To Everything There Is a Season; Lessons from Four Seasons of Phosphorus Removal at Greene County Sugarcreek WRRF

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ABSTRACT

This case study analyzed phosphorus (P) removal from municipal wastewater during the past four summer permit seasons at the Greene County Sugarcreek Water Resource Reclamation Facility. The facility has utilized both chemical removal and enhanced biological phosphorus removal (EBPR) to provide supplemental P removal in excess of metabolic P removal in order to comply with concentration-based effluent P limits. Both methods were demonstrated to achieve an effluent total phosphorus (TP) concentration less than 0.5 mg/L. Alum was utilized for chemical phosphorus removal. The EBPR process was a first-of-its-kind with Continuously Sequencing Reactor (CSR) technology developed by Schreiber coupled with single-stage, variable-output centrifugal blowers provided by Turblex.

KEYWORDS: chemical phosphorus removal, Alum, enhanced biological phosphorus removal, metabolic P removal, continuously sequencing reactor, total phosphorus, total maximum daily load

INTRODUCTION

Today, the Greene County Sugarcreek Water Resource Reclamation Facility (SCWRRF) is a modern facility utilizing state-of-the-art technology to cost-effectively produce a high-quality effluent for discharge into the Little Miami River, a State and National Scenic River. In 2003, the Greene County Sanitary Engineering Department (GCSED) was operating a plant that had not had a major improvements project for nearly 20 years and was treating wastewater flow over 50% above design flow. To make matters worse, new and more stringent discharge requirements were written into the 2003 NPDES permit renewal including a compliance plan for total phosphorus (TP) load reduction from treated effluent. A General Plan Update published in 2005 proposed a three-pronged strategy to reduce phosphorus loading to the Little Miami River:

1. Maximize phosphorus removal by operating the Schreiber counter-current system in a biological nutrient removal (BNR) mode.
2. Develop non-point phosphorus removal projects in the Little Miami River watershed and seek water quality trading credits from the Ohio EPA. This would help achieve the SCWRRF phosphorus limit.
3. If the above tasks were insufficient to meet permit conditions, negotiate with Montgomery County and Ohio EPA to remove phosphorus at the Eastern Regional WRF (effluent limit trading) located upstream in the watershed.

Treatment was the major component of this strategy and is the focus of this manuscript. However, performance data for BNR systems did not indicate that SCWRRF could meet its mass load limit by BNR with treatment alone so the other two components were proposed to make up the difference between the load limit and what could be achieved with treatment.

Little Miami River Watershed

Designated a State and National Scenic River, the Little Miami River main stem contains some of Ohio's most scenic and diverse riverine habitat and is a popular recreational resource (Ohio EPA, 2002). However, 17 segments of the watershed were identified as impaired in Ohio's 1998 303(d) list including the segment containing the SCWRRF outfall resulting in the development of a Total Maximum Daily Loads (TMDL) for phosphorus. Sources of impairment cited in the TMDL report (Ohio EPA, 2002) included habitat degradation and nutrient loadings.

NPDES Permit Conditions

The NPDES permit for the Sugarcreek WRRF included a two-step compliance requirement. The SCWRRF was required to first attain operational compliance with treatment facility improvements constructed to achieve a technology-based limit of 1.0 mg/L TP limit by April 30, 2008. For the second step, the SCWRRF was required to achieve a 9.3 kg/d TP mass limit by 2013 based on the wasteload allocation according to the following calculation:.

$$Q_{med} \text{ x } P_{med} \text{ x } F - LR$$

Where

- Q_{med} = 5-year median daily effluent flow rate during May - October (mgd),
- P_{med} = median daily effluent total phosphorus concentration during May – October (mg/l),
- LR = water quality credits accrued through participation in a water quality trading program (kg/day),
- F = 3.7854 conversion factor.

This load is the equivalent of an effluent TP of 0.25 mg/L at the projected future design flow of 9.9 MGD. NPDES permit limits are shown in Table 1.

