City of Post Falls, Idaho

2012 Water Reclamation Facility Plan

TECHNICAL MEMORANDUM TM 8 - DRAFT

Tertiary Treatment to Meet Anticipated Permit Limits For Phosphorus "Next Level Treatment"

Mark H. Esvelt, P.E., BCEE

February, 2012
Revised: May, 2012
July, 2012

ESVELT ENVIRONMENTAL ENGINEERING

REGISTERED PROFESSIONAL ENGINEER 11461 STATE OF IDAHO MARK H ESVELT

7-9-12

Contents

FIGURES

TABLES

Background:

The Environmental Protection Agency Region 10 has issued a revised Fact Sheet and Preliminary Draft NPDES Permit for the City of Post Falls Wastewater Treatment Plant (Permit No. ID0025852). The Preliminary Draft Permit and Revised Fact Sheet outline the steps the City will take to meet requirements for discharge to the Spokane River, including meeting the Waste Load Allocation (WLA) for effluent phosphorus, consistent with the *Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load: Water Quality Improvement Report,* Completed by the Washington State Department of Ecology (2010), and approved by EPA with waste loads for total phosphorus assigned to upstream dischargers across the State Line in Idaho.

The permit includes limitations for conventional pollutants as well as toxics, and the facilities to address these constituents and consistently meet permit limitations are discussed in other technical memoranda associated with this facility planning effort.

This technical memorandum focuses on the tertiary treatment facility alternatives for removing phosphorus to the concentrations necessary to meet the WLA.

The Preliminary Draft Permit requires development of a Phosphorus Management Plan. The permit language regarding the phosphorus management plan are as follows:

> *The permittee must provide written notice to EPA and IDEQ that the plan has been developed within 1 year after the effective date of the final permit and implemented within 18 months of the effective date of the final permit.*

The Preliminary Draft Permit lists the required elements of the Phosphorus Management Plan. The Plan will identify phosphorus reduction goals, which must be consistent with the final effluent limitations in the permit, for the facility, and the improvements required to meet the goals.

Memo Purpose

This memo summarizes the process for developing recommendations for the "Next Level of Treatment" (NLT) for the removal of phosphorus to meet the waste load allocations in the City of Post Falls' new NPDES permit. An evaluation of feasible alternatives is presented, followed by comparison of alternatives, conclusions regarding most economically feasible technology and recommendations.

Design Criteria

The draft NPDES permit for the City of Post Falls sets a waste load allocation (WLA) of 3.19 lb total phosphorus per day for effluent discharged to the Spokane River on a seasonal average basis. The WLA of 3.19 lb/day is based on meeting an average effluent concentration of 50 μg/L at the design flow of 7.65 mgd.

Current flows and projected increases in flows are presented in technical memorandum TM 3. The initial tertiary phosphorus removal project is anticipated to be implemented with a design flow of 4.0 mgd. At 4.0 mgd, the effluent total phosphorus concentration required to meet the 3.19 lb/day WLA would be 95 μg/L. As flows increase due to growth, meeting the mass limit of the WLA will require lower concentrations. The average effluent concentration requirements are presented in Table 1 for the 4-mgd and 5-mgd capacity phases, along with the concentration required for the "ultimate" design capacity of 18.0 mgd.

Table 1 – Performance criteria (total phosphorus average), each phase to meet WLA.

Design phases	Design flow (seasonal ave)	WLA	Concentration μg/L
Phase 1	4 mgd	3.19 lb/d	95 μg/L
Phase 2	5 mgd	3.19 lb/d	75 μg/L
Ultimate	18 mgd	3.19 lb/d	21 μg/L

Next Level Treatment (NLT) process units are physical and chemical. Design is governed by:

- Average and peak hydraulic loading
- Average and peak solids loading, a function of chemical addition, which is related to phosphorus concentration at the process inlet.

The planned equalization for Post Falls limits the peak loading to the tertiary phosphorus removal facilities to the maximum day projections. This proposed equalization would be expected to result in significant cost savings for the NLT implementation. Projected flows for the NLT units are summarized in Table 2.

Table 2 – Average and Maximum Flows

Design phases	Design flow (seasonal ave)	Peak flow (Max day)
Phase 1	4 mgd	6.1 mgd
Phase 2	5 mgd	7.7 mgd
Ultimate	18 mgd	27.5 mgd

Peaking factor 1.53 per TM3 Table 3-2.

Tertiary Phosphorus Removal

The state-of-the-industry methods for reducing phosphorus to 0.1 mg/L (100 μg/L) and below are based on chemical precipitation of phosphorus and removal of the precipitated solids. All known facilities that are considered "exemplary" in achieving the lowest concentrations of effluent phosphorus use one or more stages of effluent polishing by chemical coagulation and removal of the precipitated solids. For the lowest levels of total phosphorus effluent, metal salt coagulants are added at significantly higher than the stoichiometric theoretical dose. The precipitated solids generated by alum, the most commonly used coagulant, include aluminum phosphate and aluminum hydroxide. The solids are removed at the final stage using a filter to achieve high capture efficiency for the smallest precipitates. Upstream stages of coagulation and solids removal (prior to final filtration) can use clarifiers, since the downstream filter would remove the solids carry-over. In a two-stage tertiary system the first stage (usually clarifier) can take a high solids loading, reducing the coagulant dose (and solids loading) for the final filter.

The Post Falls WWTP currently utilizes enhanced biological phosphorus removal (EBPR) activated sludge. This existing first stage phosphorus reduction is a critical component for limiting the tertiary coagulant dose to amounts that result in a manageable solids loading to subsequent units, as well as in reducing the expense associated with high coagulant doses.

The maximum dose rate of alum that can consistently be applied to tertiary filters is approximately 100 mg/L (as $Al_2(SO_4)_3 \cdot 14H_2O$). This was found through investigation of the existing "exemplary" phosphorus removal facilities in Colorado, and confirmed in local installations and in pilot studies in the Spokane basin investigating treatment technologies to achieve very low effluent phosphorus concentrations. Dose rates in excess of about 100 mg/L tend to result in excessive solids load on the filters, resulting in shortened filter runs or filter blinding (clogging).

The following general guidelines for tertiary phosphorus removal are based on known chemical reaction processes, supported by extensive evaluation of the operation of existing facilities and large-scale pilot units.

- At a feed phosphorus concentration of 0.5-0.8 mg/L (achievable with biological P-removal), further reduction to 0.1 to 0.2 mg/L (100 to 200 μg/L) TP would require alum dose rate of about 10:1 on a Mole Ratio basis, or about 75 to 150 mg/L alum (as $Al_2(SO_4)_3 \cdot 14H_2O$), to the effluent from the activated sludge system.
- To achieve TP of 0.05 mg/L (50 μg/L), starting at 0.5 to 0.8 mg/L from the secondary effluent, a mole ratio (MR) coagulant dose rate of 50 to 150 would be required, which would amount to 200 to 800 mg/L for single stage treatment. This is a higher alum dosage than could be handled by filters, so an intermediate chemical precipitation / sedimentation step is typically needed to consistently achieve this lower concentration.
    - The intermediate stage would reduce TP from approximately 0.8 mg/L to about 0.1 to 0.2 mg/L, at a Mole Ratio (Al:P) dose of about 10, or 75 to 150 mg/L (as Alum).
    - The filtration step could then reduce the TP from 0.1 to 0.05 mg/L (50 μg/L) with a Mole Ratio of about 50. Since the incoming phosphorus is now at a lower concentration, this ratio translates to a dose of about 100 mg/L (as $Al_2(SO_4)_3 \cdot 14H_2O$), which is within the range that most tertiary filter systems have been shown to be capable of accommodating.

<u>Reject Water</u>

All of the settling and filter units considered require reject to carry away the accumulated coagulant precipitate. Reject water flow ranges from 5% to 10% of production for all of the units, and is probably not a distinguishing factor in the comparison. The reject water, with the solids it carries would necessarily be transported back to the plant for treatment to separate out the solids. Returning the reject to the headworks with the plant influent (full secondary treatment) is a viable option for this material. Some of the existing facilities in Colorado (see the section below) have found it advantageous to recycle the reject streams back to the secondary clarifier inlet, where it can be combined with the mixed liquor flowing to the clarifiers. Where this may slightly overload the secondary clarifiers (in terms of solids loading rate), the escaped floc is removed in the downstream tertiary clarifier or filter, and extra contact time and mixing improves coagulant efficiency.

The chemical sludge wasted (either directly from the tertiary process or if wasted with the secondary sludge) would join the biosolids stream for beneficial use or disposal.

<u>Alkalinity and pH Control</u>

- For all chemical polishing alternatives for phosphorus removal the dose of alum (or other coagulants, including ferric) required will deplete the available alkalinity in the wastewater. It will be necessary to add alkalinity to offset the depletion due to the chemical (coagulant, alum) addition. Six moles of alkalinity will be required to offset each mole of alum. On a weight ratio basis this would result in about 40% of the alum feed rate (in mg/L as $Al_2(SO_4)_3 \cdot 14H_2O$) (in mg/L) for NaOH (caustic) or $Ca(OH)_2$ (lime). Magnesium hydroxide ($Mg(OH)_2$) (in mg/L) would need to be fed at about 25% the rate for alum (in mg/L as $Al_2(SO_4)_3 \cdot 14H_2O$).

- In addition to alkalinity feed for the coagulant reaction, it may be necessary to feed additional alkalinity to the effluent to maintain the effluent pH at the permit requirements. This may be necessary if the coagulant reaction for phosphorus removal is optimized at near to or lower than pH 6.0 (Permit lower limit). Some of the pilot runs at the Spokane RPWRF P-Pilot plants ran most efficiently at near pH 6.0. It would require continuous monitoring to assure that the effluent did not slip below that following the phosphorus removal reactions.

AlgEvolve

AlgEvolve is a biological tertiary process proposed as a means to polish wastewater treatment plant effluent to the low phosphorus concentrations of interest in Post Falls (and at other treatment plants discharging to the Spokane River). The AlgEvolve process provides an environment where algae grows in the wastewater, uptaking the trace amount of phosphorus. The algae is then separated from the waste stream by using membrane filters. A reject stream of algae-laden water is produced by the process. AlgEvolve has been pilot tested in Post Falls, but there are no known full-scale installations specifically designed for phosphorus polishing of secondary effluent in a municipal facility where solids handling is done on-site. The AlgEvolve process is considered in this memorandum as a potentially cost-competitive alternative to compare against chemical treatment. The potential for being cost-competitive is based primarily on the pilot testing performed at Post Falls.

Evaluation Outline

The summary of the evaluation presented in the next sections of this technical memorandum follows this outline:

- Effectiveness for TP meeting limitations. In the next section, alternatives are screened to determine the capability to meet the concentrations required to stay within the waste load allocation at the initial implementation, as well as at future phases of build-out. Given the range of effluent concentrations required over the course of the build-out schedule, as indicated in Table 1, the first-phase technology may need to be compatible with add-on technology in future phases, to meet lower concentration limits in the future. The effectiveness at removing phosphorus by a variety of technologies was determined based on information gathered from the following sources:

    1. EEE conclusions from evaluation of exemplary phosphorus removal facilities in Colorado, 2005.
    2. City of Moscow low-P performance full scale (2010, 2011 seasonal operation)
    3. Liberty Lake SWD P-Pilot tertiary membrane filtration (January, 2010 report by Esvelt Environmental Engineering).

4. City of Spokane P-Pilot project performance and technology comparison (2009 – 2011 provisional data).
5. Preliminary AlgEvolve pilot results, Post Falls, reports 2011, 2012.

- Relevant data summaries from the above facilities is presented below, along with discussion of observations of the data that are of importance in the technology selection for Post Falls.
- Using the determination of effectiveness as a screening tool, the viable technologies for Post Falls are presented.
- In subsequent sections of this memo, additional discussion of the specific technologies is presented.
- After the presentation of technologies, Preliminary alternatives are then developed at the conceptual level in order to prepare comparative-level capital project costs and footprint requirements for the initial 4-mgd implementation and the subsequent expansion to 5-mgd (since the different effluent TP concentration criteria at 5-mgd impact how each alternative can be expanded).
- A comparison matrix with preliminary sizing, cost, and building footprint is presented to summarize.
- The comparison of alternatives is expanded by developing the estimated difference in operation and maintenance (O&M) costs between the alternatives that appear to be most cost-competitive at the capital project costs, for the 4-mgd initial phase and the 5-mgd expansion.
- A section is devoted to how the alternatives compare for effectiveness in removing other parameters of future concern, particularly heavy metals, PCBs, and dioxin.
- A comparison of present worth estimated cost, incorporating the projected operation, maintenance, and replacement costs is presented.
- Conclusions and recommendations are then presented.

Effectiveness of tertiary phosphorus removal at other facilities

This section summarizes findings from recent investigations into the effectiveness of different tertiary treatment technologies at exemplary phosphorus removal facilities as well as piloting in this region specific to the Spokane River TMDL.

1. In late November / early December 2005, select wastewater treatment facilities in Colorado, meeting the lowest effluent total phosphorus limitations in the U.S. were visited to assess the then-current state of technology of effluent tertiary phosphorus removal. A summary of the facilities' performance is presented below in Table 3.

   Observations from the trip included the following, considered to be important in the selection of technology for Post Falls.

   - All of the P-removal plants visited have normally operated at about 50% of design flow according to operator statements and data provided for review.

- The coagulant dose rate (see Table 3) was reported by the operators, and in some cases was included in data received from the plant after return from the trip. Method for calculation of the dose was not verified between plants.
- All plants used a polymer flocculent-aid in addition to the metal-salt coagulant.
- The Breckenridge Sanitation District plants at Iowa Hill and Farmers Korner achieved the best TP effluent concentration, and had the highest coagulant dose rate (150 to 200 mg/L as Alum). The Iowa Hill Plant is a "scalping" plant, which sends its residual (including chemical sludge from the tertiary treatment and filtration) back into the sewer interceptor to be treated at the Farmers Korner Plant. The Farmers Korner Plant operates at nominally 1/3-1/2 of design capacity.
- All of the exemplary facilities achieved their results with two stages after the secondary treatment process – a chemical coagulation and settling step followed by a filtration step.
    - Two of the facilities achieved the two-steps by recycling the poorly-settling chemical (alum) sludge through the secondary clarifiers and allowing it to overflow the weirs (to some degree) and to pass through filtration again.
    - Chemical coagulation and settling process observed included both "conventional high-rate" settling (tube- or plate-settlers) and "solids contact" or slurry-recycle" clarification (DensaDeg in one case). A water treatment facility using ballasted sedimentation (Actiflo) was also visited. Since it was a water treatment plant application instead of wastewater phosphorus polishing, it is not included in Table summary of performance.
    - All the filtration processes observed utilized granular media filtration, either continuous backwash upflow filters (CBUF) or downflow multi-media filters.
- Reported performance summarized in Table 3 does not identify testing methods used for monitoring total phosphorus. This is a consideration when using these results to predict future performance, since testing methods have been shown to produce different results for split samples.

