Evaluation of Blue PRO Process at the Hayden Wastewater Research Facility - Final Summary Report

PREPARED FOR:	Blue Water Technologies, Inc.
PREPARED BY:	William Leaf Bruce Johnson
DATE:	July 12, 2006 (Revised October 23, 2006)
PROJECT NUMBER:	331243.01.RP

CH2M HILL is contracted by Blue Water Technologies, Inc to develop the testing and operations plan for the Hayden Wastewater Research Facility (HWRF), along with providing a report summarizing the findings from the testing program. The HWRF has been constructed by Blue Water Technologies, Inc. to provide a full-scale test of the Blue PRO™ and Blue PRO-CEPT™ reactive filtration system. Blue PRO-CEPT™ is the reactive filtration system where the reject stream is recycled to the front of the treatment plant.

The testing effort includes two major tasks for evaluation of the Blue PRO™.

- Task 1 – Operational Parameter Testing: This task includes the operation of the Blue PRO™ filtration system under various operating and iron dosage conditions, which includes the chemical feed, influent rate, and air rate.
- Task 2 – Long-term Operational Testing: This task includes estimating the reliable effluent total phosphorous concentration that the filters can produce, over a long-term operating period. Records of maintenance and operation are kept during this testing period.

This report provides a summary of the findings from the testing completed to date by Blue Water Technologies, Inc., and includes evaluations of conventional tertiary filtration technologies. A comparison of the results against conventional direct filtration systems using the same chemicals for phosphorus removal is included. An evaluation of other tertiary filtration systems is provided.

System Description

The HWRF is located at the Hayden Regional Wastewater Treatment Plant (WWTP). The Hayden Area Regional Sewer Board operates the WWTF, serving the greater Hayden, Idaho, area. The facility includes preliminary treatment, secondary treatment, and disinfection. Solids handling systems include aerobic sludge stabilization and dewatering. The HARSB WWTP is permitted to discharge effluent to the Spokane River from June 1 to September 30, when the Spokane River flow is greater than 2,000 cfs and from October 1 to May 31. WWTP effluent is conveyed to a land application system during the year when seasonal restrictions against discharging to the Spokane River are in effect.

Table 1 presents the major unit processes located at the HARSB WWTP.

TABLE 1
HARSB WWTP: Existing Unit Processes

Process	Description
Preliminary Treatment	Screening System
	Grit Removal
Secondary Treatment	(2) 0.60-Mgal Oxidation Ditches
	(2) 50-ft-dia Secondary Clarifiers, (1) 60-ft-dia Secondary Clarifier
Disinfection	Chlorine Disinfection
Solids Handling	(1) 0.279-Mgal Aerobic Digester
	Dewatering System
Tertiary Treatment	Hayden Wastewater Research Facility
	(2) 50-ft^2 Filters – Contracted to Blue Water Technologies, Inc. for partial treatment of effluent
	(4) Filter cells (unused)
	(3) 1,500-gal Chemical Feed Tanks – 50% is contracted to Blue Water Technologies, Inc.

The facility treated an average influent flow of 1.2 mgd of wastewater in 2005. During this time, the minimum flow to the WWTP was 0.25 mgd and the maximum flow 2.0 mgd. The HWRF receives a portion of the secondary effluent for use with the Blue PRO™. The HWRF effluent is combined with the WWTP effluent prior to disinfection and discharge. The reject stream from the HWRF is returned to the front of the WWTP.

The Blue PRO™ filtration system includes moving bed filtration technology preceded by chemical addition and the proprietary pre-reactor zone. The moving bed filter used is the Centra-flo continuous backwashing filter manufactured by Applied Process Technologies, Inc., Conroe, Texas. Two 50-ft^2 filters are included within the HWRF. The filtration system can be operated as a single-pass filtration system or dual-pass filtration system.

Analytical Methodology

Industry standard testing methods and procedures were used by HWRF to develop the test results. The testing protocol established by CH2M HILL is presented in Appendix A. The following laboratories complete the analyses:

- Accurate Testing Labs LLC (ATL), Coeur d'Alene, Idaho

- In-house testing by Blue Water Technologies, Inc., Hayden, Idaho
- Hayden Regional Wastewater Treatment Plant laboratory, Hayden, Idaho
- University of Idaho Analytical Sciences Laboratory (ASL), Moscow, Idaho
- University of Idaho Environmental Chemistry and Toxicology Laboratory, part of the Environmental Research Institute, Moscow, Idaho

Table 2 includes the standard testing methods for the associated wastewater constituents.

TABLE 2
Standard Testing Methods

Constituent	Units	Method	PQL	MDL
Total Phosphorus (TP)	mg/L	SM 4500-P	0.01	0.002
Ortho-phosphate (PO4)	mg/L	SM 4110B	0.05	0.01
Total Suspended Solids (TSS)	mg/L	SM 2540D	1.0	0.2
Alkalinity (Alk)	mg/L as $CaCO_3$	SM 2320	0.05	0.01
Biological Oxygen Demand (BOD), 5-day test	mg/L	SM 5210B	2.0	0.4
Total Zinc (Zn)	mg/L	SM 3120	0.013	0.003

Method – from Standard Methods for the Examination of Water and Wastewater, 21st Ed. (2005), APHA, AWWA, WEF

PQL – Practical Quantitation Level

MDL – Method Detection Limit

Test Results

Task 1 – Operational Parameter Testing

Blue Water Technologies, Inc., developed an interim report on December 23, 2005, "Tertiary Facilities Phosphorus Removal Study at the Hayden Wastewater Research Facility". This interim report provides the results from the operational parameter testing. The goal of Task 1 was to determine the performance characteristics of the Blue PRO filtration system given a range of operating conditions, and to optimize the associated operational variables. Four operational parameters were evaluated:

- Subtask 1.1 – Air Use
- Subtask 1.2 – Chemical Use
- Subtask 1.3 – Loading Rate Step Increases
- Subtask 1.4 – Loading Rate Spikes

The operational parameter testing was completed from August 31, 2005 through October 24, 2005. During this timeframe, the influent Total Phosphorus (TP) to the Hayden WWTP ranged from 2 mg/L to 8 mg/L. The variable influent characteristics did prove to impact testing, resulting in the repeat of the chemical use tests.

