Town of Falmouth, Massachusetts

Final Blacksmith Shop Road Wastewater Treatment Facility Phosphorus Removal Evaluation

March 2014

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1. Introduction

This report provides an evaluation of methods to polish the phosphorus from the treated water at the Blacksmith Shop Road Wastewater Treatment Facility in Falmouth, Massachusetts to meet a limit of 1 mg/L total phosphorus (TP) and 0.2 mg/L TP. A conceptual design and cost estimate will also be developed for the effluent polishing process that uses metal salt precipitation and cloth filtration, as requested by the Town of Falmouth and the Water Quality Management Committee.

1.1 Background

The Town of Falmouth owns and operates a wastewater treatment facility (WWTF) located at 154 Blacksmith Shop Road, Falmouth. The Blacksmith Shop Road WWTF receives flow from the Jones Palmer Pump Station, a pump station at the Falmouth High School and septage from all unsewered properties in Town. The Blacksmith Shop Road WWTF was originally constructed in 1986 and consisted mainly of a lagoon system and a control building. It was last upgraded in 2005 to incorporate two sequencing batch reactors (SBRs) for secondary treatment with a denitrification filter for enhanced nitrogen removal, having a capacity of initial average design flow of 1.0 million gallons per day (mgd) and future summer average of 1.5 mgd (per the Draft Falmouth WWTF O&M Manual and the design drawings titled Town of Falmouth, Massachusetts, Wastewater Treatment Facility Improvements, MA DEP Project No. CW SRF-1132, Falmouth Contract No. WW-03-01-C, dated February 2003, by Maguire Group Inc., Foxborough, Massachusetts). Biosolids from the Falmouth WWTF are thickened and currently hauled to an incineration facility in Cranston, Rhode Island.

Effluent from the Blacksmith Shop Road WWTF is currently discharged to Infiltration Beds Nos. 1 through 13 within the WWTF (see Figure 1). In order to reduce nitrogen load to the West Falmouth Harbor, Falmouth has evaluated new discharge sites outside the West Falmouth Harbor Watershed. Site 7, located approximately one-tenth of a mile north of the existing Infiltration Bed Nos. 9 through 13, has been chosen for additional infiltration bed construction as indicated in the Comprehensive Wastewater Management Plan (CWMP). GHD/Ecologic has evaluated the phosphorus adsorption capacity of the soils under Site 7 and between Site 7 and Crocker Pond and has found the binding capacity of the soils is sufficiently large to protect the water quality in the pond (refer to “Crocker Pond, Falmouth: Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Wastewater at Site 7.” See Table 5). Therefore, plant effluent being sent to Site 7 will likely not require additional phosphorus removal. However, this evaluation has been conducted in order to get a sense of potential technological options and costs if phosphorus removal were to be required in the future.

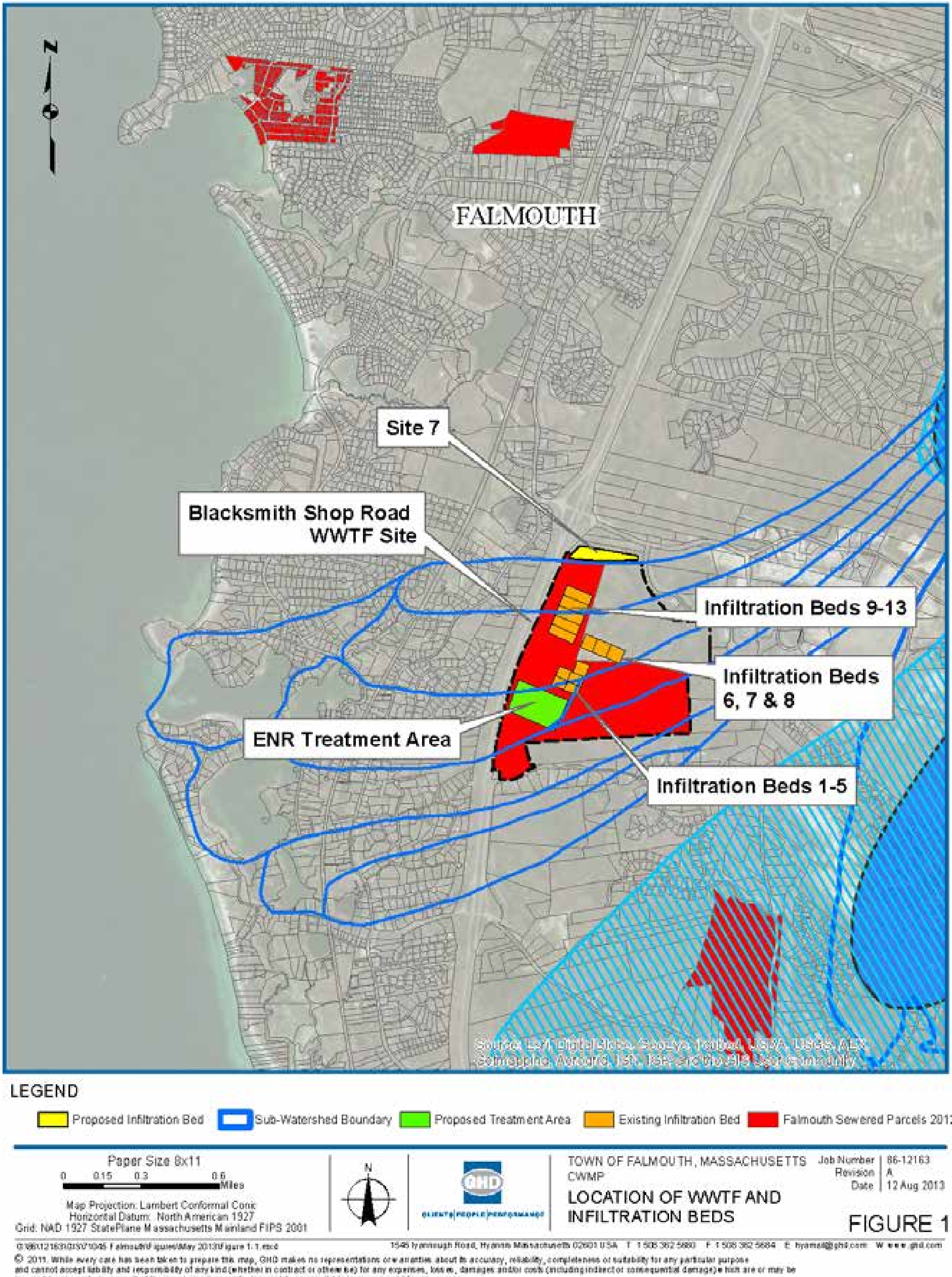

Figure 1 Location of WWTF and Infiltration Beds

1.2 Scope

There are several methods to polish the phosphorus from the treated water at the Blacksmith Shop Road WWTF. The scope of this project is to review various technologies that could be used to polish the phosphorus from the treated water to 1 mg/L as well as to 0.2 mg/L total phosphorus. The major tasks of this project are as follows:

- Review conventional metal salt addition to the existing sequencing batch reactor (SBR) treatment process for phosphorus precipitation to achieve an effluent total phosphorus level of 1 mg/L.
- Review effluent polishing with metal salt precipitation in the following tertiary processes. As part of this review, include comparative information relative to the other processes based on experience from other similar projects
  - Metal salt precipitation in a CoMag™ process
  - Metal salt precipitation with ballasted flocculation (Kruger ACTIFLO®)
  - Metal salt precipitation with high rate flocculated settling (IDI DensaDeg®)
  - Metal salt precipitation followed by sand filtration
  - Metal salt precipitation followed by adsorption type filtration (Blue PRO®)
  - Metal salt precipitation followed by membrane filtration
  - Metal salt precipitation followed by cloth filtration
- Review phosphorus adsorption in an horizontal permeable reactive barrier that would be constructed in one of the old lagoon basins.
- Consider metal salt addition to the SBRs as the best alternative to achieve a limit of 1.0 mg/L and effluent polishing with chemical addition to the SBRs and cloth filtration as the generally accepted best practical technology for phosphorus removal to meet a 0.2 mg/L total phosphorus, develop a conceptual design for its integration into the WWTF process flow, and develop planning level capital costs. The only costs that are included in this report are for the chemical addition to the SBR and cloth filtration because these technologies have been shown to be the most cost effective for similar sized facilities meeting similar limits.

