

Pilot Testing Reveals Alternative Methods to Meet Wisconsin's Low Level Phosphorus Limits

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ABSTRACT

As part of ongoing efforts to develop a Study of Feasible Alternatives, the City of Fond du Lac, Wisconsin and the City of Waukesha, Wisconsin conducted four separate pilot studies to explore options for meeting upcoming ultra-low total phosphorus (TP) limits in the State of Wisconsin. The tests included multipoint chemical feed using ferric chloride, phosphorus removal using SorbX®-100, Blue Water Technologies BluePRO® filters, and Evoqua Water Technologies LLC's CoMag® ballasted-flocculation system. The primary goal of the tests was to demonstrate the ability to consistently meet the potential TP discharge limit of 0.04 milligrams per liter (mg/L) for Fond du Lac and 0.075 mg/L for Waukesha. The pilot tests took place in 2013, 2014, and 2015.

The multipoint chemical feed and SorbX®-100 pilot tests either did not meet the target or experienced reliability issues in meeting the target. The BluePRO® and CoMag® systems both reliably met the effluent target concentration.

KEYWORDS: Advanced phosphorus removal, multipoint chemical feed, SorbX®-100, BluePRO® system, CoMag® system, magnetite ballasted settling, pilot study, water quality based effluent limit

INTRODUCTION

Nutrients including TP and nitrogen are essential for life. However, excessive nutrients in surface waters can lead to excessive aquatic plant and algae growth. This, in turn, can create unfavorable conditions for recreation and cause reductions in dissolved oxygen to levels that are harmful to aquatic life.

Recognizing the prevalence of excessive nutrients in surface waters, the United States Environmental Protection Agency (USEPA) in 2000 issued recommendations for state nutrient water quality standards (USEPAa, 2000 and USEPAb, 2000). Most states, including Wisconsin,

have elected to develop their own criteria using state-specific scientific approaches that attempt to link nutrient concentrations to biological or recreational impact. In 2010, the Wisconsin Department of Natural Resources (WDNR) adopted numeric TP criteria for all surface waters throughout the state (WDNR, 2010). These standards establish how much phosphorus can be in a body of water without having negative effects, such as contributing to excessive algae growth. The adopted criteria are provided in Table 1.

Table 1. Phosphorus Criteria for Wisconsin Surface Waters.

Waterbody Type	Criterion, mg/L
Rivers (non-wadeable)	0.1
Streams	0.075
Reservoirs	0.03-0.04
Inland Lakes	0.015-0.04
Great Lakes	0.005-0.007

Lower standards for TP in a water body result in more stringent discharge limits on the amount of TP that a water resource recovery center (WRRC) may discharge into that water body. As a part of the new regulations, the WDNR included a conservation of mass calculation for determining water quality-based effluent limits (WQBELs) from the criteria (WDNR, 2011). With this approach, if the upstream concentration of TP exceeds the criterion, the WQBEL will be set equal to the criterion. Each community in Wisconsin faces a different set of constraints and time frames affecting the available options to address the new TP rules. Some point source facilities may have to undergo major upgrades (WDNRa, 2012) to meet TP discharge limits, which have been as low as 0.03 mg/L as a 6-month average in permits reissued to date.

The Fond du Lac WRRC is designed to treat 37,100 cubic meters per day (m^3/d [9.8 million gallons per day (mgd)]) average daily flow with a discharge to Lake Winnebago. According to the WDNR, the lake has a water quality criterion of 0.04 mg/L. The Fond du Lac WRRC utilizes fine screens, grit removal, primary clarification, activated sludge with total N removal, secondary clarification, and ultraviolet (UV) disinfection. Historically, the Fond du Lac WRRC adds aluminum sulfate (alum) to the primary and secondary clarifiers to achieve an interim TP effluent limit of 1.0 mg/L. Like many wastewater treatment facilities in Wisconsin, the Fond du Lac WRRC's discharge permit was recently reissued with an extremely low TP limit. Because the Fond du Lac WRRC discharges to Lake Winnebago, and the current TP concentration in the lake is above the established criterion, the Fond du Lac WRRC is required to meet a future 6-month average limit of 0.04 mg/L.

The Waukesha WRRC is designed to treat 53,000 m^3/d [14 mgd] average daily flow with a discharge to the Illinois-Fox River in Wisconsin. According to the WDNR, the river has a water quality criterion of 0.075 mg/L. The Waukesha WRRC utilizes fine screens, grit removal, primary clarification, activated sludge, secondary clarification, tertiary clarification ("coagulation basins"), sand filtration, and UV disinfection. Currently, the Waukesha WRRC

adds ferric chloride to the secondary clarifiers and coagulation basins to achieve an interim TP effluent limit of 0.7 mg/L. Like many wastewater treatment facilities in Wisconsin, the Waukesha WRRC's discharge permit was recently reissued with an extremely low TP limit. Because the Waukesha WRRC discharges to the Illinois-Fox River, and the current TP concentration in the river is above the established criterion, the Waukesha WRRC is required to meet a future 6-month average limit of 0.075 mg/L.