Subtask 1.1 – Air Use

The filtration system utilizes an air system to control how fast sand is pumped through the continuous backwash filter, controlling the bed turnover rate. Subtask 1.1 monitored the performance of the system given a variation in airflow rates. The phase of testing operated from August 31, 2005 to September 3, 2005. This short time frame included a relatively consistent influent total phosphorus (TP) concentration of approximately 3.5 mg/L. One filter was in service, operating as a single-pass system for the air use test. Table 3 presents the phosphorus removal performance for the filtration system with different airflow rates.

TABLE 3
Subtask 1.1 – Air Use

Air Flow (scfm)	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	Filter Flow Rate (gpm/ft^2)
3.33	3.26	0.297	2.82	0.08	3.60
2.83	3.77	0.67	3.21	0.16	3.54
2.33	3.10	0.35	2.73	0.07	3.48
1.83	3.98	1.00	3.00	0.98	3.22
1.50	3.9	0.386	2.94	0.05	3.22

Chemical Dose – 15 mg/L Fe

Without seeing a significant trend in TP removal performance, the average airflow rate of 2.33 scfm was used for the follow-on performance tests.

Subtask 1.2 – Chemical Dose

Subtask 1.2 was completed in two phases in an attempt to capture a consistent influent TP load and optimize the molar ratio of iron to phosphorus. Subtask 1.2A was completed on September 7, 2005 to September 14, 2005 and Subtask 1.2B was completed from September 19, 2005 to September 24, 2005. During this period, the influent TP varied from 2 mg/L to 7 mg/L. As a result, steady-state conditions were difficult to achieve.

Ferric Chloride ($FeCl_3$) is used by the filtration system prior to filtration. Blue Water Technologies, Inc., notes that ferric chloride creates iron oxide-coated sand promoting an active filtration system. One filter was in service, operating as a single-pass system for the chemical dose tests. Table 4 includes the results from the initial chemical dose test. The calculation of Ferric dose to PO_4 removed molar ratio is included within the table as well. Within this calculation, the non-detect value was assumed to be 0.01 mg/L.

TABLE 4
Subtask 1.2A – Chemical Dose

Fe Dose (mg/L)	Fe:PO_4rem Molar Ratio	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	TSS – Influent (mg/L)	TSS – Effluent (mg/L)	Filter Headloss (in)	Filter Flow Rate (gpm/ft^2)
1.1	4.40	2.09	1.75	1.67	1.42	3	ND	6.64	3.48
2.4	4.44	2.26	1.64	1.86	1.32	4	ND	7.64	3.48
5.3	4.86	2.83	1.44	2.36	1.27	2	ND	6.64	3.44
8.6	4.55	2.73	0.56	2.24	0.35	2	1	6.0	3.42
13.6	7.91	2.51	0.65	2.13	0.41	ND	ND	5.53	3.38
13.6	5.86	3.5	0.28	3.21	0.89	3	1	9.38	3.42
24.7	12.72	2.63	ND	2.41	0.468	2	7	12.53	3.42
30.0	15.71	2.22	0.71	1.92	ND	1	18	14.0	3.38

The results from the second chemical dosage test are presented in Table 5. As in the previous table, the calculation of Ferric dose to PO_4 removed molar ratio is included.

TABLE 5
Subtask 1.2B – Chemical Dose

Fe Dose (mg/L)	Fe:PO_4rem Molar Ratio	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	TSS – Influent (mg/L)	TSS – Effluent (mg/L)	Filter Headloss (in)	Filter Flow Rate (gpm/ft^2)
4.9	3.68	1.98	0.60	1.63	0.30	2	ND	7.12	3.42
6.0	2.33	3.36	0.98	3.15	0.58	2	1	6.59	3.46
11.8	2.78	5.64	1.62	4.93	0.68	3	ND	7.88	3.24
21.9	3.30	6.90	0.94	6.88	0.24	2	1	12.13	3.34
27.6	4.11	7.34	3.75	6.72	ND	2	4	16.83	3.34
29.1	4.55	7.07	3.18	6.40	ND	2	37	17.06	3.40

Subtask 1.3 – Filter Hydraulic Loading Rate (Feedrate)

Subtask 1.3 provided a test to determine the system performance given a variable influent feedrate or hydraulic loading rate. For this task one filtration unit was in operation. The test was operated from October 9, 2005 to October 14, 2005. The results from subtask 1.3 are presented in Table 6.