It should be noted that the scope of this project did not include an analysis of natural aquatic systems, engineered wetlands or any other process not specifically mentioned above. In addition, nutrient recovery was not considered as part of this evaluation.

1.3 Existing Blacksmith Shop Road WWTF

1.3.1 Flows and Loads

According to the Draft Falmouth WWTF O&M Manual, the Blacksmith Shop Road WWTF is designed to handle flows as shown in Table 1. At the time, it was anticipated that these conditions would be included in the final permit.

Table 1 WWTF Influent Flows Under Initial Operation and 2023 Design Conditions

Conditions	Initial Operation Flow (mgd)	2023 Design Flow (mgd)
Average Day	1.0	1.2
Summer Average Day	1.25	1.5
Maximum Day	1.83	2.2
Peak Hour	4.3	4.3

The Blacksmith Shop Road WWTF is designed to handle influent design concentrations as shown in Table 2.

Table 2 WWTF Influent Design Concentrations Under Initial Operation and 2023 Design Conditions

Influent Parameters	Design Loadings (Initial Operation and 2023 Design)
BOD	250 mg/L
COD	460 mg/L
TSS	180 mg/L
Total Nitrogen	34 mg/L
Ammonia Nitrogen	22 mg/L
TKN	30 mg/L
Total Phosphorus	8 mg/L
Alkalinity	130 mg/L

In 2011, a new groundwater discharge permit was issued to the Town. Both the Town and the Buzzards Bay Coalition appealed this permit, which, among other restrictions, included an average annual total nitrogen effluent limit of 3.0 mg/L. The appeal was settled and the final permit took effect June 28, 2012. The final permit requirements are listed in Table 3.

Table 3 WWTF Groundwater Discharge Permit Requirements

Influent Parameters	Discharge Permit Limits
Flow (Total)	800,000 gallons per day (treated effluent to sand beds or spray irrigation) No more than 570,000 gallons per day from outside of the Falmouth Harbor Watershed No more than 230,000 gallons per day from inside the Falmouth Harbor Watershed
BOD5	30.0 mg/L
Total Suspended Solids	30.0 mg/L
Oil and Grease	15.0 mg/L
Total Nitrogen (NO2 + NO3 + TKN)	10 mg/L (maximum day) Best efforts to meet an annual average of 3 mg/L and 5,204 lbs annual load
Nitrate Nitrogen	10 mg/L (maximum day) Best efforts to meet an annual average of 3 mg/L
Fecal Coliform	200 colonies per 100 mL

1.3.2 Blacksmith Shop Road WWTF Liquid Stream Treatment Processes

The Blacksmith Shop Road WWTF consists of the following liquid stream treatment processes:

Preliminary Treatment. The facility has an aerated grit chamber, which is currently bypassed. Influent is directed to the headworks screening channel, where flow is directed through a mechanical fine screen with a coarse bar rack bypass. Both pieces of equipment were placed into service in 2005.

Preliminary Treatment

The mechanical fine screen is a Marck XV-Cw screw screen, supplied by Schloss Engineering with a quarter-inch bar spacing and a 35 degree angle of inclination. A bypass channel allows flow to be directed to the coarse bar rack if the fine screen is taken off-line. The coarse bar rack has one and a quarter-inch bar spacing and a 60 degree angle of inclination.

Influent Pumping. From preliminary treatment, influent flows to one of two influent wet wells. The total tank volume of the two wet wells is 90,000 gallons. Either tank can be isolated by a sluice gate. The dry well contains four vertical constant speed centrifugal pumps which pump wastewater from the influent wet well to the SBR tanks. The dry well also contains a set of duplex sump pumps, manufactured by Redlon & Johnson, with a pump capacity of up to 185 gpm at 38 total dynamic head (TDH). The sump pumps discharge into wet well No. 1. A magnetic flow meter is installed on the discharge force main from the influent wet well to measure flow to the SBRs.

Sequencing Batch Reactors. Wastewater is pumped from the influent wet well into one of two AquaSBR Sequencing Batch Reactor (SBR) tanks. The total volume of both tanks is 0.884 million gallons. Sludge is wasted by gravity using a manual valve set at approximately 300 gpm and a pneumatic motor operated valve controlled by a timer. There is a flow meter on the sludge line. The system also has a waste activated sludge (WAS) pump. The SBR sequence goes through six steps:

Sequencing Batch Reactor

1. Mixed Fill—Anoxic mixing, independent of aeration, with influent. Mixing is accomplished with a DDM-FSS Direct Driver Mixer/Blender.
2. React Fill—Aerated mixing with influent introduction into the tank. The tank is aerated through an Enduratube ER-2000 fine bubble diffuser system.
3. React—Aerated mixing under batch conditions.
4. Settle—Solids/liquids separation.
5. Decant/Idle—Effluent withdrawal to the post-equalization tank through a mechanical floating-type gravity decanter.
6. Sludge Waste—Removal of excess biological sludge to sludge holding tanks.

Oxygen is fed to the system through three SBR aeration blowers. Each blower is designed to provide process air over the range of 1,000 SCFM to 2,030 SCFM. Under normal operating conditions each tank has a dedicated blower with the third used as a standby unit.

The SBR tanks are programmed to work in tandem so that one tank is always in a fill mode. During the decant mode the same amount of water that entered the tank during the mixed fill and react fill stage flows to the post-equalization tank.

Denitrification Filters and Related Equipment. Flow is pumped by two 1,650 gpm variable speed centrifugal Flowserve pumps from the post equalization tanks to three Severn Trent denitrification filters. The pumps are designed with 23 feet of Total Dynamic Head (TDH). Denitrification filters are designed to remove nitrates through a fixed film biological process and to filter out suspended solids. Effluent flows through seven feet of media in the denitrification filters to a 36,000 gallon clearwell. Periodically two Flowserve 15 HP centrifugal backwash pumps pump treated wastewater from the clearwell to backwash the filter, releasing the solids that have collected in the tank. Each backwash pump has a 1,410 gpm capacity with 27 feet TDH. Two Aerzen positive displacement blowers located in the blower room in the SBR building feed air to the denitrification filters for backwash. Each blower has a 1044 SCFM capacity at 14.5 psia (pounds per square inch relative to atmosphere) and 100 degrees F. Effluent from the clearwell overflows into the ultraviolet (UV) disinfection channel.

Denitrification Filters

Disinfection. Effluent flows from the clearwell into a Sunlight Systems UV disinfection system. Sunlight Systems LLC was bought by Siemens Water Technologies in 2007 and then Siemens dropped the product line in 2011. Parts for the system are now available from Donnellan UV. The UV system is made up of 48 UV lamps divided into two banks and is designed to treat an average flow of 1.2 mgd with a peak design flow of 1.83 mgd and future max day design flow of 2.2 mgd. UV dosage, which is the rate at which energy is delivered to the system, is 36,048 microwatt seconds per square centimeter (uWs/cm2) at 1.83 MGD and 36,000 uWs/cm2 at 2.2 MGD. The system can be upgraded from design flow to future flow, by expanding the channel width, up to a future max day flow of 2.2 mgd. The system was designed with 100 percent redundancy, meaning either bank of lamps is capable of disinfecting the maximum daily flow.

Disinfection

Effluent Distribution and Metering. Effluent flow is measured by a Siemens XPS-10 ultrasonic transducer upstream of each of the three V-notch weirs at the effluent distribution system. Three separate channels at the back of the effluent distribution structure allow flow to be directed—depending on which weir is lowered—to Infiltration Beds 1 through 8, Infiltration Beds 9 through 13, or to the spray irrigation wet well.

Effluent Distribution and Metering

Sludge Storage and Thickening—The existing WWTF has one unthickened sludge tank (Blended Sludge Tank) that is used to store waste activated sludge and septage. From this tank, sludge is typically pumped through a Somat sludge thickening system with the goal of increasing the solids concentration from about 1- to 6-percent. The thickened sludge is then stored in one of two thickened sludge storage tanks prior to being hauled offsite for disposal. A number of improvements are planned for this portion of the facility including the addition of more sludge storage capacity and improvements to the sludge thickening processes and pumping.

