Report for

Madison Metropolitan Sewerage District

Badger Mill Creek Phosphorus Compliance Preliminary Engineering Feasibility Report

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EXECUTIVE SUMMARY

The Madison Metropolitan Sewerage District's (MMSD's) current Wisconsin Pollutant Discharge Elimination System permit proposes more stringent effluent total phosphorus (TP) concentration limits of 0.225 milligrams per liter (mg/L) as a monthly average and 0.075 mg/L as a 6-month average. The Nine Springs Wastewater Treatment Plant (NSWWTP) currently achieves an average effluent TP concentration of 0.3 mg/L. MMSD has two permitted discharge locations: Badfish Creek (BFC) and Badger Mill Creek (BMC). BMC is the smaller of the two discharges with an average annual flow of 3.6 million gallons per day (MGD).

The proposed TP effluent limits will take effect on March 31, 2028. In preparation, MMSD has evaluated various compliance options to meet the proposed discharge requirements at the BMC outfall, one of them being the addition of tertiary treatment. From 2018 through 2019, MMSD conducted pilot studies of several tertiary treatment technologies to demonstrate the feasibility of meeting the proposed TP limit.

The focus of this Phosphorus Compliance Preliminary Engineering Feasibility Report is to develop a design concept and budgetary planning costs for tertiary treatment to meet the future effluent TP limits at the BMC discharge. Based on the existing NSWWTP infrastructure, influent characteristics, and pilot test performance, the following three alternatives were short-listed for potential implementation at the NSWWTP:

1. Alternative 3–Reactive Filtration
2. Alternative 4–Cloth Disk Filtration
3. Alternative 5–Ballasted Settling

A hydraulic assessment of the NSWWTP was conducted to aid in the evaluation of the tertiary treatment technologies. Each of the short-listed technologies have similar hydraulic infrastructure requirements.

The total present worth cost is expected to be in the range of $23.8 to $30.6 million depending on the selected alternative. Pricing considers system footprint and redundancy.

All the alternatives are established technologies and were successful during pilot testing; however, Alternative 4 gave the most inconsistent results. Despite this limitation, Alternative 4 has a lower maintenance requirement and is easier to operate compared to Alternative 5. Alternative 3 combines the functionality of Alternative 4 with the performance of Alternative 5.

Based on the monetary and nonmonetary analysis, MMSD has selected Alternative 3, the installation of the BluePRO® reactive filtration system. This technology has a total present worth cost of approximately $24.3 million.

In addition to TP effluent concentration limits, the United States Environmental Protection Agency is expecting states to develop water quality standards for total nitrogen (TN) in future permit cycles. The addition of BluePRO denitrifying filters could be added in the future to allow for TN removal.

Alternative 3 is the selected technology for reliably treating TP in the BMC discharge with the current average flow of 3.6 MGD. A different technology would likely be used if MMSD was required to treat the entire plant effluent flow of approximately 80 MGD. Other technologies may be better suited to scale up to the required capacity for the combined BFC and BMC discharge flow.

ABBREVIATIONS

The following list of abbreviations is included as an aid to the reader:

AASI	Aqua-Aerobic Systems, Inc.
BFC	Badfish Creek
BMC	Badger Mill Creek
BNR	biological nutrient removal
CO_2	carbon dioxide
DO	dissolved oxygen
Evoqua	Evoqua Water Technologies
Feasibility Report	Phosphorus Compliance Preliminary Engineering Feasibility Report
ft	feet
ft^2	square feet
HVAC	heating, ventilation, and air conditioning
lb/day	pounds per day
lb/yr	pounds per year
mg/L	milligrams per liter
MGD	million gallons per day
ML	mixed liquor
MMSD	Madison Metropolitan Sewerage District
Mw-h/yr	megawatt hour per year
N_2	nitrogen gas
NH_3-N	ammonia nitrogen
NO_3	nitrate
NO_x	nitrogen oxide
NSWWTP	Nine Springs Wastewater Treatment Plant
O&M	operation and maintenance
OPCC	Opinion of Probable Capital Costs
PO_4	phosphate
RAS	return activated sludge
SE	secondary effluent
SO_2	sulfur dioxide
TN	total nitrogen
ton/yr	tons per year
TP	total phosphorus
TSS	total suspended solids
UV	ultraviolet
WAS	waste activated sludge
WDNR	Wisconsin Department of Natural Resources
WPDES	Wisconsin Pollution Discharge Elimination System
WQBELs	water quality based effluent limits

BACKGROUND AND SCOPE

The Madison Metropolitan Sewerage District (MMSD) is a municipal corporation in Madison, Wisconsin that provides service to 25 municipal customers, including cities, villages, utility districts, and sanitary districts in the area. The MMSD service area includes approximately 187 square miles with a population of approximately 407,000 people. All the wastewater collected in the MMSD service area is conveyed to the Nine Springs Wastewater Treatment Plant (NSWWTP) for treatment. The NSWWTP is an advanced activated sludge plant and includes biological nutrient removal (BNR) process to remove phosphorus and nitrogen. MMSD has two permitted discharge locations: Badfish Creek (BFC) at outfall 001 and Badger Mill Creek (BMC) at outfall 005. BMC is the smaller of the two outfalls with an average annual design flow of 3.6 million gallons per day (MGD).

The proposed effluent total phosphorus (TP) concentration limits included in MMSD's most recent Wisconsin Pollutant Discharge Elimination System (WPDES) permit are 0.225 milligrams per liter (mg/L) as a monthly average and 0.075 mg/L as a 6-month average. The proposed TP effluent limits will take effect on March 31, 2028, based on the WPDES permit compliance schedule. The NSWWTP achieves a relatively low effluent TP concentration that has ranged from approximately 0.2 to 0.5 mg/L with an average value of 0.3 mg/L over the past 5 years (Table 1).

	Monthly Average Effluent TP Concentration (mg/L)				
	2018	**2019**	**2020**	**2021**	**2022**
January	0.28	0.28	0.26	0.26	0.24
February	0.25	0.25	0.20	0.26	0.23
March	0.21	0.20	0.20	0.21	0.25
April	0.21	0.22	0.24	0.32	0.30
May	0.31	0.29	0.29	0.31	0.35
June	0.31	0.26	0.26	0.29	0.38
July	0.35	0.34	0.34	0.39	0.38
August	0.32	0.33	0.31	0.55	0.40
September	0.36	0.34	0.29	0.36	0.43
October	0.36	0.30	0.26	0.32	0.30
November	0.37	0.23	0.26	0.41	0.33
December	0.28	0.26	0.37	0.32	0.26
Annual Average	0.30	0.28	0.27	0.33	0.32

Note: BMC has an average annual flow of approximately 3.6 MGD.

Table 1 NSWWTP Effluent TP Data (2017 to 2022)

MMSD published a study in June of 2022 titled, *Preliminary Compliance Alternatives Assessment Phosphorus Compliance Badger Mill Creek, Outfall 005 Madison Metropolitan Sewerage District*. In this study MMSD evaluated six compliance options that would allow them to meet the proposed effluent phosphorus limit. From this study, MMSD narrowed down their potential compliance options, one of them being the addition of tertiary treatment to meet the BMC discharge requirements.

The focus of this *Phosphorus Compliance Preliminary Engineering Feasibility Report* (Feasibility Report) is to develop a design concept and budgetary planning costs for tertiary treatment to meet the future effluent TP limits at the BMC discharge. Additionally, this feasibility report will provide a high-level analysis of the nonmonetary factors for the proposed tertiary treatment alternatives.

IDENTIFICATION AND SCREENING OF ALTERNATIVES

A. Description of Alternatives

In this section, potential tertiary treatment technologies are identified and screened for further evaluation. Previously in 2018 through 2019, MMSD conducted pilot studies of several technologies to demonstrate the feasibility of meeting the proposed phosphorus limit. Alternatives previously identified for potential implementation at NSWWTP are as follows:

1. Alternative 1–Membrane Filtration

This alternative consists of ultrafiltration membranes, which are used to remove suspended particulates, macromolecules, and some dissolved compounds from water. There are various types of ultrafiltration membranes, as shown in Figure 1. Submersible membranes are preferred for media filter retrofits, whereas pressurized ultrafiltration membranes are preferred where there are space constraints.