Table 1 – NPDES Permit Limits for the Sugarcreek WRRF

		Winter		Summer	
Parameter	Units	Weekly	Monthly	Weekly	Monthly
Flow	mgd	9.9			
TSS	mg/l	31.5	21	24	16
NH_3-N	mg/l	11.25	7.5	1.88	1.25
TP	mg/l	monitor		1.5	1.0
TP (2013)	kg/day	-		-	9.3
$CBOD_5$	mg/l	26.3	17.5	15	10

Wastewater Facilities
The Sugarcreek Water Resource Reclamation Facility (SCWRRF) Facility Planning Area (FPA) encompasses southwestern Greene County, southeastern Montgomery County, and a small portion of northern Warren County in southwestern Ohio. Treatment facilities consist of the following operations:

- Pumping – The Influent Pump Station (IPS) located remotely from the treatment plant is designed to pump up to 35 mgd to meet the peak projected flow rate from a 2-yr. 24-hour storm;
- Screening - Two continuous belt filter screens with ¼- inch openings;
- Equalization - A 5.1 million gallon equalization basin was included to equalize the peak flow between the 2-year 24-hour design storm (35 mgd) and the plant hydraulic capacity of 24 mgd. Influent is diverted to the Equalization (EQ) Basin after screening;
- Grit Removal – Grit removal consists of two vortex grit separators;
- Activated Sludge BNR - The secondary treatment component of the SCWRRF upgrade included three Schreiber counter-current 2 million gallon aeration basins outfitted with Continuously Sequencing Reactor (CSR) technology, two single-stage, dual point control high efficiency Turblex centrifugal blowers, three 212-ft. diameter final clarifiers, and a new secondary pump station including four return activated sludge (RAS) pumps and two waste activated sludge (WAS) pumps;
- Alum feed system - The alum feed system consists of two 3,650 gallon polyethylene alum storage tanks and three progressive cavity metering pumps. Alum is fed into a manhole upstream from the secondary clarifier splitter box to facilitate mixing of the chemical with the mixed liquor;
- Effluent ultraviolet light disinfection;
- Solids handling – Two 300 gpm centrifuges with landfill disposal.

A flow diagram for the SCWRRF is shown in Figure 1. An aerial view of the SCWRRF is shown in Figure 2.

