimed water TN levels from both facilities have not consistently met the National Pollutant Discharge Elimination System (NPDES) permit limit for TN of 3mg/L. The WRWRF, in addition to not meeting TN effluent compliance, had not been able to meet the 1.0 mg/L TP limit consistently.

As a result of these discharge permit violations, in 2008, the Florida Department of Environmental Protection (FDEP) issued a consent order to the City of Daytona Beach to evaluate alternatives to achieve compliance with the phosphorus and nitrogen discharge permit limits.

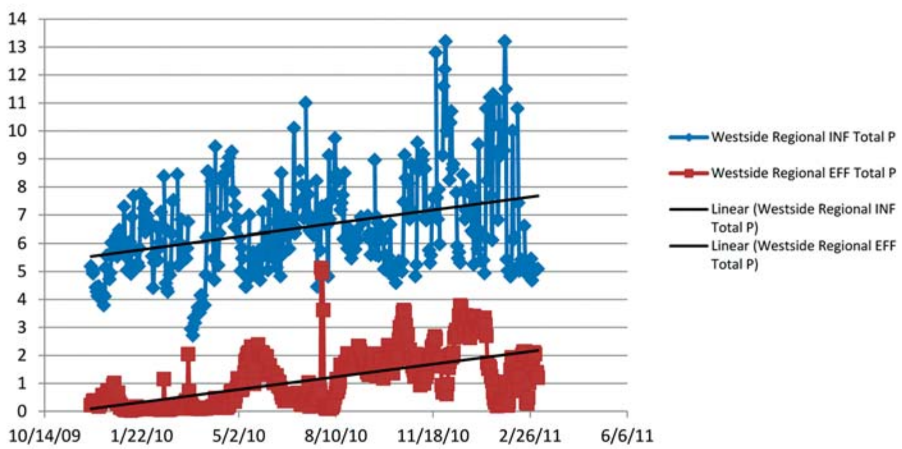

Figure 1. Westside Regional Influent and Effluent Total Phosphorus with Alum Feed Only

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The phosphorus removal study recommended the addition of alum for phosphorus control. The study recommended alum addition at two points in the process train at the influent distribution box before the anaerobic zone, and at the reaeration distribution box just prior to final clarification. Alum storage and feed tanks were installed and the facility began feeding alum in October 2009.

The effluent performance during the alum addition time frame (December 2009 to March 2011) was inconsistent and did not achieve permit compliance (Figure 1). Effluent TP averaged greater than 2.0 mg/L, which was above the 1.0 mg/L monthly average TP per the NPDES permit limit. Figure 1 also shows TP removal for the alum addition during the December 2009 to March 2011 time period. During this period, alum was fed to various combinations of distribution box No. 1 influent and after reaeration. The feed rate was also varied from 200 to 300 ml/min to each feed point.

Glycerol Evaluation

Beginning in March 2011, the WRWRF began feeding MicroC2000™ (a glycerol-based

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carbon source) as a supplemental carbon source to the second anoxic zone to enhance TN removal. The test evaluation criterion was set to remove the combined total of nitrate and nitrite (NO_x) to below 1.5 mg/L consistently from the final effluent in order to achieve a final effluent TN of 3 mg/L to meet the NPDES permit.

After the March 2011 start of supplemental carbon addition to the second anoxic zone (Figure 2), the plant staff began to notice a reduction in the effluent phosphorus composite samples for both TP and orthophosphates. This reduction began almost immediately after the glycerol addition.

Subsequent to the first-phase testing and success in lowering the TN to less than the 3 mg/L threshold, evaluation of the additional benefit to enhanced biological phosphorus removal (EBPR) began. Grab samples were taken across the second anoxic zone for TP and orthophosphates and a profile was observed along with on-line nitrate analyzer data from the second anoxic zone influent and effluent. It was observed that the NO_x levels were being lowered to less than 1 mg/L consistently, thus resulting in anaerobic conditions in part of the second anoxic zone.