Source: Veolia Water Technologies (formerly Suez Water Technologies)

Figure 1 Ultrafiltration Membrane Models

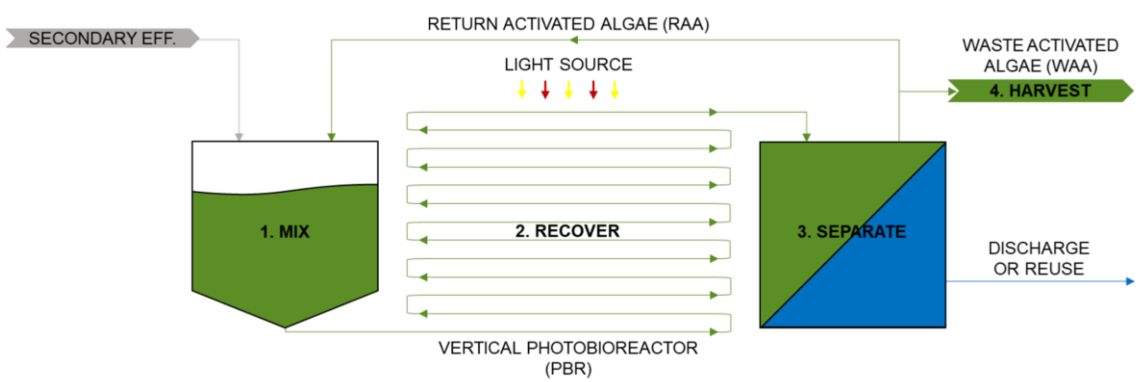
Pilot testing was not conducted for the ultrafiltration membrane technology at MMSD. However, this well-established technology is anticipated to be capable of achieving effluent TP below 0.05 mg/L. There is potential to save on capital costs as this alternative may meet *E. coli* limits without a dedicated disinfection process (pending Wisconsin Department of Natural Resources [WDNR] approval). Although ultrafiltration membranes are relatively simple to operate, they are more energy intensive than other alternatives and require additional pumping. The benefits and limitations of this technology are summarized in Table 2.

Benefits	Limitations
▪ Anticipated to be capable of achieving effluent TP below 0.05 mg/L target ▪ Potential to meet *E. coli* limits without a dedicated disinfection process ▪ Potential removal of some contaminants of emerging concern	▪ More energy intensive than other alternatives ▪ Chemical use ▪ High capital and operation and maintenance (O&M) cost ▪ Requires additional pumping

Table 2 Membrane Filtration Benefit and Limitation Summary

2. Alternative 2–Algae Photobioreactors

CLEARAS Water Recovery manufactures an algae-based tertiary treatment technology that removes both phosphorus and nitrogen from secondary effluent. In this system, secondary effluent is mixed with return activated algae and carbon dioxide before flowing through transparent tubes in which the algae take up phosphorus and nitrogen for cell growth while producing oxygen through photosynthesis. These tube reactors are installed in a greenhouse that can be illuminated with artificial light during periods of low light intensity, allowing for continuous operation. A membrane is used to separate the algae from the treated wastewater, with most of the algae being returned to the beginning of the algae treatment system while a portion is wasted. A visual summary of this process is shown in Figure 2.



Source: CLEARAS

Figure 2 Suspended Growth Algae Photobioreactor

Pilot testing was conducted in September 2019 at the NSWWTP to determine if the algae photobioreactor could achieve an effluent water quality of less than 0.075-mg/L TP. The pilot test had three distinct phases to test the technology under different situations. Phase I focused on treating the secondary effluent at the NSWWTP with no supplemental ammonia dosing. The purpose of this was to evaluate the technology's performance using the existing nitrogen (primarily in the form of nitrate [NO_3]) in the secondary effluent for algae growth and nutrient recovery. Phase II evaluated the effects of changing the nitrogen source on nutrient recovery. Here ammonia was dosed into the influent of the algae photobioreactors. Phase III evaluated system performance given a mixed feed of primary effluent and secondary effluent. This mixture required no additional ammonia dosing as there was sufficient ammonia in the primary effluent. Here the algae had both NO_3 and ammonia available for growth.

Pilot testing results are summarized in Table 3. In Phase I and Phase III, the CLEARAS system successfully reduced the effluent TP levels to well below the 0.075-mg/L target. The pilot testing effectively demonstrated that CLEARAS can efficiently operate on the NSWWTP's secondary effluent with no addition of metal salts or ammonia required.

	Phase I	Phase II	Phase III
Total Phosphorus			
Pilot Test Feed (mg/L)	0.20	0.18	1.56
Pilot Test Effluent (mg/L)	0.029	0.089	0.058
Percent Removal	86	50	96

Table 3 CLEARAS Pilot Testing Results

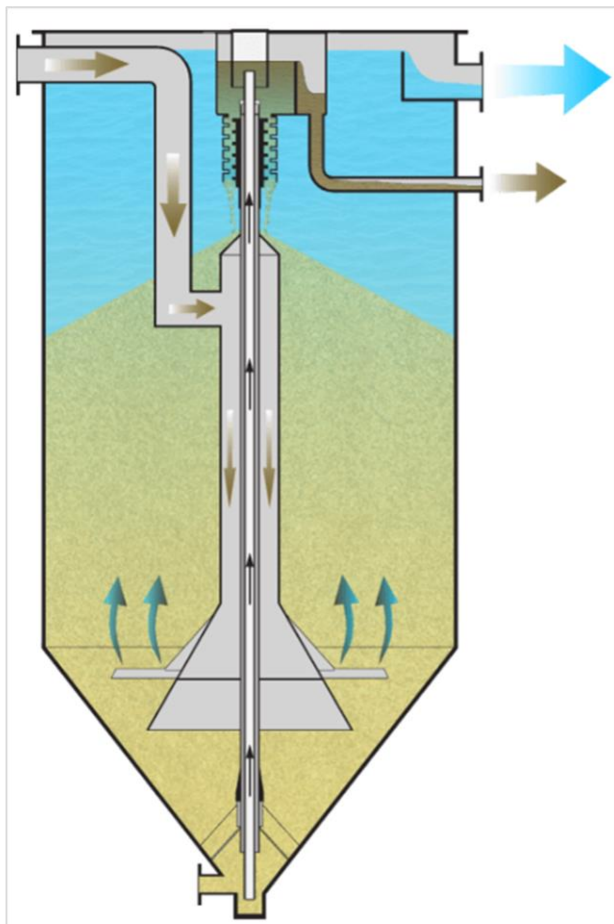
The CLEARAS system is a relatively new technology with few full-scale installations. As a biological system, this technology is less robust and thus may not handle system upsets as well as nonbiological systems. While the potential for continuous operation is a benefit, the illumination of the greenhouse at night has the potential for light pollution. If MMSD were to move forward with this alternative, approximately one acre of space is required on the site, which will be difficult to site without impacting other future site needs. Additional benefits and limitations of this technology are summarized below in Table 4.

Benefits	Limitations
▪ Measured effluent TP during pilot test well below 0.05 mg/L ▪ Potential for resource recovery in the form of algal biomass recovery ▪ No metal salt addition	▪ Large footprint required ▪ Biological system less robust ▪ Potential light pollution ▪ New process with few installations ▪ Proprietary technology ▪ Requires additional pumping ▪ Complicated system operation ▪ Low secondary effluent TP results in low algae production

Table 4 Algae Photobioreactor Benefit and Limitation Summary

3. Alternative 3–Reactive Filtration

This alternative consists of either a single or dual stage upflow sand filter. The BluePRO® system by Nexom™ consists of a fluidized sand bed through which the wastewater flows, and on which the phosphorus is removed through the sand filtration process by removal of suspended solids, as well as reacting with the iron in the filtration media to precipitate as a solid and collect on the sand media. Abrasion within the bed removes phosphorus precipitates off the sand particles, and the solids are recycled to the headwork or the primary clarifiers for removal with the primary sludge. A schematic of the BluePRO system is shown in Figure 3.

