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From: Isabella Altier, Nabil Djafi, Rachel Hardtke, Josh McLelland,

RE: PFAS Removal Technology for the GCWW Charles M. Bolton Plant

Date: April 18th, 2023

Dear Greater Cincinnati Water Works Team,

Forefront Consulting is excited to deliver the completed proposal and preliminary designs for the most feasible treatment technology to remove perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) at the Charles M. Bolton Water Treatment Plant.

Attached is the proposal, detailing the following:

- Background and Scope of the Issue
- Water Treatment Technology Review
- Water Treatment Technology Alternative Analysis
- Water Treatment Technology Recommendation
- Granular Activated Carbon Design & Drawings
- Granular Activated Carbon Construction Cost Estimate
- Forefront Consulting Team Qualifications

Respectfully,

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Analysis of Perfluoroalkyl and Polyfluoroalkyl (PFAS) Treatment at the Charles M. Bolton Water Treatment Plant for Greater Cincinnati Water Works Design Proposal

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EXECUTIVE SUMMARY

Greater Cincinnati Water Works (GCWW) has detected per- and polyfluoroalkyl (PFAS) compounds in both their source water and treated water at the Charles M. Bolton Plant (CMBP) and is interested in evaluating treatment modifications to reduce the levels of PFAS in the drinking water. Currently, the CMBP is detecting levels of PFOA as high as 4.7 ppt and PFOS as high as 5.7 ppt in their treated water and would like to know the most cost-effective treatment technology for lowering concentrations to below 2 ppt for both compounds.

Forefront Consulting conducted a literature review of possible treatment technologies for PFAS removal including granular activated carbon (GAC), anion exchange, reverse osmosis, and advanced oxidation. The four technologies were analyzed based on seven alternative analysis criteria including effectiveness, site feasibility, impact on the current treatment process, impact on necessary plant additions to meet the EPA's Lead and Copper Rule Revisions, waste stream, cost, and industry acceptance. In the alternative analysis, GAC received 96 points, anion exchange received 92 points, reverse osmosis received 66 points, and advanced oxidation received 55 points. The maximum possible score for the alternative analysis was 112 points. While the GAC and anion exchange results were close, GAC was favored particularly in the cost and industry acceptance categories. Forefront Consulting is pleased to recommend to GCWW the implementation of GAC treatment at the CMBP for removing PFOA and PFOS compounds to below 2 ppt.

The Forefront Consulting team designed a new separate GAC facility to remove PFAS on the GCWW property. The facility will include five GAC contactors, four operational and one for storage, and a backwash system. The current process at CMBP will be intercepted at the sand filter effluents and the water will be pumped to the new GAC building. After GAC treatment the water will gravity flow to the clearwells and receive chlorine and fluoride doses before distribution. The backwash process will need to occur around every 10 days, with the used water going to the lagoon instead of being routed through the treatment process. Once the carbon in the GAC contactors becomes spent it will be transported to RMTP to be reactivated with their incinerator. The total cost for this new design will be \$25.7 million, which includes process materials, reactivation, earthwork, and labor and subcontracts.

1. INTRODUCTION

1.1 Problem Statement

Forefront Consulting is responding to the request from Greater Cincinnati Water Works (GCWW) to conduct a preliminary investigation and design for PFAS removal at the Charles M. Bolton Plant (CMBP). GCWW has detected PFAS compounds in both their source water and treated water at the CMBP and is interested in treatment modifications to reduce the levels of PFAS in the drinking water. The two PFAS compounds of interest for the CMBP are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). Currently, the CMBP is detecting levels of PFOA as high as 4.7 ppt and PFOS as high as 5.7 ppt in their treated water. The detection concentrations can be seen in Appendix 9.1 and 9.2. GCWW set an internal treatment target of 2 ppt for PFOA and 2 ppt for PFOS.

1.2 Site Background

CMBP makes up 12% of GCWW water and services Northwest Hamilton County. The plant has a maximum capacity of 40 million gallons per day (MGD) but averages around 12 MGD. CMBP treats ground water that is drawn from 13 wells located along the Great Miami River in the Great Miami Buried Valley Aquifer (Greater Cincinnati Water Works n.d). Groundwater is naturally pre-filtered and requires less intensive treatment to reach high standards of quality. The groundwater then retrieves lime softening, lime clarification and pH adjustment, chlorine disinfection, fluoridation, and sand filtration before wet well storage and distribution (Figure 1).

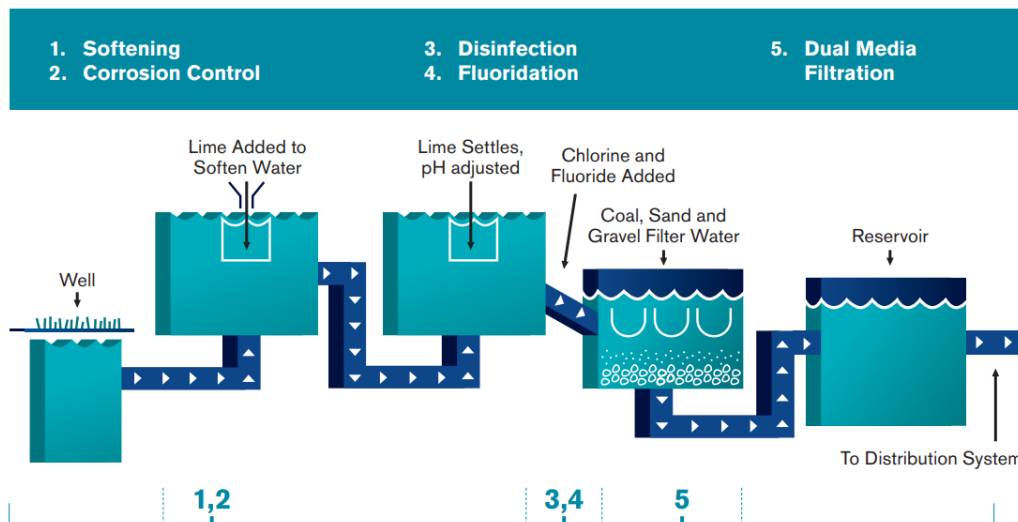


Figure 1: Current process for treating groundwater at the CMBP (Reproduced from Greater Cincinnati Water Works, n.d.)

The current treatment process at the CMBP consists of softening, corrosion control, disinfection, fluoridation, and dual media filtration. In the softening step of the process, calcium oxide in the form of hydrated lime is added to the primary solids contact basins to reduce the hardness of the water. The calcium oxide raises the pH of the water and leads to a chemical reaction that creates calcium carbonate which settles out. Next, the water chemistry is adjusted by controlling the pH and alkalinity. These adjustments are corrosion control measures to reduce lead and copper from entering the water due to corrosion of distribution pipe materials that contain both metals. Sodium hexametaphosphate is also added as a sequestering agent that reduces calcium carbonate build up in the system.

Chlorine and fluoride are added to the water as part of the disinfection and fluoridation steps. Chlorine kills viruses, bacteria, and other disease-causing organisms and it is required to be added to the water by federal and state laws. Fluoride is added to the water to protect people's teeth from cavities and is also required by state law. Following the addition of chlorine and fluoride, the water passes through dual media filters that contain both sand and anthracite. These filters remove any remaining calcium carbonate and any additional contaminants that may remain. From the filters, the water enters the clearwells and eventually the reservoir where it then enters the distribution system.

1.3 Scope of the Issue

PFAS are manufactured chemicals that have been widely used in consumer products and industry since the 1940s. They are also known as "forever chemicals" because they don't break down naturally in the environment which has led to widespread contamination and accumulation. PFAS compounds can be found in various types of food packaging, household products, personal care products, and fire extinguishing foam, and have made their way into drinking water, soil, and food. Exposure to PFAS can come from working in industries where these chemicals are widely used, drinking water and consuming foods that contain PFAS, and using products made or containing PFAS. The health effects due to exposure to PFAS are not yet fully understood. Currently, what is known is that PFAS can cause reproductive effects, developmental effects in children, increased risks of cancer, reduced immune system strength, and interference with the body's natural hormones (EPA 2022b).

There are thousands of different PFAS compounds, all with varying effects and toxicity levels. The two most widely used and studied compounds are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). The EPA released a health advisory level on June 15, 2022, that the minimum concentration that may present health risks to an individual over a lifetime of

exposure is 0.004 ppt for PFOA and 0.02 ppt for PFOS (EPA 2022a). The EPA also released Minimum Reporting Levels (MRL) for PFOA and PFOS at 4 ppt, which is the minimum quantitation level that can be achieved using EPA Analytical Method 533.

On March 14, 2023, the EPA proposed the first-ever national standard for PFAS in drinking water. While these regulations are currently just proposed, the EPA anticipates finalizing the regulations by the end of 2023. If this proposal is finalized, PFOA and PFOS will be regulated as individual contaminants and four additional PFAS compounds including PFNA, PFHxS, PFBS, and GenX Chemicals will be regulated as a mixture. PFOA and PFOS will be regulated at a maximum contaminant level (MCL) of 4 parts per trillion, which is the level that can be reliably measured. The other compounds would be regulated to limit any mixture containing one or more of the compounds and water systems would use a hazard index (HI) calculation to determine if the combined levels of PFAS pose a potential risk. The proposed HI is 1.0, which is the level at which no known or anticipated adverse effects on human health are expected to occur.

Finalizing these proposed regulations would mean that public water systems would be required to monitor for these chemicals and communicate with the public if levels exceed the regulatory standards. If levels exceed the standards, they will also be responsible for reducing PFAS contamination. EPA states that “the rule will, overtime, prevent thousands of deaths and reduce tens of thousands of serious PFAS-attributable illnesses” (EPA 2023).

Data provided by GCWW for the CMBP was analyzed to determine the necessary percentage reductions and identify any trends in PFOA and PFOS concentrations. The average PFOA concentration in the well water is 3.3 ppt. To reach the desired level of 2 ppt, a 39% reduction is required for PFOA. The average PFOS concentration in the well water is 3.9 ppt. To reach the desired level of 2 ppt, which is below the MRL level of 4 ppt, a 49% reduction is required for PFOS. The calculated percentage reductions require that the new treatment technology will need to be at least 49% effective at removing PFAS compounds to meet the goals of GCWW (see appendix 9.2). The team also plotted PFOA and PFOS data to determine if there was a trend in concentration over time. It was determined that there was no significant correlation for either PFOA or PFOS concentrations over time. Additionally, the team found no relationship between other water quality parameters, such as pH, temperature, or hardness with levels of PFOA and PFOS. The data provided by GCWW is provided in Appendix 9.1 and the plotted data is included in Appendix 9.2.

In addition to reducing the PFOA and PFOS concentrations to the desired levels, the team also needed to consider possible future additions or changes due to EPA's Lead and Copper Rule Revisions (LCRR). The CMBP already had proposed locations for the addition of orthophosphate and recarbonation to the treatment process. The new treatment technology for PFAS removal must be able to function with these future treatment additions and not cause corrosion issues that would cause lead and copper to enter the distribution system.

1.4 Approach

The Forefront Consulting team started solving the proposed problem from GCWW by reading the request for proposal and having an initial meeting with the GCWW sponsors to understand the task. We went to CMBP and toured the facility to help visualize the process and learn specifics about the chemicals and technologies used. After this, we started our research by reading up on PFAS and relevant treatment technologies in the industry. We continued to meet with our sponsors and other contacts that are well-versed in the PFAS removal industry. Once we decided on four different treatment technologies that were the most likely to solve CMBP's issue, we assigned each member of the team a different technology to research. We investigated effectiveness, site feasibility, impact on process, LCRR, waste stream, cost, and industry acceptance for each technology. From this information we created an alternative analysis to compare the different treatment technologies, this helped us to decide which one was the best to move forward with at CMBP.

2. TREATMENT TECHNOLOGIES

2.1 Technology Overview

When considering the treatment technology necessary to reduce PFAS at the CMBP the main criteria we started to research were treatment efficiency, site feasibility, and industry acceptance. We needed to find technologies that had an efficiency of at least 49% for PFOA and PFOS removal since that is the percent reduction required at the CMBP (Appendix 9.1 and 9.2). There is not a lot of room to expand at the CMBP so finding a technology that logistically fits into their space was something that needed to be considered. Granular activated carbon and anion exchange were the first two technologies that we seriously considered due to their more mainstream use. Reverse osmosis and advanced oxidation were also considered as emerging technologies. These four technologies were the ones that seemed to be optimal at achieving all GCWW's parameters to remove PFAS.

2.2 Feasible Technologies

Granular Activated Carbon

Water treatment using granular activated carbon (GAC) is performed by incorporating porous adsorption media within the process. The extremely high internal surface area of GAC allows for the adsorption removal of taste and odor-producing compounds, disinfection byproduct (DBP) precursors, and organic compounds. The process works best for organic compounds with high molecular weights. The removal of PFAS also increases when the pH of water is lower. The properties of GACs are based on the raw materials and manufacturing processes used. GAC can be manufactured from materials like bituminous coal, lignite coal, peat, wood, or coconut shells to generate a product with the desired porosity, iodine number, molasses number, abrasion number, bulk densities, and effective volumes. Granular activated carbon is proven to have high removal efficiency of total organic carbon (TOC) as well as PFAS compounds. When in use, GAC removes up to 99% of these compounds. The use of GAC in a treatment process allows for the adjustment of parameters including empty bed contact time (EBCT), bed volumes, pressure vessels or gravity-fed systems, breakthrough time, loading rates, and flow rates. GAC is set in a configuration similar to conventional filtration methods that are used for other adsorption media such as sand filters.

Granular activated carbon must be backwashed the same way that conventional sand filters operate, this is to remove physical contaminants and solid particles that make their way through the filter and eventually clog them. Backwashing procedures remove absorbed materials from the GAC surface and upper layers. To remove the adsorbed contaminants, the GAC particles are reactivated through high temperature incineration. Incineration processes will break down the TOC and PFAS contaminants within the pore structure of the spent adsorption media at high enough temperatures, generally 1,000 degrees Celsius. Spent GAC is then revived with around 20% new GAC material after incineration occurs.

Anion Exchange

Anion exchange is also an acceptable treatment technology for removing long-chain PFAS from public water infrastructure. This is an adsorption-based process similar to activated carbon, however, instead of carbon being the adsorption material, gels or macro-porous resins are used to perform the removal process. As PFOS and PFOA compounds contain predominantly negatively charged functional groups, an anionic exchange resin will work well. The process is similar to GAC but relies more on electrostatic attraction as the removal mechanism (McCleaf et al. 2017). While both gel and microporous anion resins can have

similar rates of PFAS removal, gel resins are able to reach the same removal efficiencies with a significantly reduced contact time, which is well below two hours due to its larger pore size (Liu et Sun, 2021). Anion exchange consists of an array of anion exchange vessels installed in lead/lag configurations (Figure 2). These vessels are typically filled with approximately 23% of a gel resin such as Purolite® Purofine® PFA694E or equivalent resin designed specifically for the removal of PFAS to below non-detect levels (OCWD 2021). Depending on the design characteristics of the vessels, an additional building to house the columns may be constructed due to the freezing months frequently seen in Southern Ohio.



Figure 2: Example anion exchange vessels in a lead/lag configuration (Reproduced from OCWD 2021)

Reverse Osmosis

Reverse Osmosis (RO) is a treatment technology used primarily for desalination but can be effective at removing other types of contaminants and ions from water. The process of RO starts with water being fed into a high-pressure pump that leads to a system of vessels containing a semi-permeable membrane. The high-pressure water overcomes osmosis and passes through the membrane, which is called permeate or recycled water. The water retained behind the membrane contains all the removed contaminants, which is called concentrated reject water, and leaves the RO vessels through a different pipe than the recycled water (Sydney Water 2022). The reject water continues to another set of RO vessels where the previous process is repeated twice (Figure 3). The reason the reject water is put through the RO vessels multiple times is to increase efficiency and the amount of recycled water. After the

reject or concentrated water has gone through multiple RO vessels the water is stored in a discharge water tank (Sydney Water 2022).

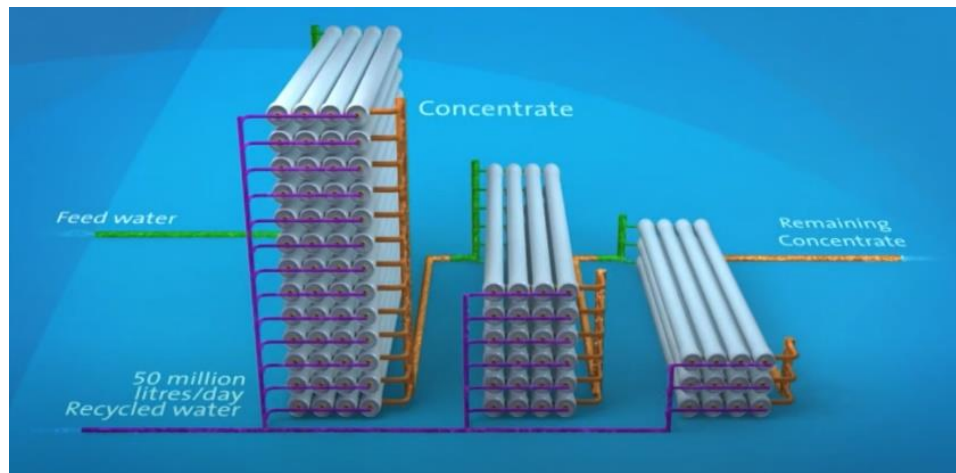


Figure 3: RO vessel system and process example (Reproduced from Sydney Water 2022)

Figure 3 represents a water recycling facility that has an average inlet feed of around 15 MGD or 58 million liters/day, which is slightly larger than CMBP's 12 MGD. The CMBP would need to perform small-scale tests to decide how many vessels would be needed to achieve the PFAS removal goal. While this process describes RO, there are several important steps that need to happen before the water is fed into the high-pressure pumps. Whether the water is seawater, groundwater, or surface water it needs to go through a pretreatment process before entering RO (Cornelissen et al. 2021). The pretreatment process needs to lower the turbidity and remove some contaminants. Types of processes that may be used for pretreatment are sand filters or flocculation and coagulation. After RO, the recycled water needs to be re-mineralized. During RO, the membrane extracts a majority of the ions from the water. If re-mineralization does not happen it could lead to the potential for corrosion in the pipes after distribution. The addition of limewater and adjusting the pH of RO treated water prior to its contact with aged pipes may minimize the dissolution of carbonates and oxides (Sedlak 2019). The most common way to re-mineralize RO treated water is the addition of carbon dioxide and excess hydrated lime (El Azhar et al. 2012). A lime saturator is used to create limewater. In the lime saturator, a milk of lime solution is fed into the reactor where it mixes with recycled lime solids (Dunn 2009). From this, limewater is created then mixed into the recycled water after RO. The limewater will re-mineralize the recycled water and increase the pH. Carbon dioxide is added after to then decrease the pH enough for distribution. Ions like chlorine and fluoride will also need to be added after RO since these ions will be removed through the semi-permeable

membrane. Factors that influence how effective RO can be are turbidity and membrane fouling. The turbidity of the water prior to entering the vessels needs to be below 1 NTU (Cornelissen et al. 2021). To get lower than 1 NTU the water must enter a sand filter or similar technology. However, for the CMBP the raw source water would meet this requirement. Fouling of the membranes can occur when the feed water has microorganisms or large contaminants. RO is a very expensive treatment technology due to the amount of energy necessary to overcome osmosis from the high pressure of the pumps. The advantage of RO is that it is very effective at removing a lot of contaminants and ions from the water. RO has not yet been widely used to extract PFAS from water but through testing and some treatment facilities, it has been shown to be effective. A big concern about RO removing PFAS is that it creates a very concentrated stream of PFAS in the reject water. There is no ideal option for disposal of the reject water containing PFAS due to it being an environmental hazard. The options for disposing of the reject water are to put it into a hazardous waste landfill, solidify and incinerate it, or use super critical oxidation to degrade it.

Advanced Oxidation

Advanced oxidation technologies involve the use of powerful oxidizing intermediates that oxidize and degrade pollutants from contaminated water (Collins and Bolton 2016). For the purpose of this project, heterogeneous photocatalysis, a type of advanced oxidation, was researched for the removal of PFAS compounds from water. Heterogeneous photocatalysis can be conducted under a wide range of light wavelengths which increases the ability to break down PFAS compounds. Heterogeneous photocatalysis involves photon absorption using a light-sensitive photocatalyst (Xu et al. 2017). In this case, titanium dioxide was the chosen photocatalyst. In this process, photons are absorbed and negatively charged electrons and positively charged hole pairs are generated that then migrate to the surface of TiO₂ particles and react with the PFAS compound resulting in the decomposition of the contaminant (Xu et al. 2017).

The heterogeneous photocatalysis process can take place with various reactor configurations. A few configurations include slurry of photocatalysts, fluidized media, flat sheet membrane, and optical or electrospun fiber. The four reactor designs are included in Figure 4.

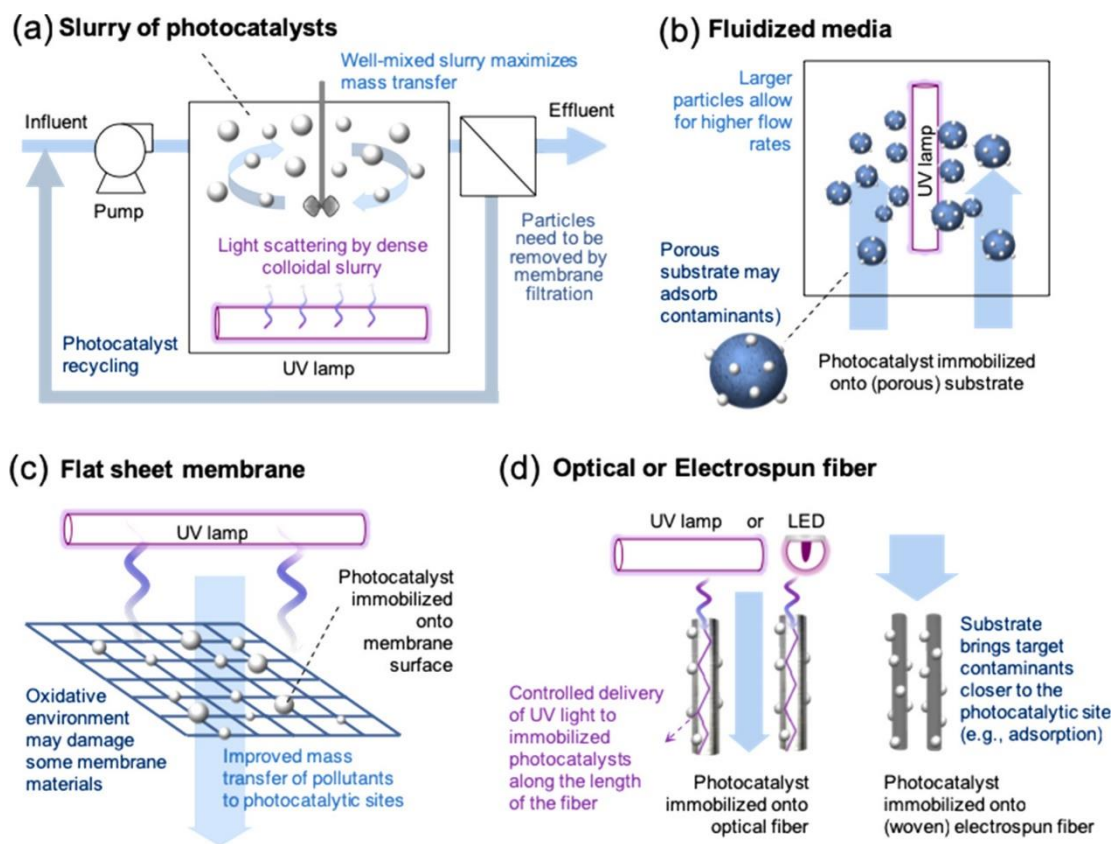


Figure 4: Reactor Designs for Photocatalytic Water Treatment (Reproduced from Loeb et al., 2019)

Titanium dioxide is a favorable photocatalyst because it is both chemically and physically stable. It is readily available for a low cost and can break down a wide range of contaminants in water. Titanium dioxide is also non-toxic, which is important for drinking water treatment processes (Xu et al. 2017). There are other photocatalysts that can be used in the heterogeneous photocatalysis process such as transition metal modified titanium dioxide, gallium oxide, and indium oxide. However, given its common and favorable use, titanium dioxide was the main photocatalyst researched.

Heterogeneous photocatalysis has many unique conditions needed to break down PFAS compounds successfully. The main factors affecting the process include the light source, solution temperature, and solution pH. Photocatalysis is largely dependent on light because photons from the light source are absorbed by the contaminant and catalysts to initiate the reaction. Catalysts absorption occurs at wavelengths in the UV zone ranging from 200 to 380 nm. Regarding solution temperature, preliminary research suggests that higher temperatures speed up the reaction and increase PFAS degradation. The solution pH appears to have a significant effect on effectiveness of PFAS degradation. In one study, titanium oxide and UV

photodegradation achieved a 90% removal of PFOA at a pH of 2 (Xu et al. 2017). In the same study, percent removal decreased significantly with a pH of 5. Acidic conditions are favored for higher percent removal of PFAS compounds (Xu et al. 2017). In addition to the other factors, the solution needs to have low turbidity in order to allow the UV light to hit the desired contaminants and photocatalyst.

2.3 Non-Feasible Technologies

Supercritical Water Oxidation

Supercritical water oxidation (SCWO) is when a supercritical fluid is kept at a temperature and pressure above its critical point, so it is neither liquid nor gas (Marrone n.d.). Battelle Memorial Institute has a process of SCWO called the PFAS Annihilator. This is a closed-loop process that can destroy PFAS from a concentrated water stream. The process happens when oxidants such as air or hydrogen peroxide used in the oxidation reaction, break the carbon-fluorine bond in PFAS. Sodium hydroxide must then be added to the water to neutralize the hydrofluoric acid before the water can be distributed (BATTELLE, 2021). This type of treatment can only be used on a very concentrated stream of PFAS. So, SCWO is not feasible to treat the well water at CMBP since there is no concentrated stream of PFAS, but it can be used on the reject water from RO since it contains concentrated PFAS.

Dual Media Filters

Adding GAC on top of the current sand filters to create a dual media filtration system was researched. The difficulty of implementing this process involves flow rates and backwash processes. With the abrasiveness of sand particles and GAC mixed, breakage and mixture will occur within the filter bed. When backwashing a sand filter with GAC on top, there will be some powdered GAC media that backwashes out of the filter due to the densities of the particles, this media would be lost and built up within the piping. A mixture of GAC and sand particles would be tricky, media would displace during backwash based on particle size, abrasion, and density which would make it difficult to remove the GAC for reactivation. Similarly, the sand filters are intended to remove particulates and other contaminants before GAC filtration, which would otherwise build up in the GAC media and reduce its efficiency for adsorption.

3. ANALYSIS CRITERIA

The criteria we chose for the alternative analysis were effectiveness, site feasibility, impact on current process, LCRR, waste stream, cost, and industry acceptance. These seven criteria were chosen because they represent all the possible differences that exist between the

technologies, and they are important to the solution of the problem. The criteria themselves and the weight we assigned for each one, were all reviewed and agreed upon with GCWW.

3.1 Effectiveness

Effectiveness was defined as how well the desired treatment technology can remove PFOA and PFOS from the water. The CMBP wishes to have the levels of PFOA and PFOS both at or below 2 ppt. The current mean of PFOS in the source well water is 3.9 ppt and PFOA in the source well water is 3.3 ppt (Appendix 9.2). This means that the minimum percentage of PFAS that needs to be removed is 49%, since PFOS has a higher level detected than PFOA. If a treatment technology has lower than a 49% effective removal rate, then the technology was not considered since it could not achieve the most important goal. The treatment technologies were compared based on their individual effectiveness at removing PFOA and PFOS.

Effectiveness was weighted highest in our alternative analysis because it is the main goal of the presented project. If the treatment technology cannot remove the necessary PFAS, then it is not feasible.

3.2 Site Feasibility

The CMBP is established on a small property with little space to expand. The natural landscape of the property and existing utilities create a situation where a minimal change in the footprint of the plant is optimal and implementing new processes into the treatment facility requires delicate use of space. The analysis of the existing site conditions acknowledged some options for available use. Areas of interest included the west and southwest side of the primary and secondary clarifiers, on either side of the existing parking lot and access road. Ease of access, constructability, operations, and maintenance accessibility were all considered for a new facility. Ultimately, further treatment process upgrades will require areas of available use and minimal required change to existing conditions. The proposed treatment systems would need to be implemented within this area or within the existing site with no footprint expansion, treatment processes with a smaller overall footprint were ranked higher. Thus, considerations of water chemistry changes and requirements for ample treatment were also reviewed. Each of the treatment processes studied was ranked based on their footprint, constructability, and operational and maintenance properties.

3.3 Impact on Current Process

This criterion focused on how the proposed solution interacts with the existing infrastructure at the CMBP. A ranking of 4 indicated that this option had the least effect on the current processes and the rest of the system will largely be unimpacted, the lowest ranking of 1 was

assigned to the alternative that will heavily impact the rest of the process in a negative way, which may require additional systems to be put in place at the CMBP. This could be due to having to adjust the pH of the water, adding additional pretreatment, or having to include additional systems such as re-mineralization after the proposed alternative to meet the water quality standards of GCWW. In addition, if the proposed alternative was able to streamline other processes to make them more efficient, it was given a higher ranking during the alternative analysis process.

3.4 LCRR

The Lead and Copper Rule was initially published by the US EPA in 1991 to control lead and copper in drinking water. Lead and copper often enter drinking water supply due to corrosion of the pipe system that distributes water to communities. The LCRR uses testing to find sources of lead and copper within the distribution system, which triggers actions that help address lead or copper like managing corrosion control treatment or replacing lead service lines. In 2021, US EPA issued Lead and Copper Rule Revisions (LCRR) and further improvements are expected in the coming years to significantly reduce lead and copper levels in drinking water (EPA 2020). To rank the technologies for the LCRR criterion, each treatment technology and waste stream were evaluated for corrosivity and how the technology would function with the addition of orthophosphate and recarbonation to the treatment process. The technologies that were more corrosive and that had challenges with the new additions to the treatment process were ranked lower than those with non-corrosive products that functioned well with the process additions.

3.5 Waste Stream

The waste stream of each treatment technology, including the concentration of waste, for both PFAS and other contaminants within the waste stream were considered. Similarly, the required treatment of waste streams was analyzed. Treatment options included consolidation and destruction of PFAS contaminants through reactivation and incineration processes at above 1000 degrees Celsius, disposal of concentrated contaminants and spent filter media at a hazardous waste landfill, sending the waste stream through supercritical oxidation processes, or recycling the waste through the head of the treatment process. The cost and feasibility of waste stream treatment or disposal was considered in this section.

3.6 Cost

This consideration will factor in the total cost of the project to GCWW including capital costs for construction of the PFAS removal system as well as operational costs once the system is installed. While finalized costs cannot be calculated for each treatment technology with the

preliminary research conducted, costs are estimated based on other drinking water plants who have implemented the technology and published their costs. If this information is not available, then the project team developed theoretical costs estimated from literature research. When possible, costs will be compared on a dollar (USD) per million-gallon value to quantify the differences between alternatives as well as generate an annual expected operating. For the purposes of the decision matrix, the cheapest alternative will be given a ranking of 4 with the most expensive alternative receiving a ranking of 1.

3.7 Industry Acceptance

Industry acceptance is a measure of how well a particular technology is received by industry. It is a combination of what scale the technology has been tested or used at and how long a technology has been used for contaminant removal or destruction. The EPA has identified five stages for the development of wastewater treatment technologies that were loosely applied to the water treatment technologies examined for the purpose of this project. The first stage is research, which applies to technologies in development or that have been tested at the laboratory or bench scale only. The second stage is emerging, which applies to technologies that have been tested at the pilot scale, demonstration scale, or implemented at full scale in three or fewer instances or for less than a year. The third stage is innovation, which is for technologies that have been implemented at full scale for less than five years or have some degree of initial use. The fourth stage is establishment, which is for technologies that have been used at greater than one percent of United States treatment facilities or that have been widely implemented for more than five years. Finally, the last stage is adaptation use, which applies to technologies that have been established for years but haven't been used consistently (Tetra Tech, Inc 2013 and EPA 2013). These five stages as well as reviews of the technologies in the literature were combined to determine industry acceptance. Technologies that have greater industry acceptance received a higher ranking than technologies that had lower industry acceptance.

4. ALTERNATIVE ANALYSIS

An evaluation of the four treatment options was conducted to determine the best option for removing PFOA and PFOS at the CMBP.

4.1 Decision Matrix

The decision matrix for comparing the four alternatives is provided in Table 1.

Table 1: Alternative Analysis for Best Treatment Option

Criteria	Weight	Advanced Oxidation	Reverse Osmosis	Anion Exchange	Granular Activated Carbon
Effectiveness	7	2 (14)	4 (28)	3 (21)	3 (21)
Site Feasibility	6	2 (12)	1 (6)	4 (24)	3 (18)
Impact on Current Process	5	2 (10)	3 (15)	4 (20)	4 (20)
LCRR	4	1 (4)	2 (8)	3 (12)	4 (16)
Waste Stream	3	4 (12)	1 (3)	2 (6)	3 (9)
Cost	2	1 (2)	2 (4)	3 (6)	4 (8)
Industry Acceptance	1	1 (1)	2 (2)	3 (3)	4 (4)
Final Score		55	66	92	96

Maximum Score Possible: 112

4.2 Effectiveness Results

Granular Activated Carbon

The removal efficiency of contaminants such as PFOS and PFOA can be reduced by the co-removal of TOC. Granular activated carbon has a PFAS removal efficiency of greater than 90% when the co-removal requirements are minimized and there is less competition with total organic carbon being adsorbed. An efficiency of 49% on average is required to bring PFAS concentrations down to the advised levels.

Long-chain PFAS are more efficiently removed by GAC adsorption than short-chain or precursor compounds (EPA 2021a). Different properties of GAC allow for different removal efficiencies for TOC, PFAS, and other contaminants. Abrasion, iodine, and molasses numbers are associated with different GAC types. Iodine number is a relative measure of pore size

between 10 and 2 Angstroms. The area on the GAC to adsorb low molecular weight compounds is determined. Similarly, molasses number measures the degree to which larger pore structures can adsorb large molecular weight organic compounds. GAC has a high capacity for PFOS and PFOA removal, however, short-chain can show desorption behavior when in competition with high concentrations of TOC or long-chain PFAS (McCleaf et al. 2017). In practice, the ability of GAC to remove TOC and PFAS compounds drops over operation time due to reduced surface area for adsorption as the contactors back up with contaminants.

Anion Exchange

Resins designed for PFAS removal are generally very effective at removal of PFOA and PFOS reaching removal efficiencies of greater than 90% (Liu et Sun, 2021). However, most studies have not tested PFAS removal at concentrations as low as what's seen at the Bolton treatment plant ranging from 1.4 ppt to 6.6 ppt with an internal treatment goal of 2 ppt. While the treatment efficiency of >90% greatly exceeds the average 49% removal efficiency needed at the Bolton plant, pilot studies will have to be conducted in order to ensure this technology is effective at this target level.

While anion exchange performs well at removing long chain PFAS (C>6), the anion resin struggles to effectively remove short chain PFAS compounds (C<6) (Wang et al. 2020). Since the scope of this project focuses on PFOA (C₈HF₁₅O₂) and PFOS (C₈HF₁₇O₃S) this consideration had a minimal effect in the ranking process. However, if GCWW wishes to treat short chain PFAS in the future another alternative will have to be considered. The overall effectiveness of PFOA and PFOS removal also decreases as the Total Organic Carbon (TOC) concentration increases in the influent water stream because it competes with the adsorption of long chain PFAS (Franke et al. 2021). This should not be a major issue as the GCWW plant is a ground water treatment plant with relatively low levels of total organic carbon generally ranging from 0.37 to 0.87 mg/L for treated water and 0.20 to 1.26 mg/L for well water sampled from 2016 to 2022 (see Appendix 9.1).

Another consideration for the effectiveness of the anion exchange resin was the magnesium concentration of CMBP. With reported concentrations of magnesium ranging from 22 mg/L to 32 mg/L (average 26.6 mg/L), the effectiveness for PFAS removal could be diminished (see appendix 9.1). Magnesium has the ability to cause scaling on ion exchange membranes and affect the pore structure of the resin, decreasing the overall electro-negativity and the effectiveness of the treatment process (Zuo et al. 2013, Deng et al. 2010). The largest effect is typically seen on cation exchange resins as Magnesium is a positively charged ion, with

diminished effects on anion resins (Zuo et al. 2013). CMBP does have the ability to raise the pH in the settling basins high enough to settle out magnesium before going through the plant's sand filters, so the plant could have adjusted the processes needed during pilot scale testing if the alternative was chosen.

Reverse Osmosis

With semipermeable membranes RO removal ranges from to 55-99.3% for PFOA and 93-99% for PFOS (EPA 2021a). RO is more effective at removing larger particles since the process is controlled through the size of the pores in the membrane. PFAS can be long or short-chained, but PFOA and PFOS have long chains and are rigid molecules due to the strength of C-F bonds that lack rotation at the carbon-carbon bonds (Mastropietro et al. 2021). It has been tested that the semipermeable membrane is still able to remove a majority of the PFAS found in water no matter their size. This could come into use in the future if the EPA or CMBP ever needs to lower the levels of short chain PFAS, as RO would be able to reduce the concentrations to non-detectable levels. RO is also effective at removing pesticides, pathogens, and organic contaminants.

Advanced Oxidation

Heterogeneous photocatalysis using TiO_2 as the photocatalyst can reach 100% degradation but this removal depends heavily on the process parameters. For the photocatalyst itself, band gap and surface area affect the percent degradation as well as process parameters such as light source, light intensity, and solution pH. One study showed that TiO_2 alone had a 15% degradation of PFOA in 720 minutes but combining TiO_2 with perchloric acid (HClO_4) increased the degradation to 86% in 420 minutes. Another modification to the photocatalyst is transition metal modification which allowed degradation to reach 100% in 300 minutes when TiO_2 was modified with platinum (Xu et al. 2017).

Ranking

While all the technologies considered exceeded the baseline removal efficiency needed to meet GCWW's goal for PFOS and PFOA removal, the technologies varied greatly when looking at the effectiveness as a treatment technology. A treatment efficiency ranking of 4 was given to the RO alternative for achieving a range of removal efficiency up to 99% for both PFOS and PFOA removal. Following RO, a ranking of 3 was given to GAC and anion exchange as both technologies had a removal capacity of greater than 90% once certain pre-treatment processes are met. Advanced oxidation was deemed to be the least efficient of the

processes considered with a given ranking of 2. While it can meet the same levels of effectiveness as RO in some specific circumstances, the extremely long time to treat and wide band of treatment effectiveness reduced its ranking.

4.3 Site Feasibility Results

All the technologies considered will need a separate space on the CMBP campus for when the system is implemented. During Forefront Consulting's initial site visit, two locations were considered West of the current treatment facility. These locations are not on top of clear wells and do not require significant removal of utilities during construction. The main proposed location is located adjacent to the current primary and secondary basins as there is more space for a given alternative (Figure 5). If CMBP is installing additional treatment systems in the initial proposed location, then a secondary location North of the proposed location would be considered.

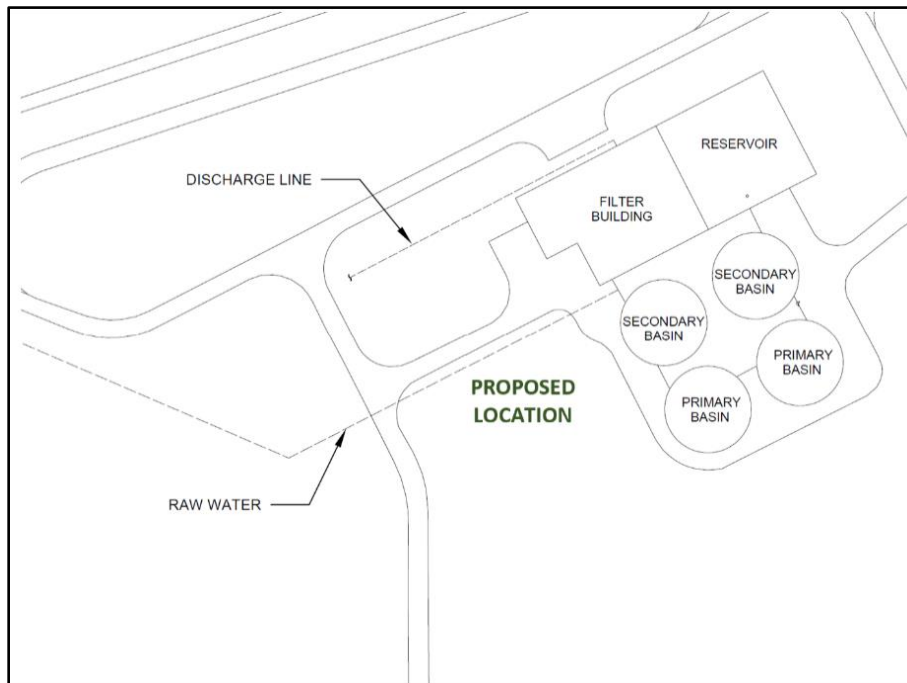


Figure 5 – Proposed facility location at CMBP produced from GCWW standard drawing shown in appendix 9.10.

Granular Activated Carbon

Implementing GAC contactors into the treatment process would require substantial space at the CMBP. GAC contactor size is dependent upon desired treatment capacity, empty bed contact time (EBCT) and site limitations. The GAC contactors would be capable of backwash in-place and would have a recycled stream to the head of the treatment process. GAC

reactivation through incineration would be performed offsite, not requiring the additional construction of an incineration facility at CMBP. However, formidable access to the contact basins would be necessary for maintenance trucking to bring GAC material in and out as needed. The proposed location of the GAC facility is shown below in Figure 6, where access for maintenance is optimal from the parking lot and plant access road.

Dimensions of typical RMTP contactors were provided by GCWW (see Appendix 9.9). The 12 contactors at RMTP are 65' long, 30' wide, and 11.4' deep. Considering the difference in treatment capacity between the RMTP and CMBP facilities, the scale and quantity of contactors will be reduced for CMBP use. An EBCT of 20min with a plant capacity of 40MGD was used for the initial size estimate of the GAC facility. A needed volume of 73,000 ft³ was calculated with a typical contactor for GCWW having a volume of 20,520 ft³. In order to meet the volume needed, 4 contactors would need to be constructed in the proposed location (Figure 6).