Table 3. Summary of Phosphorus-Removal Performance for Colorado Wastewater Treatment Plants

Treatment Facility	*Period*	*Influent*			*Biological Effluent*			*Final Effluent*	
		50%	95%	99%	50%	95%	99%	50%	95%
Aurora WRP	2002	5.06	6.89	7.83	0.18	0.71	1.25		
	2003	5.74	6.38	6.95	0.18	0.6	0.99		
	2004	5.79	6.43	7.01	0.13	0.29	0.4		
	2005	5.82	6.29	6.71	0.23	1.08	2.03		
Breckenridge Sewer District – Iowa Hill const. flow, densedeg @ 4.3 gpm/sf and dynasand (CBUF) @									
- Iowa Hill WRP	2003	3.54	6.41	8.36	1.54	3.53	4.99	0.007	0.026
	2004	3.99	5.53	6.33	1.20	3.26	4.93	0.005	0.017
	2005	3.09	5.01	6.11	1.27	2.29	2.89	0.008	0.019
- Farmers Korner WRP	2003	3.38	8.76	12.98	0.57	2.02	3.41	0.006	0.020
	2004	3.67	6.74	8.98	0.63	2.18	3.64	0.004	0.013
	2005	3.56	6.04	7.01	0.73	1.63	2.05	0.007	0.029
Frisco WRP	11/03-10/04	5.72	7.81	8.89				0.049	0.093
	11/04-10/05	6.24	8.99	10.46				0.069	0.124
Snake River WRP	2003	6.44	11.22	14.12	0.61	2.29	3.96	0.015	0.035
	2004	6.72	9.75	11.37	1.32	3.53	5.31	0.018	0.038
	2005	6.21	9.12	10.7	0.82	3.35	6.00	0.014	0.034
Pinery WWTP	2002	8.78	10.25	10.92	0.337	0.709	0.965	0.029	0.060
	2003	8.89	10.55	11.32	0.238	0.337	0.389	0.027	0.050
	2004	9.14	10.23	10.72	0.218	0.401	0.516	0.029	0.054

2. The Moscow, Idaho Wastewater Treatment Plant is permitted for seasonal effluent phosphorus concentrations of 0.136 mg/L for average monthly limitation and 0.270 for maximum average weekly concentration limitation.

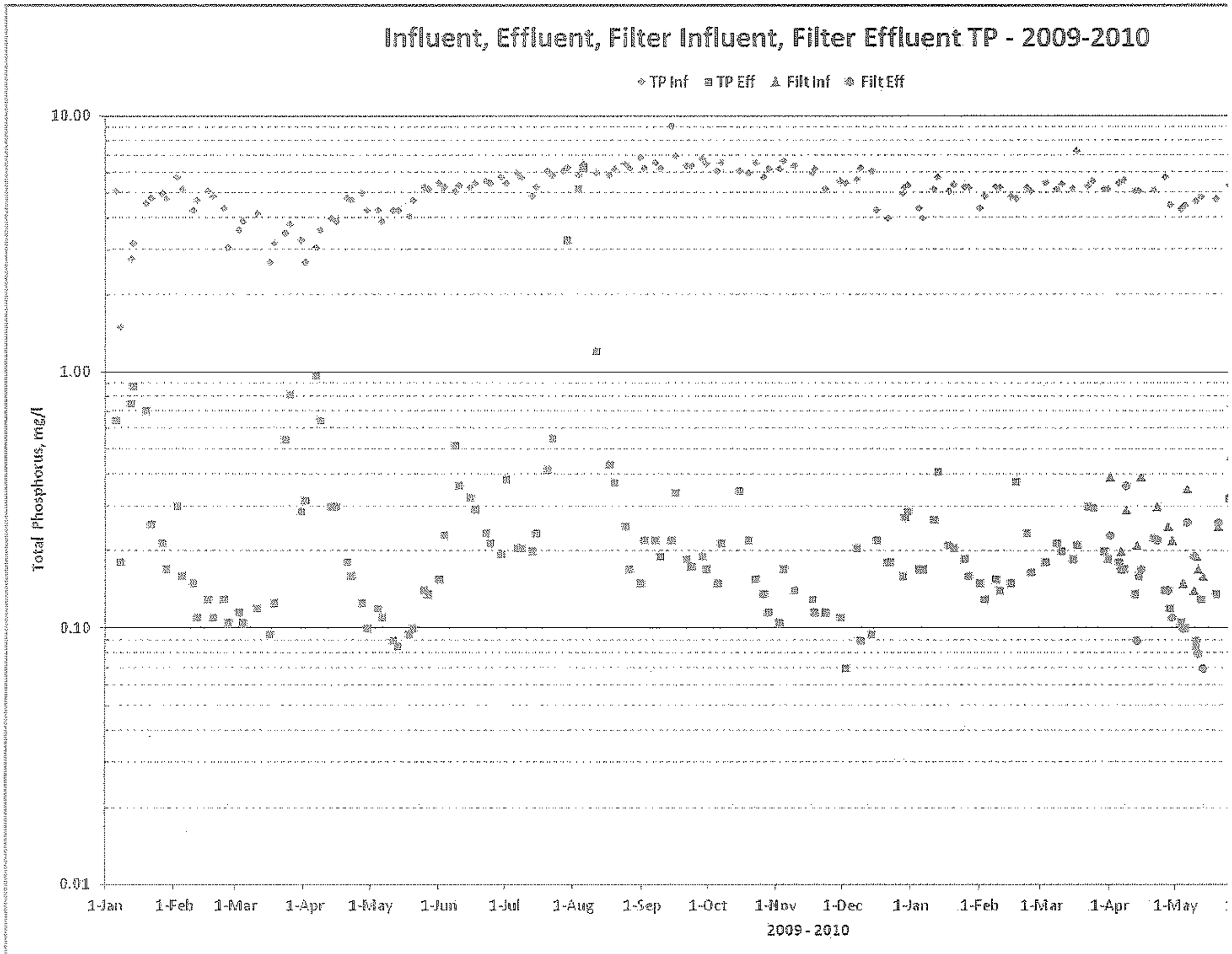
   The enhanced biological phosphorus removal (EBPR) facility was constructed in 2001. Facility operations have been optimized, such that by 2009-2010, phosphorus concentration in the EBPR effluent had been fairly consistently below 0.30 mg/L, but with occasional excursions above 0.40 mg/L.

   The effluent filtration system was added in a project begun in 2008. The project constructed continuous backwash upflow filters (CBUF). The project also included a plate-settler unit to concentrate the residuals stream. The processes came on line in 2009. There are 20 filter modules (standard CBUF 50 sf each) in 5 cells of four modules each. The cells are configured to allow dual pass operation, but have been operated in single pass mode regularly since start-up.

   With the effluent filtrations system, the Moscow facility has been able to consistently meet permit limitations for the flow of approximately 3 mgd. Figure 1 shows the 2009-2010 phosphorus data. After the first two seasons of operation, the following observations were made:

   - The City's EBPR is an important component in meeting the effluent limitations:
     - The low phosphorus concentration in the tertiary filter feed allows the coagulant dose to be low enough to avoid overloading the filters with solids and allow a reject rate of no more than 10% of feed flow.
     - There is still significant chemical use. Alum solution is fed at approximately 50-60 mg/L with the filter feed phosphorus concentration of around 0.3-0.5 mg/L. If the feed concentration were 1.0 mg/L, it is predicted the alum dose would need to be approximately 100 mg/L.
   - The filter facility requires an estimated 32-35 hours per week for operation, maintenance, and testing.

Figure 1 – City of Moscow Low-P Performance, (EBPR followed by single-pass CBUF)



3. In 2008, The City of Airway Heights and the Liberty Lake Sewer and Water District collaborated on a pilot study of tertiary membrane filters to determine the capability for phosphorus removal from a biological nutrient removal plant. The study lasted four months, and utilized a Pall microfiltration pilot unit. The pilot unit had a rated capacity of 30 gpm.

   During the study, the system was operated at a target flux rate of 40 to 50 gfd, with feed water alum doses of 70 to 170 mg/L, and a trans-membrane pressure range of 4 to 43 psig. The percent recovery, the percentage filtrate quantity produced of the total feed water quantity, ranged between 93.6% and 96.2% for the 3 testing cycles.

   The pilot system achieved an effluent (filtrate) Total Phosphorus of <70 μg/L at the 50%ile. The flux rate through the test met the target of a continuous 32 GFD corrected for 20°C, and the recovery exceeded 93%. The Clean-in-place interval was greater than 30 days, with a maintenance clean interval of more than 24 hours. A portion of the testing results for the 2008 Liberty Lake pilot are presented on Figure 2, and a probability distribution of the effluent TP is presented in Figure 3.

   The data shows that single-stage treatment consisting of coagulation and membrane filtration, following EBPR activated sludge, can achieve average results of less than 95μg/L, and possibly lower.

   Note that the poorest results were during the first four to six weeks of the test, when the BNR system lost phosphorous removal efficiency. After this period, the filter feed phosphorus concentration was around 0.4 mg/L. The alum dose, as shown on Figure 2, was normally in the 80 – 110 mg/L range during the pilot test.

   Another observation from the pilot study at Liberty Lake, and reflected Figure 3, is that the effluent TP results can be significantly different depending on the testing method used. In this case, the testing method difference was as much as 9-fold, though this difference is somewhat skewed by the effect noted above (worst performance early in the study), since the testing methods do not cover the same sampling dates.

Figure 2 – Filtrate Total Phosphorus Concentration and Feed Alum Dose, LLSWD Pilot, 2008.

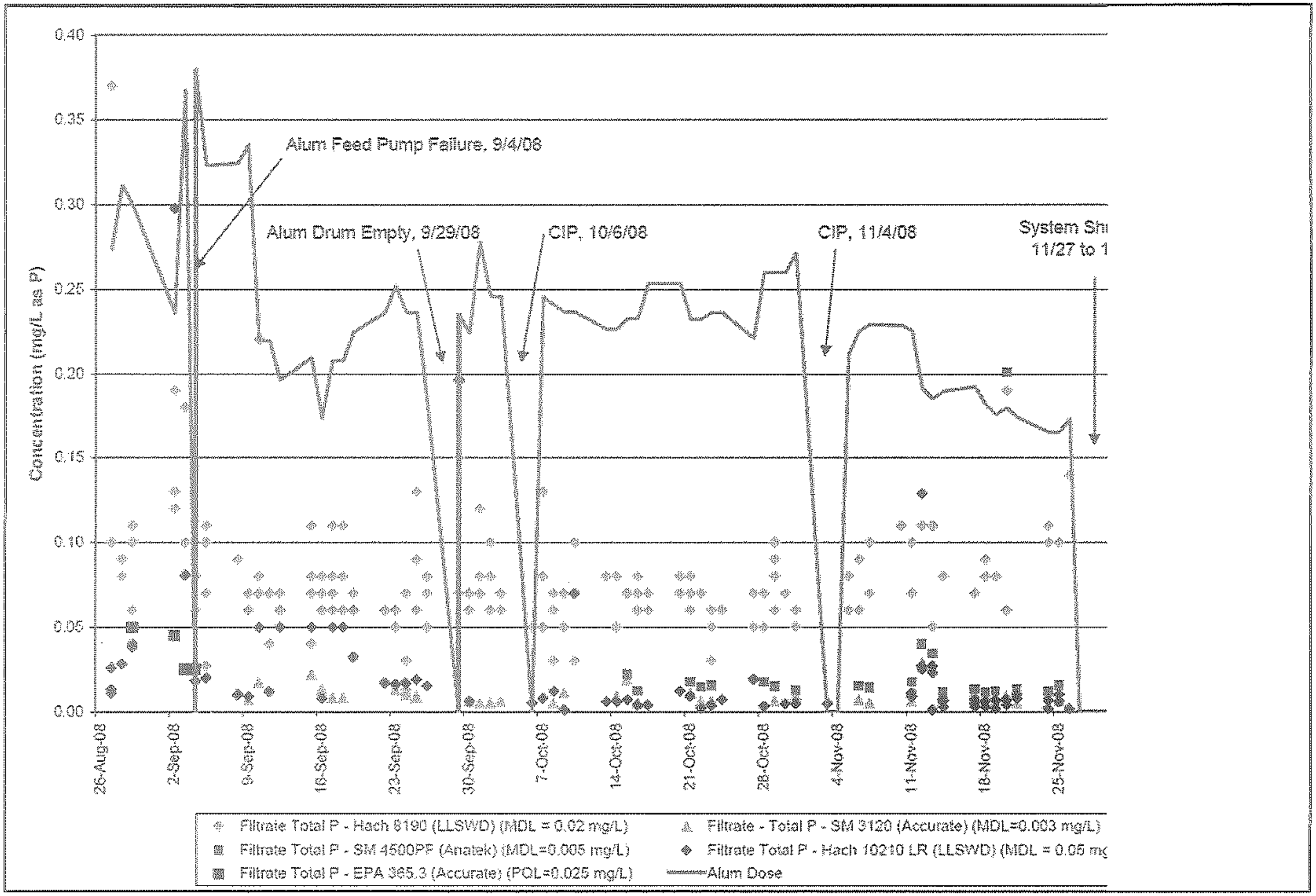
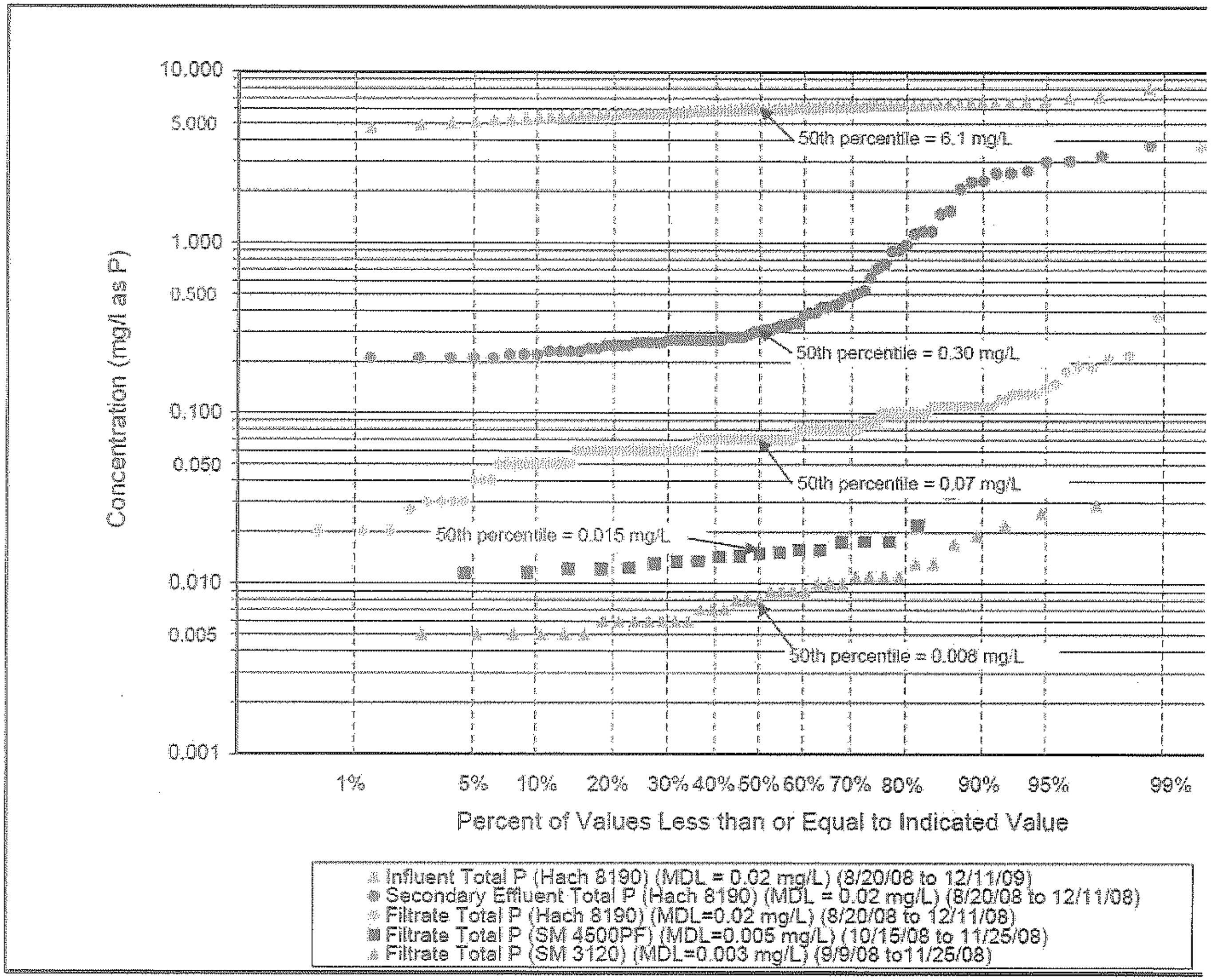