TABLE 6
Subtask 1.3 – Filter Hydraulic Loading Rate

Feedrate (gpm)	Hydraulic Loading Rate (gpm/ft2)	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	TSS – Influent (mg/L)	TSS – Effluent (mg/L)	Filter Headloss (in)
106	2.1	4.85	1.09	4.65	0.68	2	1	7.11
145	2.9	4.69	1.06	4.18	0.32	4	4	10.50
191	3.8	4.65	1.42	4.03	0.22	6	12	13.27
235	4.7	4.42	1.64	3.63	0.11	6	14	20.73
310	6.2	4.39	1.65	0.70	0.11	1	15	23.67

Chemical Dose – 15 mg/L Fe; Air Rate = 140 scfh

Subtask 1.4 – Hydraulic Loading Rate (Feedrate) Spikes

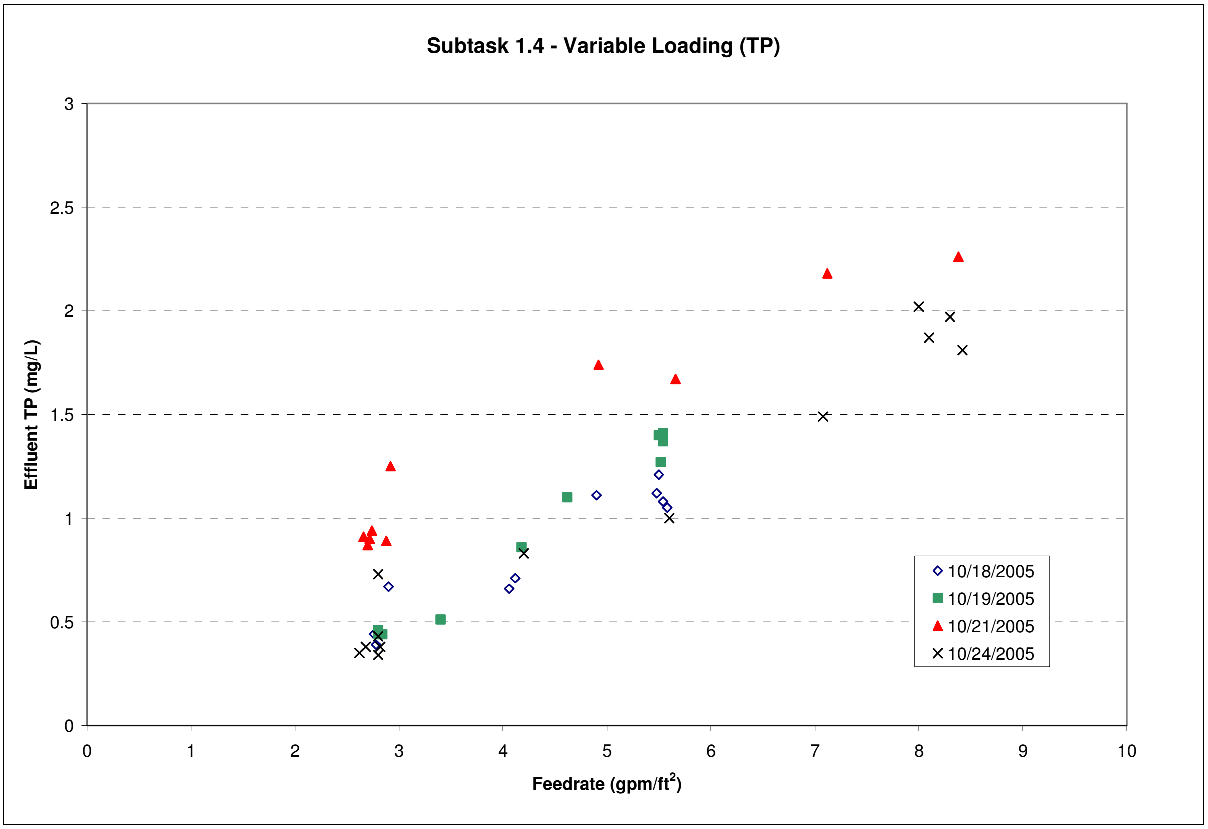
This subtask was completed to simulate excessive loading to the filters. The loading was initially set at 140 gpm to one filter (2.8 gpm/ft2). Over a period of four days, the flow to the filters was increased by 45 gpm to simulate a spike at the facility. The flow increase was completed in four steps over a period of 45 minutes, and then held at two hours at the specific hydraulic loading rate. During the time of testing the secondary effluent phosphorus varied, as shown in Table 7.

TABLE 7
Subtask 1.4 – Secondary Effluent (HWRF Influent) Phosphorus

Date	Influent TP (mg/L)	Influent PO_4 (mg/L)
10/18/05	4.05	3.37
10/19/05	3.9	3.71
10/21/2005	4.79	4.57
10/24/05	3.68	3.32