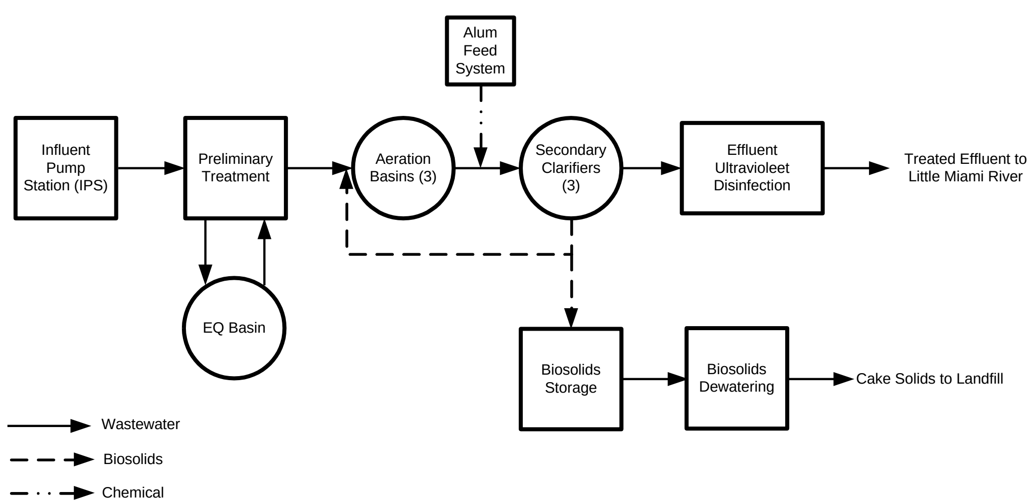

Figure 1 – Flow Diagram for Greene County Sugarcreek WRRF

Figure 2 – Aerial Photograph of Greene County Sugarcreek WRRF

Fundamentals of EBPR

Enhanced biological phosphorus removal (EBPR) using the CSR technology was chosen as the primary means of compliance with effluent TP limits because of its lower life-cycle cost compared with chemical phosphorus removal. At the microbial level, the EBPR process represents a fairly complex interaction of biochemical reactions. Fortunately, a complete and fundamental understanding of the process is not required for successful plant design and operation. In simplest terms, bacteria known as phosphorus accumulating organisms (PAO) release stored phosphorus under anaerobic conditions (primary release) and uptake the phosphorus released and excess phosphorus in a subsequent aerobic stage. Based on the present state of knowledge, the six most critical factors for reliable EBPR are as follows:

- A sufficiently high ratio of influent readily biodegradable chemical oxygen demand (rbCOD) such as volatile fatty acids (VFAs) to facilitate primary phosphorus release
- A strictly anaerobic zone to minimize competition with denitrifying bacteria and promote primary phosphorus release
- Efficient sedimentation to capture phosphorus sequestered in biomass
- Maintain at least 2 mg/L dissolved oxygen (DO) in the initial segment of the oxic zone to maximize phosphorus uptake
- Minimize secondary release of phosphorus due to excessive retention time in bioreactors, clarifiers, and liquid sludge storage
- Minimize microbial competition between phosphorus accumulating organisms (PAO) and glycogen accumulating organisms (GAO).

The Schreiber CSR process was selected for its capability for EBPR. Three stages are created: oxic, anoxic, and anaerobic by turning air on and off. This requires online monitoring of dissolved oxygen and oxidation reduction potential (ORP). A unique feature of the Schreiber unit is that the diffusers are hung from a rotating bridge which bridge provides mixing for when the air is off. In the oxic stage DO is maintained between high and low setpoints by cycling air on and off. BOD is consumed and ammonia is nitrified causing an increase in nitrate. Meanwhile, soluble P is being taken up. As ORP reaches a maximum, the air is shut off and the reactor enters the anoxic stage. During the anoxic stage, nitrates are consumed. A change in slope of the ORP curve indicates that nitrate has been consumed and the reactor is entering the anaerobic stage, at which point the PAOs go to work, taking in readily degradable BOD at the expense of releasing stored P into the wastewater. Ideally, at the end of the anaerobic stage, nitrates are low and soluble P is high. During the subsequent oxic phase, all of the soluble P is taken up.

METHODOLOGY

This case study examined various modes of P removal for a medium-sized wastewater treatment facility. The following methodology was utilized to evaluate performance and capabilities of phosphorus removal systems:

Step 1: Measurement of TP concentration in routine composite samples taken from the influent and final effluent to characterize the extent of various phosphorus removal modes over four summer permit seasons 2007 through 2010:

- Metabolic P uptake,
- Chemical P removal,
- EBPR and chemical P removal – Season 1,
- EBPR – Season 2;

Step 2: Identifying design and operation factors that limited performance;

Step 3: Evaluating the feasibility and effectiveness of proposed solutions to overcome limitations identified in Step 2.

RESULTS & DISCUSSION

Phosphorus removal performance is described over four summer permit seasons (May through October) beginning with 2007 when only influent and effluent monitoring was required. The 2007 season was analyzed to characterize raw wastewater characteristics and to establish baseline metabolic P removal to compare with chemical and EBPR methods utilized subsequently. Chemical removal only was utilized in 2008; the first season for an effluent TP concentration limit went into effect. EBPR was the predominant means of P removal in 2009, although some chemical P removal was practiced when performance degraded late in the season. It was hoped that with the experience gained during the 2009 season that the required effluent TP limit could be achieved with EBPR only in 2010.

2007 – A Time to Prepare

TP removal performance was evaluated in 2007 to obtain an understanding of the extent of metabolic P removal that occurred and what additional TP removal would be required when effluent TP concentration limits went into effect in 2008. Effluent TP concentration and load and wastewater flow for May through October 2007 are shown in Figure 3.

