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# Technical Memorandum

To: MVD Board of Commissioners

From: Mike Metcalf, Lynnette Carney, Billy Kitchens

Date: December 14, 2018

Subject: **Evaluation of PFAS Treatment for Wells 2, 3, 7 & 8**

**Merrimack Village District (MVD), Merrimack, NH**

## BACKGROUND

Merrimack's water distribution system serves an estimated 25,000 customers. The source for all of Merrimack's water is groundwater with the exception of emergency interconnections with Pennichuck Water Works (PWW) and Manchester Water Works (MWW). It is noted that the MWW connection would only be used in the case of an extreme emergency since MWW disinfects with chloramines. Merrimack has six (6) active and one (1) inactive gravel-packed well located in the towns of Merrimack and Hollis as follows:

| Well | Location | Status |
|---|---|---|
| Well #2 | Central Merrimack | On-line |
| Well #3 | Central Merrimack | On-line (elevated Fe/Mn) |
| Well #4 | Front Street in northern Merrimack; piped together with Well #5. Well is about 8,000 ft south of the Saint Gobain facility. | Off-line, due to PFOA concentrations exceeding NHDES AGQS. |
| Well #5 | Front Street in northern Merrimack; piped together with Well #4. This well is about 8,000 ft south of the Saint Gobain facility. | Off-line, due to PFOA concentrations exceeding NHDES AGQS. |
| Well #6 | Southern Merrimack | Inactive/removed from service; no longer permitted |
| Well #7 | Northeastern Hollis; piped together with Well #8 to Fe/Mn WTP | On-line |
| Well #8 | Northeastern Hollis; piped together with Well #7 to Fe/Mn WTP | On-line |

The current NH Ambient Groundwater Quality Standard (AGQS) is 70 ppt for PFOA, PFOS or the sum of PFOA+PFOS which, per NHDES regulations, is enforceable as a maximum contaminant level (MCL). USEPA's Unregulated Contaminant Monitoring Rule 3 (UCMR 3) included monitoring of four other PFAS compounds, including perfluorononanoic acid (PFNA), perfluorohexanesulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA), and perfluorobutanesulfonic acid (PFBS). The governor signed legislation earlier this year providing NHDES with a toxicologist and human risk assessor position to aid in proposing and establishing drinking water MCLs for for PFOA, PFOS, PFNA, and PFHxS by January 1, 2019. NHDES held stakeholder and technical work sessions in October to obtain public input on this process. At this time, the regulatory changes are uncertain.

MVD is proceeding with the design phase of a GAC treatment plant for PFAS removal at Wells #4 and #5, per the settlement agreement with Saint Gobain, since these wells have concentrations above the current 70 ppt regulatory limit.

Wells #2, #3, #7 and #8 have PFOA and PFOS present, but at levels below the 70 ppt regulatory standards (8 to 48 ppt combined PFOA & PFOS). It is not known at this time if new MCL's will be set that would result in exceedances. This Memorandum documents the potential approach for, and costs involved, to treat these wells to reduce 14 PFAS chemicals currently monitored by MVD. We have included conceptual layouts for PFAS treatment options. It is noted that these are conceptual only and would be updated in a preliminary design phase. Although there are hundreds of potential compounds, NHDES now typically tests for 24 compounds when evaluating sites. Although monthly monitoring at Wells #2, #3, #7 & #8 included 23 compounds when monitoring began in 2016, monitoring was reduced to 14 compounds in March 2017 after several compounds had never been found above detection limits. Since historic data is available for 14 PFAS compounds, removal of these compounds was included in the RFPs to vendors, as part of this study.

It is our understanding that the treatment goal desired by MVD is to remove all PFAS compounds to below detection. The unit sizing shown herein would be applicable regardless of the treatment goals for the various compounds. However, the media life will vary significantly depending on the specific treatment goal for each compound since certain ones have been shown to break through the available medias well before others.

## PFAS TREATMENT FEASIBILITY – GENERAL

As part of this evaluation, we met with representatives from Purolite, a resin manufacturer; Emerging Contaminant Treatment Technologies (ECT2), a manufacturer of resin treatment systems; Calgon Carbon, a manufacturer of GAC treatment systems and GAC; and Cabot Norit, a manufacturer of GAC. We also spoke with a representative for TIGG, who is a manufacturer of tank and treatment systems using either GAC or resin and visited the GAC demonstration system currently operating at the Pease Tradeport, treating water from the City of Portsmouth's Smith and Harrison wells.