Given that nearly all WRRCs will require physical modifications to meet these ultra-low effluent TP levels, the WDNR has provided a compliance schedule in the latest Wisconsin Pollutant Discharge Elimination System (WPDES) permit to comply with the future limit (WDNRb, 2012). The Fond du Lac and Waukesha WRRC's compliance schedules are provided in Table 2.

Table 2. The Fond du Lac and Waukesha WRRC's WPDES Phosphorus Compliance Schedules.

Item	Date	
Facility	Fond du Lac	Waukesha
Permit Effective	1/1/13	6/30/13
Operational Evaluation Report	12/31/13	6/30/14
Study of Feasible Alternatives:		
Start	12/31/13	6/30/14
Status Report	12/31/14	6/30/15
Preliminary Compliance Plan	12/31/15	6/30/16
Final Compliance Plan	12/31/16	6/30/17
Achieve Compliance with WQBEL	1/1/2022	6/30/2020

The first step in the compliance schedule is the Operational Evaluation Reports (OER), which was completed in 2013 and 2014 for Fond du Lac and Waukesha, respectively. The purpose of each OER was to determine whether effluent TP could be reduced through source reduction, operational improvements and/or minor facility modifications. As a result of the OERs, several optimization actions were proposed, including the collection of additional TP data [WRRC side streams, hauled wastes, etc.], working with contributing sources (industries and businesses) to minimize TP loads, optimizing/increasing chemical addition for TP removal, and evaluating biological phosphorus removal (Fond du Lac WRRC only). Even with these proposed optimization actions, the results of the OERs indicated that it would not be possible for the Fond du Lac WRRC or the Waukesha WRRC to comply with the future TP WQBEL. Therefore, WRRC staffs began evaluating additional compliance options in 2013 and 2014 as part of the Study of Feasible Alternatives.

The Study of Feasible Alternatives includes the evaluation of compliance options to achieve the TP WQBEL, including advanced TP treatment technologies, watershed-based strategies, and regulatory alternatives. The City of Fond du Lac and City of Waukesha have considered numerous technologies for advanced TP removal. Many of these are relatively new technologies

that are only being used full-scale at a few facilities around the country. To validate the viability and applicability of these technologies, Fond du Lac and Waukesha have performed pilot testing of four of these technologies, which will be highlighted in this paper, and are as follows:

- Test A - The Waukesha WRRC tested full-scale application of multipoint chemical feed using ferric chloride, combined with existing tertiary clarification and filtration.
- Test B - The Fond du Lac WRRC completed a full-scale chemical phosphorus removal test using SorbX[®]-100 to determine the lowest concentration of TP that could be reliably achieved with this compound and without tertiary treatment facilities.
- Test C - The Waukesha WRRC completed a pilot study of the Blue Water Technologies BluePRO[®] filters.
- Test D - The Fond du Lac WRRC completed a pilot study of the Evoqua Water Technologies LLC CoMag[®] ballasted-flocculation system.

METHODOLOGY

Test A

The Waukesha WRRC treatment process includes primary clarifiers, secondary clarifiers following activated sludge treatment, tertiary coagulation/clarification basins, and sand filters as key parts of the process that allow for solids separation. The overall treatment process is shown in Figure 1. Traditionally ferric chloride has been applied to the mixing chambers upstream of the coagulation basins, and TP was settled in the coagulation basins with carryover removed in the sand filters. Sludge from the coagulation basins is returned to the primary influent upstream of the primary clarifiers, which allows residual ferric chloride to remove phosphorus in the primary clarifiers.