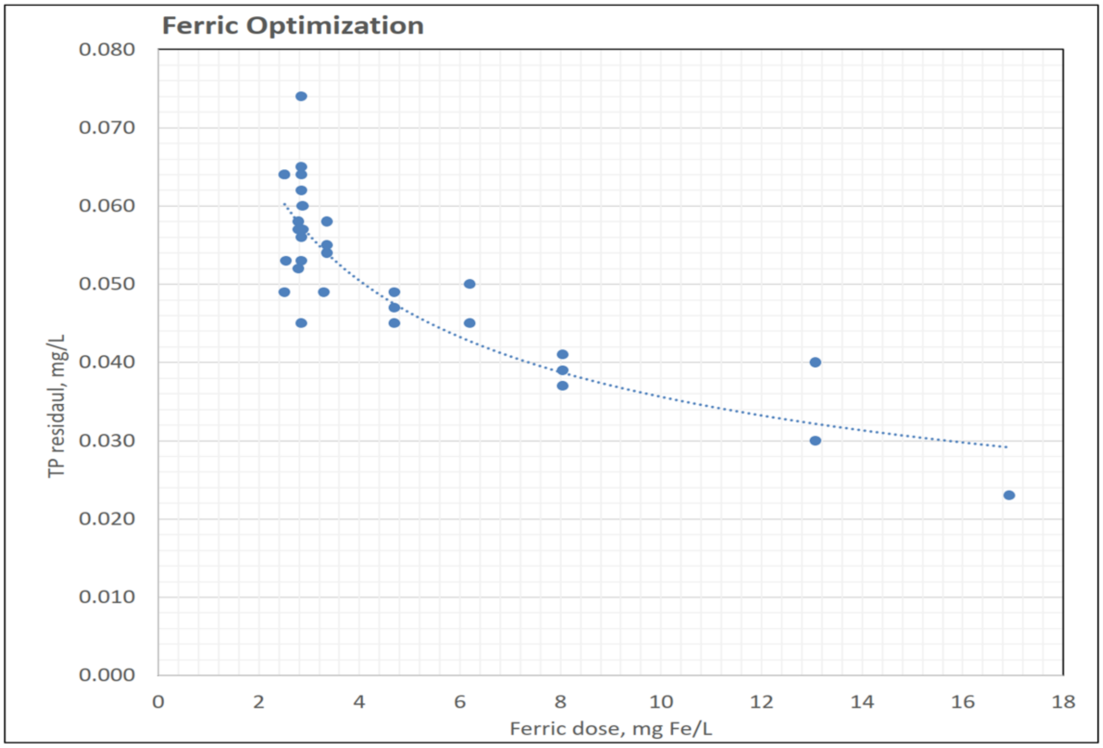


Source: Nexom

Figure 3 Schematic of BluePRO Reactive Filtration

Pilot testing was conducted in June 2019 at the NSWWTP to determine whether the BluePRO reactive filtration system could achieve a secondary effluent TP concentration of less than 0.075 mg/L. A two-stage treatment system was used for pilot testing. Filters A and B were operated in series as the first and second stage, respectively. The goal of Filter A was to determine the optimal ferric dosage necessary to consistently reach the target effluent

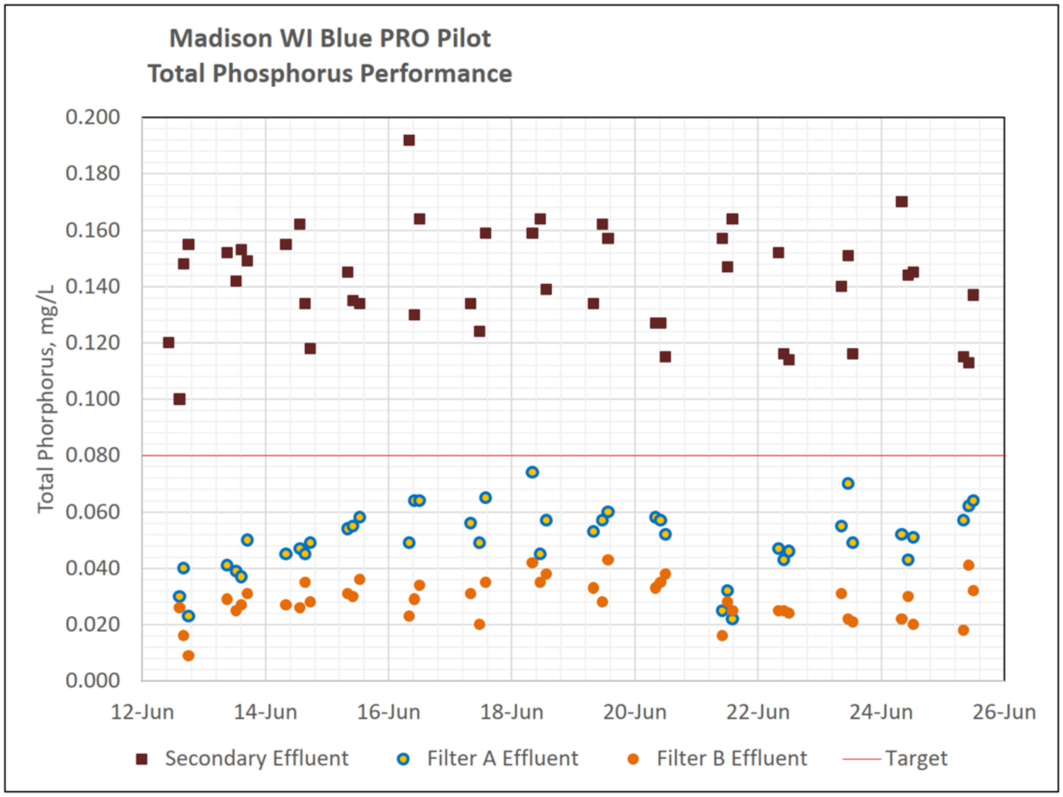
TP concentration. A ferric dosage range of 2.5 to 17 milligrams per liter as iron (mg-Fe/L) was piloted, and the results are shown in Figure 4. Analysis shows that a ferric dose of approximately 2.5 to 3.0 mg-Fe/L is sufficient to meet the treatment goal.



Source: Nexom

Figure 4 BluePRO Pilot Test Ferric Dosage for Filter A

In comparison, the goal of Filter B was to determine the feasibility of this technology to reach even lower effluent TP concentrations. During pilot testing, Filter B was operated continuously with a ferric dosage ranging from 2.5 to 17 mg-Fe/L. Filter B was successful in reaching effluent TP concentration ranging from 0.009 to 0.043 mg/L. The pilot tests were successful in showing that the BluePRO reactive filtration system can achieve the proposed water quality based effluent limit (WQBEL) and that this technology has the potential to meet more stringent phosphorus limits. The performance of Filters A and B are summarized in Figure 5.



Source: Nexom

Figure 5 BluePRO Pilot Testing TP Results for Filters A and B

The BluePRO reactive filtration system has a relatively simple operation and does not require the addition of polymer. This technology can meet the required effluent limit using a single-stage system but has the flexibility to add an additional stage. Additional benefits and limitations of this technology are summarized below in Table 5.

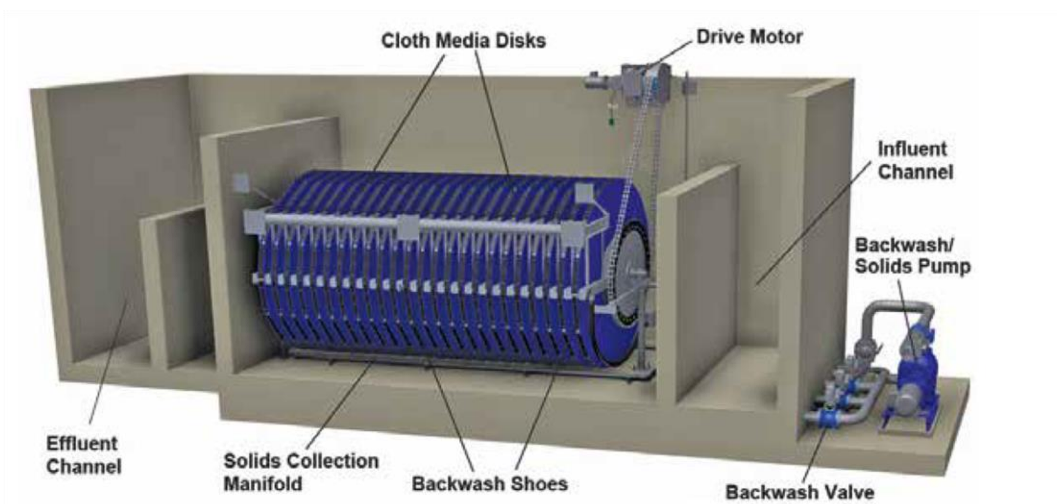
Benefits	Limitations
▪ Met effluent targets without polymer during pilot test ▪ Target effluent TP met with one stage ▪ Relatively simple operation ▪ Flexibility to add second stage if future lower TP or total nitrogen (TN) limits are imposed	▪ Height of units impacts hydraulics and/or building layout

Table 5 BluePRO System Benefit and Limitation Summary

4. Alternative 4–Cloth Disk Filtration

Cloth disk filters remove insoluble phosphorus that is associated with the total suspended solids (TSS). A rapid mix tank, coagulation tank, and flocculation tank are required upstream of the cloth disk filtration system, and ferric chloride and polymer are added to precipitate soluble phosphorus before filtration. There are many cloth disk filter manufacturers, and for the purpose of this Feasibility Report, the AquaDisk® woven cloth media filters manufactured by Aqua-Aerobic Systems, Inc. (AASI) was evaluated.