We requested treatment proposals from vendors to reduce the 14 currently sampled PFAS compounds (see table below) to below detection limits. It is noted that after the draft of this study was submitted, we also met with EVOQUA, a manufacturer of GAC, resin, and treatment systems using both medias. The RFP sent to the manufacturers noted above was forwarded to EVOQUA. We will review their response and supplement this report as appropriate.

| | Chemical | CAS number | Abbreviation | Detection Limit, PPT |
|---|---|---|---|---|
| 1 | ***Perfluorooctanoic Acid*** | ***335-67-1*** | ***PFOA*** | 0.26 |
| 2 | ***Perfluoro-octanesulfonate*** | ***1763-23-1*** | ***PFOS*** | 0.35 |
| 3 | N-ethyl perfluorooctanesulfonamidoacetic Acid | 2291-50-6 | NEtFOSAA | 0.87 |
| 4 | N-methyl perfluorooctanesulfonamidoacetic Acid | 2355-31-9 | NMeFOSAA | 0.87 |
| 5 | Perfluorotridecanoic Acid | 72629-94-8 | PFTRDA | 0.35 |
| 6 | Perfluorobutanesulfonate | 375-73-5 | PFBS | 0.26 |
| 7 | Perfluorodecanoic Acid | 335-76-2 | PFDA | 0.78 |
| 8 | Perfluorododeconaoic Acid | 307-55-1 | PFDOA | 0.43 |
| 9 | Perfluoroheptanoic Acid | 375-85-9 | PFHPA | 0.35 |
| 10 | *Perfluorohexanesulfonate* | *355-46-4* | *PFHxS* | 0.35 |
| 11 | Perfluorohexanoic Acid | 307-24-4 | PFHxA | 0.35 |
| 12 | *Perfluorononanoic Acid* | *375-95-1* | *PFNA* | 0.35 |
| 13 | Perfluorotetradecanoic Acid | 376-06-7 | PFTEDA | 0.26 |
| 14 | Perfluorodundecanoic Acid | 2058-94-8 | PFUNA | 0.35 |

Notes: ***Bold & Italic*** = currently regulated by NHDES
*Italic* = will be regulated by NHDES by January 2019
Detection limits as identified as method detection limit on Eurofins Lancaster Laboratory Environmental testing report July 31, 2018 (EPA 537 Version 1.1 Modified)

MVD should be aware that the chemicals, test methods, and detection limits we are currently using are transient. As noted, there are currently 24 PFAS chemicals being monitored/evaluated by EPA, and MVD is currently monitoring regularly for 14 of these PFAS chemicals. DES believes this is only a low percentage of the total PFAS chemicals that may be monitored in the future. DES has also reported that EPA is developing new testing methods that will include up to 39 compounds within the next year or two. Eurofins, the current laboratory used by MVD for PFAS testing, is now able to report 36 compounds, including 4 'replacement' compounds (replacement for PFOA), in a single scan.

In evaluating PFAS treatment for Wells #2, #3, #7 & #8, the need to treat for removal of iron and manganese at Wells #3, #7 & #8 must be taken into consideration. In the case of Wells #7 & #8, Greensand Plus filters are already in place (***Figure 1***), and similar filters will be required for Well #3 (***Figure 12***). (**NOTE**: All figures are included in ***Appendix 1***.)

There are currently two technologies commonly used for removal of PFAS compounds; granular activated carbon (GAC) and resin. Advanced oxidation (A/O) processes have been considered but studies have indicated that A/O will only remove <10% of PFOA and <10-50% of PFOS so this process was not considered in this evaluation. The use of zeolite media is also being investigated, but is currently still in the testing and development phase so this may be worth revisiting in the future. This evaluation therefore included use of GAC and resin. The two media have the following similarities:

- Both use pressure filters.
- Both are single-use media (removed and disposed after use; not regenerated).
- Both require only an initial backwash to remove fines and stratify the bed.
- Both will require either replacement of the well pumps, or booster pumps after the greensand filters (where applicable), to accommodate the additional headloss through the GAC or resin filters (both systems have similar headloss of about 10-12 psi for a single filter, however a resin system will have higher total headloss because of the need for bag filters ahead of the resin filter).

Each media has different advantages, some of which are outlined below:

| Media Advantages | |
|---|---|
| **GAC** | **Resin** |
| Lower media cost (about ¼ the cost of resin) | Faster kinetics result in a shorter empty bed contact time (EBCT) required, so smaller vessels/less media volume is necessary |
| Can accommodate low levels of residual chlorine so no post greensand filter dechlorination is required | Better removal of short chain PFAS compounds is reported |
| Does not require micron filtration before filter (bag filters not required) | More capacity for PFOS/PFOA removal reported |
| Lower overall headloss because there are no pre-filters | Significantly lower backwash rates/volumes |
| Can be backwashed with chlorinated water from a clearwell, the distribution system, or raw water. | |