Effluent TP would not have met concentration or load limits. Effluent TP concentration was strongly influenced by wastewater flow with the lowest values occurring at the beginning and end of the season on account of dilution. Concentrations ranged from 0.25 mg/L up to 10 mg/L with an average of 2.3 mg/L and median of 2.0 mg/L. For a median flow of 6.5 mgd, a median effluent TP load of 50 kg per day was calculated per the permit methodology.

On average, influent wastewater contained 5.5 mg/L TP which calculates to a removal of 3.2 mg/L TP without supplemental treatment. Approximately 1 mg/L soluble P is removed for every 100 mg/L BOD removed. Nearly complete removal of 100 mg/L of wastewater BOD was achieved in 2007 resulting in about 1 mg/L soluble P removed with waste sludge. The remaining 2.2 mg/L removed was wastewater particulate P removed by sedimentation.

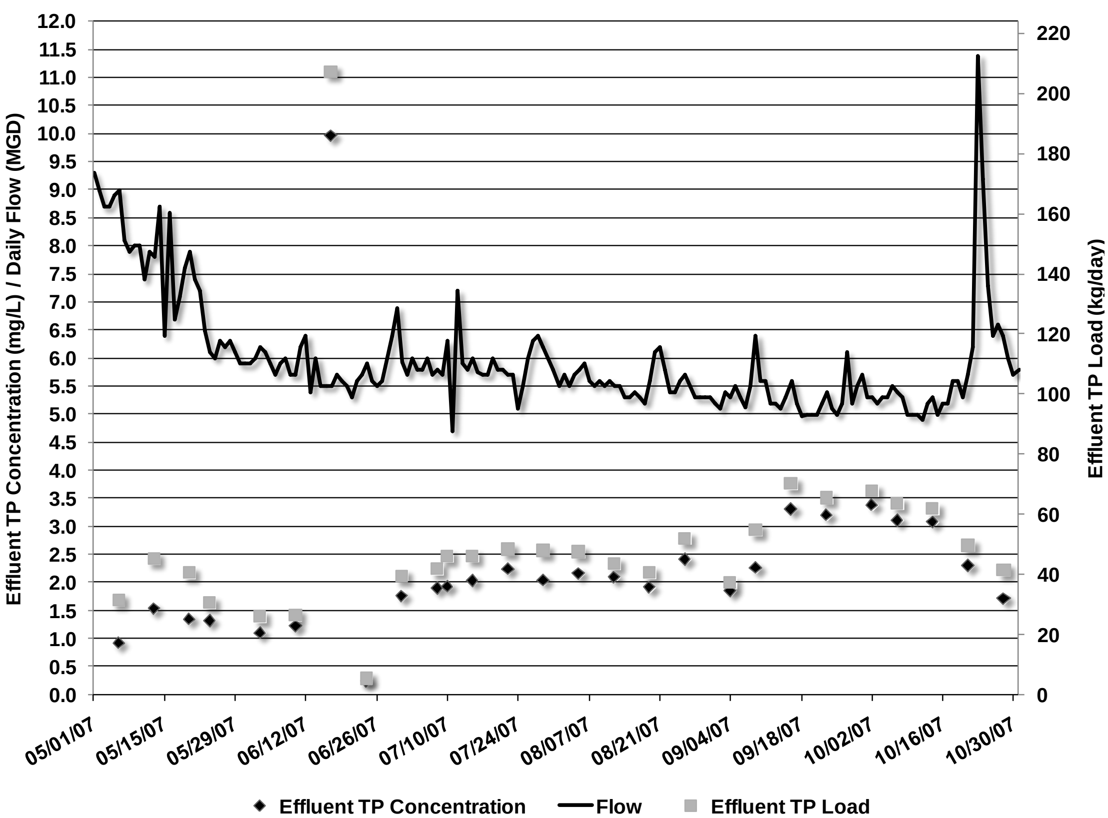

Figure 3 –Effluent TP concentration and load and wastewater flow for May through October 2007

Metabolic P removal was limited by the low organic content of the wastewater and the relatively high ratio of wastewater particulate P to total P. For an average effluent TSS of 10 mg/L and assuming biomass is 1.5% P, effluent soluble P averaged 2.15 mg/L which represents the potential for additional P removal by chemical or biological means.