1.4 Design Criteria for Phosphorus Removal

Given the results of the Ecologic Report entitled "Crocker Pond, Falmouth: Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Wastewater at Site 7", it is likely that none of the flow at the Blacksmith Shop Road WWTF will be required to receive phosphorus polishing at this time. For the purposes of this analysis, it was determined in an email to the Town dated June 27, 2013 that a flow of 0.26 mgd will be used in this evaluation in the event that future phosphorus polishing is required.

This report evaluates the processes needed to remove phosphorus from the treated water at the Blacksmith Shop Road WWTF to 1 mg/L as well as 0.2 mg/L, currently considered the lowest practical limit by MassDEP. It should be noted that although only 0.26 mgd of plant flow would need to be treated, for the purposes of this evaluation and for treatment to 1 mg/L, the full plant flow is assumed to be treated because existing infrastructure with only small additions can be used. However, to reduce the effluent phosphorus levels from 1 mg/L to 0.2 mg/L, it is anticipated that the plant effluent would be split to only send 0.26 mgd for further treatment.

2. Preliminary Screening Evaluation

This report provides an evaluation of metal salt precipitation to polish phosphorus from the treated water at the Blacksmith Shop Road WWTF to meet a limit of 1 mg/L total phosphorus as well as metal salt precipitation along with various technologies to meet a limit of 0.2 mg/L total phosphorus. A conceptual design and cost estimate will be developed for the effluent polishing process that uses metal salt precipitation and cloth filtration. The processes that are reviewed cover the range of physical processes that are commonly used for phosphorus removal including precipitation, surface complexation (a type of adsorption) and solid liquid separation. It should be noted that by removing solids, many of these processes will help to decrease nitrogen levels slightly.

2.1 Overview

The following will be reviewed:

- Innovative Phosphorus Removal Process
  - Permeable reactive barrier
- Phosphorus removal to achieve 1 mg/L effluent total phosphorus
  - Metal salt addition
- Technologies to achieve 0.2 mg/L effluent total phosphorus
  - Ballasted flocculation (Siemens CoMag™)
  - Ballasted flocculation (Kruger ACTIFLO®)
  - High rate flocculated settling (IDI DensaDeg®)
  - Sand filtration
  - Adsorptive type filtration (BluePro®)
  - Tertiary membrane filtration
  - Cloth filtration

2.2 Permeable Reactive Barrier

The permeable reactive barrier (PRB) technology was initially developed as an innovative in-situ groundwater remediation technology that continuously and passively captures a plume, removes or breaks down the contaminants, and releases the water with a reduction of the contaminants. The reactive material of the PRB extends below the water table and intercepts and decontaminates the plume. The PRB is a barrier to the contaminants, not water. It can also be used as a polishing technology after active source removal, including but not limited to, physical removal, thermal treatment, etc. The contaminant removal methods used by the PRB include adsorption and precipitation, chemically enhanced, and biologically enhanced. Although most PRBs are installed vertically, the PRB reactive media can be placed in a horizontal position with the flow passing through the PRB in a vertical direction, such as in the base of the source area excavation to treat infiltrating groundwater as a polishing treatment for a waste stream in a tank. The horizontal PRB is a potential technology that can be applied to a lagoon rather than in a tank for this project.

Iron was the first material used in PRBs. The PRB technology has evolved and biological barriers, zeolites (i.e. ion exchange agents), and peat moss are also used in PRB nowadays.

As for the horizontal PRBs, the longevity of the PRB material is hard to predict. One supplier of a horizontal PRB system claimed that the PRB is capable of removing total phosphorus to less than 0.1 mg/L, along with other contaminants. However their installations are mainly for nitrogen removal and do not show phosphorus removal results. Another vendor indicates that their product achieves 99 percent removal of total phosphorus from a sewage lagoon. Despite the positive results claimed by vendors, the technology is not widely used and thus the permeable reactive barrier alternative would require further review and possible piloting before it is considered for full scale application in Falmouth. This could be evaluated as a future demonstration project if the more traditional methods described below are not acceptable.

2.3 Phosphorus Removal to Achieve 1 mg/L Effluent Total Phosphorus

Biological phosphorus removal, along with metal salt precipitation, can typically remove phosphorus from wastewater to 1 mg/L effluent total phosphorus or lower.

The two existing SBRs at the Blacksmith Shop Road WWTF were designed for and have been operating to provide nitrogen removal. The manufacturer of the existing SBRs, Aqua-Aerobic Systems, Inc., indicated that the current operations of the SBRs do not need to be changed to accommodate phosphorus removal because the “Mix-Fill” phase of the SBR operations is already long enough to achieve anaerobic conditions and biological phosphorus release. Metal salt addition is recommended towards the end of the “React” phase of the SBR operations, when biological phosphorus removal has been maximized, to further reduce the effluent total phosphorus concentration from an existing concentration of approximately 2.4 mg/L to approximately 0.6 to 0.8 mg/L. It should be noted that for the purposes of a permitted limit, it is anticipated that 1 mg/L would be able to be met most of the time using single point chemical addition. It is also likely that 0.6 to 0.8 mg/L could be met most of the time as this range represents the phosphorus removal limit with single point chemical addition. This treatment would be for the full plant flow, however, and not just the 0.26 mgd that would be disposed of at Site 7.

The infrastructure requirements include a small building that will house a chemical storage tank (to house the metal salt chemical) and pumps. The infrastructure would also include support systems including minimal yard piping, electrical, and controls to feed the chemical into the influent wastewater. The cost of this system is approximately $800,000 with the costs explained in more detail in Section 3.

2.4 Technologies to Achieve 0.2 mg/L Effluent Total Phosphorus or Lower

Several technologies are capable of removing phosphorus from wastewater to achieve 0.2 mg/L effluent total phosphorus or lower. These technologies are presented below. All of these technologies will incorporate metal salt precipitation before and with the specialized treatment process. When comparative statements are made about such characteristics as costs, footprint, etc., these are being made in comparison to other technologies being reviewed herein and are based on GHD's experience with these technologies on other projects. It should also be noted that the sludge production impacts are based on the level to which phosphorus is being removed and not on the process itself.

2.4.1 Ballasted Flocculation Using the Siemens CoMag™ Process

The CoMag™ process utilizes conventional coagulation and flocculation with the addition of magnetite, which is inert, finely ground, non-abrasive iron ore ballast with a specific gravity of 5.2. The CoMag™ process was developed by Cambridge Water Technology (CWT); however, in 2012 Siemens Water Technologies acquired CWT and is the owner of the CoMag™ process. The process starts with the addition of a coagulant to secondary effluent. Coagulation is followed by flocculation and it is there that the magnetite becomes an integral part of the flocs which significantly increases the specific gravity of the flocs. Magnetite infused flocs settle significantly faster than conventional floc or microsand due to their increased specific gravity. The increased settling rate results in smaller clarifiers. Additionally, the CoMag™ process returns the majority of the settled solids from the clarifiers into the reaction tanks to enhance precipitation kinetics and promote the development of sweep floc. Figure 2 shows a simplified process schematic of the CoMag™ process.