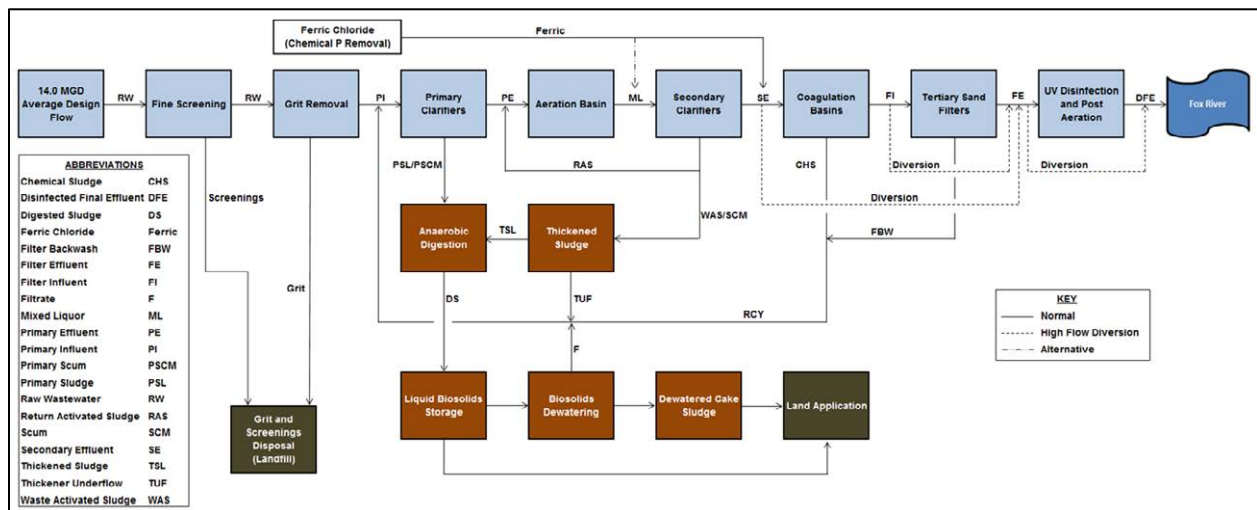


Figure 1. City of Waukesha, Wisconsin, WRRC Process Schematic.

During this pilot test, the ferric chloride feed was split between the traditional application point upstream of the coagulation basins and the aerated channel downstream of the aeration basins. The pilot study was initiated in December 2014 and continued through April 2015. Data from January 15, 2015, through January 30, 2015, has been omitted because of a chemical feed pump malfunction during this period. Throughout the test, orthophosphorus (OP) from the coagulation basin effluent and TP from the plant effluent were monitored.

The Waukesha WRRC is operating at approximately two thirds of its average day hydraulic capacity. The filter sensitivity to hydraulic loading was tested three times during the multipoint chemical feed test. Filters were taken out of service for a limited numbers of days to see whether there were any changes in effluent phosphorus concentration. Filters were removed from service for the following dates: December 15 through 18, 2024, and February 23 through 26, March 2 through 4, and April 11 through 14, 2015.

Test B

The City of Fond du Lac completed jar tests to evaluate the most appropriate phosphorus removal chemical (PRC). The City developed dose-response curves for alum (historical PRC being used at the WRRC), ferric chloride, an industrial aluminum byproduct, and a proprietary rare earth metal chloride (SorbX[®]-100). These chemicals are shown in Figures 2 and 3. Based on the results of the jar tests, a full-scale chemical phosphorus removal test was completed using SorbX[®]-100. The test was run for approximately 60 days, and SorbX[®]-100 was added to attempt to meet target effluent phosphorus concentrations of 0.04 mg/L, 0.4 mg/L, and 0.8 mg/L.

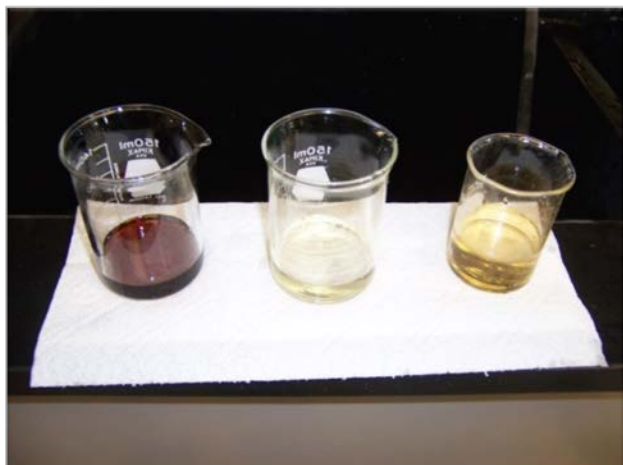


Figure 2. City of Fond du Lac, Wisconsin, Left to Right – Ferric Chloride, Alum, SorbX[®]-100.

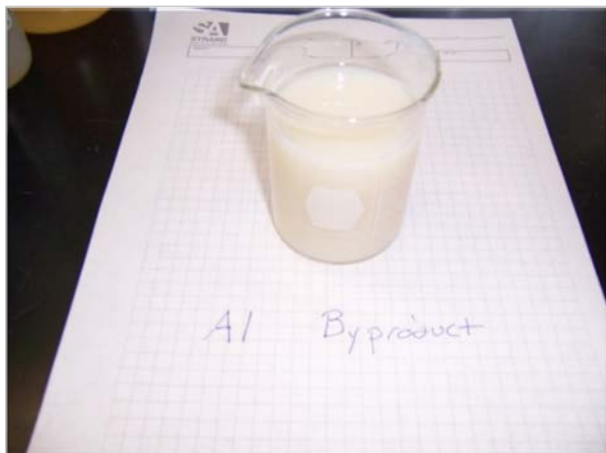


Figure 3. City of Fond du Lac, Wisconsin, Jar Test Aluminum Byproduct.