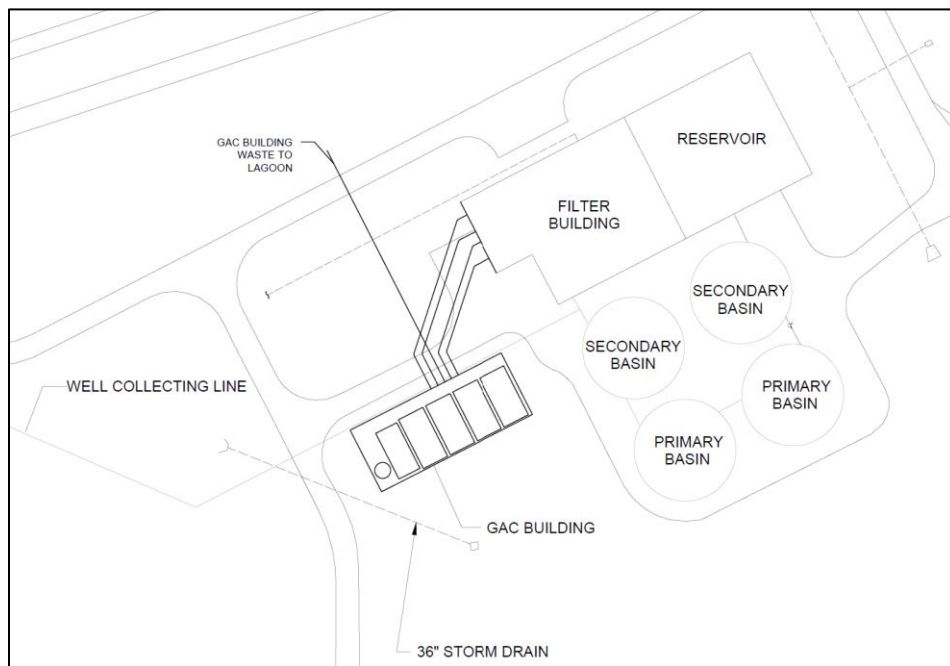
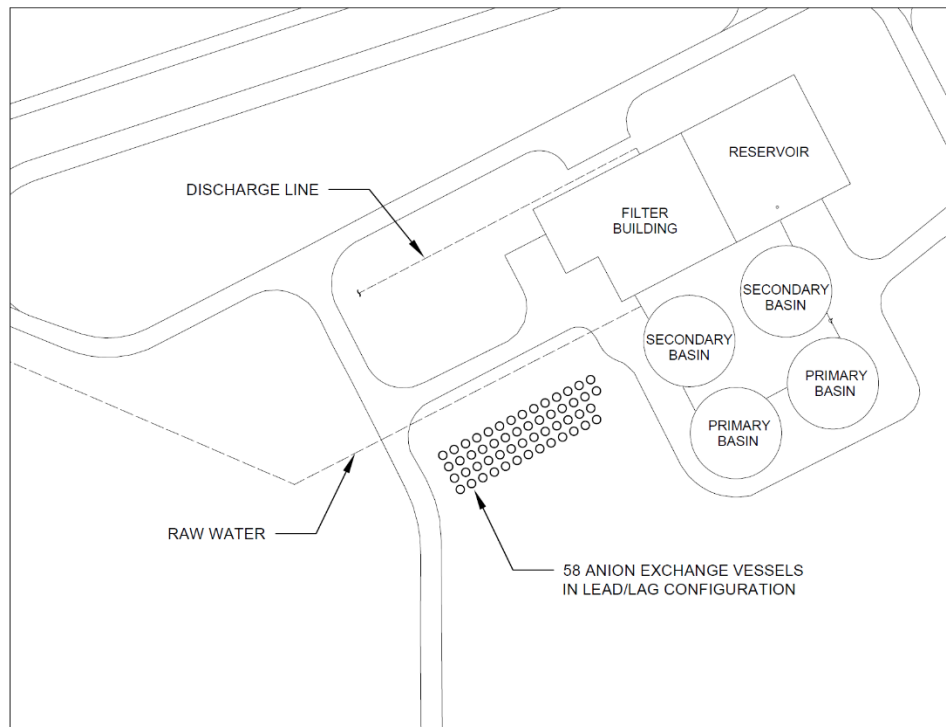


Figure 6 – Proposed GAC facility at CMBP. Approximate size and location. Produced from GCWW standard drawing shown in appendix 9.10.

Anion Exchange

An anion exchange facility was proposed to be constructed to the West of the current primary and secondary basins (Figure 7). Due to the necessity to truck the ion exchange resin in and out once it is fully saturated, the anion exchange reactors should be easy to access from the

road or parking lot of the facility. Due to the reduced EBCT compared to GAC reactors, the footprint of the anion exchange facility would be greatly reduced and would not need significant excavation to install. The Yorba Linda groundwater treatment plant under the Orange County Water District of California (OCWD) is able to treat a minimum of 1.4 MGD of water with each Anion treatment train, consisting of two vessels 12 ft in diameter (OCWD 2021). To meet CMBP targeted capacity of 40 MGD, 29 treatment lead/lag trains will be needed. The approximate size of the vessels on the CMBP property is shown (Figure 7). There is ample space to add in any extra pumps or facilities required for this alternative without being placed on top of any inlet or pump discharge lines. The footprint may change, though, to meet the needs of CMBP working alongside vendors. In addition, it may need to be constructed in a closed building that is climate controlled to better maintain the installed equipment during the harsh Ohio winter months.



**Figure 7 – Proposed anion exchange facility at CMBP. Approximate size and location.
Produced from GCWW standard drawing shown in appendix 9.10.**

Reverse Osmosis

The CMBP would need to install high pressure pumps, a system of RO vessels, a basin to hold the reject water, and a lime saturator. In addition to needing some form of pretreatment before the groundwater enters the RO treatment process (Cornelissen et al. 2021). The current lime

softening and sand filters at CMBP would be used to decrease fouling potential and turbidity in the feed water. Once the feed water goes through RO the recycled water needs to be re-mineralized. Post treatment would consist of the addition of carbon dioxide, limewater, chlorine, and fluoride (El Ahzar et al. 2012). This means that RO must go after sand filtration and there would need to be processes added after treatment to the current site. There is not much space available so the new building with the RO treatment would need to go next to the basins as shown in Figure 5. This would require the current piping network to be rerouted. Then a lime saturator would need to be added to the site so limewater could be produced and mixed with the recycled water to create a water stable enough to distribute. Lime saturators tend to be the size of a clarifier and it may be hard for CMBP to find space for both a RO facility, lime saturator, and a basin to hold the reject water (Dunn 2009).

Advanced Oxidation

While heterogeneous photocatalysis has not been implemented at full scale based on the research found, to implement this treatment at CMBP, the plant would need to install reactors with UV lamps after sand filtration. This facility would be placed as shown in Figure 5 as the proposed location. Chlorination would not be able to occur prior to the photocatalysis treatment so pipes and steps in the process would need to be rerouted and moved to chlorinate the water after. Additionally, the pH would need to be adjusted both before and after the treatment requiring additional equipment and space.

Ranking

Anion exchange was given the ranking of 4 for this decision criterion due to its minimal footprint and ease of installing the pre-built vessels. While GAC was very similar to anion exchange, it was given a lower ranking of 3 due to the slightly larger footprint and the need to excavate the existing stormwater catchment area to accommodate the depth of GAC contactors. While anion exchange and GAC were similar, it was clear that RO and advanced oxidation were significantly less feasible for implementation at the CMBP site. A ranking of 2 was given to RO due to the additional processes and additions needed to make the alternative work and it possesses a larger footprint. The piping system will need to be significantly modified with the addition of additional pumps, filters, lime saturator, and increased electrical service of the plant. Advanced oxidation was given the lowest ranking of 1 due to the solution requiring even more modifications to the plant to adjust the pH to levels needed and the large UV facility that would have to be installed. This is in addition to needing additional electrical services similar to the needs of RO.

4.4 Impact on Current Process Results

Granular Activated Carbon

Generally, granular activated carbon systems are implemented after sand filtration processes and prior to disinfection processes. A PFAS targeted approach to treatment would have the GAC contactors within the process when the conditions of chlorine demand, turbidity, DBPs and hardness are optimal. Removal of organics and PFAS by GAC is affected by water hardness (McCleaf et al. 2017). The lime softening system at CMBP would interfere with the efficiency of GAC due to calcium carbonate blocking the adsorption passages. To avoid premature backwashing and reactivation of GAC, the system would be located after the sand filters. GAC reduces the amount of chlorine required for disinfection, as it removes organic compounds and DBP precursors. However, some chlorine is required before the sand filters, to reduce buildup and extend their usable life. Figure 8 provides the treatment schematic proposed for GAC. After GAC treatment, chlorination and fluoridation for distribution can occur. Removal of organic compounds by GAC is reduced when pH values of the water are higher. The average total organic carbon (TOC) levels at the influent of the CMBP were 0.70 mg/L, and after the existing treatment process, TOC was measured at an average of 0.58 mg/L. GAC contactors would further reduce the TOC levels of the treated water as well as perform the targeted PFAS removal. While TOC and PFAS compounds compete for adsorption with GAC, the TOC levels of the raw well water are low compared to other source waters.

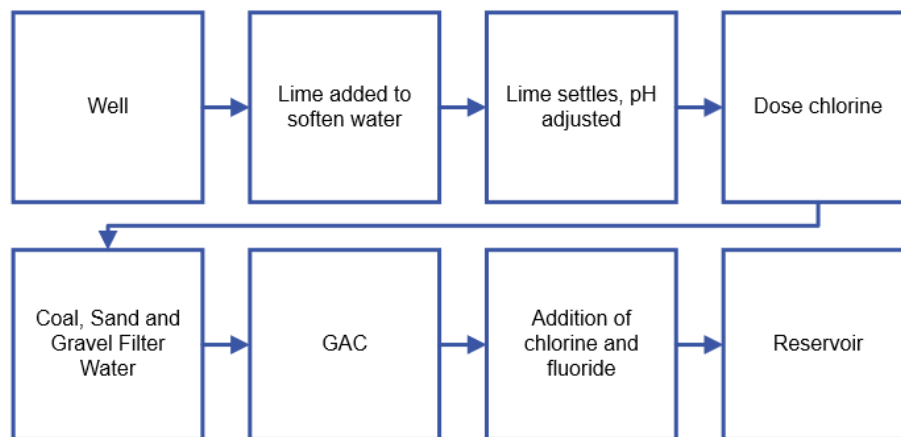


Figure 8: Proposed process for GAC

Mechanically, GAC contactors would affect head loss throughout the treatment process, where finer particles of GAC will give the best removal efficiency of PFAS and TOC compounds, increasing head loss while reducing EBCT. The backwash of the contactors will need occur and the waste will be routed to the existing lagoon.

Anion Exchange

The proposed Ion exchange facility would be added in the existing treatment process at the Bolton plant after the sand filtration (Figure 9). At this point, the total number of dissolved solids in the influent will be at a minimum, while PFOA & PFOS is still present at around the same levels as from the well water. This will maximize the life span of the anion exchange resin and increase PFAS removal as there is less competition from other dissolved solids on the adsorption site. As it will be added at the end of the process, the current softening and filtration process will remain unchanged. However, slight changes in the fluoridation, corrosion control, and chlorination process may be needed after the anion exchange resin so added chemicals are not removed by the anion resin. In addition to the processes' effect on the LCRR described below.

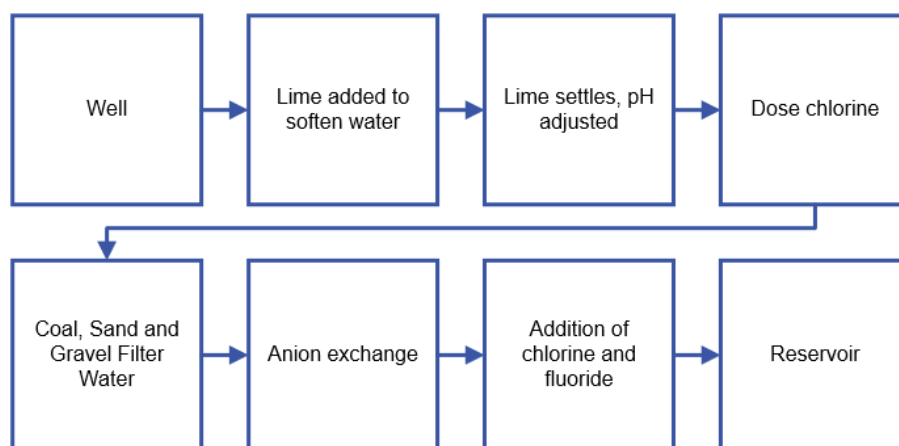


Figure 9: Proposed process for anion exchange

Reverse Osmosis

Before the feed water goes through RO the CMBP would need to use the current lime softening and sand filtration as a pretreatment process. This will remove solids and some contaminants before the tightly wound membranes can become fouled. The turbidity before RO needs to be below 1 NTU (Cornelissen et al. 2021). After sand filtration the turbidity will be below this level (Appendix 9.1). The maximum raw water turbidity at CMBP is 0.25 NTU and should be below this level after the lime softening process moves through the sand filters. The reason that RO cannot be put before the lime softening step is because there needs to be some sort of prior filtration before RO to remove contaminants. This will increase the efficiency of the RO vessels and reduce fouling in the semipermeable membrane. Most of the impact to the process will occur after RO happens (Figure 10).

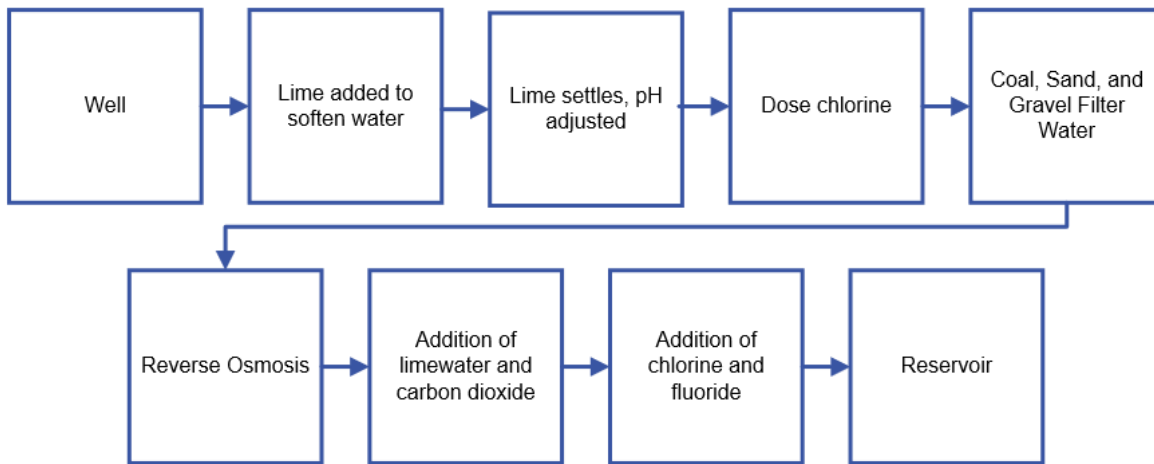


Figure 10: Proposed process for RO

The recycled water must be re-mineralized, so corrosion does not happen. RO effluent typically has a pH of 5-6 while the CMBP distributed water currently can't go lower than a pH of 8.8, as reported by GCWW. The most widely used post treatment process for recycled water is the application of carbon dioxide and excess hydrated lime (El Azhar et al. 2012). This will dose the water with calcium and bicarbonate at an equivalent ratio of 1:1. The disadvantage of this is that lime does not dissolve easily and has the potential to increase the turbidity to 5 NTU (Shemer et al. 2015). Hydrated lime will need to be fed into a lime saturator as lime slurry. The limewater created by the lime saturator is mixed with the recycled water then carbon dioxide is injected after the limewater (Shemer et al. 2015). The addition of fluoride and chlorine will need to be added after the RO process as well since the semipermeable membrane will extract these types of ions.

Advanced Oxidation

The photocatalysis process would require several changes to the current CMBP treatment process. Photocatalysis would need to take place after sand filtration because turbidity in the feed to the photocatalysis reaction should be low and not exceed 5 NTU (Bodzek and Rajca 2012). The provided data from CMBP indicates that the maximum turbidity in the source well water is 0.25 NTU and the maximum turbidity in the treated water is 0.28 NTU. While these values aren't near levels of 5 NTU, it is still recommended that the photocatalysis be implemented after the sand filters. Additionally, the chlorination step in CMBP's current treatment process would need to be moved to the very last step. Chlorine ions have been found to decrease the photocatalytic reaction efficiency because they have a screening effect of UV rays, create adsorption competition, and have direct interaction with the photocatalyst making it difficult for PFAS compounds to interact and be degraded (Bodzek and Rajca 2012).

Chlorination would have to be moved to after photocatalysis. The updated treatment process is shown in Figure 11.

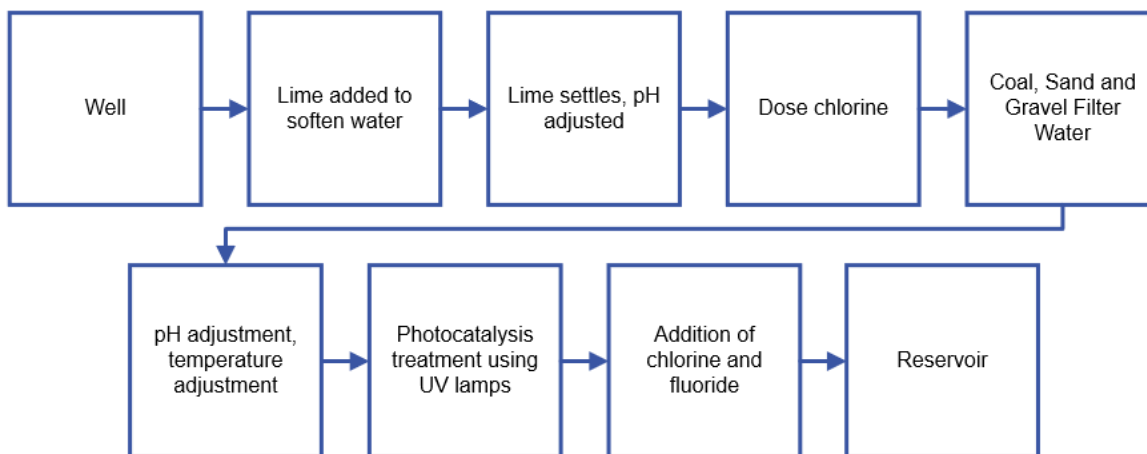


Figure 11: Proposed process for advanced oxidation

The photodecomposition of PFAS compounds also depends on the light source, reaction temperature, solution pH and dissolved oxygen. For a TiO_2 photocatalyst, the use of ultraviolet A (UVA 315-400 nm) is best. Current research suggests that higher solution temperatures appear to enable better degradation of PFAS compounds and decreased reaction times which is important to maintain an efficient rate through the treatment process. Additionally, lower solution pH results in positive surface charges of TiO_2 and creates the optimal environment for interactions between PFAS and TiO_2 (Xu et al. 2017). Acidic conditions are favorable for the photocatalysis process to take place which would require a decrease in pH of the water in the system.

Ranking

Due to having a very similar effect on the current processes as GAC, anion exchange was given the same ranking of 4. All treatment technologies will need to be placed after the sand filters to remove some ions and increase the efficiency of the PFAS removal treatment technology. RO requires the pH of the effluent water to be adjusted and re-mineralized after going through the process. Although the current chlorination and fluoridation process will need to be moved with anion exchange and GAC alternatives, the mineralization process is significantly more intensive for RO which is why it was ranked a 3. Advanced oxidation does not need more corrosion control post treatment, but it needs to have an extremely low pH prior, which will impact the current processes. Advanced oxidation received a ranking of 2 because it could be detrimental for the plant to have such a low pH during treatment.

4.5 LCRR Results

Granular Activated Carbon

Many contaminants are removed by GAC, including lead and copper. Variables affecting the adsorption of these heavy metals include the bed height of the GAC contactor, the EBCT, and the competition with other contaminants that GAC is removing (Sulaymon et al. 2009). Faster breakthroughs of these contaminants, when treated with GAC, are seen with higher flow rates and higher concentrations. The pH value of solutions was found to be the biggest factor for the adsorption of these metals, along with the competition for adsorption. It is determined that the lowest optimum pH for the removal of copper and lead is a pH of 4 to maximize adsorption (Netzer et al. 1984). GAC does not provide any lasting effect for the remainder of the treatment process or distribution systems against these contaminants. GAC does interact with the chlorine dosing procedures, but chlorination after GAC treatment will require readjustment corrosion control measures for discharge without hindering adsorption efficiency of GAC.

Anion Exchange

Anion exchange can have a sizable impact on the chloride-to-sulfate mass ratio (CSMR) as well as the lead corrosion potential when implemented in a drinking water system. CSMR is generally used as an indicator for the corrosivity of water, as the concentration of chlorine increases in relation to the concentration of sulfate, the galvanic corrosion between copper and lead increases (Willson et Boyer 2011). When implemented, anion exchange resins replace a stoichiometric amount of chloride for sulfate, organic matter, and other anions in the drinking water (Willson et Boyer 2011). Therefore, potentially increasing the CSMR ratio and rate of lead leaching, if implemented at the CMBP. However, the effect on corrosivity is dependent on absolute concentrations of chloride and sulfate, not just their relative amounts. With the CMBP generally benefiting from having sulfate levels ranging around 42 mg/L to 55 mg/L from well water samples taken from 2016 to 2022 (see appendix 9.1). This is slightly above the median level the EPA has determined to be at 24 mg/L, helping to keep sulfates higher in the CSMR ratio (EPA 2003). As GCWW is considering re-carbonization and PO₄ additions to the current treatment process, these LCRR affects from implementing an anion exchange solution can be easily adjusted as the process is implemented to meet the necessary levels of corrosion control.

Reverse Osmosis

Once the feed water goes through RO it has a low pH of between 5-6 and has a low alkalinity (OSMO SISTEMI 2020). The semipermeable membrane will remove most of the ions from the water leaving the recycled water in a harsh state. These factors can contribute to corrosive water and when in contact with aged pipes would cause the dissolution of carbonates and oxides (Mastropietro et al. 2021). To avoid this the recycled water must be re-mineralized by adding limewater and adjusting the pH. A lime saturator would need to be installed to create limewater which is mixed with the recycled water to re-mineralize (Shemer et al. 2015). Then to decrease the pH, carbon dioxide must be added before distribution.

Advanced Oxidation

The heterogeneous photocatalysis process requires an acidic solution pH to effectively remove PFAS compounds. The process degrades PFAS compounds and does not produce a toxic waste stream, however, coming out of the reaction the pH of the treated water will still be acidic. Acidic water is corrosive and can cause lead and copper to enter the water supply if it leaves the plant. The pH would need to be increased after the photocatalysis process to prevent corrosion in the system. Looking at the process itself, it would have a negative impact on the LCRR and would require additional steps to meet regulations.

Ranking

GAC was given a ranking of 4 due to the technology having no significant change in the effluent CSMR or pH of the water. Anion exchange was shown to have the potential to change the CSMR of the effluent water making it slightly more corrosive, and therefore ranking below GAC with a ranking of 3. RO was decided as the third worst with a ranking of 2, since most of the ions are removed and the pH is between 5-6. There is an intensive process for post treatment to create noncorrosive water with RO. For advanced oxidation there are no chemicals that add to the corrosivity of the water, but the pH prior to the process would have to be very acidic for the technology to be effective. Therefore, advanced oxidation received a ranking of 1, with the pH so low it could be a hazard to only increase it after treatment without any contingency if things go wrong.

4.6 Waste Stream Results

Granular Activated Carbon

The waste stream produced by GAC use includes the backwash of the contactors. This waste stream can be sent to the lagoon as it is composed of bound-up solids and particles that were absorbed by the GAC and will not include PFAS or TOC that has been adsorbed. Blowers and reverse flow, similar to sand filter backwash will be used for the backwash process. PFAS and TOC waste is disposed of through incineration of the GAC media. Incineration processes must be carried out at temperatures greater than 1000 degrees C to destroy PFAS compounds. New GAC must be added to the media after reactivation due to some product being lost during the process. About 20% virgin media is added to the beds after reactivation occurs. AWWA Standard B605-13 breaks down the requirements of reactivation processes for water treatment.

Anion Exchange

The three most popular gel resins used for PFAS removal are not recommended by the manufacturer to be reactivated after use if it is treating for PFAS (Resin Tech Inc. 2020, Dupont 2020, Purolite 2022a). The saturated gel resin could either be incinerated or disposed of in a hazardous waste landfill. This poses a significant operating cost to GCWW to haul and properly dispose of the PFAS containing resin as the organization is responsible for any hazardous waste created. Due to the liability implications of transporting and storing a lifetime pollutant in a landfill, most municipalities will opt to incinerate the saturated resin instead. Depending on the chosen resin and concentration of contaminants, an incinerator would need to be constructed or contracted that is able to reach temperatures possibly as high as 2000 °C to fully dispose of contaminants from pilot scale testing (Dixit 2020). However, depending on lime concentrations and the final composition of the saturated resin, a lower incineration temperature ranging from 650 °C to 2000 °C could be used reducing cost and energy needed to dispose of the saturated resin (Dastgheib et al. 2021). The resin can last anywhere from 12 to 24 months before it is saturated depending on the lead lag configuration, making incineration and replacement infrequent occurrence for the plant (OCWD 2021). CMBP could store saturated resin to be incinerated in one large batch, or stagger the adsorption tank's replacement times to continually be incinerating small batches of the spent resin.

There is no backwash needed during the operation of the resin unless there are concerns of air pockets forming in the resin bed when being newly installed (OCWD 2021). In this instance Purolite, a popular resin manufacturer, recommends backwashing for 10-15 minutes resulting in a waste stream that could be recycled to the start of the plant (Purolite 2022b).

Reverse Osmosis

After RO about 20% of the feed water becomes reject water, this could have an impact on the amount of water CMBP distributes (EPA n.d.). The reject water is highly concentrated with PFAS after RO since it is only a separation technology not destructive. There isn't a current solution that is viewed as an effective way to destroy the PFAS from the reject water. The reject water concentrated with PFAS could potentially be transported to a hazardous waste landfill. This can be costly to transport and is not sustainable, while also putting liability on CMBP for handling hazardous waste. The other option is to invest in supercritical oxidation techniques. These types of equipment rapidly breakdown compounds that don't oxidize readily at standard temperatures and pressures. Supercritical oxidation could be expensive and take up more space at CMBP (Battelle 2022).

Advanced Oxidation

Heterogeneous photocatalysis breaks down contaminants which eliminates the presence of a highly concentrated waste stream after the reaction takes place. The process breaks down contaminants to their by-products and mineralizes to carbon dioxide and water. For PFAS degradation using TiO_2 as the photocatalyst, long chain PFAS compounds are broken down into shorter chain compounds.

Ranking

Advanced oxidation processes produce almost no waste stream and was thus ranked a 4. The breakdown of contaminants is optimal for the reduction of a waste stream. Granular activated carbon was ranked a 3 due to the feasibility of contactor backwash and the existing disposal facilities of GCWW, including the existing incineration facilities and contracts for purchasing new GAC to supplement the 10-20% media loss during reactivation. Anion exchange procedures have a waste of highly concentrated filter media cells that must be disposed of in a hazardous waste landfill or be incinerated, posing further operating costs for CMBP. The consideration of waste stream was ranked 2 for the anion exchange process. The waste products of RO were ranked 1 due to the highly concentrated stream of PFAS and the fouling of up to 20% of the feed water.

4.7 Cost Results

Granular Activated Carbon

Generally, a GAC facility is the lowest cost treatment system for PFAS removal. In use at the RMTP, GAC media is reactivated for about \$110,000 per contactor per regeneration. A GCWW estimate for the cost of GAC is \$2380/ton. A breakdown of RMTP O&M costs was provided by GCWW as a basis for estimating CMBP expenses (Appendix 9.3). Other associated costs with this treatment method include freight costs for regeneration, where trucking GAC media to and from RMTP for reactivation is required. Estimated O&M costs are around \$350,000 annually for regenerations and around \$60,000 for virgin media annually. Similarly, new GAC media addition with each reactivation will be necessary as mentioned above. O&M expenses at RMTP would also increase due to the additional GAC media from CMBP being reactivated at their facility.

The initial supply of GAC is estimated from the RMTP data, where the 12 deep bed GAC contactors required \$4.5 million in media. Scaling this down for CMBP, the media is estimated to cost between \$1-2 million. The construction of a new GAC facility would be reduced due to the proposed location requiring minimal change to the existing structures, and only the need for changing process piping routes to accommodate a new GAC building. The use of GAC will incorporate further O&M costs regarding power to due the increased power. There will be head loss associated with GAC contactors that will increase pump use within the treatment process.

Anion Exchange

An anion exchange facility will have a similar design and construction to a GAC facility, however, the key difference lies in factors such as different EBCT, tanks volumes, and retention times. Changing the size and scope of the constructed facility's overall cost. These cost items will be calculated thoroughly if this alternative is chosen for the design phase.

Depending on the type of adsorbent chosen and the distributor's cost to the municipality, the operational costs of anion exchange can vary greatly (Franke et al. 2021). Similar to how GAC needs to be hauled to be incinerated, saturated resin will need to be hauled away and new resin will have to be hauled into the site. However, anion exchange poses an additional operating expense when all new anion resins need to be purchased instead of being reactivated. The saturated resin needs to be disposed of in a hazardous waste landfill or incinerated and all new resin needs to be purchased. Increasing the estimated operating cost to be above GAC in this analysis.

A very preliminary cost could be estimated from the Orange County Water District Yorba Linda Drinking Water Treatment Plant. A 19 MGD ground water treatment plant that is currently treating for PFAS in their water supply using anion exchange vessels. When installing the treatment in 2021, the plant budgeted \$27 million USD for the total capital budget with an operations and maintenance budget of \$150/Acre-ft (\$460.33 per one million gallons) (OCWD 2021). Assuming that capital costs scale linearly to the MGD of a given plant, an anion exchange facility at the Bolton plant would have an estimated capital cost of 54 million USD. With the Bolton plant operating at about 12 MGD over the course of a full calendar year, the annual operating cost can be estimated at 2.02 million USD.

Reverse Osmosis

Due to the high-pressure pumps necessary to complete RO, there is a large energy cost associated with the treatment technology. A plant in Sydney uses 9,673 MWh of electricity for every million liters produced, as it treats 60 million liters per day on average (Sydney Water 2022). This can be compared to CMBP because 60 million liters/day is around 15 MGD and CMBP produces an average capacity close to that. So, CMBP can expect to use around 9,673 kWh/m³ a day when operating the plant. A research article on RO reports that the cost per cubic meter for a brackish water treatment plant using RO has a fixed charge of \$0.18/m³, energy \$0.056/m³, membrane replacement \$0.02/m³, water cost \$0.344/m³ with a capacity of 45,455 m³/day (Wenten and Khoiruddin 2016). The calculated cost is \$27,273 m³/day or 9.9 million annually at 12 MGD. There was a new RO plant designed in Alabama that costs 30 million to install and \$1 million dollars to operate annually (Stoiber et al. 2020). The brackish water treatment plant and the new treatment plant in Alabama both have a capacity comparable to CMBP. While the annual costs are significantly different, the difference could be due to the type of water being treated, location, the current market, and what is included in individual pricing.

Advanced Oxidation

Very few cost estimates exist for implementing heterogeneous photocatalysis due to the difficulties of scaling-up the technology to a full-size plant. Literature values based on bench scale studies estimate the energy and cost needed for 80% removal to be 2106 kWh/m³ and \$295/m³; however, this cost estimate is for indium oxide photocatalysts. This translates to a cost over \$1 per gallon of water treated (Leonello et al. 2021). In addition, pretreatment and post treatment systems would need to be installed further increasing the cost of the proposed treatment.

Ranking

With an estimated annual operating cost of less than \$500,000 and the lowest estimated construction, GAC was deemed to be the cheapest alternative for both capital and operating costs receiving a ranking of 4. Anion exchange came in as the second cheapest alternative considered for PFAS removal receiving a ranking of 3. Based on costs from a recently completed project, the technology is estimated to have a capital cost of \$54 million with an annual operating cost of \$2.02 million. RO had a significantly more expensive estimate of \$9.9 million as an annual operating cost. This estimate mostly includes the energy needed to operate the system but does not include the operational cost of the needed secondary treatment systems to perform remineralization. The lowest ranked alternative was advanced oxidation with an estimated literature cost being over \$1/gallon. Advanced oxidation was deemed to be orders of magnitude more expensive than any of the other alternatives considered. Therefore, this alternative was given the lowest ranking of 1 during the alternative analysis process.

4.8 Industry Acceptance Results

Granular Activated Carbon

Granular activated carbon is a widely accepted treatment technology within the water treatment industry for its many desirable qualities including PFAS removal. Familiarity of GAC processes by GCWW were considered throughout research. PFAS removal through GAC is effective with up to a 99% removal rate and includes additional contaminant treatment. The simplicity and hands-off approach to GAC filtration is why these systems are so common for TOC and other contaminant adsorption as well as the recent growth of PFAS removal. The Orange County Water District in California is one example of successful PFAS-targeting treatment using GAC in a municipal water treatment setting (Jacobs and OCWD 2021).

Anion Exchange

While not as widely used as GAC, anion exchange is one of the most popular ways to treat drinking water for PFAS and highly recommended by the US EPA for this purpose (EPA 2021b). This treatment method for PFAS removal is a widely accepted method for treatment as large municipalities have already been utilizing the technology. Currently, the largest anion exchange treating for PFAS using an anion exchange resin is the Yorba Linda treatment plant in Orange County, California with a maximum capacity of 19 MGD (OCWD 2022). With a capacity of 40 MGD, CMBP would be double the size of the Yorba Linda plant, the largest

anion exchange drinking water plant in North America. This could pose implementation and design problems unique to CMBP as a plant of this size has not yet been constructed. Contractors such as Evoqua and AqueoUS vets currently make these systems and would be consulted for quotes if this alternative is chosen.

Reverse Osmosis

Currently, RO is mainly used for the purpose of desalinating seawater. It has not been widely used to remove PFAS but there has been research done and some treatment plants testing this removal process. It is difficult to integrate RO into an already existing treatment plant. This means water treatment plants that are already in use tend to find treatment technologies that can be easily added to the existing process.

Advanced Oxidation

Based on the EPA developmental stages for water treatment, photocatalytic processes for pollutant removal are classified as emerging technologies. Most advanced oxidation technologies have only been tested on the bench scale, so they are in the preliminary stages (Loeb et al. 2019). For heterogeneous photocatalysis, information on PFAS removal and the practical applications and limitations of the process is limited. Further research is needed to prove advanced oxidation technologies effectiveness for PFAS removal.

Ranking

GAC was ranked 4 because it is a commonly used or more established form of treatment and GCWW is familiar with the GAC process and maintenance. Anion exchange was ranked 3 because it is more widely accepted than both RO and advanced oxidation. RO was ranked 2 because the process itself is more frequently used for water treatment but it has not been specifically used for PFAS removal. Advanced oxidation was ranked 1 because it is the least accepted treatment method and has not been implemented larger than a bench scale for PFAS degradation.

5. RECOMMENDATION

Forefront Consulting recommends the use of GAC at the CMBP to remove PFOA and PFOS compounds from the water. From the alternative analysis, GAC had the highest score of 96 out of 112 possible points. Anion exchange was close behind with a score of 92 but ultimately, GAC scored higher for cost and industry acceptance. GCWW is familiar with the use of GAC because of its implementation at the RMTP. An advantage of GAC is that the CMBP would be

able to use the incinerator at the RMTP to regenerate the carbon. This would eliminate the additional capital cost to build an incinerator onsite. The main change needed to be made to the current process is adding chlorine and fluoride after the GAC treatment, rather than before the sand filters. This change was the same for all treatment alternatives due to higher concentrations of chlorine ions impacting the effectiveness of each technology. Adding GAC at the CMBP would require the addition of four, 65' x 30' x 11.4' contactors given the design specification of a 20-minute EBCT. While this is a major investment for the plant, Forefront Consulting believes that GAC is the best treatment technology to reduce the levels of PFOA and PFOS to GCWW's desired concentrations.

6. DESIGN

Utilizing this recommendation, Forefront consulting produced a preliminary design for the addition of GAC to CMBP. For the design, all existing site information was gathered through multiple site visits, meeting with Cheri Woody, and referencing the Charles M. Bolton Treatment Plant & Pump Station drawing set prepared by Black & Veatch Consulting Engineers, sealed on November 30th, 1973. In addition, the scope of the capstone design only covered the initial process mechanics of the treatment process. Electrical, control systems, civil, mechanical, and other necessary designs for construction of the project were not in the scope of the capstone project.

The current design at the CMBP consists of several wells, two primary clarifiers, two secondary clarifiers, eight dual media sand filters, two clearwells and a reservoir. The treatment process starts with pulling water from the Great Miami Aquifer through wells. Lime is then added to this water to soften it in the primary clarifiers and then goes to the secondary clarifiers for additional settling of solids. After the clarifiers, water is routed to the dual media sand filters. Once the water runs through the sand filters, it enters the clearwells and then goes to the reservoir for distribution.

To add GAC to the current layout and treatment process at the CMBP, a new building will need to be constructed to house the GAC contactors. New piping will also need to be added to connect treatment in the current facility to the new GAC building in both the sand filter room basement and yard piping spanning the distance to the new building.

6.1 Treatment Process

The treatment process that we are proposing will introduce GAC to the current process at the CMBP. Everything will remain mostly the same with adjustments occurring after the secondary

contact basins. Currently, after settling, chlorine and fluoride are added to the water. While these are required and necessary additions to the water, chlorine will need to be added after the water passes through the GAC contactors as well. This is because chlorine will adsorb onto the carbon more easily than PFAS compounds, therefore outcompeting the harmful compounds and reducing the effectiveness of the GAC. The chlorine will be removed from the water and need to be added again after the GAC even if PFAS wasn't a concern. To determine the exact dosing of chlorine before the sand filters to reduce manganese in the water, CMBP will conduct pilot studies utilizing Rapid Small Sample Carbon Testing (RSSCT) techniques (Woody 2023). GCWW possesses the capability to perform these trials in house.

The water will pass through the dual media filters but rather than entering the clearwell, the water will be routed from each of the dual media filters into one large collection pipe. This pipe will split into two separate pipes, each equipped with a 20 MGD pump that will pump the water to the GAC filters and provide redundancy for the system. The water will pass through the GAC filters with an EBCT of 20 minutes and drain to one of two outlet pipes. These outlet pipes will route the water to the clearwells.

Currently, after the clearwells there is a chlorine feed location where chlorine can be added as needed. We would like to make this the primary location where chlorine is added into the water. This chlorine will be added right before the water enters the reservoir and then water will enter the reservoir for distribution as normal. Even though CMBP is regulated based off a Ground Water Rule Triggered Monitoring, the plant prefers to operate as if they're abiding by chlorine contact time with the existing system being constructed to meet this requirement. This means that there is enough existing baffling in the reservoir to properly mix the chlorine being added in the reservoir (Woody 2023).

6.2 Site Layout

Overview of Existing Site

The current CMBP site layout is included in Figure 5 which also shows the proposed location of the new GAC treatment facility. The CMBP is located on River Road in Fairfield, Ohio. The existing site is relatively flat with only minor changes in elevation. At grade, the elevation is 575 feet which was obtained from the Black and Veatch drawing set from 1973. Four clarifiers sit behind the plant's filter building and are used for primary and secondary settling. The addition of chemicals, dual media filters, and the clearwells are located in the main building. The reservoir sits underground adjacent to the filter building.

New Building Location

The new GAC building will be located adjacent to the road onsite, shown in Figure 6. During the preliminary design process, the team investigated whether this location was classified as a wetland due to it being saturated often. The Soil and Water Conservation District in Butler County verified that the location was not a wetland and therefore no additional approvals were required (2023). A summary of the report's findings is located in Appendix 9.5.

At this location, there is an existing 36" storm drain that will need to be relocated once construction of the GAC facility begins. While finding a new location for the storm drain was out of scope, the team suggests moving it around the same area of land at a low point so that the stormwater still reaches the drain.

Hydraulic Grade Line

The existing hydraulic grade line (HGL) profile was provided by GCWW. Since the current process flow will change at CMBP, an adjustment was made to the HGL. The GAC building will be added to the plant layout which makes the head of the plant go from nine at the sand filters, to thirteen at the GAC, then back down to six at the clearwells as seen in Figure 12. Due to the increase in elevation and pressure head from the sand filters to the GAC building, it was evident the use of pumps will be necessary to reach the GAC building. Then from the GAC building to the clearwells the head is decreasing, and gravity pipe flow will be sufficient.

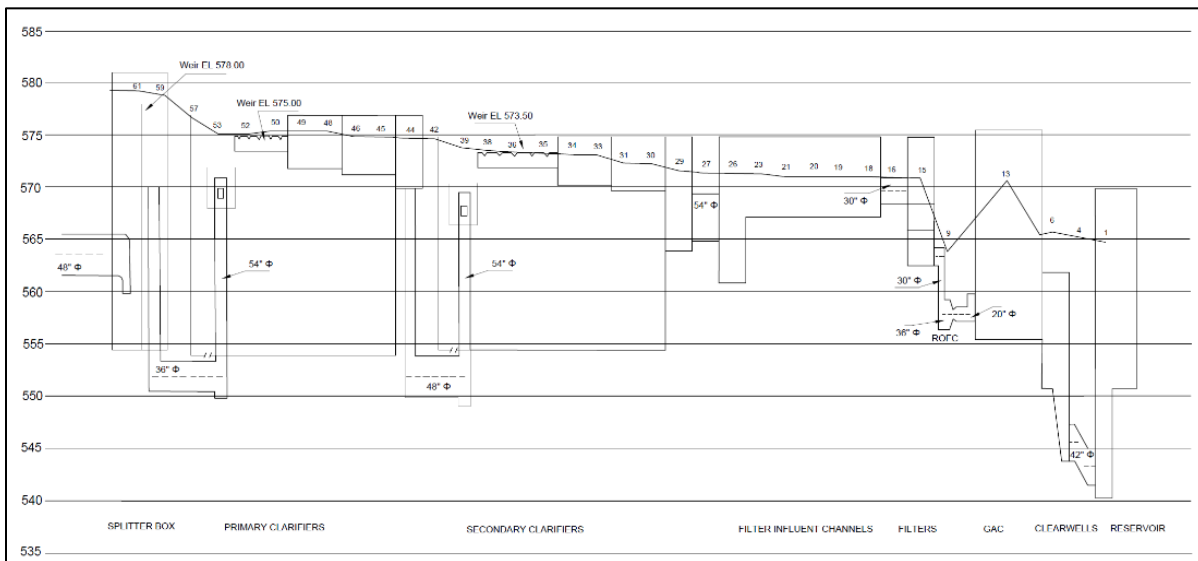


Figure 12: Hydraulic Grade Line with GAC Forefront Consulting Drawing Set Page 19, Appendix 9.6

6.3 Filter Basement

Since the CMBP is a fully constructed and operating plant, the addition of a GAC facility meant that connections would have to be made to the existing process, requiring minimal impact to reduce any downtime of the plant. Once the original Process & Instrumentation Diagrams (P&IDs) of the plant were analyzed, it was determined that the tie-in should be located after the sand filters, but directly before the water enters the clear wells. The existing piping for each sand filter is shown in Figure 13. Refer to page 7 of the Forefront Consulting drawing set in Appendix 9.6 to see the existing filter basement P&ID.