2008 – A Time to Feed (Alum)
The alum feed system was online in time to utilize chemical P removal in 2008. SCWRRF achieved a very low effluent TP concentration, much lower than required. Operation was simple and reliable but the unexpectedly low Alum dosages required fell outside the operating envelope of the feed system. Effluent TP concentration and load and wastewater flow for May through October 2008 are shown in Figure 4.

Chemical treatment with Alum was demonstrated to be capable of producing a very low effluent TP concentration and meeting effluent TP concentration limits in effect for the first time in 2008. Concentrations ranged from 0.04 mg/L up to 1.07 mg/L with an average of 0.32 mg/L and a median of 0.36 mg/L. For a median flow of 6.3 mgd, a median effluent TP load of 8.6 kg per day was calculated per the permit methodology. Thus the effluent would also have met the load limit had it been in effect.

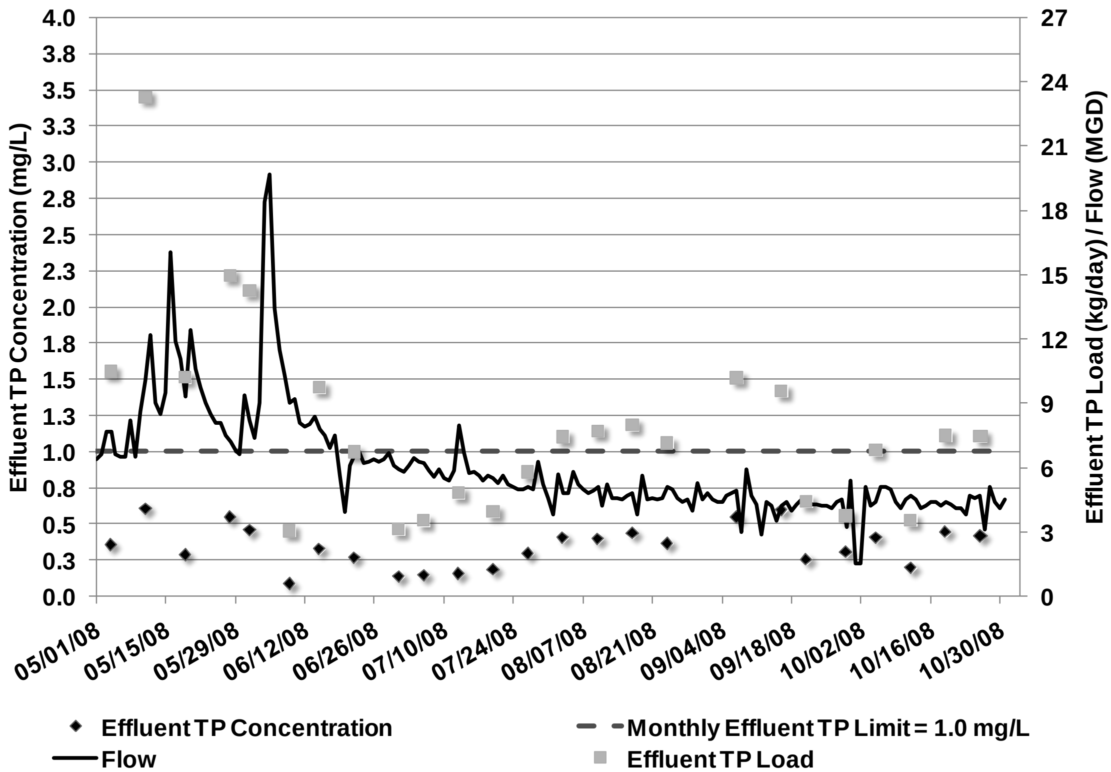

Figure 4 –Effluent TP concentration and load and wastewater flow for May through October 2008

