ravenvolt

Pilot Test Summary Report
City of Rome, Georgia
PFAS Mitigation Technologies

Prepared for:

The City of Rome, Georgia
and
InSite Engineering, LLC

July 2021

Executive Summary

The City of Rome conducted a Pilot Test spanning the period of mid-January through the end of April 2021, during which CERAFILTEC flat sheet ceramic membranes were evaluated for effectiveness in PFAS removal from the City's drinking water treatment process. CERAFILTEC membranes are uniquely capable of removing dissolved contaminants with a process that combines ultrafiltration and adsorption, reducing energy and chemical costs, as well as increasing recovery compared to other technologies currently used.

Using a fine layer of powdered activated carbon on the surface of the membrane, called Active Cake Layer Filtration, CERAFILTEC membranes consistently averaged over 99.5% (often times 99.9%) PFAS removal. CERAFILTEC started the Pilot Test in direct filtration mode with no pretreatment, and then revised the operation of the equipment to filter pre-treated (settled) water and extend the filtration cycles of the membranes to 24 hours.

The pilot unit supplied by CERAFILTEC is equipped with pH adjustment systems, coagulation systems and membrane cleaning systems for normal use. However, once the feed water was revised to take pre-treated water, no coagulation or pH adjustment was needed and the schedule for membrane cleanings was extended from daily to weekly, significantly reducing the cost of treatment.

The objectives of the Pilot Test and Report are to:

- Determine operating parameters for CERAFILTEC membranes to be effective on a full-scale implementation in Rome
- Provide options for capital projects to incorporate CERAFILTEC for PFAS removal in the existing treatment plant scheme
- Estimate the capital cost required to install CERAFILTEC
- Estimate the operating expenses for a full-scale implementation of CERAFILTEC and the auxiliary systems
- Provide the City's engineer with data needed for regulatory approval by Georgia EPD

Remote operations and preliminary technical design assistance were provided by CERAFILTEC and CERAFILTEC US. RavenVolt Water Systems is the exclusive agent of CERAFILTEC in the Southeastern United States.

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1. Introduction

1.1. Purpose of the Pilot Test

The City of Rome, Georgia's drinking water supply is affected by levels of PFAS contamination that regularly exceed the Environmental Protection Agency's current guidance levels. Source water is pumped from both the Oostanaula River and the Etowah River, each with varying levels of PFAS contamination. The current method used by the City to treat for PFAS contamination, beds of granular activated carbon (GAC), is both costly and limited in its effectiveness. Alternate treatment systems are being evaluated in part by an extended side stream treatment pilot test.

The parameters of the Pilot Test were designed and managed by InSite Engineering and key staff members at the Hamler Treatment Plant. Multiple technology strategies were tested and evaluated for both pretreatment of raw water and PFAS removal. During the pilot test the raw water supply was varied to include pumping direct from the Oostanaula River, direct from the Etowah River and a blend of the two. Each test phase lasted approximately 30 days. Wastewater generated was pumped to the City's water pollution control plant for treatment and the permeate was routed to a storm drain for discharge.

1.2. Existing Water Treatment Facility

The City's Bruce Hamler Water Treatment Facility needs to be upgraded, and an advanced treatment technology selection could coincide with rehabilitation. Structural concrete in some areas is believed to have exceeded its useful life and a major capital project is being considered. Upgrades of the conventional, multimedia filters and the existing settling basins are being contemplated along with PFAS mitigating technologies.

The existing plant is a conventional treatment process with rapid mix, coagulation, flocculation, sedimentation, and filtration in mixed media filters. The City currently uses granular activated carbon (GAC) to treat PFAS levels to below EPA recommended levels. The plant is designed for a treatment capacity of 18 million gallons per day (MGD) and, at the time the Request for Proposals was written, demand was approximately 7 MGD.

The existing filter basins are 525 square feet in surface area and rated for 3.0 gpm per square foot. A possible solution for the City includes upgrade of existing filter basins with CERAFILTEC membranes. Such a retrofit could be accomplished in approximately one half of the basins and provide the full permitted capacity without expansion of the physical structure.

2. Pilot Test Process Description

RavenVolt Water Systems deployed a CERAFILTEC Liquid Life mobile water treatment plant for use in the Pilot Test. The standard unit is designed to be a self-contained water treatment plant, capable of producing drinking water in direct filtration mode. Basic equipment in the mobile plant container includes a raw water pump, four (4) chemical feed systems, instrumentation, a raw water tank, a buffer tank, a small filtration tank, a service water tank (filled with permeate), and a set of three small pumps for filtration, backwash and surface spray. Typical installations of the Liquid Life units produce up to 40 gallons per minute at full capacity with four (4) membrane modules.

In Rome, the process included these treatment units:

- A self-priming influent pump to deliver a consistent supply of raw and settled water and a raw water flow meter
- An inlet pH and temperature sensor and pH adjustment system (pump and tank)
- A coagulant feed system (pump and tank)
- A buffer tank and multiple sample points to check pH and influent turbidity
- A filtration tank loaded with a 6 square meter ceramic membrane module
- A filtration (permeate) pump with variable speed drive to control based on flow rate, pressure, or speed
- A finished water flow meter and discharge pressure gauge
- A finished water pH and temperature sensor
- A finished water tank to supply filtered water for backwash and membrane cleaning cycles
- A backwash pump and flow meter with variable speed drive to control based on flow rate, pressure, or speed
- A membrane cleaning pump and two chemical dosing pumps to address scaling and biological fouling that may occur
- A regenerative blower for air scour during backwash.

To adjust to site conditions, modifications to the equipment were accomplished on site or prior to delivery to the site. Those adjustments included:

- Removal of the inlet tank and float switch to instead receive feed water flow directly from the City's tank (due to the elevation differential and pressure losses through the 2-inch hoses, incoming flow and the resulting flux rate was restricted to between 7.5 and 8 gpm maximum).
- Installation of a powdered activated carbon (PAC) tank and stirrer plus slurry feed pump. (The equipment was originally designed as a hydrous manganese oxide (HMO) feed system for adsorption of other contaminants). Unfortunately, the PAC feed system did not work properly on a small scale the PAC slurry had to be added manually each 24 hours rather than fed automatically from the slurry tank. In a full-scale operation, operators do not handle the PAC and all dosing is automatic.

The Liquid Life process flow diagram for the Rome Pilot Test is shown in Figure 2-1.