Test C

The Waukesha WRRRC engaged Blue Water Technologies to complete a pilot study at the WRRRC using its BluePRO[®] filters. BluePRO[®] is an adsorptive filtration system that was tested on secondary effluent at the Waukesha WRRRC. The BluePRO[®] system uses chemically impregnated sand in conjunction with chemical addition to cause the phosphorus in the secondary effluent to precipitate onto the surface of a sand particle and settle out of the effluent. This system consists of a fluidized sand bed through which the wastewater flows and on which the phosphorus is adsorbed. Abrasion within the bed scrubs the adsorbed phosphorus off the sand particle, which is continuously recycled to the head of the plant in the reject stream. Chemical is also recycled to the head of the plant in this reject stream, enhancing phosphorus removal in the primary clarifiers. The system is installed in free-standing fiberglass units in smaller applications or concrete structures in larger installations.

A pilot trailer (shown in Figure 4) was brought to the Waukesha WRRC for approximately two weeks. The pilot was adjusted to meet target effluent phosphorus concentrations of 0.075 mg/L and 0.03 mg/L.



Figure 4. BluePRO[®] Pilot Trailer at Waukesha, Wisconsin WRRC.

Test D

The goal of the CoMag[®] pilot study at Fond du Lac WRRC was to demonstrate that a TP effluent limit of 0.04 mg/L could be consistently achieved. Tests were conducted using three coagulants: alum, ferric chloride, and polyaluminum chloride (PACl). Each coagulant was closed for a period of approximately seven days. For each coagulant, the system was run under steady-state conditions followed by a high solids and a high flow stress test.

Grab samples were taken daily throughout the pilot test from the pilot influent and pilot effluent to form an influent and effluent composite sample. The grab samples and composites were analyzed daily by Evoqua for TP, total suspended solids (TSS), pH, and turbidity. Evoqua also recorded the amount of coagulant and polymer used and the amount of sludge produced. A split sample of the daily composites was provided to the WRRC lab and analyzed for TP, TSS, biochemical oxygen demand (BOD), fecal coliforms, and UV transmittance. Periodic samples were sent to an outside certified laboratory for analysis of TP, ortho-phosphate, soluble nonreactive phosphorus, and metals.

The 50 gpm CoMag[®] pilot trailer is shown on site at the Fond du Lac WRRC in Figure 5.



Figure 5. CoMag[®] Pilot Trailer Onsite at Fond du Lac, Wisconsin WRRC.

RESULTS

Test A

Results of the Waukesha WRRC multipoint chemical feed pilot test are shown in Figure 6. There are several periods of time where the plant effluent TP was lower than the effluent target limit of 0.075 mg/L such as during the second half of December 2014 and the majority of March 2015. There were also periods of time where the effluent TP are higher than the target effluent limit. The filter hydraulic loading rate and corresponding effluent TP is shown in Figure 7. Under routine operating conditions, the filters are loaded between 1.5 and 2 gallons per minute per square foot of surface area (gpm/ft²). The stress test conditions increased the loading rate to between 2.5 and 3 gpm/ft². In all but one of these hydraulic stress tests, the effluent TP increased to a level significantly higher than the effluent target. The design capacity of the filters is 5 gpm/ft². Effluent TP would be expected to be even higher at those loading rates.