Figure 3 – LLWSD tertiary membrane filtration pilot data, probability distribution



4. The City of Spokane installed, in 2009, full-scale treatment units (0.15 – 0.5 mgd each) to pilot test and compare technologies for phosphorus removal following the biological treatment facilities at the Riverside Park Water Reclamation Facility (RPWRF). The RPWRF uses nitrifying activated sludge to treat approximately 44 mgd on average. During the critical phosphorus removal season, alum is added in the secondary process to precipitate phosphorus for removal with the secondary sludge, resulting in consistently achieving total effluent phosphorus concentrations of 0.5 mg/L to 0.7 mg/L.

   Six different technologies were tested in the pilot study: 3 chemical coagulation and settling units, and three filtration technologies:

   a. Chemical coagulation and settling

      i. "High-Rate" sedimentation with rapid mixing, two-stage flocculation, and a clarifier with tube-settlers.

      ii. Kruger Actiflo ballasted sedimentation – utilizing ballast consisting of micro-sand to achieve high-rate sedimentation, with the micro-sand recovered in a cyclone, which also knocks off the floc to be sent to the reject stream.

      iii. Cambridge Water Technologies "CoMag" ballasted sedimentation, which uses magnetite for ballast, with the floc separated from the magnetite using intense agitation, and the magnetite recovered using a magnetized drum for reuse.

   b. Final filtration

      i. Granular Media - Continuous backwash, upflow filter (CBUF), which was installed to allow either single-pass or dual-pass operation.

      ii. Granular Media - Conventional downflow dual-media filter, with high-rate coagulation and two-stage flocculation ahead of the downflow filter.

      iii. Membrane filtration – consisting of GE-Zenon submerged membrane system.

   The pilot testing was performed in anticipation of forthcoming limitations for effluent phosphorus to meet waste load allocations for the facility's discharge to the Spokane River. Final waste load allocations were issued after the pilot testing was underway, and have been written into the Spokane NPDES permit as a seasonal average mass load limitation based on 42 µg/L TP.

   Table 4 summarizes the performance results (provisional until officially released) of the pilot study at Spokane.

Table 4 – Provisional Combined Results of RPWRF Pilot Testing

Constituent	Winter Average	Summer Average
Pilot Plant Influent TP (Winter=activated sludge, summer=activated sludge with alum addition)	2.3 mg/L	0.52 mg/L
Pilot Plant Sedimentation Step TP (combined 3 technologies)	0.26 mg/L	0.06 mg/L
Pilot Plant Filtration Step TP (combined granular media technologies)	0.08 mg/L	0.025 mg/L
PP membrane filt TP*	0.05 mg/L	0.017 mg/L

The combined performance data for the sedimentation units (three technologies) is presented in Figure 4 below. The data for the three settling technologies are combined in Figure 4 because the data analysis has not shown substantial performance differences between the three technologies piloted at the Spokane RPWRF.

The "high-rate" sedimentation with tube-settlers was operated at a surface overflow rate of 1.17 gallons per minute per square foot. This is higher than a typical rate for a conventional clarifier without the tube settlers. Without tube-settlers, a typical overflow rate would be in the range 0.30 to 0.60 gpm/sf. The two ballasted settling units were operated at overflow rates of 4 gpm/SF (ave comag) and approximately 14-15 gpm/sf for the actiflo by Kruger. These are overflow rates for the settling surface area only, and do not account for the surface area of the flocculation / maturation fully-mixed zones employed by these technologies. Total surface area, and thus footprint, are important considerations in the selection of preferred technology for Post Falls.

Effluent from the three sedimentation units at the Spokane RPWRF pilot study was directed to the three filtration units. The pilot study area was plumbed to allow the effluent from any of the sedimentation units to be directed to any of the filtration units.

The final filter performance for the pilot study (2010 critical season), are shown in the probability distributions plotted in Figure 5. On the plot, "B1E & B2E" represent the CBUF effluent, "F1E&F2E" is the label for the dual-media downflow results, and "Z1E&Z2E" is the label for the ultrafiltration membranes. The data presented in Figure 5 includes only data where the filters received effluent from one of the sedimentation units (trial runs using effluent direct from the secondary process were excluded from Figure 5 data).

In addition to the two-stage (sedimentation plus filtration) testing during the pilot study at RPWRF, limited runs were performed where the filtration units received effluent directly from the secondary process to determine the capability of the final filtration units without a sedimentation step ahead of them. Also, the CBUF units were run for a limited time in series operation to determine the capability of the CBUF in two stage operation where both stages are CBUFs.

Figures 6, 7, and 8 show TP effluent data for select periods of the RPWRF pilot study for the three filtration technologies, where the data shown within the ovals was from the pilot runs where the filters received secondary effluent directly (no upstream settling step).

Figure 9 shows CBUF effluent TP data, with a bracketed area to indicate the period when the CBUFs were operated in dual-pass mode, with the first stage receiving effluent directly from the secondary process.

Figure 4 – Spokane RPWRF Low-P Pilot testing provisional results - Settling units combined.

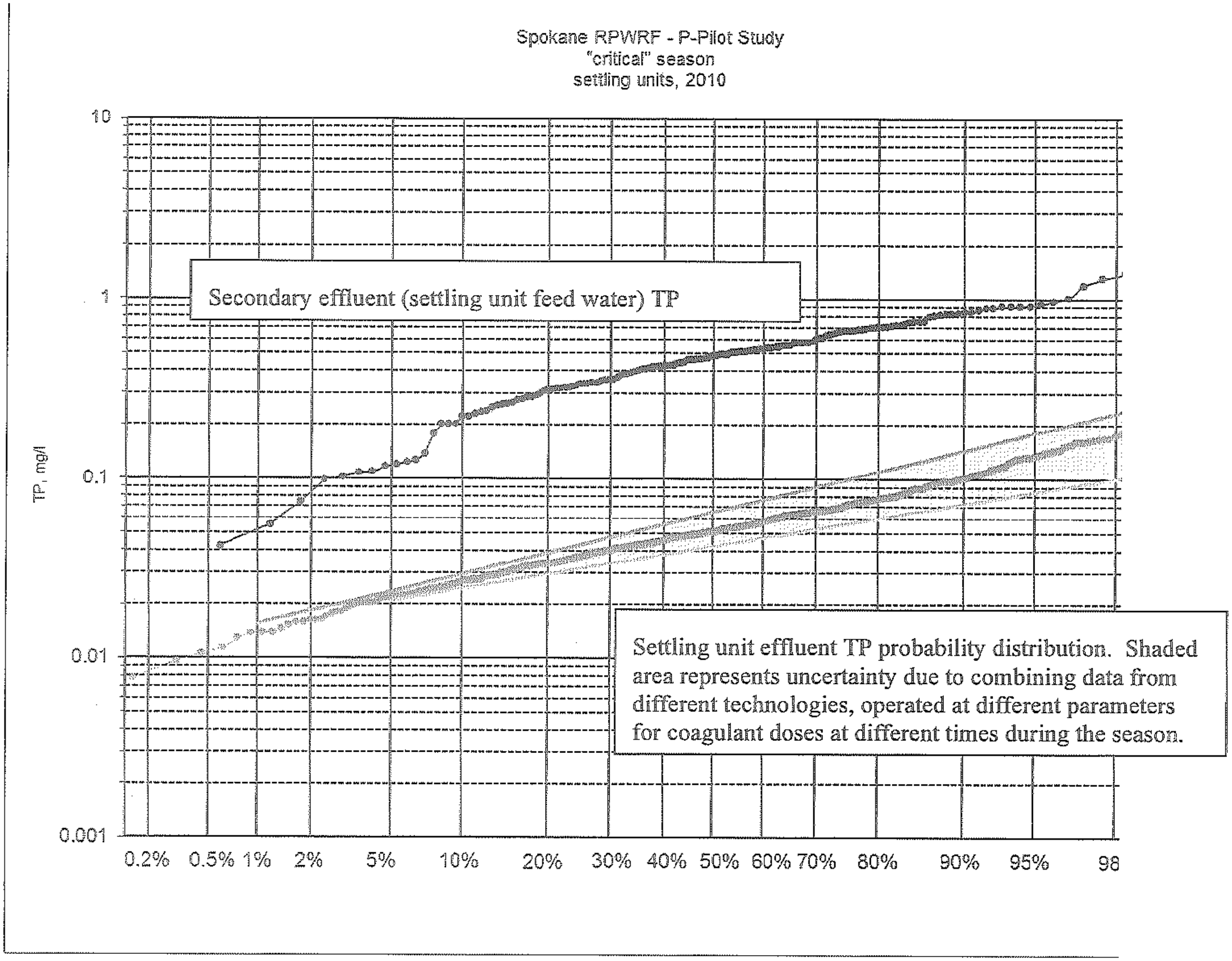


Figure 5 – Spokane RPWRF Low-P Pilot testing provisional results – Filter units.

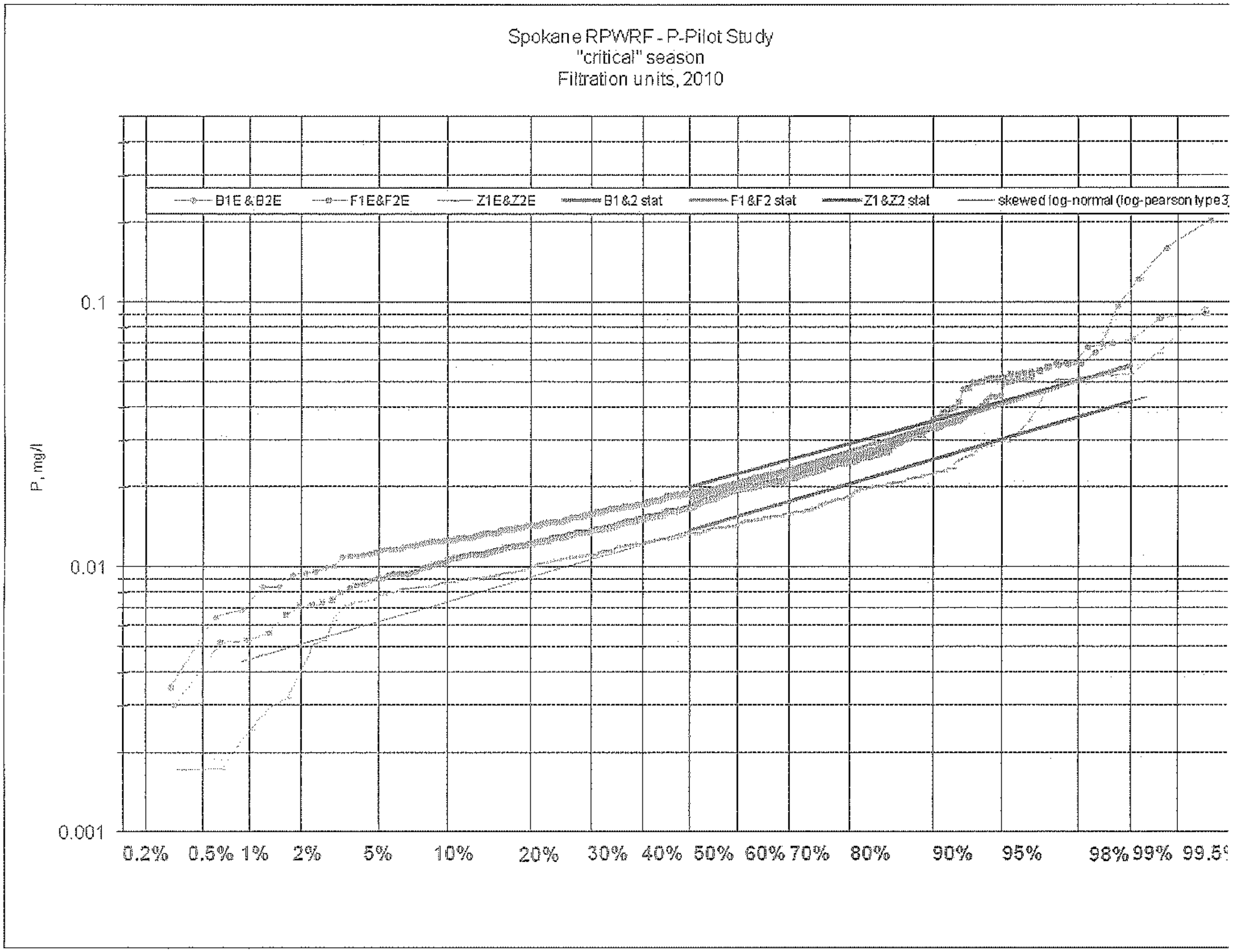


Figure 6 – Spokane RPWRF Pilot - Dual media performance (including no upstream settling step).