Wastewater characteristics did not limit the potential for P removal using Alum as the majority of the soluble P remaining after metabolic P removal was removed. Remarkably, this was achieved at much lower than expected chemical dosages. One chemical metering pump set to its lowest speed setting was sufficient to provide the treatment required. Thus, the unexpected problem was optimizing chemical usage and operating cost. Operations personnel experimented with intermittent dosing through automatic control of pump operation cycles. However, this led to the discovery that static head was pushing Alum through the pumps when they were 'off', requiring an engineering solution. Two solutions were proposed to restrict flow through offline pumps: replacing the rubber stator or build up the rotor. Neither solution was immediately adopted since it was desired that EBPR, set to go online in 2009 was intended to be the predominant mode of P removal in the future.

2009 – A Time to Learn

CSR mode was online in time to utilize EBPR in 2009. Operation was more complex than chemical treatment and required the interaction of multiple major pieces of equipment. As a result, it was a challenging season with many hard lessons learned. Nonetheless, treated effluent successfully met permit limits for the entire season, although chemical addition had to be implemented late in the season when performance degraded. Effluent TP concentration and load and wastewater flow for May through October 2009 are shown in Figure 5.

EBPR was demonstrated to be capable of an achieving an effluent TP concentration less than 1 mg/L. Concentrations ranged from 0.24 mg/L up to 3.39 mg/L with an average of 0.8 mg/L and a median of 0.66 mg/L. For a median flow of 5.9 mgd, a median effluent TP load of 14.7 kg per day was calculated per the permit methodology.

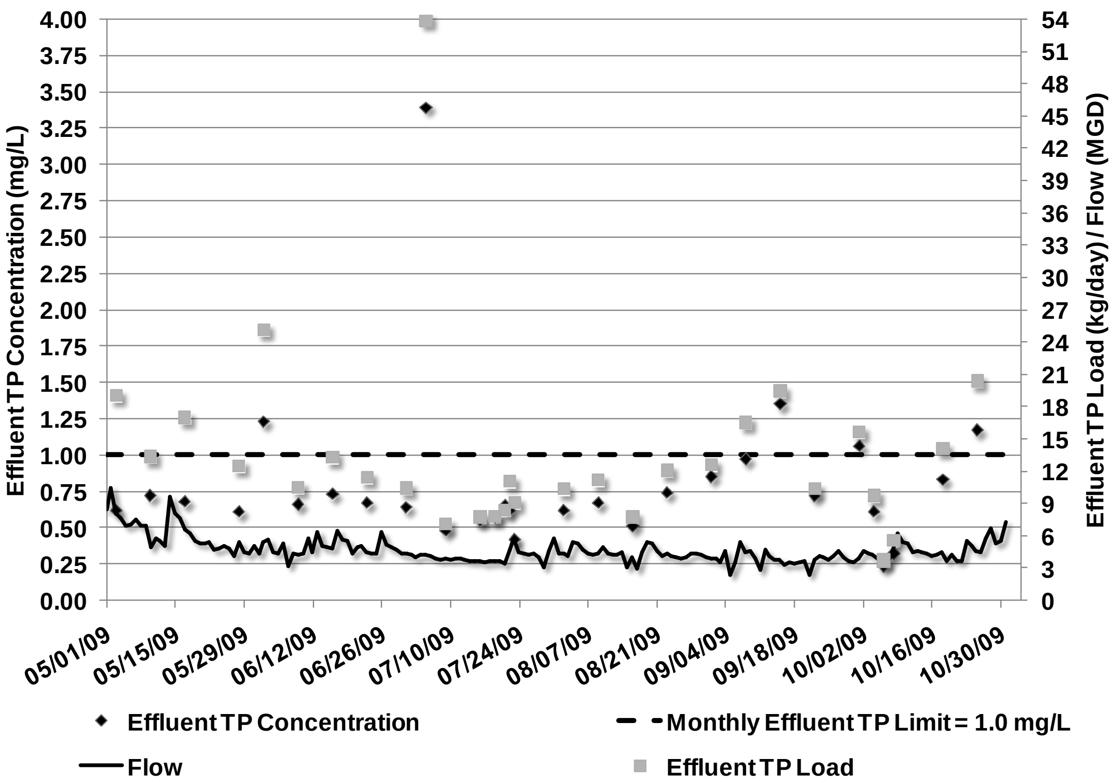

Figure 5 –Effluent TP concentration and load and wastewater flow for May through October 2009