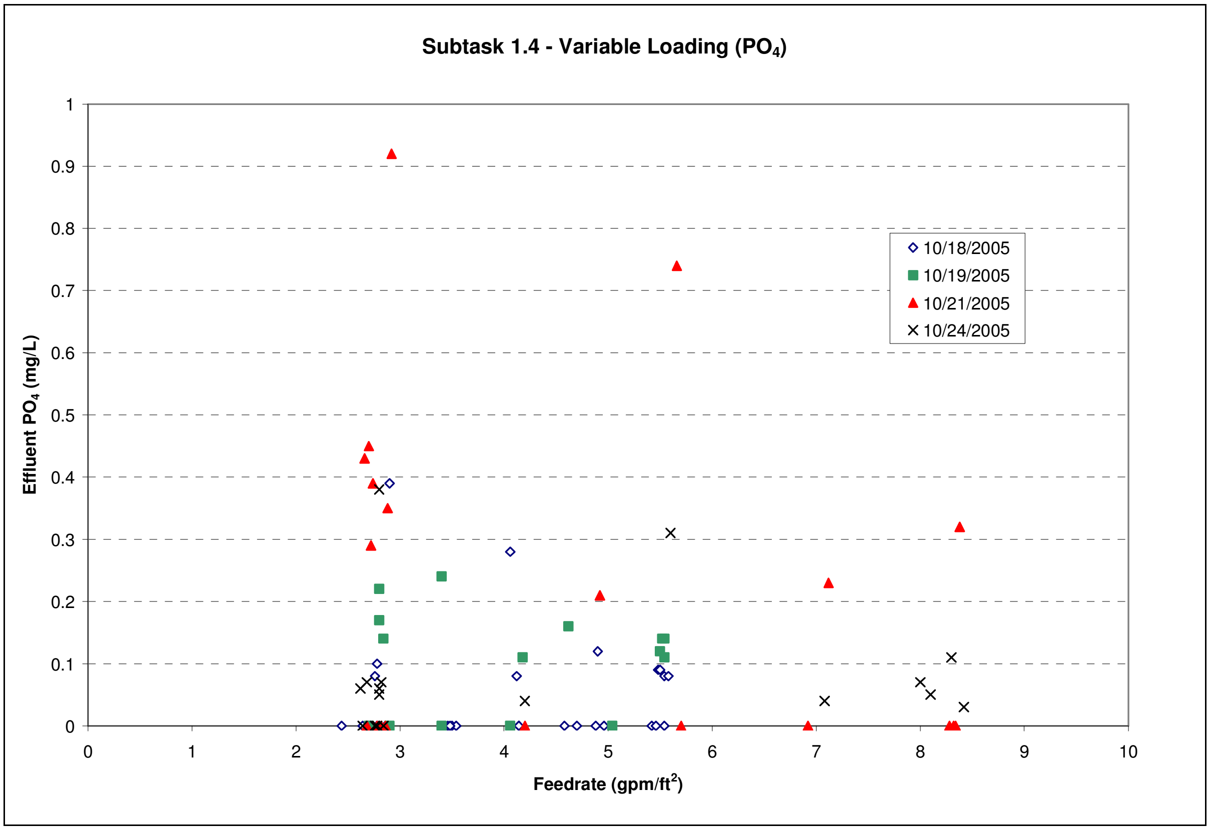
The data are presented in Figure 1, detailing the filter effluent total phosphorus given the influent feedrate.

FIGURE 1



The effluent ortho-phosphate levels from Subtask 1.4 are shown in Figure 2.

FIGURE 2



Task 2 – Long Term Operation

The long term operational testing was documented by Blue Water Technologies, Inc. within the report, "Phosphorus Removal from Wastewater at the Hayden Wastewater Research Facility with Blue PRO™ and Blue PRO-CEPT™", April 2006. The report presents the results from the study starting November 30, 2005 and running to February 2006. During operation in December 2005, the filtration system had not been optimized as a dual-pass system. By January 2006, the system was optimized to operate in a dual-pass scenario. The goal of the study was to determine the performance of the system over a longer operational period. During this period, the filtration system was operated in a steady-state condition, receiving 0.25-mgd of secondary effluent. In addition, the filters were operated as a dual-pass system with the reject stream returned to the front of the facility.

The monthly average results from the long-term test are summarized in Table 8. A complete summary of the long-term operational test is included in the Appendix B.

TABLE 8
Task 2 – Long Term Operation Summary

Date	Loading Rate (gpm/ft2)	Fe:PO_4rem Molar Ratio	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	TSS – Influent (mg/L)	TSS – Effluent (mg/L)	Backwash Flow (gpm)

Filter 1									
Dec	3.44	5.25	3.365	0.509	2.969	0.128	6.81	2.63	15.05
Jan	3.58	24.38	0.683	0.068	0.455	ND	3.16	1.70	15.28
Feb	3.48	20.85	0.780	0.061	0.529	ND	3.57	1.19	14.92
Filter 2									
Dec	3.07	20.46	0.509	0.036	0.128	ND	2.63	0.45	14.99
Jan	2.98	170.05	0.068	0.009	ND	ND	1.70	0.40	15.15
Feb	3.10	220.47	0.061	0.016	ND	ND	1.19	0.79	14.99

Note: System was not optimized as a “dual-pass” system during December 2006. December 2006 PO_4 monthly average calculation includes 0.01 mg/L used for ND values.

January data indicate the lowest average effluent TP achieved at the HWRF. Table 9 includes the minimum and maximum values for that month.

TABLE 9
Task 2 – January 2006 Summary

Parameter	TP – Influent (mg/L)	TP – Effluent (mg/L)	PO_4 – Influent (mg/L)	PO_4 – Effluent (mg/L)	TSS – Influent (mg/L)	TSS – Effluent (mg/L)
Filter 1						
Jan Ave	0.683	0.068	0.455	ND	3.16	1.70
Jan Max	1.370	0.174	1.030	0.050	8.00	5.00
Jan Min	0.190	0.023	0.070	ND	1.00	0.20
Filter 2						
Jan Ave	0.068	0.009	ND	ND	1.70	0.40
Jan Max	0.174	0.018	0.050	0.050	5.00	3.00
Jan Min	0.023	0.002	ND	ND	0.20	0.20

A mass balance around HRWF provides information on phosphorus removal from the system. Secondary effluent provides the influent TP load to the HRWF. The effluent flow from the second stage filter along with the backwash flow from both filters includes the TP load leaving the system. Table 10 details the TP balance around HRWF for the average conditions in January 2006.