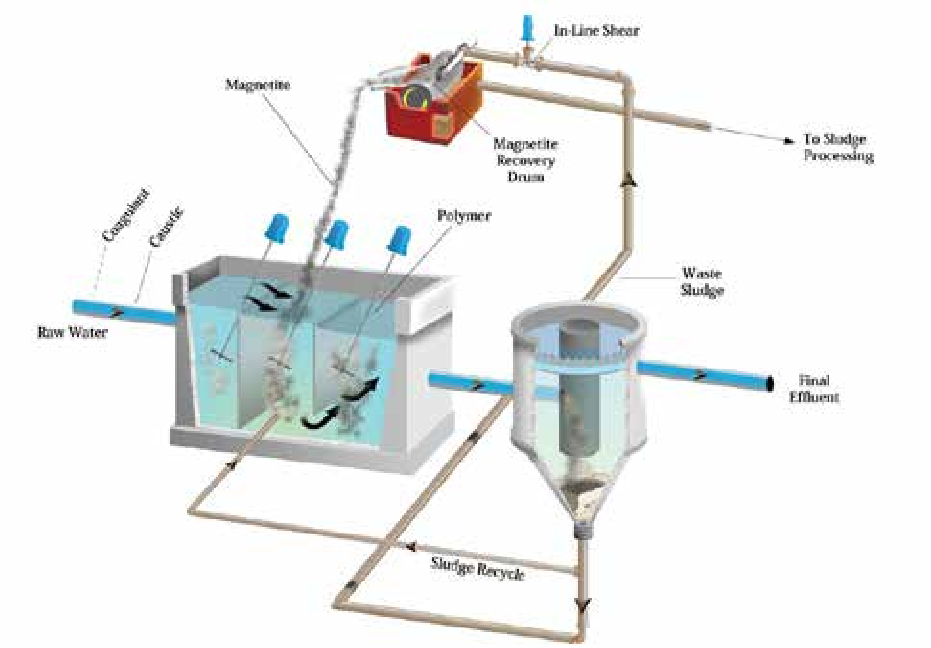

Figure 2 Schematic of the Siemens CoMag™ Process

The process influent flow rate is measured and used to control the addition of the coagulation and flocculation reagents. Coagulant is added to an in-line static mixer upstream of the CoMag™ reactors. Coagulant addition can affect the pH of the process influent; therefore, sodium hydroxide may be added in the in-line static mixer to control the pH. The treated influent enters the reaction tank followed by the flocculation tank, which are equipped with variable speed mixers to provide the correct mixing to achieve coagulation and flocculation.

Following coagulant addition, magnetite is added to create dense flocs which will settle rapidly. Polymer is added to promote floc formation. The treated wastewater flows by gravity to final clarifiers which are used to remove the magnetite flocs. No tubes or plates are required within the clarifiers. A large portion of the settled sludge is pumped by the sludge recycle pumps to the reaction tank to help promote floc formation. The remaining settled sludge is pumped through the sludge shear system which breaks up the floc to separate the ballast particles (magnetite) from the floc. The slurry is passed over a magnetic drum separator that captures the magnetite which is then returned to the process. The floc particles are sent to the sludge system for disposal.

Table 4 lists the advantages and disadvantages of ballasted flocculation using the Siemens CoMag™ process.

Table 4 Siemens CoMag™ Process Advantages and Disadvantages

Advantages	Disadvantages
– Quick response time due to reliance on magnetite for floc formation – Small footprint – Low energy usage	– Proprietary equipment – Magnetite is required and may be expensive to obtain based on location of provider – Magnetite likely to be abrasive which could result in increased wear on pipes and pumps – Magnetite included in sludge will increase the frequency of clean out for the solids handling processes – Process upset could result in magnetite in the plant effluent – Process guarantee highly dependent upon non-reactive phosphorus concentrations

Typically the CoMag™ process is capable of producing plant effluent having as little as 0.05 mg/L total phosphorus. However, given the higher capital costs and the high level of sophisticated equipment required for the CoMag™ process, it is not considered appropriate for this project.

2.4.2 Ballasted Flocculation Using the Kruger ACTIFLO® System

The ACTIFLO® process is a high-rate flocculated settling system using chemical addition and ballasted settling to efficiently remove phosphorus. Figure 3 shows a schematic of the ACTIFLO® process.

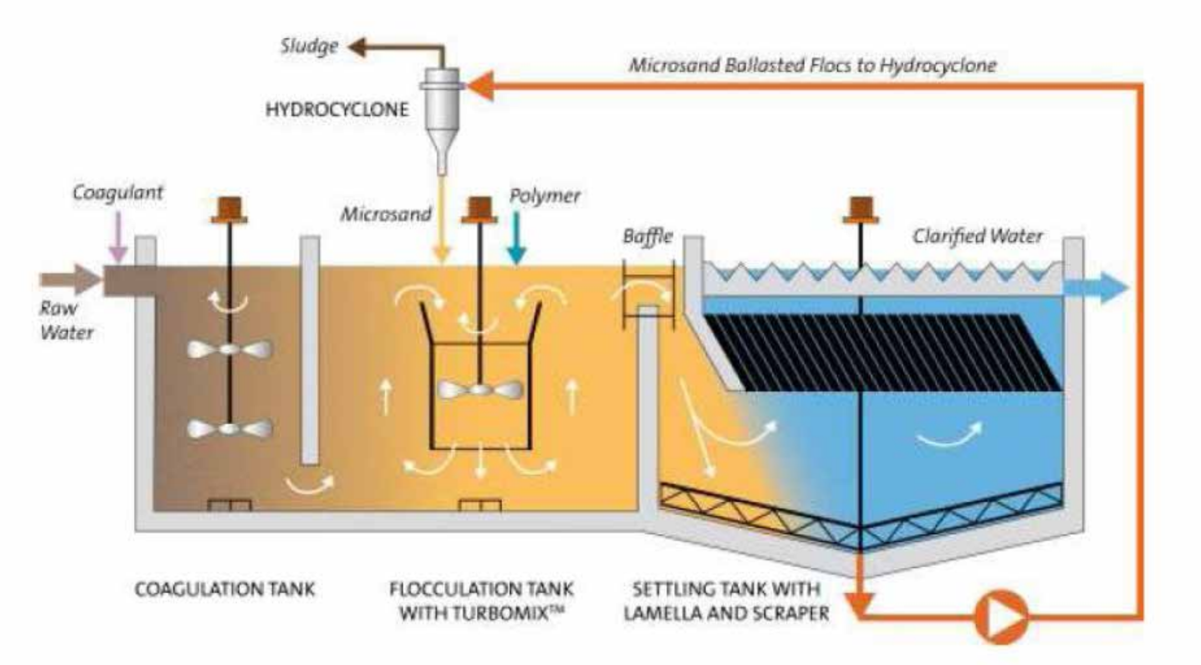

Figure 3 Schematic of the Kruger ACTIFLO® System

The ACTIFLO® process is accomplished in several discreet steps. First, a coagulant is added to the wastewater in a separate coagulation tank to destabilize the colloids that bind the phosphorus. A mechanical mixer blends the water and coagulant. The well-mixed coagulant-heavy wastewater then enters a second tank called the maturation tank, where microsand (80- to 120-micron diameter) and polymer are added. These flocculant aids assist in the formation of dense, well-formed floc. Low-shear mechanical mixing in this tank prevents any settling.

The flocs flow over a submerged outlet weir into the settling tank. The efficiency of settling is further increased by the quiescent conditions created in the settling tank by the use of lamella tubes in the outlet section of the tank.

The settled floc is collected in the cone shaped settling tank, and pumped to hydrocyclones. The sludge and microsand are efficiently separated by the centrifugal force in the hydrocyclone. The recovered microsand is then recycled to the injection tank and the separated solids are continuously discharged.

Table 5 lists the advantages and disadvantages of ballasted flocculation using the Kruger ACTIFLO® process.

Table 5 Kruger ACTIFLO® Process Advantages and Disadvantages

Advantages	Disadvantages
– Easy operations – Quick response time due to reliance on sand for floc formation – Small footprint – Low energy usage	– Safety and handling concerns with silica sand – Sand is very abrasive which results in significant wear on pipes and pumping equipment – Sand included in sludge will increase the frequency of clean out for the solids handling processes – Potential for sand in the effluent with process upset – Tube settlers used in clarification step require cleaning – Although smaller overall footprint, a large building is required due to access requirements for cleaning tube settlers

Typically the ACTIFLO® system is capable of producing plant effluent having 0.1 mg/L total phosphorus. However, given the higher capital costs and sophisticated equipment for the ACTIFLO® system, it is not appropriate for further consideration.

2.4.3 High Rate Flocculated Settling (HRFS) Process Using IDI DensaDeg®

The DensaDeg® HRFS process by Infilco Degremont Inc. (IDI) incorporates three integral process zones: the rapid mix zone, reactor and clarifier/thickener. Figure 4 shows a schematic of the DensaDeg® process. Influent wastewater enters the top rapid mix zone where it is treated with the coagulant. Treated water leaves the bottom rapid mix zone and enters through the inlet pipe into the bottom of the reactor underneath an axial flow impeller.