EBPR performance in 2009 can be attributed to many factors. As is typical, there is a learning curve associated with starting a BNR process. The learning curve was made even steeper by the fact that the properties of the CSR are different from a typical plug-flow BNR process. Additionally, this project was the first coupling of the Schreiber CSR BNR process with Turblex, single-stage, variable-output blowers. Tuning of blower parameters required consideration of the cycling of oxic/anoxic/anaerobic stages required for the CSR process. Likewise, typical CSR system parameters, which had been developed based on experience with ‘on’ / ‘off’ blowers required adjustment for use with variable output blowers.

The Schreiber CSR process is different from other BNR processes in that the various metabolic stages are separated by time instead of by space. Also, the diffusers, which are hung from rotating bridges, move through the wastewater, as opposed to the wastewater moving past the diffusers. As a result, the entire contents of the basin must cycle through the stages required for EBPR. The most obvious consequence of this is that some of the P released during anaerobic stages is lost with the overflow. Another consequence is that the reactors are limited by the time it takes to raise dissolved oxygen (DO) in the basin following the anaerobic stage. To maximize P uptake in EBPR systems, DO should not be limiting at the beginning of the oxic stage. Therefore, optimizing the process starts with minimizing the duration of the anaerobic stage to the time it takes for P release, which generally happens readily if sufficient readily degradable substrate is available. For SCWRRF, a 40 minute anaerobic stage was found to work best. The rate of oxygenation can be increased by increasing the rate of air supply at the beginning of the oxic stage. This requires a programming change to increase the short-term aeration rate up to the maximum recommended rate for the diffusers. This strategy has not been pursued. One reason is that increasing airflow would require operating a second blower which would increase operating cost and complexity.

Operations also experimented with the operational configuration of the basins. In order to optimize performance it was desirable to allow each operating basin to cycle independently through oxic, anoxic, and anaerobic stages. However, the air flow demand was less than the minimum air supply rate with only one basin in oxic stage. This led to difficulty keeping the blower out of surge. As a short-term solution, it was decided to synchronize operation such that all online basins would be in the same stage, thereby increasing the minimum air demand above the minimum air supply rate. Also, the number of operating basins was reduced from three to two, increasing the air demand per basin.

Optimization required matching feedback from the instrumentation system with the physical capabilities of the blower system. For instance, although online DO probe was capable of taking many readings per second, the time-scale for adjustment in air flow required a time-scale on the order of minutes for opening and closing valves and re-balancing header pressure. Thus as short-term conditions changed, for instance, as the diffusers hung from the rotating bridge passed underneath the probe, the changes in DO would occur at a rate the blower control system could not keep up forcing the blower system to ‘hunt’ for a stable operating point. One solution to this problem was to utilize data conditioning to smooth out measurements of DO from the online probe. The smoothing period was selected to be the period of rotation of the aeration bridges, roughly three minutes. Additionally, it was necessary to optimize dead band, which is the programmed range below and above the DO setpoint in which the air supply would not be adjusted. It was found that a deadband of up to +/- 0.3 mg/L would allow satisfactory operation.

2010 – A Time to Dance

EBPR has been much more successful so far in 2010. Effluent TP concentration and load and wastewater flow for the first six weeks of summer 2010 are shown in Figure 6.

EBPR has been demonstrated to be capable of consistently achieving an effluent TP concentration less than 0.5 mg/L. Concentrations ranged from 0.19 mg/L up to 1.9 mg/L with an average of 0.40 mg/L.