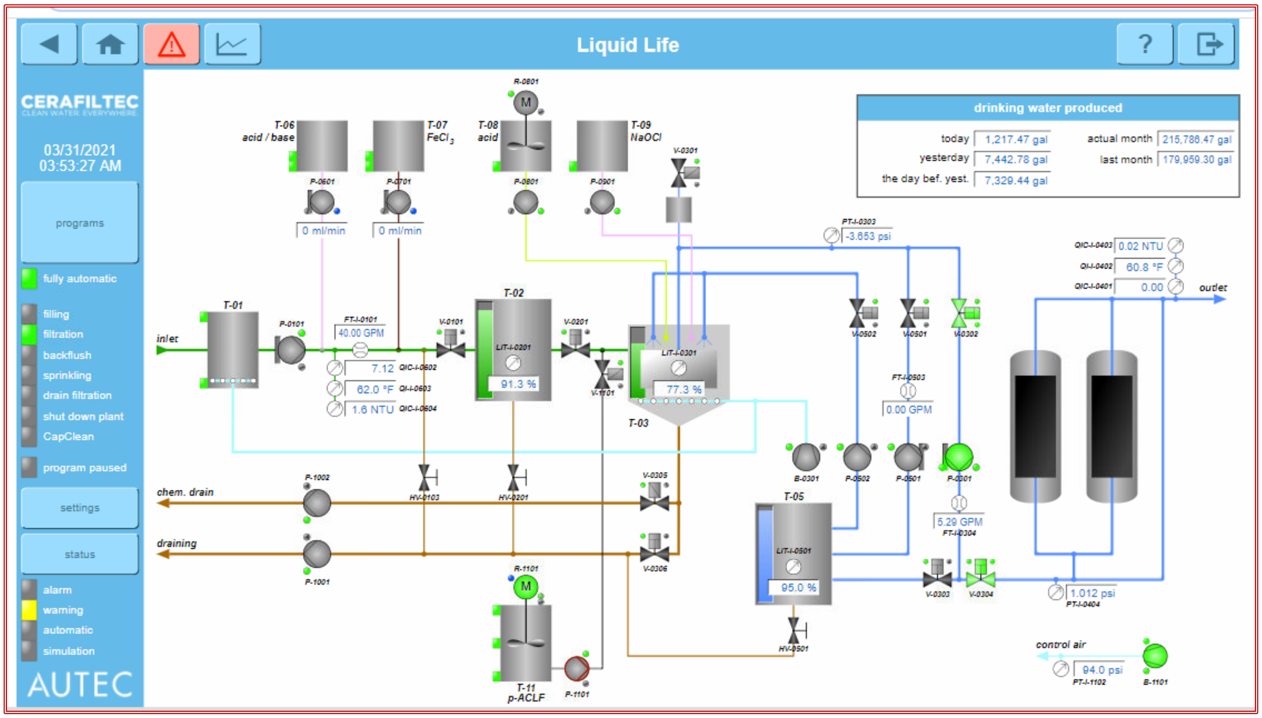


Figure 2-1

The Piping and Instrumentation Diagram is shown in Figure II-2.

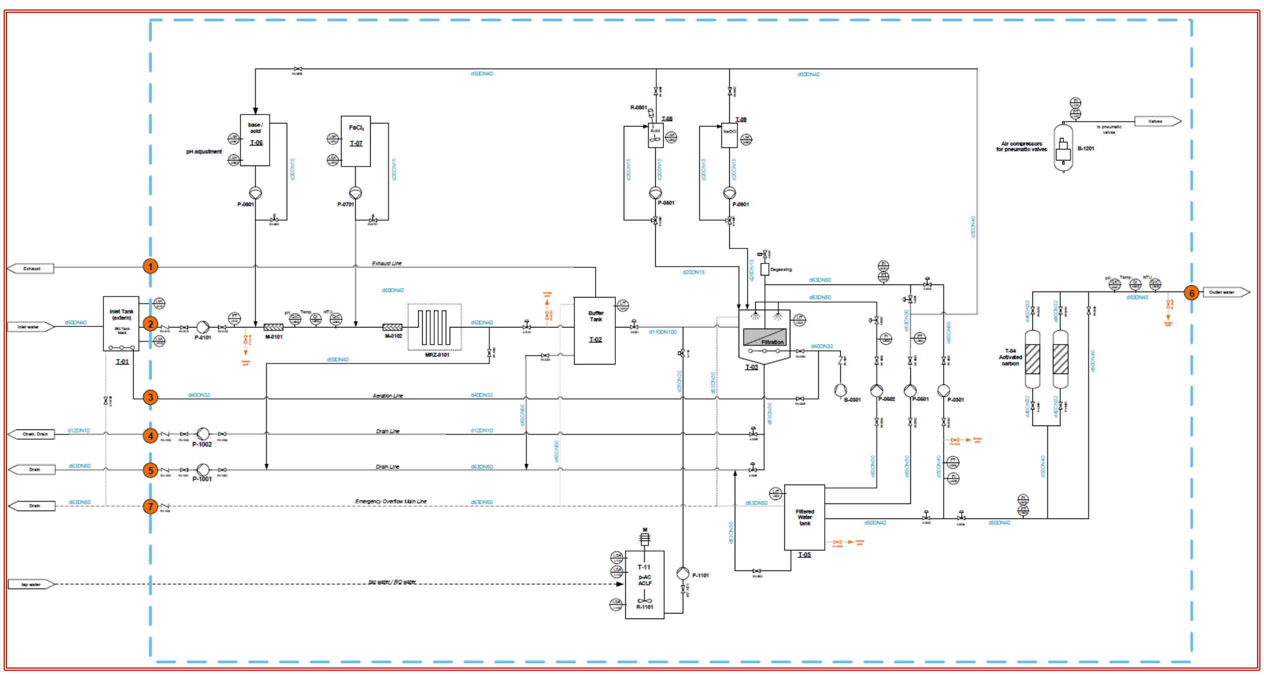


Figure 2-2

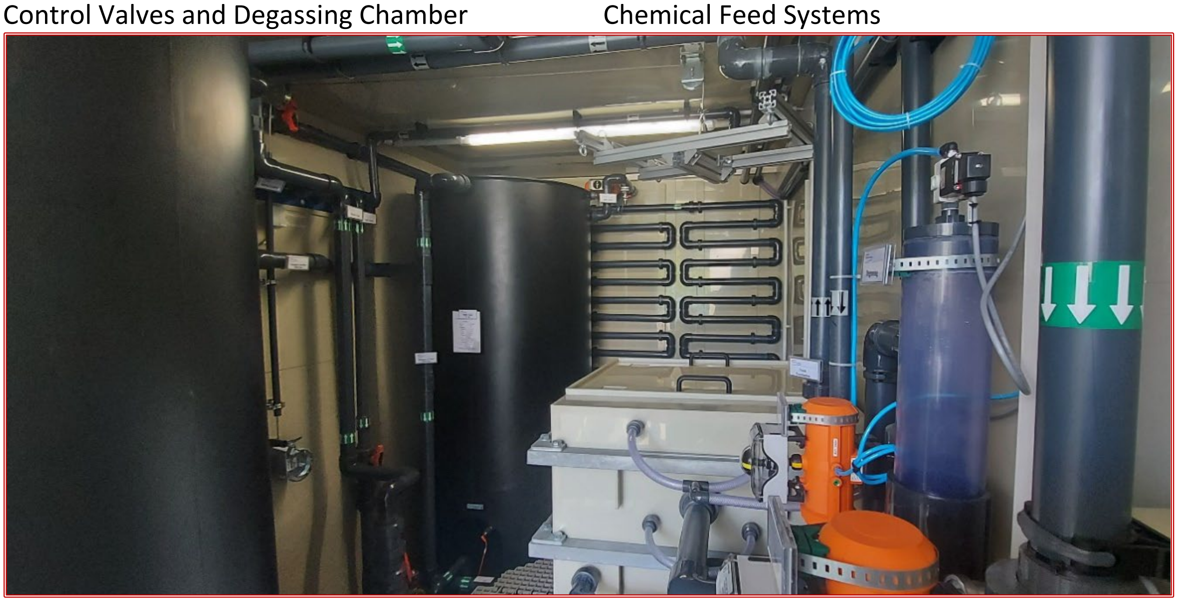
Pilot Equipment Photos – Rome, Georgia

Pilot Container

Piping Connections

Control Valves and Degassing Chamber

Chemical Feed Systems



Inside of Liquid Life Container

Figure 2-3

3. Pilot Test Process Optimization

3.1 PreTreatment Process

CERAFILTEC ceramic membranes operate with minimal pretreatment or in a direct filtration mode in many drinking water applications globally. Initially the goal for the Rome Pilot Test was to perform in this mode, without pre-treatment from other processes and performing full PFAS removal. However, after assessing current Georgia EPD review guidelines that discourage direct filtration even with perfectly successful pilot tests, the process mode was altered. With the consent of the lead operator and maintenance supervisor at the plant (Mr. Baker and Mr. Koch), the feed water supply hose was connected to the Aqua-Aerobic disc filter effluent on February 5, 2021 at 7 pm.