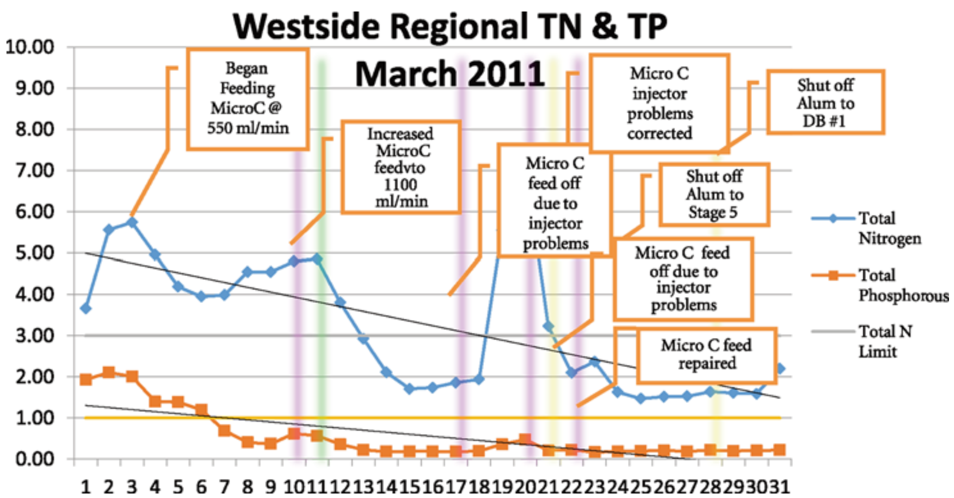

Figure 2. Initiation of Supplemental Carbon Addition to the Second Anoxic Zone

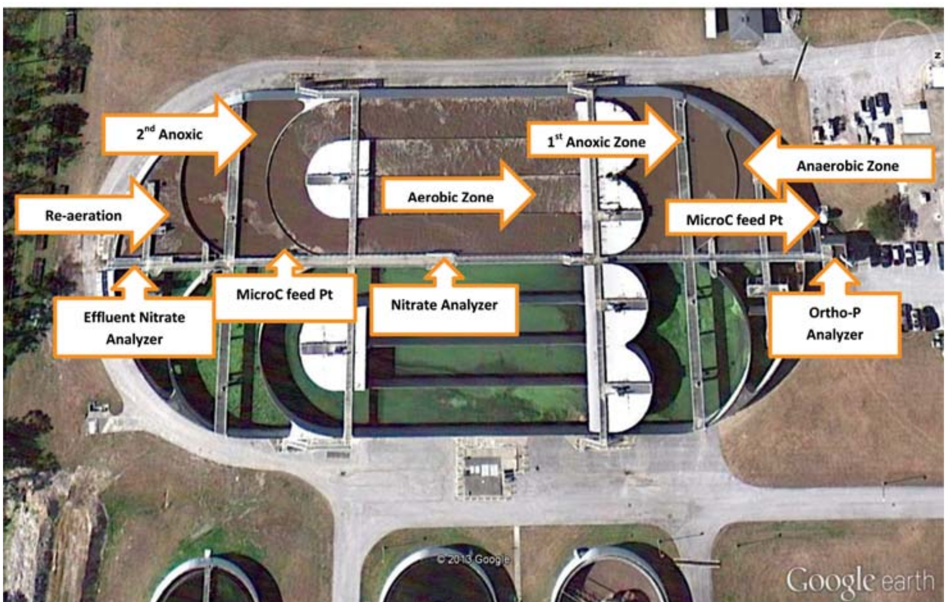

Figure 3. Supplemental Carbon Feed Points and Analyzer Locations

The very low NO_x levels in the second anoxic process allowed for a secondary release of phosphorus and subsequent uptake in the reaeration zone. This condition, though not ideal for EBPR, was occurring and lowering the effluent TP at the facility.

After operating both an alum feed and supplemental carbon glycerol feed to the second anoxic, the plant staff discontinued the use of alum in June 2011. Both effluent TN and TP levels were below permit limits for TN of 3 mg/L and for TP of 1 mg/L.

In June 2011, a further evaluation of the process was conducted with additional grab sampling of the entire process for both orthophosphate and TP. The plant influent characteristics were also evaluated and it was determined that the influent carbonaceous biochemical oxygen demand (CBOD) was typically low in this facility. The average influent CBOD was 130 mg/L and the average influent TP was 7 mg/L. This resulted in a BOD:P of approximately 18.5. The ratio was consistently below 25, typically referenced in the literature for five-stage Bardenpho processes. Given the weak influent CBOD, it was suggested that supplemental carbon be supplied to the anaerobic zone to enhance phosphorus release and subsequent uptake in the aerobic zone (Figure3). On July 1, 2013, the facility began feeding glycerol to distribution box No. 1 located just upstream of the anaerobic zone (Figure 5).