TABLE 10
Task 2 – January 2006 Average TP Balance at HWRF

HWRF Influent TP (lbs/d)	HWRF Effluent TP (lbs/d)	Backwash Filter 1 TP (lbs/d)	Backwash Filter 2 TP (lbs/d)	TP Leaving HRWF (lbs/d)	Difference (lbs/d)

1.453	0.016	1.37	0.13	1.52	-0.06

Evaluation of Results

The results from Task 1 and Task 2 of the full-scale testing identify the level of performance anticipated from the Blue PRO™ and Blue PRO-CEPT™ systems. The short term testing assisted with the optimization of parameters for the long-term test. In addition, some physical adjustments to the Blue Water system were completed prior to the start of the long-term test.

As noted in Table 7, the phosphorus removal performance from the steady-state system was very good, indicating very low final TP effluent values. The system was operated in a steady-state condition with continuous day-time staff attention, but the data indicate a variable TP influent load to the filtration system. Good TP removal was still achieved with the variable influent TP conditions. January 2006 provided the lowest average TP level at 0.009 mg/L with a maximum value of 0.018 mg/L from the second stage filter. This was achieved with the dual-pass filtration system and chemical addition. The first-stage filter received a chemical dose of 15 mg Fe/L (44 mg $FeCl_3$/L) and the second-stage filter received a chemical dose of 10 mg Fe/L (29 mg $FeCl_3$/L). The reject stream from the filters was returned to the front of the Hayden WWTP. With a feedrate of 0.25-mgd to the filters, the system was operating with a hydraulic load of 3.5 gpm/ft^2. The air rate was held constant at 180 scfm for the first-stage filter and 140 scfm for the second-stage filter.

The January 2006 data show that the dual-pass system could achieve an average TP effluent <0.010 mg/L under steady state conditions. The next phase in the testing, that Blue Water has planned, is to verify the performance of the system under the influence of diurnal and seasonal variations in influent flow and load. As noted in Subtask 1.3 and Subtask 1.4, the TP effluent does degrade as the hydraulic load to the filters is increased. These short-term tests indicate the possibility of a reduction in effluent phosphorus given variable influent flow and loads.

Comparison with Conventional Direct Filtration

CH2M HILL completed an evaluation of a dual-pass, direct filtration system to compare results with the Blue PRO-CEPT™ system. A process simulation of the Hayden WWTP and HRWF was completed using the operational conditions noted within the Blue Water report. The chemical dosage used in the simulation matches that used in the steady-state test completed by Blue Water Technologies, Inc.

CH2M HILL's proprietary Pro2D (Professional Process Design) wastewater simulator is used to develop a process model for this analysis. Pro2D includes multiple mathematical models within to assist in the calculation of a mass balance through multiple unit processes. These models are based on the International Water Quality's ASM 2d and ADM mathematical models. The calculations for metal addition are based on the methodology provided in Biological and Chemical System for Nutrient Removal, (1998), Water Environment Federation.

The process simulation of the Hayden WWTP is developed from the WWTP information included in the Blue Water report. A complete calibration of the WWTP simulation is not included in this task, but rather existing operational data are used to verify the simulation results. The model is used to develop a mass balance of the WWTP, including the HWRF, and determine the performance of a dual-pass conventional direct filtration system. Table 11 includes the results from the Pro2D simulation for the conventional active filtration system.

TABLE 11
Pro2D Simulation Results – Direct Filtration System

Parameter	Pro2D Value	HRWF Value (Jan 2006 Ave)
WWTP Influent Flow	1.31 mgd	1.31 mgd
WWTP Influent TP	4.2 mg/L	4.2 mg/L
WWTP Secondary Effluent TP	1.34 mg/L	1.34 mg/L
HWRF Feedrate	0.25 mgd	0.25 mgd
1st-pass Filter Effluent TP	0.189 mg/L	0.068 mg/L
2nd-pass Filter Effluent TP	0.056 mg/L	0.009 mg/L

Chemical Addition: 1st Pass – 45 mg/L $FeCl_3$, 2nd Pass – 29 mg/L $FeCl_3$

Additional chemical was added to the system to see if a significant improvement in phosphorus removal was achieved. A lower TP effluent was possible with a higher chemical dose, but a significant amount of ferric chloride was required to achieve a higher level. Even with the higher chemical feed, the simulation results for the direct filtration system did not meet those from the steady-state operation of the Blue PRO-CEPT™ system.

As noted previously, the calculations for chemical removal included in the Pro2D simulation are based on the methodology noted in WEF's Biological and Chemical System for Nutrient Removal, (1998). The reference presents the theory behind the use of ferric or alum addition to assist in the removal of phosphorus. From this reference, the theoretical solubility limit for P concentration using alum is approximately 0.01 mg/L when in the best pH range, and approximately 0.04 mg/L when using ferric. This indicates that the chemistry of metal phosphate precipitation always results in some remaining soluble P concentration. Recent studies have shown even lower solubility levels using ferric (Szabo, et al, WEFTEC 2006 Presentation; Takacs, et al, IWA World Congress 2004) that what is possible using the Pro2D phosphorus precipitation model. A physical process such as membranes or filters cannot remove this soluble portion. Based on this evaluation the effluent from any plant typically will have, as a minimum, about 0.01 mg/L to 0.001 mg/L soluble P plus whatever P is associated with particulate matter in the effluent. To remove the particulate portion of the TP, colloidal solids along with the total suspended solids fraction within the wastewater must be reduced.

Results from Blue Water Technology, Inc., indicate that progress is being made in reducing the level of TP from wastewater effluent when compared to traditional coagulation and filtration technologies. To achieve TP concentrations 0.01 mg/L suggests a more complete precipitation of soluble phosphorus, or the presence of other reactions. The Blue Water report includes ideas as to how this additional TP removal is occurring.