Although removal of PFOA and PFOS (both 8-carbon or "long chain" compounds) has been demonstrated using both GAC and resin, the shorter chain compounds, particularly 4-carbon compounds are the most difficult to remove. Additionally, compounds with a carboxylic functional group (those ending in "A"), are more difficult to remove than those with a sulfonate functional group (those ending in "S"). Therefore, in a treatment system with equal amounts of PFOA and PFOS, PFOA will break through before PFOS. All of the GAC and resin suppliers consulted with as part of this evaluation indicate that the 4-carbon compound, PFBA, is the most difficult to remove. It is said to typically be the limiting compound in design of either a GAC or a resin system, since it breaks through relatively quickly, requiring more frequent media replacement. Resin is reported to have better removal capability for these short chain compounds including PFBA. However, since this is an emerging field and limited studies have been conducted, pilot testing would be recommended, especially when considering short chain compound removal. The RSSCT tests that are currently being conducted for Wells #4 & #5 will provide some additional information about the capabilities of GAC for these wells. It is noted that different source waters may behave differently, so the results from Wells #4 & #5 cannot be directly applied to the other wells, but given that the water quality of the wells is reasonably similar, the results should give an indication of what can be expected.

Since the goal of this feasibility study is to remove PFAS compounds that are at concentrations below current regulatory limits to below detection limits, per MVD's request, it was assumed that only lead treatment vessels systems are necessary at this time. When PFAS removal is required to below regulated limits, treatment vessels are typically constructed in series (lead/lag), so when the first vessel exhibits breakthrough, the second vessel can continue to provide treatment while the media in the lead vessel is replaced. For the purposes of this evaluation, only lead vessels have been included, and space has been allocated for the future addition of a second (lag) vessel for each treatment train, should the treatment of these compounds become a regulatory requirement in the future, or should a combined system with a polishing filter be desired (for example a polishing resin filter could be used after a GAC filter to aid in removal of short-chain compounds).

## Granular Activated Carbon (GAC)

Granular activated carbon is available from several sources, the most common being bituminous coal, coconut-based carbon, or lignite coal carbon. Several studies have shown that coal-based carbon provides better removal (longer time to breakthrough) of PFOA and PFOS than coconut carbon, however, in the past, coconut carbon was less expensive than coal carbon, making both types worth consideration. However, current widespread climate conditions (drought and flooding) have reportedly caused a shortage of coconuts/raw materials for coconut carbon, which has caused the price to equalize with that of the coal carbon. For these reasons, coconut carbon was not be considered in this evaluation.

Calgon is a leader in the use of bituminous coal GAC for PFAS treatment, and supplies turn-key systems. The Calgon Filtrasorb 400 GAC is manufactured in the US and is currently being used in the City of Portsmouth, NH demonstration plant for PFAS removal at the Pease Tradeport. Calgon carbon was also used in Hoosick Falls, NY.

Cabot-Norit is a manufacturer of granular activated carbon and other specialty chemicals. They manufacture bituminous coal GAC, coconut based GAC, and lignite based GAC. They conducted a study that identified that GAC's ability to remove PFAS was dependent on total organic carbon (TOC) concentration in the source water and mesopore volume of the GAC. They performed testing of all three of their carbons to evaluate the effects of TOC on PFAS removal and found that the lignite based GAC, which has the highest mesopore area (compared to bituminous or coconut based GAC) provided the longest run-time before breakthrough of PFOA and PFOS in both simulated ground water and surface water (different TOC concentrations). Their bituminous based carbon had slightly faster breakthrough than the lignite-based carbon, and coconut carbon had much faster breakthrough. The higher the TOC concentration in the raw water, the faster the breakthrough of PFOS and PFOA. The larger the mesopore volume of the media, the longer run-time of the media before break-through. Rapid Scale Small Column Testing (RSSCT) or pilot testing is recommended to evaluate the performance of specific GAC products (raw materials, activation process, etc.) with the specific water being treated.

Although GAC has been demonstrated to provide good removal of PFOA and PFOS, the two currently regulated PFAS compounds (both 8-carbon compounds), it is said to be less effective at removing shorter chain compounds like PFBA (4-carbon), PFPeA (5-carbon) and PFHxA (6-carbon). Shorter, 4-chain carbons are said to exhibit breakthrough after less than 20% of the bed volumes compared to the 8-chain compounds. Two additional compounds, PFNA (9-carbon) and PFHxS (6-carbon) are anticipated to be regulated in New Hampshire soon.

Although there are physical properties of the GAC that can be measured and compared (density, iodine number, abrasion number, particle size, effective size and uniformity coefficient), materials that appear to be the same based on physical property comparison, can produce different treatment results depending on the source water, contaminants to be removed and concentrations, competing or inhibitory compounds, raw GAC materials and manufacturing/activation procedures. Therefore, testing is recommended to evaluate the actual removal capacity and bed life for each specific GAC material and each source water.