Most current EPBR phosphorus removal processes rely on the function of a specific group of polyphosphate-accumulating microorganisms (PAOs) that are capable of taking up excessive phosphorus as intracellular storage. The phosphorus is then removed from the system by sludge wasting. In facilities with a weak influent soluble BOD, the fermentation reactions in the anaerobic zone will be significantly slow. This will result in reduced phosphorus release and subsequent uptake from insufficient anaerobic poly-b-hydroxyalkanoates (PHA) storage to support subsequent aerobic poly-p storage.

In cases where the influent does not contain sufficient volatile fatty acids (VFAs) to support PAO enrichment, an external VFA or an external supplemental carbon can be added to the anaerobic process. Traditionally, acetic acid, a mixture of acetic and propionic acid, acetate, or fermented primary sludge overflow streams, has been used as a source of VFAs.

In the case of the WRWRF, the influent BOD:P ratio is lower than recommended for good biological phosphorus release and uptake, resulting in insufficient EBPR performance.

The use of glycerol fed to the influent chamber upstream of the anaerobic zone specifically as a VFA source from fermentation of the glycerol to VFAs within the anaerobic zone has been utilized continuously at the WRWRF since June 2011. The external carbon supplementation has provided a unique approach to solving an EBPR performance problem and has resulted in permit compliance for the TP permit limit of 1 mg/L.

The feed rates to both the denitrification and EBPR processes were constant-feed, with approximately 1.1 liters per minute to the second anoxic zone and 0.65 liters per minute to the influent to the anaerobic zone. The constant feed scenario for denitrification was utilized at the facility until March 2013, when the feed to the second anoxic zone was automated from a feed-forward control loop with two nitrate analyzers (Figure 3). The automatic control system allowed for pacing of the supplemental carbon feed for meeting nitrogen concentration, flow, and load conditions, resulting in a significant reduction in supplemental carbon use. The supplemental carbon feed and control improvement projects covered the storage feed and control system for nitrogen removal at both water reclamation facilities (WRFs), as shown in photos 1 and 2.

The supplemental carbon feed and control of the anaerobic zone at the WRWRF was not part of the improvement project and the system continues to be operated in a manual feed configuration.

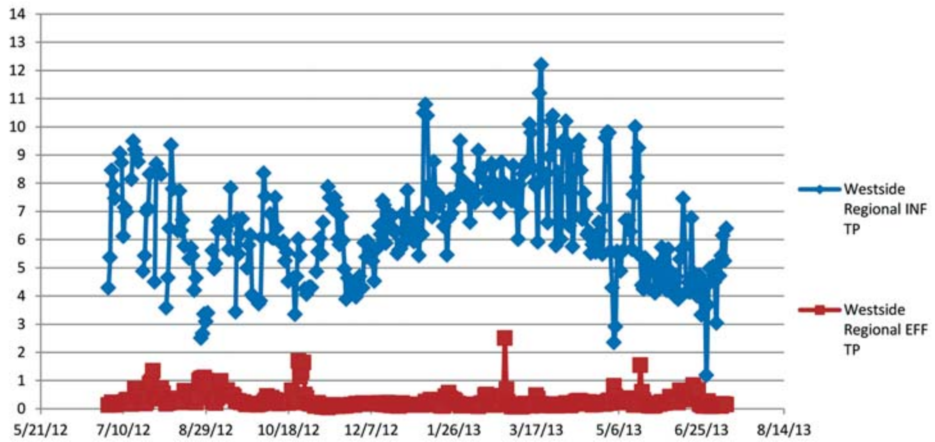

Figure 4. Westside Regional Average Phosphorus Influent and Effluent (July 2012-July 2013) in mg/L Daily Composite Data

2012-2013 Enhanced Biological Phosphorus Removal and Nitrogen Removal Performance

The overall one-year July 2012-July 2013 WRWRF nutrient removal performance has been exceptional (Figure 4), with the effluent TN averaging 1.74 mg/L, (NPDES permit limit of 3 mg/L) and effluent TP averaging 0.28 mg/L, (NPDES permit limit of 1 mg/L). The average monthly flow, CBOD, total kjeldahl nitrogen (TKN), and TP for the April 2012-March 2013 period were as follows: flow, 23,848 m^3/d (6.3 mgd); CBOD, 134 mg/L; TKN, 42 mg/L; and TP 7, mg/L.

