



Pilot Project Report

Phosphorus Removal from Wastewater
Located at a Municipal Wastewater Treatment Plant in Florida

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Executive Summary

A phosphorus removal pilot project was conducted at a municipal wastewater treatment plant (WWTP) in southeastern Florida in November and December, 2007. The purpose of this project was to provide a treatment process to maintain a total phosphates limit of 0.01 mg/L in the discharge water. Two Blue PRO[®] reactive filtration configurations were able to meet the required discharge permit.

Blue Water Technologies, Inc. (Blue Water) provided a Blue PRO[®] series system, comprised of two reactive filters with peripherals sized to treat an average flow of 10 gpm. The two Blue PRO[®] reactive filters were run in series after the secondary clarifiers. The system was able to consistently produce <0.010 mg/L total phosphorus for discharge with a chemical dose of <10 mg/L Fe in each filter pass. Two chemical dosing solutions were found to produce the required result, providing options to the plant.

Capital and operating costs for Blue PRO[®] are very low compared to competing technologies. Blue PRO[®] is designed to be gravity fed, and typically uses only one process chemical for phosphorus removal. No adjustments for alkalinity or pH are needed. The O&M costs are comprised chiefly by chemical costs and the cost of operating a compressed air system for the filter air lifts.

Project results include:

- The Blue PRO[®] series system pilot unit was able to meet the plant's current total phosphates discharge level, <0.01 mg/L total phosphates.
- Ortho-phosphate concentrations were often below the detection limit of the analytical method, 0.0023 mg/L.
- Two alternative chemical dosing solutions were found to meet the required discharge limit, the best solution was <10 mg/L Fe from a ferric blend (CB-9001F, CCI Chemical Corporation) per pass.
- Blue PRO[®] significantly reduced turbidity, with effluent readings <0.2 ntu. Blue PRO[®] is accepted as the filtration component for water reuse applications.
- The effluent iron concentration was maintained below 0.3 mg/L Fe, which is the level that may begin to interfere with UV disinfection.
- No other chemicals are required for this process.
- No backwash of the system or exchange of media is necessary; the reactive filter media continually regenerates.
- Application of the Blue PRO[®] reject recycle option at full-scale is expected to lower the secondary effluent phosphorus concentrations at the facility, further improving results. The reject recycle option is an easy way to handle waste from the Blue PRO[®] process with potential bonus beneficial effects, such as improved sludge dewatering and odor control.

Introduction

The purpose of this pilot project was to demonstrate phosphorus removal to low levels at a municipal wastewater treatment plant in Florida. The plant includes headworks, oxidation ditches, and secondary clarifiers before disinfection and discharge. The range of flow rates at the plant is 0.5-1.0 MGD. In the future the plant will need to meet a discharge limit of 0.01 mg/L total phosphates.

Most phosphorus regulations are written for control of total phosphorus (TP) in the discharge stream. Total phosphates, a subset of TP, may include ortho-phosphate (OP) as well as other phosphate species, such as poly-phosphate. Through extensive research with the Blue PRO[®] reactive filtration process Blue Water has developed processes which remove all of the various forms of phosphorus, and has achieved <0.010 mg/L TP at full-scale.

Blue Water's phosphorus removal technology is the patent-pending Blue PRO[®] reactive filtration process, which is distinguished from other processes by its mechanism of removal. Blue PRO[®] optimizes adsorption of contaminants by hydrous ferric oxide (HFO) coated sand, rather than relying on coagulation-filtration. Adsorption within the filters lowers contaminants to extremely low concentrations by overcoming equilibrium and diffusion limitations. Continuous regeneration of the reactive filter media is accomplished by using a moving bed filter to constantly grind the surface of the media, creating fresh sites for new HFO coating. This process creates unusually high adsorptive capacity, even greater than aged iron oxide-coated sand (IOCS) media. For this reason no backwashing or exchange of media is necessary, which minimizes cost and O&M labor.