According to Calgon, pH does not affect PFAS removal using GAC, and the low level of chlorine in the Greensand Plus filter effluent at the Well 7/8 WTP is not anticipated to affect the GAC life significantly. The carbon may increase the pH initially when first installed which is reportedly a function of ash remaining in the carbon pores. The City of Portsmouth is experiencing a pH increase to approximately 9 for more than a month. Therefore, less caustic may be needed until the filters are conditioned, after which more caustic would likely be needed once there is no pH change through the GAC filters. It is noted that the ash in carbon can be reduced by using acid washed carbon.

When the GAC media needs to be changed, a 24-hour wetting of the new media is required, followed by an initial backwash to remove fines and stratify the bed. Recommended backwash rates varied between 8.5 gpm/sf and 15 gpm/sf and will vary depending on the density of the carbon and water temperature. Therefore, a wide range of backwash volumes is presented in the design summaries below. Additional research will be necessary in the design phase to further investigate the necessary backwash rate.

Empty Bed Contact Time (EBCT) is a common variable used to size GAC filters for PFAS removal. This is a calculated value that is dependent upon the pounds of carbon in the vessel, the density of the GAC, and the flowrate through the vessel. Because this variable is dependent on the density of the GAC, the EBCT will vary by manufacturer and type of GAC, due to the variation in density between carbons.

## Resin Media

Resin filters are said to exhibit dual removal mechanisms of ion exchange and adsorption, which takes advantage of the unique properties of PFAS compounds. ECT2 claims that resin may have 5-6 times greater PFOA removal capability than GAC, and 8-10 times greater PFOS removal capability than GAC.

PFAS removal by resins has faster kinetics than GAC, which results in smaller size vessels and lower empty bed contact times (EBCT). Resins do however have minimum flowrates (about 6 gpm/sf) to prevent channeling within the media bed.

Resins have been said to have better capability to remove shorter chain compounds, however, based on PFBA as the limiting compound, ECT2 indicates an estimated time to breakthrough of only 4-6 months. Purolite has developed models for removal of several compounds using their resin. They estimated effective treatment of 110,000 bed volumes at Well #7/8 for PFOA, whereas only 9,500 bed volumes for PFBA.

RESIN MEDIA

Chlorine and other oxidants are destructive to the resin and must be removed prior to the resin filter. Chemical dechlorination using sodium bisulfite will need to be further evaluated in future phases for those locations where iron and manganese are present, because of the presence of oxidants from that treatment process. We received a quote of approximately $500,000 for a UV system for dechlorination; therefore, it appears chemical dechlorination will be more feasible.

**GREENSAND PLUS MEDIA (for size comparison)**

Additionally, 5-10 micron bag filters are required ahead of the resin filters, because of the small size of the resin media. Any carryover from the greensand filters or other suspended solids can turn the resin into a "filter" (instead of an ion exchange/adsorption bed), increasing the headloss, and causing premature bed failure (backwashing during service is not recommended because it would mix PFAS-loaded resin throughout the bed, causing premature PFAS leakage).

These additional processes will require additional building floor space. In addition, the resin media is substantially more costly than the GAC media.

Because the kinetics of the resin reaction are faster than GAC, the filters are smaller, only approximately 17 ft in height, compared to 20-26 ft GAC tanks. Backwash rates are also much less than GAC. Similar to GAC, backwashing is only required at startup to remove fines and stratify the bed.

## WELLS 7/8 PFAS TREATMENT FEASIBILITY

Wells 7 & 8 are located in Hollis and have concentrations of iron and manganese above the respective secondary MCLs. An iron and manganese treatment plant was constructed and put on-line in 2016 to remove iron and manganese from the blended water from Wells 7 and 8. Wells

7&8 have PFOA+PFOS concentrations of approximately 20-30 ppt, which is below the current regulatory limits of 70 ppt.

The existing iron and manganese treatment plant was designed for the following:

| | | |
|---|---|---|
| Well #7 Permitted Production volume: | | 500 gpm (1997) |
| Well #8 Permitted Production volume: | | 750 gpm (1999) |
| Design Capacity: | | 1,250 gpm |
| Water Quality: | | |
| Raw Water: | Iron | 2.9 mg/l |
| | Manganese | 0.75 mg/l |
| | pH | 5.5-6.0 |
| | TOC | 1.1-1.7 mg/l |
| Post Filtration (Greensand Plus): | | |
| | Iron | <0.3 mg/l |
| | Manganese | <0.05 mg/l |
| | pH | 6.8 (currently 6.3 to 6.6) |
| | chlorine residual | 0.5-1.0 mg/l |
| Finished Water (from clearwell): | | |
| | Chlorine residual: | 0.5-2 mg/l |
| | Phosphate: | 1-2 mg/l |
| | Alkalinity: | 50 mg/L as $CaCO_3$ |