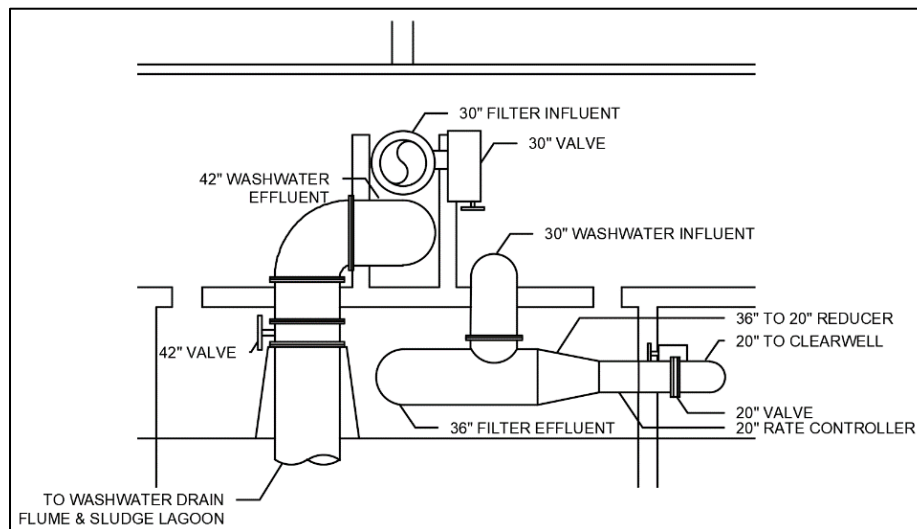


Figure 13: Existing Sand Filter Piping Forefront Consulting Drawing Set Page 19, Appendix 9.6, Reproduced From Black and Veatch (1973)

It was determined that new piping will be installed directly on the sand filter effluent line, before the pipe goes into the clear well influent, with a valve added in to allow easy bypassing of the GAC facility if needed. This design was chosen because any modifications to the clear wells would require extensive concrete and structural modifications to the filter building, in addition to modifying the current reservoir system. This design method will allow the filters to remain operational for as long as possible during the construction phase of the project, as well as being able to smoothly place new pumps and piping in the space between the two symmetrical sets of sand filters. Each sand filter effluent line will be modified to have a pipe teeing off of it into one large GAC influent pipe running down the center of the filter basement. This large pipe will then feed the pumps that will provide the treatment water for the GAC facility. Once the water has passed through the GAC facility, it will enter the respective north and south

clearwells through the west side of the filter building (Figure 14). Refer to page 8 of the Forefront Consulting drawing set to see the modified filter basement P&ID in Appendix 9.6.

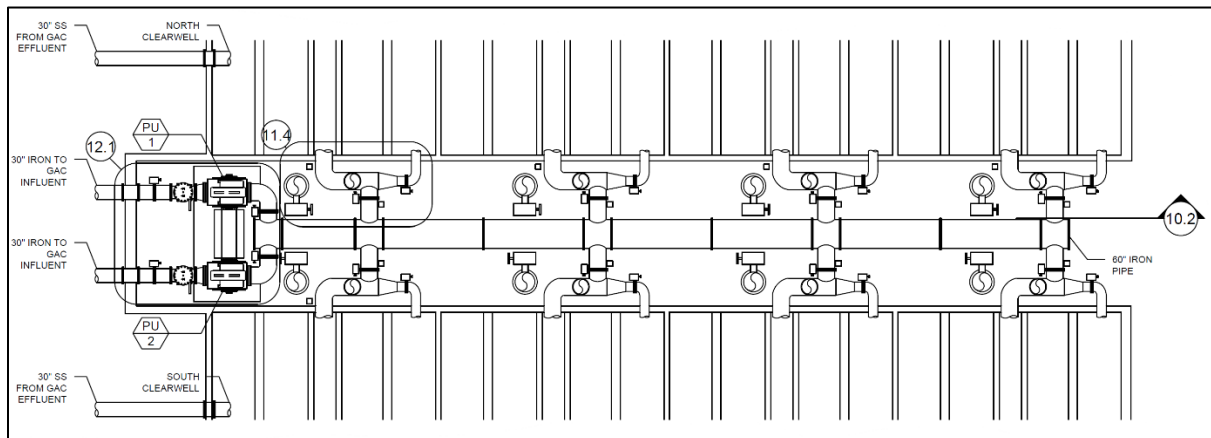


Figure 14: Modified Clearwell Basement From Forefront Consulting Drawing Set Page 9, Appendix 9.6

Pipe sizing

Several new pipes will need to be added to transport water to and from the GAC facility. The first new pipe added will collect the sand filter effluent before it enters the clearwells. Each existing sand filter effluent line will have a tee that allows water to enter the larger pipe in the center of the filter basement. This pipe will collect water from all sand filters and therefore must meet the plant's maximum flow capacity of 40 MGD. We sized the tees to fit to the current 36" sand filter effluent pipe and used Bernoulli's equation to determine the diameter of the new pipe. The equations and assumptions used to solve for the pipe diameter are included in Appendix 9.7. The new pipe diameter was determined to be 60" and because the water has not been filtered by GAC at this point in the process, the pipe will be made of ductile iron. This pipe will end with a cross that will send the water through two redundant pumps.

It was determined that two pipes would be needed to transport water to the new GAC facility to introduce redundancy to the process. One pump for each pipe is required because the GAC contactors are at a higher elevation. Each pump and pipe must be able to handle half of the plant's maximum flow capacity, which equates to 20 MGD. Bernoulli's equation was used again to determine the necessary pumping head and pipe diameters. The starting point for the calculation was the pump and the ending location was where the GAC effluent enters the clearwell. It was assumed that each pump and pipe would be nearly identical and the results for the calculation would apply to both loops, with the most hydraulically remote path being chosen for the length calculations. The specifics of the calculations are included in Appendix

9.7. The pipe diameter for each pipe was determined to be 30" and the necessary pumping head for each pump was found to be 14 ft.

Pumps

With a maximum duty point of 20 MGD and 14 ft of pressure, two Flyght 24x24x36 NSY Model 150 pumps were selected to be placed in the filter building basement to feed influent water to the GAC building. The pump curve for each pump is shown in Figure 15 for the pump being driven at 396RPM from a Variable Frequency Drive (VFD) needing 70 HP, with the quote for the pumps in Appendix 9.8.

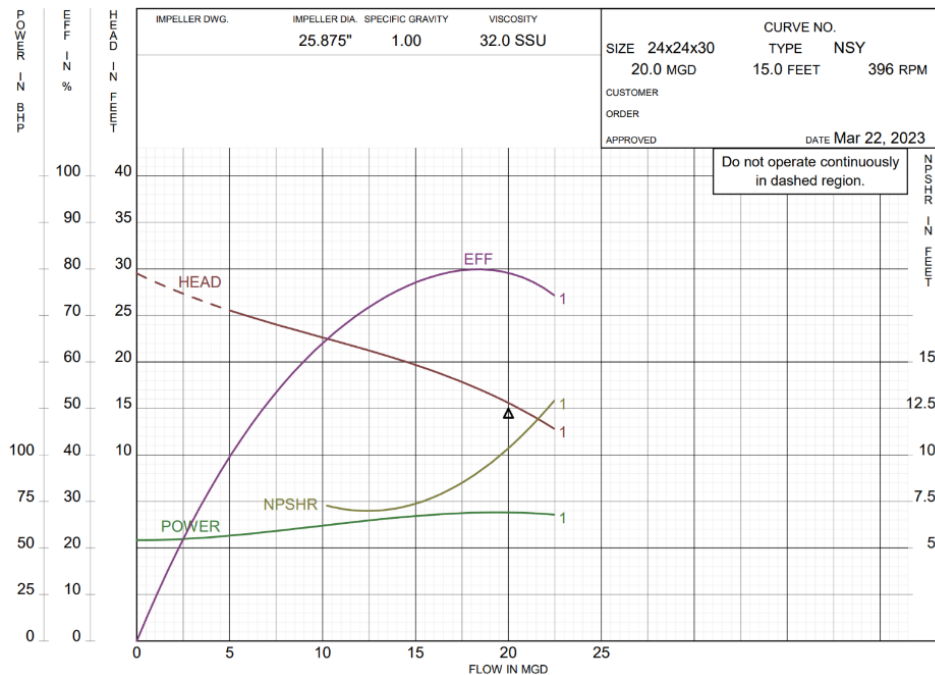


Figure 15: GAC service pump curve from Xylem Inc, Appendix 9.8

Two pumps were selected in order to provide redundancy in the system, following the redundant pumps and pump valving standard from Section 6.6.1 of the Ten State Recommended Standards for Waterworks, 2012 edition. Following that standard, every pump will have a butterfly valve before the unit, then a check valve followed by another butterfly valve located after the pumping unit (Figure 16). With the two pumps running in parallel, the total amount of flow going towards the GAC facility will match CMBP’s capacity of treating 40 MGD and maintain a rated pressure of 14 ft. While Flyght pumps, a subsidiary of Xylem, were used for the preliminary design, GCWW typically works with Worthington pumps for their horizontal pumps, a similar model from them may be chosen during the bid process.

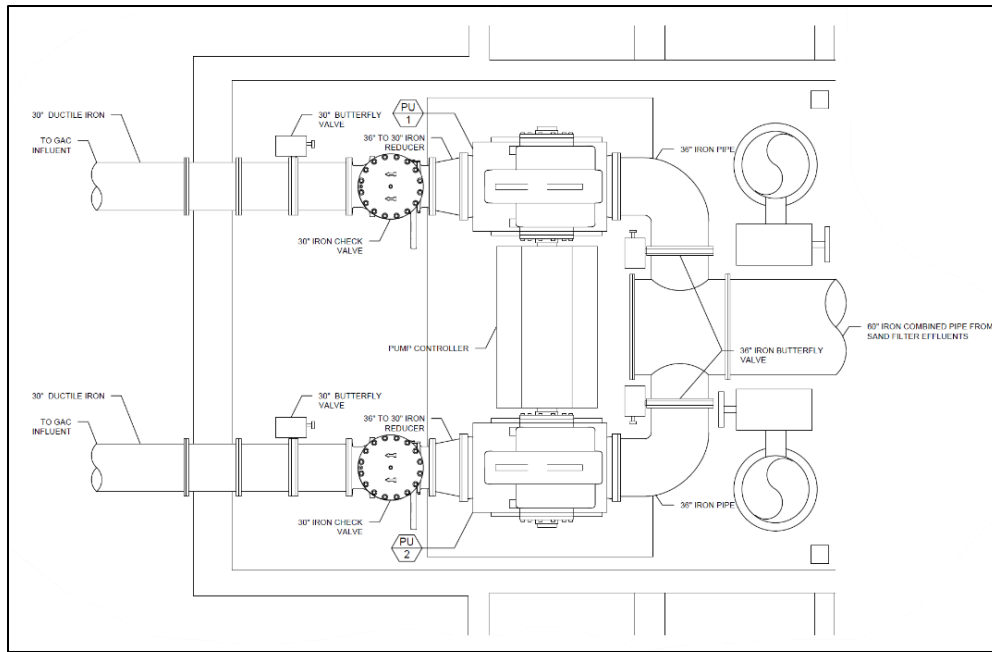


Figure 16: GAC service pump detail from Forefront Consulting drawing set page 12, Appendix 9.6

6.4 New GAC Building

Building

The new GAC building will have dimensions of 216' by 87.8' and be made of concrete masonry units (CMU) with steel truss and metal sheet roofing. It will house four GAC contactors and one contactor-sized bin for storage, along with the backwash supply tank. The building will have four garage doors located next to the current access road, one at each contactor so that they can be accessed for cleanout and reactivation (Figure 17).

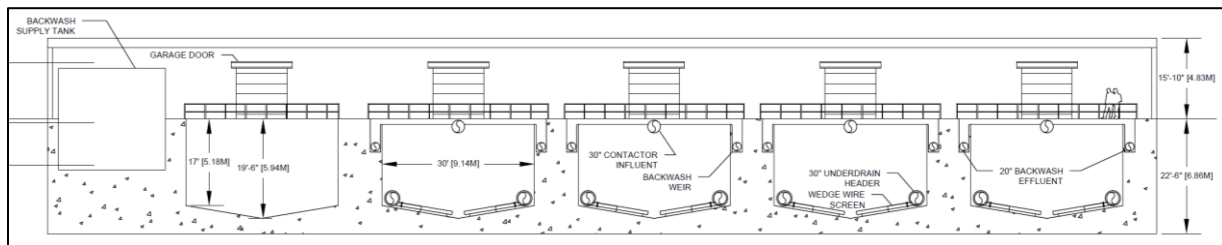


Figure 17: GAC Facility section view from Forefront Consulting drawing set page 15, Appendix 9.6

Contactors

The dimensions for the contactors were decided by first calculating the total amount of GAC needed. This was achieved by using the empty bed contact time (EBCT), which was set to 20 minutes, and a plant capacity of 40 MGD. The total volume of GAC needed is 74,262 ft³, see calculations in Appendix 9.7. The area of the contactor was decided to be 30' x 65' based on the design currently in use at RMTP (Springer 2023). The contactor bed depth was calculated to be 9.52' using the 20-minute EBCT, 40 MGD, and contactor bed area (30' x 65'). Each contactor bed was designed to be 30' x 65' x 9.52' with a volume of 18,565 ft³, there will need to be four contactor beds to reach the total volume of 74,262 ft³. An extra contactor will be installed with the same dimensions as the other four contactors but will only be used for storage of carbon and not treatment (Figure 18). The layout of the piping for the contactors is designed for each contactor to be run independently and in parallel. This will allow each contactor to be taken out of operation without affecting the treatment occurring in the other three contactors. The type of carbon that will be used in the contactor beds is Filtrasorb 400 by Calgon Carbon (2019), the same that is used at RMTP.

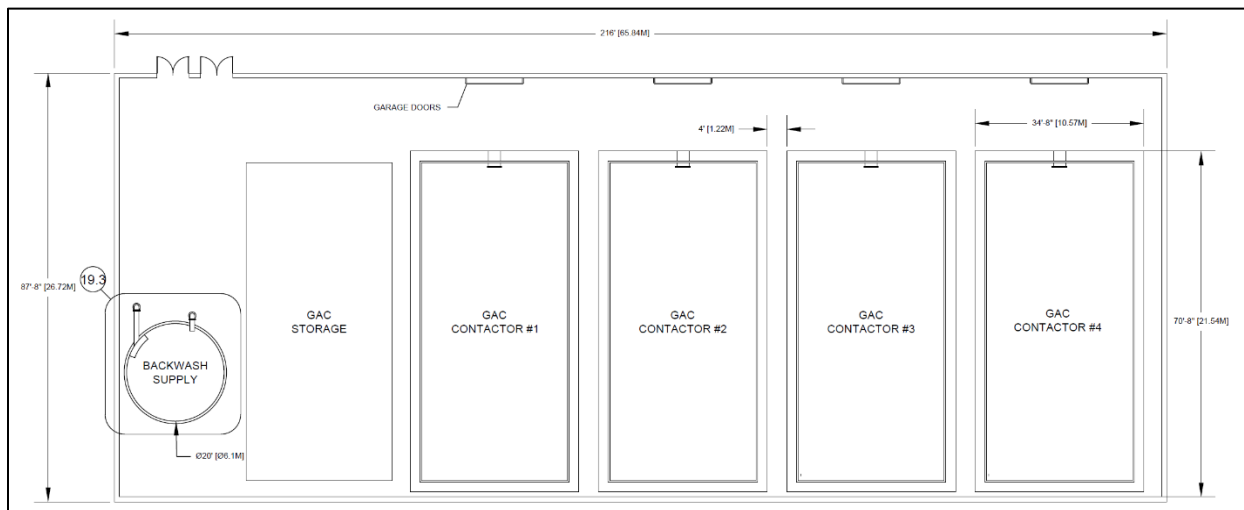


Figure 18: GAC Facility Layout From Forefront Consulting drawing set page 15, Appendix 9.6

The contactors will be made out of reinforced concrete with an underdrain system that serves as a treated water collection system during normal operations and a distribution system during backwash. Similar to the design of the RMTP, the underdrain system will consist of 50, 8" cylindrical wedge wire screens spanning the bottom length of the contactor spaced 12" on center as seen in Figure 19. Each of the wedge wire screens will feed a 30" stainless steel

underdrain header pipe located on either side of the contactor that will then be piped back to the North clearwell, South clearwell, or both clearwells during normal treatment flow.

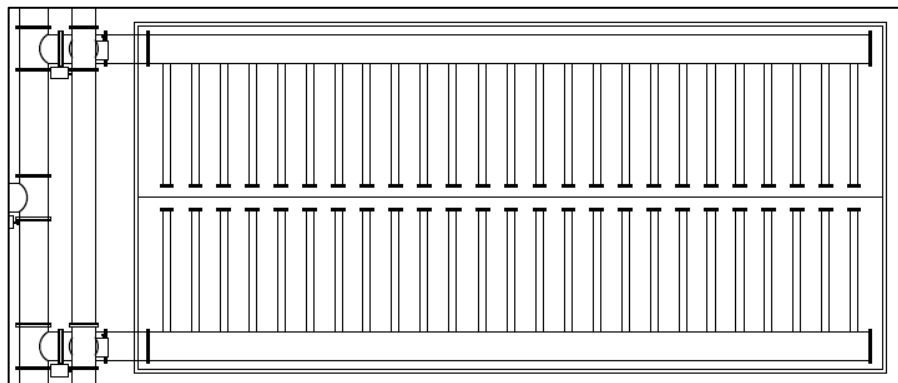


Figure 19: Contactor with Underdrain Wedge Wires From Forefront Consulting Drawing set page 18, Appendix 9.6

Treatment Flow

Coming from the GAC service pumps located in the filter building basement, the water that is to be treated is transported through the yard piping into the GAC facility. Each influent line in the facility has a check valve to ensure there is no backflow during periods of changing which pump is operational, during periods when one pump is providing more flow than another pump, or when only one pump is being utilized. There is also a typically closed butterfly valve between the influent lines to ensure that if there is more pressure coming from one of the pumps, it does not act as backpressure against the other pump increasing wear and tear as well as electricity costs. After passing through the check valves, the influent water will travel through one 30" ductile iron pipe that is connected to each of the four GAC contactors. Each pump will be able to provide water to any of the four contactors during times of maintenance. In addition, a line will branch from the combined influent line to fill the backwash supply tank when needed.

After passing through the filters and the underdrain system, water from each of the contactors will flow into one 30" stainless steel pipe that has the ability to flow back through the yard piping into either the North clearwell, South clearwell, or both clearwells. Stainless steel pipe will be utilized for any piping following the GAC contactors, as the introduction of fine particulates can increase pipe degradation through increased abrasion (Springer 2023). There will be a butterfly valve in the GAC building for each of the pipes going to the clearwells. This will allow GCWW control over which clearwell to fill from any of the contactors. In addition, each contactor will have a total of seven butterfly valves allowing control of each contactor to be backwashing or operating under normal treatment flow. The P&ID of the GAC facility is shown in Figure 20 with

the initial process layout being derived from Ohio Environmental Protection Agency (2007) and the New York State Bureau of Water Supply Protection (2021) recommendations.

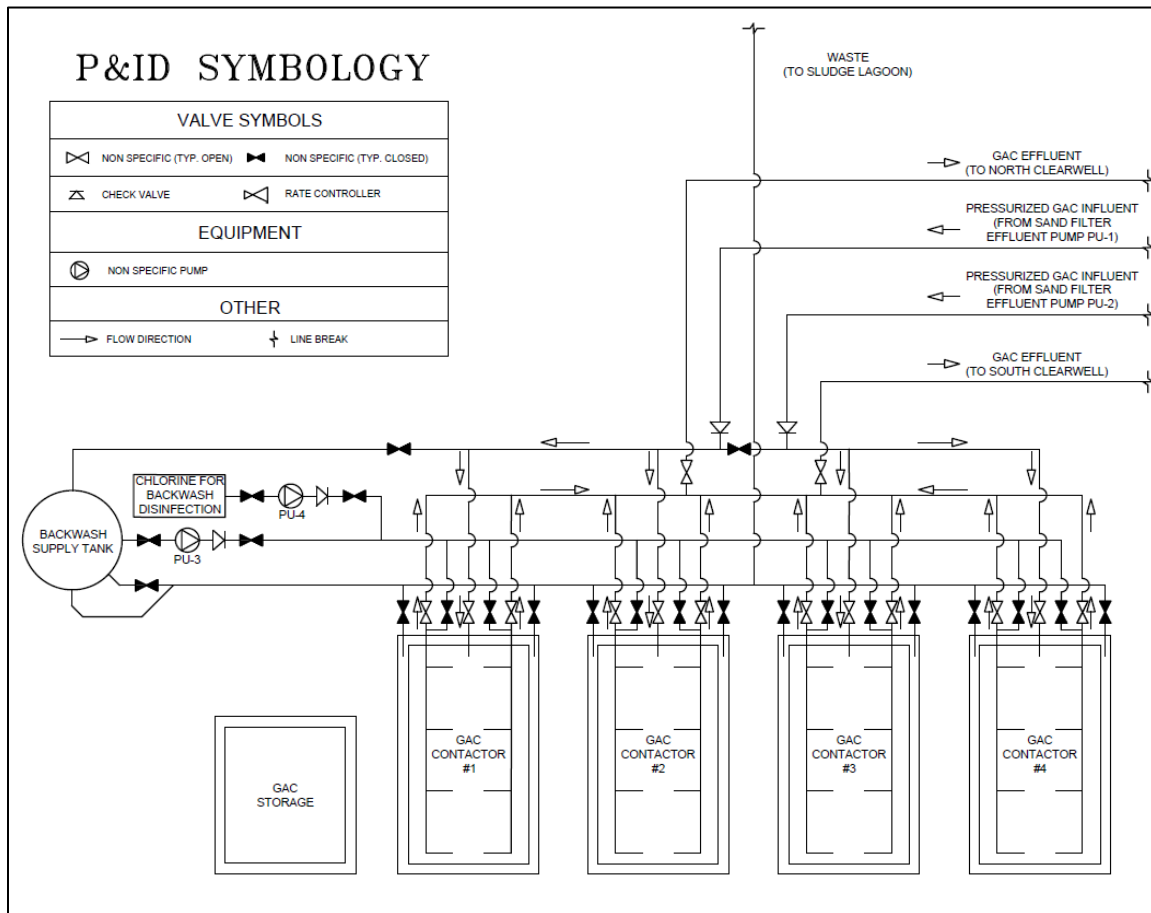


Figure 20: GAC Facility Treatment Flow P&ID From Forefront Consulting Drawing Set page 13, Appendix 9.6

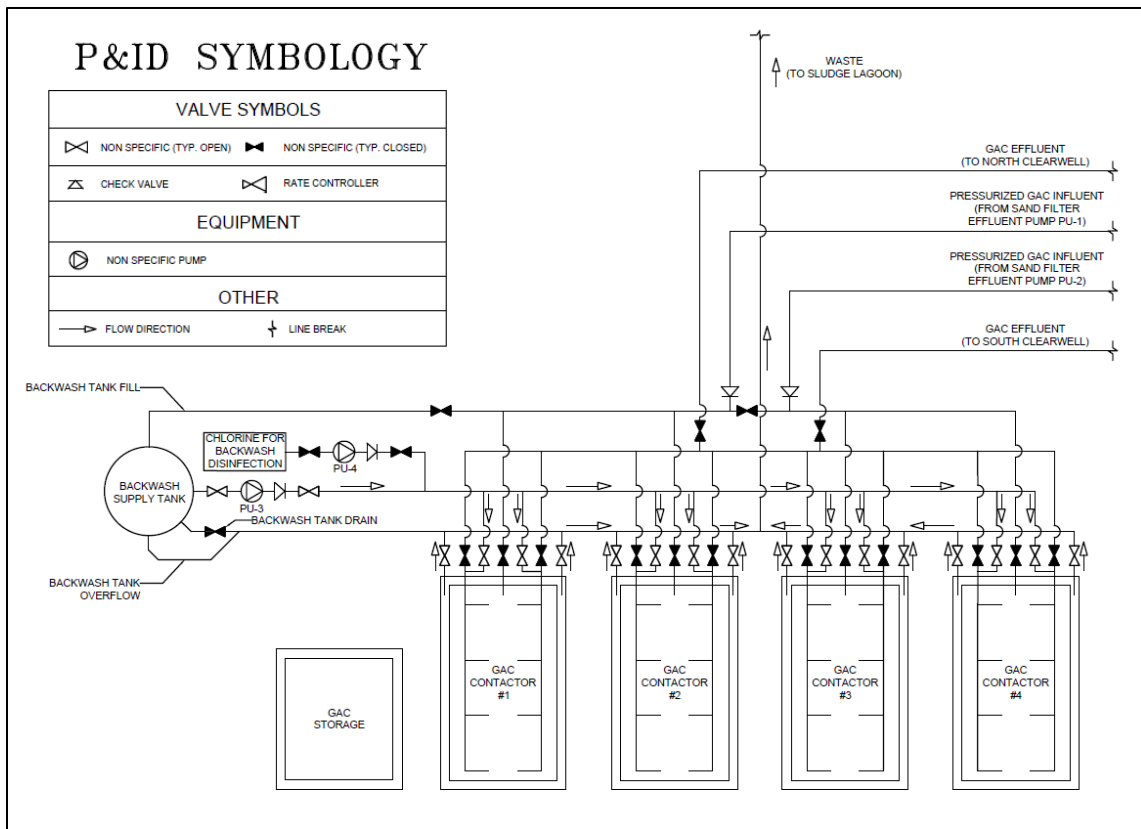
The pipe sizes for GAC influent and effluent are included in the calculations described previously in Section 6.2 and are included in Appendix 9.7. These calculations factored in the headloss through the GAC contactors which was found to be 5.5 ft of head. This headloss was calculated based on the Filtrasorb 400 carbon that will be used in the beds. The GAC influent and effluent pipes will have diameters of 30". The influent will be pumped using two pumps with 14 ft of head and the effluent will be transported to the clearwells by gravity.

Backwash

Like the dual media filters, the GAC contactors will need to be backwashed on a regular basis. With current GCWW procedures at the RMTP having each contactor backwashed every 10 days (Springer 2023). The new GAC building will include a backwash supply tank that will be

filled with water after it passes through the GAC filters. This cylindrical tank will hold 104,166 gallons with a diameter of 28 feet and a height of 20 feet. The tank volume calculation can be found in Appendix 9.7. It was determined that 10 feet of the backwash tank will be below grade to minimize the building cost in addition to fittings necessary for the backwash process. The concrete tank will be fitted with a 12" inlet being supplied from the GAC service pumps, an overflow weir, a tank outlet feeding a backwash pump, and a tank drain. Both the overflow weir and tank drain will gravity feed to the lagoon as needed. The overflow weir has no valving between the weir and lagoon allowing the line to drain through gravity alone without the need for controlled intervention.

Since the main purpose of backwash is to resettle the GAC bed and "fluff" the carbon, utilizing pre-GAC treated water is standard for GCWW as long as there are low concentrations of chlorine (Springer 2023). While CMBP has existing elevated backwash tanks for sand filter backwashing, they are filled from the reservoir with a set amount of chlorine levels making it unsuitable for the GAC backwash (Black & Veatch, 1973). Only one GAC contactor will be backwashed at a time and therefore the flow rate for backwash will be one-fourth of the maximum plant flow capacity at 10 MGD (MECC n.d.). Water from the backwash supply tank will be pumped through the GAC filter from the backwash supply tank and through the contactor underdrain system. The water will then overflow into weirs located on the perimeter of the GAC contactors and be routed to the sludge lagoon as waste. Refer to Figure 21 for the backwash flow P&ID.



**Figure 21: GAC Facility Backwash Flow P&ID From Forefront Consulting Drawing Set
page 13, Appendix 9.6**

The diameters of the pipes and necessary pumping head for the pump used in the backwash process were calculated using Bernoulli's equation. Stainless steel pipes will be used for the backwashing process because the backwash waste will have gone through GAC. Stainless steel can withstand potential abrasion by GAC fines and will prolong the life of the pipes. The starting point for calculations was at the bottom of the backwash supply tank and the ending point was the waste lagoon. The backwash calculations required that the headloss up through the GAC contactors be included in the major headloss. The headloss up through the GAC was assumed to be the same as during regular treatment; however, the backwash must overcome gravity and therefore the force of gravity was added to make the headloss through GAC 15.4 feet. The pipe diameter for all pipes involved in backwash will be 20" and the necessary pumping head is 15.4 feet. All calculations are included in Appendix 9.7. A Flyght 18x18x23 NSY 423 rpm pump was chosen for the facilities' backwash needs being driven at 33 HP through a VFD. Similar to the GAC pumps, during the bid process a similar pump from a preferred GCWW vendor may be chosen for the project. The selected pump curve is shown in Figure 22.

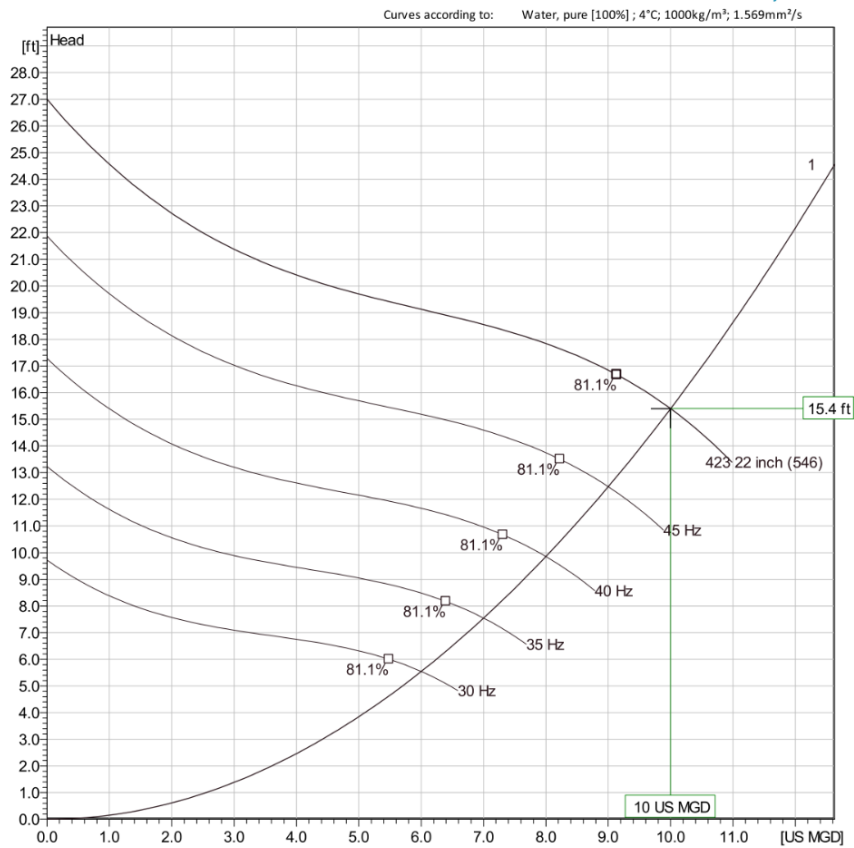


Figure 22: Backwash Pump Curve From Xylem Inc. Appendix 9.8

In some rare instances chlorine may need to be added to the water being used to backwash the GAC contactors. This is predominantly used when disinfection needs to occur in the process. In order to accomplish this a chemical tote will feed a chlorination pump that can inject chlorine into the backwash flow. A Pro Series Flex Pro A3 by Blue-White peristaltic pump was chosen as it can dynamically deliver 0.1 GPH all the way up to 35 GPH if needed. While a venturi-based liquid chlorine injection system could be used and require less maintenance, the proposed chlorine pump was chosen due to its ability to dynamically adjust the amount of chlorine to what the GCWW operator desires for a given backwash.

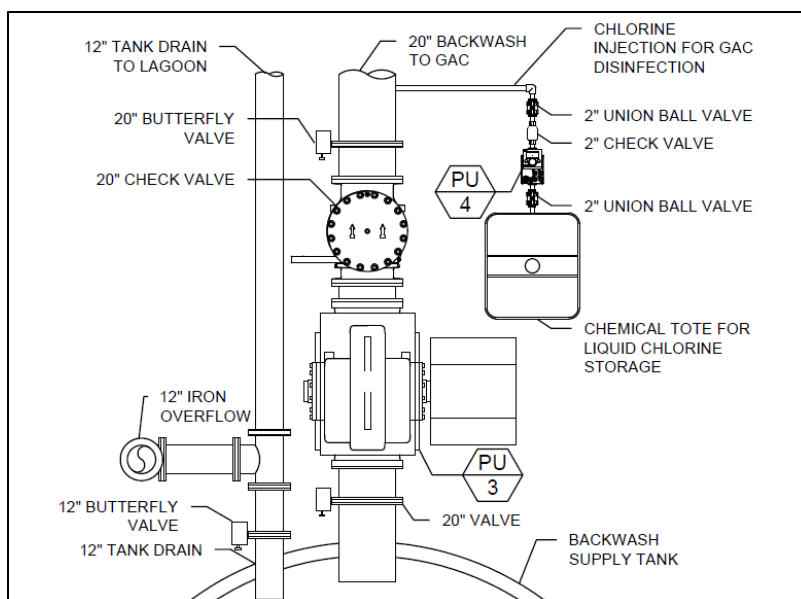


Figure 23: Backwash Supply Outlet From Forefront Consulting Drawing Set Page 19, Appendix 9.6

The design routes backwash waste to the lagoon. If the backwash waste needs to be treated at the head of the plant instead of being placed in the sludge lagoon, then minimal modifications would have to be made to the overall design. The backwash line would be re-routed to the plant well water intake with the addition of a check valve and pump able to produce a greater pressure than the well pumps feeding the plant. However, the introduction of GAC fine particles may increase pipe abrasion throughout the treatment process.

6.5 Reactivation

The carbon reactivation process at CMBP will be carried out using the incinerator facilities at RMTP. After the carbon becomes saturated in the contactors the carbon will be removed as a slurry via vacuum trucks with a hose. The four contactors and storage tank will run parallel to the current access road for easy entry to the garage doors located next to each of the contactors. To reactivate one contactor, around 18,500 ft³ of carbon, it will take three vacuum trucks and one week of work to transfer the spent carbon. Once the carbon is at RMTP they will use the incinerator above 1,000 degrees Celsius to reactivate the carbon, then it will be transferred back to CMBP as a slurry. Due to the incineration process some carbon is lost, so to keep up with the necessary carbon volume there will need to be an 8% addition of new virgin carbon added every year. This 8% equates to around 80 tons of new carbon every year.

The two incinerators at RMTP do have the capacity to add in extra reactivation load with carbon from CMBP. RMTP typically shuts off both incinerators in the winter for at least a 2-month maintenance period and because natural gas costs are higher in the colder seasons. The incinerators do have the capacity to run for a longer duration, with the second incinerator only running for around a month every year (Springer 2023). The incinerators have been proven to hit maximum temperatures greater than 1,000 degree C, making it viable to remove PFAS from saturated carbon. However, GCWW will have to validate PFAS removal with pilot studies before the project is installed. Additional carbon storage may need to be added to RMTP depending on when each of the two treatment plants need to reactivate carbon. Analysis on whether or not this additional storage was necessary was out of the scope of this capstone.

7. COST

Cost estimates were derived from the RMTP GAC Construction Costs data provided by GCWW in Appendix 9.3. Assuming a linear scale for construction cost between plant capacities, as well as adjusting for inflation between 1984 and 2022, capital costs were estimated to be \$25.7 million as seen in Table 2 below (BLS 2023). Further cost breakdown was conducted for process materials, operations and maintenance including reactivation. Construction cost was broken into earthwork and estimated labor and foreseen subcontract work. While some construction items were not able to be estimated, the cost of them is incorporated in the estimate based on the RMTP scaled cost derivation.

Table 2. Total Cost Estimate

Deliverables	Cost (Millions)
Process Materials	10.2
Reactivation	1.4
Earthwork	0.14
Labor and Subcontractors	14
Total	25.7

7.1 Process Materials Cost

Process piping and valves throughout the designed system were quoted by different pipe and valve manufacturers and suppliers. Among them, Ferguson Waterworks (2023), US Pipe (2021), and McWane Ductile (2023) were able to provide us with preliminary costs for our list of

pipe materials. Table 3 shows the preliminary cost for pipe, pump, and valve materials as well as concrete and the GAC to be used in the proposed treatment process.

Table 3. Process Costs

Item	Preliminary Cost Sum	Quote Providers
Assorted Ductile Iron Pipe, Valves and Fittings	\$3,003,902.44	McWane Ductile Ferguson WW US Pipe
Assorted Stainless Steel Pipe, Valves and Fittings	\$2,011,034.72	Ferguson WW
Assorted PVC Pipe, Valves and Fittings	\$245.00	PVC Fittings Online Grainger Supply
Concrete Material	\$1,142,600.00	Ernst Concrete
Assorted Process Pumps	\$755,749.00	Xylem Supply Line Online
GAC Material Initial Supply	\$2,958,486.69	Calgon Carbon

As seen in Table 3, concrete costs were an estimate by Ernst Concrete (2023), local to southwest Ohio. It was estimated that about 5800 CY of ready-mix concrete was required for the new building, including the contactor basins and the storage tank. A price estimate of \$197/CY was given by Ernst for 4000 PSI RMC, which was an assumed concrete strength for this application (Ernst 2023). Not inclusive of labor, this cost for concrete amounts to \$1.142 million. Other costs associated with concrete costs would include placement labor and formwork labor described in Section 7.4.

Process pipe, including influent, effluent, and backwashing requirements, amounted to \$5.01 million based on the quotes received from Ferguson, Appendix 9.9, and McWane Ductile (2023) as well as the price sheets from US Pipe (2023). Pumps required to move water throughout the treatment process including backwash amounted to \$755,749.00 when including the chemical pump for chlorine application, Appendix 9.10.

7.2 Reactivation Cost

To start the reactivation process, a vacuum truck company will need to transport all the spent carbon as a slurry to RMTP. A quote from Champion Cleaning Specialists told us that to transfer 18,500ft³ of spent carbon, the volume of one contactor, would take three trucks and a week to complete. They were able to price this job at \$66,990 per reactivation (Appendix 9.9). It is expected that CMBP will need six reactivations a year. This means the yearly cost to transfer spent carbon will be \$401,940. The cost of energy at RMTP while the incinerator is

being used is \$0.25/lb (Springer 2023). If one contactor volume is being reactivated, then the cost of energy is \$125,313. After six reactivations in a year, the cost of energy will be \$751,882. When reactivation is carried out at RMTP some of the carbon will be lost due to incineration. It was calculated that on a yearly basis around 80 tons of new carbon will need to be incorporated into the current operational carbon. The cost of carbon is \$2,951 per ton, this means every year 80 tons of carbon will cost \$236,080.

7.3 Earthwork Cost

Earthwork cost was estimated by comparison with a similarly scaled project in Accokeek Maryland. Because of the footprint of the proposed building, the necessary removal and alteration of the landscape is a considerable cost. The general contractor of the job in Maryland provided an estimate that excavation and material hauling for an excavation of this scale would happen at a rate of 0.8 MH/QTY (Fetters 2023). Quantifying the necessary work, it was calculated that around 16,300 CY of dirt will be excavated to accommodate the proposed building. At this rate and with an average pay rate for heavy equipment operators of \$34/hour (Salary.com 2023). This came out to be about 1300 man-hours which equated to about \$45,000 in labor for this phase of work.

Likewise, diesel consumption was another large cost to consider for this phase. Using an average price of about \$5 per gallon of red-dyed diesel (AAA.com 2023) as well as an estimate of 3-12 gallons of diesel burned per hour for excavators and off-road trucks (Heavy Equipment Forums 2008), we were able to come up with about \$78,000 estimated for fuel costs, however this is highly variable based on the market for diesel, equipment quality and the workforce involved.

7.4 Labor and Subcontracts

Labor estimates were made by using resources in the RS Means Estimating handbook as well as contacting industry professionals about their respective work. Work that is expected to be subcontracted out includes but is not limited to roofing of the new building, masonry work for the building walls, transportation for carbon reactivation and other miscellaneous construction costs.

Labor costs associated with the forming and placement of concrete were not directly estimated but incorporated in the scaled capital costs calculated from the RMTP project. Similarly, the design and placement of reinforcing steel and concrete finishing were not designed nor

included directly in cost estimation. HVAC, electrical and architectural work is also considered by the scaled capital costs and not explicitly estimated.

Roofing

The cost of roofing was estimated by contacting Van Martin Roofing out of Dayton Ohio. The estimating team there was able to provide an estimate of \$1500/ SQ, including labor by their crews. An industry square (SQ) is 10'x10' placed. This would result in a total cost of \$294,840 for the square footage of our proposed roof on the new GAC building.

Masonry

An estimate for masonry cost was made using RS Means Division 4 Masonry data. Estimates included assumptions about reinforcing, finish, and block size. Assuming standard CMU construction, and normal requirements for reinforcement, RS Means data and The Home Depot provides an estimate of \$2.50/CMU (HomeDepot 2023) with an effort of 0.125 MH/SF of wall (RSMeans,2009). Therefore, the cost of material for the CMU wall will be about \$52,500.00 based on an estimated requirement of 21,000 CMUs for the required wall dimensions. The masonry field time can be estimated at \$16,470.00 for the 7320 SF of wall, which would presumably take 915 MH to complete. The 915 manhours are multiplied by the \$18 per hour average for masons in Ohio (Ziprecruiter.com 2023)

A complete list of materials and their respective amounts and prices is provided in Appendix 9.10.