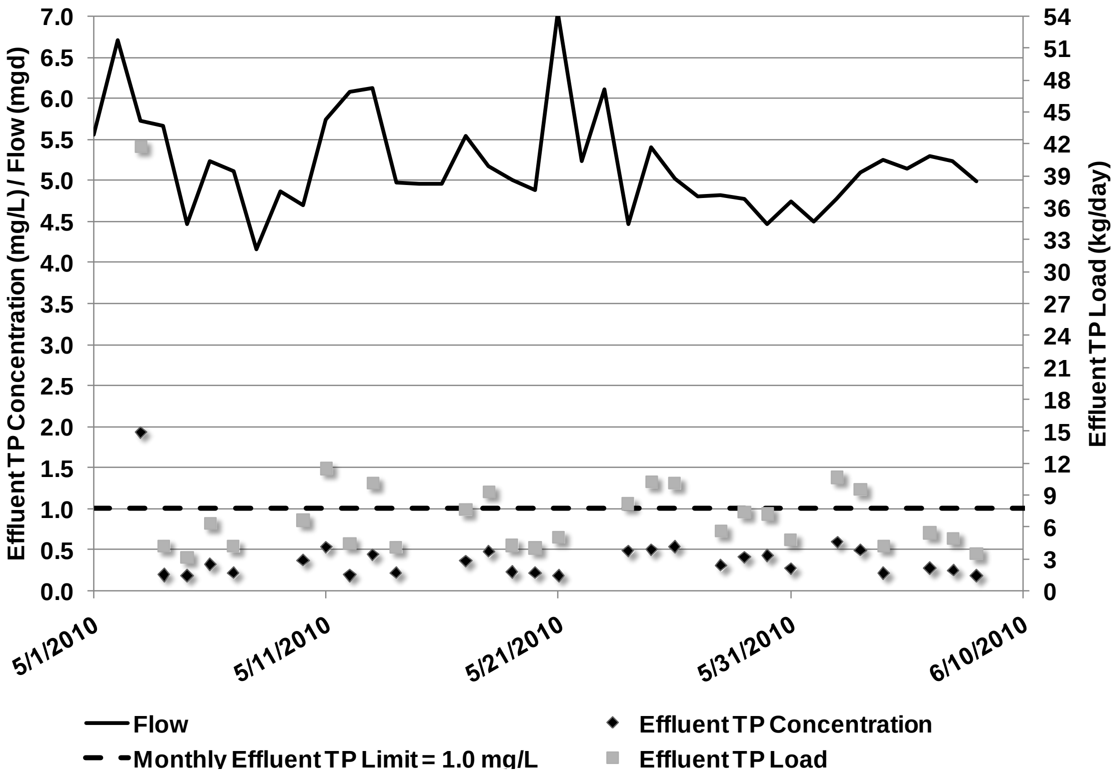

Figure 6 –Effluent TP concentration and load and wastewater flow for May through October 2010

Based on experience with EBPR, the optimized operating parameters shown in Table 2 have been targeted in 2010.

Table 2 – EBPR Operating Parameters for the Sugarcreek WRRF

Operating Parameter	Target
Max ORP setpoint (for switch from oxic to anoxic)	+100 mV
Minimum ORP setpoint (for switch from anoxic to anaerobic)	-100 mV
Anaerobic timer setting (for switch from anaerobic back to oxic)	40 minutes
Oxic DO setpoint	2.2 mg/l
MLSS	2,000 mg/L
F:M	0.07 to 0.10
Solids Retention Time	18 to 20 days

CONCLUSIONS

The conclusions from this case study based on four years of operation are as follows:

- Supplemental TP removal was required to meet effluent TP concentration limits;
- Either chemical phosphorus removal or EBPR are capable of meeting an effluent TP concentration limit of 1.0 mg/L;
- EBPR operation was more complex than chemical phosphorus removal and required one season of operation to understand how to integrate appropriate process parameters with the capabilities of instrumentation and control systems for optimized performance;
- Successful BNR operation using the Schreiber CSR process with Turblex single-stage, variable output centrifugal blowers requires careful consideration of programming and communication between the control systems that control the CSR and blower systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Shawn Hollon, Ron Volkerding, Jim Hays, Turblex, and Schreiber Water.

REFERENCES

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