It is noted that DES has been monitoring PFAS concentrations in Pennichuck Brook downgradient of Wells 7&8 and noted an increase from about 10 ppt to over 30 ppt since the Well 7&8 WTP was put on line in May of 2016 and both wells have been pumped regularly. DES has inferred that pumping of Wells 7&8 may be contributing to this increase and they are continuing to investigate. UE has consulted with Emery & Garrett Groundwater Investigations (EGGI), MVD's hydrogeologic consultant, and to date, neither UE nor EGGI are aware of any firm technical data to support this conclusion. DES's investigation and resulting conclusions should be closely monitored by MVD as there could be serious consequences on the use of these wells if DES concluded that pumping of the wells is causing surface water quality issues.

A process flow schematic of either a GAC or resin option for PFAS treatment at Wells #7 and #8 is shown on ***Figure 2***.

## Well #7/8 WTP Building Considerations:

The existing Well 7/8 WTP building plans show a 48 ft x 34 ft future expansion area, where the soils were prepared during the Well 7/8 WTP construction for a future building addition. The soils at the site were found to be loose sands that were subject to liquefaction during a severe earthquake load, and the installation of Geopier rammed aggregate piers was required to stabilize the building area against liquefaction and settlement. This expansion area was originally intended for the future addition of Greensand Plus filters if another nearby source was developed requiring iron and manganese removal. Due to site limitations and soil issues, building expansion beyond this designated area would be difficult. Therefore, if this expansion area is used for PFAS treatment, it would be difficult to add more Greensand Plus filters in the future.

We contacted Helical Drilling, Inc., the company that performed the original soil stabilization to see if a larger building addition could be accommodated. Although the area of stabilization was designed for a 48 ft x 34 ft building addition, the actual stabilization area extends approximately 8-10 ft beyond this area. They indicated that when dealing with liquefaction mitigation, the stabilized area must extend beyond the footprint of the building to control the potential settlements within the influence zone of the building's foundation. Therefore, if a building larger than the 48 ft x 34 ft building expansion area originally designated for additional Greensand Plus filter expansion is required, additional soil stabilization would be required for a larger building footprint.

The existing building has approximately an 18 ft ceiling height and a clearwell, recycle tanks and pipe gallery below the main operating floor. The GAC and resin tanks discussed below have heights of approximately 26 ft and 17 ft, respectively. The gable end wall of the existing building has reinforcing for its' existing height, and, per the structural engineer who designed the building, cannot accommodate an additional 12 ft. of height added to it to accommodate a 30 ft ceiling for the 26 ft tanks. Additionally, the existing roof trusses cannot accommodate the snow drift loading associated with an adjacent addition 10 ft higher than the existing building. The building addition for the new tanks would either have a basement, if GAC is used (***Figure 4***), matching the finished floor of the below grade tanks under the existing building (to accommodate the taller GAC tanks), or would be a slab-on-grade if the shorter resin tanks are used (***Figure 6***). Additional building space has been included in the preliminary design to accommodate more stringent regulatory requirements. This space will allow for a redundant (lag) vessel to be added to each train, should regulatory requirements change in the future. This will require a roof design to permit removal of a section in the future to install the tanks. This may be accomplished with multiple girder trusses with ladder framing between them or sloping rafters supported by intermediate beams that would in turn be supported on girder trusses to provide a 'box out' area where the roof could be removed, or an assemblage of trusses designed to be removed as a group, using steel beams placed beneath them, to allow a crane to hoist the entire assemblage of trusses across a section of the roof (if two tanks are being installed at the same time).

## Wells 7/8 GAC Option

We received proposals for GAC systems from both Calgon Corporation and TIGG. An example floor plan is shown in ***Figure 3***. The following was recommended:

| GAC System Summary | |
|---|---|
| Building addition | 34 ft x 48 ft (w/ basement level) |
| Tanks | Two vessels in parallel |
| Trains | 2 |
| Diameter | 12 ft |
| Height | 26 ft |
| Orientation | Parallel |
| GAC per vessel | 40,000 lbs |
| Vessel capacity | 1,000 gpm each (total system capacity 2,000 gpm) to maintain min 10 min EBCT |

| | |
|---|---|
| Empty Bed Contact Time (EBCT) | 14.2 - 16.5 minutes (using Calgon or Cabot Norit bituminous coal carbon) |
| Surface Loading rate | 5.5 gpm/sf |
| Anticipated headloss | 10-12 psi (for single filter train) |
| Expected life | 2+ years |
| Backwash | From clearwell |
| Backwash rate | 8.5 – 12 gpm (with lower ramp-up/ramp-down rate) |
| Backwash flowrate | 960 - 1350 gpm |
| Total backwash time | 36 minutes |
| Total backwash volume (single vessel) | 16,500 – 47,500 gallons |

PEASE WTP 10-FT DIAMETER GAC FILTERS

Alternately, three 10 ft diameter vessels could be used, each with 20,000 lb of carbon, approx. 22 ft in height, which would provide the capacity to treat 1,500 gpm.