The Liquid Life mobile treatment unit is equipped to adjust coagulant dosages and pH based on feed water turbidity, but once the supply to the unit was modified to receive effluent from the cloth disc filter, no coagulant or pH adjustment was needed to achieve 24-hour membrane filtration cycles. Influent turbidity was regularly 0.1 to 0.3 NTU and effluent turbidity was 0.012 to 0.020 NTU on a continuous basis.

3.2 Powdered Activated Carbon Selection

Once the primary objective of the Pilot Test was refocused on PFAS removal only, influent flow was maximized to just below the available flow from the 2-inch supply hose (approximately 6 – 6.5 gpm). This flow rate resulted in a very conservative membrane flux rate and very low transmembrane pressure decay rates, but also allowed for full 24-hour filtration cycles under nearly all conditions. A full day cycle was important to ensure that the plant operators only needed to add powdered activated carbon slurry once each day.

As noted, the primary objective was optimum PFAS removal for each sample taken by the City and during our 24-hour filtration cycles. These successful tests serve as a point of validation for Active Cake Layer Filtration and demonstrate that when properly operated, CERAFILTEC ceramic membranes are a cost effective and efficient means to remove PFAS compounds to near non-detectable limits.

Separate from operation of the Pilot Test equipment, we bench tested various PAC for their effectiveness on long and short chain compounds found in the raw water. Two acid washed varieties and two unwashed varieties were used for filtration and lab tested for PFAS removal efficiency. Those results are summarized in the following section.

3.3 Powdered Activated Carbon Dosing Process

A secondary goal of the Pilot Test included determining the optimum PAC dosing requirements and fine tuning the estimated costs of operation. PAC dosage was initially estimated to make handling simple for the operators – each 40 lb. bag was to be divided into 5 equal lots of 8 lbs. for the slurry. This allowed for full coating of the ceramic membranes, but also resulted in some waste since excess PAC settles to the tank bottom.

Once the process was fully optimized, standard daily operations followed a set routine. Backwash was initiated remotely at approximately 7:50 each morning and the filtration pumps remained paused after the tank waste was pumped out of filtration tank. The on-duty operator then added approximately 8 lbs of powdered activated carbon in slurry form (Cabot Darco S-51) and pressed the HMI button to resume operation at approximately 8:00 am. The Pilot Equipment then ran in filtration mode continuously for 23.75 hours unattended and without additional chemical addition, water usage, or membrane backwash.

On a weekly basis for the first 3 weeks of the test, the remote operator sprayed the membranes with a solution of 3% sodium hypochlorite and citric acid during the backwash operation. Once operation was revised to filter pre-treated water, the hypochlorite and acid CapClean process was generally performed only once per week, or less frequently if transmembrane pressure decay rates were lower than normal.

Calculations based on observed film thickness and membrane area correlations yielded an estimate of 25% carbon cake layer and 75% carbon settled to the floor of the tank unused. Similar carbon (PAC) dosages were used in trials with a clear test tank to validate the calculations. Figure 3-1 shows the settled PAC in the first 15 minutes of an extended filtration test.

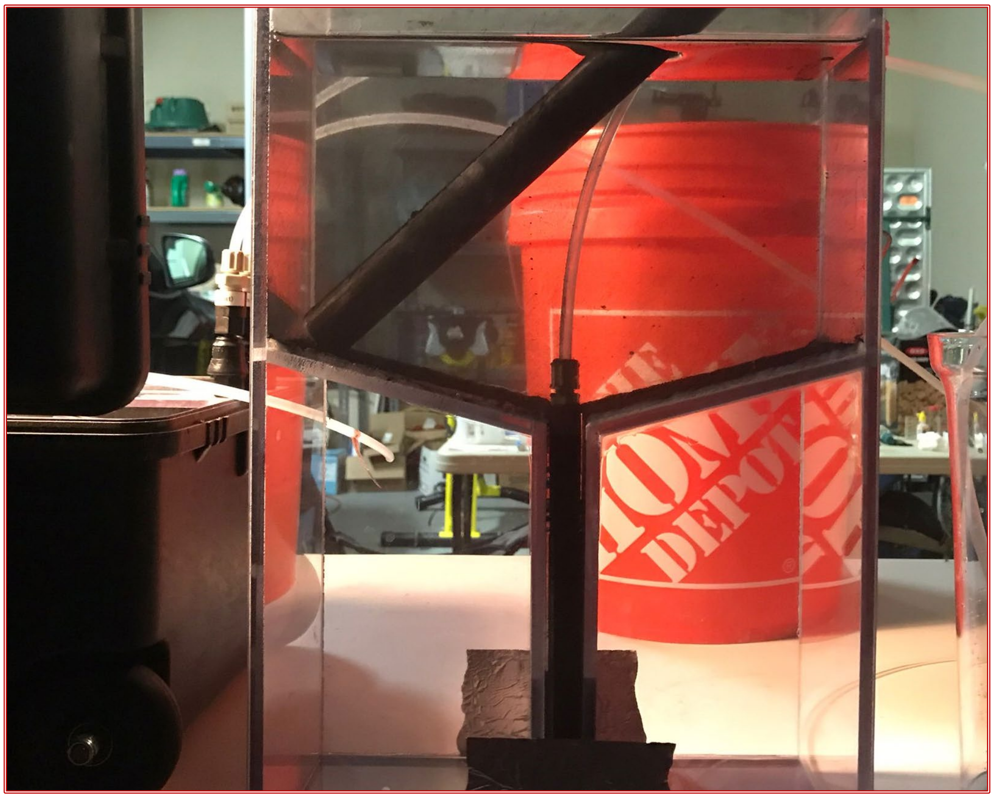


Figure 3-1

Figure 3-2 on the following page shows the PAC coated ceramic membranes prior to backwash and prior to PAC addition. The PAC film attached to each membrane is very thin (approximately 0.33 mm).