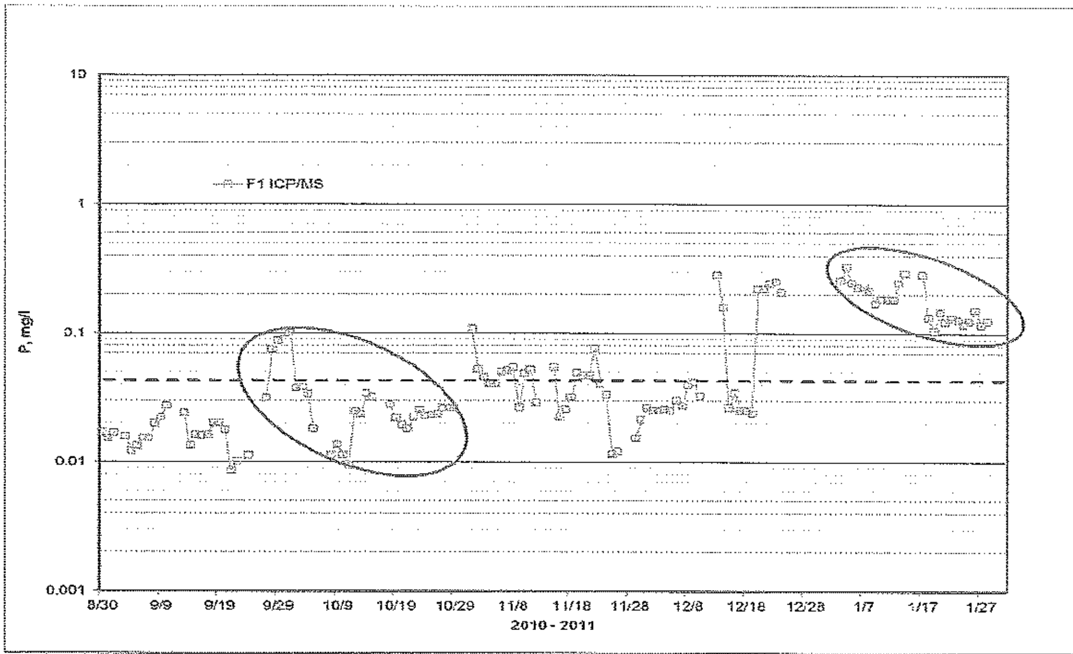


Figure 7 – Spokane RPWRF Pilot – CBUF performance, (including no upstream settling step).

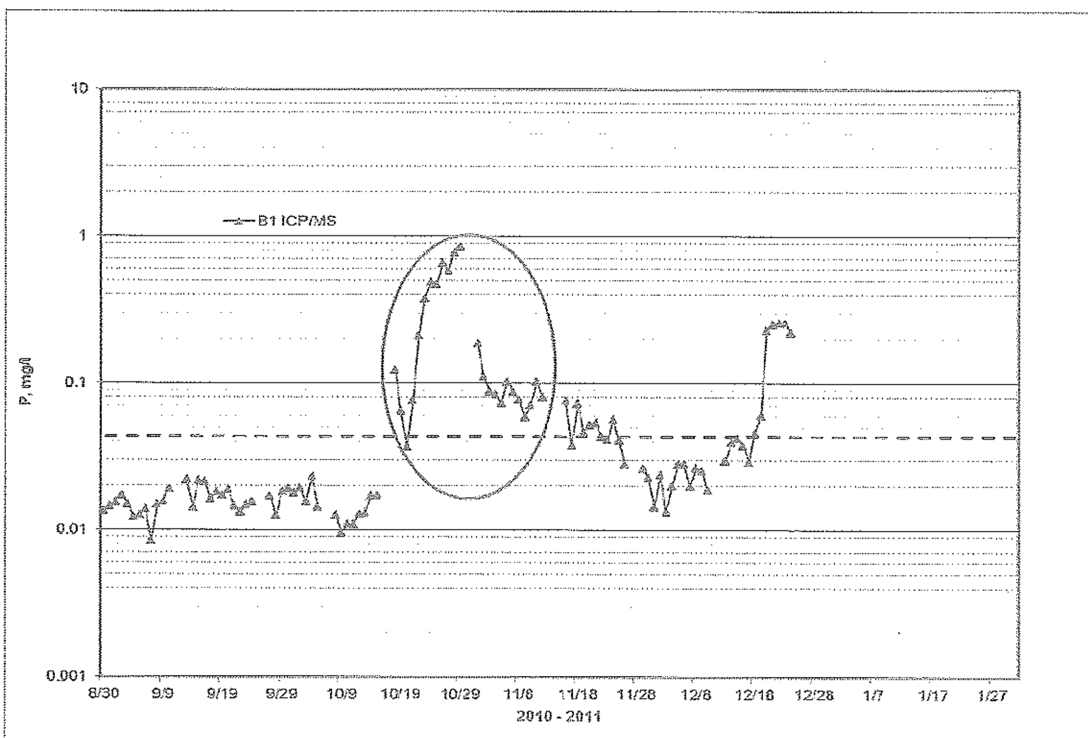


Figure 8 – Spokane RPWRF Pilot – Ultrafiltration performance, (including no upstream settling step).

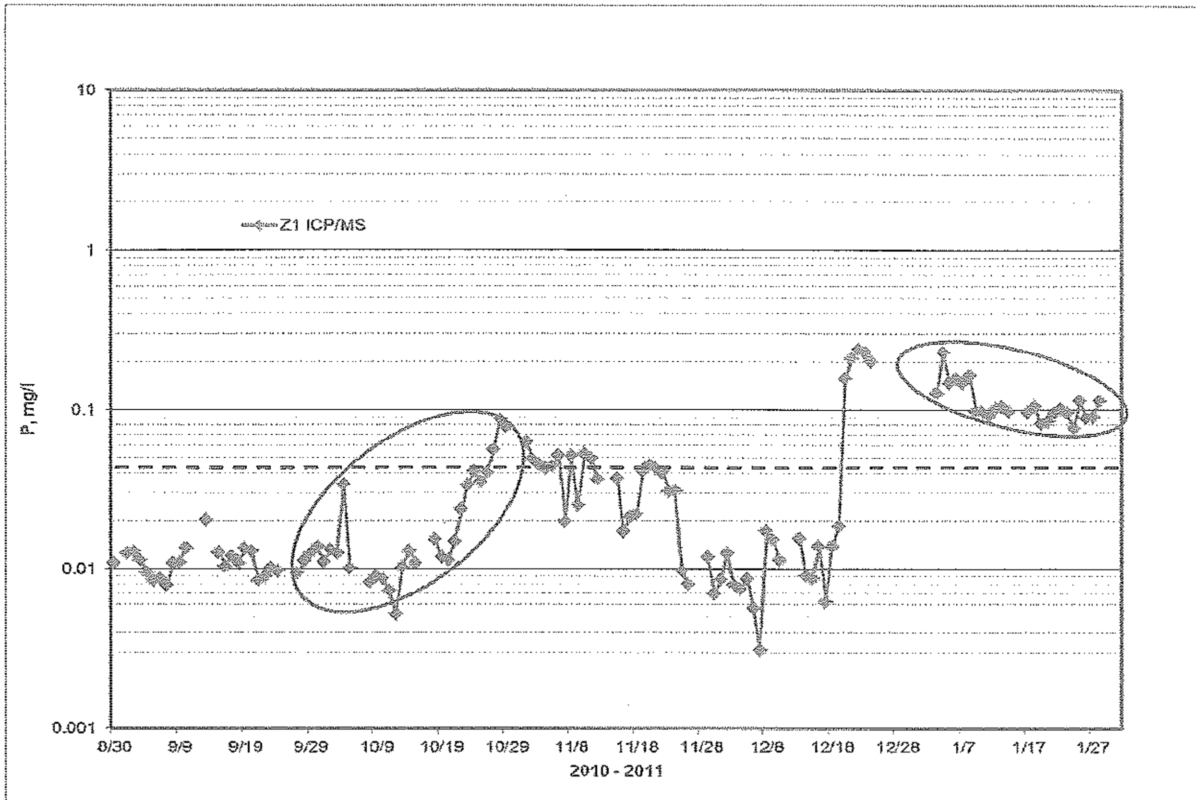
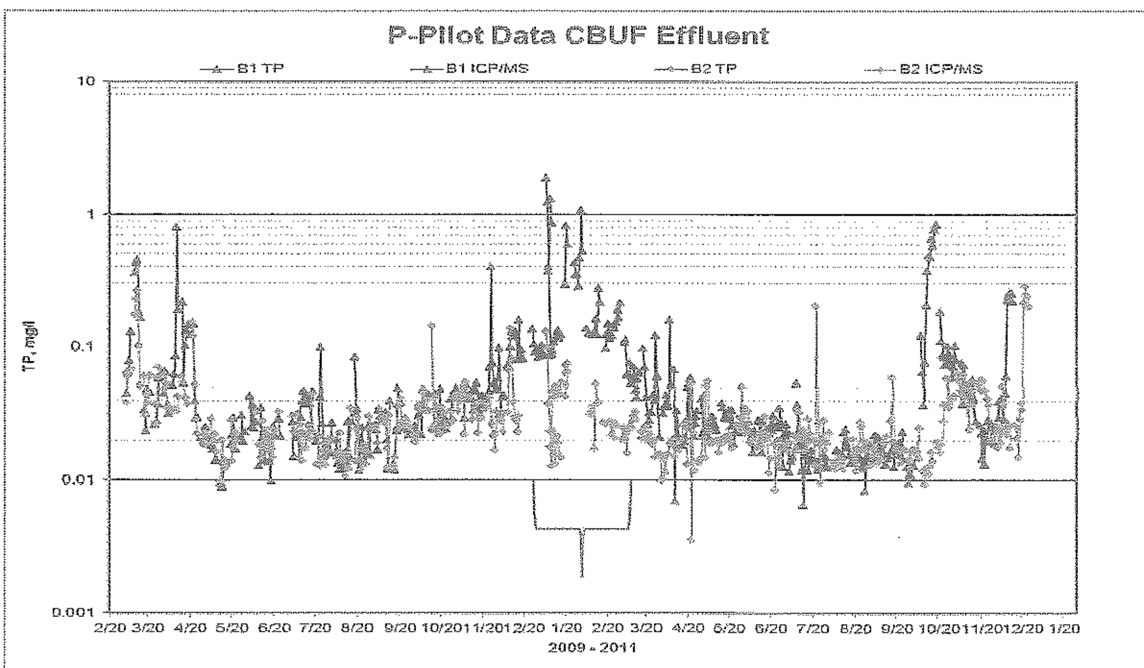


Figure 9 – Spokane RPWRF Pilot – CBUF performance – dual-pass operation shown bracketed



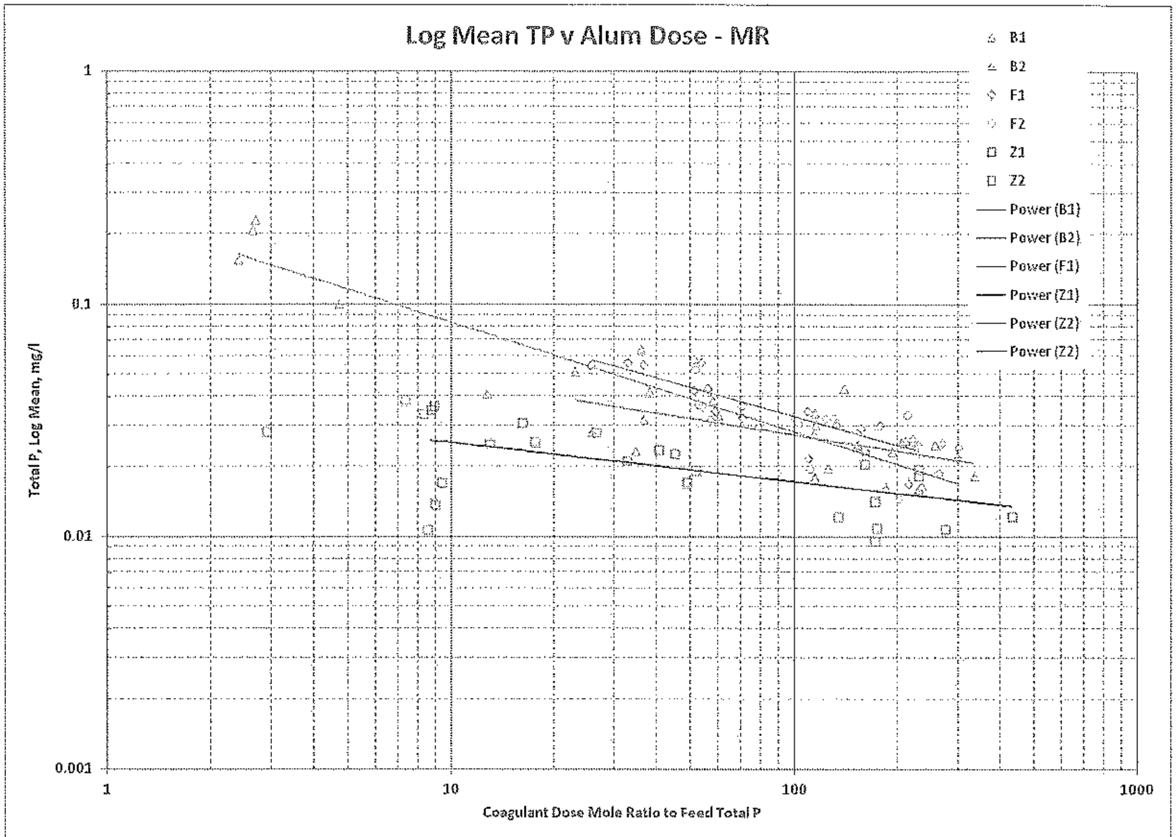
Observations of the Spokane RPWRF pilot study data presented in the Figures above that are of particular interest in the selection of preferred technology for the Post Falls WWTP include:

- The season average concentration for the filtration effluents can be expected to be 20% to 50% higher than the 50^{th} percentile values for the seasonal effluent data.
- The overall two-stage (settling followed by filtration, with coagulant addition at each stage) performance data confirms that two-stage technology is capable of meeting the WLA at the initial 4-mgd implementation, and through the phased expansions, likely out to about 8-10 mgd at least (effluent concentration to meet the WLA at 8-mgd average flow is 0.048 mg/L or 48 µg/L).
- Limited data suggests that dual media downflow and ultrafiltration alone (no upstream settling) could meet the WLA through the first phase of expansion (4.0 mgd, meeting 95 µg/L), and possibly into subsequent phases:
  - The dual media downflow unit was able to achieve less than 100 µg/L consistently when the settling step was bypassed (during the critical season when chemical phosphorus-removal was occurring in the secondary process).
  - The ultrafiltration unit was able to achieve less than 100 µg/L consistently when the settling step was bypassed (during the critical season when chemical phosphorus-removal was occurring in the secondary process).
  - The CBUF unit was not able to meet the phase 1 (4-mgd) target effluent total phosphorus concentration of 95 µg/L when there was no upstream settling step. But is must be recognized that these trials occurred after the critical season, so there was no alum addition in the upstream secondary process.
- When operated in series (dual-pass mode), the CBUF unit was capable of achieving effluent TP in the range needed to meet the WLA at least through the first phase of expansion (target concentration 95µg/L), and likely the concentration target (75 µg/L) through the 5-mgd capacity.