Over the last 12 months, the feed rate of supplemental carbon has been at a constant feed rate of 0.65 L/min. This feed rate was established early in the trial and has provided a level of phosphorus removal that has consistently met the NPDES permit. A high supplemental carbon feed rate was maintained due to the need to maintain complete permit compliance for both TN and TP consistently for six months of uninterrupted compliance as required in the consent order from FDEP. As a result of the need to achieve full compliance with the consent order, the facility staff was hesitant to change any of the operation conditions, including supplement carbon feed rates, until the consent order was noted in full compliance. This has most likely included times when the use of supplemental carbon was greater than required.

The supplemental carbon feed system utilized at the facility consisted of a pair of peristaltic pumps. Each pump operates with two pump heads that are capable of up to 0.84 L/min total (photo 3). Supplemental carbon for this process was not covered in the recently completed carbon storage and feed improvement project that provided new bulk storage and pumping facilities for the denitrification process. Budget limitations for the project did not include any new facilities for the supplemental storage and feed to the anaerobic process.

In order to better understand the EBPR process at the WRWRF, a number of plant profile grabs were taken to better understand the release and uptake of phosphorus across the five-stage Bardenpho process. Profiles were taken at six separate intervals in 2013 that represented different times of the day and operating conditions. Grab samples were taken as follows: 1) at the influent distribution No 1, which is the combined raw influent, return activated sludge (RAS), filter, and filtrate streams; 2) anaerobic zone effluent; 3) aeration effluent; 4) midsecond anoxic zone; 5) midreaeration zone; and 6) final reaeration before clarification. The samples were field-filtered and analyzed for orthophospate, TP, TKN, ammonia, and NO_x. Due to the tank concentric layout, it was impossible to grab a final second anoxic sample, as access to this point was not possible.

During the most recent grab sample profile of June 26, 2013, an additional sample point was added to evaluate the uptake of phosphorus in the preanoxic zone. In all sample profiles, a very distinct release of phosphorus occurred in the anaerobic zone, followed by uptake in the aerobic zone. A secondary release of phosphorus was also noted in the second anoxic zone, followed by P uptake in the reaeration zone. In all sampling profiles, the additional reduction in orthophospate and TP occurred across the reaeration zone after the postanoxic P release. Typically, an additional 0.1-0.2 mg/L reduction of both orthophosphate and TP were observed.

The secondary phosphorus release did not appear to cause any undesirable plant performance or operating conditions. The reason for the additional release is most likely due to anaerobic conditions, with available VFAs in the reactor from denitrification at less than 1 mg/L.

Two plant profiles representing different operating conditions are shown in Figures 5 and 6. The figure profile represents a period of high plant loading. The WRWRF sewer service areas include the Daytona International Speedway. The profile was taken the day after the Daytona 500 race, where approximately 150,000 spectators were in attendance, with hotels and restaurants operating at full capacity.

During the high loading profile, the plant was experiencing difficulty in maintaining a high enough dissolved oxygen level for complete nitrification, and ammonia was breaking through the aeration basin. This resulted in a higher-than-normal effluent TN. The low dissolved oxygen condition also resulted in incomplete phosphorus uptake in the aeration basin. What is interesting to note is that the poor uptake of phosphorus was compensated for in the second anoxic zone. As shown in

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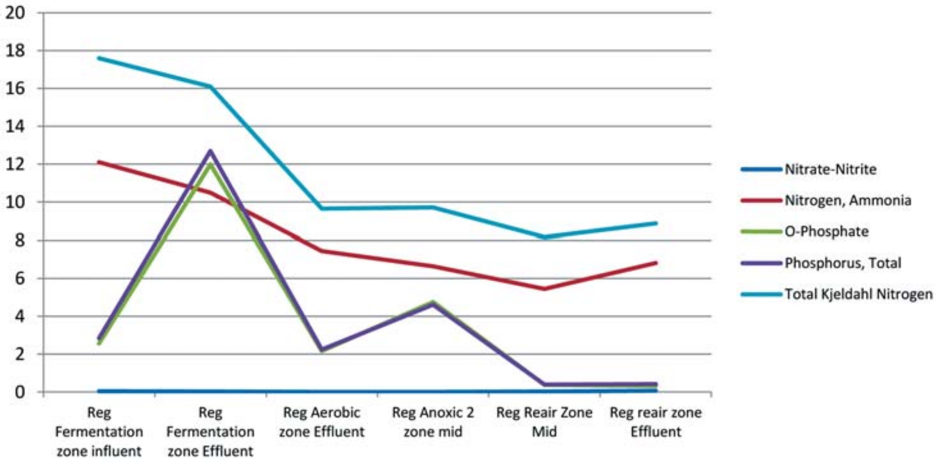