Before PAC Addition

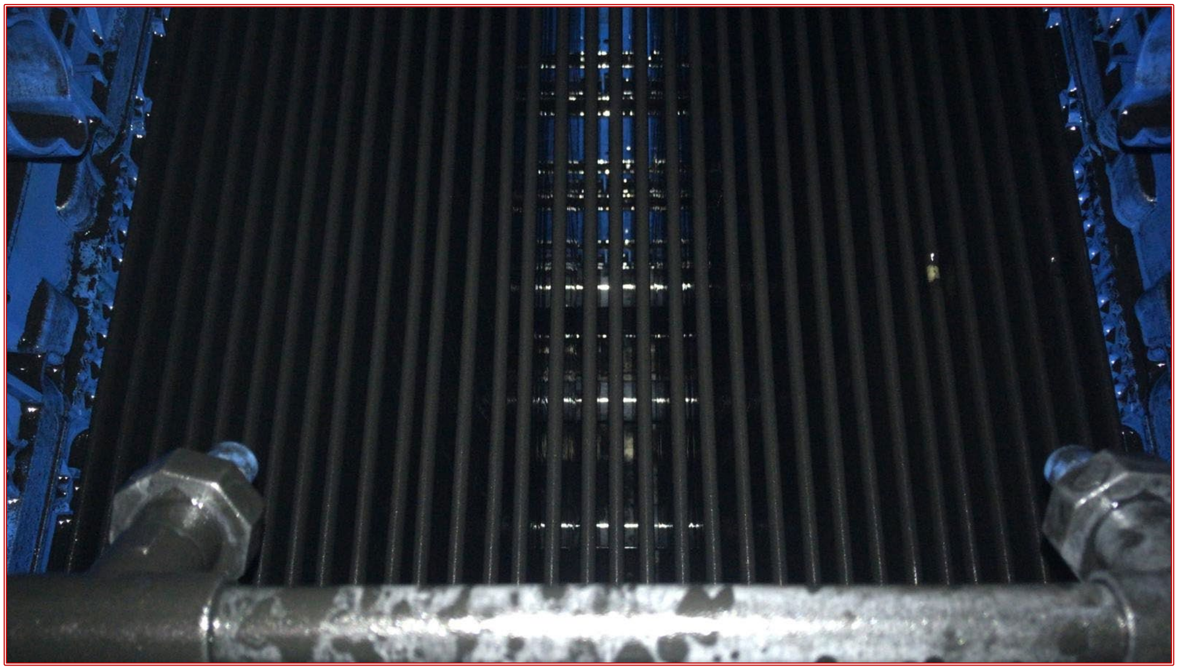

After PAC Addition

Figure 3-2

4. Summary of Operations and Test Data

4.1 Laboratory Test Results - City

The City collected basic water chemistry and PFAS samples more or less weekly for the duration of the test and reported them to RavenVolt every 3-5 weeks. A summary of those test results is tabulated below:

TABLE 4-1
City Test Results

Sample Date	Sample No.	Source Water	Feed Water Total PFAS (ppt)	Filtered Water Total PFAS (ppt)	Removal Efficiency
January 20, 2021	1	Raw - Oostanaula	447.00	48	89.3%
January 27, 2021	2	Raw - Oostanaula	1,316.83	70.19	94.7%
February 2, 2021	3	Raw - Oostanaula	791.08	N/A	N/A
February 10, 2021	4	Filtered - Oostanaula	797.58	4.89	99.4%
February 15, 2021	5	Filtered - Oostanaula	683.32	N/A	N/A
February 23, 2021	6	Filtered - Mixed	276.28	1.13	99.6%
March 3, 2021	7	Filtered - Mixed	313.23	0.88	99.7%
March 10, 2021	8	Filtered - Mixed	240.81	1.10	99.5%
March 16, 2021	9	Filtered - Mixed	622.42	5.05	99.2%
March 24, 2021	10	Filtered - Mixed	258.71	0.49	99.8%
March 31, 2021	11	Filtered - Etowah	91.05	0.32	99.6%
April 7, 2021	12	Filtered - Etowah	40.06	0.40	99.0%
April 14, 2021	13	Filtered - Etowah	42.64	0.00	100%
April 21, 2021	14	Filtered - Etowah	39.97	0.00	100%
April 28, 2021	15	Filtered - Etowah	44.45	0.00	100%

Results from the City's tests were generally good, starting with the change to the feed water set up and throughout the remainder of the Pilot Test period. Before the supporting systems were properly adjusted (i.e., loose flanges tightened on the filtration pump suction), filtration runs were abbreviated by air in the lines or improper coagulant dosing.

Test results from January 20 reflect an unknown dosage of powdered activated carbon. Bagged carbon was available on site starting that date, but we have no record of any amount being added to the process and the feed system had not been started up by that date. On February 2 and February 15, samples were either not pulled or pulled when the equipment was not running. The sample in between and successive samples thereafter were satisfactory.

Results shown are based on EPA Methods 537.1 and 533, selecting the higher of the two results where they differ. The "Total PFAS" columns reflect the sum of all detected compounds in each series of tests for the date indicated.

4.2 Laboratory Test Results – RavenVolt Water Systems / CERAFILTEC

RavenVolt Water Systems also collected treated water samples for testing PFAS removal efficiency twice during the pilot test. The purpose of both tests was to provide insight into potential breakthrough conditions when PFAS loading exceeds the adsorptive capacity of the PAC.

The first test during direct filtration spanned 6 hours and the purpose was to determine the capacity of the Powdered Activated Carbon for PFAS removal on an hourly basis.

TABLE 4-2
6 Hour Test Results – January 28, 2021

Hours after Backwash	Source Water	Feed Water PFAS (ppt)	Filtered Water PFAS (ppt)	Removal Efficiency
1	Raw - Oostanaula	1,316.83	8.34	99.4%
2	Raw - Oostanaula	1,316.83	1.05	99.9%
3	Raw - Oostanaula	1,316.83	1.98	99.8%
4	Raw - Oostanaula	1,316.83	1.51	99.9%
5	Raw - Oostanaula	1,316.83	3.69	99.7%
6	Raw - Oostanaula	1,316.83	3.84	99.7%

Details of the lab tests indicate some background levels of PFAS not found in the raw source water on any other tests commissioned by the City or by RavenVolt (for instance, 9-Cl-PF3ONS). The results of those outlier tests do not change the removal percentage reported. Only PFBA was present in all six hourly tests, generally from 1 to 2 ppt. Since the tests were performed on samples taken in Direct Filtration (e.g. no pre-treatment), we surmised the higher level of organics was in competition for adsorptive capacity on the PAC and limited the effectiveness of the PAC to remove PFBA.

The second test, performed during filtration of pre-treated water, spanned a 22 hour period.

TABLE 4-3
22 Hour Test Results – February 26 – 27, 2021

Hours after Backwash	Source Water	Feed Water PFAS (ppt)	Filtered Water PFAS (ppt)	Removal
1	Filtered - Mixed	244.16	8.22	96.6%
2	Filtered - Mixed	244.16	0	100%
4	Filtered - Mixed	244.16	0	100%
6	Filtered - Mixed	244.16	0	100%
8	Filtered - Mixed	244.16	7.35	97.0%
10	Filtered - Mixed	244.16	13.42	94.5%
13	Filtered - Mixed	244.16	15.47	93.7%
16	Filtered - Mixed	244.16	33.69	86.2%
19	Filtered - Mixed	244.16	48.14	80.3%
22	Filtered - Mixed	244.16	49.76	79.6%

Evaluation of the 24-hour test data shows that PFBS, PFBA and PFPeA were removed less efficiently after approximately 12 hours, but still well below any established thresholds. Also, for 19 hours overall removal efficiency exceeded 80%. At 22 hours, levels of PFBA exceeded the amount in the feed water sample, which indicated that either the feed water concentrations were quickly increasing (levels only sampled at hour 0), or that competitive adsorption was taking place and PFBA molecules were being displaced by an increase in TOC or other contaminants. Feed water turbidity varied from 0.2 to 0.4 NTU over the test period.

Figure 4-1 shows the removal efficiency versus time, as well as the overall PFAS concentration (all compounds summed) versus time. As indicated, a 12-hour filtration cycle should produce a consistently high removal efficiency and allow for a significant safety factor. Detailed results for all samples tested by RavenVolt are included in the Appendix for review.