8. CONCLUSION

The Forefront Consulting team was tasked with conducting a thorough literature review of current PFAS removal techniques, performing an alternative analysis on the chosen viable treatment technologies, creating preliminary drawings of the recommended treatment technology, and preparing a preliminary construction cost estimate. The treatment technology had to be able to reduce PFOA and PFOS levels to less than or equal to 2 ppt. The four researched technologies, i.e., GAC, anion exchange, RO, and advanced oxidation, all have the capability to meet the desired levels. Anion exchange effectively removes PFAS in a smaller footprint than GAC, however it comes with an increased operational cost. RO was researched because when done correctly it can be a very effective option for removing all types of PFAS. Advanced oxidation has the potential to be a more environmentally friendly treatment technology where compounds are degraded rather than adsorbed and removed. GAC adsorption is a simple, inexpensive, and effective method for PFAS treatment that is widely

accepted in the drinking water industry. While each technology had advantages and disadvantages, Forefront Consulting determined that GAC was the best alternative.

The team designed the GAC facility for the CMBP based on as-built drawings provided by GCWW and sized the needed pumps and pipes using Bernoulli's equation. Approximately 2400 feet of new pipe will be added to the existing treatment process, connecting the new 215 ft x 88 ft GAC facility to the existing filter building. Four new pumps will be added, two for regular treatment, one for backwashing the GAC, and one for disinfection during backwash. Altogether, the total estimated cost of adding GAC to the CMBP is \$25.7 million. The Forefront Consulting team is confident that GAC is the best technology to reduce concentrations of PFAS below the EPA's proposed MCL of 4 ppt and GCWW's internal goal of 2 ppt at the CMBP.

9. APPENDICES

9.1 Data Provided by GCWW

PFOA, PFOS, pH, temperature, and total hardness data was received from GCWW with 16 sample dates ranging from February 2016 to March 2022 for well water (Table A-1). 11 samples of treated water were received from February 2016 to March 2022 for treated water (Table A-2). Values marked with a "<" sign indicates less than limit of detection and values marked with a “–” indicate no sample was taken.

Table A-1: Well water PFAS sampling

Well Water					
Sample Date	PFOA (ppt)	PFOS (ppt)	pH	TEMP (°C)	Total Hardness (mg/L as CaCO ₃)
2/22/2016	3.8	< 2.5	7.6	14.2	276
6/7/2016	3.4	3.5	7.6	13.4	226
3/28/2017	2.9	2.9	7.5	14.6	280
5/1/2018	< 2.5	2.5	7.9	13.1	276
3/26/2019	4.4	3.2	7.5	13.7	284
12/12/2019	4.0	5.3	7.6	15.4	280
1/28/2020	2.6	3	7.6	13.8	258
2/26/2020	2.4	4.0	7.5	14.4	272
3/25/2020	3.3	4.3	7.6	14.1	282
7/9/2020	2.6	3.7	7.5	13.7	260
10/6/2020	4.6	6.6	8.1	15.9	272
1/11/2021	4.8	5.7	7.6	15.4	278
3/29/2021	2.4	4.3	7.5	14.8	282
7/12/2021	1.5	1.4	7.6	13.8	260
11/17/2021	2.7	4.8	7.6	15.4	270
3/28/2022	< 4.5	4.7	7.5	13.4	285
Min	< 2.5	< 2.5	7.5	13.1	226.0
Average	3.3	3.9	7.6	14.3	271.3
Max	4.8	6.6	8.1	15.9	285

Table A-2: Treated water PFAS sampling

Treated Water					
Sample Date	PFOA (ppt)	PFOS (ppt)	pH	TEMP (°C)	Total Hardness (mg/L as CaCO ₃)
2/22/2016	4.4	< 2.5	9.2	14.6	141
6/7/2016	3.4	3.6	9.3	14.4	141
3/28/2017	4.4	4.0	9.3	15.6	138
5/1/2018	3.6	4	8.9	14.6	144
3/26/2019	4.1	3.7	9.3	14.8	129
12/12/2019	-	-	-	-	-
1/28/2020	2.7	3.1	9.4	14.6	128
2/26/2020	4.7	5.3	9.3	15.4	135
3/25/2020	3.5	4.5	9.3	15.3	139
7/9/2020	-	-	-	-	-
10/6/2020	-	-	-	-	-
1/11/2021	4.7	5.7	9.2	16.1	137
3/29/2021	2.4	4.1	9.1	16	134
7/12/2021	-	-	-	-	-
11/17/2021	-	-	-	-	-
3/28/2022	< 4.6	< 4.6	9	14.3	124
Min	2.4	< 2.5	8.9	14.3	124
Average	3.9	4.1	9.2	15.1	135
Max	4.7	5.7	9.4	16.1	144

Well water sulfate data was compiled from 16 samples taken from February 2016 to April 2022 and treated water sulfate data was compiled from 11 samples taken from April 2017 to April 2022 (Table A-3).

Table A-3: CMBP sulfate concentrations

CMBP Sulfate Concentrations				
	Well Water		Treated Water	
Min	39	mg/L	38.4	mg/L
Average	46	mg/L	44	mg/L
Max	55	mg/L	52	mg/L

Well water nitrate data was compiled from 77 samples taken from April 2016 to August 2022 and treated water nitrate data was compiled from 9 samples taken from January 2016 to April 2022 (Table A-4).

Table A-4: CMBP nitrate concentrations

CMBP Nitrate Concentration				
	Well Water		Treated Water	
Min	0.17	mg/L	0.62	mg/L
Average	1.28	mg/L	1.27	mg/L
Max	2.49	mg/L	1.79	mg/L

Well water TOC data was compiled from 77 samples taken from February 2016 to October 2022 and treated water TOC data was compiled from 9 samples taken from February 2016 to September 2022 (Table A-5).

Table A-5: CMBP TOC concentrations

CMBP TOC Concentration				
	Well Water		Treated Water	
Min	0.20	mg/L	0.37	mg/L
Average	0.70	mg/L	0.58	mg/L
Max	1.26	mg/L	0.87	mg/L

Turbidity minimum, average, and max values received from GCWW (Table A-6).

Table A-6: CMBP Turbidity levels

CMBP Turbidity				
	Well Water		Treated Water	
Min	0.02	NTU	0.03	NTU
Average	0.25	NTU	0.28	NTU
Max	0.05	NTU	0.08	NTU

Cl₂ minimum, average, and maximum values received from GCWW (Table A-7).

Table A-7: CMBP chlorine concentrations

CMBP Cl₂ Concentration		
	Sand Filter Effluent	
Min	1.19	mg/L
Average	1.5	mg/L
Max	1.35	mg/L

Manganese data was compiled from 246 samples taken from from April 6th 2016 to September 9th, 2022 (Table A-8).

Table A-8: CMBP manganese influent concentrations

CMBP Manganese Influent Concentration		
Min	10	ug/L
Average	169	ug/L
Max	485	ug/L

Magnesium data was compiled from 11 samples taken on May 1st, 2018 (Table A-9).

Table A-9: CMBP magnesium influent concentrations

CMBP Magnesium Influent Concentration		
Min	22	ug/L
Average	27	ug/L
Max	32	ug/L

9.2 Analyzed Data

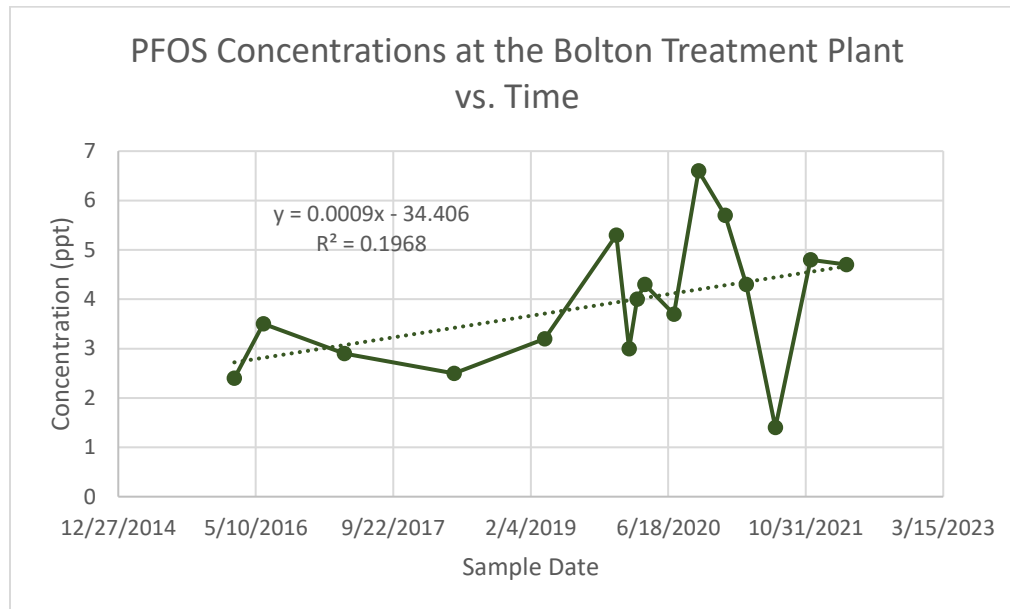


Figure A-1: PFOS Concentrations at CMBP vs time

Table A-10: Well water PFOS confidence interval

Well water PFOS Confidence Interval		
Confidence	95%	
Lower Bound	3.2	ppt
Mean	3.9	ppt
Upper Bound	4.6	ppt

Table A-11: Reduction needed for PFOS

PFOS Reduction Needed - CMBP		
GCWW Goal	2	ppt
Average in Well Water	3.9	ppt
Reduction needed from mean	49%	

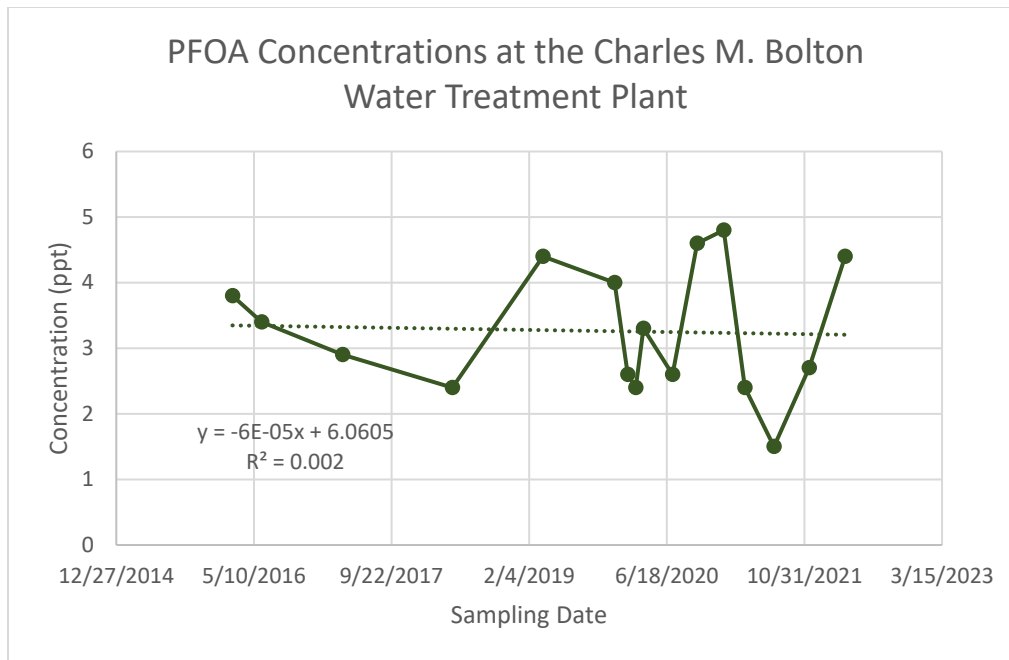


Figure A-2: PFOA Concentrations at CMBP vs time

Table A-12: Well water PFOA confidence interval

Well water PFOA Confidence Interval		
Confidence	95%	
Lower Bound	2.7	ppt
Mean	3.3	ppt
Upper Bound	3.8	ppt

Table A-13: Reduction needed for PFOA

PFOA Reduction - CMBP		
GCWW Goal	2	ppt
Average in Well Water	3.3	ppt
Reduction needed from mean	39%	

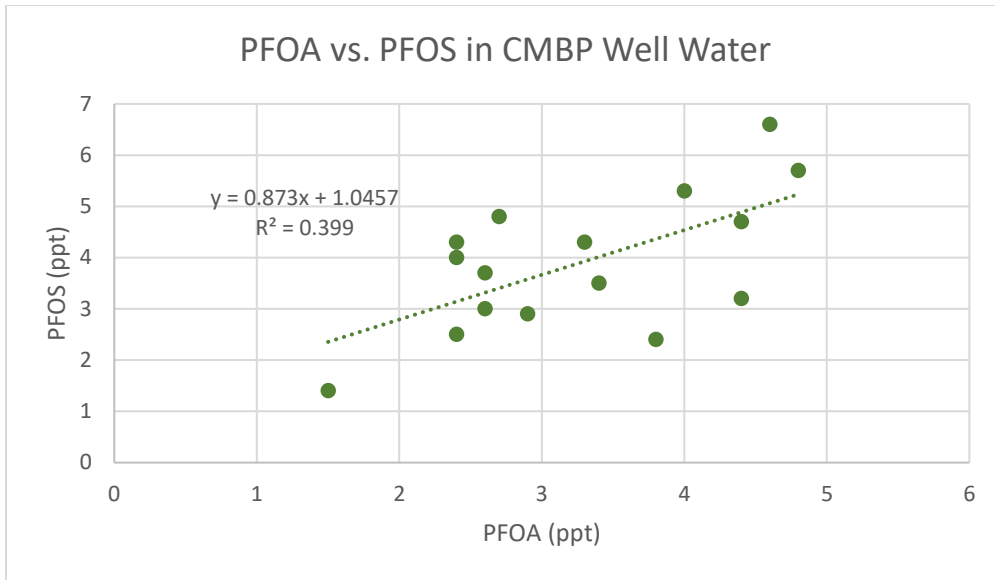


Figure A-3: PFOA Concentrations at CMBP vs time

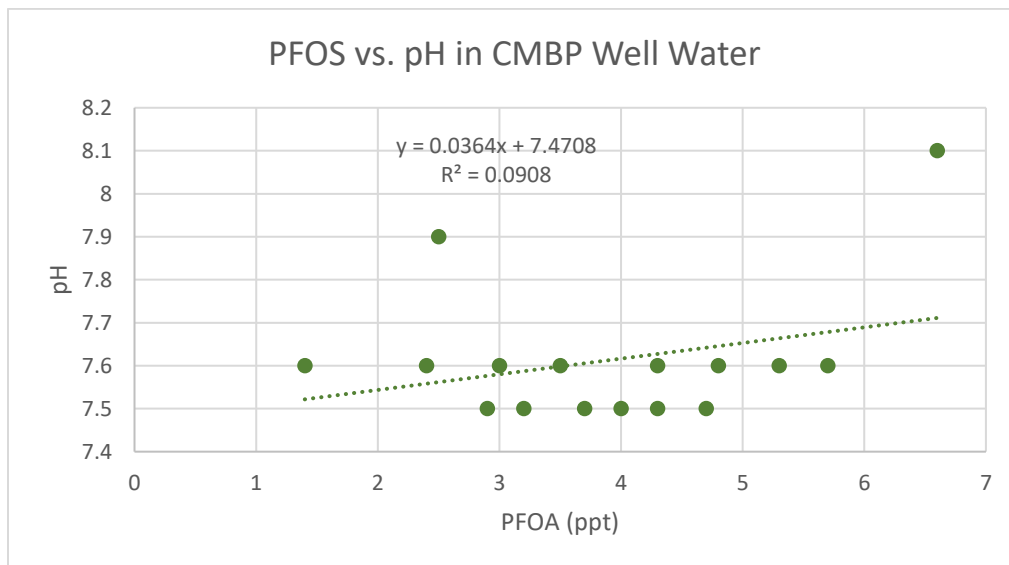


Figure A-4: PFOS vs. pH in CMBP Well Water

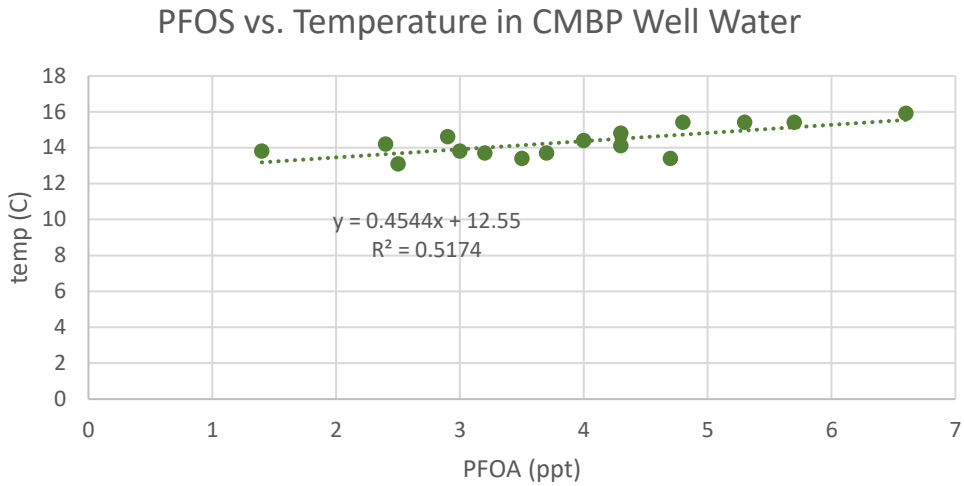


Figure A-5: PFOS vs. Temperature in CMBP Well Water

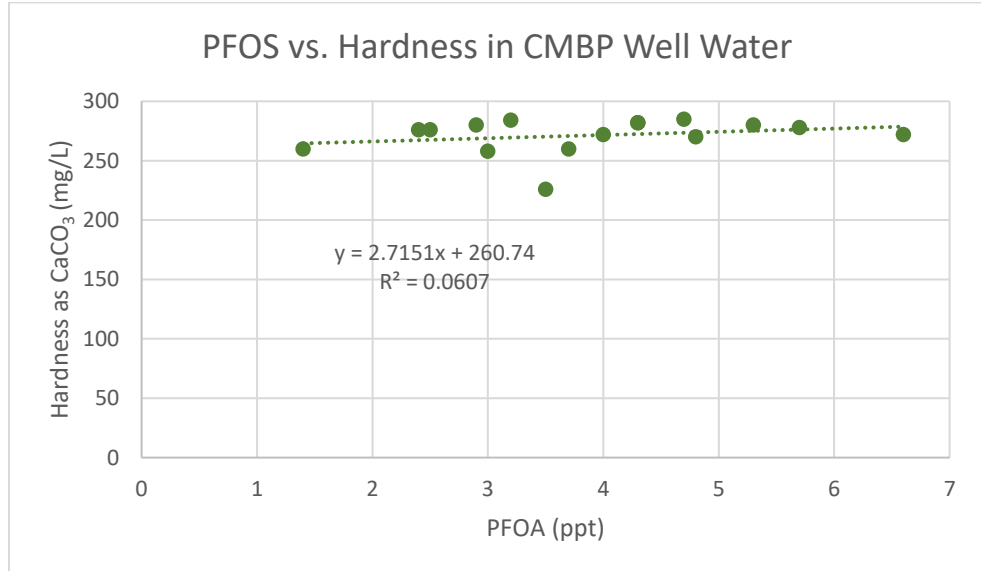


Figure A-6: PFOS vs. Hardness in CMBP Well Water

9.3 GCWW Richard Miller Treatment Plant GAC Contactors Data Sheet

Plant Information for Carbon Contactors

Plant design of 220 mgd.

Annual Average Raw Flow Rate = 117 mgd

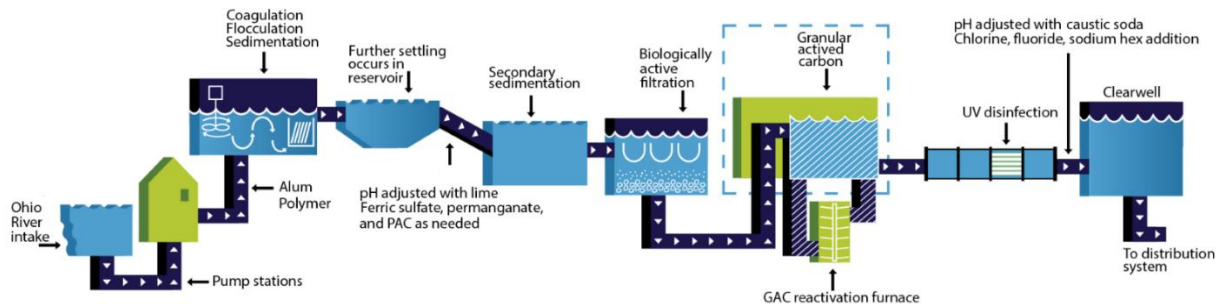
Maximum Day Raw Flow rate = 196 mgd

Annual Average Flow Rate through GAC = 106 mgd

Maximum Day Flow Rate through GAC = 150 mgd

Minimum Day Flow Rate through GAC = 81 mgd

The surface water treatment plant draws water from the Ohio River. The water is treated using coagulation, flocculation, sedimentation, sand filtration, carbon adsorption, ultraviolet (UV) disinfection, fluoridation, corrosion control, pH adjustment and chlorine disinfection (see schematic below). If the need arises, additional treatment steps can be employed such as powdered activated carbon (PAC), copper sulfate, potassium permanganate, and ferric sulfate.



GAC Capital (Construction) Cost

Construction started in 1984, process online 1992.

GAC Facility = \$48 M

Reactivation Facility = \$ 6.1 M

GAC initial supply = \$4.5 M

Engineering = \$5.4 M

O & M Cost

\$3 M includes:

- 18 regenerations per year @ \$110,000 each
- Replacement GAC = 420 tons at a cost of \$999,600 (\$2,380/ton)

GAC Contactor Information

12 gravity, deep bed GAC contactors

Treatment goal of 1 mg TOC/L for GAC contactor effluent.

Empty bed contact time (EBCT) typically ranges between 15 and 20 min.

The contactor design parameters, which are based on 11 contactors in service, are:

- EBCT at 175 mgd (662 ML/d) = 15.0 minutes.
- EBCT at 124 mgd (470 ML/d) = 21.2 minutes.
- EBCT at 220 mgd (833 ML/d) = 12.0 minutes.
- Total surface area per contactor 65 ft x 30 ft = 1950 sq ft (180 m²)
- Total surface area = 21450 sq ft (1990 m²)
- Surface loading rate at 175 mgd (662 ML/d) = 5.5 gpm/sq ft (3.7 mm/s)
- Surface loading rate at 220 mgd (833 ML/d) = 6.9 gpm/sq ft (4.7 mm/s)
- Surface loading rate at 124 mgd (470 ML/d) = 3.9 gpm/sq ft (2.6 mm/s)
- GAC depth = 11.4 ft (3.5 m)
- GAC volume per contactor = 22 230 cu ft (630 m³)
- Total GAC volume = 244 530 cu ft (6925 m³)
- Backwash bed expansion = 5-30 percent (with 35°F [2° C] backwash)
- Facility capacity per GAC contactor = 9.1 percent

For design purposes, the GAC was assumed to have: a bituminous base, a particle size of 12 X 40 mesh, a surface area (BET)* of 1000 m²/g, an iodine number of 1000 mg/g, an effective size of 0.55-0.75 mm, a uniformity coefficient of 1.9, and an apparent density of 25-29 lb/cu ft (400-465 kg/m³).

Contactors Run Hours

Another study we did recently asked us the number of bed volumes treated between reactivations. This is what I came up with.

Using table below and calculated based on 15-minute EBCT:

Average run days between regen is 172.8 days = 4147.2 hours = 248,832 minutes. Divide by 15 min. EBCT and get 16,589 bed volumes.

Regeneration # for the year	Run days between reactivations	Contactors being regenerated
1	247	CN11
2	248	CN3
3	249	CN9
4	246	CN2
5	266	CN10
6	278	CN5
7	278	CN12
8	277	CN1
9	119	CN8
10	112	CN4
11	103	CN7
12	113	CN6
13	106	CN11
14	91	CN3
15	91	CN9
16	91	CN2
17	87	CN10
18	109	CN5
	172.83	average run days

9.5 Summary of Custom Soil Resource Report

The United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) created a Custom Soil Resource Report for the Forefront Consulting team on the area of interest (AOI) at CMBP (2023). The area where we are planning to put the new GAC building is indicated by the red circle with a number 1, as indicated in the figure A-7 below.

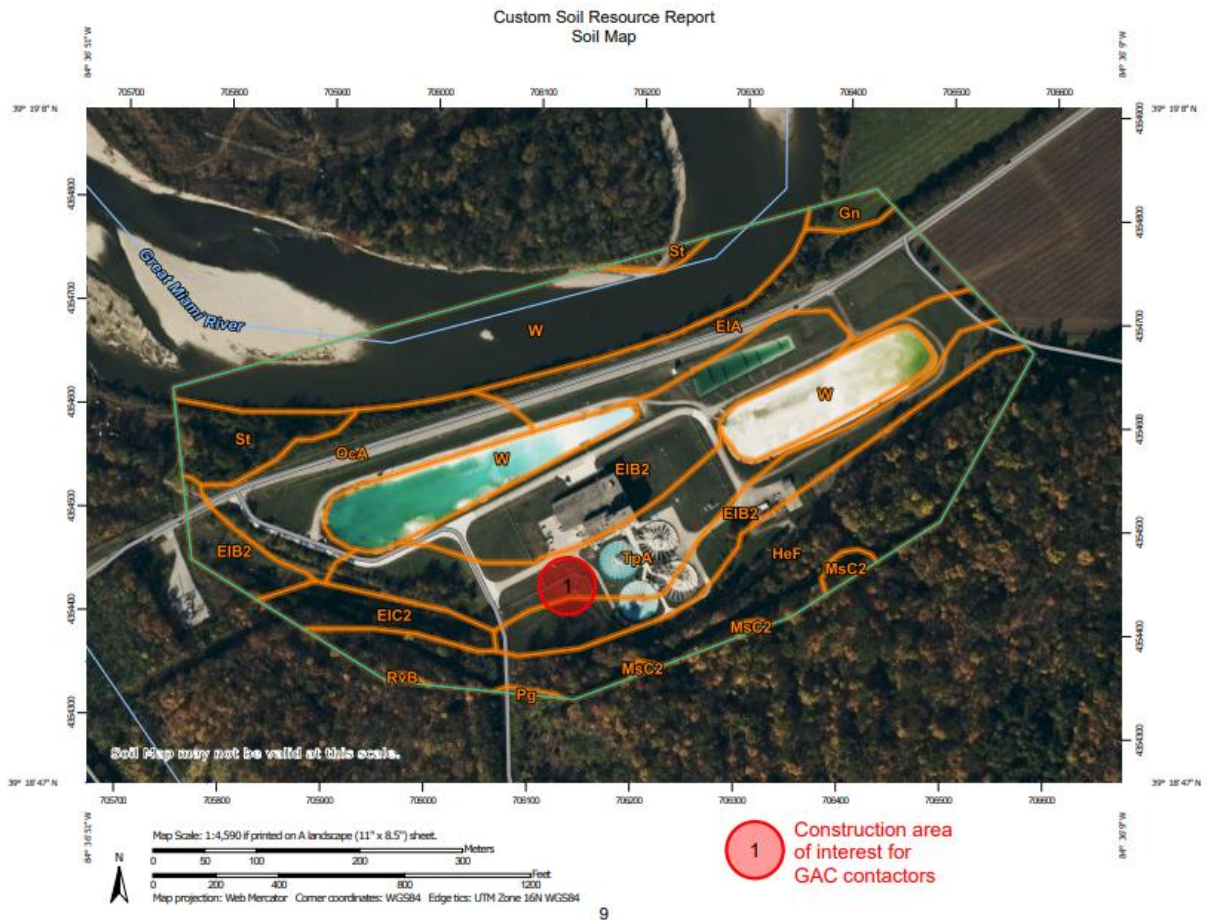


Figure A-7: Soil Map of GCWW

The orange section labeled as EIB2 is defined as “Eldean loam, 2 to 6 percent slopes, eroded” and the section TpA is defined as “Tippicanoe silt loam, 0 to 2 percent slopes”. The properties and qualities of EIB2 are well drained, low runoff, no flooding or ponding, and hydrologic soil group B. The properties and qualities of TpA are moderately well drained, low runoff, no flooding or ponding, and hydrologic soil group B.

This report indicates that the properties of the area we want to construct on do not show any signs of being a wetland. The Figure A-8 below from the National Wetlands Inventory also shows that where the new GAC building would go is not considered a wetland.



January 31, 2023

Wetlands

- | | | | | | |
|---|--------------------------------|---|-----------------------------------|---|----------|
|  | Estuarine and Marine Deepwater |  | Freshwater Emergent Wetland |  | Lake |
|  | Estuarine and Marine Wetland |  | Freshwater Forested/Shrub Wetland |  | Other |
| | |  | Freshwater Pond |  | Riverine |

This map is for general reference only. The US Fish and Wildlife Service is not responsible for the accuracy or currentness of the base data shown on this map. All wetlands related data should be used in accordance with the layer metadata found on the Wetlands Mapper web site.

National Wetlands Inventory (NWI)
This page was produced by the NWI mapper

Figure A-8: National Wetlands Inventory at CMBP


9.6 Design Drawings

GAC ADDITION FOR PFAS TREATMENT
 CHARLES M. BOLTON WATER TREATMENT PLANT
 GREATER CINCINNATI WATER WORKS

6800 RIVER ROAD, FAIRFIELD, OH 45014



UNIVERSITY OF CINCINNATI
 COLLEGE OF ENGINEERING AND APPLIED SCIENCE
 DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING
 SENIOR DESIGN CAPSTONE

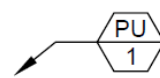
	DESIGNERS: FOREFRONT CONSULTING UNIVERSITY OF CINCINNATI COLLEGE OF ENGINEERING AND APPLIED SCIENCE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING SENIOR DESIGN CAPSTONE	PROJECT: CHARLES M BOLTON WATER PLANT GAC ADDITION FOR PFAS TREATMENT GREATER CINCINNATI WATER WORKS 6800 RIVER ROAD, FAIRFIELD, OH 45014	SHEET TITLE: LEAD SHEET	DRAWN BY: NABIL DJAFI	DATE: 27-MAR-2023	PAGE # 1 of 19
			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E

SHEET LIST	
PAGE	CONTENTS
1	LEAD SHEET
2	SCHEDULE
3	EXISTING SITE LAYOUT
4	SITE LAYOUT WITH GAC BUILDING
5	HYDRAULIC PROFILE
6	EXISTING OVERALL P&ID
7	EXISTING FILTER P&ID
8	NEW SAND FILTER P&ID
9	FILTER BASEMENT
10	FILTER SECTION VIEW
11	FILTER DETAILS
12	GAC PUMP DETAILS
13	GAC BUILDING P&ID
14	GAC NE SECTION
15	GAC NW SECTION
16	GAC FLOOR PLAN
17	GAC SUBFLOOR PIPING
18	GAC DRAIN PIPING
19	GAC FACILITY DETAILS

GENERAL NOTES:

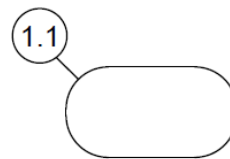
- THIS DRAWING SET DEPICTS THE ADDITION OF GAC TO THE DRINKING WATER TREATMENT PROCESS AT THE CHARLES M. BOLTON WATER TREATMENT PLANT FOR TREATMENT OF PFOS AND PFOA IN GROUND WATER.
- THIS DRAWING SET IS PREPARED EXCLUSIVELY FOR GREATER CINCINNATI WATER WORKS AND INTENDED SOLELY FOR PRELIMINARY DESIGN PURPOSES.
- EXISTING PLANT INFORMATION TAKEN FROM CHARLES M. BOLTON TREATMENT PLANT & PUMP STATION DRAWING SET PREPARED BY BLACK & VEATCH CONSULTING ENGINEERS, SEALED ON NOVEMBER 30TH, 1973. PLEASE REFER TO THIS DRAWING SET FOR COMPLETE PLANT DRAWINGS.
- THE SCOPE OF THE CAPSTONE PROJECT DOES NOT COVER ANY CIVIL, ELECTRICAL, MECHANICAL, OR CONTROL DESIGNS NEEDED FOR THE FINAL CONSTRUCTION OF THE GAC FACILITY.
- FOR ADDITIONAL INFORMATION, PLEASE REFER TO THE FALL 2022 DESIGN PROPOSAL AND SPRING 2023 FINAL REPORT FROM THE FOREFRONT CONSULTING CAPSTONE GROUP.
- ALL ELEVATION DATA REFERS TO ABOVE MEAN SEA LEVEL.
- CAPSTONE TEAM MEMBERS: ISABELLA ALTIER, NABIL DJAFI, RACHEL HARDTKE, JOSHUA MCLELLAND.

PUMP SCHEDULE							
TAG	DESCRIPTION	MAKE	MODEL	FLOW	HEAD	HP	OUT DIA
PU-1	GAC INFLUENT	FLYGHT	24x24x36 NSY	20 MGD	14 FT	70	30" FLANGE
PU-2	GAC INFLUENT	FLYGHT	24x24x36 NSY	20 MGD	14 FT	70	30" FLANGE
PU-3	GAC BACKWASH	FLYGHT	18x18x23 NSY	10 MGD	15 FT	33	20" FLANGE
PU-4	CHLORINATION	BLUE-WHITE	FLEX PRO A3B	0.01 TO 35 GPH	< 120 PSI	-	1/4" TUBING




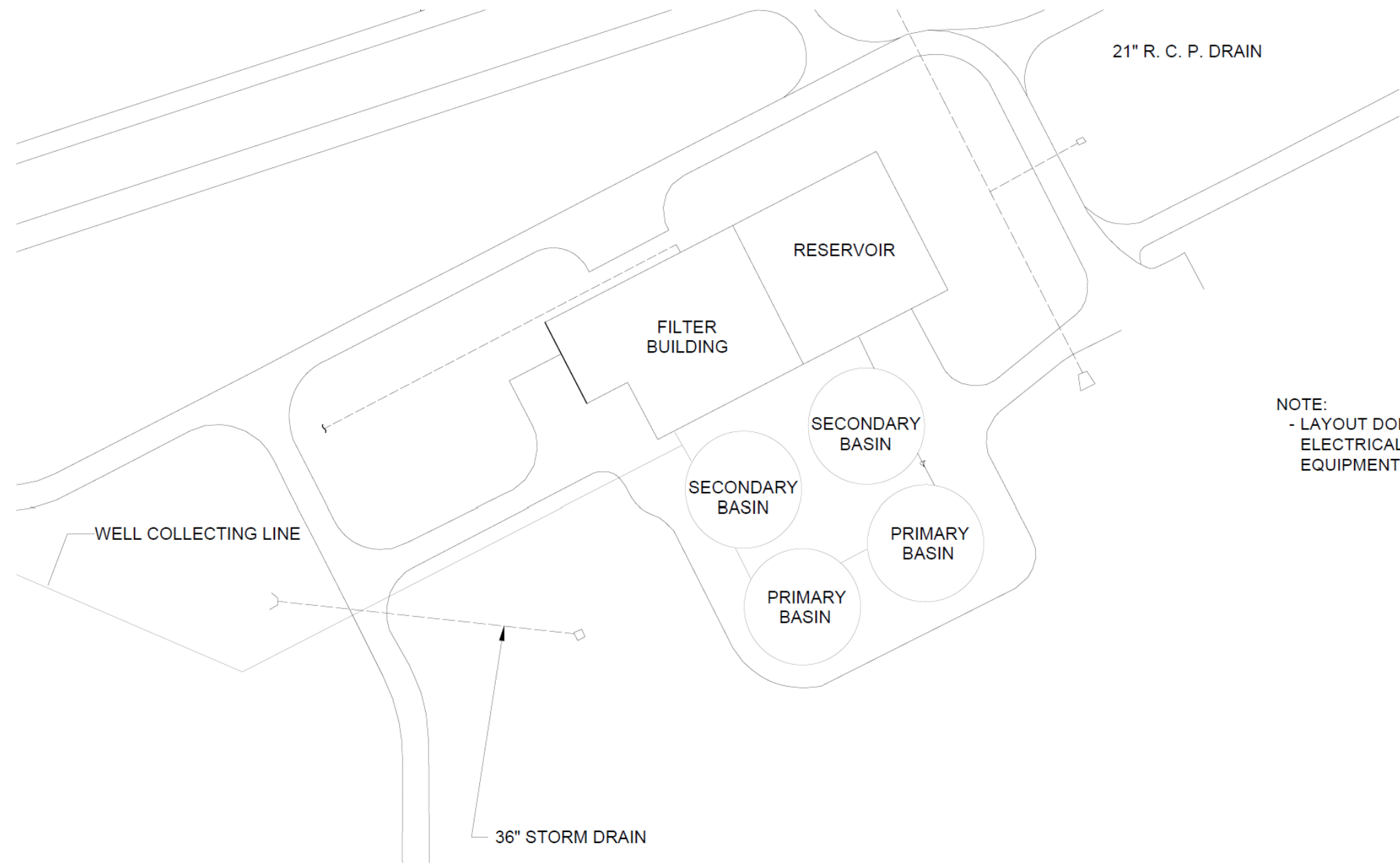
TAG DESCRIPTORS:
 - TOP LETTERS REFERS TO EQUIPMENT TYPE
 - BOTTOM NUMBER REFERS TO EQUIPMENT NUMBER

ACRONYMS:
 GAC - GRANULAR ACTIVATED CARBON
 IRON - DUCTILE IRON
 RMTP - RICHARD MILLER TREATMENT PLANT
 SS - STAINLESS STEEL
 TYP. - TYPICAL





DETAIL BUBBLE:
 - FIRST NUMBER REFERS TO PAGE NUMBER
 - SECOND NUMBER REFERS TO VIEWPORT NUMBER

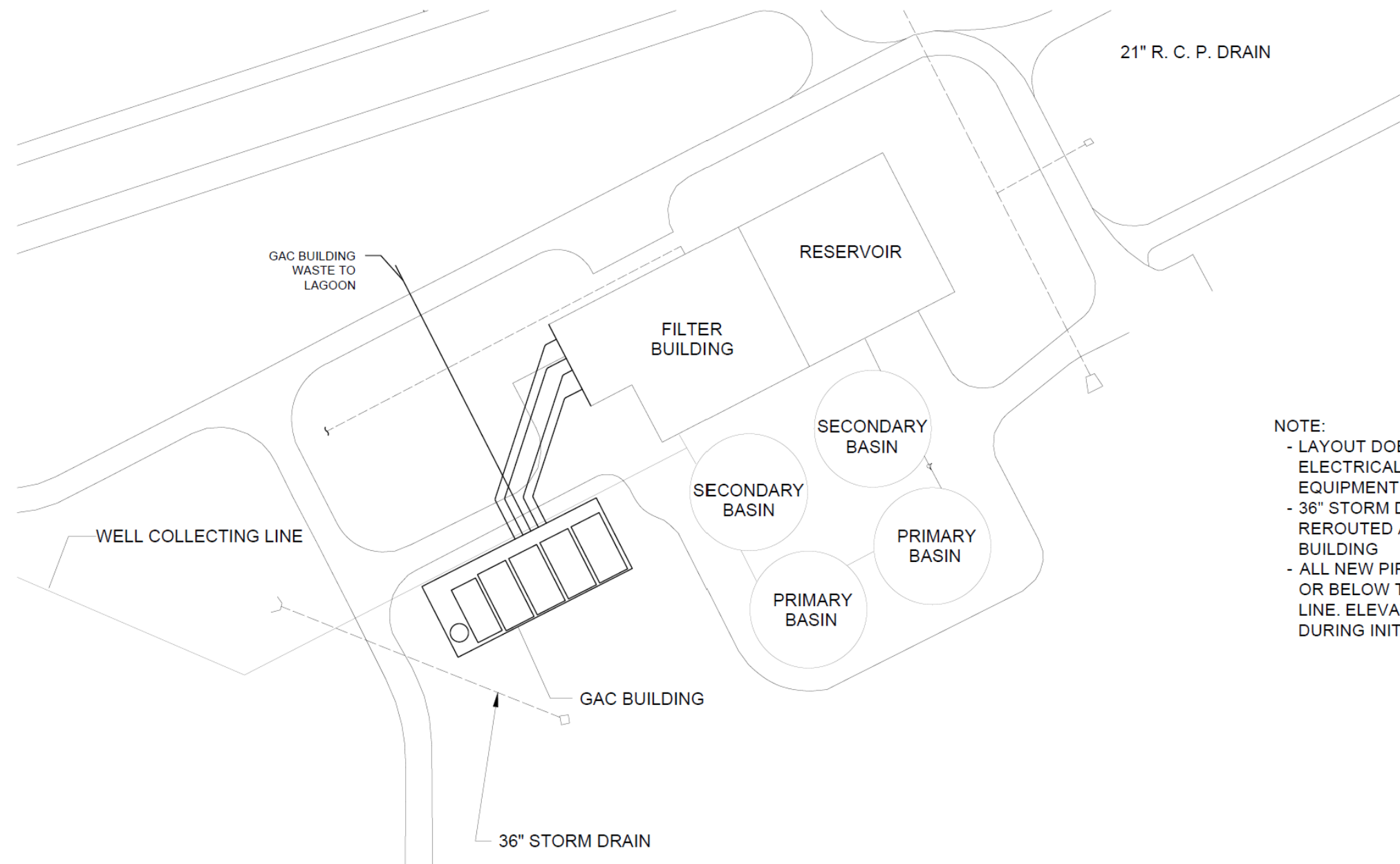
	DESIGNERS: FOREFRONT CONSULTING UNIVERSITY OF CINCINNATI COLLEGE OF ENGINEERING AND APPLIED SCIENCE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING SENIOR DESIGN CAPSTONE	PROJECT: CHARLES M BOLTON WATER PLANT GAC ADDITION FOR PFAS TREATMENT GREATER CINCINNATI WATER WORKS 6800 RIVER ROAD, FAIRFIELD, OH 45014	SHEET TITLE: SCHEDULE	DRAWN BY: NABIL DJAFI	DATE: 27-MAR-2023	PAGE # 2 of 19
			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



NOTE:
 - LAYOUT DOES NOT SHOW ANY ELECTRICAL OR OTHER PLANT EQUIPMENT

3.1 EXISTING LAYOUT
 SCALE: 1/128" = 1' 

	DESIGNERS: FOREFRONT CONSULTING UNIVERSITY OF CINCINNATI COLLEGE OF ENGINEERING AND APPLIED SCIENCE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING SENIOR DESIGN CAPSTONE	PROJECT: CHARLES M BOLTON WATER PLANT GAC ADDITION FOR PFAS TREATMENT GREATER CINCINNATI WATER WORKS 6800 RIVER ROAD, FAIRFIELD, OH 45014	SHEET TITLE: EXISTING SITE LAYOUT	DRAWN BY: NABIL DJAFI	DATE: 27-MAR-2023	PAGE # 3 of 19
			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