Other relevant RPWRF observations include the following:

- There were substantial operational challenges with the pilot units due primarily to the high doses of coagulant applied, along with the correspondingly high alkalinity supplementation. It is believed that these challenges can be mitigated during design of the full-scale installation.
- Initial coagulation mixing energy was found to be an important parameter in not just coagulant utilization efficiency, but also in final TP performance.
- For each filtration technology, effluent total phosphorus concentration is a function of the mole ratio metal salt addition (Al:P). However, the data appears to support the observation that the ultra filtration units were able to achieve a lower effluent TP concentration for the same coagulant dose in comparison to the two granular media technologies. This observation is illustrated in Figure 10 below.

Figure 10 – RPWRF Pilot study. Effluent TP vs mole ratio (Al:P) coagulant addition.



5. The City of Post Falls hosted its own pilot study during the Fall of 2011. The technology piloted was "AlgEvolve", which is a system where an environment is provided to encourage phosphorus uptake by algae. The phosphorus-laden algae then must be separated from the effluent by micro- or ultra- filtration. Other methods of algae removal have not proved to be viable, confirming a long history of difficulty removing algae in natural treatment systems.

   The pilot study results were presented in a report furnished by AlgEvolve, dated January 3, 2012. The effluent membrane filters utilized in the latest pilot runs were cross flow membranes, which AlgEvolve also proposed for an upsized pilot study (20,000 gallons per day proposed). The cross-flow membranes were operated up to 15 gpm feed flow. The recommendation in the pilot report proposes 0.77 gpm as the scale-up feed flow, which is estimated to be the most economical sizing, as it allow single-pass operation. Refer to the pilot reports by AlgEvolve and Koch Membrane Systems for further details regarding the pilot study and the conclusions.

   The City has requested additional clarification regarding the pilot reports to help estimate the potential for long-term economic competitiveness with the more established chemical polishing. Significant unknowns remain regarding the viability of the AlgEvolve process in a full-scale installation, including:

   - Cost competitiveness for the initial capital project. Budget-level proposals have been requested, but there are still elements of the process that AlgEvolve acknowledges need to be worked out, therefore making it difficult to prepare such proposals for a full-scale system that would present no more risk to the City than more established technologies. AlgEvolve has proposed to install, at the City's cost, a 20,000 gallon per day system to operate for 12 months to determine operational parameters and data necessary to design a full-scale system (3-mgd and larger).

- Operational cost competitiveness. This concern is addressed in operating cost comparison presented below in another section of this technical memorandum.
- Waste algae handling concerns. Algae is known to be incompatible or poorly compatible with municipal sludge handling, including belt filter press dewatering, as used in Post Falls. Special provisions for dealing with waste algae, and the costs associated with any special provisions are still unknown, adding a significant cost risk at this time to implementing this technology.

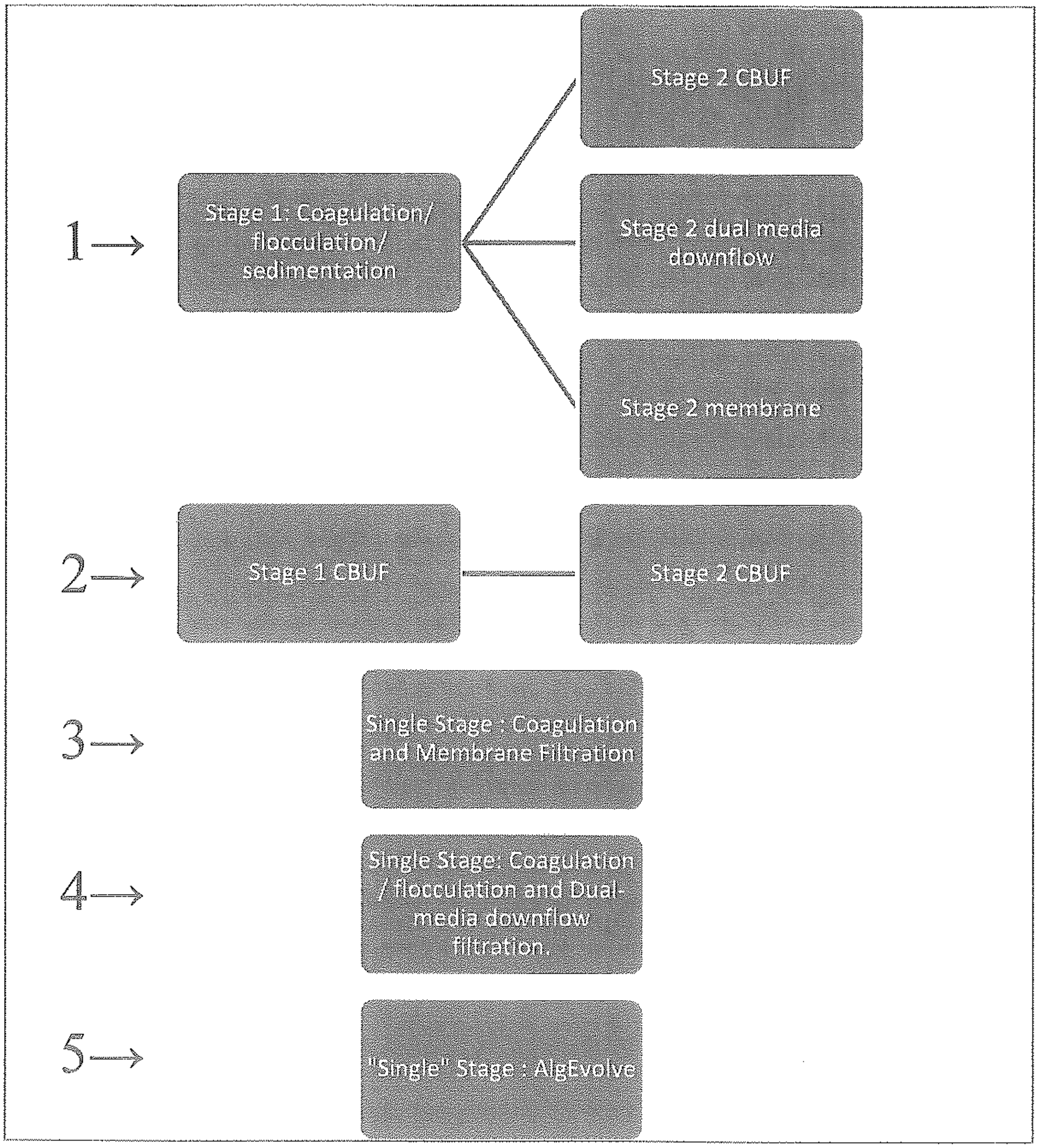
Conclusions from the above evaluations of performance for the various technologies at the above locations and applications are:

1. The WLA structure of the permit, as outlined in Table 1 results in the finding that some technologies or combinations of technologies would be appropriate for the initial phase of implementing Next Level of Treatment but may not be adequate for meeting subsequent phases, when the average effluent TP concentration will need to be lower.
2. For the initial phase, to meet the WLA of 3.19 lb/day seasonal average, the seasonal average effluent concentration must be 95 µg/L or lower.
    a. The data summaries presented above indicate that this initial phase seasonal effluent phosphorus concentration can be met on a consistent basis by two-stage treatment alternatives (two stages of chemical treatment following the activated sludge with enhanced biological phosphorus removal), as summarized in alternatives "1" and "2" Figure 11.
    b. The phase 1 effluent TP concentration level appears to also be achievable with select single stage treatment alternatives, also shown on Figure 11, alternatives 3, 4, 5.
    c. Data from full-scale operation at Moscow and from the pilot study in Spokane do not support utilization of the CBUF in a single-pass mode to meet the phase 1 TP concentration target.
3. Future expansion will require more stringent effluent TP concentrations. At the 5-mgd average annual flow facility capacity, as indicated in Table 1, the effluent TP concentration will need to be 75µg/L. The two-stage treatment alternatives shown in Figure 11 will still be capable of meeting the effluent TP requirement. However, the single-stage treatment alternatives that could be expected to be effective are limited now to the following:
    - Membrane
    - AlgEvolve

    Therefore, if the dual-media downflow filter technology were implemented as a single-stage NLT treatment for the initial 4-mgd phase, future phases are expected to require the addition of a new first stage chemical coagulation / flocculation / sedimentation step upstream of the filter units.

4. At ultimate flows in the 18-mgd range, the only NLT process train that could be expected to perform at the seasonal average 21µg/L effluent TP level would be a two-stage treatment consisting of coagulation / flocculation / sedimentation followed by membrane treatment. And consistent performance at this level is not certain. It appears that the AlgEvolve system may have the potential to approach this level of treatment, but at this time there is insufficient data and experience in full-scale facilities to draw that conclusion.

Figure 11 – "NLT" alternatives effective to the phase 1 TP limitations (95 µg/L)



The feasible alternatives by phase are summarized in Table 5.

Table 5 – Summary Matrix of Preliminary alternatives: Effectiveness at initial and future capacities.

	Phase 1 .095 mg/L	Phase 2 .075 mg/L	Ultimate .021 mg/L
Single-stage alts	• Membrane • Downflow dual-media • Algevolve*	• Membrane • Algevolve*	• ?
2-stage alts	• Sed-Membrane • Sed-CBUF • Sed-downflow dual media • CBUF-CBUF	• Sed-Membrane • Sed-CBUF • Sed-downflow dual media • CBUF-CBUF	• Sed-membrane

* AlgEvolve is listed as a single stage process, though the "system" consists of multiple stages

? Potential for AlgEvolve to meet this level, but currently lacking full-scale installation data to demonstrate conclusively.

Presentation of the technologies

This section presents a summary of the technologies identified above that are being considered for Post Falls NLT.

Precipitation and sedimentation technologies

There are several configurations that are capable of serving as the coagulation / flocculation / settling first stage in a two-stage NLT treatment model. In terms of P-removal capability these are presented together, based mainly on the Spokane RPWRF pilot finding that performance is comparable regardless of settling configuration, as illustrated above in Figure 4.

Standard-rate

Standard-rate clarifiers include conventional, horizontal flow (rectangular tanks) or circular, peripheral overflow tanks (similar to the secondary clarifiers currently used in Post Falls). In a chemical P-removal application, separate from the biological sludge, conventional clarifiers can be operated at an overflow rate of nominally 0.3 – 0.6 gpm/sf.

Advantages of this type of arrangement include its proven operational track-record and its accessibility for maintenance tasks. The principal disadvantage is the high footprint requirements. The 4-mgd initial phase would require a total surface area of nominally 6,000-7,000 square feet. Sludge mechanisms limit the length and width of the basins, so with multiple basins, as well as access space, sludge pumping facilities, and chemical feed facilities, total footprint would be expected to be in the range of 18,000 sf for rectangular clarifiers

"High-rate" settlers

This configuration utilizes pre-manufactured tanks with inclined-plate or tube-settlers to allow a surface loading rate in the range of 0.8 to 1.3 gpm/sf. The Spokane WPRF pilot study included two 0.5-MGD units constructed of marine-grade aluminum. Each unit included two-stage flocculation and a high-energy initial mixing zone to optimize coagulant efficiency. The RPWRF pilot unit tanks (which included the mixing and flocculating zones) each had an overall footprint of 12'w x 36'l. This is approaching the largest size that can reasonably be expected for a pre-manufactured unit to be ship-able. With feed pumps, sludge pumps, chemical feed areas, and sampling equipment, the overall footprint came to 2,120 sf (53'x40' interior building dimensions) to treat 1.0 mgd. Extrapolating to 4-mgd for the first phase at Post Falls and allowing for improved access, chemical storage, and electrical service needs for a permanent installation (as opposed to the temporary installation of the pilot unit in Spokane) results in an estimated building footprint for pre-manufacturer high-rate settler units of 10,800 sf.

Standard pre-manufactured units are typically constructed for water treatment plants. Customization would be recommended for adapting to phosphorus removal – the principal issue is sludge removal – the chemical sludges generated in piloted units settle very poorly, overwhelming the tube settlers as well as the sludge removal (underflow) piping capacity. Submerged mechanisms and/or a cleaning mechanism at the tube components may be designed that could reduce operational demands.

Ballasted Sedimentation

The following two ballasted sedimentation technologies were included in the Spokane RPWRF pilot study. Both performed well in terms of phosphorus removal, and were comparable to the high-rate tube-settlers operated in parallel.