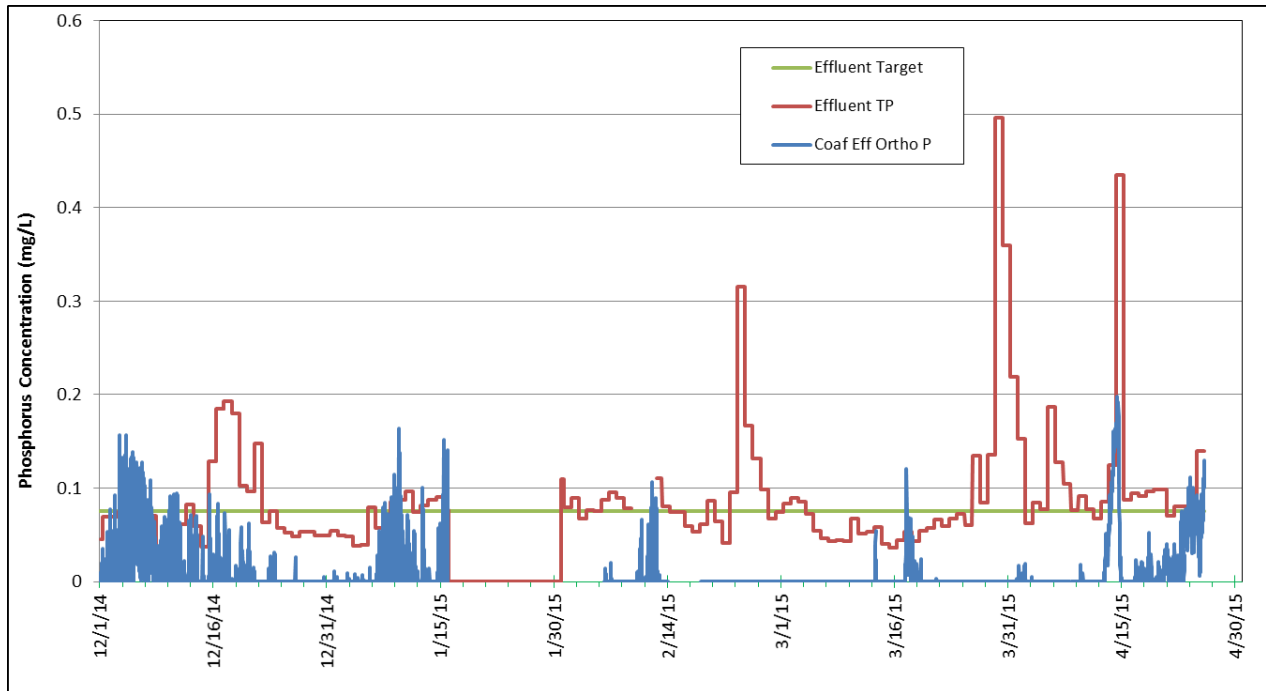


Figure 6. Waukesha, Wisconsin, WRRC Multipoint Chemical Feed Test A Data.

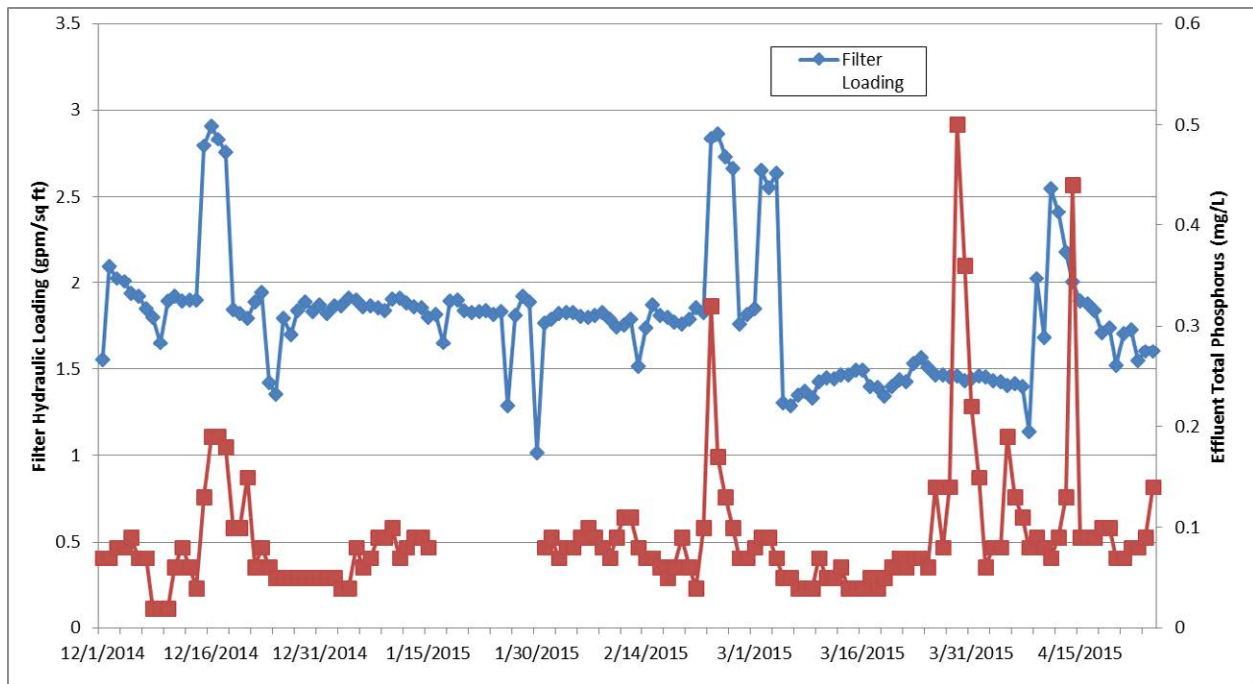


Figure 7. Waukesha, Wisconsin, WRRC Filter Hydraulic Loading Test A Data.

Test B

Results of the Fond du Lac SorbX[®]-100 trial are shown in Figure 8. SorbX[®]-100 was fed at an average rate of 459 gallons per day (gpd) from November 8, 2014, through December 17, 2014. This resulted in an average effluent TP of 0.21 mg/L and an average effluent OP of 0.05 mg/L. From January 5, 2015, through April 14, 2015, the dose of SorbX[®]-100 averaged 180 gpd, and the resulting effluent TP was 0.66 mg/L and effluent OP was 0.47 mg/L. The WRRC monitored soluble non-reactive phosphorus (SNRP) during this test as well. SNRP changes but has trended as high as 0.09 mg/L. Ongoing testing at the WRRC has successfully reduced the SNRP to 0.04 mg/L using high chemical dosages. The economic impact of using high chemical dosages will need to be considered. In addition, there is not adequate information available at this time to determine the long-term sustainability of these results.