NOTE:
 - LAYOUT DOES NOT SHOW ANY ELECTRICAL, GAS, OR OTHER PLANT EQUIPMENT
 - 36" STORM DRAIN WILL NEED TO BE REROUTED AROUND NEW GAC BUILDING
 - ALL NEW PIPING WILL BE RUN ABOVE OR BELOW THE 62" PLANT INFLUENT LINE. ELEVATIONS MAY CHANGE DURING INITIAL CIVIL LAYOUT WORK

4.1 GAC LAYOUT
 SCALE: 1/128" = 1'



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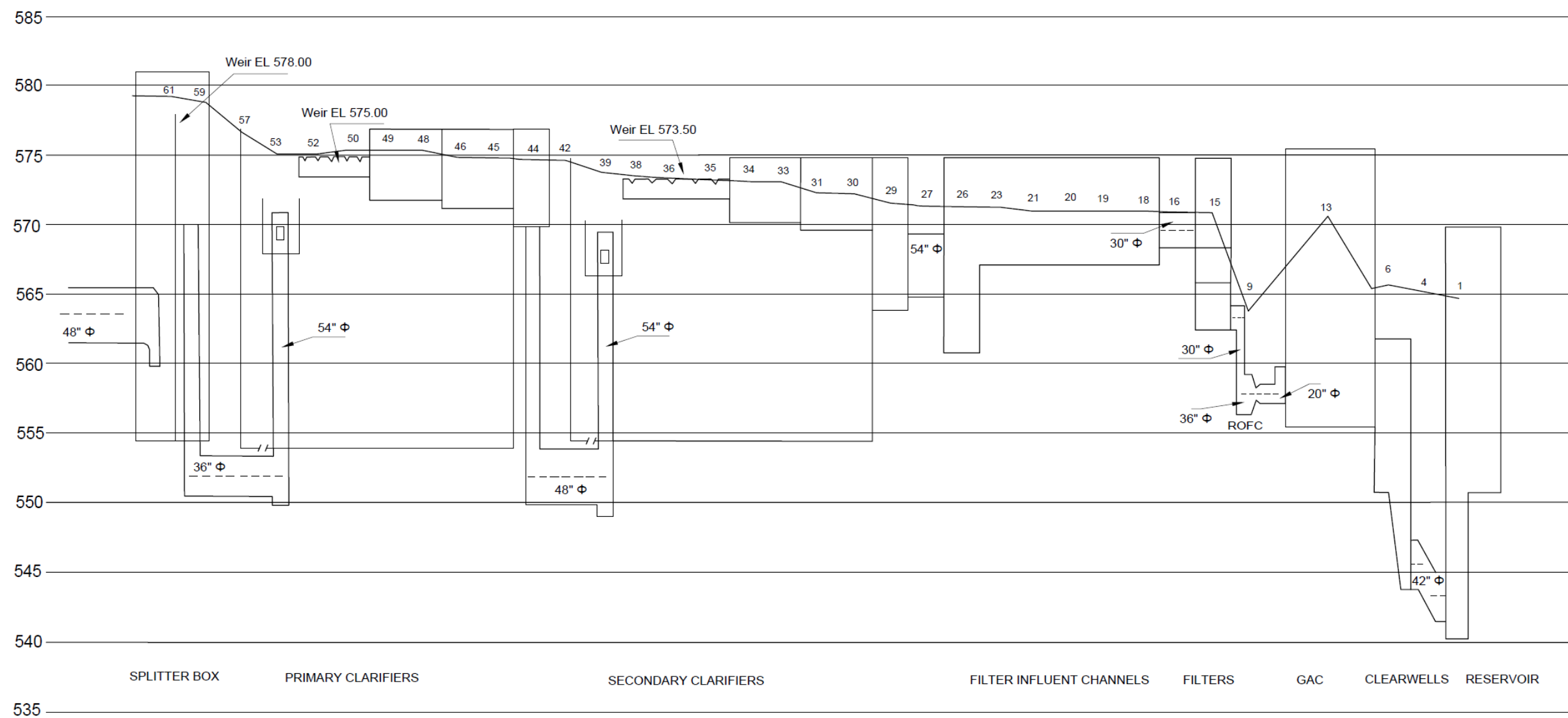
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
 FILTER BASEMENT SECTION
 PRELIMINARY

DRAWN BY:
 NABIL DJAFI
 REVIEWED BY:
 ISABELLA ALTIER

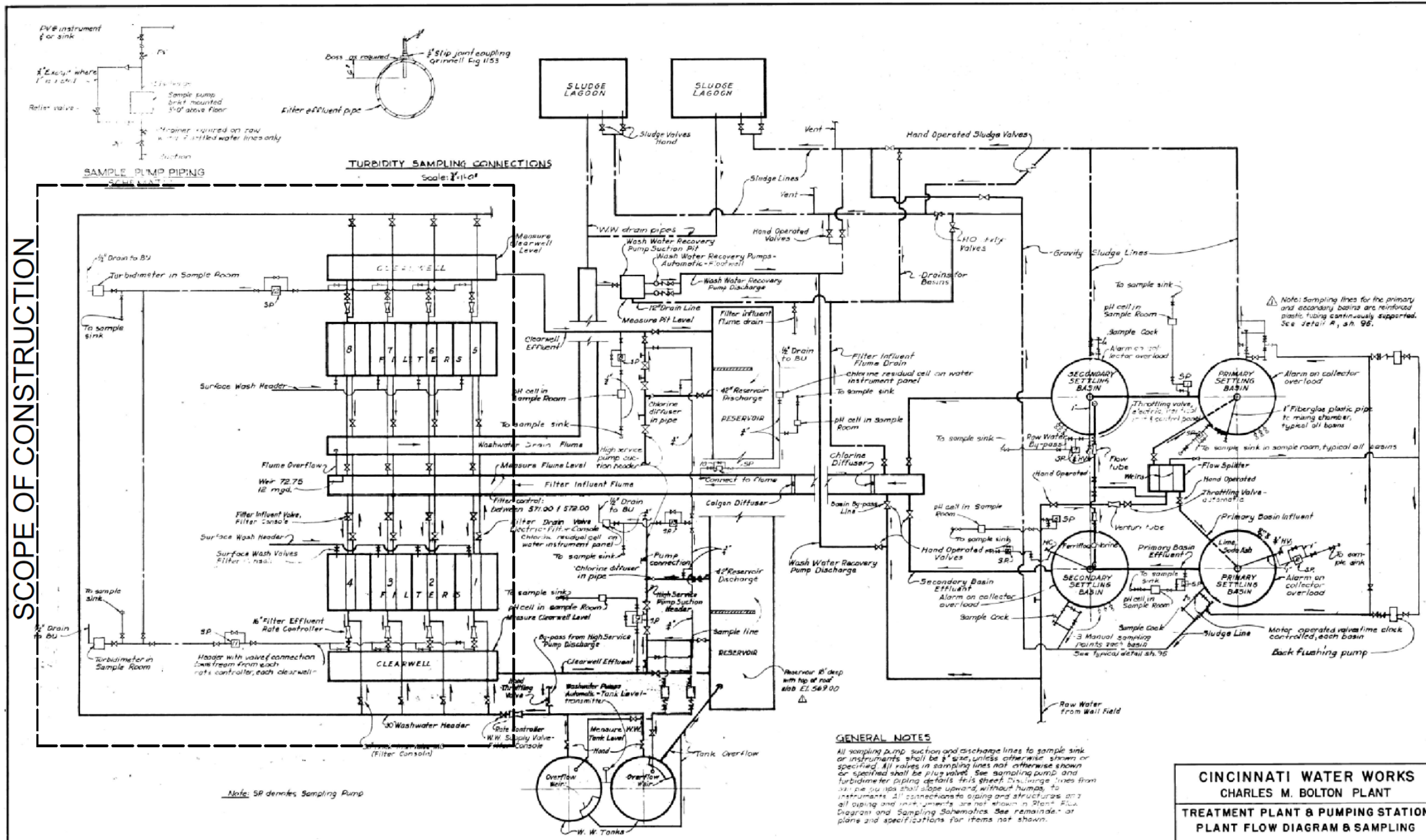
DATE:
 27-MAR-2023
 DATE:
 28-MAR-2023

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5.1 HYDRAULIC PROFILE
SCALE: N/A

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			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 07-MAR-2023	REV: E



SCOPE OF CONSTRUCTION

PLANT FLOW DIAGRAM AND SAMPLING SCHEMATICS

GENERAL NOTES
 All sampling pump suction and discharge lines to sample sink or instruments shall be 1/2" size, unless otherwise shown or specified. All valves in sampling lines not otherwise shown or specified shall be plug valves. See sampling pump and turbidimeter piping details this sheet. Discharge lines from all pumps shall slope upward, without humps, to instruments. All connections to piping and structures are as shown in Plan, P&ID, Diagram and Sampling Schematics. See remainder of plans and specifications for items not shown.

CINCINNATI WATER WORKS	
CHARLES M. BOLTON PLANT	
TREATMENT PLANT & PUMPING STATION	
PLANT FLOW DIAGRAM & SAMPLING	
BLACK & VEATCH CONSULTING ENGINEERS, KANSAS CITY, MO.	
DESIGNED: TMT	CHECKED: [Signature]
DATE: 2-23	APPROVED: [Signature]
SHEET 104 OF 154	

NO.	DATE	DESCRIPTION	BY
1	2-23	As Issued	TMT



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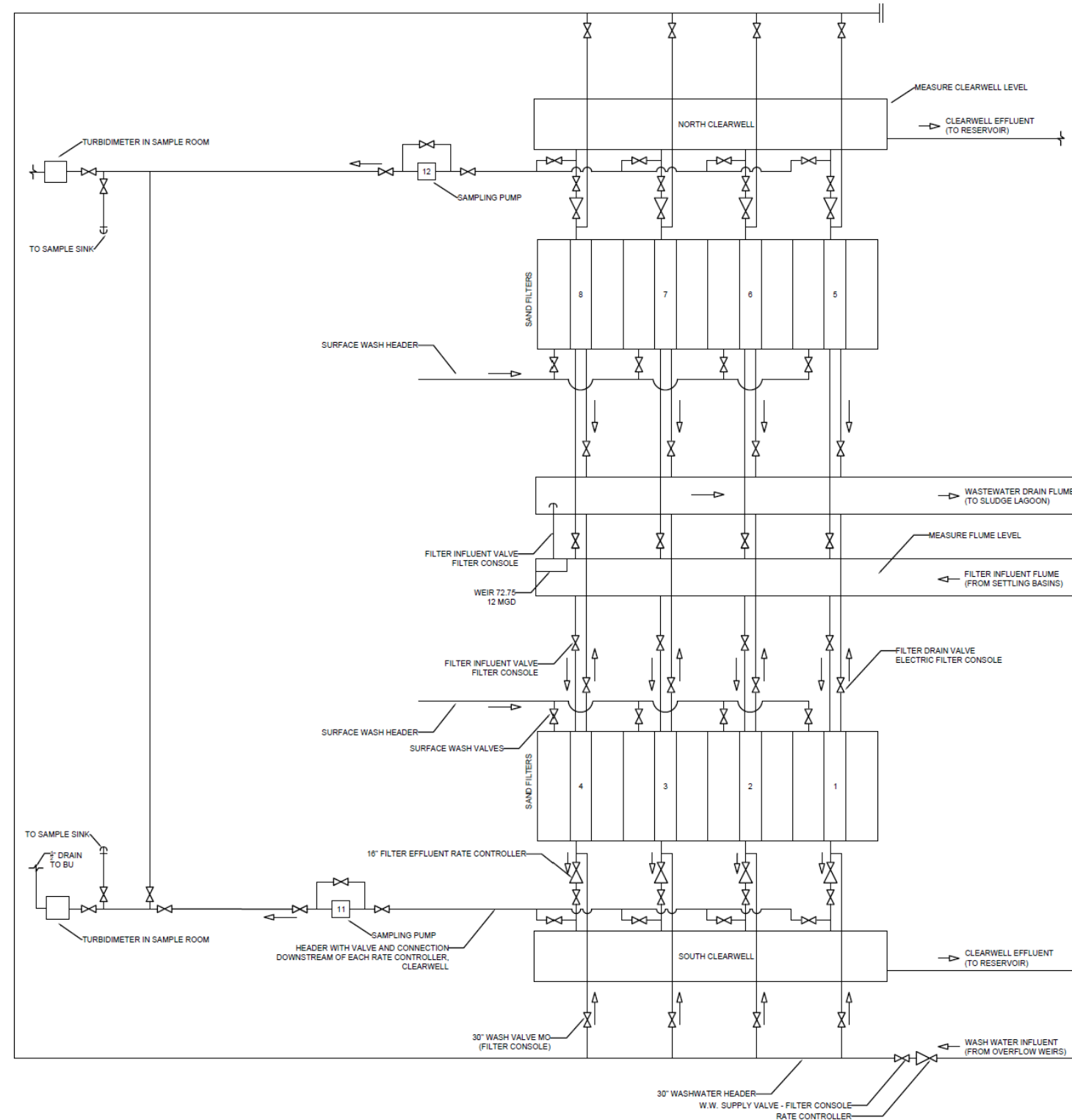
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
 EXISTING OVERALL P&ID
 PRELIMINARY

DRAWN BY:
 NABIL DJAFI
REVIEWED BY:
 ISABELLA ALTIER

DATE:
 27-MAR-2023
DATE:
 28-MAR-2023

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P&ID SYMBOLOGY

VALVE SYMBOLS	
EQUIPMENT	
	NON SPECIFIC PUMP
OTHER	
	FLOW DIRECTION
	LINE BREAK



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PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
 EXISTING FILTER BUILDING P&ID
 PRELIMINARY

DRAWN BY:
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REVIEWED BY:
 ISABELLA ALTIER

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 27-MAR-2023
DATE:
 28-MAR-2023

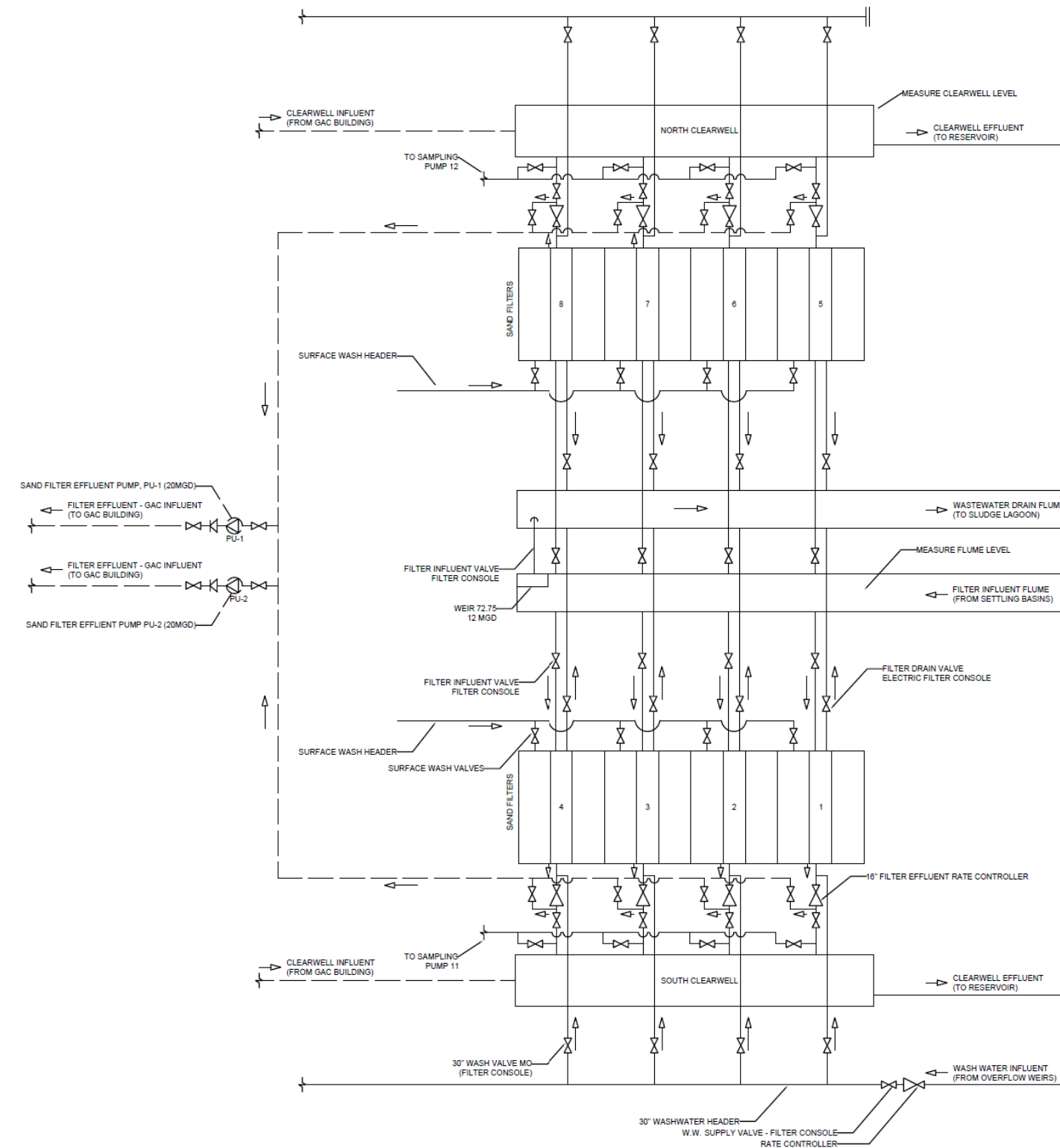
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REV:
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P&ID SYMBOLOGY

VALVE SYMBOLS	
	NON SPECIFIC (TYP. OPEN)
	NON SPECIFIC (TYP. CLOSED)
	CHECK VALVE
	RATE CONTROLLER
EQUIPMENT	
	NON SPECIFIC PUMP
OTHER	
	FLOW DIRECTION
	LINE BREAK

NOTES:

- DASHED LINES DENOTE ADDITIONS TO THE CURRENT PLANT
- SOLID LINES DENOTE EXISTING INFRASTRUCTURE
- REDUNDANT PUMPS AND PUMP VALVING FROM 10 STATE RECOMMENDED STANDARDS FOR WATERWORKS 2012 EDITION, SECTION 6.6.1



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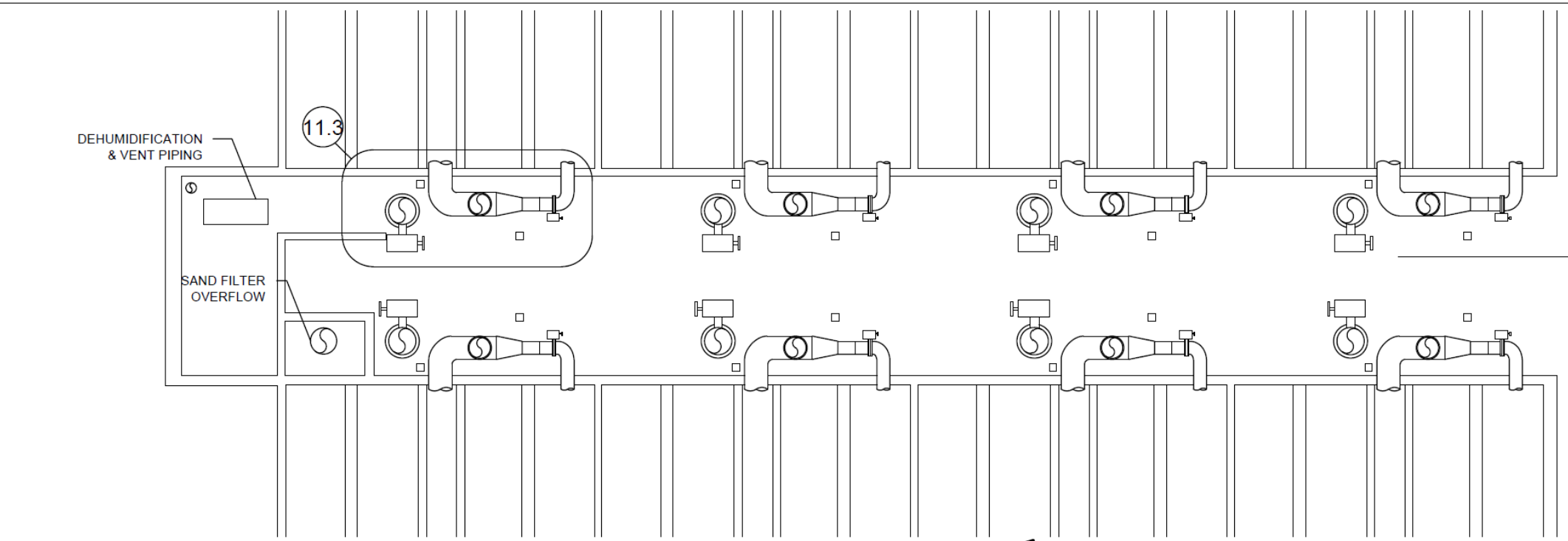
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
RENO FILTER BUILDING P&ID
 PRELIMINARY

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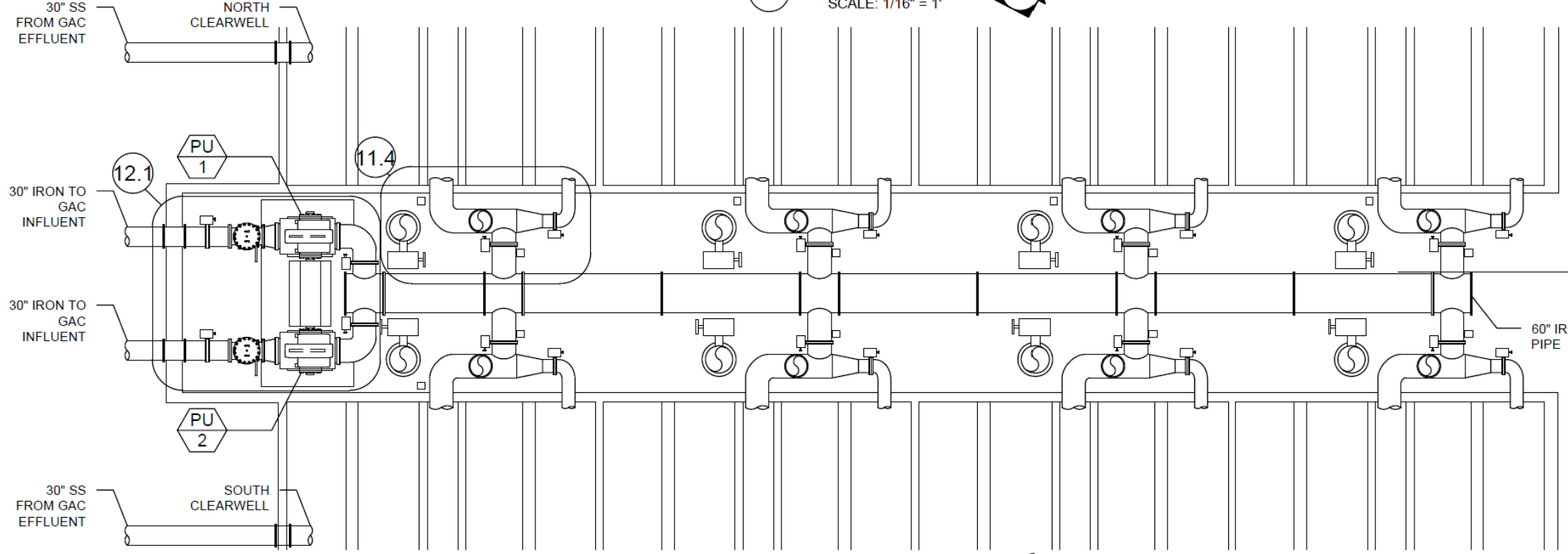
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28-MAR-2023

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NOTE:
 - EXISTING VIEW DOES NOT SHOW ALL MECHANICAL, ELECTRICAL, SAMPLING LINES, OR EQUIPMENT

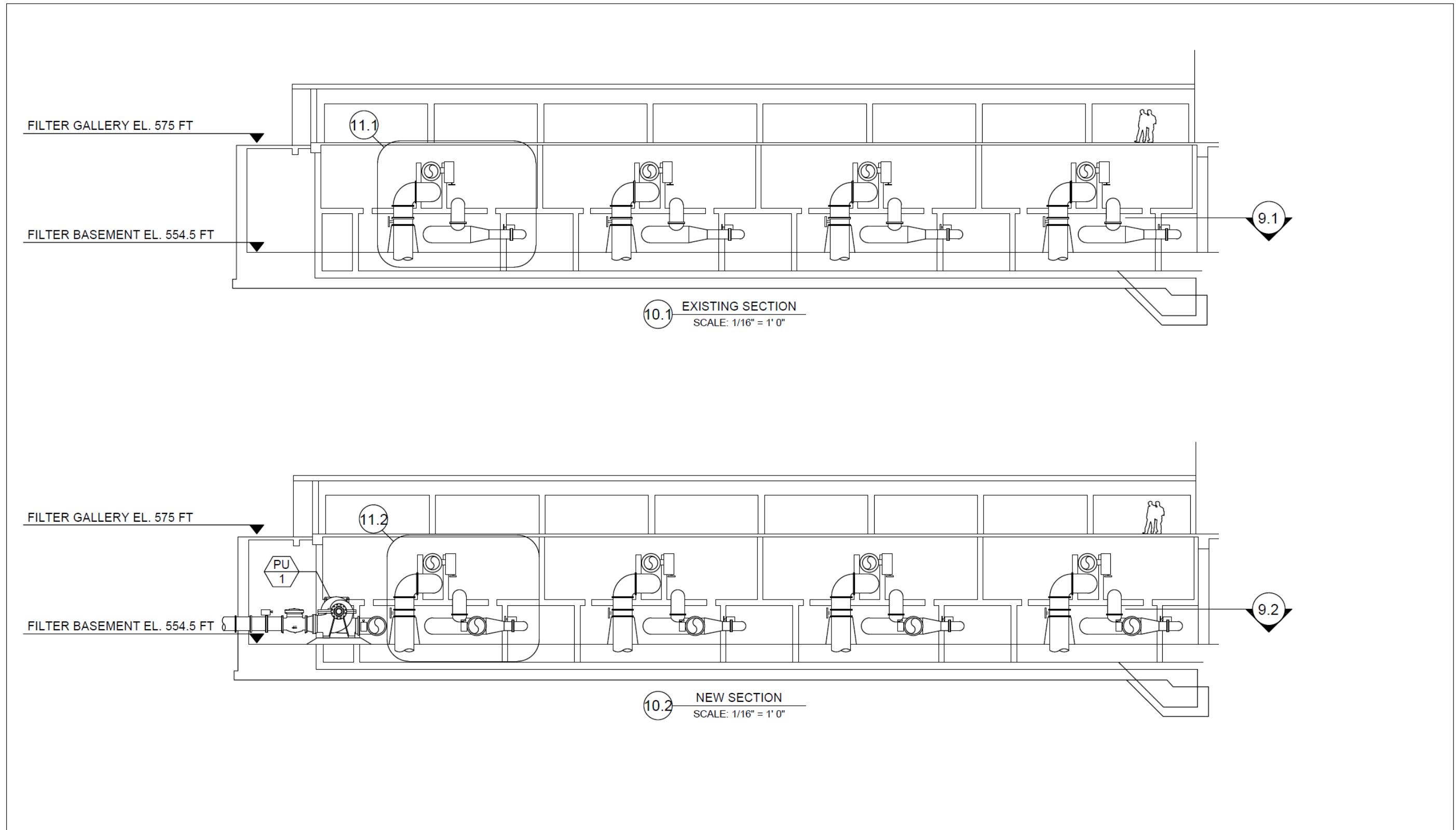
9.1 EXISTING BASEMENT
 SCALE: 1/16" = 1'




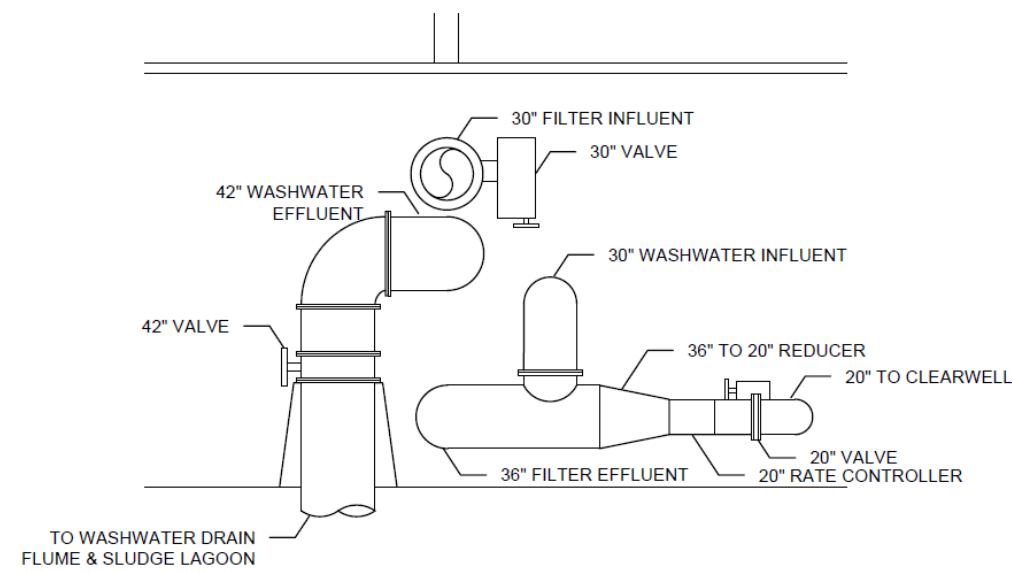
NOTE:
 - NEW GAC INFLUENT LINE WILL RUN AT 558', BELOW THE 30" WASHWATER LINE RUNNING THROUGH THE MIDDLE OF THE FILTER BASEMENT AT 569'
 - EXISTING DEHUMIDIFICATION, VENT PIPING, AND SAND FILTER OVERFLOW WILL NEED TO BE RE-ROUTED AROUND NEW GAC SERVICE PUMPS

9.2 NEW BASEMENT
 SCALE: 1/16" = 1'

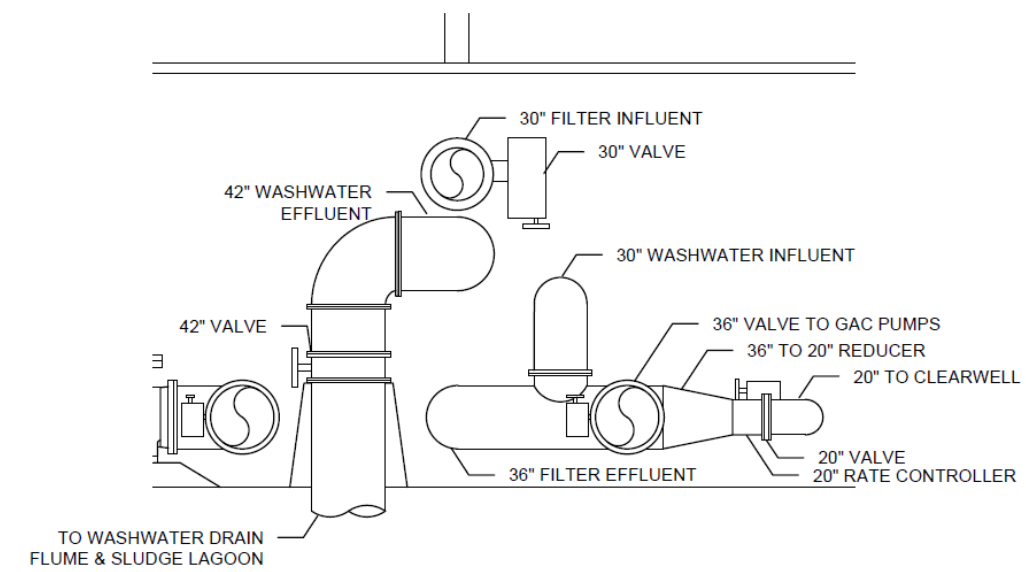
	DESIGNERS: FOREFRONT CONSULTING UNIVERSITY OF CINCINNATI COLLEGE OF ENGINEERING AND APPLIED SCIENCE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING SENIOR DESIGN CAPSTONE	PROJECT: CHARLES M BOLTON WATER PLANT GAC ADDITION FOR PFAS TREATMENT GREATER CINCINNATI WATER WORKS 6800 RIVER ROAD, FAIRFIELD, OH 45014	SHEET TITLE: FILTER BASEMENT	DRAWN BY: NABIL DJAFI	DATE: 27-MAR-2023	PAGE # 9 of 19
			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



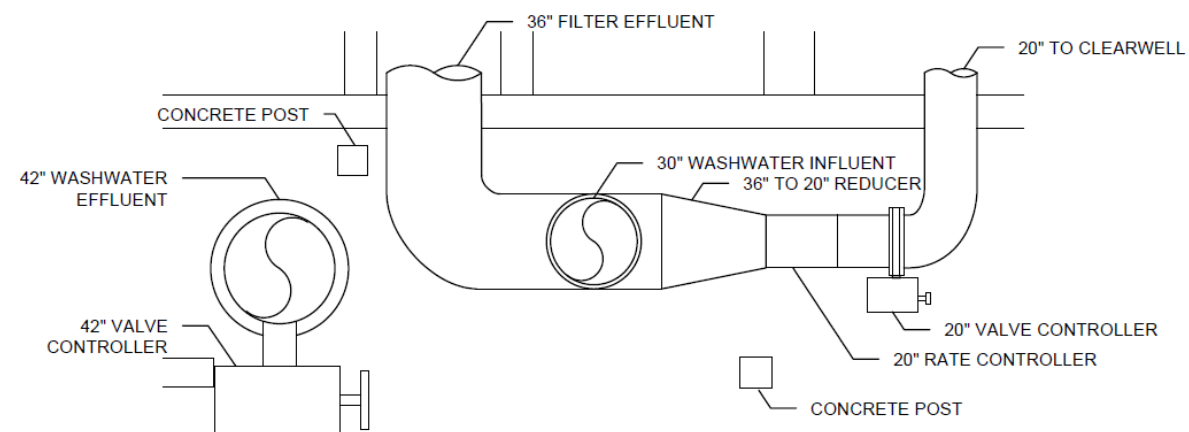
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			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



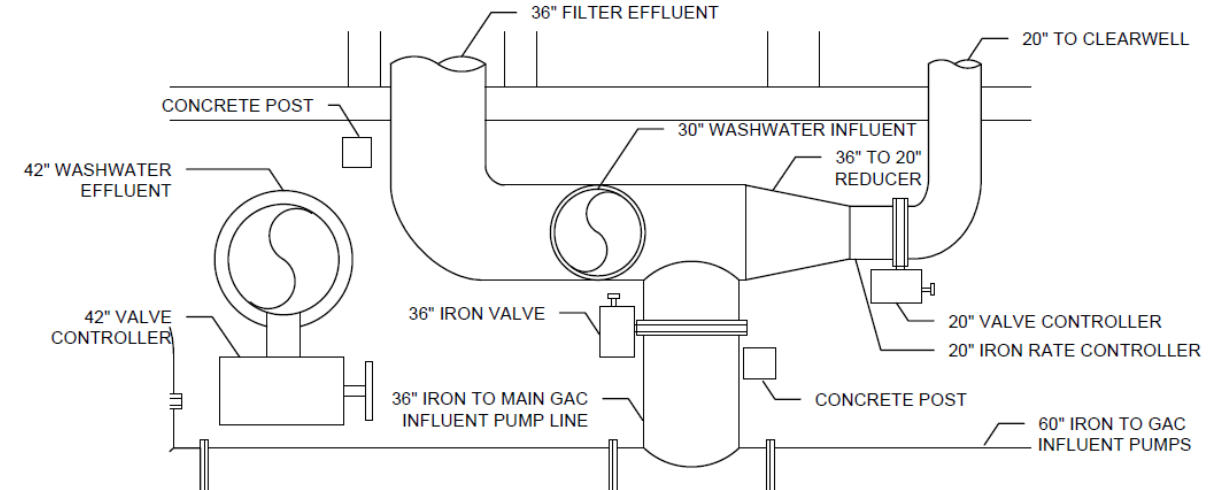
11.1 EXISTING SECTION
SCALE: 1/8" = 1'



11.2 NEW SECTION
SCALE: 1/8" = 1'



11.3 EXISTING FILTER
SCALE: 3/16" = 1' N



11.4 NEW FILTER
SCALE: 3/16" = 1' N



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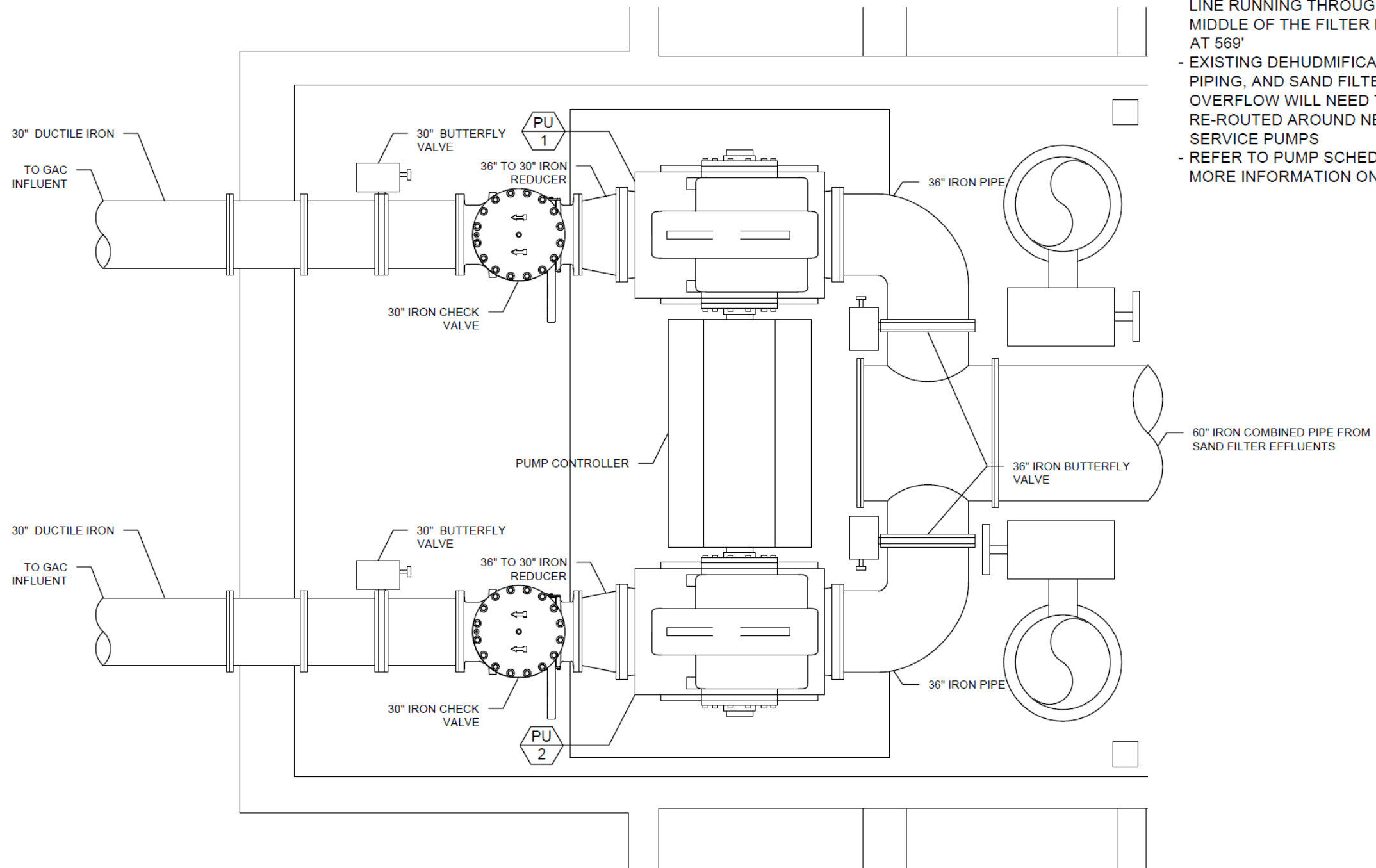
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
FILTER BASEMENT DETAILS
 PRELIMINARY

DRAWN BY:
NABIL DJAFI
 REVIEWED BY:
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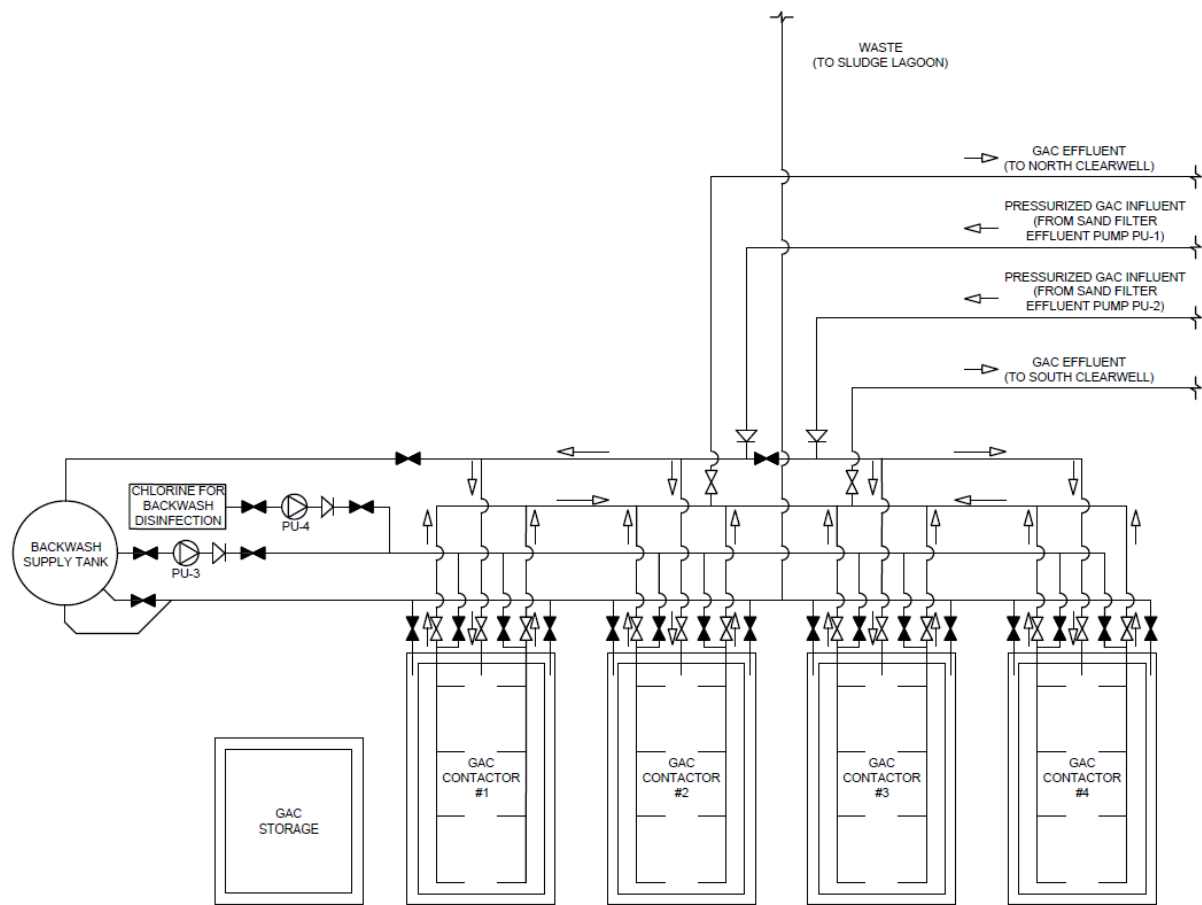