Figure 5. Westside Regional Profile (2/26/2013) as an Example of a Stressed High Organic Loading Period During Daytona 500 NASCAR Race Event

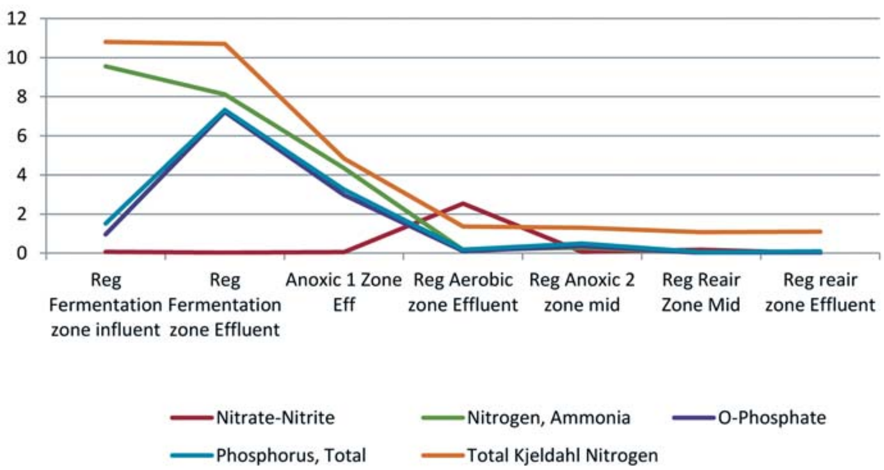

Figure 6. Regional Profile (June 26, 2013)

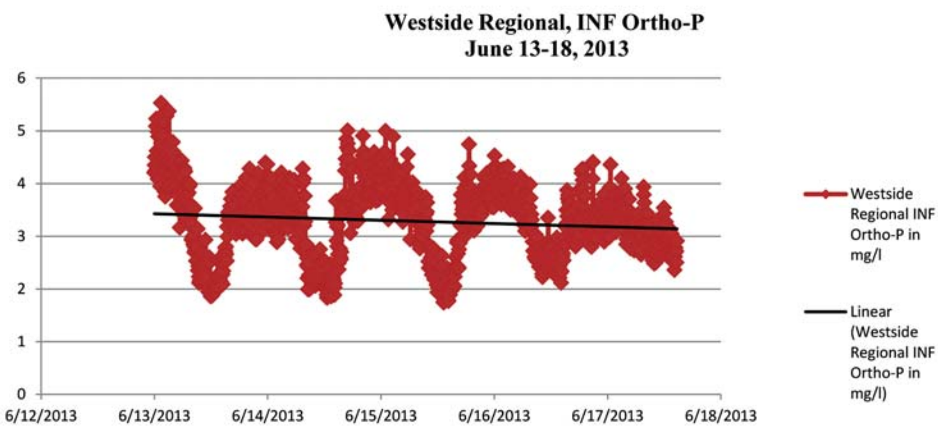

Figure 7. Orthophosphate Analyzer Data Form the Influent Distribution Box No 1 Upstream of the Anaerobic Zone Including Return Activated Sludge and Plant Recycle Streams

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Figure 5, there was a secondary release and subsequent uptake of phosphorus in the reaeration zone that resulted in a reaeration effluent orthophosphate and TP of 0.3 and 0.4 mg/L, respectively. This was most likely the result of the second anoxic basin becoming anaerobic with low nitrates and abundant VFAs to allow for a secondary phosphorus release.

Once the high organic loading passed after the Daytona 500 race, the WRWRF was back fully nitrifying within a couple of days. The dissolved oxygen/aeration limitations at the facility in peak demand periods are an ongoing problem that will be rectified with a planned aeration system upgrade.

The WRWRF profile taken on June 26, 2013, was a more representative profile of normal nonstressed operating conditions that were observed with all of the other grab sample profiles taken.