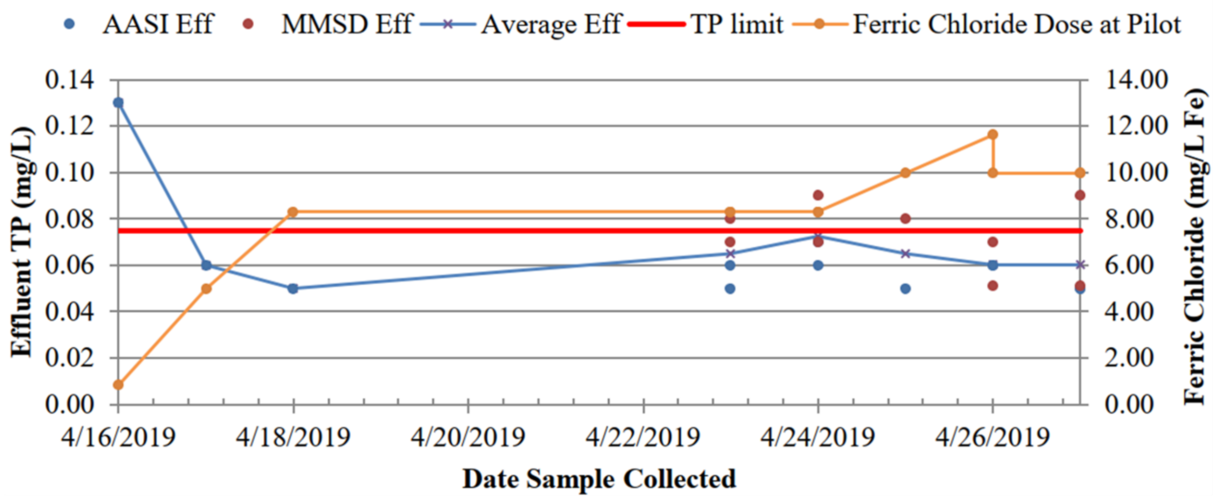
The AquaDisk operates completely submerged in the wastewater. Wastewater flows from the outside of the filtration disks to the inside, and the filtrate flows from the center of the discs to the centertube, which carries the filtered effluent out of the tank. When water levels in the tank increase to a setpoint, a backwash sequence is initiated. During the backwash, pumps are used to draw solids off the cloth media as they rotate. The backwash solids would then be discharged to the West Primary Influent Channel to allow the solids to be removed with the West Primary Sludge. A schematic of an AquaDisk cloth disk filter is shown in Figure 6.



Source: AASI

Figure 6 Schematic of Aqua-Aerobic Systems AquaDisk

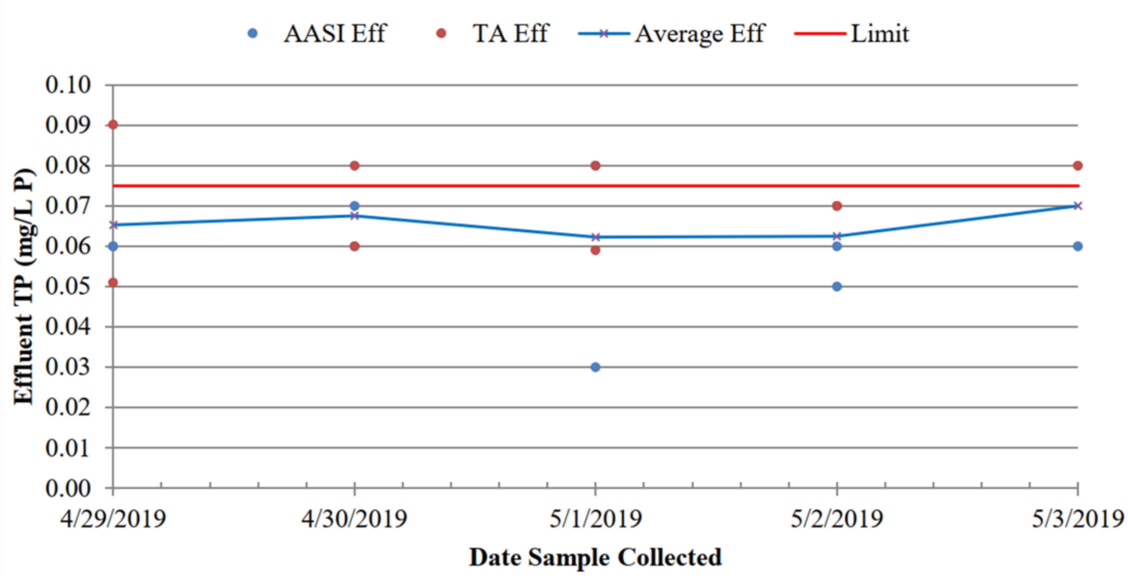
Pilot testing was conducted April through May 2019 at the NSWWTP to determine if the cloth media filtration system could achieve an effluent water quality of less than 0.075 mg/L TP. The Aqua MiniDisk cloth media filtration system was piloted, and the testing was conducted in two phases. Phase I evaluated the effectiveness of ferric chloride addition on the performance of the OptiFiber PES-14® MicroFiber cloth media. Figure 7 shows the varying ferric dosage and resulting effluent TP concentration during Phase I. There was an upset around April 24, 2019, that resulted in effluent TP concentrations over the TP limit. The average effluent TP concentration for Phase I was 0.064 mg/L.



Source: AASI
Note: Eff=effluent

Figure 7 AASI OptiFiber PES-14 MicroFiber Testing Results (Phase I)

Phase II evaluated the performance of the OptiFiber UFS-9® UltraFiber cloth filtration media. The testing results for Phase II are summarized in Figure 8. There were a few upsets with effluent TP values above the TP limit. Overall, UFS-9 reduced effluent TP to an average of 0.065 mg/L.



Source: AASI
Note: mg/L P=milligrams per liter of phosphorus

Figure 8 AASI OptiFiber UFS-9 UltraFiber Testing Results (Phase II)

Although both the PES-14 and UFS-9 cloth media were able to achieve the target effluent TP limit, there were multiple days with results above the 0.075-mg/L limit. Additional pilot testing is warranted if this technology is selected for further consideration. Additional benefits and limitations of this technology are summarized in Table 6.