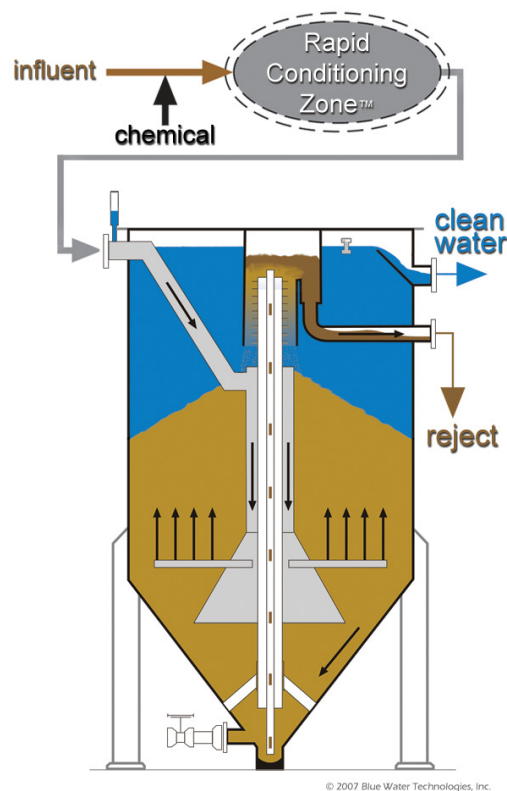


Figure 1. Blue PRO[®] process diagram.

The Blue PRO[®] process is depicted in Figure 1. Influent wastewater enters at the left of the diagram. A commonly-available water treatment chemical is added to the wastewater before it passes into the rapid

conditioning zone. The Blue PRO[®] process preferably uses ferric chloride or ferric sulfate for continuous regeneration of hydrous ferric oxide coated media for adsorption of phosphorus. Either of the iron metal salts may be used depending on current prices, preference of the operators, etc. Doses as ferric for the Blue PRO[®] process have been shown to be the same at full-scale as found in pilot-scale results. The rapid conditioning zone allows the proper contact time for the mixture to optimize the adsorption process. The mixture enters the moving bed sand filter through distribution arms at the bottom of the sand bed, and then flows upward through the sand bed.

After filtration, treated water discharges from the top of the filter on the right. Internally, the sand moves slowly from top to bottom, then returns to the top of the filter via an airlift located in the central assembly. After adsorption, the iron and phosphorus are subsequently abraded off the sand both in the sand bed and in the airlift. A washbox at the top of the filter separates sand from iron and phosphorus waste particulates. The washbox and airlift are modified specifically for the Blue PRO[®] process. The sand is retained within the filter and falls back to the top of the bed; the residuals, including the iron and phosphorus or other contaminants, exit in a reject line.

Depending on the influent phosphorus concentration and the targeted permit level, a plant may require one pass through Blue PRO[®], or may run the filters in series to attain even lower TP concentrations. The final phosphorus concentration may also be lowered with recycle of the Blue PRO[®] reject stream to the plant's secondary system. In this case, phosphorus is removed with solids from secondary clarifiers. This reject recycle option can add 60-80% additional phosphorus removal without additional chemical dosing at the plant. At full-scale the Blue PRO[®] process is able to meet the lowest TP concentrations available, as low as <0.010 mg/L P.

From the Blue PRO[®] platform, Blue Water can provide further customization for specific customer needs or to accommodate unusual chemistries in wastewater streams. An example upgrade is Blue PRO[®] Plus for enhanced phosphorus removal and solids separation. This upgrade is effected by adding oxidation, resulting in catalytic oxidation capabilities within the reactive filter.

Blue Water is proud to offer a broad platform of water treatment technologies, from primary wastewater treatment to advanced effluent polishing steps. Blue Water strives to meet the customer's need cost-effectively, considering both capital expense and ongoing operations and maintenance costs. Additionally, Blue Water keeps an eye on the future by looking for sustainability in our technologies, including environmentally-friendly materials and energy conservation.

Methods

Pilot unit equipment included two Centra-flo[™] continuous backwash filters with filtration area of 3 feet (CF-3), with internals modified for the Blue PRO[®] process. Each reactive filter was mounted on a trailer with a control system, influent water pump, air compressor, chemical containment, chemical pumps, ozone generator, and various meters, valves, and appurtenances (see Figure 2).

The reactive filters were configured in series to treat the plant's secondary clarifier effluent. The Blue PRO[®] system is simple and easy to operate, with only four operational parameters: influent flow rate, reject flow rate, air flow rate, and chemical dose. Influent flow, reject flow, and air flow have optimized values that do not change significantly between locations for phosphorus removal from wastewater. The optimized chemical dose is determined for each site individually, based on local water chemistry.

The average hydraulic loading rate for the Blue PRO[®] process is 3.5 gpm/ft², corresponding to approximately 10 gpm for the CF-3 filters used in this pilot. The load may be increased depending on how long the loading is expected to last and how stringent the site's permit is regarding performance excursions. Generally a maximum loading rate of 6 gpm/ft² is preferred to maintain phosphorus removal performance. The loading may be decreased to a relatively small flow rate, or since the filters are

installed in a modular fashion, individual filters and the Blue PRO® process may be shut off intermittently for low flow periods at a plant. The loading may be increased significantly to let large flows pass, for example 8 gpm/ft² in wet weather flows, although process performance may suffer.