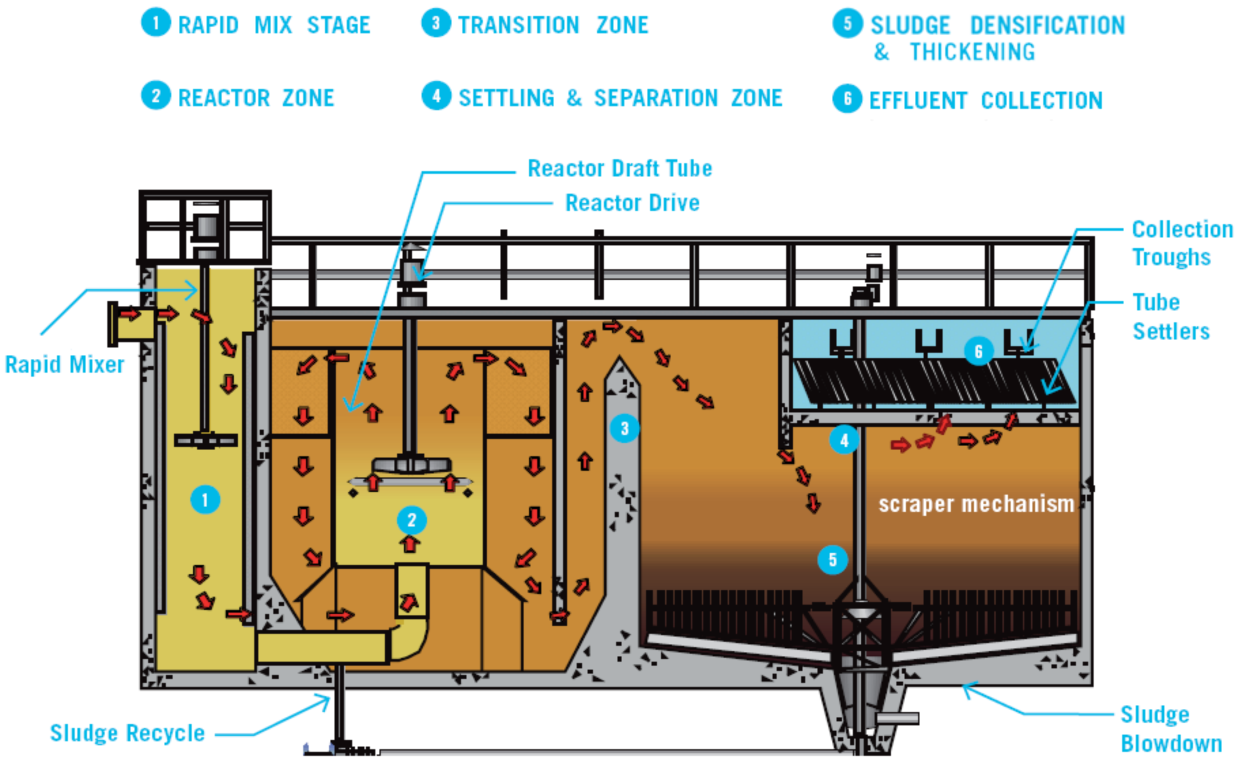

Figure 4 Schematic of the IDI DensaDeg® High Rate Flocculated Settling System

Polymer is added through a distribution ring to aid with flocculation and settling. Recycled solids enter the inlet tube to enhance the solids contact process and increase the speed of the reactions. The amount of recirculated solids is a critical issue in the operation of the DensaDeg®, and can be varied during operation.

Reactor flow is diverted via a baffled opening that allows the mixture to exit the reactor. Moving upward between the baffle and the reactor shell, the slurry passes over a submerged weir into the pre-settling/thickener zone. The well-formed floc settles to the cone shaped bottom of the tank. Aided by a slow moving rake, settled sludge solids are thickened before removal. Thickened solids are periodically pumped out based on sludge blanket depth.

A baffle at the end of the thickener zone directs the flow upward into the clarification zone. The supernatant flows upward through the clarification zone and enters the lamella tube section of the clarifier. The tubes allow any remaining solids to settle before the effluent leaves the unit over a discharge weir.

Table 6 lists the advantages and disadvantages of the IDI DensaDeg® high rate flocculated settling system.

Table 6 IDI DensaDeg® High Rate Flocculated Settling System Advantages and Disadvantages

Advantages	Disadvantages
– Easy operations – Quick response time for start-up – Relatively small footprint – Low energy usage	– Tube settlers used in clarification step require cleaning – Although smaller overall footprint, a large building is required due to access requirements for cleaning tube settlers

Typically the DensaDeg® system is capable of producing plant effluent having 0.1 mg/L total phosphorus. Jar testing and speciation of all phosphorus will be required to meet less than 0.1 mg/L total phosphorus limits. However, given the higher capital costs for the DensaDeg® system, it is not appropriate for further consideration.

2.4.4 Sand Filtration—Continuous Backwash, Upflow, Deep Bed Sand Filters

The DynaSand® Filter marketed by Parkson Corporation of Fort Lauderdale, Florida is a continuously backwashing, upflow, deep bed sand filter. The filters are equipped with an air lift pump and sand washer for continuous cleaning of the sand filter media. Dirty sand is removed from the bottom of the filter by the air lift pump and pumped to the sand washer mechanism located at the top of the filter. The sand washer mechanism provides continuous cleaning of the sand media. Clean sand is redistributed to the top of the filter bed and reject (backwash) water, containing solids removed from the filter media, is collected for treatment. Figure 5 shows the internal components of a Parkson DynaSand® filter.

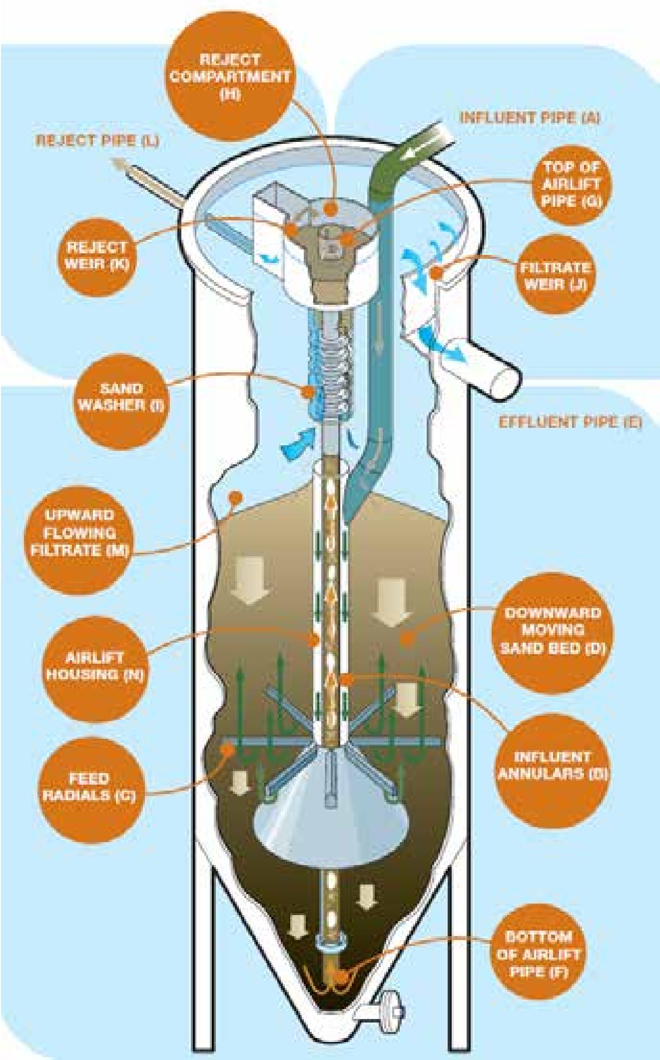

Figure 5 Schematic of the Parkson DynaSand® Filter

Wastewater enters at the top of the filter unit and flows downward through an opening in the center of the system between the feed pipe and air lift housing. The feed is introduced into the bottom of the sand bed through a series of radial feed tubes. The influent head forces the flow upward through the slowly moving sand bed, where particles are captured and retained. The clean filtrate then exits the filter over a weir located at the top of the filter.