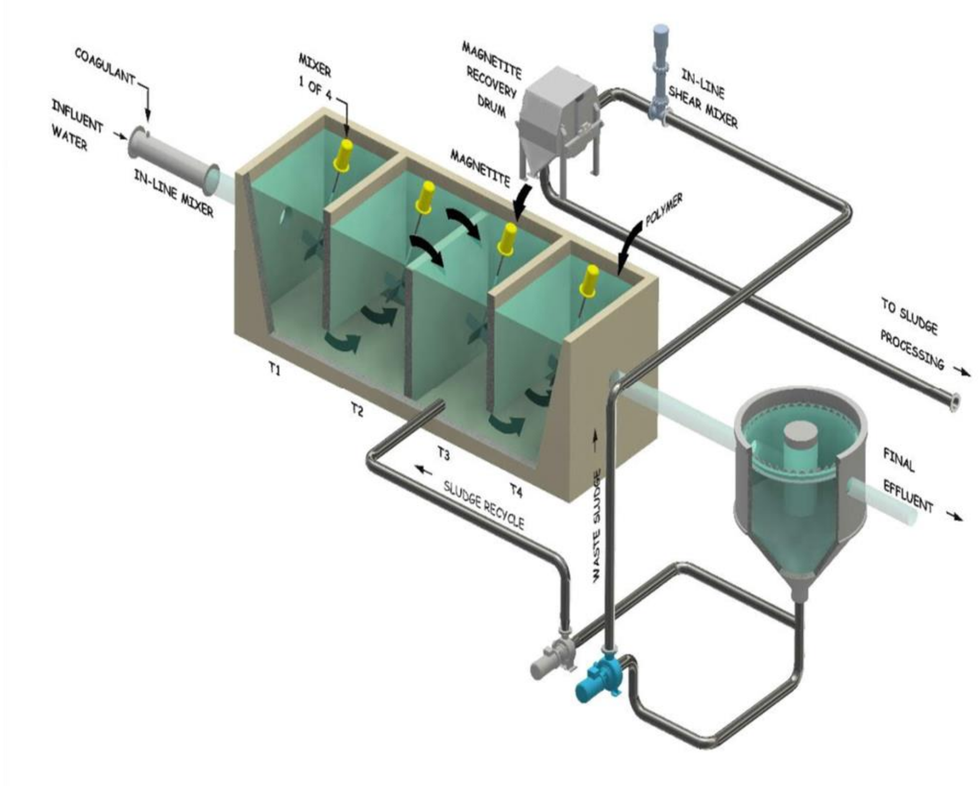
Benefits	Limitations
▪ Well-established technology ▪ Less impact on hydraulic profile than some other technologies ▪ Relatively simple operation	▪ Pilot testing performance was not as consistent as other technologies ▪ Chemical use ▪ 0.05-mg/L target is close to limit of technology

Table 6 AquaDisk Benefit and Limitation Summary

5. Alternative 5–Ballasted Settling

Ballasted settling is a coagulation and sedimentation treatment process that uses a ballast material and the addition of a coagulant and polymer to improve the settling properties of suspended solids. The ballast material provides surface area that enhances flocculation and acts as a weight to increase settling rates. The goal of a ballasted settling system is to form microfloc particles with a specific gravity of greater than two. This high-density floc enables settling rates that are 10 to 60 times greater than conventional clarification. The increased settling rates allow for more compact clarifier designs with high overflow rates and short detention times, which may result in smaller overall system footprints.

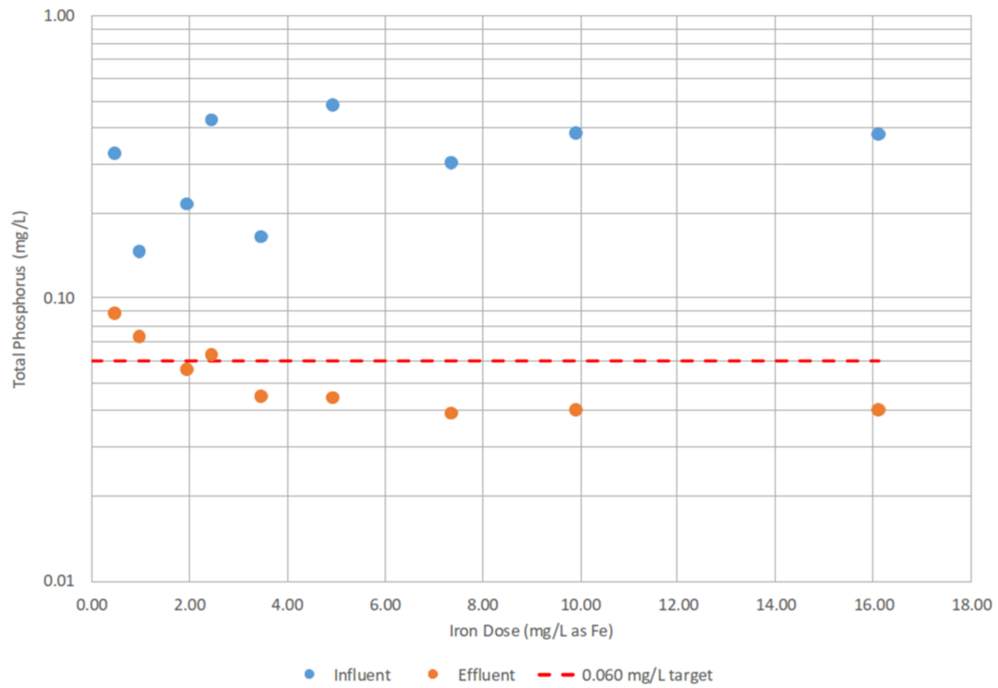
The Evoqua Water Technologies (Evoqua) CoMag™ ballasted settling system uses magnetite as the ballast material. Magnetite is a fully inert, high specific gravity (5.2), finely ground, nonabrasive, iron ore ballast. The CoMag system recycles most of settled solids from the clarifier back to the reaction tanks to increase nucleation sites, enhance precipitation kinetics, and promote sweep flocculation. A schematic of the CoMag system is shown in Figure 9.



Source: Evoqua

Figure 9 Schematic of CoMag Process

Pilot testing was conducted in December 2018 at the NSWWTP to determine if the Evoqua CoMag ballasted settling system could achieve a secondary effluent water quality of less than 0.075 mg/L TP. Coagulant dose response testing was performed using ferric chloride, which determined that the average ferric dose of 11.5 mg-Fe/L was required to consistently meet target TP limit.



Source: Evoqua

Figure 10 Pilot Testing TP Results

Although the CoMag process has a more complex operation with specialized equipment, it is a well-established technology that can consistently achieve the desired effluent TP concentration. This alternative has a lesser impact on the hydraulic profile compared to previously described technologies. Additional benefits and limitations of this technology are summarized in Table 7.

Benefits	Limitations
▪ Measured effluent TP during pilot test of approximately 0.06 mg/L ▪ Well-established technology ▪ Less impact on hydraulic profile than some other technologies	▪ Chemical use ▪ Specialized equipment (magnetic drums) ▪ More complex operation than some alternatives (filters)

Table 7 CoMag Process Benefit and Limitation Summary

B. <u>Alternatives Recommended for Further Evaluation</u>

Based on the existing NSWWTP infrastructure, influent characteristics, and performance requirements, the following three alternatives are recommended for further evaluation:

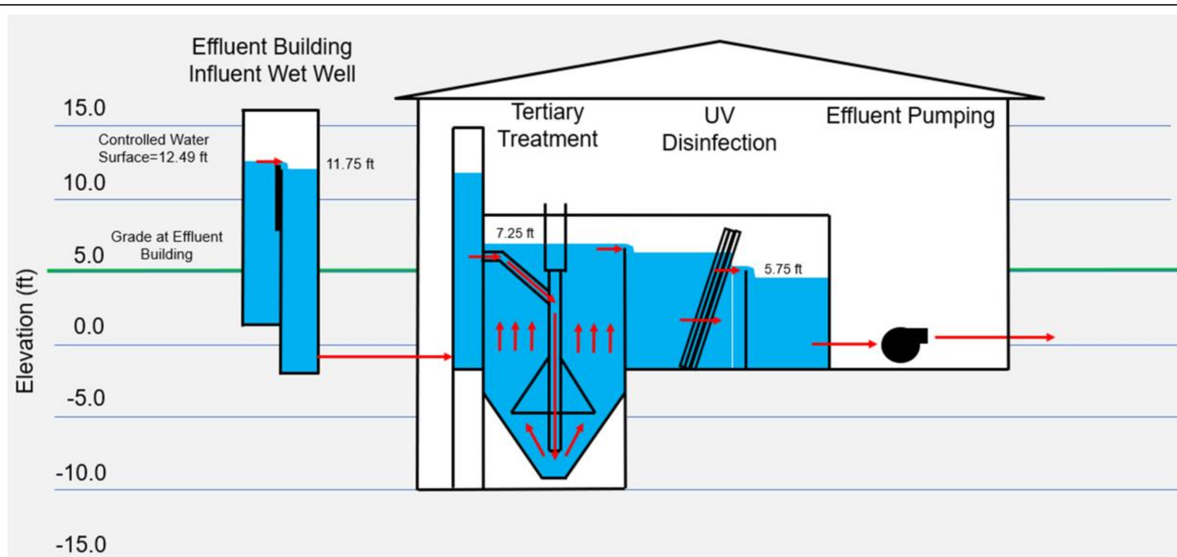
- Alternative 3–Reactive Filtration
- Alternative 4–Cloth Disc Filtration
- Alternative 5–Ballasted Settling

EVALUATION OF ALTERNATIVES

In this section, the three short-listed tertiary treatment alternatives identified in the previous section are evaluated based on hydraulic, monetary, and nonmonetary considerations. Redundancy was considered for all short-listed alternatives. For Alternative 3, the BluePRO system contains a total of six filters where one of the filters is on standby for future use. For Alternative 4, the AquaDisk has a similar setup and build to the previous alternative. Here the AquaDisk system contains a total of three cloth media filters where one of the filters is on standby. Unlike the other technologies, Alternative 5 does not have built-in redundancy as the CoMag system is a series of tanks which connect to a large 30-foot-diameter clarifier. To construct redundancy in case of failure, a duplicate CoMag system is considered.