During this sampling period, an additional grab sample point was added at the effluent of the primary anoxic zone. The reason for the additional sample point was to see if there was any phosphorus uptake taking place in the zone from anoxic phosphorus uptake. As shown in Figure 6, there was simultaneous denitrification and phosphorus uptake taking place in the preanoxic zone. The TP was reduced from 7.3 mg/L down to 3.3 mg/L, or approximately 50 percent across the primary anoxic zone. Additional grab sample profiles will be taken to confirm the uptake observed with the June 26, 2013, samples.

With the other subsequent grab samples during normal operating conditions, a smaller secondary phosphorus release was observed, with the majority of phosphorus uptake completed by the end of the aerobic zone. The overall EBPR removal was excellent, with orthophosphate at 0.06 mg/L and TP at 0.09 mg/L by the end of the reaeration process.

An additional phase of the case study was to better understand the diurnal variation in influent phosphorus loading to the facility. In order to accomplish this, an on-line orthophosphate analyzer was installed at influent distribution box No. 1, just upstream of the anaerobic zone and before the addition of supplemental carbon. The Hach Phosphax analyzer uses a colorimetric process that requires a sample to be drawn into the analyzer for analysis. This required a filtered sample, and given that the sample point was raw screened influent, it presented a number of challenges in keeping the filter equipment functioning.

The sampling equipment was operated during the month of June 2013 and the sampling interval was 15 minutes. Photo 4 shows the installed sampler at distribution box No. 1, just upstream of the anaerobic zone. The waste stream at this point included screened raw influent, RAS, and continuous recycled streams from sludge dewatering and effluent sand filter backwashing.

Use of the on-line phosphate analyzer demonstrated a clear diurnal loading cycle with peak loading periods occurring from late afternoon until early morning. The typical load varied from a low of 2 mg/L up to 5 mg/L orthophosphate daily (Figure 7). Utilization of on-line analyzers will allow for a better real-time understanding of the phosphorus loading to the facility and enable the potential future ability to pace supplemental carbon to the loading for more efficient process control.

Photo 1. Permanent supplemental carbon bulk storage and pumping system at the Westside Regional Water Reclamation Facility in Daytona Beach.

Photo 2. Permanent pumping system for supplemental carbon.

Photo 3. Temporary bulk storage and feed/pumping system used for supplemental carbon at the Westside Regional Water Reclamation Facility during the study.

Photo 4. Orthophosphate on-line analyzer located in the influent to the anaerobic zone at the Westside Regional Water Reclamation Facility to record real-time influent phosphorus loading during the study.

Conclusions

Glycerol provided a reliable, readily degradable source of supplemental carbon for enhancement of biological phosphorus removal when fed to the anaerobic zone at the WRWRF.

The use of supplemental carbon addition, for both denitrification when fed to the second anoxic zone and enhanced biological phosphorus removal when fed to the anaerobic zone, have enabled the WRWRF to achieve permit compliance for effluent TN and TP.

The FDEP consent order has been satisfied, and on July 2, 2013, the facility was noted in full compliance, with no effluent violations over the previous six months.

Glycerol was shown to improve nitrogen and phosphorus removal at the WRWRF over the seasonal variations in flow and loading conditions. The glycerol did not require any appreciable acclimation period and results were quickly observed from initiation of supplemental carbon pumping. Wastewater temperatures ranged annually from 20->30°C without any observed changes in removal efficiency.

A better understanding through the use of an on-line orthophosphate analyzer of the daily fluctuations in influent phosphorus loading to the facility from influent diurnal flow and loading variability has helped to provide information that, in the future, will more accurately and efficiently provide supplemental carbon dosing to maximize phosphorus removal.

The City of Daytona is currently in the process of installing and commissioning an on-line orthophosphate analyzer at the plant effluent of both of its water reclamation facilities to better understand the overall phosphorus removal performance.

Further analysis will be necessary to determine if an on-line phosphate analyzer can be utilized continuously at the plant influent due to the high solids present; better analyzer influent filtering equipment may make this possible. The goal will be to provide an automatic feed and control system for enhancement of biological phosphorus removal, with glycerol incorporated into the plant-wide supervisory control and data acquisition (SCADA) systems.

Overall influent phosphorus peak loading has been reduced through better biosolids management. The elimination of sludge storage that contributed to additional phosphorus released from anaerobic sludge storage and recycled to the head of the treatment process helped achieve this goal.

Use of glycerol to enhance EBPR in place of alum will result in less solids generated with a metal salt precipitation process.

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