- Kruger Actiflo ballasted sedimentation – utilizing ballast consisting of micro-sand to achieve high-rate sedimentation, with the micro-sand recovered with a cyclone for reuse.
- Cambridge Water Technologies "CoMag" ballasted sedimentation, which uses magnetite for ballast, with the floc separated from the magnetite using intense agitation, with the magnetite recovered using a magnetized drum for reuse.

The presence of ballast allows for a substantially lower surface overflow rate, as mentioned above in the presentation of results for the RPWRF pilot study. However, the ballast recovery was never 100%, and the escaped ballast cause difficulties (mainly wear and abrasion) for the downstream effluent and sludge handling units.

Another concern with the ballasted sedimentation units is the high polymer dose required (relative to the polymer use in the high-rate tube-settler units). One of the problems with high polymer is the complication of polymer carryover, if membrane units are downstream as a second stage, because too much polymer can blind membrane filters).

Reactor clarifier (slurry recirculation or sludge blanket solids contact clarifier)

This type of settling unit arrangement utilizes a sludge or slurry recirculation and/or contact reactor with the incoming water to allow the overflow rate to be dictated by the bulk settling rate rather than the settling velocity of the discreet particles. These units are typically proprietary (like the ballasted sedimentation processes).

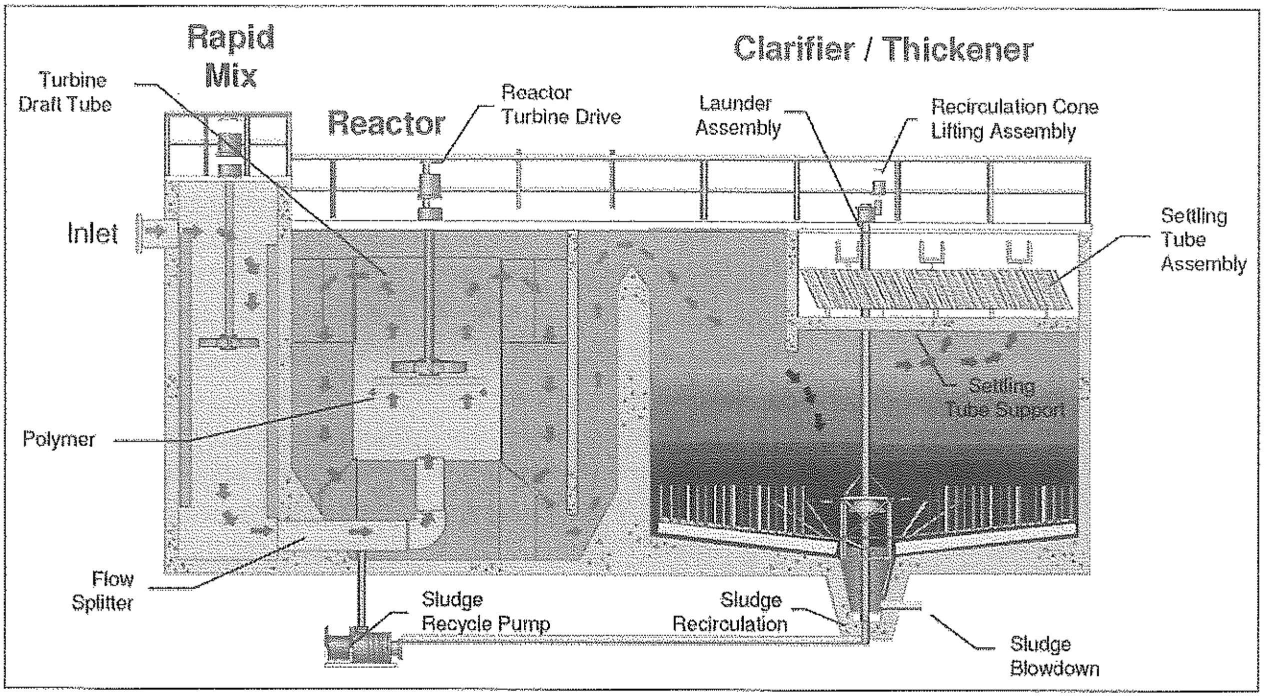
A variation of this type of clarification is utilized at the Rock Creek facility in Oregon. The configuration utilized at the Rock Creek Facility has been applied to many water treatment facilities across the country. These units are subject to upset due to hydraulic surges because a deep sludge blanket is maintained within the primary flow pattern of the effluent.

Another sludge/slurry recycle clarifier system that has been applied to wastewater effluent treatment for phosphorus polishing is the Densadeg, offered by Infilco Degremont, Inc. (IDI). A Densdeg unit was observed in operation at the Iowa Hill wastewater treatment plant in Colorado for phosphorus removal. Operators at Iowa Hill were pleased with the performance of the unit, though it was loaded at less than half its "rated" capacity. The overflow rate for this system falls between the ballasted sedimentation units and the conventional and high-rate settling processes, at 3-5 gpm/sf. The Densedeg will typically utilize polymer near to the same range as is used by the ballasted sedimentation units, so there would be a concern about possible carry-over if membranes are utilized downstream. One notable difference with the ballasted sedimentation unit, however, is that there is no high-energy ballast recovery step, which would be one opportunity for release of polymer that may be more prone to carryover.

A proposal was received for implementation of a Densadeg for Post Falls. Based in part on this proposal, it appears that Densadeg for the initial phase of NLT for Post Falls, at 4 mgd would utilize 2 parallel units to provide 100% redundancy (except there would no effective "de-rating" with one unit out of service), and a building footprint would be approximately 6,400 sf.

Figure 12 shows a Densadeg process schematic.

Figure 12 – Densadeg Process, Figure Source Infilco Degremont, Inc.



Dissolved Air flotation

There is no data available on utilization of DAF in a phosphorus removal application, though it has been piloted with mixed results in Massachusetts. Given the lack of data at this time, it is not recommended as a primary alternative for further evaluation during this facility planning effort.

Filter Technologies

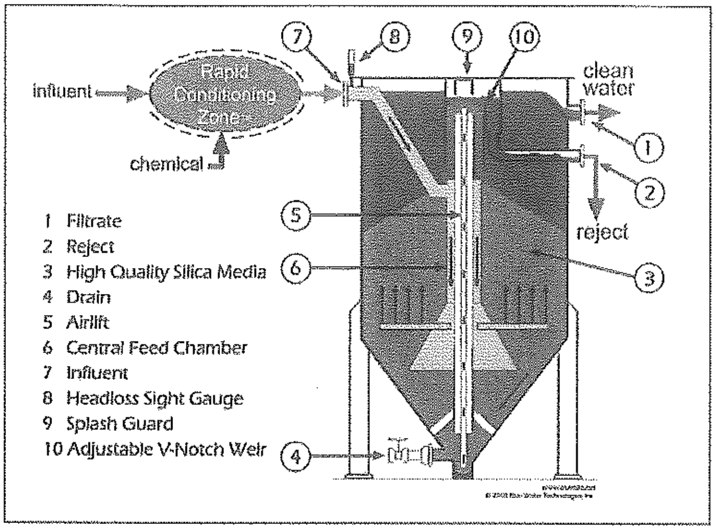
Upflow Continuous Backwash Sand Filters

Standard configuration for these filters is for individual filters with 50 square feet of filter area each. Sand depth is 1 to 2 meters at the side of the filter. Filters with 2 meter depth perform better for water reuse application, and for phosphorus removal applications. This makes the filter overall height up to 20 ft.

36 of the standard 50 sq. ft. filters would be required to treat average daily flow of 4 MGD of effluent for phosphorus reduction (sized to handle the peak flow, which will be equalized to the maximum day flow). At 5.0 mgd average flow, 44 filters would be required. The filtration rate would be about 2 gpm/sf for average flows, accommodating maximum day flows at a rate of 2.5 gpm/sf.

The above preliminary sizing is based on single-pass operation. If used in dual-pass mode with no upstream treatment after the biological process (i.e. no coagulation/flocculation/settling step), the number of units would be doubled. The filtration rate is assumed the same for both stages since the solids loading would be expected to be approximately the same for both stages.

Figure 13 – Continuous Backwash, Upflow Filter (CBUF). Figure Source Bluewater / ContraFlow



The filter units could be installed in concrete basins (e.g., Moscow WWTP Dyna-Sand filters), with more than one filter unit per filter module. It is suggested that modules of 2 to 4 filters be considered in preliminary layouts to determine an optimum configuration.

Coagulant dose rates up to about 100 mg/L as alum have been successful at Spokane pilot plants and at Moscow WWTP, so long as operators are diligent to prevent clogging due to the solids (e.g., monitor performance and provide special cleaning when needed.). Predicted dose for Post falls is in the 75-125 mg/L range per pass.

The reject stream from each filter is about 10 gpm, continuous, and is derived from the filtered water. The total water use for backwash is about 10%.

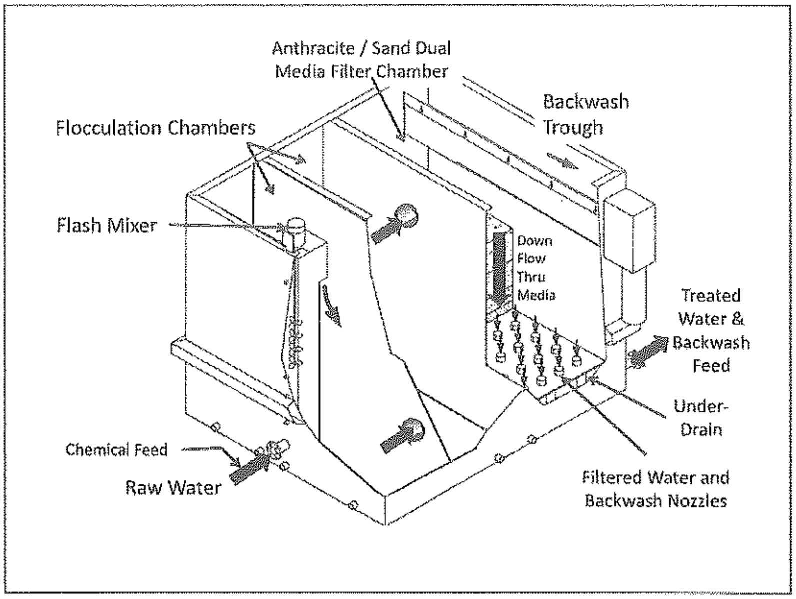
Dual-Media Gravity Filters

Pre-manufactured dual media "conventional water filters" could be installed with complete systems for operation, including backwash. Individual units with about 1.0 MGD (average) capacity would allow 6 units to treat the effluent to low phosphorus requirements. These units would be about 12 ft wide by 8 ft high by about 44 ft long, including flocculation units. Filter rate would be about 2.1 gpm/sf for maximum day flow.

These units could be pre-manufactured (package) systems, as the units at Spokane were, or constructed in concrete structures. The units have been demonstrated to successfully function with up to 100 mg/L of coagulant, as alum, added to the units at Spokane. A small dose of polymer sometimes improves performance.

Backwash water for these units must come from treated water storage. The storage would most likely consist of on-site tank with pumps used to backwash (this was the arrangement at the Spokane Pilot plants). The backwash water flow rate is high for these systems, although the duration is short which makes the total backwash water use approximately the same as for the other systems (5% to 10% of production). The backwash is automatically controlled, and is initiated by headloss, turbidity, or time. The backwash would be programmed to not permit backwash of more than a minimum number of the units simultaneously to reduce total backwash flow rate (reducing storage volume requirements and pipe-size requirements). Equalizing the backwash (flow back to the treatment plant) would likely be necessary if the dual media filter technology is used, but the equalization of the backwash waste could be combined with the planned WWTP influent equalization, resulting in minimal added cost.

Figure 14 – Dual Media Downflow Filter – Anthracite and Sand. Figure source Corix Water Systems.



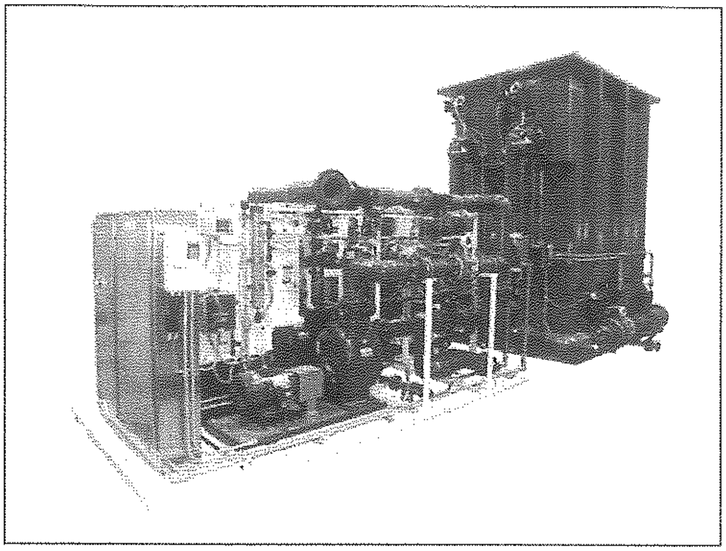
Membrane Filters

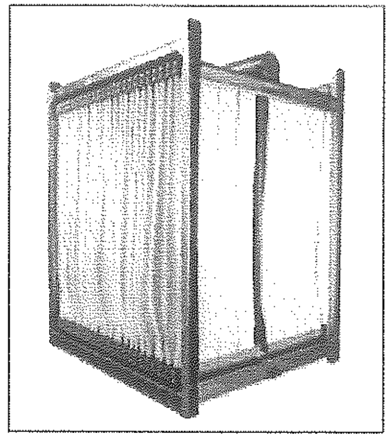
Open-tank atmospheric pressure membrane systems are assumed at this time to be preferable for this application where large alum doses may be needed to reduce phosphorus. However, the pilot unit for Liberty Lake Sewer and Water District successfully used enclosed pressure membranes, so they will not be eliminated from consideration (during the design phase if membranes are selected as the preferred technology). Modular systems consisting of individually sized units are one option, up to a production capacity of nominally 830,000 gpd each (The Zenon L128, de-rated based on pilot experience and application experience). It would take 8 such units to meet the first phase of NLT implementation (to meet maximum day when average flow is 4-mgd). One of the units would be only partially-populated membrane cassettes. At 5-mg average flow, it would take 10 such units, with one once again only partially populated.