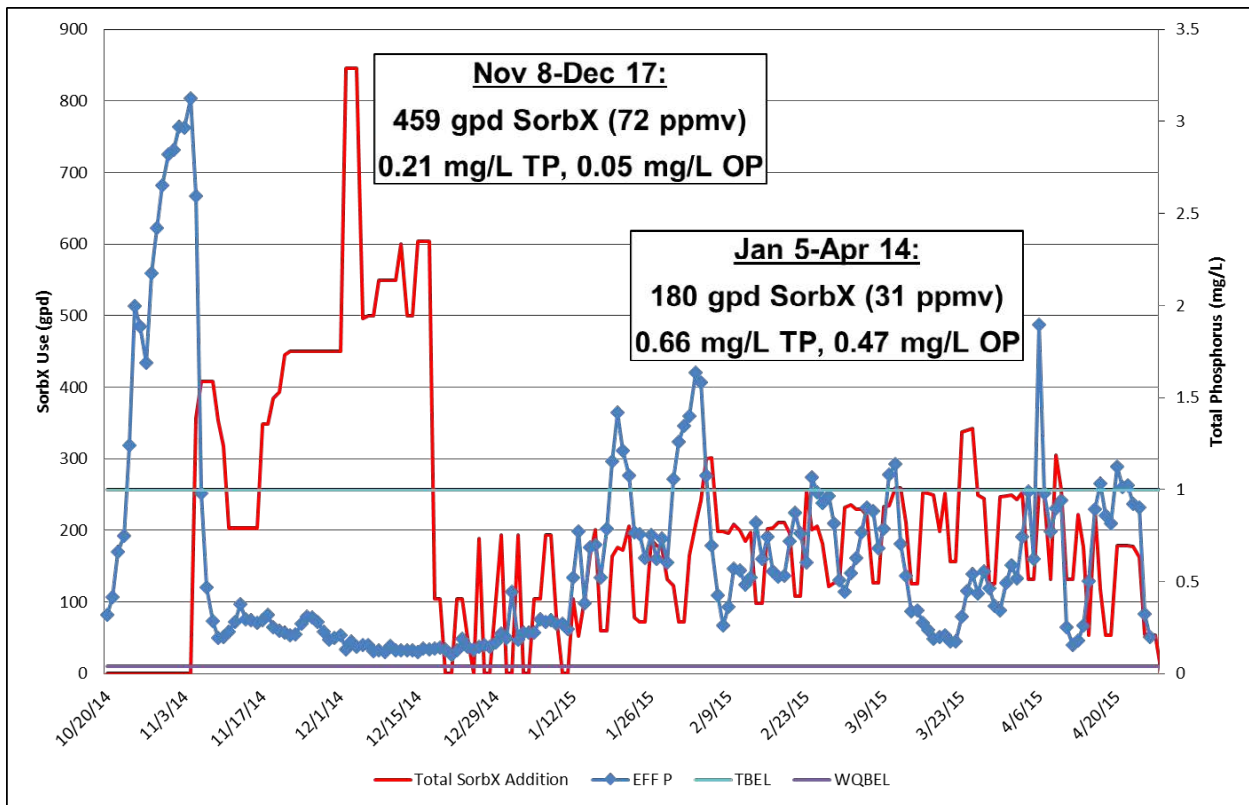


Figure 8. Fond du Lac, Wisconsin, WRRC SorbX[®]-100 Test B Data.

Test C

Results of the Waukesha WRRC BluePRO[®] pilot test are shown in Figures 9 and 10. The pilot test was able to successfully produce an effluent water quality that was below the 0.075 mg/L water quality target and the 0.03 mg/L water quality target. It accomplished this by using a single-pass through one of the BluePRO[®] sand filter beds for the 0.075 mg/L effluent TP target value and a two-pass configuration for the lower, 0.03 mg/L, effluent TP target value.