A. Hydraulic Considerations

A hydraulic assessment of the NSWWTP was conducted to aid in the evaluation of the tertiary treatment technologies. Of the three alternatives, the BluePRO reactive filtration system has the greatest headloss with an expected loss of 4 feet. A conceptual hydraulic profile of the BluePRO system is presented in Figure 11. The controlled water surface elevation in the Effluent Building Influent Wet Well is maintained above 12.49 feet by the ultraviolet (UV) disinfection system. At this elevation, pumping to the proposed tertiary treatment building would not be required; however, during the nondisinfection season, the effluent is routed to the bypass channels, lowering the water surface elevation, and requiring pumping to the tertiary treatment facilities under current conditions. To avoid pumping under all conditions, downward opening weir gates (DOWs) would be installed on the bypass channels to allow the water surface level to be monitored and maintained at or above 12.49 feet during the nondisinfection season. To divert secondary effluent flow to the proposed tertiary treatment building, a tertiary treatment splitter box would be constructed as part of the Effluent Building Influent Wet Well. For flow diversion control, a DOW would be provided at the splitter box.



Note: ft=feet

Figure 11 Hydraulic Profile for Tertiary Treatment

A. Common Elements

There are common elements between each alternative. For ease of evaluation, these common elements are detailed in the following:

1. Addition of splitter box to the Effluent Building Influent Wet Well.
2. Construction of a tertiary treatment building.
3. Installation of site piping to convey secondary effluent to tertiary treatment system.
4. Installation of site piping to convey tertiary effluent to existing force main.
5. Installation of site piping to convey backwash solids to the West Primary Influent Channel.
6. Installation of a dedicated disinfection system with DOWs.
7. Installation of two chemical storage tanks for metal salt.
8. Installation of two backwash pumps.
9. Construction of a tertiary effluent wet well
10. Construction of a waste solids wet well to collect backwash solids.
11. Installation of two waste solids pumps to convey backwash solids to the West Primary Influent Channel.
12. Replacement of the two existing effluent pumps.

B. Description of Alternatives

1. Alternative 3–Reactive Filtration

In addition to the common elements listed above, this alternative also includes the installation of one BluePRO reactive filtration system in the proposed Tertiary Treatment Building. A preliminary site layout of this alternative is presented in Figure 12. This layout is anticipated to be similar for other alternatives.

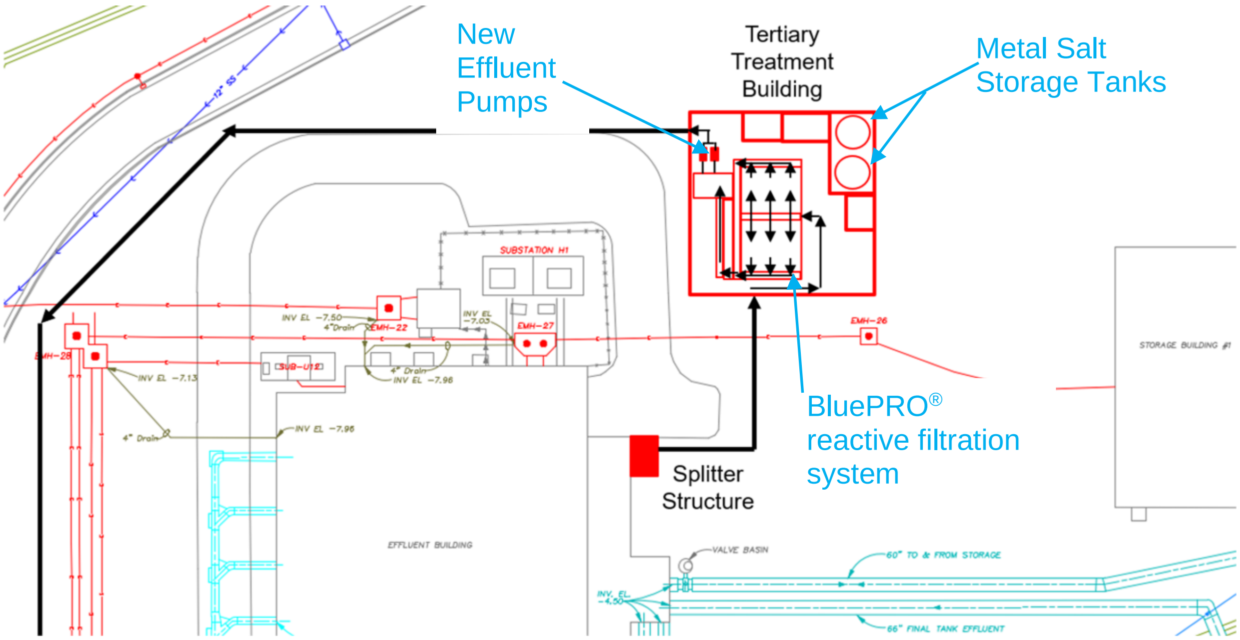


Figure 12 Alternative 3–Preliminary Site Layout Showing BluePRO System

2. Alternative 4–Cloth Disk Filtration

In addition to the common elements listed above, this alternative also includes the installation of one AquaDisk cloth media filtration system in the proposed Tertiary Treatment Building. This technology requires the installation of one rapid mix basin, one coagulation basin, and one flocculation basin. A polymer storage tank in addition to two polymer feed pumps are also included. The preliminary site layout of this alternative is the same as Alternative 3 presented in Figure 12.

3. Alternative 5–Ballasted Settling

This alternative includes the installation of one CoMag system consisting of two treatment trains and two 30-foot-diameter clarifiers for redundancy. The treatment train is made up of four concrete tanks. Tanks 1 and 2 are the first and second stage coagulation tanks, Tank 3 is the ballasting tank, and Tank 4 is the polymer addition tank in the proposed Tertiary Treatment Building. A polymer storage tank in addition to two polymer feed pumps are also included. The preliminary site layout of this alternative is similar to Alternative 3 presented in Figure 12, with the main difference being Alternative 5 requires a larger building footprint.

D. Monetary Evaluation

Table 8 summarizes the 20-year present worth analysis for each tertiary treatment alternative. Additional detail on the present worth analysis is provided in the appendix.

	Alternative 3–BluePRO	**Alternative 4–AquaDisk**	**Alternative 5–CoMag**
Equipment/Structure Subtotal	$5,480,000	$5,020,000	$7,040,000
Piping/Mechanical	$1,920,000	$1,760,000	$2,470,000
Electrical	$1,650,000	$1,510,000	$2,120,000
Plumbing/HVAC	$550,000	$510,000	$710,000
Sitework	$780,000	$760,000	$860,000
Major Yard Piping	$500,000	$500,000	$500,000
Undefined Scope	$1,100,000	$1,010,000	$1,410,000
Contractor's General Conditions	$1,800,000	$1,670,000	$2,270,000
Supply Chain Escalator	$1,380,000	$1,280,000	$1,740,000
Contingencies	$3,030,000	$2,800,000	$3,820,000
Technical Services	$2,280,000	$2,110,000	$2,870,000
Opinion of Probable Capital Costs (OPCC)	**$20,470,000**	**$18,930,000**	**$25,810,000**
Annual O&M Costs			
Relative Labor	$31,000	$31,000	$31,000
Power	$137,000	$135,000	$142,000
Chemical	$47,000	$114,000	$72,000
Additional Sludge Handling and Disposal	$14,000	$26,000	$16,000
Maintenance and Supplies	$46,000	$44,000	$79,000
BMC Operation Costs	$52,000	$52,000	$52,000
Total Opinion of Annual O&M	**$327,000**	**$402,000**	**$392,000**
Present Worth of Future Capital Costs/Replacement	$0	$0	$0
Present Worth of O&M	$4,440,000	$5,460,000	$5,330,000
Present Worth of Salvage	($580,000)	($640,000)	($510,000)
TOTAL OPINION OF PRESENT WORTH	**$24,330,000**	**$23,750,000**	**$30,630,000**

Notes:
HVAC=heating, ventilation, and air conditioning
All costs are in first quarter 2023 dollars.
20-year present worth at a discount rate of 4 percent.