Simultaneously, the sand bed, along with the accumulated solids, moves downward into the cone-shaped bottom of the filter. The movement rate is from 12 to 18 inches per hour, and can be adjusted by changing the flow rate to the air lift mechanism. The air lift pump draws sand and water from the bottom of the cone and moves the slurry up through the center of the filter. Compressed air, which powers the air lift pump, scours the sand/water slurry as it travels through the air lift pipe.

Upon reaching the top of the air lift, the dirty slurry spills into a central reject compartment. The sand is returned to the sand bed through a washer/separator. As the sand falls through the washer a small amount of filtered water passes upward, cleaning the sand particles and placing the captured pollutants in solution in the wash water. The dirty wash water flows over an exit weir, while the heavier, coarse sand falls to the top of the active sand bed. Filter reject water exits near the top of the filter. The sand bed is continuously cleaned, and both continuous filtrate and reject are produced.

Table 7 lists the advantages and disadvantages of the Continuous Backwash, Upflow, Deep Bed Sand Filters.

Table 7 Continuous Backwash, Upflow, Deep Bed Sand Filters Advantages and Disadvantages

Advantages	Disadvantages
– Easy to operate – Relatively quick start-up – Low energy usage	– Large footprint – Large and tall building required over the filters to allow for removal of air lift equipment – Proprietary equipment

Typically, continuous backwash, upflow, deep bed sand filters, such as the Parkson DynaSand® filter, are capable of producing plant effluent having 0.2 to 0.3 mg/L total phosphorus. However, given the higher capital costs, it is not appropriate for this project.

2.4.5 Adsorptive Type Filtration

The Blue PRO® filter system, marketed by Blue Water Technologies Inc. (BWT) is a continuously backwashing upflow filter similar in configuration to the Parkson DynaSand® Filters discussed in Section 2.4.4. The Blue PRO® filter is a reactive filtration process featuring continuous regeneration of reactive filter media within a moving bed filter that produces extremely high levels of phosphorus removal. Ferric chloride addition creates a hydrous ferric oxide (HFO) coating on the media surface which allows for phosphorus adsorption. The waste particles that are returned upstream to the secondary treatment processes do not re-release previously adsorbed phosphorus and will continue to adsorb phosphorus throughout the secondary processes further decreasing the effluent phosphorus concentrations and in turn improve overall performance. Figure 6 shows a schematic of the Blue PRO® filter system.

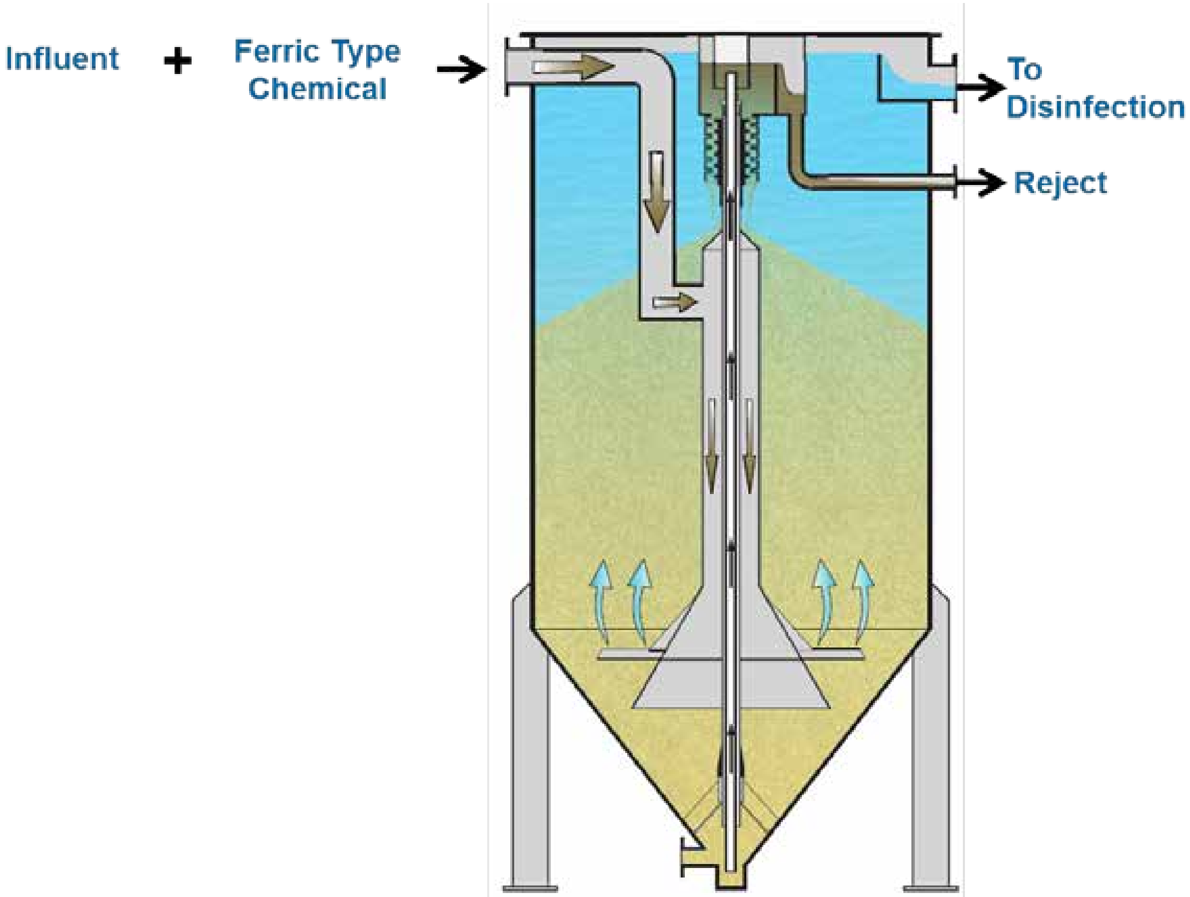

Figure 6 Schematic of the Blue PRO® Filter System

Table 8 Blue PRO® Filter System Advantages and Disadvantages

Advantages	Disadvantages
– Easy to operate – Low energy usage	– Ferric chloride required due to use of adsorption for phosphorus removal – Large footprint – Large and tall building required over the filters to allow for removal of air lift equipment – Initial response period is one (1) to two (2) SRTs for the secondary system – Proprietary equipment

Typically the Blue PRO® system is capable of producing plant effluent having 0.1 to 0.5 mg/L total phosphorus with single stage treatment and as low as 0.05 mg/L with a two-stage treatment. However, given the higher capital costs, it is not considered to be appropriate for this project.

2.4.6 Tertiary Membrane Filtration

Several membrane manufacturers can provide membranes suitable for the tertiary membrane phosphorus removal application, including the General Electric Water Process and Technologies (GE Water) ZeeWeed membranes and the Siemens Memcor membranes.

Screened influent enters the membrane tanks. The hollow fiber membrane operates in an "outside-in" configuration. Permeate is drawn through the membranes with permeate pumps. The solids remain outside the membranes in suspension in the membrane tanks. The membrane tanks are periodically drained to remove accumulated solids from the membrane tanks.

During the operation of the membranes, solids accumulate on the outside of the membrane fibers which slowly increases the pressure across the membranes (transmembrane pressure). The operation of the tertiary membrane systems involves operational strategies to maintain the membranes such as backwashing and chemical cleaning. Backwashing occurs periodically and automatically with no operator attention. During the backwash operation, permeate is reversed through the membrane fibers while simultaneously scouring the outside of the fibers with air and draining the tank to flush the solids from the tanks. The backwash pump is used to pump stored permeate from the backwash tank into the membrane fibers.

Chemical cleaning of the membrane fibers is needed to remove any foulants that are not removed during the backwash process. The chemical cleaning will typically use sodium hypochlorite or citric acid to removal organic or inorganic fouling, respectively. At the end of the cleaning period, the cleaning chemicals will be sent to a neutralization system prior to disposal.

Table 9 lists the advantages and disadvantages of the tertiary membrane filtration system.

Table 9 Tertiary Membrane Filtration System Advantages and Disadvantages

Advantages	Disadvantages
– Small footprint – Quick response time for start-up – Easy operation to handle peak flows – Operational flexibility	– Large connected horsepower and associated energy consumptions – Cleaning and neutralization chemicals required – Large replacement cost for membrane modules – Proprietary equipment

Typically a tertiary membrane system is capable of producing plant effluent below 0.05 mg/L total phosphorus. However, given that it has one of the highest capital costs and is highly sophisticated equipment, it is not considered appropriate for this project.