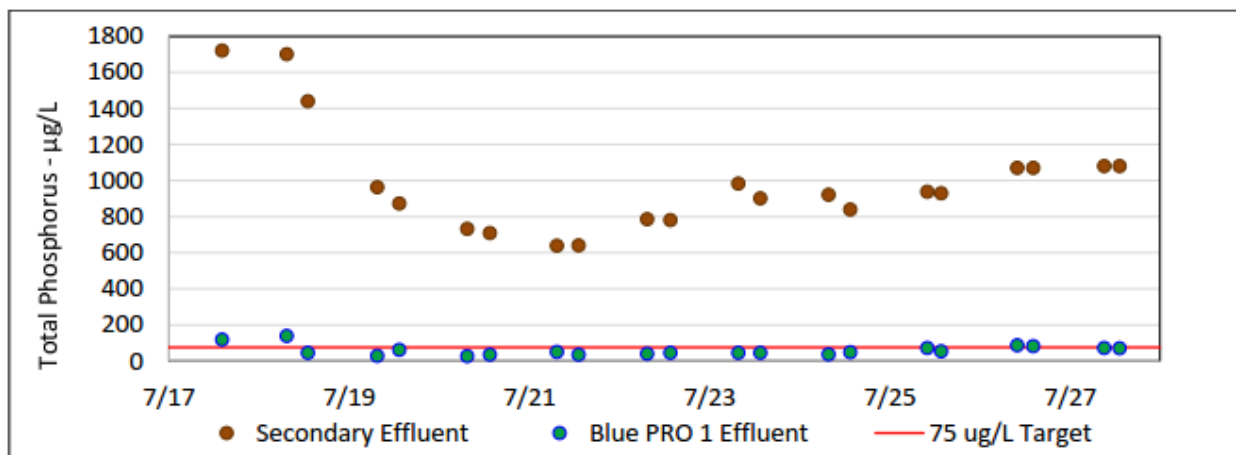


Figure 9. Waukesha, Wisconsin, WRRRC BluePRO® Single-Pass Pilot Test Results.

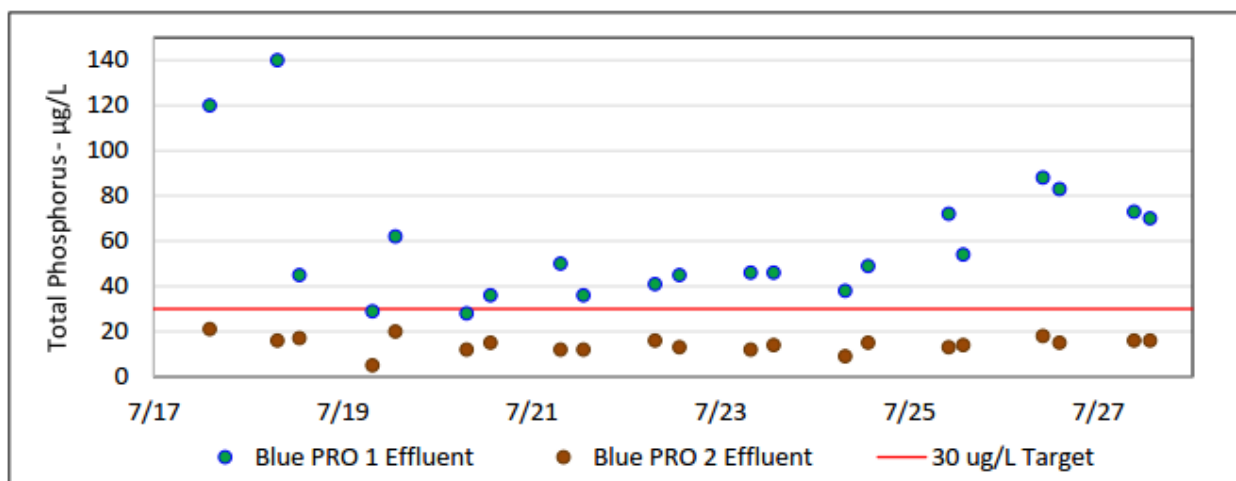


Figure 10. Waukesha, Wisconsin, WRRRC BluePRO® Two-Pass Pilot Test Results.

Test D

The results obtained from the pilot test represent CoMag® performance following multipoint chemical addition. The average TP, TSS, turbidity, and UV transmittance values measured during the testing period for each coagulant are provided in Table 3. It should be noted that these averages include the hydraulic and solids stress test values and values measured during the development of the dose response curves. The coagulant concentration was purposely varied from an overdose condition to an underdose condition to identify the optimum coagulant dose to meet the 0.04 mg/L effluent TP limit. The optimum coagulant and polymer dose was determined using a target effluent concentration of 0.03 mg/L. The chemical requirements for each coagulant to meet this target are provided in Table 4.

Table 3. Average values measured during pilot study for three different coagulants. Note the average values include both the hydraulic and solids stress test values. Analysis provided by Evoqua Water Technologies LLC and the City of Fond du Lac, Wisconsin.

Parameter	Pilot Sample Location	Alum	Ferric Chloride	PACl
TP (mg/L)	Influent	1.0	1.0	0.9
	Effluent	0.039	0.025	0.036
TSS (mg/L)	Influent	28.9	19.3	25.1
	Effluent	1.6	1.9	3.2
Turbidity (NTU)	Influent	NM	NM	NM
	Effluent	0.24	0.29	0.17
UV Transmittance (%)	Influent	67.5	65.1	67.4
	Effluent	76.0	75.1	79.0

NM = not measured

Table 4. Pilot Study Chemical Requirements to Meet a 0.04 mg/L TP Effluent Limit.