Table 8 Summary of Budgetary Costs for Tertiary Treatment Alternatives

E. Nonmonetary Considerations

The following nonmonetary considerations for each alternative were evaluated and are detailed in the following.

1. Chemical Usage

- The AquaDisk system expected to have the highest chemical usage based on pilot testing results.
- The BluePRO system has the lowest chemical usage and is anticipated to be 50 percent less than required by AquaDisk.
- The CoMag system chemical usage lays between the other alternatives.

2. Environmental Impacts

- This is not expected to vary significantly between alternatives. A more in-depth discussion on environmental impacts is provided later in this report.

3. Footprint

- Both the BluePRO and the AquaDisk systems result in a proposed Tertiary Treatment Building with an area of approximately 4,000 square feet (the difference here being the height of the BluePRO system tanks require a slightly deeper Tertiary Treatment Building).
- The CoMag system alternative requires a proposed Tertiary Treatment Building of approximately 5,600 square feet.

4. Maintenance Requirements

- The BluePRO system and the AquaDisk system are anticipated to have the same level of maintenance requirements.
- The CoMag system contains magnetic recovery drums used to recycle metal salts. This drum is a piece of specialized equipment and would require more in-depth maintenance.

5. Operational Complexity

- Both the BluePRO and AquaDisk systems are established tertiary treatment technologies expected to have a similar level of complexity. These two systems are less complicated than the CoMag system.
- The CoMag system is expected to have the most complex operation given the specialized equipment.

6. Performance

- The AquaDisk system gave the most inconsistent results during pilot testing. Here the 0.05-mg/L TP concentration is close to the limit of the technology.
- Both the BluePRO and CoMag systems gave consistent results that met performance expectations.

7. Proven Technology

- All technologies are well-known and are widely used for tertiary treatment.
- Pilot testing was successful for all alternatives.

8. Resiliency to Changing Conditions and Process

- This is not expected to vary between alternatives. Performance of tertiary treatment technologies will be impacted by the secondary effluent quality and flow. Given that there expected flow into the Tertiary Treatment Building is a constant 3.6 MGD, minimal fluctuations are anticipated.
- If MMSD were to transition to operating under low dissolved oxygen (DO) conditions, this could increase the TP concentration of the secondary effluent. Elevated TP concentrations would require additional chemical for TP removal. This would increase costs for chemical usage and sludge handling across all alternatives.

9. Solids Handling Impacts

- This is expected to vary slightly between alternatives; however, impact to the overall solids handling at the NSWWTP is likely minimal.
- Performance of tertiary treatment technologies will be most impacted by secondary effluent quality.

ENVIRONMENTAL IMPACTS

MMSD has a strong interest in mitigating their impact on the environment and climate change. This section of the Feasibility Report conducts a high-level analysis of the environmental impact of the shortlisted tertiary treatment alternatives. The building footprint and energy requirements of each alternative were quantified, and the resulting greenhouse gas (GHG) emissions calculated. GHG emissions were quantified for carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_x).

A. Energy Differences

This Feasibility Report considered the footprint of each prelisted technology to determine an appropriate size for the tertiary treatment building. The building size corresponding to each alternative is summarized in Table 9. Here the magnitude of the building footprint for each alternative is used as a proxy for GHG emissions generated from construction. Given minimal variation in the resulting footprint of each alternative, the difference in expected GHG emissions generated from the construction of these alternatives is expected to be negligible. Therefore, GHG emission generated from construction were not quantified. GHG emission calculations were based solely on the anticipated energy use for each alternative, and the energy requirement for each alternative is reported in Table 9. The Emissions & Generation Resource Integrated Database (eGRID) by the United States Environmental Protection Agency (USEPA) was used to convert energy usage to the equivalent pounds of GHG produced per year. Since MMSD falls within the Midwest Reliability Organization East (MORE) region, eGRID references GHG emission rates published by MORE. MORE reports the emission rates for CO_2, SO_2, and NO_x as 1,582.1 pounds per megawatt hour (lb/Mw-h), 0.393 lb/Mw-h, and 0.92 lb/Mw-h, respectively. The resulting GHG emissions for CO_2, SO_2, and NO_x were calculated in megatons per year and are shown in Table 9.

Technology	Building Footprint (ft^2)	Energy Usage (Mw-h/yr)	Equivalent CO_2 (Ton/yr)	Equivalent SO_2 (Ton/yr)	Equivalent NO_x (Ton/yr)
Alternative 3–BluePRO®	4,000	1,590	1,140	0.28	0.66
Alternative 4–AquaDisk®	4,000	1,570	1,130	0.28	0.65
Alternative 5–CoMag™	5,600	1,650	1,180	0.29	0.69

Notes:
ton=metric ton
ft^2=square feet
Mw-h/year=megawatt hour per year
ton/yr=tons per year
Electrical cost set at 0.085 $/kw-h

Table 9 Estimated GHG Emission Equivalent for Each Alternative

SELECTED ALTERNATIVE

Based on the monetary and nonmonetary analysis, MMSD has selected Alternative 3. This alternative includes the installation of the BluePRO reactive filtration system in the proposed Tertiary Treatment Building. The BluePRO system has an estimated capital cost and 20-year total present worth cost of 19.6 and 23.5 million dollars respectively. There is a 3 percent difference in cost between the total present worth values for Alternatives 3 and 4; monetarily, Alternatives 3 and 4 are considered equal. Although Alternatives 3 and 4 are monetarily considered equal on a 20-year basis, the BluePRO system has the lowest annual O&M costs. This is due to low chemical usage and not requiring the addition of polymer. Moreover, less chemical usage results in lower sludge production and hauling costs. The BluePRO system produces approximately 50 percent less sludge annually compared to the AquaDisk system.

Alternative 3 will not only allow MMSD to meet the proposed TP effluent concentration limits, but it will help them minimize chlorides in their effluent discharge. MMSD has a chloride limit at the BMC outfall, and compliance with the chloride limit is of significant concern. Between November 1 to March 31, their WPDES permit allows a weekly average chloride discharge concentration of 465 mg/L. This limit is more stringent April 1 through October 31 with a weekly average chloride discharge concentration of 430 mg/L. The evaluation of the tertiary treatment alternatives used ferric chloride as a coagulant source, but other chemicals may be used. Of the three shortlisted alternatives, the BluePRO system has the smallest anticipated chemical usage and thus would impart the least number of chlorides.

In addition to TP effluent concentration limits, the USEPA is expecting states to develop water quality standards for total nitrogen (TN) and other nutrient-related parameters in future permit cycles. TN includes all forms of nitrogen: organic, ammonia, and inorganic forms like nitrite and nitrate. If the WDNR were to develop a TN WQBEL, the BluePRO technology can be amended by the addition of denitrifying filters to allow for TN removal.

It is important to note that Alternative 3 is the selected technology for reliably treating TP in the BMC discharge with their current average flow of 3.6 MGD. Different technology might be used if MMSD was required to treat the entire plant effluent flow of roughly 80 MGD. This is because other technologies may be better suited to scale up to the required capacity for the BFC and BMC discharge flow.