Evaluation of Filtration Technologies

There are numerous filtration technologies that have been applied to effluent filtration, including:

- Deep bed, multi media filters
- Deep bed, mono media filters
- Traveling bridge, automatic backwash filters (granular media)
- Continuous backwash filters
- Pulsed bed filters
- Fabric filters
- Membrane filters

Of these technologies, traditionally the most common effluent filtration method used in smaller plants is the traveling bridge, automatic backwash filters. These filters are cost competitive, the backwash flow quantities are not extreme, and they are generally able to meet effluent criteria (less than 2 to 5 mg/L TSS).

Continuous backwash filters have been used for smaller plants (< 10 mgd with some exceptions), but the maximum module size is relatively small. These may not be appropriate for larger installations due to the number of modules required. The practical capacity of continuous backwash filters is site and operations staff limited as to what they consider a practical number of filters to maintain. Each treatment facility is unique and site specific, so the practical capacity will vary from facility to facility. As the number of filters increase, conventional large plant technologies will eventually be more cost effective. As an example, if the design hydraulic loading rate is 3 gpm/ft^2, one 50-ft^2 filter has a capacity of 0.22 mgd. To maintain the assumed design loading rate as the influent flow increases, the number of filters required for treatment increases linearly. In addition, the number of filters doubles when utilizing a dual-pass system. The effluent water quality from the two stage systems is typically very good. Parkson Corporation's Dynasand D2™ system is a dual-pass, continuous, upflow, granular media filtration system. Their promotional literature notes phosphorus removal to values as low as 0.01 mg/L.

Pulsed bed filters feature a unique underdrain system, with a shallow bed of mono-media, fine-grained sand, allowing for a design where the media is "pulsed" periodically as solids build up. These are not widely used as these can be are much more complex than other filtration technologies.

Deep bed filters, as are generally used in the water treatment industry, are more costly but smaller and more effective than the traveling bridge, automatic backwash units. The deep bed units are justified only where greater solids removal is required than can be achieved by traveling bridge filters.

Although membranes are seeing increased application, they generally are limited to re-use applications where extremely good water quality is mandated. Membrane filtration is costly, however, for this high level of effluent quality.

Fabric filtration is a relatively new technology, as it has been in the marketplace for less than 10 years. However, this technology is gaining in acceptance quickly due in large part to the cost advantage it generally exhibits over traveling bridge filtration and the smaller footprint.

The Blue PRO and Blue PRO-CEPT filtration systems generally fall into the continuous backwash filter category. As noted previously, one drawback with these systems are the relatively small modules available. As the size of a treatment facility increases, the number of modules required for treatment and redundancy may prove to be difficult to operate and maintain.

Summary

The short-term and long-term full-scale testing completed by Blue Water Technologies, Inc., has yielded promising results for the removal of phosphorus from municipal wastewater. The long-term steady-state test of 0.25-mgd through the Blue PRO-CEPT™ filtration system produced monthly average effluent total phosphorus levels of 0.036 mg/L, 0.009 mg/L, and 0.016 mg/L from December 2005 through February 2006. The system was not completely optimized as a dual-pass system for the December 2005 testing, but was optimized through January and February 2006. These effluent phosphorus level limits are equivalent to the best technologies currently available for phosphorus removal in the wastewater industry.

One of the key future tests for the filtration system is the examination of process control strategies for diurnal flow variation. The ability of the filtration system to address fluctuations in influent flow and load due to diurnal or seasonal conditions will be essential. Water quality permit limits are set with “not to exceed” limitations for certain parameters, requiring the treatment facilities to meet stringent effluent goals under all influent conditions without continuous supervision. This future test will provide valuable data for Blue Water Technologies as they continue evaluating their filtration technology.

Appendix A

HWRF Testing Plan

TERTIARY FACILITIES PHOSPHORUS REMOVAL TESTING PLAN FOR THE HAYDEN WASTEWATER RESEARCH FACILITY

INTRODUCTION

The intent of this Testing Plan is to document the protocol for the proposed testing of the Vandal-Ion filtration system at the Hayden Wastewater Research Facility (HWRF). The key objectives of the proposed testing protocol include:

- Collecting information to assist with the evaluation of phosphorous removal by the Vandal-Ion filtration system, and related operational characteristics.
- Development of the relationship between chemical dose and phosphorus removal for the Vandal-Ion filtration of secondary effluent.
- Develop a relationship between the solids loading rate (lb TSS per square foot per day) and rate of headloss development for the system.

This technical memorandum presents the recommendations for optimization testing and the collection of data for phosphorus removal evaluation. The evaluation of the phosphorus removal capacity of the Vandal-Ion filtration system will be presented in a final report, once the data have been collected.

ORGANIZATION OF TESTING EFFORT

Based on the objectives outlined above, there will be two major tasks for the testing effort presented in this technical memorandum:

- Operational Parameter testing: This task will include operation of the Vandal-Ion filtration system under various operating and iron dosage conditions, which includes the chemical feed , influent rate, and air rate.
- Vandal-Ion Filtration testing. This task will include estimating the reliable effluent total phosphorous concentration that the filters can produce, over a long-term operating period. Included in this will be records of maintenance and operation during the testing period.

A more detailed description of each task is given below.

Task 1 – Operational Parameter Testing

There are multiple operational variables to the Vandal-Ion filtration system that need to be evaluated. The goal of the optimization testing is to initially the performance characteristics of the unit over a range of operating conditions. Separate tests will be run to optimize each variable. The performance testing will be accomplished in three subtasks:

1. Air Use
2. Chemical Dose
3. Feed Rate (fixed)

During each test two variables will be held constant while the remaining is varied. Secondary effluent will be fed at a constant rate for the performance testing. During this period, only one filtration unit will be on-line. The flows for testing and the number of basins on-line will be revisited at the time of testing and may be revised depending on the total plant operating conditions.