Tested Coagulant	Chemical	Chemical Requirement
Alum	Alum	12 mg/L as Al
	Polymer	0.70 mg/L dry weight
Ferric Chloride	FeCl ₃	24 mg/L as Fe
	Polymer	0.80 mg/L dry weight
PACl	PACl	20 mg/L as Al
	Polymer	0.70 mg/L dry weight

Alum appeared to perform the best as it required the lowest dose (12 mg/L as Al) to meet the 0.04 mg/L limit. The higher dose required for PACl (20 mg/L as Al) to meet the limit is likely attributable to PACl being more highly buffered than alum. Even though PACl has a significantly higher Al⁺³ concentration than alum, it is expected that PACl does not lower the pH as much to make it as effective at reducing TP. Each coagulant also demonstrated significant decreases in TSS, with average reductions of 94.5 percent, 90.2 percent, and 87.3 percent for alum, ferric chloride, and PACl, respectively. Other results from the pilot study were as follows:

- The average effluent turbidity measurements were less than 0.30 for each coagulant.
- Each coagulant demonstrated an average BOD reduction of at least 74 percent.
- Each coagulant demonstrated an average increase in UV transmittance of at least 13 percent.
- Ferric chloride and PACl demonstrated a reduction in fecal coliforms of 99.7 percent (no fecal coliform tests were performed during the alum analysis).

The results of the pilot study were used to better define the coagulant, magnetite, and polymer use and the amount of sludge generated for an economic evaluation of a full-scale installation.

CONCLUSIONS

Test A

The Waukesha WRRC multipoint chemical feed pilot test proved that it is possible to reduce effluent to below the effluent target TP of 0.075 mg/L using this treatment strategy; however, the strategy could not sustain an effluent that met the limit. This was a result of several factors. The existing chemical feed system lacks the redundancy or robustness necessary to meet the demands of the target limit. Reliability is critical when the plant is attempting to meet this effluent quality. Hydraulic stress testing showed that the filters increased TP capture when they are loaded at 2 gpm/ft² or less. With a design capacity of 5 gpm/ft², the WRRC would require a significant expansion to operate at the lower rate required for enhanced TP removal at design flows. Refer to Figures 6 and 7.

Test B

SorbX[®]-100 was able to consistently meet the 0.4 and 0.8 mg/L effluent TP goals throughout the test period. Additionally, the plant noticed some ancillary benefits to using this chemical, such as reduced nuisance struvite formation in the biosolids dewatering process. The SorbX[®]-100 test did not result in effluent quality that was below the effluent target of 0.04 mg/L. This was expected since it was not coupled with a filtration or other tertiary treatment process to remove suspended solids including chemical floc. Fond du Lac is in the process of testing SorbX[®]-100 in other filtration and ballasted settling pilot tests to compare its effectiveness to other phosphorus reducing chemicals such as ferric and alum. If the WRRC used SorbX[®]-100 in combination with a filtration technology, they may be able to meet the target limit. It should be noted that having an SNRP concentration above the target effluent TP limit will create challenges for the WRRC. In subsequent pilot testing, the plant has successfully reduced the SNRP to near 0.04 mg/L; however, this comes at a great financial cost and carbon footprint.

Test C

The single pass BluePRO[®] system produced an effluent that met a 0.075 mg/L effluent TP target and would likely do so as a full-scale application, and the two-pass system met the 0.03 mg/L effluent target. As part of the next phase of its Study of Feasible Alternatives, Waukesha will be developing a full-scale cost opinion for a BluePRO[®] system among other alternatives.

Test D

Overall, the objectives of the CoMag[®] pilot test were successfully met. The CoMag[®] pilot system ran without process upsets or mechanical/electrical issues throughout the duration of the pilot program, and performed very well during hydraulic and solids stress testing. The results of the pilot test indicate that at a pilot scale, the CoMag[®] system is able to consistently treat secondary effluent to a TP effluent concentration of less than 0.04 mg/L with any of the three coagulants tested.

Next Steps

The Fond du Lac and Waukesha WRRCs continue to evaluate alternatives for meeting their target effluent limits through their ongoing Study of Feasible Alternatives development. These facilities are evaluating process improvements as well as watershed solutions like watershed adaptive management and water quality trading and regulatory solutions such as the potential statewide multi-discharger variance. These pilot and full-scale tests provided useful experience and information that will be used in subsequent evaluations. Ultimately, each facility will select the alternative that best fits its needs and economic constraints while providing regulatory compliance.

ACKNOWLEDGEMENTS

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Blue PRO[®] is a trademark of Blue Water Technologies, Inc. CoMag[®] is a trademark of Evoqua Water Technologies, LLC. SorbX[®]-100 is a registered trademark of Molycorp.

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