Figure 2. Blue PRO® pilot equipment in Florida.

Throughout the project, the average influent flow to the first pass filter was 11 gpm and the average influent flow to the second pass was 8 gpm. Reject flow rates ranged between 2.5-3 gpm per filter. Note: pilot units have a higher percentage reject flow rate than full-scale filters, due to minimum flow needed for proper separation in the washbox. The typical reject percentage for full-scale Centra-flo™ and Blue PRO® installations is 7% of the flow. The final effluent and reject streams were discharged into ponds via gravity flow. Air flow is used to return sand to the top of the filter. For CF-3 filters the air flow rate is generally 10-15 scfh; 13 scfh was used during this pilot.

Chemical optimization for the Blue PRO® process consists of varying the iron chemical dose to create the proper hydrous ferric oxide sand coating to achieve the desired phosphorus effluent, and to maintain a low iron effluent. Time constraints of the pilot did not allow for complete optimization, although final operational parameters are expected to be close to those used during the pilot. Further optimization at full-scale may allow lower chemical doses, particularly where the reject recycle option is employed.

The pilot project was conducted in November and December, 2007. Trials in November were used for process optimization to determine chemical dosing. Based on results, two configurations were run at steady-state in December to demonstrate the pilot objective of <0.01 mg/L total phosphates. The chemicals used were ferric chloride from a 40% FeCl₃ solution, ozone generated with pilot equipment, and a proprietary ferric blend (CB-9100F) obtained from CCI Chemical Corporation. Chemical doses for the first and second reactive filters in each configuration are shown in Table 1.

Table 1. Process configurations and chemical doses.

Configuration	Dates	Chemical Doses
Set-Up	Nov 5-7	
Optimization: Blue PRO [®] series system	Nov 8-14	First Pass: FeCl ₃ *, 12 mg/L Second Pass: FeCl ₃ , 15 mg/L
Optimization: First pass Blue PRO [®] Second pass Blue PRO [®] Plus	Nov 15-19	First pass: FeCl ₃ , 12 mg/L Second pass: FeCl ₃ , 15 mg/L; ozone, 0.5 mg/L
Steady-state: Blue PRO [®] Plus series system	Dec 12-17	First pass: FeCl ₃ , 10 mg/L; ozone, 0.5 mg/L Second pass: FeCl ₃ , 10 mg/L; ozone, 0.5 mg/L
Steady-state: Blue PRO [®] series system	Dec 17-19	First pass: CB-9100F*, <10 mg/L Second pass: CB-9100F, <10 mg/L

* Iron chemical doses are given as Fe.

Sample points included secondary effluent, Blue PRO[®] effluent, and reject lines. Blue Water personnel collected grab samples for field analytical methods and other recorded measurements (see Table 2).

Table 2. Field measurements and analytical methods.

Parameter	Units	Field Method or Instrument
Total iron, Fe	mg/L	Hach DR 890 colorimeter
pH		Hach handheld SensIon meter and probe
Alkalinity	mg/L	Titration
Temperature	°C	Hach handheld SensIon meter and probe
Turbidity	ntu	HF Scientific, Inc. MicroTol meter and Hach 2100 Series Portable Turbidimeter
Headloss	inches	Sight glass, pressure gauge
Influent flow	gpm	Flow gauge
Reject flow	gpm	Bucket and stopwatch
Airflow	scfh	Dwyer Instruments RMB-54-SSV rotameter
Bed turnover	hours	Custom bed turnover measurements devices

For low level phosphorus analyses, third-party analytical services were provided by KSA Labs, a local commercial laboratory (see Table 3). Influent and effluent, 24-hour composite samples were collected by KSA, with pooling of discrete hourly samples. Sample container type, sample submission requirements, labels, and chain-of-custody forms were determined and/or provided by KSA. Total phosphorus and ortho-phosphate were determined by KSA with Standard Method SM 4500-P.

Results and Discussion

During the optimization trials in November the Blue PRO[®] and Blue PRO[®] Plus processes were tested with varying iron and ozone doses. Phosphorus results are shown in Table 3 for these trials. The Blue PRO[®] series system with ferric chloride did not produce acceptable results; the OP concentration was well over the site's total phosphates limit. The trial with Blue PRO[®] for the first pass and Blue PRO[®] Plus for the second pass produced better results, with a final OP concentration averaging 0.049 mg/L.