GE/Zenon also proposed a submerged membrane system that is not made up of modular stand-alone units – requiring concrete tanks. This approach allows ancillary components, such as cleaning systems and controls to serve the entire process instead of have these components for each skid-mounted, stand-alone unit. The non-modular, concrete tank system utilizes the same membrane fibers as the modular, package units. This non-modular option appears to be significantly more cost-effective than the skid-mounted, multiple modular units option, because there is less duplication of ancillary equipment.

The modular units store water on the skid for back-pulsing the membranes and backwashing the tanks. The operation of each individual unit is controlled by a PLC controller that directs all of the functions to operate the system.

Figure 15 – Modular membrane package system and membrane cassette. Picture source GE/Zenon.





AlgEvolve

This process utilizes algae to uptake the trace amounts of phosphorus in the effluent. The algae is then removed from the effluent stream by a membrane separation process. This is a biological process, so coagulant dose is kept to a minimum. The process has not had any full-scale installations applied expressly for phosphorus polishing for discharge to a surface water. From the piloting done at Post Falls as well as at Inland Empire Paper Company, along with a review of the technology, it would appear that the main drawbacks to this technology are:

- Lack of experience
- Production of waste algae, which may present greater handling difficulties than alum sludge, and therefore unknown solids handling cost impacts, and;
- High expected initial implementation costs due to reactor footprint, which is housed in a "greenhouse" type building, as well as the membrane separation step.
- Possibly high energy costs.

For additional detail regarding the AlgEvolve system and the proposed larger-scale demonstration unit (20,000 gpd commercial demonstration project proposed for Post Falls), refer to the Pilot Project Report from AlgEvolve.

Final Alternatives Comparison

Selection criteria

The alternatives presented above are selected based on the following criteria:

1. Preliminary Screening Criterion:
   - Effectiveness – Ability to consistently meet the WLA criteria at the initial phase of implementation and in future phases. The preliminary screening, outlined in the above sections of this memorandum, and summarized in Figure 11 and Table 5, used

effectiveness as the primary means of screening, so the final alternatives listed in Table 5 are considered to be effective at meeting the WLA as the flows indicated.

2. Final Comparison Criteria:
   - Cost – Relative initial capital cost;
   - Footprint – The footprint implications are only considered in this memo in their direct effect to implementation costs. The implication for overall plant layout must be considered also, but is reserved for other technical memoranda;
   - Operations – Chemical use, headloss (energy), and operations (operating time, operator skills required, maintenance requirements);
   - Consideration of other parameters of concern – There are limitations for other constituents in the effluent, specifically, metals copper, lead, and zinc. Additionally, there are constituents that are being monitored and may potentially have regulated limits in the future. These include metals cadmium and silver, as well as total PCBs and 2,3,7,8 TCDD. The potential for the effluent polishing alternatives to remove these other parameters of concern was evaluated to determine if the effectiveness is better with any particular technology, and if the difference is significant enough to influence the technology selection.

The final comparison using these final comparison criteria is presented below.

Project Cost and Building Footprint Comparison

Table 6 below presents a comparison matrix of the one-stage and two-stage alternatives. The costs shown are the preliminary Engineer's opinion of probable costs. These costs were prepared for comparison of these alternatives, and represent the probable range of costs for implementing the alternative as a stand-alone project (it includes a contingency and engineering based on percentages of only the tertiary NLT project). The building footprint for each alternative is also presented for comparison purposes. The building footprint impact to costs are included in the cost numbers. The two-stage alternatives that include a coagulation / sedimentation first stage show a range for cost and footprint. This range is representative of two viable means of achieving the first-stage coagulation/sedimentation step – using "high-rate sedimentation" similar to the tube-settlers piloted at Spokane and observed in operation at the exemplary P-removal facilities in Colorado, and the Densadeg alternative slurry-recirculation separator.

AlgEvolve is included in the Table, though as noted above, and in the footnote to the Table, there are significant unknowns regarding the viability and cost-structure of a full-scale system. Therefore, the AlgEvolve capital project cost estimates are subject to revision based on new information which may be made available. It is not expected that satisfactory answers to critical questions about solids handling can be addressed within the City's decision time frame, so the City would be in a position of unacceptable risk in pursuing this technology as the only alternative for phosphorus polishing. As the estimated probable costs show, AlgEvolve has little potential for savings in the capital construction project.

The highlighted cells in Table 6 show the apparent lowest-cost alternatives for implementation of NLT for Post Falls. These correspond to the alternatives most likely to be economically feasible, and are the focus of the next section, a comparison of operating and maintenance costs.

The comparison of probable costs for the final feasible alternatives, as summarized in Table 6 results in the following conclusions:

- The lowest-cost alternative at the initial-phase implementation is the single stage (no upstream coagulation/settling) dual media downflow package filters. However, when the facility is expanded and a lower effluent TP concentration is required to meet the WLA, a new process would need to be constructed upstream of the filters, so that at that phase of expansion, the dual-media downflow filters are no longer the most cost-effective.
- The single-stage membrane filter alternative has the second lowest capital project cost at the first stage, but indications are that the same process will continue to be a satisfactory technology for meeting the lower TP concentration of the next phase of expansion, so while phase 2 will require an expansion of the tertiary membrane filters, a new intermediate process is not anticipated to be needed.
- The two-stage CBUF-CBUF is not cost-competitive at the initial implementation phase. It has the advantage at the next expansion phase that a new upstream component is not needed, so the only requirement is an expansion of the already-operating facility. This advantage makes the CBUF-CBUF alternative cost competitive at the phase 2 expansion with the two-stage alternatives involving the dual-media downflow filters.

Table 6 – Summary Sizing, cost, and footprint comparison.

	Phase 1 .095 mg/L	Phase 2 .075 mg/L	Ultimate .021 mg/L
	Single-stage alternatives		
Membrane – package modular units	• 8 units • $24.7 M • 23,800 SF bldg	• 11 units • $33.0 M • 32,200 SF bldg	?
Membrane – concrete tank	• 960 +/- ZW500 mods • $15.4 M • 9,000 SF bldg	• 1300 +/- ZW500 mods • $19.2 M • 12,000 SF bldg	?
Downflow dual-media	• 8 units • $14.1 M • 16,000 SF bldg	?	X
AlgEvolve*	• $28.5 M+/- • 34,500 +/-SF bldg	• $36.8 M+/- • 52,000 +/- SF bldg	X
	Two-stage alternatives		
Sed-CBUF	• 12 sed/36 filt Or 2 Densadeg and 36 filt. • $20.3M - $25.2M • 13,000 - 17,500 SF bldg	• 16 sed/44 filt Or 3 Densadeg/44 filt. • $24.9M - $31.5M • 16,500 - 22,000 SF bldg	X
CBUF-CBUF	• 72 filt • $18.3M • 11,000 SF bldg	• 88 filt • $22.0M • 13,000 SF bldg	X
Sed-downflow dual media	• 12 sed/6 filt Or 2 Densadeg / 6 filt. • $18.3M - $23.4M • 22,400 - 26,800 SF bldg • Alt. ph.1 would be downflow filters only (no sed. until ph. 2), see above single-stage, 8 units.	• 16 sed/8 filt Or 3 Densadeg / 8 filt. • $23.5M - $30.1M • 28,200 - 33,600 SF bldg	X
Sed-membrane (package modular)	• 12 sed/8 filt Or 2 Densadeg / 8 filt. • $31.7M - $36.9M • 30,000 +/- SF bldg • Alt. ph.1 would be membrane filters only (no sed. until ph. 2), see above single-stage, 8 units.	• 16 sed/10 filt Or 3 Densadeg / 10 filt. • $41.1M - $47.7M • 38,000 - 43,000 SF bldg	? (likely)
Sed – membrane (concrete tanks)	• 12 sed/800 ZW500 mods Or 2 Densadeg / 800 ZW500 mods • $21.6M - $26.7M • 15,000 - 19,400 SF bldg • Alt. ph.1 would be membrane filters only (no sed. until ph. 2), see above single-stage, concrete tank.	• 16 sed/1060 ZW500 mods Or 3 Densadeg / 1060 ZW500 mods • $27.1M - $33.7M • 20,000 - 25,400 SF bldg	? (likely)

Notes for Table:
* = AlgEvolve costs are speculative based on draft pilot report, verbal communication regarding possible full-scale build scenarios, and estimated costs for components expected to be utilized in the full-scale operation.
? = Data indicates may be potentially viable, but not conclusive, long-term operation at higher limitation concentration could establish capability to meeting lower concentration limits.
X = Data indicates the alternatives is not proven capable of meeting the limitations sufficiently to be considered at this stage.

Operating Cost Differences

This section presents a comparison of the operating costs of the two final alternatives with the lowest probable initial phase (4-mgd) costs, down-flow dual media and membrane filter. The operating cost comparison at the phase 2 expansion flows (5-mgd) is also presented. The discussion also includes the continuous backwash upflow filters in series alternative (CBUF-CBUF), since this two-stage technology appears to be cost-competitive at the phase 2 flow (approximately 15% higher total project costs). In general, the CBUF-CBUF alternative would be expected to have similar O&M costs as the down-flow dual media filter alternative. This is because the coagulant addition for these granular media alternatives are assumed to be effectively equal based on the study findings summarized above, and coagulant related costs (chemical, alkalinity, and sludge production) are the largest O&M cost categories. Higher pumping costs of CBUF-CBUF will approximately offset lower building-related energy costs (heat and light) at the first phase design flow (4-mgd), but the other costs are effectively the same for the two granular media filtration alternatives.

As stated above, the removal of phosphorus is a function of the mole ratio of metal salt added to the effluent phosphorus. The Spokane RPWRF pilot study has the best data for comparison of coagulant use, since the methods for sampling and testing was all controlled and equivalent for each technology piloted, and the technologies were piloted in parallel, utilizing the same treatment plant effluent. In general, there is a minimum required mole ratio Al:P to achieve a target TP in the effluent. The data however, did show potential for the membrane filtration to be able to perform better at lower doses of coagulant. This effect was shown in Figure 10, where the trend line shows lower TP for the same mole ratio Al:P compared to the other technologies.

Based on figure 10, as well as on individual pilot runs at the Spokane RPWRF pilot plants in Fall, 2010, it would appear that there is the potential for membrane filtration to achieve equivalent TP performance to the granular media filters for 20% - 40% lower coagulant dose. During the initial implementation phase (4-mgd) at Post Falls, this could amount to chemical use difference as follows in Table 7.

Table 7 – Coagulant use comparison for lowest-cost alternatives for phase 1.

Phase 1 alternative	Phase 1 (4-mgd) alum use, est. annual	Phase 1 (4-mgd) annual alum cost[1]
Membrane	655,000 lbs	$82,000
Granular Media Filtration	890,000 lbs	$111,000

Notes for Table:

1. 2011-2012 bulk alum prices.

At the second phase expansion (5-mgd), the difference in coagulant use will be greater, as effluent total phosphorus must be lower to satisfy the waste load allocation (Table 1 in this TM). The associated increase in coagulant dose will be greater with granular media than with membrane treatment. Expansion at the future phase 2 flow and effluent TP concentration is expected to require a new coagulation / settling process if using dual-media downflow filtration is used for the first phase, but with membranes, no new upstream or intermediate process is needed. At the 5-mgd average flow level, the difference in alum use is estimated at 580,000 lb/yr, at a cost difference of approximately $73,000 per year.

The alum use difference also impacts the amount of alkalinity addition needed. The above difference in alum consumption would result in a difference of approximately 95,000 pounds per year of sodium hydroxide at the 4-mgd average flow, and 240,000 lbs per year at the 5-mgd average flow. The cost difference associated with this chemical use difference would be about $40,000 at 4-mgd and approximately $95,000 at 5-mgd.

The chemical cost differences would be partially offset by the cleaning chemical use required for the membrane treatment system, which would not be required with any granular media filters. Preliminary cleaning chemical costs at the 4-mgd average flow are $18,000 per year, and at the 5-mgd flow are $22,000 per year.

It is also probable that dual-media downflow filters would use a small dose of polymer (.1 - .3 mg/L was found to be effective at the RPWRF, amounting to nominally $5,000 per year for 4-mgd in Post Falls).

The chemical feed difference also impacts the sludge production. The alum dose difference would be expected result in a difference of approximately 80-90 pounds per day (dry solids) of sludge (at 4 mgd), and about 210-230 pounds per day difference at 5-mgd. At typical cost per dry-ton processing and disposal costs, this could be a difference (between membrane filtration and granular media filtration of about $8,000 – $12,000 per year at 4-mgd, and $20,000-$25,000 at 5-mgd.

Media replacement costs are significant. Assuming a 10-year life for the membranes, on an annual budget basis, membrane module replacement per year would average approximately $95,000 to $115,000 (when treating an average 4-mgd on a seasonal basis). Granular media filters also require media supplementation. The annual budget for media replacement would not be expected to more than approximately $5,000 - $10,000 at the 4-mgd average flow.

Energy use would be similar for membrane and dual media down-flow systems. The primary energy costs would be for pumping and for heating and lighting the final treatment building. Pumping costs would be expected to be in the $8,000 to $12,000 range per year for a 4-mgd flow, with the lower estimate corresponding to the dual-media filter because of the lower overall average pumping head. The slightly higher energy costs predicted for the membrane system pumping would be more than offset by the higher energy costs required for the larger building footprint of the dual-media downflow filtration.

Manpower costs are not expected to be significantly different between granular media filtration and membrane filtration.

Overall, the approximate difference in annual O&M costs between the membrane filtration and dual media down flow filtration would be expected to be approximately $30,000 to $40,000 per year in favor of the dual-media downflow filters for the first phase. By the 5-mgd phase, the O&M budgetary costs, on an annual basis would favor the membrane filters by approximately $60,000 - $80,000. A summary comparison of the operation, maintenance, and replacement projections is presented in Table 8 below. The costs presented in Table 8 are suitable for comparison of these two tertiary effluent phosphorus polishing alternatives, and are based on the following assumptions and limitations:

- Power costs assume 4 mgd in phase 1 as indicated and 5 mgd in phase 2 as indicated, with pumping being a significant expense that is directly related to flow volume.
- Costs for power assume $0.08 per kW-hr. Considered a little bit conservative but reasonable given the potential variability of energy costs over then 20+ years.
- Chemical costs were based on 2011-2012 prices for chemicals, but total chemical use is based on dosing at the flow levels indicated in the Table (4-mgd and 5-mgd). Overall

O&M cost projections utilized for budgeting in the main body of this WRF facility plan may take a different approach to projected growth in flow, but this approach is useful in this context of P-removal alternatives comparison.