Each 12 ft diameter vessel is said to have a capacity of approximately 1,000 gpm, so with two vessels, the system would have a capacity of nearly 2,000 gpm, and therefore excess EBCT at a flowrate of 1,250 gpm (the minimum EBCT being 10 minutes). Theoretically, if the system were to be operated below the design flowrate, one filter could be installed now for 1,000 gpm capacity, with a second, parallel filter/train, installed later. However, the difficult logistics and cost to install tanks in the future would need to be included in the design (likely requiring a removable roof section).

The Calgon vessels come standard with plastic underdrain nozzles for use with carbon; however, they can be supplied with stainless steel nozzles that would be suitable for use with carbon or resin, for an additional cost of about $5,000 per vessel. Alternatively, the nozzles can be changed in the field later if the District wanted to change media.

The 26+ ft height of GAC tanks create challenges with the existing building. As previously noted, the existing building (with approximately 18 ft ceiling) cannot accommodate an addition with nearly a 30 ft ceiling. To accommodate the necessary height of the GAC tanks, the new building addition would be constructed with a floor at the same elevation as the clearwell/recycle tank slab (***Figure 4***). A catwalk, or partial structural floor slab could be constructed to match the existing WTP first floor, for the purposes of access to the new building addition. This area would need a sump pump and drain pump to allow draining of the tanks.

New GAC may show a pH increase for the first 10-100 bed volumes processed, which should then subside. As previously noted, the City of Portsmouth is seeing a pH increase to about 9-10 during initial backwash of new media. They run a low rate of filter to waste for about a month before the pH comes down to raw water levels. Manufacturers' report some pH increase in new media as normal and expected, depending on the raw materials and activation process, but not necessarily for the duration they are seeing in Portsmouth. The City of Portsmouth has indicated that they have a filter down for approximately 30 days to change the media, backwash, and condition the new media, before it is ready to be put back on line. With only a single filter available (not lead/lag), the District would either have no PFAS treatment during this time, or if the operation/change-out of the two filters can be staggered, the flow could be lowered to below 1,000 gpm so that one filter can be used for treatment while the other is undergoing a media changeout.

Radon was 980 pCi/L in Well #8 in 2000, and 460 pCi/L for the blended water in 2000. Radon can be a concern because it will be removed by the GAC and has the potential to affect the disposal of the spent carbon if it is considered low-level radioactive waste from adsorption of the radon. However, radon has a short half-life (about 4 days), so holding of the carbon (delaying disposal), may allow any accumulated radon on the media to diminish.

The disinfection point will need to be relocated from between the Greensand Plus filters and the clearwell, to after the GAC filters and before the clearwell (***Figure 2***).

Since the GAC filters are only backwashed once, upon media replacement, we have assumed that the backwash water could be accommodated in the existing recycle basins and infiltration basins for the Fe/Mn WTP. The existing recycle basins are sized for 1.5 times one day's backwash of all four Fe/Mn filters (about 50,000 gallons).

The GAC also requires an initial wet-out, which takes approximately 24 hours. Wet or damp carbon may preferentially remove oxygen from confined spaces and therefore, safety protocol and monitoring must be followed, particularly when working in confined spaces when the carbon is changed out.

The cost estimate for design and construction of a building addition, and installation of the two 12 ft diameter GAC filters (two trains, each with a single filter), each loaded with 40,000 lbs of carbon is **estimated to be about $3.6 Million (see *Table 1*).** (**NOTE**: All tables are included in ***Appendix 2***.) Space is included in the building expansion for the future addition of two vessels to be added in series (yielding two trains, each with lead/lag vessels).

Although the current cost opinion for GAC filters at Wells 7/8 includes only a lead set of filters (2), rather than redundant, lead/lag filters (4) as included in the 2016 cost opinion, the current cost estimate is higher than in 2016 for several reasons including the following:

- A 30 ft high building cannot be accommodated as an addition to the existing 20 ft high building, due to the effects of snow/drift loads which could pole up against the higher wall off the addition. Therefore, the addition will need to be constructed with a recessed floor to match the elevation of the existing clearwell/recycle tank floor. The previous estimate assumed a slab-on-grade building, which was less expensive than a basement.
- The cost of the GAC tank system, on a per-tank basis is higher than in the 2016 evaluation. This is reportedly because the cost of steel is significantly higher now (due to tariffs and other causes).