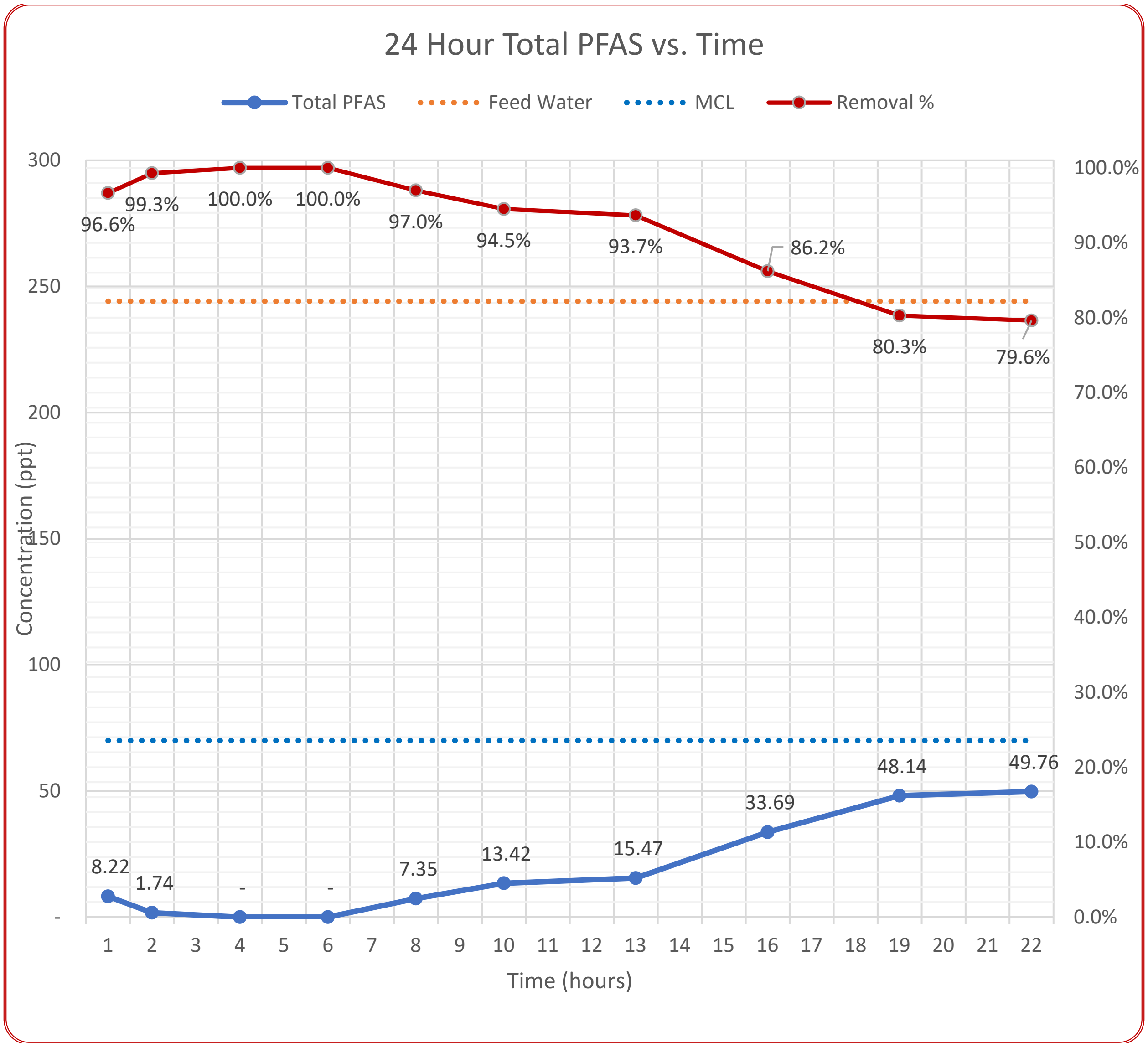


Figure 4-1

4.3 Carbon Effectiveness Test Results

Similar lab tests were performed on pre-treated water from the Rome Water Treatment Plant to determine if specific types of powdered activated carbon were more effective than others, especially as compared to the type used for the larger scale pilot test. RavenVolt Water Systems performed these tests using the same membranes used in the Pilot Test and varying only the PAC used for the initial shock dose. The membrane used for testing is a 0.01 m^2 module connected to a CERAFILTEC Suitcase Test Unit with precise flow and transmembrane pressure control. The results are shown in Table 4-4 and indicate that a more cost effective PAC can be used and should produce similar results.

Table 4-4
PAC Variation Test Results for PFAS Removal

PFAS Compound (ppt)	Feed Water	Cabot Darco S-51	Cabot Darco S-51 HF	Cabot Hydrodarco B	Cabot Hydrodarco C
NEtFOSAA					
NMeFOSAA					
PFBS	13.10				
PFBA	4.61		1.63		1.58
PFDA					
PFDOA					
PFHpS					
PFHpA	4.76				
PFHxS	1.50				
PFHxA	12.30				
PFNA	0.92				
PFOS	6.69				
PFOA	14.50				
PFPeA	11.60		0.81		0.64
PFUnA					
Total	**69.98 ppt**		**2.44 ppt**		**2.22 ppt**
% Removal		**100.0%**	**96.5%**	**100.0%**	**96.8%**

Cabot Darco S-51 was used on site at the Rome Pilot Test. It is an acid washed PAC that sells for twice the unit cost per pound of unwashed PAC. Cabot Hydrodarco B is an unwashed PAC product that is available for approximately $0.65 - $0.70 per pound in bulk. Hydrodarco B could be used in full scale implementation and would reduce the estimated operating costs significantly.

Full EPA 537.1 Method tests were performed, but the table above is limited to only the PFAS compounds previously detected in Rome water. Others have been omitted for brevity.

5. Operational Data

5.1 Data Collection

Data from the Pilot Test equipment was collected continuously by Siemens PLC for all operating parameters monitored. Those include:

- Pump drive status and % of overall drive capacity
- Water temperature and pH
- Filtration pump flow and pressure
- Backwash pump flow and pressure
- Chemical pump drive status
- Feed water and filtered water turbidity

Additional data collected for process metrics was measured and recorded throughout the pilot process.

- Influent and waste stream flows were metered by external devices installed on the feed and waste lines outside the mobile treatment unit.
- Chemical use was also manually tracked and compared with the operating hours of each pump as recorded by the PLC

5.2 Operations Summary

Operation of the Pilot Test equipment over the optimized period, when pre-treated water was processed, resulted in the following operational averages:

Table 5-1
Summary of Monthly Operating Results

Parameter	February 2021	March 2021	April 2021
Water Produced (average gpd)	6,417	7,157	8,352
Average Flux Rate (LMH)[1]	168.7	188.0	216.2
Average Filtrate Turbidity (NTU)	0.019	0.017	0.016
PFAS Removal Efficiency	99.4%	99.5%	99.8%
Power Consumption (kWh/1,000 gallons)	1.131	1.202	1.235
Water Recovery	94.7%	91.2%	92.5%
Powdered Activated Carbon consumption (25% effective dosage)	44 lb. on membrane	58 lb. on membrane	60 lb. on membrane
Total Chemical Costs per 1,000 gallons			
• PAC	$0.159	$0.170	$0.156
• Sodium Hypochlorite	$0.116	$0.116	$0.116
• Citric Acid	$0.067	$0.067	$0.067
• Poly Aluminum Chloride	n/a	n/a	n/a
Power Costs ($/1,000 gallons)	$0.102	$0.108	$0.111
Total OPEX ($/per 1,000 gal in Pilot Test)	**$0.444**	**$0.461**	**$0.450**

[1] Reduced flux rate to match available feed water flow through 2” hose

As indicated previously, the start-up and adjustment period for the CERAFILTEC pilot unit was longer than anticipated due to connectivity issues and electrical troubleshooting of motors and controls. As soon as the unit was adjusted and remote monitoring was established, operations became more efficient and treatment results improved steadily.