- NOTE:
- NEW GAC INFLUENT LINE WILL RUN AT 558', BELOW THE 30" WASHWATER LINE RUNNING THROUGH THE MIDDLE OF THE FILTER BASEMENT AT 569'
 - EXISTING DEHUMIDIFICATION, VENT PIPING, AND SAND FILTER OVERFLOW WILL NEED TO BE RE-ROUTED AROUND NEW GAC SERVICE PUMPS
 - REFER TO PUMP SCHEDULE FOR MORE INFORMATION ON PUMPS

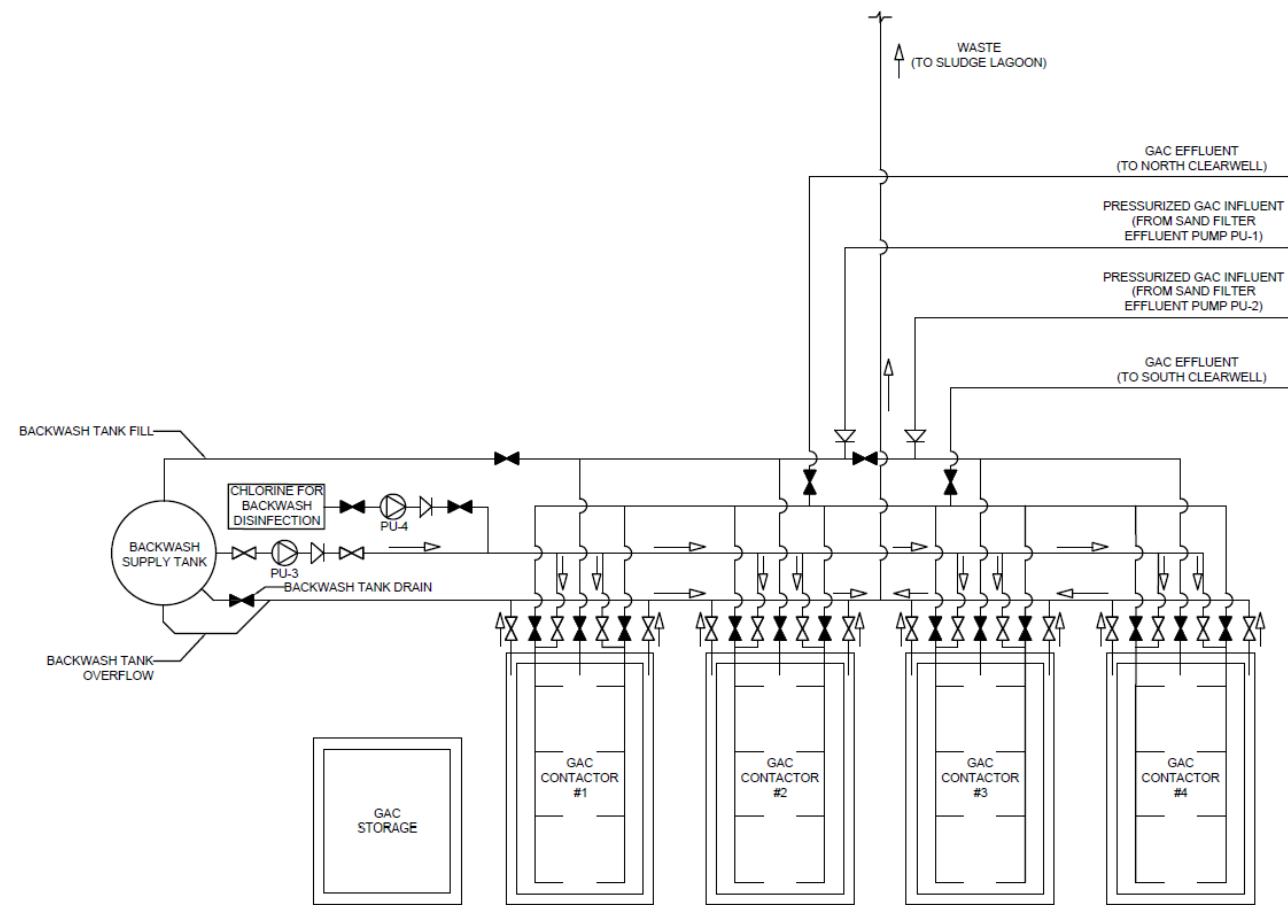
12.1 GAC PUMP DETAIL
SCALE: 1/4" = 1'



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			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



13.1 TREATMENT FLOW
SCALE: N/A



13.2 BACKWASH FLOW
SCALE: N/A

NOTES:

- ENTIRE GAC PROCESS IS NEW CONSTRUCTION
- LEFT DIAGRAM SHOWS FLOW DURING NORMAL TREATMENT
- RIGHT DIAGRAM SHOWS FLOW DURING BACK WASHING OF FILTERS
- BACKWASH WILL OCCUR BASED OFF OF GAC HEAD LOSS APPROXIMATELY EVERY 10 DAYS ACCORDING TO CURRENT GCWW OPERATIONS AT RMTP
- 45 DEGREE CONNECTION DENOTES TYP. GRAVITY FED LINE. VENT PIPING FOR BACKWASH SUPPLY TANK OVERFLOW & DRAIN NOT IN SCOPE

P&ID SYMBOLOGY

VALVE SYMBOLS	
⊗	NON SPECIFIC (TYP. OPEN)
◀	NON SPECIFIC (TYP. CLOSED)
⋈	CHECK VALVE
◁	RATE CONTROLLER
EQUIPMENT	
⊙	NON SPECIFIC PUMP
OTHER	
→	FLOW DIRECTION
⊥	LINE BREAK



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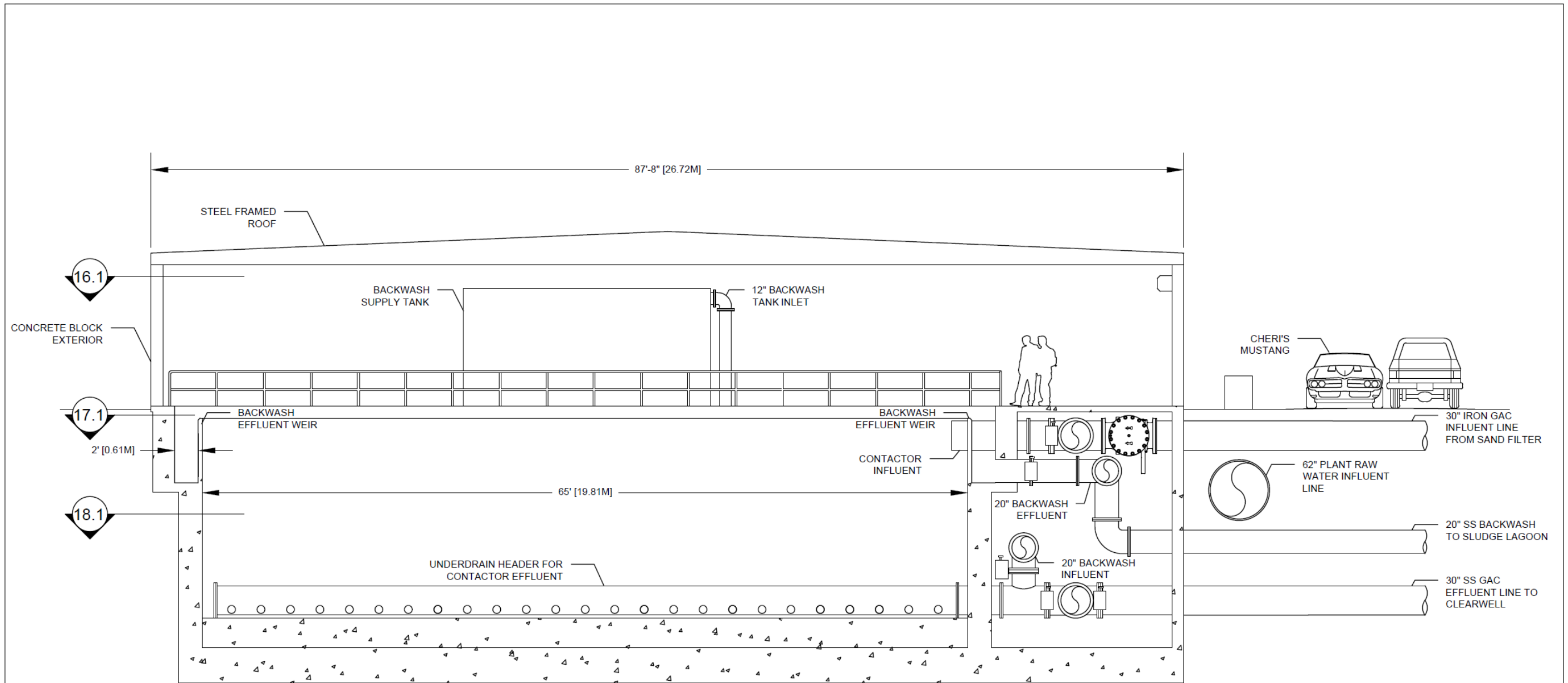
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
 NEW GAC BUILDING P&ID
 PRELIMINARY

DRAWN BY:
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 REVIEWED BY:
 ISABELLA ALTIER


DATE:
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 DATE:
 28-MAR-2023

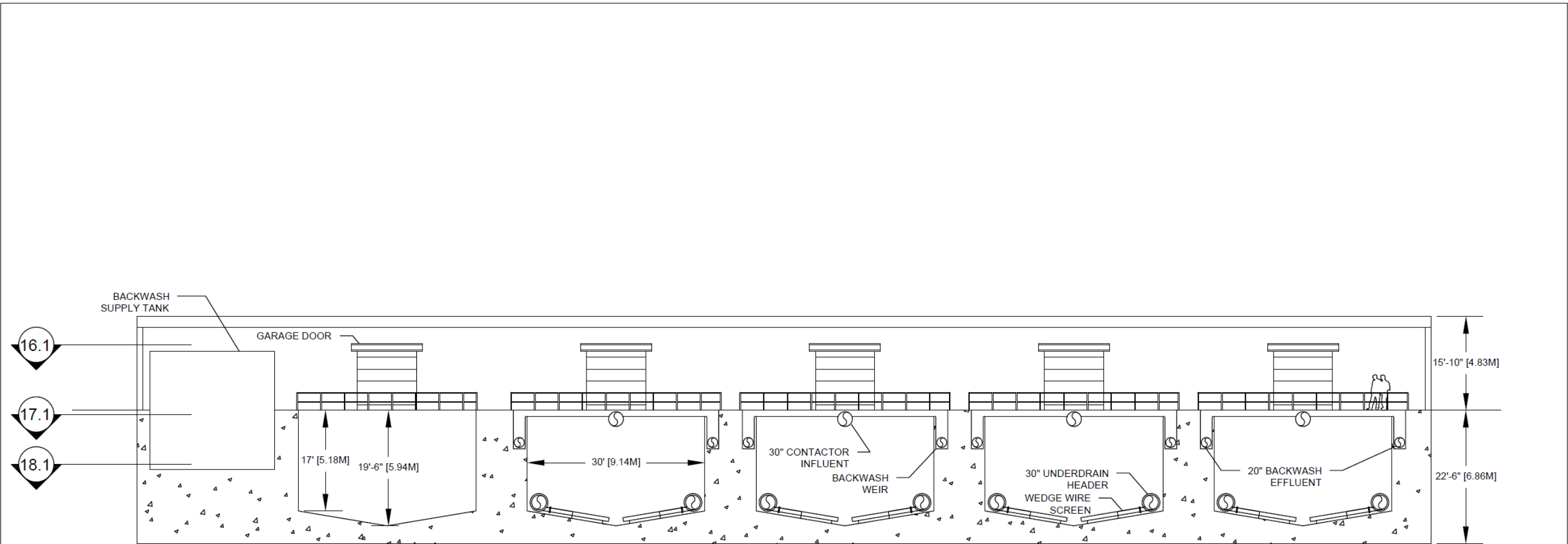
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14.1 GAC NE SECTION
SCALE: 1/8" = 1' 0"

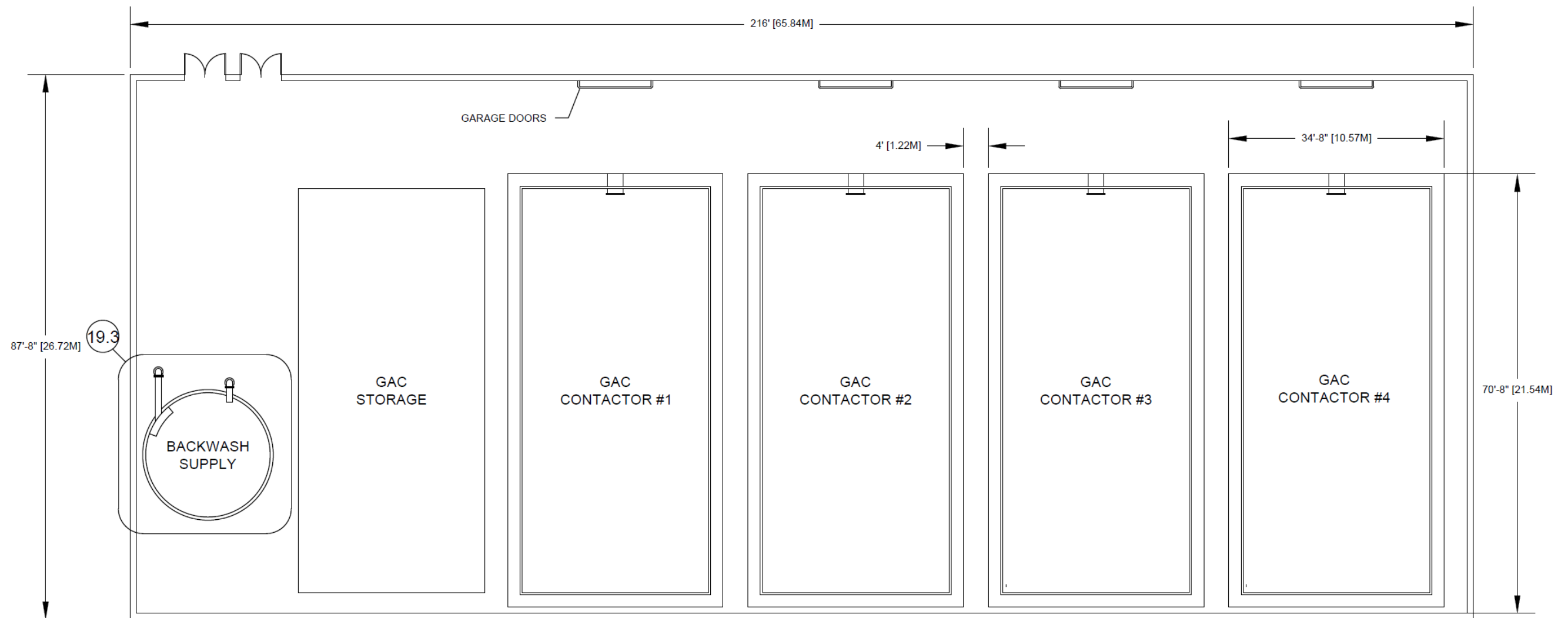
NOTE:
 - EXACT LOCATION OF PLANT WELL WATER INFLUENT LINE DEPENDANT ON A CIVIL SURVEY CONDUCTED BEFORE SITE DESIGN
 - BACKWASH WEIR HAS A UNIFORM DEPTH AND WIDTH ALONG ALL SIDES OF THE GAC CONTACTOR

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			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E




15.1 GAC NW SECTION
SCALE: 1/16" = 1' 0"

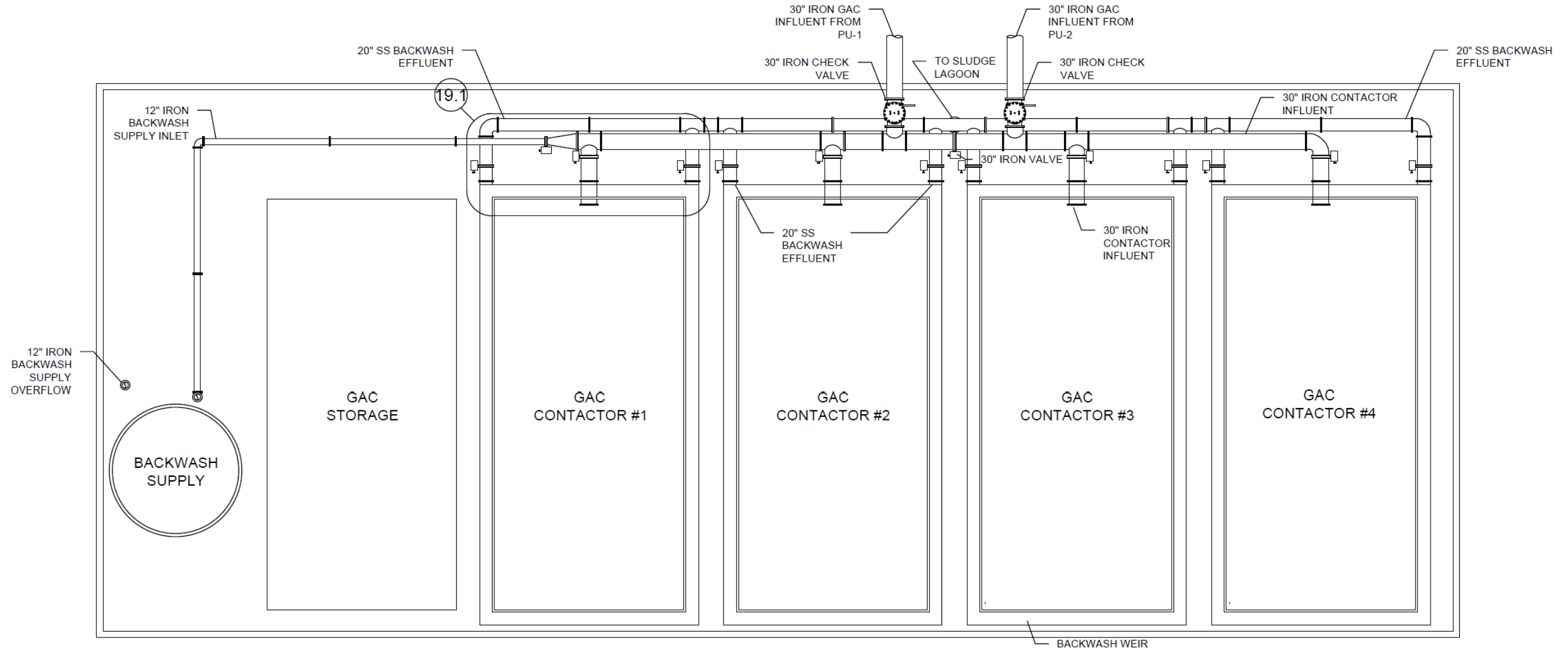
	DESIGNERS: FOREFRONT CONSULTING UNIVERSITY OF CINCINNATI COLLEGE OF ENGINEERING AND APPLIED SCIENCE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING SENIOR DESIGN CAPSTONE	PROJECT: CHARLES M BOLTON WATER PLANT GAC ADDITION FOR PFAS TREATMENT GREATER CINCINNATI WATER WORKS 6800 RIVER ROAD, FAIRFIELD, OH 45014	SHEET TITLE: NORTH WEST GAC SECTION	DRAWN BY: NABIL DJAFI	DATE: 27-MAR-2023	PAGE # 15 of 19
			PRELIMINARY	REVIEWED BY: ISABELLA ALTIER	DATE: 28-MAR-2023	REV: E



16.1 FLOOR PLAN
SCALE: 1/16" = 1' 0"

NOTE:
- GARAGE DOORS ALLOW EASY ACCESS FOR HEAVY EQUIPMENT TO TRANSPORT CARBON

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			<p>PRELIMINARY</p>	<p>REVIEWED BY: ISABELLA ALTIER</p>	<p>DATE: 28-MAR-2023</p>	<p>REV: E</p>



17.1 SUB FLOOR PLAN
SCALE: 1/16" = 1' 0"



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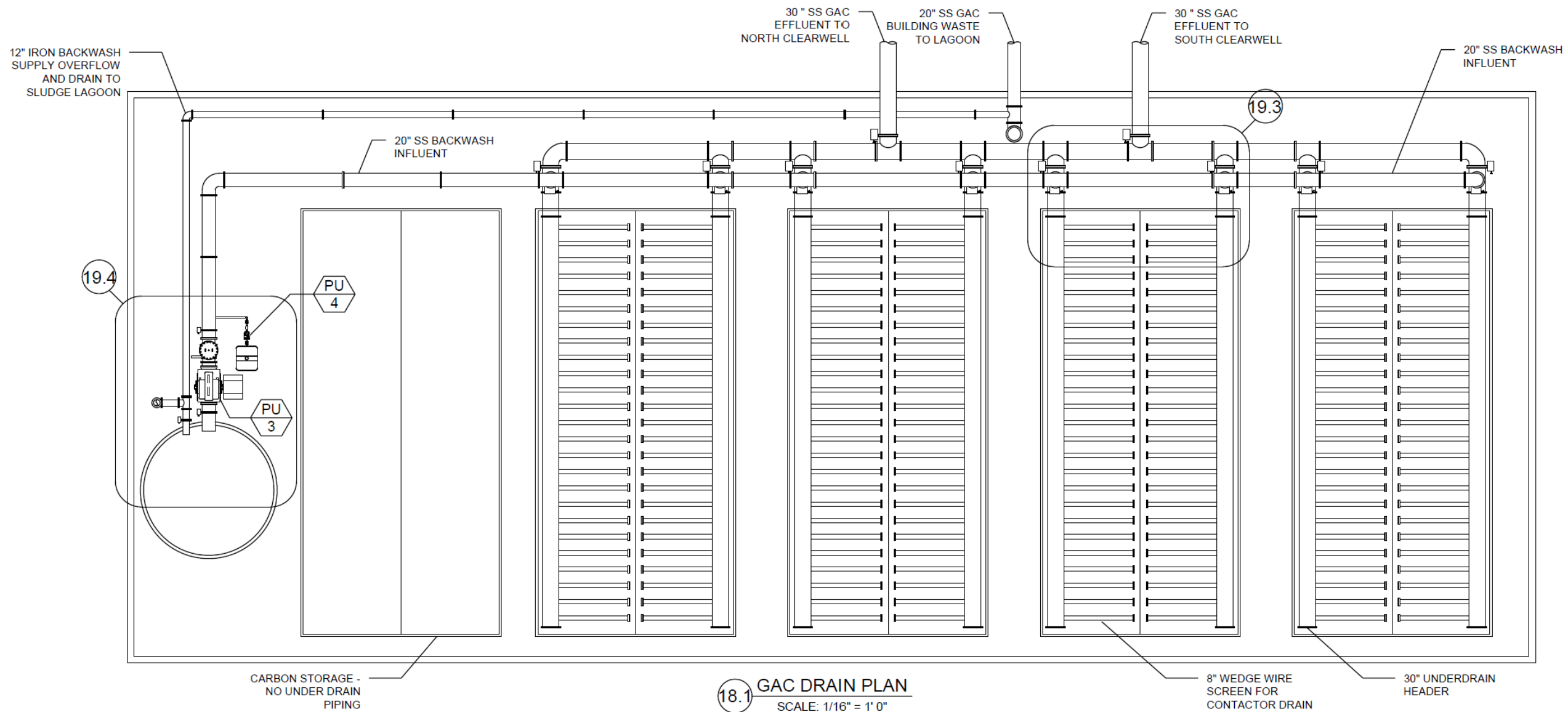
PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
GAC FACILITY SUBFLOOR PIPING
 PRELIMINARY

DRAWN BY:
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 REVIEWED BY:
 ISABELLA ALTIER


DATE:
 27-MAR-2023
 DATE:
 28-MAR-2023

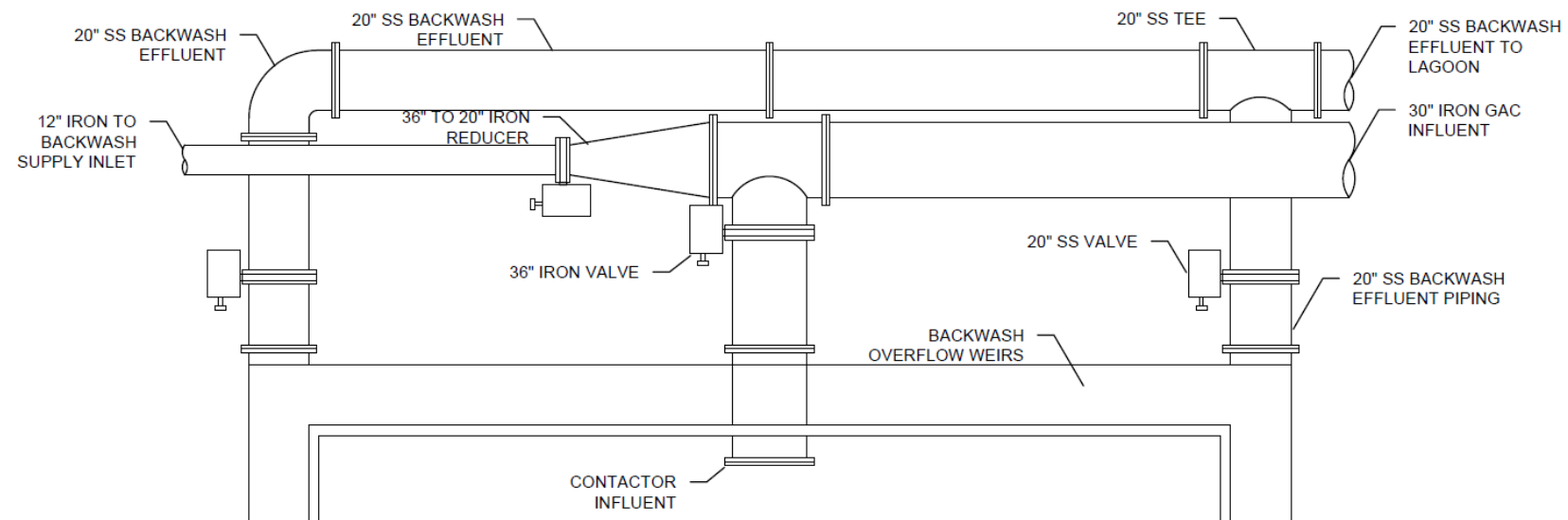
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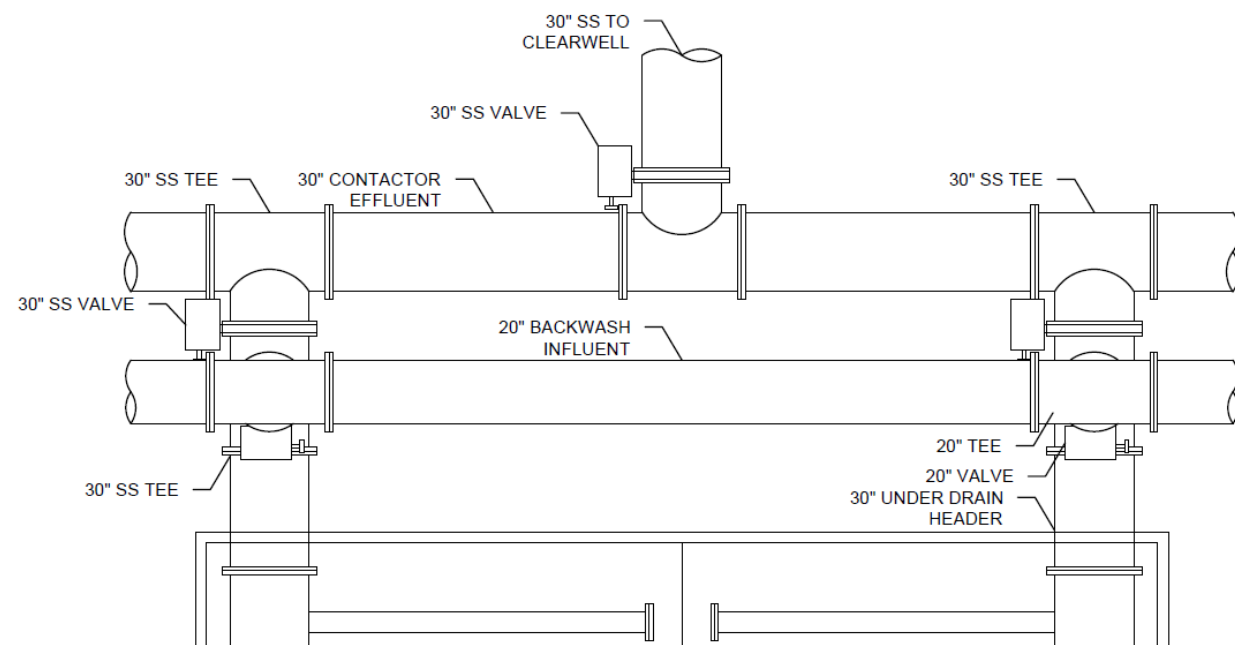
18.1 GAC DRAIN PLAN
SCALE: 1/16" = 1' 0"

NOTE:
- EACH UNDER DRAIN WILL CONSIST OF 50, 8" WEDGE WIRE SCREENS SPACED 30" APART AND 12' IN LENGTH

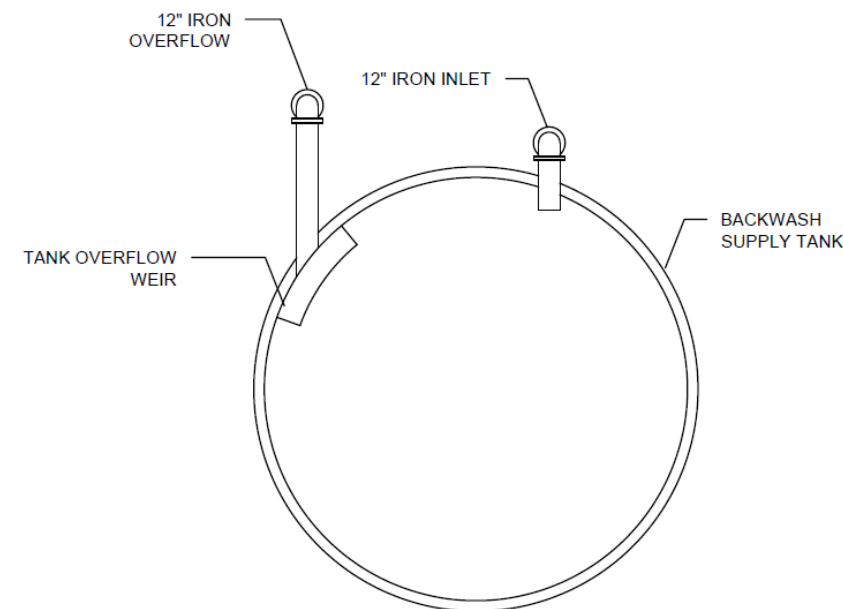
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				<p>PRELIMINARY</p>	<p>REVIEWED BY: ISABELLA ALTIER</p>	<p>DATE: 28-MAR-2023</p>



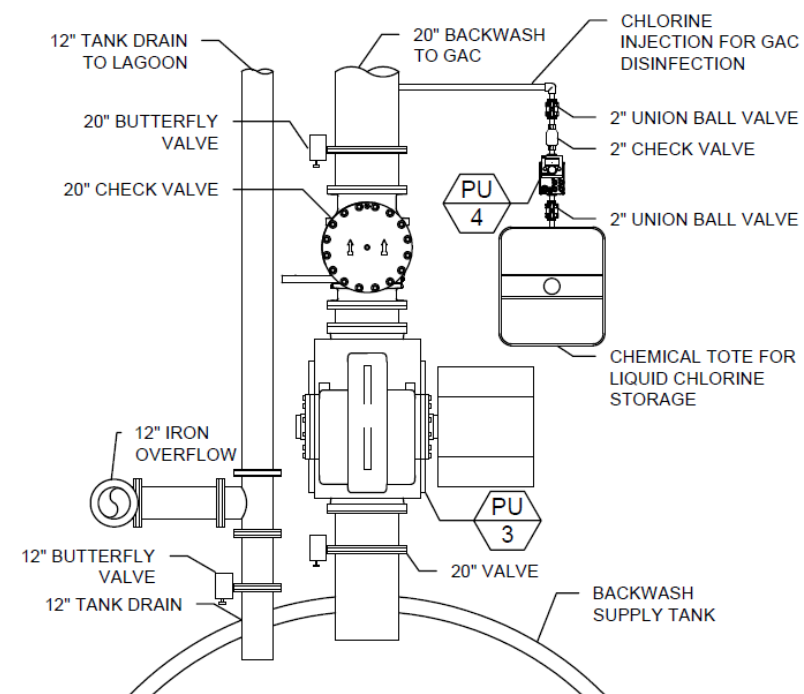
19.1 GAC INLET
SCALE: 3/16" = 1' 0"



19.3 GAC DRAIN
SCALE: 3/16" = 1' 0"



19.2 SUPPLY INLET
SCALE: 1/8" = 1' 0"



19.4 SUPPLY DRAIN
SCALE: 1/8" = 1' 0"



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 SENIOR DESIGN CAPSTONE

PROJECT:
CHARLES M BOLTON WATER PLANT
 GAC ADDITION FOR PFAS TREATMENT
 GREATER CINCINNATI WATER WORKS
 6800 RIVER ROAD, FAIRFIELD, OH 45014

SHEET TITLE:
 GAC BOTTOM
 PRELIMINARY

DRAWN BY:
 NABIL DJAFI
REVIEWED BY:
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DATE:
 27-MAR-2023
DATE:
 28-MAR-2023

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9.7 Calculations

GAC Filter Calculations

GCWW wants the GAC to have an empty bed contact time (EBCT) of 20 minutes. Based on this number and the plant's maximum flow capacity, we found the total volume of GAC needed for all four contactors.

$$\begin{aligned} \text{Total Volume of GAC (ft}^3\text{)} &= \frac{\text{EBCT} \cdot \text{Flow Rate}}{7.481 \frac{\text{gal}}{\text{ft}^3}} = \frac{20 \text{ min} \cdot \frac{1 \text{ day}}{1440 \text{ min}} \cdot 40 \cdot \frac{10^6 \text{ gal}}{\text{day}}}{7.481 \frac{\text{gal}}{\text{ft}^3}} \\ &= 74,262.2 \text{ ft}^3 \end{aligned}$$

To find the bed depth needed for each contactor, we assumed that our contactors would have the same area as the contactors at the RMTP. These dimensions are 30 ft by 65 ft. The total volume of GAC must be divided by the number of contactors to get the volume of each contactor.

$$\text{Bed Depth (ft)} = \frac{\frac{\text{Total Volume of GAC (ft}^3\text{)}}{\# \text{ of contactors}}}{\text{Filter Bed Area}} = \frac{\frac{74,262.2 \text{ ft}^3}{4 \text{ contactors}}}{(30 \text{ ft} \cdot 65 \text{ ft})} = 9.52 \text{ ft}$$

Backwash Calculations

Backwashing the GAC contactors will occur with one contactor at a time. This means that the flow rate will be one-fourth of the total plant flow rate, 10 MGD.

$$\text{Backwash Rate} = \frac{\text{Flow Rate}}{\text{Filter Area}} = \frac{\frac{1 \text{ day}}{1440 \text{ min}} \cdot 10 \cdot \frac{10^6 \text{ gal}}{\text{day}}}{30 \text{ ft} \cdot 65 \text{ ft}} = 3.56 \frac{\text{gpm}}{\text{ft}^2}$$

To determine how large of a backwash supply tank we needed, we calculated the gallons of water used per ft² of filter, assuming backwash would take 15 minutes. Then we determined the total gallons needed based on the total area of the filter.

$$\text{Gallons of water used per ft}^2 \text{ of filter} = \text{Backwash Rate} \cdot \text{Backwash Time}$$

$$\text{Gallons of water used per ft}^2 \text{ of filter} = 3.56 \frac{\text{gpm}}{\text{ft}^2} \cdot 15 \text{ minutes} = 53.41 \frac{\text{gal}}{\text{ft}^2}$$

$$\text{Gallons required for backwash} = \text{Gallons of water used per ft}^2 \text{ of filter} \cdot \text{Area of filter}$$

$$\text{Gallons required for backwash} = 53.41 \frac{\text{gal}}{\text{ft}^2} \cdot (30 \text{ ft} \cdot 65 \text{ ft}) = 104,166 \text{ gallons}$$

Pipe Sizing and Pumping Head Calculations

Pumps to GAC to Clearwells

The below calculations were performed to calculate the pipe diameter and pump head needed for the system starting at the new pump from the existing building after the sand filters, to the GAC building and through the GAC contactors, and back to the clear wells.

We propose to add two pumps with flows of 20 mgd each. The water will be pumped in two separate pipes from the sand filters to the GAC building. The water will filter through the GAC and be carried to the clearwells in two separate pipes, one emptying into the north clearwell and one into the south clearwell.

The calculations were performed in Microsoft excel using solver.

Flow

The flow in one loop of the system is 20 mgd which is half of the maximum flow capacity, 40 mgd. Converting this to m³/s:

$$Q \left(\frac{m^3}{s} \right) = 20000000 \frac{gal}{day} \cdot \frac{1 m^3}{264.17 gal} \cdot \frac{1 day}{24 hr} \cdot \frac{1 hr}{3600 s} = 0.8763 \frac{m^3}{s}$$

Hazen William Coefficient

The pipe from the pump to the GAC filters will be made of ductile iron and the pipe from the GAC filters to the clearwells will be made of stainless steel due to its high durability and high abrasion from the fine GAC particles. The roughness coefficient of ductile iron is 130 and the roughness coefficient of stainless steel is 100. For the purpose of the headloss calculations, we used the lower roughness coefficient of stainless steel.

Pipe Length

Pump to GAC influent

The horizontal distance from the pump to the GAC influent is 190 feet. The elevation of the pump is 556 feet, and the elevation of the GAC influent is 576 feet, making the vertical distance 20 feet. Using Pythagorean theorem to find the distance from the pump to the GAC influent, we obtained a distance of 191 feet.

$$d = \sqrt{190^2 + 20^2} = 191$$

GAC effluent to Clearwells

The horizontal distance from the GAC effluent to the clearwells is 266 feet. The elevation of the GAC effluent is 566 feet and the elevation of the clearwells is 556 feet, making the vertical distance 10 feet. Using Pythagorean theorem to find the distance from the GAC effluent to the clearwells, we obtained a distance of 266 feet.

$$d = \sqrt{266^2 + 10^2} = 266$$

The headloss calculation was performed for the loop from the pump to GAC influent, through GAC effluent, and to the clearwells. This loop makes the total pipe length:

$$Pipe Length (ft) = 191 + 266 = 457 \text{ feet } Pipe Length (m) = 457 \text{ feet} \cdot \frac{0.3048 m}{1 ft} = 139.2936 m$$

Elevation Start and End

The elevation of the pump and the elevation of the clearwells are the same at 556 feet. Converting this to meters:

$$\text{Elevation (m)} = 556 \text{ feet} \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 169.4688 \text{ m}$$

Minor Losses

The pipe from the pump to the GAC influent will have two check valves, fully open; two butterfly valves, fully open; two 45-degree elbows, flanged; one 90-degree elbow, flanged; and one tee, dividing line flow. The minor loss coefficients for this pipe are:

Component	Coefficient	Quantity	Total Coefficient
Check valve, fully open	2	2	4
Butterfly valve, fully open	0	2	0
45-degree elbow, flanged	0.2	2	0.4
Tee, branch flow	1	2	2
Tee, dividing line flow	0.2	1	0.2

The pipe from the GAC effluent to the clearwells will have two butterfly valves, fully open; two tees, branch; and two 45-degree elbows, flanged. The minor loss coefficients for this pipe are:

Component	Coefficient	Quantity	Total Coefficient
Butterfly valve, fully open	0	2	0
Tee, branch	1	2	2
45-degree elbow, flanged	0.2	2	0.4

The total minor loss coefficient is the sum of all the minor losses:

$$\text{Minor Loss Coefficient} = 4 + 0 + 0.4 + 2 + 0.2 + 0 + 2 + 0.4 = 9$$

Pressure Loss through GAC

To find the pressure drop through GAC, we used the Filtrasorb 400 fact sheet typical pressure drop graph. In the system loop, two GAC contactors would be getting 20 mgd of flow so using a flow of 20 mgd, we calculated flow in gallons per minute.

$$\text{Flow (gpm)} = \frac{20000000 \text{ gal}}{\text{day}} \cdot \frac{1 \text{ day}}{24 \text{ hours}} \cdot \frac{1 \text{ hour}}{60 \text{ minutes}} = 13889 \text{ gpm}$$

The dimensions of the GAC contactor are 30 feet by 65 feet. The area of the contactor is:

$$\text{Area GAC Contactor (ft}^2\text{)} = 35 \text{ ft} \cdot 65 \text{ ft} = 1950 \text{ ft}^2$$

The superficial velocity in gpm/ft² is:

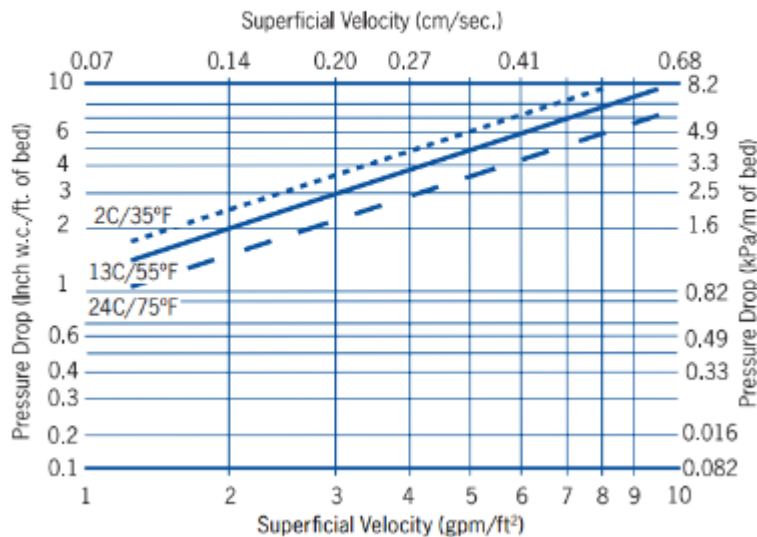
$$\text{Superficial Velocity } \left(\frac{\text{gpm}}{\text{ft}^2} \right) = \frac{13889 \text{ gpm}}{1950 \text{ ft}^2} = 7.1225$$

Locating this superficial velocity on the graph, the pressure drop is 7 inch w.c./ft of bed. The depth of the bed is 9.52 feet which makes the total pressure drop through the GAC:

$$\text{Total Pressure Drop (m)} = \frac{7 \text{ inch w.c.}}{\text{ft of bed}} \cdot 9.52 \text{ feet} \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 1.6927 \text{ m}$$

Typical Pressure Drop

Based on a backwashed and segregated bed



Pressure Start and End

Pressure Start

The starting pressure was calculated by finding the difference between the elevation of the hydraulic grade line (HGL) and the elevation at the pump. The elevation of the HGL at the pump is 564 feet and the elevation of the pump is 556 feet. Therefore, the pressure start is:

$$\text{Pressure Start (m)} = (564 \text{ ft} - 556 \text{ ft}) \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 2.4384 \text{ m}$$

Pressure End

The ending pressure was calculated by finding the difference between the elevation of the HGL and the elevation where the pipe will enter the clearwell. The elevation of the HGL at the clearwell is 564.5 feet and the elevation of the clearwell is 556 feet. Therefore, the pressure end is:

$$\text{Pressure End (m)} = (564.5 \text{ ft} - 556 \text{ ft}) \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 2.5908 \text{ m}$$

Velocity Start

We assumed that the pump inlet size was 16 inches but we will finalize this value once we finalize a pump. For the starting velocity, we assumed a value of 2.1 m/s and this value will not significantly affect the calculated pipe diameter and pumping head.