- Costs used in the 2016 evaluation have been increased based on ENR indexes to account for inflation to 2018 costs.

Carbon replacement costs ranged from about $1.50/lb to $3.00/lb. With an estimated change-out every year, at a cost of about $60,000-$120,000 per vessel, the total annual cost is estimated to range between $120,000-240,000 for media replacement. This cost includes only carbon changeout and disposal of the spent carbon. It does not include other smaller operational costs such as additional electricity for the building addition, additional pumping costs and/or heating costs associated with the larger building. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $10-15,000 and therefore the **total annual O&M cost for the addition of GAC at Wells #7/8 would be $130,000 to $255,000**.

## Wells 7/8 Resin Option

The following was recommended by ECT2:

| Resin System Summary | |
|---|---|
| Building addition | 34 ft x 48 ft (slab-on-grade) |
| Tanks | Two in parallel |
| Trains | 2 |
| Diameter | 10 ft |
| Height | 17 ft |
| Orientation | Parallel |
| Resin per Vessel | 393 CF |
| Vessel Capacity | 785 gpm each (total system capacity 1,570 gpm) |
| Minimum Vessel Flow | 470 gpm |
| Empty Bed Contact Time (EBCT) | 3.7 minutes at design flow of 785 |
| Surface Loading Rate | 8 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single resin filter ) + bag filter headloss |
| Expected Life | 1.5 years for PFOA; 4-6 months for shorter chain compounds |
| Backwash | From raw water (cannot accommodate chlorine in finished water) |
| Backwash Rate | 1.5-2 gpm/sf |
| Backwash Flowrate | 118-157 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 4,300 – 5,700 gallons |
| Additional Equipment | Dual bag filters and dechlorination system |

Refer to ***Figure 5*** for a conceptual layout.

Purolite, a resin manufacturer, proposed the use of a single 12 ft diameter vessel, with a 3-minute EBCT, and estimated a 300-day media life. Although this option may be less costly, by reducing the number of tanks, it would limit flexibility, and require a minimum flow of approximately 679 gpm at all times. This could be problematic if one of the wells were taken off-line.

The advantage of a resin system is that the faster kinetics allow the use of tanks with smaller footprints, as well as shorter tanks (***Figure 6***). They require significantly lower backflow rates than GAC because of the density of the media, and the resin is said to have better removal capability for shorter chain compounds than GAC.

Disadvantages of the resin system include a higher media cost than GAC and the need for micron filtration prior to the resin vessels, which requires additional floor space, cost and O&M. For the purposes of this evaluation, we assumed the use of a dual filter housing unit, each with 8 bags, with each vessel about 30 inches in diameter. The resin also cannot accommodate the presence of any oxidants (i.e. chlorine), and therefore, the finished water from the Greensand Plus filters at Wells #7 and #8 will need to be dechlorinated prior to being sent to the resin vessels. This would likely be accomplished by the addition of sodium bisulfite or sodium metabisulfite. For the purposes of this evaluation, we have assumed that a small chemical feed room would need to be included in the building for the purposes of dechlorination.

The cost estimate for design and construction of a building addition, and installation of the two 10 ft diameter resin filters, each loaded with resin, dechlorination and 5-10 micron bag filtration is **estimated to be about $4.4 Million** (see ***Table 1***).

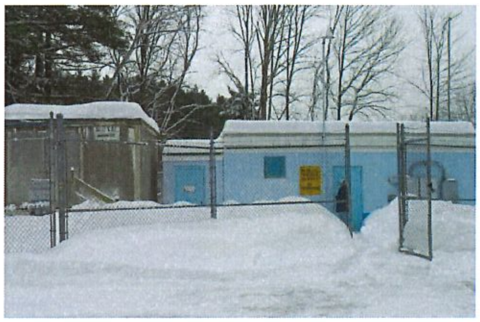
ECT2 estimates that the resin would need to be changed out about every 1.5 years for PFOA removal, but every 4-6 months for PFBA, at a cost of about $415,000 for the two vessels, plus $8,000-60,000 for resin disposal. This yields a total annual cost of $300,000 for media changeout if the resin is changed every 1.5 years, based on PFOA removal (not shorter chain compounds, which would result in an annual cost of about $890,000 per year). This cost includes the resin changeout and disposal of the spent resin. It does not include other smaller operational costs such as additional electricity for the building, additional chemical costs for dechlorination, bag replacements, additional pumping costs and/or heating costs associated with the larger building. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $15-20,000 and therefore the **total annual O&M for the addition of resin treatment at Wells #7/8 would be about $320,000** to **$910,000**.