- Only costs associated with the tertiary P-removal (Next Level of Treatment) are incorporated into the comparison in Table 8. No O&M costs for other facilities or processes in the wastewater treatment plant are included in Table 8. This includes the category "Sludge Handling / Disposal", which accounts only for the sludge produced in the effluent phosphorus treatment, and does not include biological sludge. Refer to the main body of the report for overall O&M cost projections.
- As noted above, the CBUF-CBUF alternative would have estimated operation and maintenance costs comparable to the downflow dual-media alternative at the 4-mgd flow (within about $3,000 per year at this level of estimating). At the 5-mgd flow, the estimated operating costs of the CBUF-CBUF alternative could be up to $15,000 less per year than the dual-media downflow alternative, because of building-related energy expenses. CBUF-CBUF would still have substantially higher O&M costs than the membrane filter alternative at the 5-mgd flow.

Table 8 – O&M Cost Comparison, Membrane Treatment and Downflow Filters

	Phase 1 (4-mgd flow) comparison		Phase 2 (5-mgd flow) comparison	
O&M Category	Membrane	Dual Media Down-flow	Membrane	Dual Media Down-flow
Power (process)	$12,000	$10,000	$15,000	$12,000
Power – lights and heat	$14,000	$24,000	$18,000	$46,000
Equipment Maintenance / Parts	$57,000	$44,000	$71,000	$55,000
Media replacement –Budget	$99,000	$7,000	$124,000	$9,000
Labor	$33,000	$33,000	$39,000	$39,000
Coagulant	$82,000	$111,000	$131,000	$204,000
Alkalinity	$108,000	$147,000	$174,000	$271,000
Cleaning Chemicals	$18,000	-	$22,000	-
Polymer	-	$5,000	-	$6,000
Sludge Handling / Disposal	$27,000	$37,000	$44,000	$68,000
Sub-Total O&M annual	$450,000	$418,000	$638,000	$710,000

The AlgEvolve system, which would appear to be more costly for the capital construction (see Table 6), would have a very different mix of O&M costs compared to the dual-media filters and the membrane filters. With AlgEvolve, there would be potential for reduced chemical costs. At the 4-mgd level, the alum costs in Table 7 and 8 could be eliminated or very severely reduced.

On the other hand, the power costs would be substantially higher for AlgEvolve. Based on the AlgEvolve proposal for the 20,000 gpd demonstration plant, a 4-mgd plant could draw approximately 2,000 kW, resulting in a power bill in the $1,000,000 per year range (assuming operating 280 days per year for phosphorus polishing). It is not clear if the power use estimate from AlgEvolve includes pumping for the reactor, mixing, and permeate, or if this is strictly for the lights. Even if all pumping use is included in this power cost, it is substantially more than the total O&M costs expected for the granular media or membrane filters. Even if the full-scale system were 50% more efficient than the 20,000 gpd demonstration unit, its power costs would be higher than all O&M costs for the other alternatives.

Media replacement would still be needed with the AlgEvolve, expected to be in the same order of magnitude as the media replacement costs projected for the membrane filtration alternative.

Another O&M consideration with AlgEvolve is the potentially high dewatering and sludge disposal costs, because of the production of algae, which is known to be difficult to separate and may cause operational challenges if mixed with biological and chemical sludges.

It appears that the AlgEvolve system would have a higher O&M cost than the dual media or membrane filter alternatives, in addition to the higher expected capital costs. Because of these cost differences, until more information is provided, and new design parameters are available based on full-scale operations, further consideration of AlgEvolve is not recommended.

Consideration of other effluent parameters potentially of concern in the future.

The preliminary screening of technically feasible alternatives and the comparison of final alternatives above was based on effectiveness at meeting the limitations for total phosphorus. In addition to total phosphorus, the City of Post Falls is facing increasingly stringent effluent limitations for a range of other constituents. Specifically, the following constituents are incorporated into the new NPDES permit with limitations or with a monitoring schedule with reporting requirements that my results in future specific numerical limits.

- Total Polychlorinated Biphenyls (PCB's). According to the NPDES Permit Fact Sheet, there is reasonably sufficient evidence to suggest that the Post Falls discharge may potentially be contributing to some portions of the Spokane River downstream of Long Lake Dam not meeting water quality standards. The Fact Sheet also states insufficient data precludes establishing numerical limitations at this time, but a monitoring program and implementation of best management practices (BMPs) are required under the NPDES Permit. If any of the phosphorus-polishing technologies can more efficiently remove PCBs, then this is a long-term consideration that should be factored into the technology selection for phosphorus removal.
- 2,3,7,8 Tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD) is also suspected to be above the water quality standards in the Spokane River and downstream in Lake Spokane and below Long Lake Dam. Monitoring required in the new NPDES permit is intended to establish the likely contribution from the Post Falls effluent to any excursions above the water quality standards. If there is any measurable difference in removal efficiency between the phosphorus-removal technologies, then it should be taken into consideration in the selection of technology.
- The Post Falls NPDES permit includes numerical limits for dissolved metals Copper, Lead, and Zinc. Additionally, Cadmium, and Silver are monitored in the effluent consistent with the NPDES permit requirements. Effluent monitoring records indicate there have been no violations of the permit limits during the period of record reviewed, January, 2001 – July, 2011. Nevertheless, given the risk of future changes to effluent regulations and the opportunity to minimize the potential for these constituents to result

in water quality violations, it is still reasonable to compare capability of the effluent phosphorus polishing technologies at removing dissolved metals.

PCBs and 2,3,7,8 TCDD

The NPDES permit requires new monitoring for PCBs and 2,3,7,8 TCDD. No limitations are imposed at this time. Ultimately, when limitations are imposed, they are likely to be based on downstream water quality standards for Idaho, Washington, and the Spokane Tribe of Indians, and possibly taking into consideration the City of Post Falls wastewater treatment plant performance. The existing facility is most likely removing approximately 90% of incoming PCBs.

There is limited PCB data available from regional wastewater treatment plants, and even less available data on 2,3,7,8 TCDD. During the City of Spokane Pilot testing, PCBs were sampled on two occasions in order to determine if any of the phosphorus removal technologies studied can be expected to outperform the others for PCB removal.

The two sampling events both occurred when the pilot units were being operated in 2-stage treatment modes, with the activated sludge effluent first receiving a chemical coagulation step followed by a filtration step. The removal in the first stage after the secondary process (coagulation and sedimentation processes) was fairly consistent, with the combined removal for the "sedimentation" processes averaging 80%, with a range of 73.4% to 98.8%. Additional removal beyond the sedimentation stage was inconsistent, particularly for the membrane processes, where negative removal was commonly observed for this limited amount of data. Note that during the July, 2010 sampling, there was no alum addition in the sedimentation units ahead of the membrane units. The sampling and testing for PCBs for the RPWRF pilot study are summarized in Table 9.

Table 9 - Spokane RPWRF PCB Performance Summary

Process	Range Effluent Total PCBs	PCB removal	
Secondary Treatment	1,260 – 1,490 pg/L	91.3% (through activated sludge)	
	415 - 835 pg/L	92.8% (through activated sludge)	
Additional treatment		Additional Removal (after secondary)	Overall Removal (Activated sludge plus advanced pilot units)
CBUF following tertiary sed	150 – 182 pg/L	86% - 90%	99.0%
	25.4 – 102 pg/L	75% - 97%	99.3%
Conventional downflow dual-media filter following tertiary sed	163 – 248 pg/L	80% - 89%	98.6%
	63.2 – 57.5 pg/L	86% - 95%	99.3%
Membrane filtration following tertiary sed	428 – 425 pg/L	66% - 71%	97.2%
	101 pg/L	75% - 88%	98.8%

The rate of removal for PCBs through the secondary system demonstrated in the Spokane testing (nominally 92% removal) is consistent with observed performance of other activated sludge treatment plants in this region. For example, studies at the Pullman, Washington wastewater treatment facility have found removal rates of 94%-95%.

Drawing conclusions from the data taken during the Spokane Pilot studies is not straightforward with respect to comparing different technologies. PCBs adhere to solids, and the removal process in wastewater treatment plants is sorption to solids and removal with waste sludge. The adherence to solids implies that the filtration technology with the best solids removal will also be the best at PCB removal. However, piloting at the Spokane SAWTP did not indicate that this was the case, as shown in Table 9.

One factor to consider in reviewing the data from Spokane, is the extremely low concentration of PCBs following the sedimentation step (which is after the secondary treatment), in the range where PCB testing accuracy is very poor. The pilot study did not therefore conclude that any of the three technologies under consideration would necessarily result in better PCB removal. No specific data was found to contradict this conclusion from other facilities that could compare technologies.

The SAWTP phosphorus pilot study did not measure 2,3,7,8 TCDD, but the dioxin compound is an organic molecule that, like PCBs, adheres to solids. Note membrane pores are not small enough to exclude PCB or dioxin molecules, so even for membranes, sorption to solids is the removal mechanism for these compounds.

There is not sufficient evidence to conclude that any particular technology would help to consistently achieve better performance. The ultimate PCB and/or dioxin strategy may rely on achieving the maximum removal possible through the phosphorus-removing technology, along with, perhaps, an additional unit process specifically implemented for removal of organic compounds such as PCBs. The current state of technology of PCB removal would be activated carbon, while advanced oxidation processes (AOPs) continue to be developed and gradually implemented in some special-circumstance installations. AOPs utilize the hydroxyl radical to oxidize the most difficult to destroy organics. The hydroxyl radical is generated at the point of use since it is very short-lived. Methods of generating hydroxyl radicals for AOP include peroxide/ozonation or peroxide/UV.

Metals

Copper, lead, zinc, and cadmium were included in the regular monitoring program during the Spokane RPWRF pilot study, resulting in 40-60 valid samples from each of the six technologies piloted. Silver was not monitored during the RPWRF pilot study, so results are not available for this metal. The results are summarized below in Table 10 for the technologies evaluated for the Post Falls facility. Note that the data is combined for all pilot runs, which reflects a range of coagulant doses, as well as an intermediate coagulation and sedimentation step between the secondary effluent and the final filtration.

Table 10 – Metals Removal Performance for three filtration technologies at the Spokane RPWRF Pilot Testing

Metal	Secondary Effluent	Dual Media Downflow	CBUF	Tertiary Membrane Filtration
Copper (mg/L ave)	.00940	.00558	.00507	.00594
Lead (mg/L ave)	.00063	.00047	.00059	.00046
Zinc (mg/L ave)	.04488	.04060	.04174	.04087
Cadmium (mg/L ave)	.00012	.00013	.00010	.00013

The data from the Spokane pilots shows that some removal of copper (nominally 40% removal), lead (20%), and zinc (8%) was occurring through the pilot units, but in general, the difference between the technologies is not significant enough to conclude that any particular technology performs better than another for removal of these metals. For cadmium, the data shows effectively no removal through any of the pilot units. In conclusion, with respect to metals removal performance, there is no evidence to change the recommendations of the alternatives evaluation.

Summary of Alternatives Comparison

Table 11 presents a summary of the financial comparison of final alternatives. Due to the unknowns and the limited potential for being cost competitive at least through the life-cycle of the 4-mgd phase of expansion, the AlgEvolve system is not included in this comparison.

The present worth comparison shown in Table 11 is based on assuming facility startup in 2016, projecting O&M expenses in each year of the 20-year planning horizon of this study, and finding the present worth of each annual expense. The present worth calculation assumed a 20-year life and an interest rate of 5%. This approach requires making adjustments to the assumed coagulant and alkalinity costs as flows increase in accordance with projections (and required effluent total phosphorus concentration declines). The expansion to 5-mgd is assumed to be on-line by 2024 to keep up with the projected growth.

As noted previously, the costs assume implementation of equalization to limit maximum flows as presented in Table 2.

Table 11 – Summary Cost Comparison – Present Worth

	Final Alternatives		
	Tertiary Membrane Filtration	Dual-media Downflow	CBUF-CBUF (2-pass)
Implementation Cost	$15.4 Million	$14.1 Million	$18.3 Million
O&M cost (Present Worth, i=5%)	$4.3 Million	$4.2 Million	$4.1 Million
Expansion to 5-mgd requirements	Expand by adding more modules	New coag/ floc / settling units ahead of filters	Expand by adding more cells
PW of incremental expansion	$3.8 Million	$9.4 Million	$3.7 Million
TOTAL PRESENT WORTH	$23.5 Million	$27.7 Million	$26.1 Million

Conclusions

The cost comparison at the initial, 4-mgd project favors the dual-media downflow filter alternative. At the 5-mgd level, the tertiary membrane filter has more favorable economics, due to the ability to expand without adding a process, and the expected lower chemical costs. This expansion capability also results in a lower present worth for the membrane alternative for 20-year operation incorporating future expenses into the comparison.

The tertiary membrane alternative has the distinct advantage of permitting direct expansion to occur by adding to the previously constructed facilities, without the need to implement yet another technology. This would be true at the 5-mgd average flow, and likely out to the 8-mgd range at least. Thus, operational experience will be directly applicable to the design and operation of future expansions.

These future expansion considerations, along with the cost comparison for future facilities offset the higher cost of the tertiary membrane system for the initial implementation project.

With respect to constituents likely to be regulated in future permit cycles with numerical limits, including PCBs and metals, there is no substantial evidence that the performance capability for any of the final alternatives is superior to any of the other alternatives, and any differences in performance that may be found based on future study are unlikely to come close to offsetting the cost differences.

Recommendation

The conclusions presented above favor tertiary membrane filtration for effluent phosphorus polishing.

It is recommended the City of Post Falls incorporate the following into the preparation of the Phosphorus Management Plan that will be prepared in compliance with City's NPDES Permit:

1. Include budgeting for tertiary phosphorus removal in the City's Facility Planning, as summarized in Table 11.

2. Include piloting of tertiary membrane filter in the City's Phosphorus Management Plan. Budgeting should be based on soliciting proposals from suitable manufacturers for piloting. Piloting should ideally be performed during the low-phosphorus removal season, including the early part of the season (February), when cooler wastewater temperatures may make effective removal most challenging. The piloting should also overlap, if possible, periods during which EBPR transitions through more and less stable phases (this typically occurs during summer for most EBPR plants).

   The purpose of the piloting would be:

   a. Confirm capability to meet target TP concentrations at the initial implementation phase, as well as at future phases of expansion, when effluent TP concentrations will need to blower to meet the WLA.

   b. Provide verification of operational parameters that can influence design sizing, including chemical feed capacity for coagulant and alkalinity, and to improve the sludge production estimates for use in sizing solids handling improvements.