2.4.7 Cloth Filtration

Aqua-Aerobic Systems, Inc. is one of the companies that manufacture cloth filters that can be used to provide solids separation. The cloth filter is composed of a carrier fiber and pile filaments. In their natural state, the pile filaments are perpendicular to the carrier fiber; however, when completely wetted the fibers overlay each other and create a depth of media to achieve solids removal. During operation, the influent is passed through the fibers and solids accumulate on the surface of the cloth. When the headloss across the filter exceeds the set point, the filter is backwashed. Filtrate (treated water) is drawn back through the cloth and the suction associated with the backwash returns the fiber to their natural state. Solids are removed from the cloth filter and backwash is sent for further treatment.

Aqua-Aerobic Systems, Inc. manufacturers several types for cloth filters including rotating disc filters (AquaDisk® and Aqua MiniDisk® filters) and the AquaDiamond® filters (designed to be a retrofit for existing travelling bridge filters and not applicable to the Blacksmith Shop Road WWTF). For the purpose of this evaluation, we will focus on the AquaDisk® which is the most appropriate application of these Aqua-Aerobic Systems' cloth filters for Falmouth. Figure 7 shows an AquaDisk® cloth filter system. The cloth filter disks are submerged during the filtration operation. Filtrate is collected within the disk and flows by gravity to the downstream process. Solids accumulate on the outside of the filter and accumulate within the filter tank.

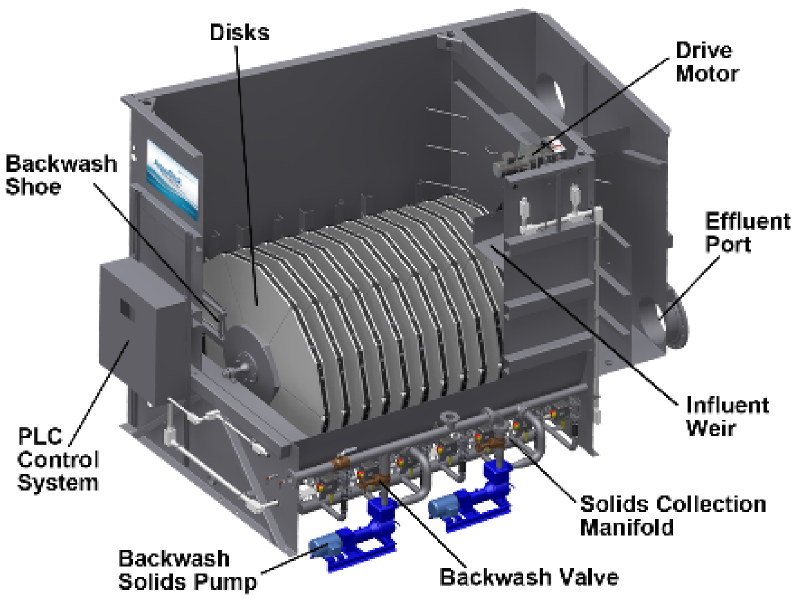

Figure 7 Schematic of the Aqua-Aerobic AquaDisk® Cloth Filter System

The cloth filters are periodically backwashed to remove solids. The backwash pump provides the suction to the vacuum heads which are used to vacuum solids from the cloth filter surface. Some solids will accumulate in the bottom of the filter bed; therefore, suction headers are located within the filter. The solids collection system utilizes the backwash pumps to draw solids from the bottom of the tank.

Table 10 lists the advantages and disadvantages of the cloth filtration system.

Table 10 Cloth Filtration System Advantages and Disadvantages

Advantages	Disadvantages
– Lower headloss than deep bed sand filtration – Less maintenance than deep bed sand filtration – Low backwash rate – Small footprint	– Disproportionate experience among suppliers

Typically the Aqua-Aerobic cloth filter system is capable of producing plant effluent having 0.1 to 0.2 mg/L total phosphorus. Given the capability to meet the 0.2 mg/L effluent total phosphorus requirement and the relatively low capital costs, it has been chosen on the basis of costs for phosphorus polishing to 0.2 mg/L.

3. Detailed Evaluation

3.1 Introduction

It was determined that cloth filtration would be selected for a detailed evaluation. As discussed in Section 2.4.7, cloth filtration (based on the AquaDisk®) is considered to be the best practical technology for phosphorus removal to 0.2 mg/L at the Blacksmith Shop Road WWTF.

Cloth filtration systems are provided by several manufacturers. One of these manufacturers is Aqua-Aerobic, the manufacturer of the Town's SBR equipment.

3.2 Cloth Filtration

3.2.1 General

The phosphorus removal process begins with the reduction of the influent total phosphorus level from approximately 2.4 mg/L on average to approximately 0.8 to 1 mg/L in the existing SBRs using biological phosphorus removal and metal salt precipitation. Effluent from the SBRs then proceeds to the post equalization tank, denitrification filters, UV disinfection, effluent flow measurement, and distribution prior to a second metal salt injection point and cloth filtration.

Since only 0.26 mgd of the total flow needs to receive further phosphorus removal, the flow will be drawn from the existing effluent distribution structure in a controlled manner using a motor operated pinch valve. A flow meter will also be installed to measure the amount of flow that will receive further phosphorus removal.

Following flow measurement, metal salt will be added to the flow in order to further reduce the effluent total phosphorus from 0.8 mg/L to 0.2 mg/L. The flow, injected with metal salt, enters a rapid mix tank followed by a flocculation tank and the cloth filters. Two filter units are proposed in accordance with TR-16 requirements for redundancy, as further explained in Section 3.3.2.

Although the flow has gone through UV disinfection prior to cloth filtration, UV disinfection does not leave a disinfectant residual and that poses a concern of microbial regrowth in the cloth filters. Therefore, it is recommended that the flow be disinfected again prior to final disposal at Site 7.

There are several types of metal salts that can be used for coagulation and precipitation of phosphorus, such as aluminum sulfate (alum), polyaluminum chloride (PAC), and ferric chloride. Some UV equipment manufacturers have expressed concerns about the use of ferric chloride in the upstream processes because the iron particles tend to reduce the UV transmissivity of the flow. Therefore, this evaluation focuses on the use of alum as the metal salt used for phosphorus precipitation, but PAC can also be used as an alternative to alum. Alum is associated with higher sludge generation compared to other metal salts used for coagulation and precipitation of phosphorus. It is used in this phosphorus removal evaluation to provide a more conservative estimate of the operational costs.

Given the cold temperatures experienced in New England, a masonry building is recommended to be constructed to house the rapid mix tank, flocculation tank, cloth filtration equipment, UV disinfection equipment, and the 6,000-gallon chemical storage tank and chemical pumping system in order to protect the equipment and chemicals from freezing. Figure 8 shows the proposed location of the new Phosphorus Removal Building.