For all testing, the rate of backwash production will be measured at least once daily, or upon changes in air rate or feed flow rate. The backwash rate will be measured through the "bucket and stopwatch" method. The backwash will be diverted to a bucket of known volume and the time measure that it takes to fill will be recorded. The bucket needs to be of adequate volume to allow at least 20 seconds of flow to be captured. This will be done in duplicate to confirm flow rates.

Data entry sheets are provided in an Excel Workbook for each test series. Data entry will be logged electronically in these sheets.

Subtask 1.1 – Air Use

An air system is provided within the BWT filtration system. To determine the operational characteristics of the filter at different sand pumping rates, the filters will be operated at up to 5 different air flow rates. Secondary effluent will be fed to one filter at a constant rate with a constant dose of chemical. The initial setting for each variable will be as shown in Table 1.

TABLE A-1
Initial Setting for all Variables

Variable	Initial Setting
Chemical Dosage	Per BWT Recommendation
Feed Rate	3 gpm/ft^2

After the filter bed has had at least one complete turnover, to be determined by plant staff through the measurement of the sand bed decent rate, and the filter bed headloss change has stopped, a 1 hour composite sample will be taken from the influent and effluent on the filter in use. The composite sample shall be made up of six equal volume grab samples taken approximately every 10 minutes by an automated sampler. The two samples will then be analyzed for pH, alkalinity, total suspended solids (TSS), total phosphorus (TP), and orthophosphate (OP) according to the most recent version of Standard Methods by an independent analyzing laboratory. Table 2 summarizes these methods for each analysis.

pH will be measured on site by operational staff with a properly calibrated pH meter. A final headloss measurement will also be logged.

TABLE A-2
Vandal Ion Performance Testing
Analytical Methods

Test	Standard Methods ID
TSS	2540D
Total Phosphorus	4500-P
Soluble Phosphorus	4110B
Alkalinity	2320

The sand bed descent rate will be measured by placing three PVC pipes equidistant in the sand bed and marking an initial elevation on these pipes relative to an easily used level, such as the top of the filter wall, or the water surface. The time it takes for the pipes to drop at least 6 inches will be measured. It is recommended that the pipes be inserted at least 12″ into the sand bed at about mid radius.

Over the course of the test, filter bed headloss will be monitored and logged at 30 minute intervals.

Subtask 1.2 - Chemical Dosage

The air system will be set to the preferred rate as determined above and the feed rates will be the same as in Task 1. The chemical dosage rates will be based on the molar ratio of iron added per mole of soluble phosphorus in the feed. Since the true soluble phosphorus level will not be able to be determined from the laboratory work, it will be necessary to do on-site analysis of the soluble phosphorus in the feed using a quick assay system such as by Hach. Once the approximate feed soluble phosphorus is known, the dosage will be adjusted to give the target molar ratio as described in Table 3 below.

TABLE A-3
Vandal Ion Performance Testing
Chemical Dosage Molar Ratios

Test	Approximate Molar Ratio
Test 1	0.25
Test 2	0.5
Test 3	1
Test 4	3
Test 5	7

The chemical dosage will be calculated by the following formula:

> Chemical Dosage (mg Chemical/L) = Influent P (mg P/L) x Molar Ratio x molecular weight of chemical / 31

For a $FeCl_3$ solution this formula would be:

> Chemical Dosage (mg FeCl3/L) = Influent P (mg P/L) x Molar Ratio x 162 / 31

Each operating conditions will be run for a minimum of one day. 8 hour composite samples of the feed and effluent with sampling intervals of 30 minutes will be begun after a minimum of 12 hours of operation at the new dosage. The samples will be analyzed as described in 1.1.

Headloss and feed rate will be logged during the entire period, beginning on when the new dosage is begun. Data logging will be done hourly during the acclimation period when the filter facility is manned and then every 30 minutes during the composite sampling period. Also, any operation or maintenance issues that occur during the test shall be logged.

Subtask 1.3 - Feed Rate (constant)

The air use and chemical dosage will be set to their rates as determined above. The feed rate will be operated at 5 different set points (from zero to maximum) for a minimum of one day each and composite sampling will be completed as per section 1.2. The feed rates will be as per Table 4.

TABLE A-4
Vandal Ion Performance Testing
Feed Rates

Test	Approximate Feed Rate, gpm/ft^2
Test 1	2
Test 2	3
Test 3	4
Test 4	5
Test 5	6

Note: At the higher flow rates close monitoring will be necessary to ensure the filter is not becoming solids overloaded.

Task 2 – Long Term Operational Testing

The goal of this test is to determine the long term operating characteristics of the Vandal-Ion Filter. As such, the feed rates will be allowed to change with the plant flow rates, and the long term performance will be monitored over a three month period. The parameters shown in Table 5 will be monitored on a daily basis.

TABLE A-5
Vandal Ion Performance Testing
Feed Rates

Parameter	Sampling Method
Feed Flow, Average	SCADA
Feed Flow, Hourly	SCADA
Backwash Flow Rate	Weekly Grab
Backwash TSS	Daily Grab
Backwash TP	Daily Grab
Influent and Effluent	
Total Suspended Solids	Daily Composite
Total Phosphorus	Daily Composite
Soluble Phosphorus	Daily Composite
Alkalinity	Daily Composite
pH	Daily Grab
O&M Log	Daily

If possible, all daily composite samples shall be taken on a flow proportional basis.