APPENDIX
OPCC

Madison Metropolitan Sewerage District
Badger Mill Creek Phosphorus Compliance Preliminary Engineering Feasibility Report
Opinion of Present Worth Cost **Discount Rate** 4.000%

Alternative 3-BluePRO

ITEM	Initial Capital Cost	Future Capital Cost	Replacement Year	Replacement Cost (P.W.)	20-Year Salvage Value	Salvage Value (P.W.)
Effluent Pumping Equipment	$ 220,000	$ -	20	$ -	$ -	$ -
Waste Solids Pumping Equipment	$ 110,000	$ -	20	$ -	$ -	$ -
Splitter Structure	$ 150,000	$ -	40	$ -	$ 75,000	$ 30,000
Tertiary Treatment Building	$ 1,400,000	$ -	40	$ -	$ 700,000	$ 320,000
Process Equipment and Controls	$ 1,663,000	$ -	20	$ -	$ -	$ -
Chemical Feed Tank	$ 110,000	$ -	20	$ -	$ -	$ -
Chemical Feed Equipment	$ 60,000	$ -	20	$ -	$ -	$ -
UV Disinfection Equipment	$ 740,000	$ -	20	$ -	$ -	$ -
Downward Opening Weir Gates	$ 140,000	$ -	40	$ -	$ 70,000	$ 30,000
Process Structural	$ 890,000	$ -	40	$ -	$ 445,000	$ 200,000
Subtotal	$ 5,480,000	$ -		$ -	$ 1,290,000	$ 580,000
Piping/Mechanical	$ 1,920,000					
Electrical	$ 1,650,000					
Plumbing/HVAC	$ 550,000					
Sitework	$ 780,000					
Major Yard Piping	$ 500,000					
Undefined Scope	$ 1,100,000					
Subtotal	$ 11,980,000					
General Conditions	$ 1,800,000					
Subtotal	$ 13,780,000					
Supply Chain Escalator	$ 1,380,000					
Subtotal	$ 15,160,000					
Contingencies	$ 3,030,000					
Technical Services	$ 2,280,000					
Total Capital Costs	$ 20,470,000	$ -		$ -	$ 1,290,000	$ 580,000
Present Worth of Capital Costs	**$ 20,470,000**	**$ -**		**$ -**	**$ 1,290,000**	**$ 580,000**

Estimated Annual O&M Costs	
Relative Labor	$ 31,000
Power	$ 137,000
Chemicals:	
Ferric	$ 47,000
Maintenance and Supplies	$ 38,000
Lamp Replacement	$ 8,000
Additional Sludge Handling and Disposal	$ 14,000
BMC Operation Costs	$ 52,000
Total O&M Costs	$ 327,000
Present Worth of O&M	**$ 4,440,000**

Summary of Present Worth Costs	
Capital Cost	$ 20,470,000
Future Capital Costs/Replacement	$ -
O&M Cost	$ 4,440,000
Salvage Value	$ (580,000)
Total Present Worth	**$ 24,330,000**

Madison Metropolitan Sewerage District
Badger Mill Creek Phosphorus Compliance Preliminary Engineering Feasibility Report
Opinion of Present Worth Cost **Discount Rate** 4.000%

Alternative 4-AquaDisk

ITEM	Initial Capital Cost	Future Capital Cost	Replacement Year	Replacement Cost (P.W.)	20-Year Salvage Value	Salvage Value (P.W.)
Effluent Pumping Equipment	$ 220,000	$ -	20	$ -	$ -	$ -
Waste Solids Pumping Equipment	$ 110,000	$ -	20	$ -	$ -	$ -
Splitter Structure	$ 150,000	$ -	40	$ -	$ 75,000	$ 30,000
Tertiary Treatment Building	$ 1,090,000	$ -	40	$ -	$ 545,000	$ 250,000
Phorphorus Removal Equipment and Controls	$ 1,641,000	$ -	20	$ -	$ -	$ -
Chemical Feed Tank	$ 110,000	$ -	20	$ -	$ -	$ -
Chemical Feed Equipment	$ 60,000	$ -	20	$ -	$ -	$ -
Polymer Tank and Feed Equipment	$ 60,000	$ -	20	$ -	$ -	$ -
UV Disinfection Equipment	$ 740,000	$ -	40	$ -	$ 370,000	$ 170,000
Downward Opening Weir Gates	$ 140,000	$ -	40	$ -	$ 70,000	$ 30,000
Process Structural	$ 700,000	$ -	40	$ -	$ 350,000	$ 160,000
Subtotal	$ 5,020,000	$ -		$ -	$ 1,410,000	$ 640,000
Piping/Mechanical	$ 1,760,000	$ -				
Electrical	$ 1,510,000	$ -				
Plumbing/HVAC	$ 510,000	$ -				
Sitework	$ 760,000	$ -				
Major Yard Piping	$ 500,000	$ -				
Undefined Scope	$ 1,010,000	$ -				
Subtotal	$ 11,070,000	$ -				
General Conditions	$ 1,670,000	$ -				
Subtotal	$ 12,740,000	$ -				
Supply Chain Escalator	$ 1,280,000					
Subtotal	$ 14,020,000	$ -				
Contingencies	$ 2,800,000					
Technical Services	$ 2,110,000					
Total Capital Costs	$ 18,930,000	$ -		$ -	$ 1,410,000	$ 640,000
Present Worth of Capital Costs	**$ 18,930,000**			**$ -**	**$ 1,410,000**	**$ 640,000**

Estimated Annual O&M Costs	
Relative Labor	$ 31,000
Power	$ 135,000
Chemicals:	
Ferric	$ 83,000
Polymer	$ 31,000
Maintenance and Supplies	$ 36,000
Lamp Replacement	$ 8,000
Additional Sludge Handling and Disposal	$ 26,000
BMC Operation Costs	$ 52,000
Total O&M Costs	$ 402,000
Present Worth of O&M	**$ 5,460,000**

Summary of Present Worth Costs	
Capital Cost	$ 18,930,000
Future Capital Costs/Replacement	$ -
O&M Cost	$ 5,460,000
Salvage Value	$ (640,000)
Total Present Worth	**$ 23,750,000**

Madison Metropolitan Sewerage District
Badger Mill Creek Phosphorus Compliance Preliminary Engineering Feasibility Report
Opinion of Present Worth Cost

Discount Rate 4.00%

Alternative 5-CoMag

ITEM	Initial Capital Cost	Future Capital Cost	Replacement Year	Replacement Cost (P.W.)	20-Year Salvage Value	Salvage Value (P.W.)
Effluent Pumping Equipment	$ 220,000	$ -	20	$ -	$ -	$ -
Waste Solids Pumping Equipment	$ 110,000	$ -	20	$ -	$ -	$ -
Splitter Structure	$ 150,000	$ -	40	$ -	$ 75,000	$ 30,000
Tertiary Treatment Building	$ 1,420,000	$ -	40	$ -	$ 710,000	$ 320,000
Phosphorus Removal Equipment and Controls	$ 3,320,000	$ -	20	$ -	$ -	$ -
Chemical Feed Tank	$ 110,000	$ -	20	$ -	$ -	$ -
Chemical Feed Equipment	$ 60,000	$ -	20	$ -	$ -	$ -
Polymer Tank and Feed Equipment	$ 60,000	$ -	20	$ -	$ -	$ -
UV Disinfection Equipment	$ 740,000	$ -	20	$ -	$ -	$ -
Downward Opening Weir Gates	$ 140,000	$ -	20	$ -	$ -	$ -
Process Structural	$ 710,000	$ -	40	$ -	$ 355,000	$ 160,000
Subtotal	$ 7,040,000	$ -		$ -	$ 1,140,000	$ 510,000
Piping/Mechanical	$ 2,470,000	$ -				
Electrical	$ 2,120,000	$ -				
Plumbing/HVAC	$ 710,000	$ -				
Sitework	$ 860,000	$ -				
Major Yard Piping	$ 500,000	$ -				
Undefined Scope	$ 1,410,000	$ -				
Subtotal	$ 15,110,000	$ -				
General Conditions	$ 2,270,000	$ -				
Subtotal	$ 17,380,000	$ -				
Supply Chain Escalator	$ 1,740,000					
Subtotal	$ 19,120,000	$ -				
Contingencies	$ 3,820,000					
Technical Services	$ 2,870,000					
Total Capital Costs	$ 25,810,000	$ -		$ -	$ 1,140,000	$ 510,000
Present Worth of Capital Costs	**$ 25,810,000**			**$ -**	**$ 1,140,000**	**$ 510,000**

Estimated Annual O&M Costs	
Relative Labor	$ 31,000
Power	$ 142,000
Chemicals:	
Ferric	$ 52,000
Polymer	$ 15,000
Magnetite	$ 5,000
Maintenance and Supplies	$ 71,000
Lamp Replacement	$ 8,000
Additional Sludge Handling and Disposal	$ 16,000
BMC Operation Costs	$ 52,000
Total O&M Costs	$ 392,000
Present Worth of O&M	**$ 5,330,000**

Summary of Present Worth Costs	
Capital Cost	$ 25,810,000
Future Capital Costs/Replacement	$ -
O&M Cost	$ 5,330,000
Salvage Value	$ (510,000)
Total Present Worth	**$ 30,630,000**