Table 3. Average phosphorus results during optimization trials.

Configuration	TP Inf mg/L	TP Eff 1 mg/L	TP Eff 2 mg/L	OP Inf mg/L	OP Eff 1 mg/L	OP Eff 2 mg/L
Optimization: Blue PRO [®] series	2.94 ± 0.44; n=6*	0.884 ± 0.542; n=6	1.269 ± 0.668; n=6	2.82 ± 0.34; n=6	0.418 ± 0.239; n=6	0.550 ± 0.263; n=5
Optimization: 1st pass Blue PRO [®] 2nd pass Blue PRO [®] Plus	2.43 ± 1.28; n=5	0.799 ± 0.46; n=6	0.143 ± 0.180; n=9	2.60 ± 1.49; n=5	0.367 ± 0.224; n=6	0.049 ± 0.085; n=9

TP = total phosphorus; Inf = influent to the pilot; Eff 1 = first pass effluent; Eff 2 = second pass effluent; OP = ortho-phosphate
* Standard deviation; number of samples

Most wastewater treatment plants require no special chemical dosing in the Blue PRO[®] process; ferric chloride is usually sufficient to achieve extremely low phosphorus levels. Occasionally however, wastewater contains a component that makes it difficult to create a proper adsorptive, hydrous ferric oxide coating on the sand. Examples of such a component include organic matter, algae, or phosphorus species which are difficult to remove (i.e., soluble, non-reactive phosphorus). Through extensive research Blue Water has found solutions to these unusual water chemistry problems. This pilot project site had water chemistry that produced poor results with ferric chloride. The cause was not specifically found during the pilot project; algae is suspected. Findings in the optimization trials led to the solutions that were demonstrated in the steady-state trials. Two solutions were found to this site's water chemistry challenges: ozone and a proprietary ferric blend.

Table 4. Phosphorus results from steady-state Blue PRO[®] Plus series system.

Date	TP Inf mg/L	TP Eff 1 mg/L	TP Eff 2 mg/L	OP Inf mg/L	OP Eff 1 mg/L	OP Eff 2 mg/L
12/12/07			0.0391			<0.0023
12/13/07	1.95	0.429	0.0377	1.8	0.400	0.0160
12/14/07	2.21	0.063	0.0121	2.1	0.038	<0.0023
12/14/07			0.0354			<0.0023
12/15/07	2.55	0.201	0.0165	2.5	0.160	0.0058
12/15/07			0.0394			0.0046
12/16/07			0.0040			<0.0023
12/16/07			0.0030			<0.0023
12/17/07	2.46	0.122	0.0250	2.5	0.110	0.0091
Average	2.29	0.204	0.0236	2.2	0.177	<0.0052
Standard deviation	0.27	0.161	0.0151	0.3	0.157	NA

TP = total phosphorus; Inf = influent to the pilot; Eff 1 = first pass effluent; Eff 2 = second pass effluent; OP = ortho-phosphate;
NA = not applicable

Results for the Blue PRO[®] Plus series system trial, utilizing ozone in both filter passes, are shown in Table 4. This configuration produced an average TP effluent concentration of 0.0236 mg/L. The detection limit for OP was 0.0023 mg/L as P; more than half of the samples were below the detection limit. The average

OP effluent was therefore <0.0052 mg/L, under the total phosphates limit of 0.010 mg/L. Only one OP analysis out of nine exceeded the 0.010 mg/L limit.

Results for the Blue PRO® series system trial with a ferric blend are shown in Table 5. In this trial, the many of the TP analyses were below the detection limit for the method, or <0.0029 mg/L as P. The average TP effluent concentration was <0.0044 mg/L. Most of the OP analyses were also below the method detection limit, producing an OP average of <0.0026 mg/L. In this trial, every TP analysis was less than the site’s limit for total phosphates, clearly meeting their discharge requirement.

Table 5. Phosphorus results from steady-state Blue PRO® series system with ferric blend CB-9100F.