Table 5-2
Power Consumption Details By Month

February

Pump / Motor	Pump Description	Total Run Time (hrs)	Motor Rated kW	Average Output	Total kWh	Total Cost
B-0301	Blower	6.60	0.55	100.0%	3.63	$ 0.33
P-1101	p-ACLF Dosing pump	1.25	1.40	100.0%	1.75	$ 0.16
P-0301	Filtration pump	549.90	0.75	47.5%	195.90	$ 17.63
P-0501	backflush pump	0.75	0.75	100.0%	0.56	$ 0.05
P-0502	sprinkler pump	1.17	1.10	100.0%	1.29	$ 0.12
P-0801	dosing pump acid	0.16	0.18	100.0%	0.03	$ 0.00
P-0901	dosing pump base	0.28	0.18	100.0%	0.05	$ 0.00
Monthly Total					**203.21**	**$ 18.29**

March

Pump / Motor	Pump Description	Total Run Time (hrs)	Motor Rated kW	Average Output	Total kWh	Total Cost
B-0301	Blower	6.60	0.55	100.0%	3.63	$ 0.33
P-1101	p-ACLF Dosing pump	-	1.40	100.0%	0.00	-
P-0301	Filtration pump	690.00	0.75	50.5%	261.34	$ 23.52
P-0501	backflush pump	0.90	0.75	100.0%	0.68	$ 0.06
P-0502	sprinkler pump	0.90	1.10	100.0%	0.99	$ 0.09
P-0801	dosing pump acid	0.10	0.18	100.0%	0.02	$ 0.00
P-0901	dosing pump base	0.10	0.18	100.0%	0.02	$ 0.00
Monthly Total					266.67	**$ 24.00**

April

Pump / Motor	Pump Description	Total Run Time (hrs)	Motor Rated kW	Avg. Output	Total kWh	Total Cost
B-0301	Blower	6.80	0.55	100.0%	3.74	$ 0.34
P-1101	p-ACLF Dosing pump	-	1.40	100.0%	0.00	$ -
P-0301	Filtration pump	693.00	0.75	58.4%	303.53	$ 27.32
P-0501	backflush pump	1.10	0.75	100.0%	0.83	$ 0.07
P-0502	sprinkler pump	1.10	1.10	100.0%	1.21	$ 0.11
P-0801	dosing pump acid	0.10	0.18	100.0%	0.02	$ 0.00
P-0901	dosing pump base	0.20	0.18	100.0%	0.04	$ 0.00
Monthly Total					309.36	**$ 27.84**

6. Pilot Test Conclusions

Based on the data collected and operation of the Pilot Test Equipment, the CERAFILTEC ceramic membranes are an effective means of ultrafiltration for drinking water and can efficiently remove large and small concentrations of both long and short chain PFAS compounds dissolved in the raw water supply. Active Cake Layer Filtration (ACLF) is unique to the CERAFILTEC submerged membrane technology and well suited for conventional filter retrofit.

Specific conclusions and recommendations are detailed in following sections, but can be summarized as follows:

- CERAFILTEC ceramic membranes and ACLF can remove dissolved PFAS contaminants in the Rome raw water supply to below detectable limits
- Shock doses of Powdered Activated Carbon are effective for over 12 hours at the projected flow rate (membrane flux) and with multiple filters in staggered operation the collective removal rate for total PFAS should exceed 99.9% continuously
- A design flux rate of 310.97 LMH (approximately 181.5 GFD) is a conservative estimate for full scale production at 18 MGD
- Recovery rate including all backwash and service water usage is conservatively estimated to be 98.8% of raw water volume (see Projection in Appendix)
- When operated following the cloth disc filters in the Pilot Test, CERAFILTEC required no coagulation aids, no pH adjustment and infrequent chemical cleaning.
- Assuming 8 treatment trains to match the existing 8 filter basins, ceramic membranes will occupy approximately 30% of the existing filter footprint to match current design capacity (18 MGD).
- Full capacity, 18 MGD, could be consolidated into four (4) existing filters with other filter basins re-purposed for pumping equipment or backwash supply water tanks. The compact footprint of CERAFILTEC membrane modules also lends itself to upgrade of several filters while the plant remains online meeting current demand.

Example Upgrade of Existing Filters

Figure 6-1

7. Recommended Process – Ceramic Membranes (w/ACLF)

7.1 Project Component Summary

A full project design Projection is included in the Appendix. The Projection details the complete ceramic membrane design and array recommendations for retrofitting existing filter basins. A summary of those recommendations is included in Table 7-1 and a simplified Process Flow Diagram is shown in Figure 7-1:

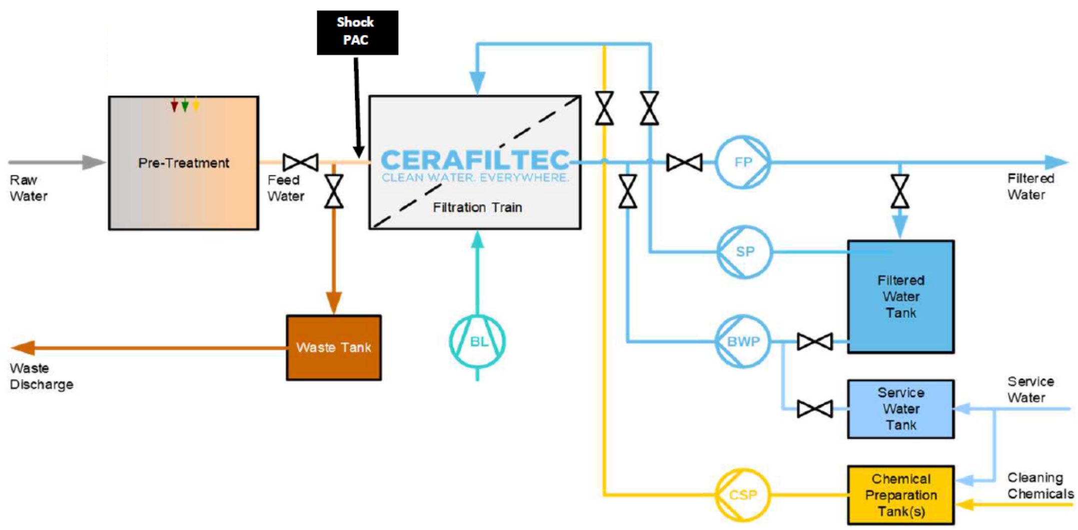
Table 7–1 Process Components				
MEMBRANES				
Component	**Capacity**	**Quantity**	**Configuration**	**Description**
Ceramic membrane modules	6.0 square meters each; 9,216 square meters total (99,150 SF)	1,536 Modules	8 Trains (2 per existing filter)	CERAFILTEC Module 6.0S
PUMPS & BLOWERS				
Component	**Capacity**	**Quantity**	**Configuration**	**Description**
Filtration Pumps	1,565 gpm nom. 1,786 gpm max.	8 Each	1 per Filter Train	End suction pump with VFD; suction pressure between 0.7 and 7 psi
Backwash Pumps	3,130 gpm nom.	1 duty 1 standby	1 common unit	End suction pump with VFD; discharge pressure up to 17 psi
Sprinkler Pumps	2,112 gpm nom.	1 duty 1 standby	1 common unit	End suction pump with VFD; discharge pressure up to 28.4 psi
Citric Acid Dosing Pump	3.0 gpm	1 duty	1 common unit	28.4 psi
HCl Dosing Pump	0.2 gpm	1 duty	1 common unit	28.4 psi
Sodium Hypochlorite Dosing Pump	2.5 gpm	1 duty	1 common unit	28.4 psi
Powdered Activated Carbon Slurry Pump	200 gpm	1 duty 1 standby	1 common unit	Double disc pump for shock dose of PAC to Filtration Tanks
Blower	750 cfm	1 duty	1 common unit	Discharge pressure 5 psi
Direct Integrity Test – Rotary Vane Compressor	260 cfm	1 duty	1 common unit	Discharge pressure of 8.52 psi with VFD