Velocity

The velocity was used as a constraint when calculating the pipe diameter and pumping head. The velocity cell was set equal to

$$V = \frac{0.8763 \frac{m^3}{s}}{\pi \cdot \left(\frac{d}{2}\right)^2}$$

And the constraint was that velocity must be less than or equal to 2.5 m/s because this is the typical maximum velocity in pipe flow.

Minor Head Loss

The minor head loss was calculated using the minor head loss equation below and adding head loss through GAC:

$$h_{L,m} = K \frac{V^2}{2g}$$

Where K is the minor head loss coefficient calculated.

$$\text{Minor Head Loss (m)} = 1.6927 m + 9 \cdot \left(\frac{V^2}{2 \left(9.81 \frac{m}{s^2} \right)} \right)$$

Major Head Loss

The major head loss was calculated using the Hazen Williams equation:

$$h = \frac{L \cdot 10.67 q^{1.85}}{(c^{1.85} \cdot d_h^{4.8655})}$$
$$h = \frac{139.3 m \cdot 10.67 \cdot \left(V \cdot \frac{\pi}{4} \cdot d^2 \right)^{1.85}}{(100^{1.85} \cdot d_h^{4.8655})}$$

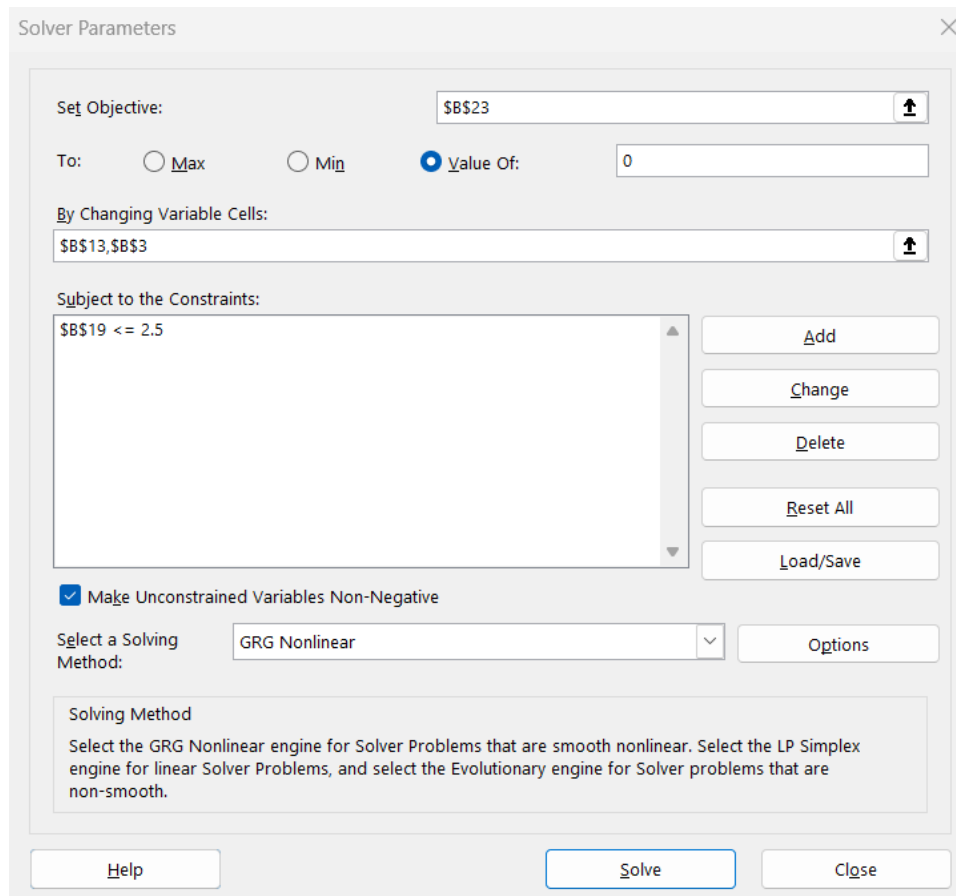
Solving for Pipe Diameter and Pumping Head

To solve for pipe diameter and pumping head, the difference between the left-hand side of the Bernoulli's equation and the right-hand side of the Bernoulli's equation was set equal to zero.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + h_1 + h_p - h_m - h_f = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_2$$

Where h_p is the pumping head, h_m is the minor head loss, and h_f is the major head loss.

The solver parameters are shown below:

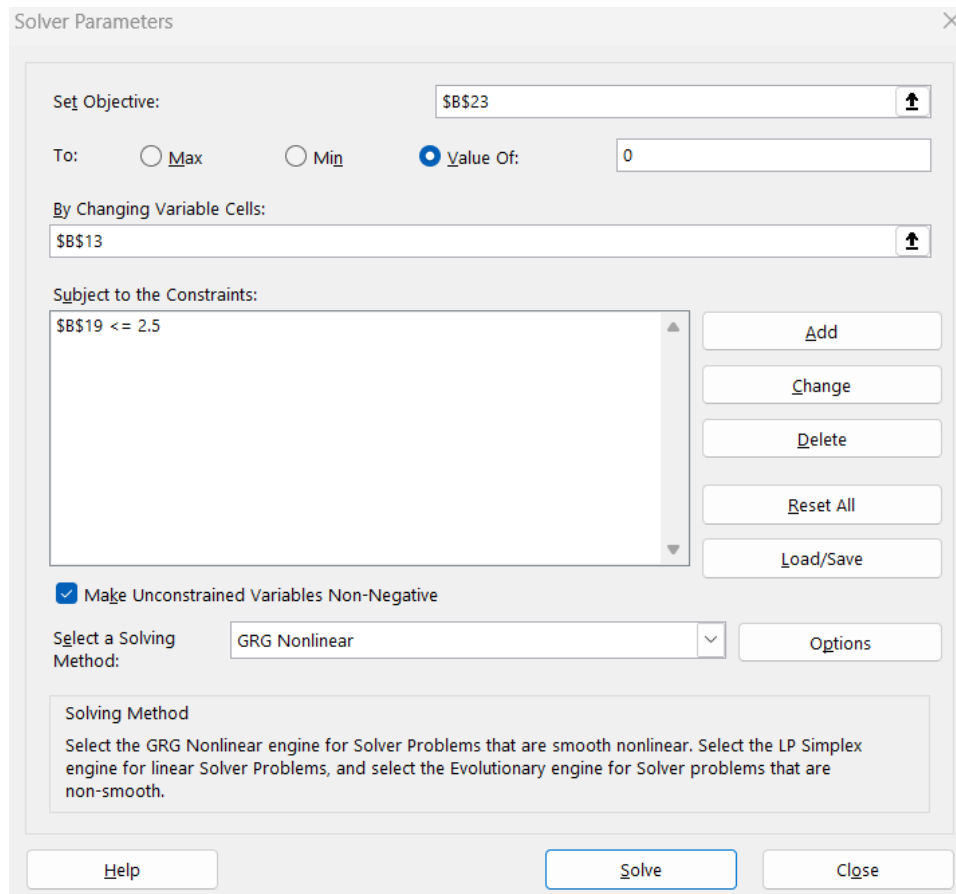


Running the solved using GRG Nonlinear, the pipe diameter and pumping head were as follows:

Pipe Diameter (m) = 0.67 m

Pumping Head (m) = 5.6 m

Rounding the pipe diameter up to the closest standard size of 30 inches, the pipe diameter was set to 0.762 m. The solver was run again with the below parameters:



The pumping head needed with a 30 inch diameter pipe was determined to be 3.88 m. Therefore, we will need two pumps with a pumping head of 4.21 m each.

$$Pumping\ Head\ (ft) = 4.21\ m \cdot \frac{1\ ft}{0.3048\ m} = 13.8 \approx 14\ ft$$

Sand Filter Effluent to Pumps

The calculations below were performed to calculate the pipe diameter needed for the system starting at the sand filter effluent and ending at the new pumps.

The pipes coming out of the sand filters are 36-inch diameter pipes. We propose to add a saddle tee with a 36-inch diameter to connect this effluent pipe to the new pipe that will collect water from all the sand filters. This new pipe will collect the sand filter effluent before it enters the clearwells and route it to the pumps where it will be transported to the GAC facility.

The calculations were performed in Microsoft excel using solver.

Flow

This pipe will collect water from all 8 sand filters. All the water will enter this pipe as part of the process so the flow will be the maximum capacity of 40 mgd. Converting this to m³/s:

$$Q \left(\frac{m^3}{s} \right) = 40,000,000 \frac{gal}{day} \cdot \frac{1 m^3}{264.17 gal} \cdot \frac{1 day}{24 hours} \cdot \frac{1 hr}{3600 s} = 1.75 \frac{m^3}{s}$$

Hazen-Williams Coefficient

This pipe will be a ductile iron pipe. Ductile iron has a Hazen-Williams coefficient of 130.

Pipe Length

The pipe will run the length of the filter room for a total length of 158 feet.

$$Length (m) = 158 ft \cdot \frac{0.3048 m}{1 ft} = 48.1584 m$$

Elevation Start and End

The elevation of the pipe will not change. It will maintain a constant elevation of 556 feet.

Minor Losses

The minor losses between the sand filter effluent to the pumps include 2 tee, branch flow and three crosses. The coefficient for the crosses was estimated to be the same as a tee, dividing line flow.

Component	Coefficient	Quantity	Total Coefficient
Tee, branch flow	1	2	2
Cross	0.2	3	0.6

$$Minor Loss Coefficient = 2 + 0.6 = 2.6$$

Pressure Start and End

The starting and ending pressure was calculated by finding the difference between the elevation of the hydraulic grade line (HGL) and the elevation at the sand filter effluent/pump. The elevation of the HGL at the sand filter effluent/pump is 564 feet and the elevation of the sand filter effluent/pump is 556 feet. Therefore, the pressure start is:

$$Pressure (m) = (564 ft - 556 ft) \cdot \frac{0.3048 m}{1 ft} = 2.4384 m$$

Velocity Start

For the starting velocity, we assumed a value of 2.1 m/s and this value will not significantly affect the calculated pipe diameter and pumping head.

Velocity

The velocity was used as a constraint when calculating the pipe diameter and pumping head. The velocity cell was set equal to

$$V = \frac{1.75 \frac{m^3}{s}}{\pi \cdot \left(\frac{d}{2}\right)^2}$$

And the constraint was that velocity must be less than or equal to 2.5 m/s because this is the typical maximum velocity in pipe flow.

Minor Head Loss

The minor head loss was calculated using the minor head loss equation below:

$$h_{L,m} = K \frac{V^2}{2g}$$

Where K is the minor head loss coefficient calculated.

$$\text{Minor Head Loss (m)} = 2.6 \cdot \left(\frac{V^2}{2 \left(9.81 \frac{m}{s^2} \right)} \right)$$

Major Head Loss

The major head loss was calculated using the Hazen Williams equation:

$$h = \frac{L \cdot 10.67 q^{1.85}}{(c^{1.85} \cdot d_h^{4.8655})}$$
$$h = \frac{48.2 \text{ m} \cdot 10.67 \cdot \left(V \cdot \frac{\pi}{4} \cdot d^2 \right)^{1.85}}{(130^{1.85} \cdot d_h^{4.8655})}$$

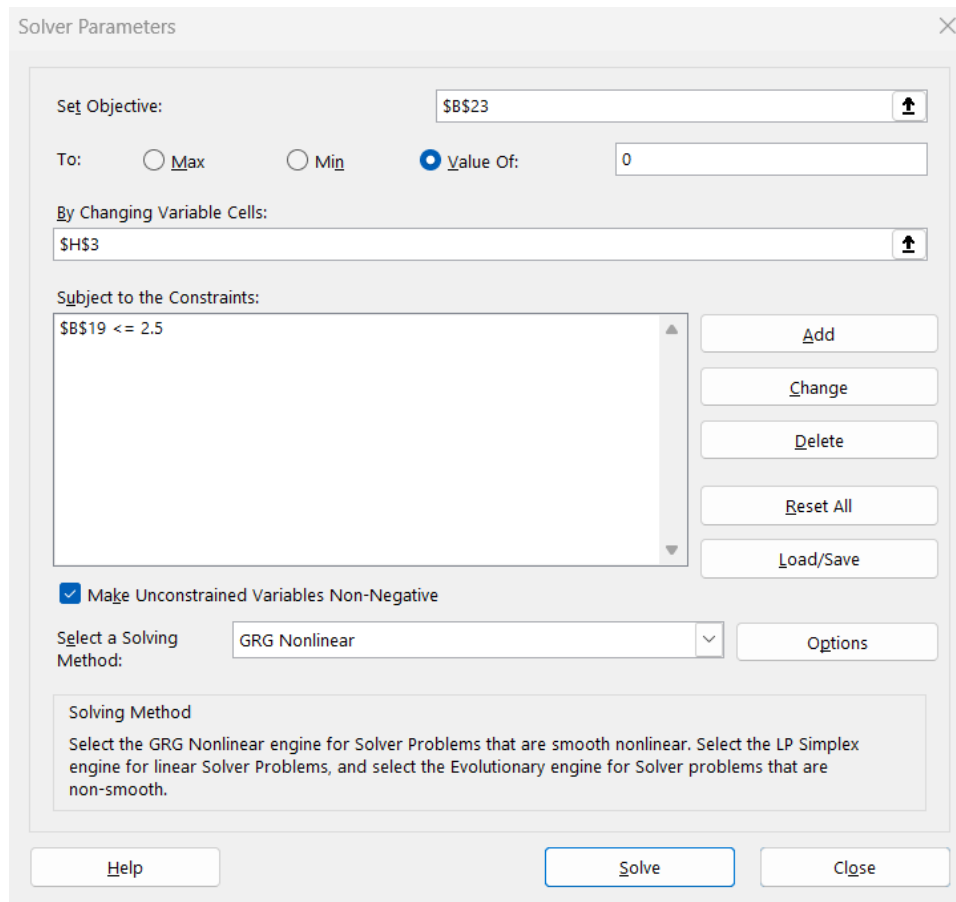
Solving for Pipe Diameter and Pumping Head

To solve for pipe diameter and pumping head, the difference between the left-hand side of the Bernoulli's equation and the right-hand side of the Bernoulli's equation was set equal to zero.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + h_1 + h_p - h_m - h_f = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_2$$

Where h_p is the pumping head, h_m is the minor head loss, and h_f is the friction head loss.

The solver parameters are shown below:



The resulting pipe diameter was 1.47 m. This diameter in inches is

$$Diameter \text{ (inches)} = 1.47 \text{ m} \cdot \frac{1 \text{ ft}}{0.3048 \text{ m}} \cdot \frac{12 \text{ inches}}{1 \text{ ft}} = 57.7 \text{ inches}$$

Rounding up to the next standard pipe size, we will need a 60-inch diameter pipe to collect sand filter effluent and route it to the pumps.

Backwash

The calculations below were performed to calculate the pipe diameter needed for the system starting at the bottom of the backwash supply tank and ending at the lagoon. This pipe will be used to transport water to waste after backwashing the GAC contactor.

The calculations were performed in Microsoft excel using solver.

Flow

The backwash process will occur for only one GAC contactor at a time. Since there are four contactors sized to handle 40 mgd, backwashing one contactor will have a flow rate of 10 mgd. Converting this to m³/s:

$$Q \left(\frac{m^3}{s} \right) = 10,000,000 \frac{gal}{day} \cdot \frac{1 \text{ m}^3}{264.17 \text{ gal}} \cdot \frac{1 \text{ day}}{24 \text{ hours}} \cdot \frac{1 \text{ hr}}{3600 \text{ s}} = 0.438 \frac{m^3}{s}$$

Hazen-Williams Coefficient

The pipe from the GAC effluent to the lagoon will be carrying water that has passed through the GAC. The pipe will need to be made from stainless steel due to its high durability and high resistance to abrasion from GAC fines. The Hazen-Williams Coefficient for stainless steel is 100.

Pipe Length

The horizontal distance from the GAC effluent to the lagoon is 353 feet. The elevation of the GAC effluent is 566 feet, and the elevation of the lagoon is 551 feet, making the vertical distance 15 feet. Using Pythagorean theorem to find the distance from the pump to the GAC influent, we obtained a distance of 353.32 feet.

$$d = \sqrt{353^2 + 15^2} = 353.32 \text{ ft}$$

There is also an additional 235 feet of pipe taking water from the backwash tank to the contactors and to the pipe that carries waste water to the lagoon. The total length of pipe is:

$$\text{Pipe Length (m)} = (353 \text{ ft} + 235 \text{ ft}) \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 179.32 \text{ m}$$

Elevation Start and End

The starting elevation at the bottom of the backwash supply tank is 565 feet and the ending elevation at the lagoon is 551 feet. Converting to meters:

$$\text{Elevation Start (m)} = 565 \text{ feet} \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 172.21 \text{ m}$$

$$\text{Elevation End (m)} = 551 \text{ feet} \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} = 167.94 \text{ m}$$

Minor Losses

The minor losses for the backwash process and carrying water to the lagoon include one check valve, fully open, three butterfly valves, four tee, branch flow, and three 90-degree elbows, flanged.

Component	Coefficient	Quantity	Total Coefficient
Check valve, fully open	2	1	2
Butterfly valve, fully open	0	3	0
Tee, branch flow	1	4	4
90-degree elbow, flanged	0.3	3	0.9

$$\text{Minor Loss Coefficient} = 2 + 0 + 4 + 0.9 = 6.9$$

Headloss through GAC

During the backwash process, water must go up and through the GAC. The headloss through the GAC contactor previously calculated was 1.6927 m. Because backwash will go against gravity, the bed depth of the contactor was added to the headloss through the filter.

$$\text{Headloss through GAC (m)} = 1.6927 \text{ m} + \left(9.52 \text{ ft} \cdot \frac{0.3048 \text{ m}}{1 \text{ ft}} \right) = 4.59 \text{ m}$$

Pressure Start and End

The pressure at the backwash supply tank and at the lagoon will both be atmospheric.

Velocity Start

The starting velocity at the bottom of the tank is 0 m/s.

Velocity

The velocity was used as a constraint when calculating the pipe diameter and pumping head. The velocity cell was set equal to

$$V = \frac{0.438 \frac{\text{m}^3}{\text{s}}}{\pi \cdot \left(\frac{d}{2}\right)^2}$$

And the constraint was that velocity must be less than or equal to 2.5 m/s because this is the typical maximum velocity in pipe flow.

Minor Head Loss

The minor head loss was calculated using the minor head loss equation below and adding head loss through GAC:

$$h_{L,m} = K \frac{V^2}{2g}$$

Where K is the minor head loss coefficient calculated.

$$\text{Minor Head Loss (m)} = \left(6.9 \cdot \left(\frac{V^2}{2 \left(9.81 \frac{\text{m}}{\text{s}^2} \right)} \right) \right) + 4.59$$

Major Head Loss

The major head loss was calculated using the Hazen Williams equation:

$$h = \frac{L \cdot 10.67q^{1.85}}{(c^{1.85} \cdot d_h^{4.8655})}$$
$$h = \frac{179.32 \text{ m} \cdot 10.67 \cdot \left(V \cdot \frac{\pi}{4} \cdot d^2 \right)^{1.85}}{(130^{1.85} \cdot d_h^{4.8655})}$$

Solving for Pipe Diameter and Pumping Head

To solve for pipe diameter and pumping head, the difference between the left-hand side of the Bernoulli's equation and the right-hand side of the Bernoulli's equation was set equal to zero.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + h_1 + h_p - h_m - h_f = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_2$$

Where h_p is the pumping head, h_m is the minor head loss, and h_f is the major head loss.

The solver parameters are shown below:

Solver Parameters

Set Objective:

To: Max Min Value Of:

By Changing Variable Cells:

Subject to the Constraints:

Make Unconstrained Variables Non-Negative

Select a Solving Method:

Solving Method

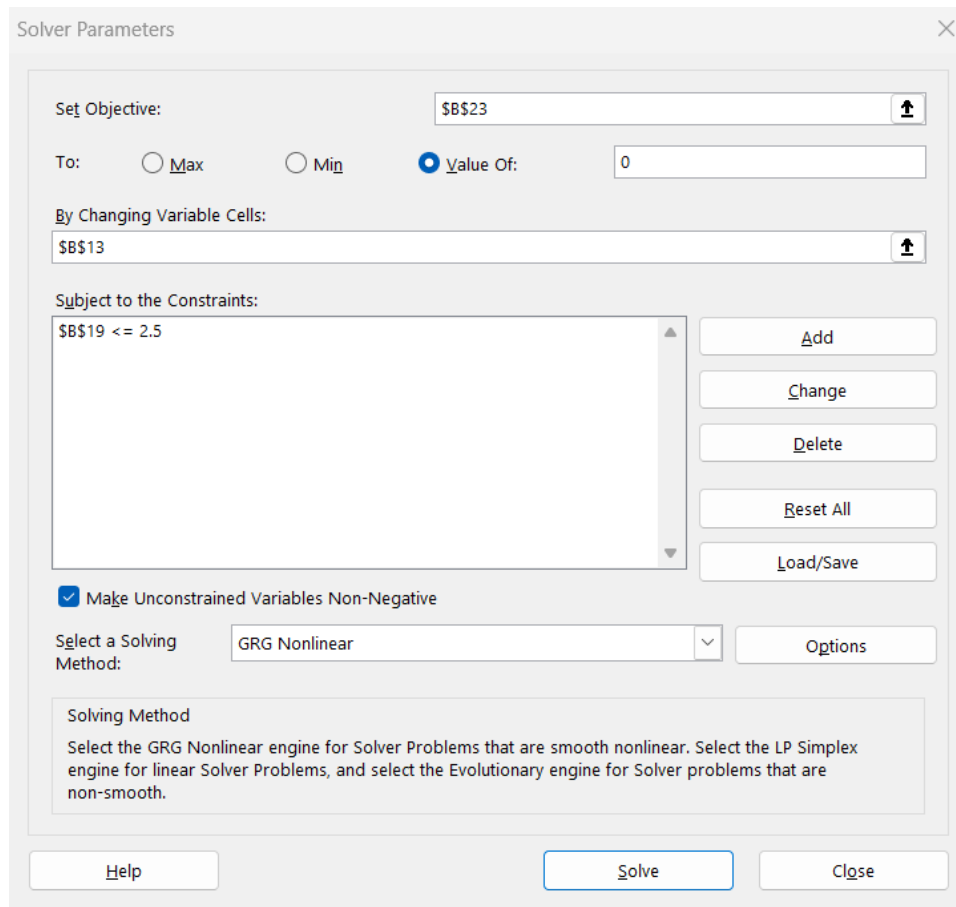
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Running the solved using GRG Nonlinear, the pipe diameter and pumping head were as follows:

Pipe Diameter (m) = 0.49 m

Pumping Head (m) = 5.45 m

Rounding the pipe diameter up to the closest standard size of 20 inches, the pipe diameter was set to 0.508 m. The solver was run again with the below parameters:



The pumping head needed with a 20-inch diameter pipe was determined to be 4.69 m. Therefore, we will need a backwash pump with a pumping head of 4.69 m or 15.4 ft.

$$\text{Pumping Head (ft)} = 4.69 \text{ m} \cdot \frac{1 \text{ ft}}{0.3048 \text{ m}} = 15.4 \text{ ft}$$

Concrete Calculations

Contactor

$$\text{Contactor Concrete (in}^3\text{)} = 268356.55 \text{ in}^2 \cdot 884 \text{ in} = 237227190.2 \text{ in}^3$$

Space Between Contactor and North Wall

$$\begin{aligned} \text{Concrete Between Contactor and North Wall (in}^3\text{)} &= 12149.29 \text{ in}^2 \cdot 2592 \text{ in} \\ &= 31490742.32 \text{ in}^3 \end{aligned}$$

Total Below Grade Concrete

$$\text{Below Grade Concrete (yd}^3\text{)} = (237227190.2 + 31490742.32) \text{ in}^3 \cdot \frac{1 \text{ yd}^3}{46656 \text{ in}^3} = 5760 \text{ yd}^3$$

Rounding up, the total amount of concrete needed is 5800 cubic yards.

9.8 Pump Information

GAC Service Pumps (PU-1 & PU-2)



Xylem Water Solutions USA, Inc.
Flygt Products

March 24, 2023

1615 State Route 131
Milford, Ohio 45150
Tel 513/831-7867
Fax 513/831-7868

CITY OF CINCINNATI

Quote # 2023-CIN-0235

Project Name: Cincinnati Waterworks 20MGD Application

Xylem Water Solutions USA, Inc. is pleased to provide a quote for the following Flygt equipment.

Flygt AC NSY Pumps				
Qty	Part Number	Description	Unit Price	Extended Price
2	24x24x30 NSY Model 150 Pump	24x24x30 NSY Model 150 Pumps Cast Iron Construction, John Crane Seal, baseplate, coupling, 200 HP 900 rpm motor. The included motor will need to be driven by a VFD (not included) at 26.6 Hz in order to meet the rating. See attached performance curve. Lead time is est. at 36-38 weeks after submittals are approved.	\$ 245,000.00	\$ 490,000.00
Total Price				\$ 490,000.00
Freight Charge				\$ 10,000.00
Total Price				\$ 500,000.00

Terms & Conditions

This order is subject to the Standard Terms and Conditions of Sale – Xylem Americas effective on the date the order is accepted which terms are available at <http://www.xyleminc.com/en-us/Pages/terms-conditions-of-sale.aspx> and incorporated herein by reference and made a part of the agreement between the parties.

Purchase Orders: Please make purchase orders out to: Xylem Water Solutions USA, Inc.

Freight Terms: 3 DAP - Delivered At Place 08 - Jobsite (per IncoTerms 2020)
See Freight Payment (Delivery Terms) below.

Taxes: State, local and other applicable taxes are not included in this quotation.

Back Charges: Buyer shall not make purchases nor shall Buyer incur any labor that would result in a back charge to Seller without prior written consent of an authorized employee of Seller.

Shortages: Xylem will not be responsible for apparent shipment shortages or damages incurred in shipment that are not reported within two weeks from delivery to the



jobsite. Damages should be noted on the receiving slip and the truck driver advised of the damages. Please contact our office as soon as possible to report damages or shortages so that replacement items can be shipped and the appropriate claims made.

Terms of Delivery: PP/Add Order Position

Terms of Payment: 100% N30 after invoice date.

Xylem's payment shall not be dependent upon Purchaser being paid by any third party unless Owner denies payment due to reasons solely attributable to items related to the equipment being provided by FLYGT.

Validity: This Quote is valid for thirty (30) days.

Please note that this pricing is valid for 30 days and contingent upon final approval of submittals and release to fabrication by (within 90 days of bid date).

This quotation is subject to change if any changes to the specifications or plans are made that alter the scope of supply.

Schedule: Please consult your local Flygt Branch Office to get fabrication and delivery lead times.

COVID 19: Delivery lead-times may be impacted by the current COVID-19 virus pandemic relative to transportation logistics.

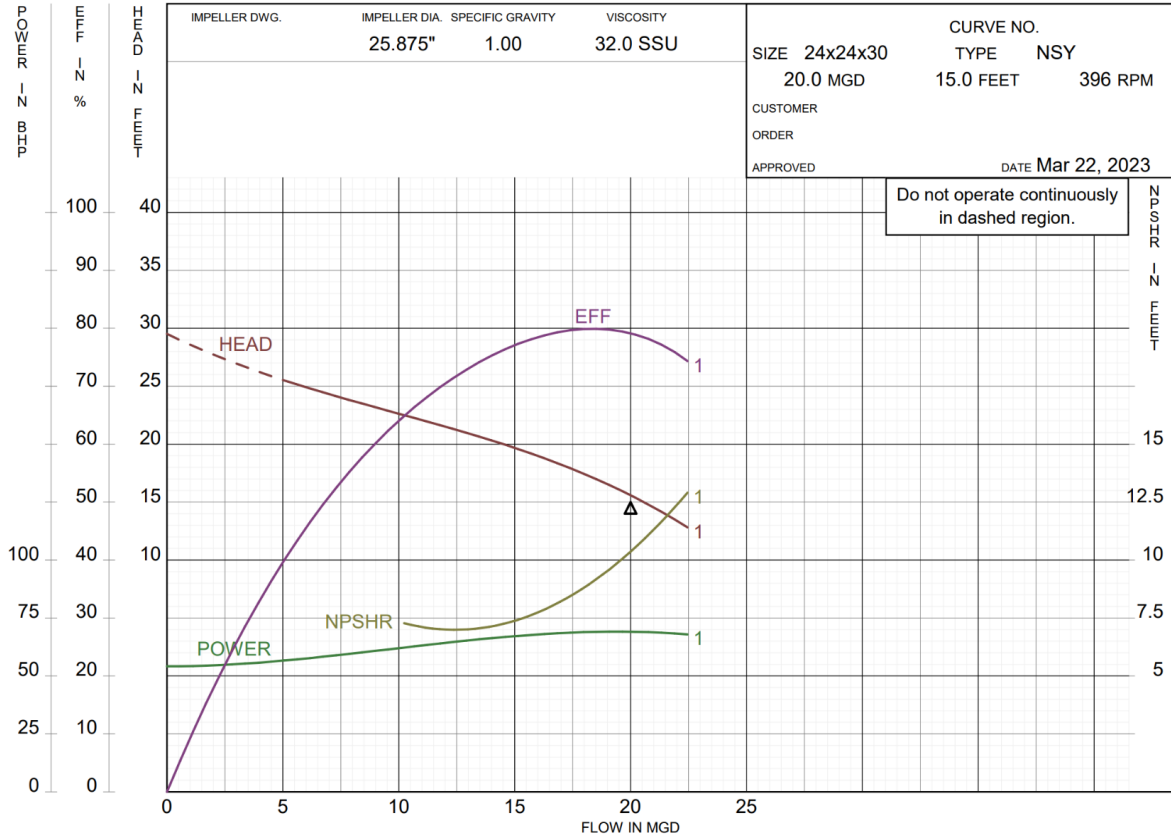
Exclusions: This Quote includes only the items listed specified above.

Thank you for the opportunity to provide this quotation. Please contact us if there are any questions.

Sincerely,

Doug Billiter
Sales Representative
Phone: 513-831-0194
Cell: 513-722-6985
doug.billiter@xylem.com
Fax: 513-831-7868





Backwash Pump (PU-3)



18 x 18 x 23 NSY 423 rpm

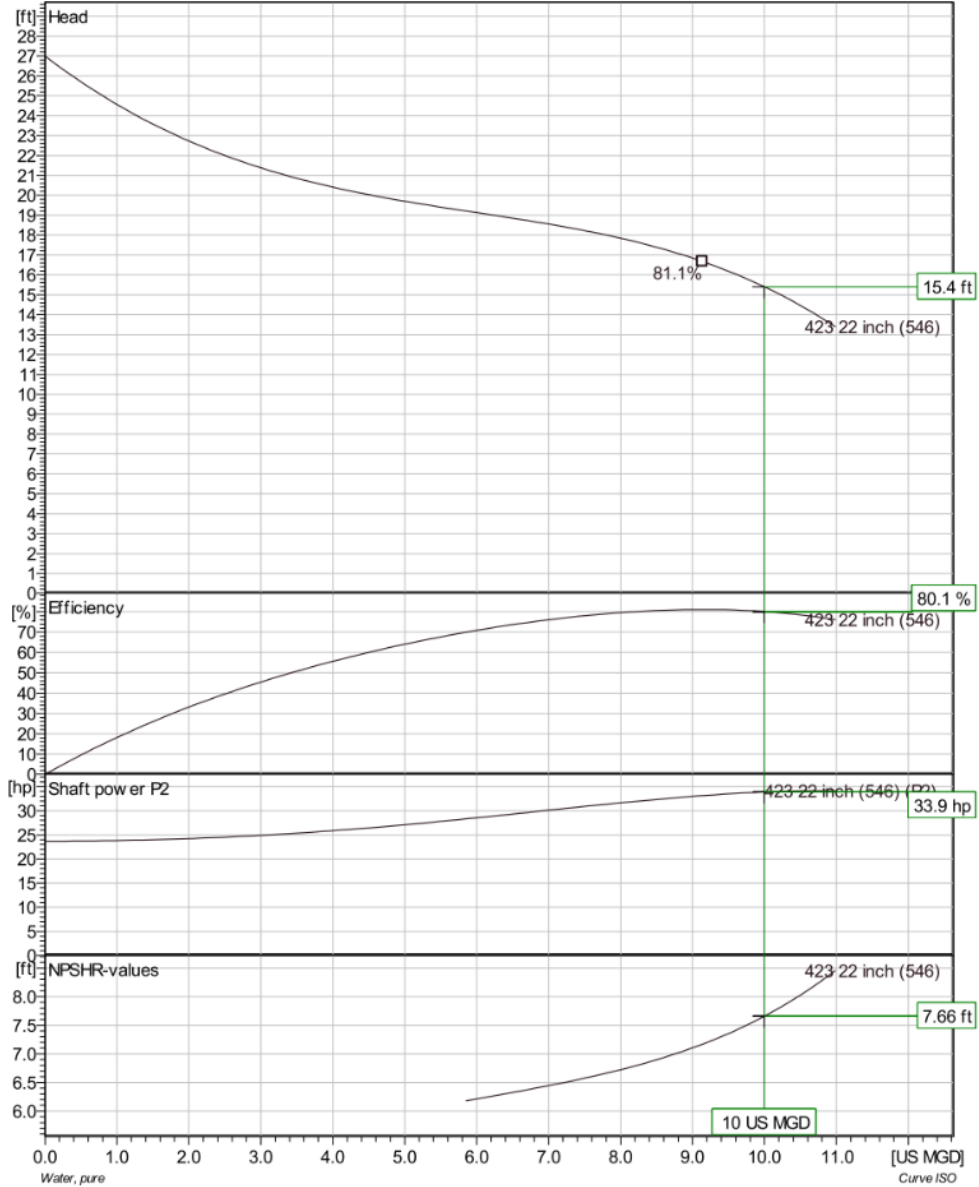
Performance curve

Pump

Discharge Flange Diameter 457.2 mm
 Suction Flange Diameter 457.2 mm
 Impeller diameter 546.19 mm
 Number of blades 2

Performance

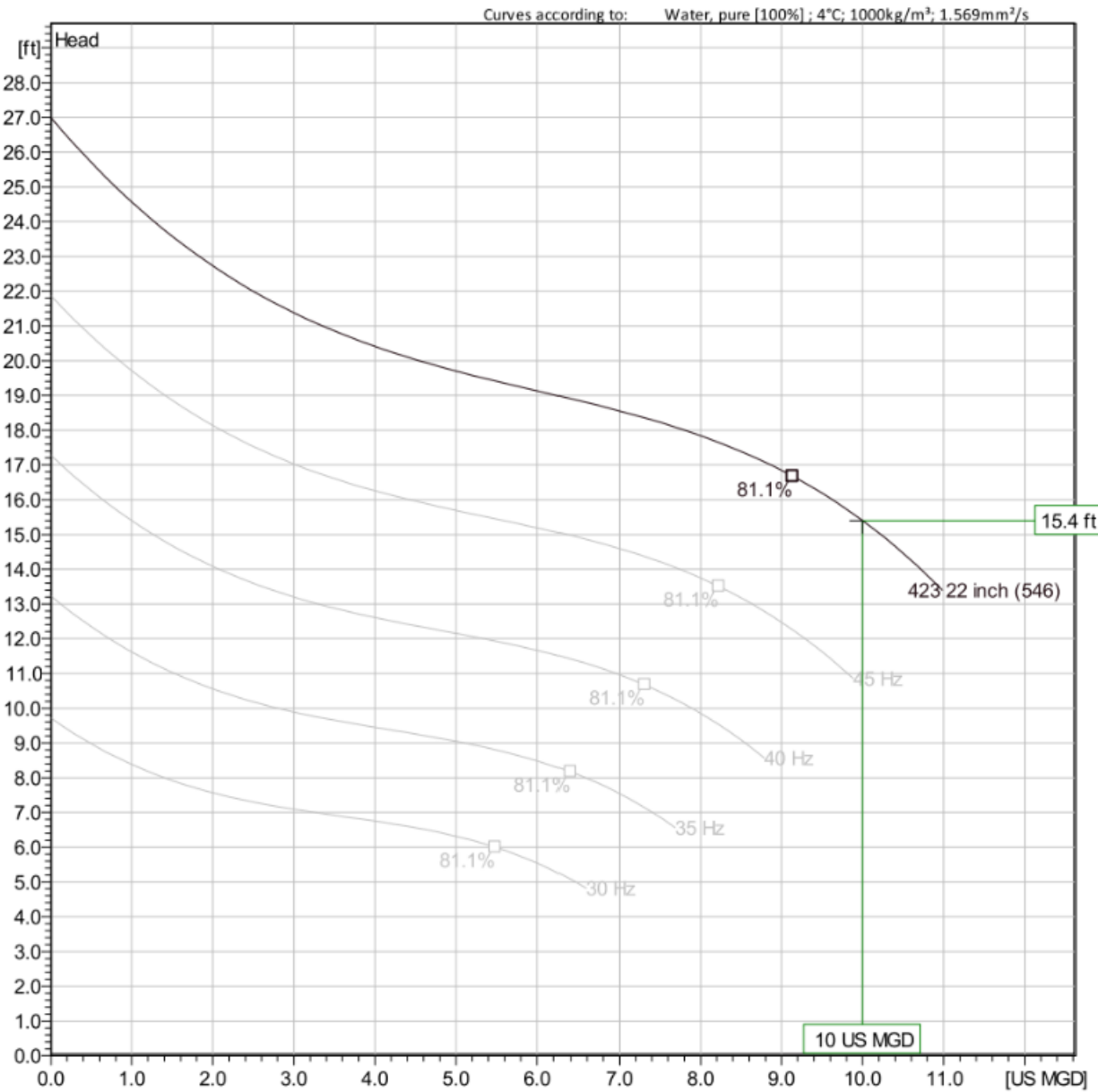
MAX_SHAFT_POWER_FPO 34.1 hp



Project	Project ID Xylet-20392975	Created by	Created on 4/5/2023	Last update 4/5/2023
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18 x 18 x 23 NSY 423 rpm

VFD Analysis



Operating Characteristics

Pumps / Systems	Frequency	Flow	Head	Shaft power	Flow	Head	Shaft power	Hydr.eff.	Specific Energy	NPSHre
1	50 Hz	10 US MGD	15.4 ft	33.9 hp	10 US MGD	15.4 ft	33.9 hp	80.1 %		7.66 ft
1	45 Hz	9 US MGD	12.5 ft	24.7 hp	9 US MGD	12.5 ft	24.7 hp	80.1 %		6.47 ft
1	40 Hz	8 US MGD	9.86 ft	17.4 hp	8 US MGD	9.86 ft	17.4 hp	80.1 %		5.36 ft
1	35 Hz	7 US MGD	7.55 ft	11.6 hp	7 US MGD	7.55 ft	11.6 hp	80.1 %		4.33 ft

Backwash Disinfection Chlorination Pump (PU-4)

ProSeries[®] FLEX-PRO[®] Peristaltic Metering Pump

by Blue-White Ind. | Engineering and Technical Data

FLEX-PRO A3 & A4

Feed Rates to 158.5 GPH
Pressures to 125 PSI
2500:1 Turndown ratio
Tube Failure Detection
Brushless DC Motor
NEMA 4X (IP 66) Washdown
2 Year Warranty



Model A4

Model A3

NEMA 4X **CE** **ETL**

Exclusive:
TFD system
Tube Failure Detection
Patent No. 7,001,153

Patents: 4,496,295 7,001,153 and other patents pending

Applications:

- Chemical Metering
- Wastewater Treatment
- Chlorination
- Chloramination
- Fluoridation
- Polymer Injection
- Pulp & Paper Slurries
- Printing Inks
- Oil Based Fluids
- Gaseous Fluids
- Shear Sensitive Fluids
- Caustics
- Chemical Slurries
- Food and Beverage

Features:

- Peristaltic pump design does not have valves that can clog requiring maintenance.
- Self priming - even against maximum line pressure. By-pass valves are not required. Cannot vapor lock or lose prime.
- Output rates to: 158.5 GPH (600 LPH) and pressures to 125 PSI (8.6 Bar).
- No maintenance brushless variable speed motor.
- Specially engineered tubing for long life at high pressures. Meets FDA 21 CFR requirements for food contact applications.
- Patented Tube Failure Detection (TFD) system. Senses tube failure by detecting chemical in the pump head. No false triggering.
- 2500:1 turndown ratio.
- SCADA Inputs include: 4-20mA, 0-10Vdc, and Pulse inputs for remote external speed control and 0-30 VDC / contact closure remote start/stop.
- Operator friendly digital touch pad with menu driven software.
- VGA Graphic multi-color backlit LCD displays remote/local control status, motor speed, output rate, input signal values, service and alarm status.
- Outputs include: Scalable 4-20mA or pulse, one 250V/6A relay and three 115V/1A contact closures assignable to monitor up to 17 different pump functions including TFD, FVS, remote/local control setting, motor on, fault, current operating mode, and others.
- Two molded squeeze rollers and two alignment rollers for optimum squeeze, unparalleled accuracy, and tube life.
- Heavy duty rotor - single piece plastic rotor means no flexing and increased accuracy with no metal springs or hinges to corrode.
- Inject at maximum pressure in either direction (clockwise and counter clockwise).
- Patent pending feature to extended tube life.
- Compatible with Blue-White's output Flow Verification Sensor (FVS) system.