Date	TP Inf mg/L	TP Eff 1 mg/L	TP Eff 2 mg/L	OP Inf mg/L	OP Eff 1 mg/L	OP Eff 2 mg/L
12/17/07		0.061	0.0089		0.034	0.0030
12/17/07		0.020	0.0076		0.016	<0.0023
12/17/07			<0.0029			<0.0023
12/18/07	2.29	0.111	<0.0029	2.1	0.086	<0.0023
12/18/07		0.043	<0.0029		0.035	<0.0023
12/18/07		0.016	<0.0029		0.006	<0.0023
12/18/07			<0.0029			<0.0023
12/19/07	2.35	0.032	0.0043	2.0	0.051	0.0037
Average	2.32	0.047	<0.0044	2.0	0.038	<0.0026
Standard deviation	0.042426	0.035	NA	0.1	0.028	NA

TP = total phosphorus; Inf = influent to the pilot; Eff 1 = first pass effluent; Eff 2 = second pass effluent; OP = ortho-phosphate; NA = not applicable

Results for other parameters measured during the steady-state trials are shown in Table 6. Data for pH, alkalinity, and turbidity show the two solutions had similar affects on these water quality indicators. The pH value dropped slightly over two passes through each of the reactive filtration processes; this is expected with use of ferric chemicals. Some alkalinity was consumed across each configuration, again this is expected. The effluent turbidity values are attractive for tertiary effluent. The average effluent turbidity for the Blue PRO® Plus series system was 0.16. The average effluent turbidity for the Blue PRO® series system with the ferric blend was 0.17, although there were only two samples at this configuration.

Table 6. Results for pH, alkalinity, and turbidity from the steady-state trials of Blue PRO® Plus series system and Blue PRO® series system with ferric blend CB-9100F.

Configuration	pH Inf mg/L	pH Eff 2 mg/L	Alk Inf mg/L	Alk Eff 2 mg/L	Turb Inf ntu	Turb Eff 2 ntu
Steady-state: Blue PRO® Plus series	7.31 ± 0.16; n=8*	6.70 ± 0.29; n=8	75 ± 9; n=8	51 ± 11; n=8	2.05 ± 0.31; n=8	0.16 ± 0.04; n=8
Steady-state: Blue PRO® series	7.33 ± 0.26; n=2	6.64 ± 0.14; n=2	75 ± 5; n=2	52 ± 1; n=2	2.19 ± 0.07; n=2	0.17 ± 0.05; n=2

Inf = influent to the pilot; Eff 2 = second pass effluent; Alk = alkalinity as CaCO₃; Turb = turbidity

* Standard deviation; number of samples

Other results include iron concentrations, temperature, and headloss. Iron effluent averages were 0.25 and 0.19 mg/L for the steady-state configurations, below the 0.3 mg/L concentration that may begin to interfere with UV disinfection. Temperature remained around 24 °C for influent and effluent of each configuration. Headloss for the first and second pass in both configurations was 20 inches and 14 inches, respectively.

Conclusions

Two solutions based on the Blue PRO[®] reactive filtration process were able to meet the site's required discharge limit of 0.01 mg/L total phosphates. The availability of two solutions allows the plant some flexibility in choosing a solution that best fits their needs.

The first solution was a Blue PRO[®] Plus series system configuration with 10 mg/L Fe (from ferric chloride) and 0.5 mg/L ozone doses to each pass of the process. This configuration was able to produce average TP and OP effluent concentrations of 0.0236 and <0.0052 mg/L, respectively. Through the use of ozone for catalytic oxidation, this solution may assist the disinfection capabilities of the plant, requiring less chemical use for disinfection.

The second solution, a Blue PRO[®] series system utilizing a ferric blend (CB-9100F) dosed at <10 mg/L Fe per process pass, achieved TP and OP effluent concentrations of <0.0044 and <0.0026 mg/L, respectively. Most of the sample analyses produced results lower than the detection limits for both TP and OP, those limits were 0.0029 mg/L and 0.0023 mg/L. Every analysis for TP was lower than the plant's 0.01 mg/L discharge limit for total phosphates, which is a subset of TP.

At full scale and with more time for optimization the effluent phosphorus concentration may be improved from these trials. Additional process work can be done to optimize chemical dosage. With a full-scale installation of Blue PRO[®] with the reject recycle option, the secondary effluent TP concentration may be lowered by 60-80% without additional chemical use at the plant, further improving results or adding another layer of process stability. With reject recycle, the Blue PRO[®] process residuals do not release phosphorus through the secondary system; P is removed from the plant with the biosolids. Iron in sludge can also improve dewatering and reduce odor. The reject recycle option is an easy way to handle waste from the tertiary phosphorus removal process with bonus beneficial effects.

Both solutions produced excellent turbidity results, <0.2 ntu. This turbidity level easily qualifies for the filtration component of water reuse applications, and the Centra-flo™ filters are accepted for water reuse under California Title 22 and other states' water reuse regulations. This low turbidity value may reduce chemical demand for disinfection. Also implied in the low turbidity effluent are reductions in BOD through removal of particulate material.