Table 7–1 Process Components				
TANKS				
Component	**Capacity**	**Quantity**	**Configuration**	**Description**
Filtration Tanks	165 SF internal 9'-9" tall 8'-6" SWD	8 Each – one per Train	Install 2 per existing Filter	Each tank filters 2.25 MGD (equiv. to 9.47 gpm/sf)
Citric Acid Prep & Storage Tank	550 gallons	1 Each	1 common unit	
Hydrochloric Acid Storage Tank	550 gallons	1 Each	1 common unit	
Sodium Hypochlorite Storage Tank	550 gallons	1 Each	1 common unit	
Filtered Water or Backwash Tank (if not elevated tank at Plant)	16,500 gallons	1 Each or 4 Evenly divided or use existing Elevated Tank	Supply for backwash and sprinkler pumps	Filtered water diversion storage tank for membrane process
CapClean Prep Tank #1	2,650 gallons	1 Each	1 common unit	
CapClean Prep Tank #2	1,850 gallons	1 Each	1 common unit	
Powdered Activated Carbon Storage	200 cubic feet	1 Each	1 common unit	Day storage for dry PAC – integral with slurry delivery system

Our Powdered Activated Carbon supplier, Cabot Norit, recommends two (2) Porta Pac feed systems to supply dry PAC to the slurry make up and delivery system. Arrangement drawings of the proposed equipment are included in the Appendix. The estimated cost to construct a pneumatically loaded PAC silo and feed system is approximately $600,000 based on recent design estimates.

7.2 Process Flow Diagram

General Process Flow Diagram & Description



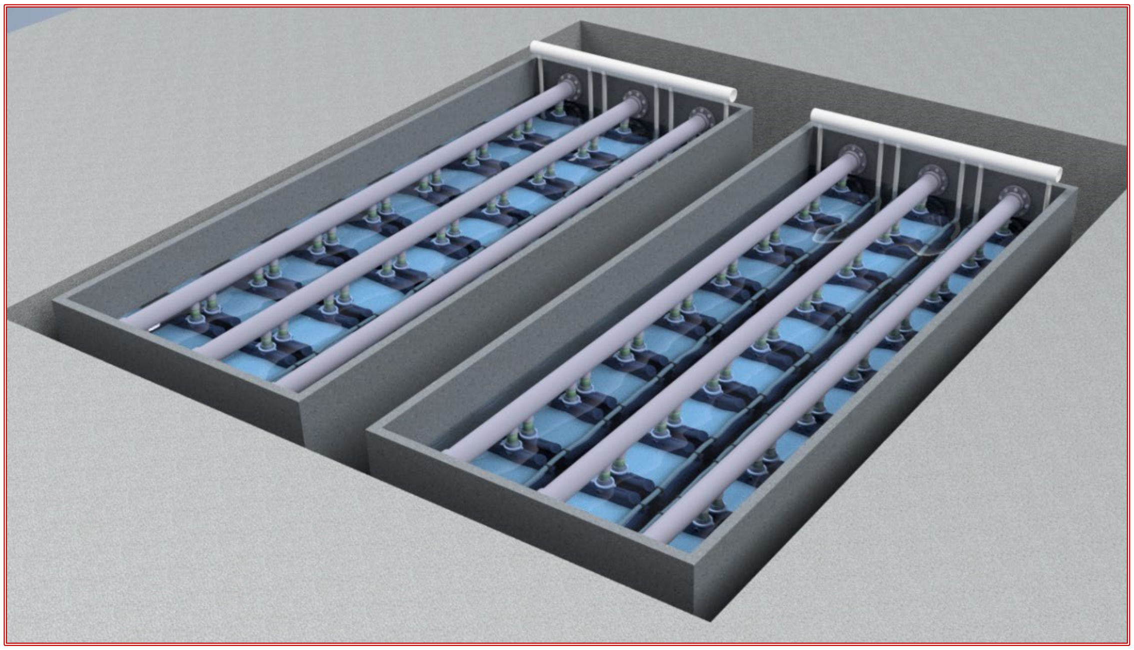
1. Legend

C/F	Coagulation/Flocculation		BWP	Backwash Pump(s)
FP	Filtration Pump(s)		CSP	Chemical Sprinkler Pump(s)
SP	Sprinkler Pump(s)		BL	Blower(s)

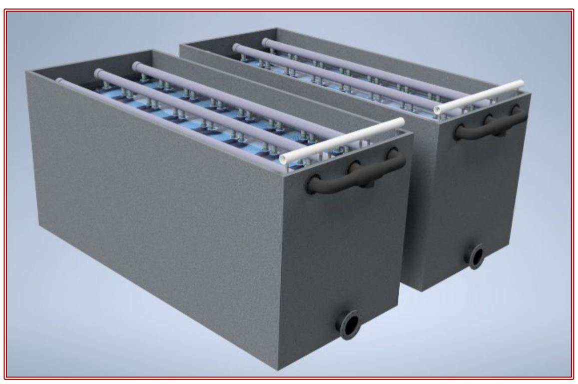
Figure 7-1

7.3 Preliminary Layout

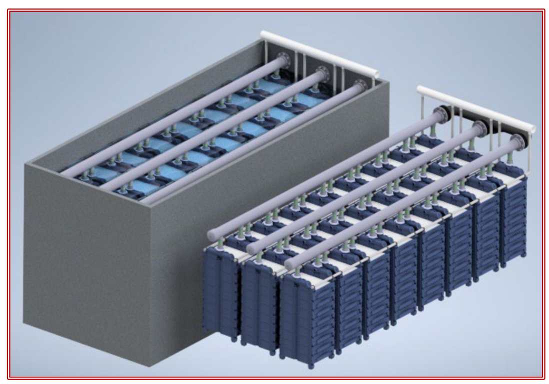
The Projection includes dimensions for each train of ceramic membrane modules. As indicated, the footprint of one (1) train installed as part of an existing filter basin upgrade will cover approximately 30% of the available area. We recommend installing two (2) treatment trains in each of four (4) existing filter beds and reserving four (4) filter beds for ancillary equipment or future expansion.



24 Towers per Train / 2 Trains per Existing Filter Basin



Tank in Tank Upgrade



Tank and Without (8 modules per Tower)

Figure 7-2

Figure 7-3 below is a photo of a typical Tank-in-Tank retrofit currently under construction. The membrane towers are partially installed in the photo.