Materials and Methods

Process Monitoring. Process monitoring during the testing plans require the verification of the following parameters:

- Filtration Rate
- Chemical Dose
- Head Loss Through Filter

Sampling/Analysis. Two portable composite samplers are recommended for the collection of samples of secondary effluent (filter influent) and filter effluent. Typical industry procedure is to perform analyses on 24-hour flow weighted composite sample.

Testing Documentation. Sample spreadsheets are provided at the end of this memorandum for each type of the testing recommended. These include sections to note the run information, parameter values, and operational settings.

Operations Monitoring

As the full-scale testing is ongoing, an operation log and recording of daily operations and maintenance issues should be complete. As typical in treatment facilities, a log documenting the daily operational checks and maintenance should be kept.

Appendix B

HWRF Task 2 – Long Term Operational Data Summary

TABLE B-1
Task 2 – Long-term Operation Summary

	Daily Flow	Headloss	Air Rate	Chemical Dosage	Influent (Daily)							Effluent (Daily)							Backwash (daily)			
Date	MGD	inches	scfm	mg Fe/L	TSS (mg/L)	TSS (lbs/d)	TP (mg/L)	TP (lbs/d)	OP (mg/L)	Alk	pH	TSS (mg/L)	TSS (lbs/d)	TP (mg/L)	TP (lbs/d)	OP (mg/L)	Alk	pH	Flow (gpm)	TSS (mg/L)	TP (mg/L)	TP (lbs/d)
1st Filter																						
December Average	0.248	33.6	174.8	15	6.81	14.48	3.365	7.156	2.969	118.0	6.9	2.63	5.60	0.509	1.083	0.128	82.1	6.9	15.05	455.1	31.88	5.76
December Maximum	0.263	38.0	180.0	15	22.00	46.79	4.680	9.953	4.330	166.0	7.7	8.00	17.01	3.430	7.295	2.730	128.0	7.6	16.40	600.0	51.50	9.65
December Minimum	0.173	10.0	140.0	15	2.00	4.25	1.580	3.360	1.000	23.0	3.0	0.20	0.43	0.168	0.357	ND	5.6	3.4	14.50	38.0	6.23	1.14
January Average	0.258	32.1	180	15	3.16	6.72	0.683	1.453	0.455	124.6	7.1	1.70	3.71	0.068	0.145	ND	87.5	7.1	15.28	365.2	7.50	1.37
January Maximum	0.276	36.0	180	15	8.00	17.01	1.370	2.914	1.030	155.0	7.7	5.00	10.63	0.174	0.370	0.050	118.0	7.6	17.90	490.0	14.70	2.67
January Minimum	0.219	27.0	180	15	1.00	2.13	0.190	0.404	0.070	24.0	6.6	0.20	0.43	0.023	0.049	ND	30.0	6.6	14.80	290.0	2.31	0.42
February Average	0.251	32.3	180	15	3.57	7.60	0.780	1.660	0.529	121.4	7.1	1.19	2.54	0.061	0.129	ND	82.5	7.1	14.92	378.2	8.22	1.47
February Maximum	0.264	35.0	180	15	35.00	74.43	2.230	4.743	1.990	146.0	8.1	3.00	6.38	0.212	0.451	0.030	113.0	7.6	15.50	460.0	30.00	5.33
February Minimum	0.226	29.0	180	15	1.00	2.13	0.210	0.447	0.080	84.0	6.4	0.20	0.43	0.015	0.032	ND	20.0	6.5	14.60	330.0	2.40	0.42
2nd Filter																						
December Average	0.221	24.9	140	9.7	2.63	4.46	0.509	0.862	0.128	82.1	6.9	0.45	0.77	0.036	0.061	0.068	63.9	6.7	14.99	252.0	5.92	1.07
December Maximum	0.242	34.0	140	15.0	8.00	13.54	3.430	5.807	2.730	128.0	7.6	2.00	3.39	0.341	0.577	0.140	101.0	7.5	15.60	580.0	46.70	8.53
December Minimum	0.151	22.0	140	0.0	0.20	0.34	0.168	0.284	ND	5.6	3.5	0.20	0.34	0.007	0.012	0.020	28.0	2.7	14.70	150.0	1.27	0.23
January Average	0.215	23.7	140	10	1.70	3.75	0.068	0.115	ND	87.5	7.1	0.40	0.68	0.009	0.016	ND	60.9	6.8	15.15	223.5	0.73	0.13
January Maximum	0.246	26.0	140	10	5.00	8.47	0.174	0.295	0.050	118.0	7.6	3.00	5.08	0.018	0.030	0.050	89.0	7.5	17.90	550.0	1.42	0.26
January Minimum	0.176	22.0	140	10	0.20	1.69	0.023	0.039	ND	30.0	6.6	0.20	0.34	0.002	0.003	ND	5.5	3.0	14.40	19.0	0.17	0.03
February Average	0.223	22.4	140	10	1.19	2.58	0.061	0.103	ND	82.5	7.1	0.79	1.33	0.016	0.026	ND	56.2	6.9	14.99	209.3	0.82	0.15
February Maximum	0.243	25.0	140	10	3.00	5.08	0.212	0.359	0.030	113.0	7.6	9.00	15.24	0.046	0.078	ND	87.0	7.5	15.30	250.0	3.64	0.66
February Minimum	0.183	9.0	140	10	0.20	1.69	0.015	0.025	ND	20.0	6.6	0.20	0.34	0.005	0.008	ND	13.0	6.1	14.50	170.0	0.23	0.04