FLEX-PRO® Peristaltic Metering Pump

Engineering and Technical Data

Output Specifications:

Feed Rate			Max Speed	Max Pressure	Max Temperature	A3 Model Numbers		
Flex-A-Prene® A3 Tube Pumps								
Meets FDA criteria for food Excellent chemical resistance CIP SIP								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.001 - 2.10	.003 - 7.8	.05 - 132	125	125 (8.6)	185 (85)	A3V24-*ND	A3V25-*ND	A3V26-*ND
.010 - 25.3	.038 - 96.0	.6 - 1596	125	125 (8.6)	185 (85)	A3V24-*NJ	A3V25-*NJ	A3V26-*NJ
.013 - 33.3	.050 - 126	.8 - 2100	125	125 (8.6)	185 (85)	A3V24-*NK	A3V25-*NK	A3V26-*NK
.013 - 33.3	.050 - 126	.8 - 2100	125	30 (2.1)	185 (85)	A3V24-*NKL	A3V25-*NKL	A3V26-*NKL
Flex-A-Prene® A3 Tube Pumps								
Meets FDA criteria for food Excellent chemical resistance Extra long tube life								
GPH	LPH	ML/MIN	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.002 - 4.76	.007 - 18.0	.12 - 300	125	110 (7.6)	185 (85)	A3V24-*NEE	A3V25-*NEE	A3V26-*NEE
.007 - 19.02	.03 - 72.0	.48 - 1200	125	110 (7.6)	185 (85)	A3V24-*NGG	A3V25-*NGG	A3V26-*NGG
Flex-A-Chem® A3 Tube Pumps								
Meets FDA criteria for food Superior chemical resistance								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.006 - 15.06	.022 - 57.0	.4 - 950	125	50 (3.4)	130 (54)	A3V24-*TH	A3V25-*TH	A3V26-*TH
.011 - 28.5	.043 - 108	.72 - 1800	125	50 (3.4)	130 (54)	A3V24-*TK	A3V25-*TK	A3V26-*TK
Flex-A-Thane® A3 Tube Pumps								
Meets FDA criteria for food Resistant to oils, greases and fuels								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.002 - 4.6	.007 - 17.4	.1 - 290	125	65 (4.5)	130 (54)	A3V24-*GE	A3V25-*GE	A3V26-*GE
.004 - 10.1	.015 - 38.4	.3 - 637	125	65 (4.5)	130 (54)	A3V24-*GG	A3V25-*GG	A3V26-*GG
.010 - 24.9	.038 - 94.2	.6 - 1570	125	65 (4.5)	130 (54)	A3V24-*GH	A3V25-*GH	A3V26-*GH
.011 - 28.5	.043 - 108	.7 - 1800	125	65 (4.5)	130 (54)	A3V24-*GK	A3V25-*GK	A3V26-*GK
.007 - 18.23	.03 - 69.0	.46 - 1150	125	65 (4.5)	130 (54)	A3V24-*G2G	A3V25-*G2G	A3V26-*G2G
Feed Rate			Max Speed	Max Pressure	Max Temperature	A4 Model Numbers		
Flex-A-Prene® A4 Tube Pumps								
Meets FDA criteria for food Excellent chemical resistance CIP SIP								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.01 - 28.5	.04 - 108	.7 - 1800	125	125 (8.6)	185 (85)	A4V24-*NH	A4V25-*NH	A4V26-*NH
.02 - 44.4	.07 - 168	1.1 - 2800	125	100 (6.9)	185 (85)	A4V24-*NJ	A4V25-*NJ	A4V26-*NJ
.02 - 50.7	.08 - 192	1.3 - 3200	125	80 (5.5)	185 (85)	A4V24-*NK	A4V25-*NK	A4V26-*NK
.02 - 54.0	.09 - 204	1.4 - 3400	125	100 (6.9)	185 (85)	A4V24-*NHH	A4V25-*NHH	A4V26-*NHH
.02 - 54.0	.09 - 204	1.4 - 3400	125	65 (4.5)	185 (85)	A4V24-*NHHL	A4V25-*NHHL	A4V26-*NHHL
.04 - 100.0	.15 - 378	2.5 - 6300	125	50 (3.4)	185 (85)	A4V24-*NL	A4V25-*NL	A4V26-*NL
.06 - 158.5	.24 - 600	4.0 - 10000	125	30 (2.1)	185 (85)	A4V24-*NP**	A4V25-*NP**	A4V26-*NP**
Flex-A-Chem® A4 Tube Pumps								
Meets FDA criteria for food Superior chemical resistance								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.02 - 54.00	.08 - 204	1.36 - 3400	125	30 (2.1)	130 (54)	A4V24-*TK	A4V25-*TK	A4V26-*TK
.05 - 126	.20 - 477	3.2 - 8000	125	30 (2.1)	130 (54)	A4V24-*TKK	A4V25-*TKK	A4V26-*TKK
Flex-A-Thane® A4 Tube Pumps								
Meets FDA criteria for food Resistant to oils, greases and fuels								
GPH	LPH	ML/Min	RPM	PSI (bar)	F (C)	115V AC	230V AC	220V AC
.01 - 39.6	.06 - 150	1.0 - 2500	125	65 (4.5)	130 (54)	A4V24-*GH	A4V25-*GH	A4V26-*GH
.02 - 55.5	.09 - 210	1.4 - 3500	125	65 (4.5)	130 (54)	A4V24-*GK	A4V25-*GK	A4V26-*GK
.04 - 100	.20 - 378	2.5 - 6300	125	65 (4.5)	130 (54)	A4V24-*GKK	A4V25-*GKK	A4V26-*GKK

* Inlet/outlet connection types available: **S** = 3/8" OD x 1/4" ID flexible tubing with compression type connections (A3 models only), **M** = 1/2" male NPT **MB** = 1/2" male BSPT **B** = 1/2" ID tubing barb type connections (ND, NKL, NEE, NGG, G2G, and A4 models only), **C** = 3/4" tri-clamp connections (ND, NKL, NEE, NGG, and G2G only), **Q** = Quick Disconnect (A3 models: ND, NKL, NEE, NGG, and G2G only, and A4 single Flex-A-Prene® tube models only) (Valves sold separately)
 **NP flow rate reduced 16.5% with Quick Disconnect connections.
 Note: output volumes based on testing with water at 72 degrees F, 5 foot suction lift, atmospheric conditions at sea level.

9.9 Pipe, Valve, and Vac-Truck Quotes



FERGUSON WATERWORKS #7835
 8520 PENNSYLVANIA AVE SERV RD
 UPPER MARLBORO, MD 20772-4884

Phone: 301-870-7901
 Fax: 301-736-1582

Deliver To: From: Jeff Bentley Comments:
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12:48:46 MAR 21 2023

Page 1 of 2

FERGUSON WATERWORKS #7835

Price Quotation
 Phone: 301-870-7901
 Fax: 301-736-1582

Bid No: B000683
Bid Date: 03/20/23
Quoted By: MJH

Cust Phone: 937-910-9900
Terms: NET 10TH PROX

Customer:

Ship To:

Cust PO#:

Job Name: SENIOR PROJECT

Item	Description	Quantity	Net Price	UM	Total
	FOR DESIGN PURPOSE ONLY WILL NOT BE USED FOR PURCHASE				
	----- DUCTILE PIPE & FITTINGS				
AFR52PD12	12 CL52 DCL DI FLEX RNG PIPE	20	126.757	FT	2535.14
AFR52PD30	30 CL52 DCL DI FLEX RNG PIPE	20	498.257	FT	9965.14
AFR52PD36	36 CL52 DCL DI FLEX RNG PIPE	20	670.972	FT	13419.44
AFT350PD60	60 CL350 DCL DI FASTITE PIPE	20	3216.300	FT	64326.00
DF912	DOM 12 DI 125# C110 FLG 90 BEND	1	1827.000	EA	1827.00
DFT30	DOM 30 DI 125# C110 FLG TEE	1	35760.000	EA	35760.00
DF430	DOM 30 DI 125# C110 FLG 45 BEND	1	13920.000	EA	13920.00
DF930	DOM 30 DI 125# C110 FLG 90 BEND	1	17343.000	EA	17343.00
SP-DF936	DOM 36 150# FLG 90 BEND	1	24802.000	EA	24802.00
SP-DFT36	DOM 36 150# FLG TEE	1	36252.000	EA	36252.00
SP-DF436	DOM 36 150# FLG 45 BEND	1	24258.000	EA	24258.00
SP-MJT6036LA	60X36 C153 MJ CROSS	1	118235.290	EA	118235.29
	FLANGE N/A, QUOTING 60X36 CROSS WITH 36X30 REDUCER				
	////////// STAINLESS MATERIAL:				
IS14LAW420	20 SS S10 304L LR 45 A403CR	1	2867.430	EA	2867.43
DS14LWS920E	20 SS S10 304L SR 90 ELL A403WPW	1	5418.710	EA	5418.71
IS14LWT20E	20 SS S10 304L TEE	1	2464.970	EA	2464.97
DSP14L20	20 SS S10 304L A312 WELD PIPE	20	262.386	FT	5247.72
SP-30S104774TEE	30" A774 304 S10 TEE	1	7371.900	EA	7371.90
SP-30304SS1090	30" 304SS S10 45	1	5012.330	EA	5012.33
SP-30304SSS1045	30" 304SS S10 90	1	8837.100	EA	8837.10
GSP16L30-B	30 SS S10 316L A312 WELD PIPE	20	738.872	FT	14777.44
	** quoting 304SS S10 pipe **				
	////////// VALVES				
V20121616	12 FLG BFV O/L H/WHL OP	1	5764.290	EA	5764.29
HGHF30	30 FLG BFV W/EPOX	1	50000.000	EA	50000.00
MB321106OL36	36 FLG OL BFV	1	57142.860	EA	57142.86
SP-SWINGFLEXCHK30	30 150# SWINGFLEX CHK VLV	1	85714.290	EA	85714.29



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Scan the QR code or use the link below to
 complete a survey about your bids:

<https://survey.medallia.com/?bidsorder&fc=7835&on=2656>

Fax: 301-736-1582

12:48:46 MAR 21 2023

Reference No: B000683

Item	Description	Quantity	Net Price	UM	Total
M202FF0255EELNP402	20 FLG BFV SS 316 150B 200 PSI OL	1	26235.710	EA	26235.71
M302FF0542EELNPA02	30 FLG BFV SS 316 150B 200 PSI OL	1	75178.570	EA	75178.57
Net Total:					\$714676.33
Tax:					\$50027.34
Freight:					\$0.00
Total:					\$764703.67

Quoted prices are based upon receipt of the total quantity for immediate shipment (48 hours). SHIPMENTS BEYOND 48 HOURS SHALL BE AT THE PRICE IN EFFECT AT TIME OF SHIPMENT UNLESS NOTED OTHERWISE. QUOTES FOR PRODUCTS SHIPPED FOR RESALE ARE NOT FIRM UNLESS NOTED OTHERWISE.

CONTACT YOUR SALES REPRESENTATIVE IMMEDIATELY FOR ASSISTANCE WITH DBE/MBE/WBE/SMALL BUSINESS REQUIREMENTS.

Seller not responsible for delays, lack of product or increase of pricing due to causes beyond our control, and/or based upon Local, State and Federal laws governing type of products that can be sold or put into commerce. This Quote is offered contingent upon the Buyer's acceptance of Seller's terms and conditions, which are incorporated by reference and found either following this document, or on the web at <https://www.ferguson.com/content/website-info/terms-of-sale>
Govt Buyers: All items are open market unless noted otherwise.

LEAD LAW WARNING: It is illegal to install products that are not "lead free" in accordance with US Federal or other applicable law in potable water systems anticipated for human consumption. Products with "NP" in the description are NOT lead free and can only be installed in non-potable applications. Buyer is solely responsible for product selection.
COVID-19 ORDER: ANY REFERENCE TO OR INCORPORATION OF EXECUTIVE ORDER 14042 AND/OR THE EO-IMPLEMENTING FEDERAL CLAUSES (FAR 52.223-99 AND/OR DFARS 252.223-7999) IS EXPRESSLY REJECTED BY SELLER AND SHALL NOT APPLY AS SELLER IS A MATERIALS SUPPLIER AND THEREFORE EXEMPT UNDER THE EXECUTIVE ORDER.
Buyer shall accept delivery of products within 60 days of Seller receiving the products at Seller's warehouse. If Buyer causes or requests a delay in delivery of the products, Buyer may be subject to storage fees and additional costs caused by such delay. Seller reserves the right to requote the products and reschedule the delivery date, subject to manufacturer's lead times and price increases, if Buyer is unable to accept delivery within 60 days.



HOW ARE WE DOING? WE WANT YOUR FEEDBACK!

Scan the QR code or use the link below to complete a survey about your bids:

<https://survey.medallia.com/?bidsorder&fc=7835&on=2656>



March 1, 2023

U.C.
Environmental Engineering
Attn: Rachel Hardtke

SCOPE OF WORK: VAC TRUCK SERVICES _ 2025

Champion Cleaning Specialist, Inc. (CCSI) will provide (3) Vacuum Trucks, (3) Operators, (1) On-Site Safety Technicians, Hoses, Materials & PPE to vacuum remove roughly 18,500 cubic feet of Carbon waste. All waste vacuum removed will be transported off-site and disposed of at a disposal facility provided by the Customer.

We estimate this project taking (1) week to complete. The lump sum price provided is based on prevailing wage rates.

All proper safety precautions will be followed on this project.

PROPOSAL:

- Total Project Cost\$66,990.00

Conditions:

- Payment is net 60 days.
- Sales tax will be added to the total invoiced amount if required.
- Lump sum price provided is based on prevailing wage rates.
- All work will be completed during regular business hours.
- Disposal location will be provided.
- All disposal fee's will not be billed to CCSI.
- A Contract will need to be in place prior to scheduling this project.
- Project will need to be scheduled a few weeks in advance to avoid additional charges.

March 1, 2023

Jon Parnell - Champion Cleaning Specialists, Inc. / Date:

9.10 Materials List

Description	Material	Unit	Unit Cost	Quantity	Total Cost	Notes
12" Ductile Iron 90	DIP	EA	\$1,827	6	\$ 10,962.00	Ferguson Quote in folder
12" Ductile Iron Pipe	DIP	LF	\$13,149/ 20'	16	\$ 205,288.76	US Pipe
30" Ductile Iron Tee	DIP	EA	\$35,760	5	\$ 178,800.00	Ferguson Quote
30" Ductile Iron 45	DIP	EA	\$13,920	4	\$ 55,680.00	Ferguson Quote
30" Ductile Iron 90	DIP	EA	\$17,343	1	\$ 17,343.00	Ferguson Quote
30" Ductile Iron Pipe	DIP	LF	\$45,038/ 19'6"	8	\$ 342,019.34	US Pipe
36" Ductile Iron Tee	DIP	EA	\$36,252	0	\$ -	Ferguson Quote
36" Ductile Iron 45	DIP	EA	\$24,258	0	\$ -	Ferguson Quote
36" Ductile Iron 90	DIP	EA	\$24,802	2	\$ 49,604.00	Ferguson Quote
30" Ductile MJ Yard Pipe	DIP	LF	\$255/LF	430	\$ 109,650.00	McWane Ductile email
36" Ductile Iron Pipe	DIP	LF	\$54,550/ 17'6"	3	\$ 162,091.43	US Pipe
60" Ductile Iron Pipe (Fastite)	DIP	LF	\$3216/LF	120	\$ 387,260.00	Ferguson Quote
36"x60" Ductile Iron Cross MJ	DIP	EA	\$118,235.29	5	\$ 591,176.45	Ferguson Quote
36" to 30" Ductile Reducer	DIP	EA	\$22,700.00	2	\$ 45,400.00	US Pipe Mexico (2021)
20" Stainless Steel 45	304 SST	EA	\$2,867	0	\$ -	Ferguson Quote
20" Stainless Steel 90	304 SST	EA	\$5,418.71	6	\$ 32,512.26	Ferguson Quote
20" Stainless Steel Tee	304 SST	EA	\$2,464.97	11	\$ 27,114.67	Ferguson Quote
20" Stainless Steel Pipe (weld)	304 SST	LF	\$262.38/LF	830	\$ 217,775.40	Ferguson Quote
30" Stainless Steel Tee	304 SST	EA	\$7,371.90	8	\$ 58,975.20	Ferguson Quote
30" Stainless Steel 45	304 SST	EA	\$5,012.33	4	\$ 20,049.32	Ferguson Quote
30" Stainless Steel 90	304 SST	EA	\$8,837.10	2	\$ 17,674.20	Ferguson Quote

30" Stainless Steel Pipe (weld)	304 SST	LF	\$738.87/LF	559	\$ 412,905.19	Ferguson Quote
12" Ductile BFV	DIP	EA	\$5,764.29	2	\$ 11,528.58	Ferguson Quote
30" Ductile BFV	DIP	EA	\$50,000.00	7	\$350,000.00	Ferguson Quote
36" Ductile BFV	DIP	EA	\$57,142.86	2	\$ 114,285.72	Ferguson Quote
30" Check Valve	DIP	EA	\$85,714.29	4	\$ 342,857.16	Ferguson Quote
20" Check Valve	DIP	EA	\$29,956	1	\$ 29,956.00	Ferguson Quote email
20" Stainless BFV	316 SST	EA	\$26,235.71	18	\$ 472,242.78	Ferguson Quote
30" Stainless BFV	316 SST	EA	\$75,178.57	10	\$ 751,785.70	Ferguson Quote
2" Union Ball Valve	PVC	EA	\$33.27	2	\$ 66.54	PVC Fittings Online
2" Check Valve	PVC	EA	\$158.41	1	\$ 158.41	Grainger
1" PVC Pipe	PVC	LF	\$30.79/ 20'	0.65	\$ 19.89	PVC Fittings
Chlorine / Chemical Pump		EA	\$5,749	1	\$ 5,749.00	SupplyLine
Treatment						
Filtrisorb 400 by Calgon Carbon	GAC	CF	\$2951/ton		\$ 2,958,486.69	74262 CF of carbon
Chlorine dosing at backwash tank	Cl	GAL				
215'x90'x12' CMU Wall w/ openings	CMU	EA	\$2.50/CMU	21000	\$ 52,500.00	RS Means Estimating Handbook
Masonry Field Time	CMU	SF	0.125 MH/SF 915 MH	7320 SF	\$ 16,470.00	RS Means Estimating Handbook
12'x10' Garage Doors	Al	EA	\$1387/door	5	\$ 6,935.00	Overhead Door Outlet
3'x7' Man doors	Al	EA	\$1981/door	2	\$ 3,962.00	Door Closers USA
216'x91' Steel Truss and Metal Sheet Roofing	Steel	SF	\$1500/SQ	195	\$ 294,840.00	Van Martin Roofing
Concrete						

4000 PSI Ready Mix Concrete	RMC	CY	\$197/CY	5800	\$ 1,142,600.00	Ernst Concrete Phone call
3/4" Reinforcing Steel	Steel	LF	\$2/LF 0.1 MH/LB			Every 12" assumption with +25% at corners
Excavation of Existing Site		CY	0.08-0.10 MH/QTY 1300 MH	16300	\$ 44,200.00	USC Estimate from Piscataway assume \$35/hr for operator
Equipment Diesel Consumption		GAL	3-12gal/hr 1300 MH	15600	\$ 78,000.00	gal/hr diesel estimate + 10% and assume \$5 per gallon (red)
Vac Truck			\$66,990	6	\$ 401,940.00	Champion Cleaning Specialists Inc. Quote
Power for Reactivation			\$0.25/lb		\$ 751,882.50	Sourced form Jim. 6 reactivations a year
Filtrisorb 400 by Calgon Carbon Replacement	GAC	CF	\$2951/ton	80 tons	\$ 236,080.00	8% carbon replacement due to reactivation loss means 80 ton per year
Flygt NSY model 150 pump			250000	3	750000	Xylem
			earthwork	reactivation	materials	Total
			\$ 138,670.00	\$ 1,389,902.50	\$ 10,230,254.68	\$ 11,758,827.18

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9.12 Gantt Schedule for Design Phase

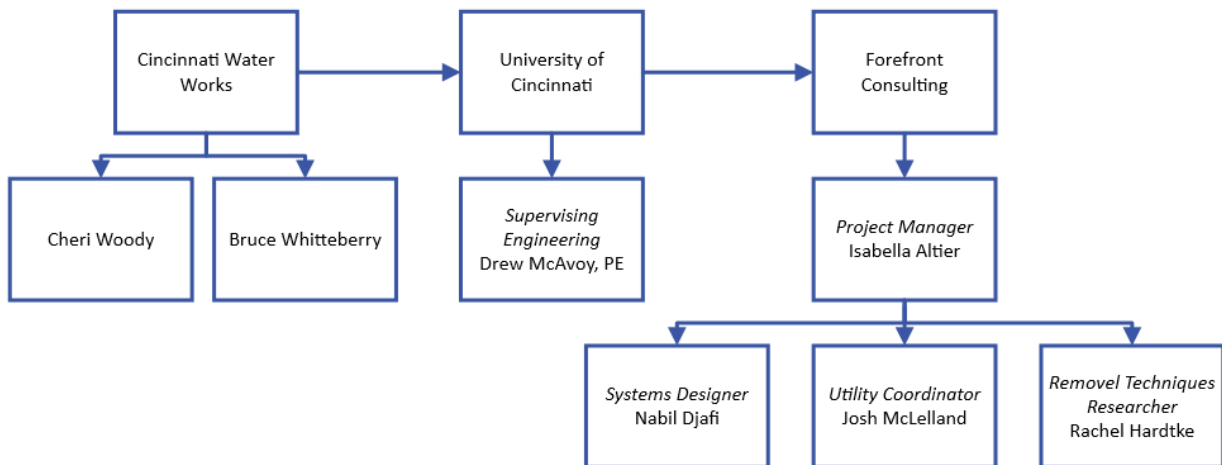
Design and Cost Estimate of PFAS Treatment at the Charles M. Bolton Water Treatment Plant															
Week of	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date (Monday)	1/9/2023	1/16/2023	1/23/2023	1/30/2023	2/6/2023	2/13/2023	2/20/2023	2/27/2023	3/6/2023	3/13/2023	3/20/2023	3/27/2023	4/3/2023	4/10/2023	4/17/2023
Notes										Spring Break					
Spring Kickoff	█														
Research Design Parameters		█	█	█	█										
Site Layout				█	█	█	█	█	█						
Process Design					█	█	█	█	█						
Cost Estimate						█	█	█	█	█					
Research					█	█	█	█	█	█					
Report on Key Findings									█	█	█	█	█	█	
Presentation on Findings													█	█	█

9.13 Vision Statement and Organization Chart

Forefront Consulting Vision Statement: To act at the forefront of applied treatment technologies to protect the public against emerging environmental hazards.

Forefront Consulting Organizational Chart

Investigation and Preliminary Design of PFAS Treatment at the Charles M. Bolton Water Treatment Plant



9.14 Forefront Consulting Bios



Isabella Altier is a fifth-year environmental engineering major at the University of Cincinnati. She is also pursuing her Master of Business Administration through the ACCEND program at the Lindner College of Business. She has completed four co-op rotations with Louisville Metropolitan Sewer District (MSD) in their MS4 Environmental Programs group. She was able to gain experience with stormwater and floodplain, as well as learn about the wastewater treatment plants operated by MSD.



Nabil Djafi is a fifth-year environmental engineering student at the University of Cincinnati. He is also pursuing his Master of Business Administration through the ACCEND program in the Lindner College of Business. Nabil hosts a variety of project experience completing co-ops at Rough Brothers Inc., Battelle Memorial Institute, the University of Cincinnati, and Ove Arup and Associates. In addition, he has been actively involved in international water projects through Engineers Without Borders.



Rachel Hardtke is a fifth-year environmental engineering major at the University of Cincinnati. She has completed co-op rotations at Optim Environmental Resources, The David J. Joseph Company, and Burgess & Niple. She has had experience with EPA permitting, environmental auditing of scrap metal recycling facilities, creating SWPPPs and SPPs, and designing site plans in AutoCAD.



Josh McLelland is a fifth-year environmental engineering major at The University of Cincinnati. He has completed five co-op rotations at Ulliman Schutte Construction, working in Maryland, North Dakota, Ohio, and Virginia. Through his co-op terms, he gained experience with construction management practices including, site layout and materials handling, project document review and budgeting.

9.15 Forefront Consulting Resumes

Isabella Altier

altierim@mail.uc.edu | 740-971-3885

Education

University of Cincinnati, Cincinnati, OH

- Bachelor of Science in Environmental Engineering
- Master of Business Administration
- University Honors Program

April 2023

GPA: 3.88

GPA: 4.00

Work Experience

Engineering Co-op — MS₄ Environmental Programs

January 2020-May 2020

Louisville Metropolitan Sewer District, Louisville, KY

August 2020-December 2020

Municipal Separate Storm and Sewer System (MS₄):

May 2021-Present

- Wrote and submitted quarterly reports to the state for Mill Creek 319 grant including progress updates, budget updates, and reimbursement invoices.
- Facilitated monthly 319 partners meetings and shared updates from Louisville MSD.
- Planned 319 Mill Creek sampling events and prepared field staff with forms and site information.
- Researched and developed sections of the Watershed Plan for Middle Fork Beargrass Creek for EPA approval.
- Developed a Quality Assurance Project Plan for the MS₄ program and various 319 grants.
- Wrote Standard Operating Procedures for Algae Tile Sampling for state approval.
- Developed ArcGIS story map for Jefferson County watersheds for public use.
- Wrote the 319-grant application for a Watershed Coordinator position and received funding.
- Facilitated workgroups and updated Louisville MSD's level of service for drainage.
- Participated in stormwater master planning initiative to determine how Louisville MSD will prioritize and manage stormwater needs throughout Jefferson County.
- Informed and tested the digitization of field data capture sheets to improve QAQC processes.
- Updated Stormwater Pollution Prevention Plans to meet permit requirements.
- Organized and executed trash cleanup events with over 80 volunteers.
- Created the MS₄ SharePoint site for organization use to track outreach events to meet MS₄ permit requirements.

Floodplain:

- Responded daily to flood determination requests to inform realtors or property owners of whether a property was in the FEMA, local, or combined sewer floodplain.
- Corresponded with property owners via email and phone on their interest in participating in the FEMA buyout program.

Fieldwork:

- Planned and executed the placement and collection of algae tiles at Louisville MSD's 27 Long Term Monitoring Network Sites to meet MS₄ permit requirements.
- Collected water quality parameters monthly at five sites using sonde equipment for 319 Grant monitoring requirements.
- Collected E. coli samples monthly for 319 Grant monitoring requirements.

Skills and Certifications

- Quality Post Construction Inspector Certified February 2020
- Erosion Prevention and Sediment Control Contractor Certified July 2021
- ArcGIS, VBA, Microsoft SharePoint, MATLAB, Python, Adobe Acrobat, EPANet, SWMM

Nabil A. Djafi

djafina@mail.uc.edu | (614) 365-0360

EDUCATION

University of Cincinnati – Cincinnati, Ohio Spring 2023
Bachelor of Science in Environmental Engineering GPA 3.71
Master of Business Administration GPA 3.83
Mortar Board Senior Honorary Society

WORK EXPERIENCE

Plumbing and Fire Protection Engineer Co-op – Arup 05/22 – 08/22
New York, New York

- Designed three plumbing and fire protection systems to be constructed in public buildings meeting IPC & NYC codes.
- Maximized plumbing efficiency utilizing head and heat loss calculations for a global restaurant chain.
- Created 3D models of current and new construction to resolve all MEP system conflicts before construction began.

Biosolids Student Researcher – University of Cincinnati 01/22 – 05/22
Cincinnati, Ohio

- Performed risk analysis of over 1,000 hazardous compounds in land applied bio-solids for the US EPA.
- Automated data entry and analysis of US EPA datasets utilizing VBA scripts to decrease labor time by 96%.

Crop Protection Research Co-op – Battelle 05/21 – 08/21
Columbus, Ohio

- Prototyped and constructed a 155mph wind tunnel for continued commercial lab use.
- Conducted pesticide drift studies in environmentally controlled wind tunnels for approval by the US EPA.
- Prepared agro-chemical mixtures a day under US EPA standards for volatility and aerosolized particle size analysis.

Systems Design Engineer Co-op – Rough Brothers Inc. 08/20 – 12/20
Cincinnati, Ohio 01/20 – 05/20

- Designed environmental systems implemented in over 12 hybrid and fully sealed commercial greenhouses.
- Created 15-page drawing sets for installation by contractors utilizing AutoCAD.
- Customized water treatment and fertigation systems implemented in growing operations across the US.
- Instituted Excel based tools to generate lighting, irrigation, fertigation, and design quotes for the sales team.

LEADERSHIP EXPERIENCE

President – Engineers Without Borders UC 01/21 – 01/23
Cincinnati, Ohio & Shirati, Tanzania

- Led a 60-person organization in local, domestic, and international outreach.
- Mediated two water agreements between separate rural communities to establish ownership of water systems.
- Doubled organization revenue through creation of financial partnerships and a business affairs team.
- Standardized engineering and accounting best practices throughout the organization.

Project Lead – Engineers Without Borders UC 01/19 – 01/21
Cincinnati, Ohio & Burere, Tanzania

- Designed and implemented a water distribution system in Tanzania serving 3,500 people.
- Negotiated a new agreement between three non-profits to increase the long-term success of the water system.
- Led a 20-student committee through the EWB-USA water system design and approval process.

SOFTWARE SKILLS

Revit MEP (BIM 360) – AutoCAD – Excel (VBA) – EPANet – Python – MATLAB – AGDISP – ArcGIS

Rachel Hardtke

Cincinnati, OH | 513-378-2415 | hardtkrj@mail.uc.edu

Education

Bachelor of Science | Class of 2023 | University of Cincinnati, Cincinnati, OH

- Major: Environmental Engineering
- GPA: 3.648/4

Work Experience

Water/Wastewater Engineer Co-Op for Burgess & Niple | 1/22 - 8/22 | Cincinnati, OH

- Designed and made corrections to site plans in AutoCAD for pump stations and water/wastewater treatment plants
- Lead and designed the cost estimate for over 400 water treatment plants that needed generators
- Operated a Leica 3D scanner to create digital AutoCAD plans for a major hospital and a pump station
- Created hydraulic profiles for multiple water treatment facilities

Environmental Co-Op for The David J. Joseph Company | 5/21 - 8/21 | Cincinnati, OH

- Prepared and finalized seven Stormwater Pollution Prevention Plans and three Spill Prevention Plans for scrap metal recycling facilities
- Audited two scrap metal recycling facilities to inspect and ensure environmental compliance pertaining to waste management, source control, cleanliness, stormwater, and production flow.
- Worked with two Indiana State Inspectors to help our site achieve the Indiana Clean Yard-Gold Level Award
- Observed plans to build a stormwater pond and gave my thoughts on the project design and implementation

Air Quality Engineer Co-Op for Optim Environmental Resources | 1/20 – 5/20 and 8/20 – 12/20 | Cincinnati, OH

- Evaluated data to properly complete Tier II, GHG, Title V, FER, and SARA Title III applications
- Worked with three team members to provide maps, organized production data and emission spreadsheets to clients
- Reviewed EPA permits for clients to detect any changes in regulations and verbiage

Environmental Grant Researcher for Urban Blooms | 5/19 – 8/19 | Cincinnati, OH

- Researched databases to find grant applications for nonprofit projects

Skills

Computer Programming and Technology

- AutoCAD, Microsoft Office Excel, WaterGEMS, EPANet, SWMM, Leica 3D Scanner

Activities & Organizations

Society of Environmental Engineers | 8/18 - Present | University of Cincinnati, Cincinnati, OH

- Engage in topics concerning sustainability and the environment at the University of Cincinnati
- Participate in volunteer opportunities that help keep our community clean
- Network with fellow environmental engineering students

Half Marathon | 10/19 and 5/22 | Cincinnati, OH

- Consistently practiced and worked hard to finish in under two hours

Joshua D. McLelland
mcllelld@mail.uc.edu / (513) 338-4254
2032 Whispering Pines Dr.
Cincinnati, Ohio 45230

EDUCATION

University of Cincinnati, Cincinnati, Ohio Class of 2023
Bachelor of Science, Environmental Engineering

Turpin High School, Cincinnati, Ohio May 2018

EXPERIENCE

Co-op Engineer, Ulliman Schutte Construction LLC., **January 2020 – August 2022**
Responsibilities:

- Create submittals and RFIs for construction materials and process equipment
- Study project documents to generate bill of materials and confirm constructability
- Manage onsite materials and equipment and evaluate site storage capabilities
- Communicate with vendors and subcontractors to draft contracts and order materials
- Assist project engineer with project budget, labor audits, submittals, and RFIs
- Detail pipe layouts, concrete formwork, site layout and misc. metals installation

Project Experiences:

- Piscataway WRRF Raw WW Pump Station Upgrades – Accokeek, MD - DBB Spring/Summer 2022
- Odor Control Cover Replacement Project - Dayton, OH – Self Perform GC Summer 2021
- Lakeside Redirect Project– Middletown, OH – Progressive Design Build Summer 2021
- Hampton Roads Pressure Reducing Station Upgrades - Chesapeake, VA – CMAR Fall 2020
- Grand Forks Regional Water Treatment Plant - Grand Forks, ND – Self Perform Spring 2020

Landscape Maintenance, Ivy Hills Country Club LLC., Cincinnati, Oh **May 2015 – January 2020**

- Managed landscape crews of 2-6 people
- Operated power tools and mid-scale equipment on golf course

ACTIVITIES

Member, Theta Tau Co-ed Professional Engineering Fraternity January 2019 – Present
Volunteer, Sweet Dream House Animal Rescue January 2018 – December 2019
Volunteer, Butler County Children’s Water Festival October 2017 - Present
Volunteer, Race for Global Water Annual 5k, Fairfield Ohio August 2016 – August 2018

SKILLS

LabView, Visual Basic for Applications, AutoCAD LT, Bluebeam Revu, SWMM, EPANET
Microsoft Office Products
Power tools operation and limited heavy equipment operation
NASBLA and US Coast Guard certified boater

9.16 Acknowledgements

Forefront Consulting would like to acknowledge and thank Dr. Drew McAvoy for his guidance and feedback during the fall semester. The team would also like to thank Dr. Dionysios Dionysiou and Dr. Mallik Nadagouda for sharing their knowledge and research on PFAS removal technologies, as well as sharing contacts of various utilities working to implement PFAS treatment. Engineering advice and feedback from Jim Springer about the operations at RMTP proved to be pivotal when designing our project. Lastly, the team would like to thank Bruce Whitteberry and Cheri Woody of GCWW for being responsive and providing us with data and feedback throughout the fall and spring semesters.

9.17 Request for Proposal

University of Cincinnati Capstone Program August 2022

The Greater Cincinnati Water Works Request for Proposal

Investigation and Preliminary Design of PFAS Treatment at the Charles M. Bolton Water Treatment Plant

Introduction

Perfluoralkyl and polyfluoralkyl substances (PFAS) are a group of manufactured chemicals that have been used in consumer products since the 1940s, usually in the manufacture of non-stick coatings, clothing, carpet, and food wrappers. The compounds typically do not break down under normal environmental conditions, which has earned them the nickname of “forever chemicals.” Because of their widespread use, traces of the compounds are commonly found in drinking water and in the bloodstream of many people. According to current scientific research, exposure to high levels of certain PFAS may lead to adverse health outcomes such as reproductive effects, developmental delays in children, increased risk of some cancers, and reduced ability of the body’s immune system to fight infection. The Greater Cincinnati Water Works (GCWW) has detected some of these PFAS compounds in both source water and treated water at the Charles M. Bolton Water Treatment Plant (CMBP). GCWW is interested in evaluating and designing treatment modifications to reduce PFAS levels in the drinking water at the CMBP.

Project Description

The CMBP plant is a 40 million gallon per day (MGD) ground water treatment plant drawing water from the Great Miami Buried Valley Aquifer (Figure 1). The current treatment process includes lime softening, sand filtration, and chlorine disinfection (Figure 2). Although currently there is no enforceable federal regulation for PFAS levels in drinking water, the U.S. Environmental Protection Agency (EPA) issued new Health Advisory Levels on June 15, 2022. The Health Advisory Level is the minimum concentration of a compound that may present health risks to an individual over a lifetime of exposure. The EPA’s new interim Health Advisory Levels for two PFAS compounds of great interest to GCWW are: 0.004 parts per trillion (ppt) for PFOA and 0.02 ppt for PFOS. The EPA also plans to publish draft regulatory Maximum Contaminant Levels (MCL) for PFOA and PFOS in late 2022 with the plan to finalize the levels by the end of 2023. While the proposed MCL levels are unknown, we are speculating the MCLs will be in the range of 4-10 ppt. CMBP has detected PFOA as high as 4.7 ppt and PFOS as high as 5.7 ppt in treated water. Appendix A contains the tables showing PFAS concentrations at the CMBP.

The purpose of this project is to provide a preliminary investigation and design for treatment to remove PFOA and PFOS at the CMBP. The project will consist of the following components:

1. Conduct a thorough review and research of current PFAS removal techniques.
2. Compare the removal techniques from different perspectives via an alternative analysis.
3. Develop a preliminary design of the recommended treatment process to remove or reduce the listed PFAS compounds to GCWW's desired levels.
4. Estimate a high-level construction cost for the recommended design.
5. Provide recommendations for action beyond this project.

Services Required

Literature Review and Research

GCWW will work with the consultant team to provide requested water chemistry data and information on the existing treatment process, if available. The consultant team is expected to conduct a thorough literature review and research of current PFAS removal techniques and compare treatment alternatives from different perspectives such as feasibility, costs, treatment efficacy, ecological impact, etc. At least one treatment technique recommendation should be provided for the CMBP.

Preliminary Engineering Design

Develop a preliminary design of the recommended treatment process to remove or reduce the listed PFAS compounds to the following levels:

- a. PFOA ≤ 2 ng/L (ppt)
- b. PFOS ≤ 2 ng/L (ppt)

The design should include a preliminary construction cost estimate as well as operation and maintenance costs over the lifespan of the system. In addition, a summary of assumptions used in the cost estimate and items not estimated should be provided. The PFAS treatment design should take into consideration possible future additions or changes due to the EPA's new Lead and Copper Rule (LCRR), specifically the addition of orthophosphate and recarbonation to the treatment process.

Deliverables

Fall Semester

The consultant team should complete the following tasks by the end of Fall Semester.

- Provide a summary of the treatment techniques available and their comparisons.
- Conduct an alternative analysis of the treatment techniques and their potential ability to remove the listed PFAS compounds to the desired levels. This analysis should include a preliminary economic analysis for each of the alternatives evaluated.
- Prepare a report on the key findings and recommended treatment process.
- Provide an oral presentation to the Sponsor on the key findings and recommended treatment options.

Spring Semester

The consultant team should complete the following tasks by the end of Spring Semester.

- Provide preliminary engineering design drawings showing proposed treatment process design and location.
- Prepare an itemized Construction Cost Estimate along with operation and maintenance costs.
- Provide a final report that includes all tasks from Fall and Spring Semester.
- Provide an oral presentation to the Sponsor on key findings at the end of the semester.



Figure 1. CMBP treatment plant site view

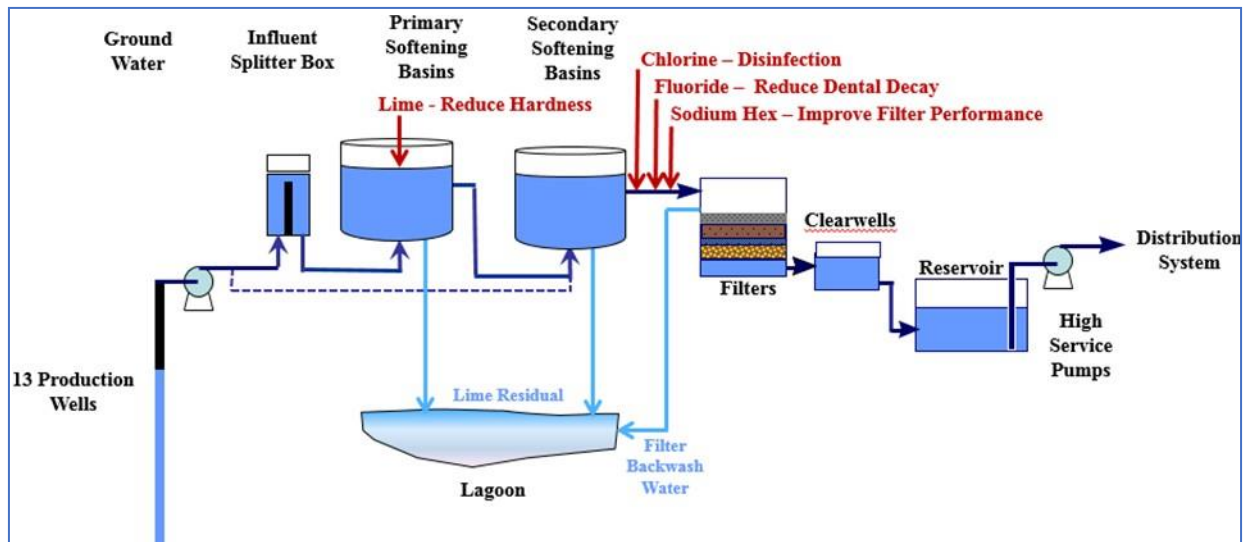


Figure 2. CMBP treatment processes