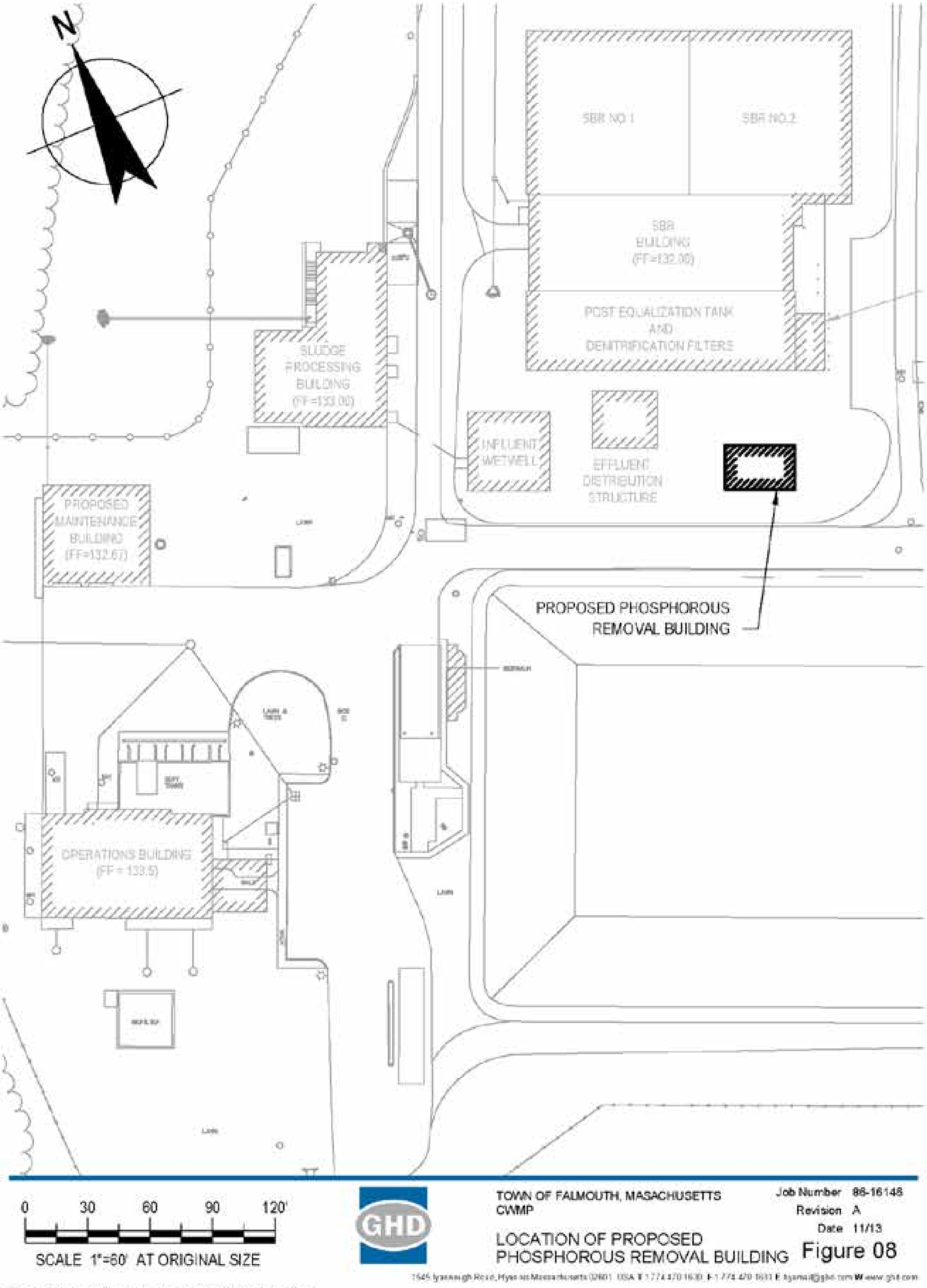

Figure 8 Location of Proposed Phosphorous Removal Building

3.2.2 Cloth Filtration Major Equipment

There are several options for achieving the redundancy requirement with cloth filtration equipment. For example, the two most practical options are: two units sized to handle 100 percent of the flow or three units each sized for 50 percent of the flow. Two filter units, each being sized to handle 100 percent of the flow (0.26 mgd), would be the most cost-effective method to meet the redundancy requirements stipulated in TR-16. Each of the proposed filter units contains a minimum of six (6) disks, housed in either a painted steel tank provided by the manufacturer or in a concrete tank.

An approximate 0.5 HP motor is provided for each filter unit and is used to drive the disks. An approximate 2 HP backwash pump is provided for each filter unit to perform backwash functions and to remove sludge/solids collected in the bottom of the tank. Solids are then returned with an internal plant recycle for settling in the activated sludge system. Instrumentation devices, such as level transmitters, vacuum transmitters, and float switches are also part of the cloth filtration system.

3.3 Cost Estimates

Capital cost estimates and annual maintenance and operations (O&M) cost were developed for both the 1 mg/L total phosphorus alternative and the 0.2 mg/L total phosphorus alternative featuring cloth filtration. The capital costs and O&M costs for the 0.2 mg/L alternative include the costs needed to achieve 1 mg/L since the cloth filtration system requires an upstream phosphorus removal process to remove phosphorus to 1 mg/L. Capital cost estimates are shown in Section 3.3.1 and operations and maintenance cost estimates are shown in Section 3.3.2.

For preparation of capital cost estimates the following items should be noted:

- A 30 percent contingency was included with all construction costs.
- Yard piping from the new Phosphorus Removal Building to Infiltration Beds 9 through 13 was included in the capital cost estimate. Yard piping costs from the existing filter beds to Site 7 was included in previous costs estimates.
- Project costs associated with legal, fiscal, and engineering were accounted for in a 30 percent increase to the total construction cost.
- Total Project Costs were inflated to 2016 dollars using an assumed inflation rate. 2016 was assumed to be the midpoint of construction.
- It should be noted that sludge quantities will increase, but the increase is in the order of 10%. No additional sludge holding capacity was included in these capital costs. Currently, the Town is in the process of doubling the sludge holding capacity and this additional sludge will use some of that capacity.

For preparation of O&M costs, the following criteria were used:

- It was assumed that no additional plant personnel would be required for any alternative. However, there will be an increase in the labor needs including slight increases in thickening time and time for periodic maintenance on new equipment.

- Electrical costs were based on a manufacturer-provided equipment horsepower associated kWh power usage, an estimated duration of operation, and a typical electrical cost of $0.15/kWh.
- Sludge hauling and disposal costs were assumed to be $0.28 per pound. Solids removal was based on reducing phosphorus levels from an average of 2.4 mg/L to 0.8 mg/L in the SBR and then from 0.8 mg/L to 0.2 mg/L in the cloth filter.
- Equipment maintenance/replacement was included in the calculated O&M costs, assuming two percent of the total equipment costs.

3.3.1 Capital Cost Estimates

Capital cost estimates determined for both the 1 mg/L total phosphorus alternative and the 0.2 mg/L total phosphorus alternative using cloth filtration are summarized in Table 11.

Table 11 Capital Cost Estimates for the 1 mg/L TP and the 0.2 mg/L TP Alternatives

Descriptions	1 mg/L TP Alternative	0.2 mg/L TP Alternative
Total Construction Costs (in 2016 Dollars)	**$500,000**	**$2,800,000**
Contingency @ 30% of Total Construction Costs	$150,000	$840,000
Legal, Fiscal, Engineering @ 30% of Total Construction Costs	$150,000	$840,000
Total Project Costs (in 2016 Dollars)	**$800,000**	**$4,500,000**
Note: General conditions, overhead and profit are included in the above costs		

3.3.2 Operation and Maintenance (O&M) Cost Estimates

Operation and maintenance cost estimates determined for both the 1 mg/L total phosphorus alternative and the 0.2 mg/L total phosphorus alternative using cloth filtration are summarized in Table 12. Assumptions for calculation of O&M costs were outlined in Section 3.3.

Table 12 Operation and Maintenance Cost Estimates for the 1 mg/L TP and the 0.2 mg/L TP Alternatives

Descriptions	1 mg/L TP Alternative	0.2 mg/L TP Alternative
Equipment Maintenance Costs	$2,400	$10,000
Alum Costs	$95,000	$100,000
Electrical Costs	$400	$40,000
Sludge Hauling and Disposal	$20,000	$30,000
Total Annual O&M Costs (in 2016 Dollars)	**$120,000**	**$180,000**

4. Recommendations

Metal salt precipitation added to the current treatment train at the Blacksmith Shop Road WWTF is a simple, cost-effective option for reducing the concentration of phosphorus in the discharge from 2.4 mg/L to below 1 mg/L.

Although the cloth filtration technology is likely the most cost effective process that could be added to this facility to achieve an effluent phosphorus concentration of 0.2 mg/L, any future work should consider modifications to the existing denitrification filter and having it serve as a means to remove both nitrate and phosphorus. Although this existing filter is capable of removing phosphorus down to a concentration of 1.0 mg/L, the manufacturer of the process indicated they could not guarantee a removal to 0.2 mg/L. However, it is expected that this filter could be used to approach an effluent phosphorus limit of 0.2 mg/L. The downside of this alternative is that the whole plant flow would need to be treated instead of just 0.26 mgd, and this would generate additional sludge quantities that would need to be handled by the Sludge Processing Facility. However, this option may be worth considering if phosphorus removal is required in the future.

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