Figure 7-3

Figure 7-4 is the Process and Instrumentation Diagram for the CERAFILTEC system. Components for two of eight trains are shown.

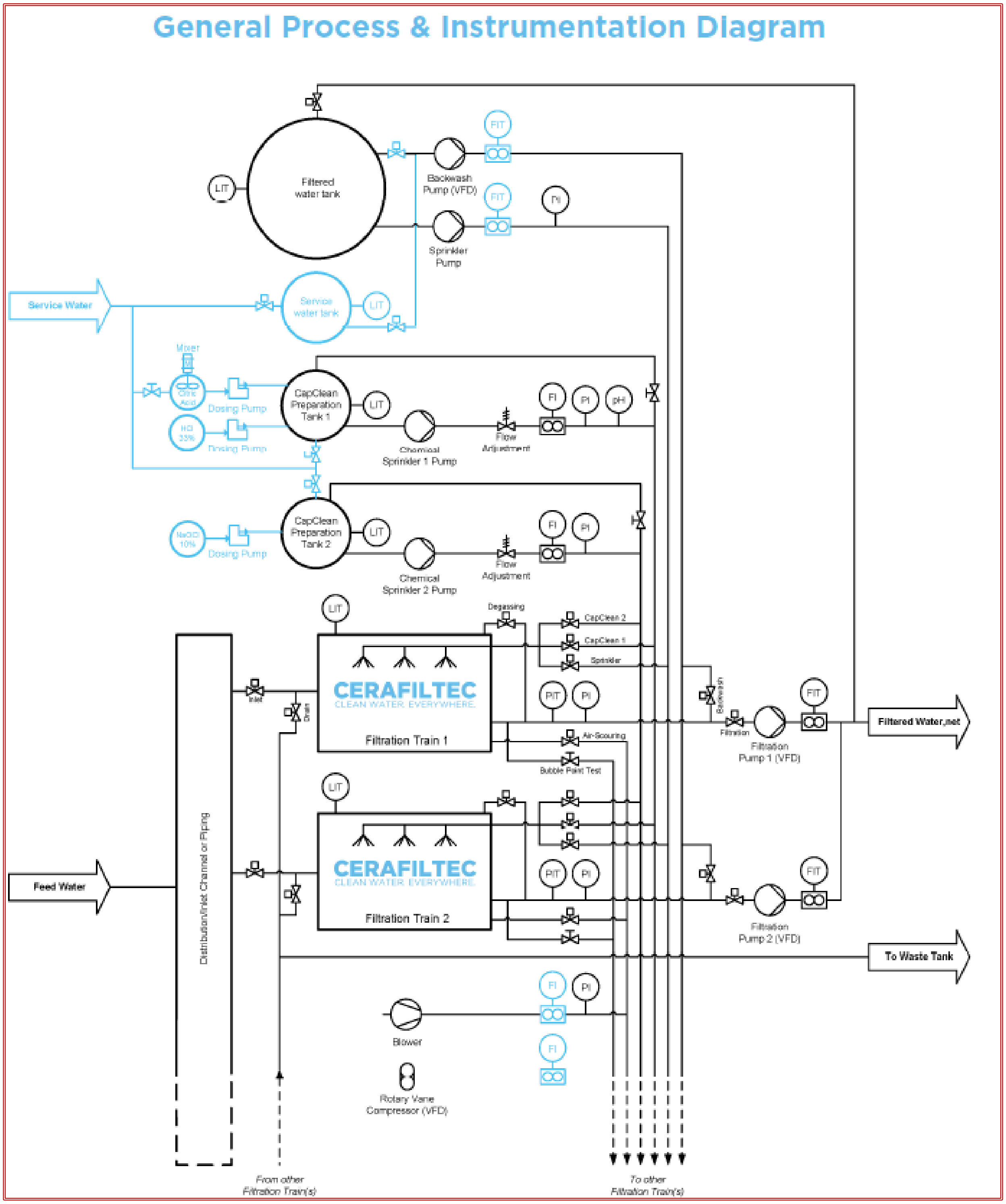


Figure 7-4

7.4 Capital Costs of Equipment

The equipment furnished by CERAFILTEC US for this project includes the ceramic membrane modules and accessories required to construct 192 towers for installation by others in the existing filter basins.

Table 7-2 Capital Cost of CERAFILTEC Supplied Scope of Work			
Item	**Description**	**Unit Cost**	**Total Cost**
CERAFILTEC Module 6.0S	6m^2 ceramic membrane modules with integrated flow channels – Capacity 18 MGD at design flux		
Project engineering support	CERAFILTEC engineering support for design, construction, and start-up; includes ladder logic for system controls	No charge	No charge
20 Year Warranty	Standard Warranty on CERAFILTEC membrane modules – 3 years full replacement, Pro Rata through year 20	No charge	No charge
Annual Monitoring and Bi-Weekly Performance Reporting	Remote monitoring of key operational parameters and bi-weekly report of metrics to assist with operations and sustained performance	$25,000 per year, No Charge for Years 1-5	No Charge for Years 1-5

The costs of external piping, pumps, tanks and chemical feed systems are not included. Pumps and piping selection by Owner and Engineer in accordance with capacity specifications in shown in Table 7.1.

7.5 Estimated Operating Costs

Based on estimates prepared for full-scale operation of the CERAFILTEC ceramic membranes, as shown in the Projection, the annual operating expenses for power and chemicals can be summarized as shown in Table 7-3. The unit costs for chemicals are derived from current chemical costs at other membrane treatment plants in north Georgia, and the power costs are specific to the current power costs for the City of Rome.

Table 7-3
Operating Cost of CERAFILTEC Ceramic Membrane System

Quantity	Description	Unit Cost	Total Cost
62.54 gal/day	Sodium Hypochlorite	$4.24/gal	$265.17/day
42.86 gal/day	Citric Acid	$7.30/gal	$312.84/day
4.62 gal/day	Hydrochloric Acid	$1.49/gal	$6.87/day
5,582 lb/day	Powdered Activated Carbon	$0.65/lb	$3,628.30/day
1,738.8 kWh/Day	Electric Power (Pumps, Blower, Compressor)	$0.09/kWh	$156.49/day
Total Daily Estimated Operating Costs			$4,369.67/day
Estimated Annual Operating Costs (@18MGD)			**$1,594,930/year**

Based on the calculations summarized above, the cost to operate the CERAFILTEC system at full capacity totals approximately $1,594,930 per year, or $0.243 per 1,000 gallons.

7.6 Cost Avoidance

In addition to the operational savings associated with ultrafiltration combined with adsorption for low cost PFAS remediation, costs associated with other, more expensive solutions can be avoided by selecting CERAFILTEC. A partial summary of those costs and related plant upgrades is as follows:

- Reduce the cost of backwash waste handling by a significant reduction in waste volume.
- Increase projected recovery rates by dewatering backwash waste and recycling the filtrate. Concentration of water treatment plant backwash waste can be dewatered to 40% solids.
- Avoid the expense of upgrading the plant electrical service that will be required by some of the alternative technologies being considered.
- Reduce the capital expenses needed for the project by working within the existing filtration building to get full capacity and future expansion capacity from existing filter basins.

A full, 20-year NPV evaluation of the total cost of ownership (TCO) of each solution being considered may include these related costs for other systems.

APPENDIX

A. CERAFILTEC Projection
B. Independent Lab Results – PFAS Removal
C. Operations Comparison – Before and After Tuning
D. Operating Data – Details
E. Reference Projects