## WELL #2 PFAS TREATMENT FEASIBILITY

Well #2 is located in the central part of Merrimack, off Amherst Rd, near exit 11 (I-93). Well #2 has exhibited historic PFOA+PFOS concentrations of approximately 10-20 ppt. The existing facilities at Well #2 include a pump building with a tablet chlorinator and liquid blended phosphate feed system, and a separate lime feed building. The well has a 1,500 gpm permitted capacity, has good water quality, and is considered the best well in the MVD system. Although permitted for 1,500 gpm, the well is typically not operated above 1,100 gpm, and the current pump may not be capable of flowrates above 1,100 gpm. However, any treatment plant should be capable of treating the permitted capacity of the well, and thus, a design flow of 1,500 gpm has been assumed for this evaluation.

Water Quality:

| | | |
|---|---|---|
| Raw Water: | Alkalinity | approx. 15-17 mg/l |
| | TOC | unknown |
| | pH | 5.5-6 typical (full range 5.58 to 7.08) |
| Typical Finished Water: | | |
| | pH | 6-6.5 |



A new building would be constructed adjacent to the existing Well #2 pump house, which would include the new PFAS treatment system, in addition to caustic feed (bulk storage & day tank) for pH adjustment, to replace the existing lime feed system, sodium hypo-chlorite (bulk storage & day tank) for disinfection, and blended phosphate for corrosion control. For the purposes of this evaluation, we have assumed that bulk sodium hypochlorite would be used for disinfection, but the use of this or calcium hypochlorite tablets can be further evaluated during design. ***Figure*** *7* shows a process flow schematic for GAC or resin treatment at Well #2.

## Well #2 GAC Option

We received a proposal from Calgon for Well #2. They recommend the following using their bituminous based coal, Filtrasorb 400, granular activated carbon. The following system was recommended:

| GAC System Summary | |
|---|---|
| Building size | 38 ft x 60 ft (w/ basement level) |
| Tanks | Two in parallel |
| Trains | 2 |
| Diameter | 12 ft |
| Height | 26 ft |
| Orientation | Parallel |
| GAC per Vessel | 40,000 lbs |
| Vessel Capacity | 1,000 gpm each (total system capacity 2,000 gpm) to maintain min10 min EBCT |
| Empty Bed Contact Time (EBCT) | 11.8 minutes with Calgon F400 |
| Surface Loading Rate | 6.6 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single filter train) |
| Expected Life | 2+ years |
| Backwash | From distribution system (need to verify capability from hydraulic model) |
| Backwash Rate | 8.5 – 12 gpm/sf (with lower ramp-up/ramp-down rate) |

| | |
|---|---|
| Backwash Flowrate | 960 – 1,350 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 16,500 – 47,500 gallons |

Refer to ***Figures 8 and 9*** for conceptual layout.

Alternatively, three 10 ft diameter GAC tanks could be used for this flowrate (they are rated for 500 gpm each). This would allow for a slightly shorter building (10 ft diameter vessels are 22 ft in height), but would require a larger footprint, and would not provide the excess capacity and flexibility of the 12 ft diameter units (refer to previous discussion in Well #7/8). The capital cost for the two 12 ft diameter units was quoted as the same as three 10 ft diameter units.

Refer to the Well #7/8 GAC Option discussion for additional information and considerations regarding the GAC tanks and system, as the same system is recommended for Well #2. The new building could be constructed with a basement/sump, to reduce the wall height of the building to about 20 ft, or a 30 ft high slab-on-grade building could be constructed.

The cost estimate for design and construction of a new 38 ft x 60 ft building, installation of the two 12 ft diameter GAC filters, each loaded with 40,000 lbs of carbon, new sodium hypochlorite, caustic and blended phosphate systems, and replacement of the well pump is **estimated to be about $4.3 Million** (see ***Table 2*)**.

At an estimated change-out rate of one year, and a cost of $1.50-$3.00/lb from different GAC vendors, a cost of about $60,000 -$120,000 per change-out per vessel is anticipated. This equates to a total annual cost of $120,000-$240,000 for media change-out. This cost includes the carbon changeout and disposal of the spent carbon. This does not include other operational costs such as power and heat for the building, chemical costs, additional pumping costs, building maintenance, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $20-25,000 and therefore the **total annual O&M cost for the addition of GAC at Well #2 would be $140,000-265,000**. This does not include chemical costs for disinfection, pH adjustment and corrosion control, which, although they would be incorporated into the new building, are assumed to already be accounted for in the existing O&M costs for the Well #2 pumping station.

## Well #2 Resin Option

The following was recommended by ECT2:

| Resin System Summary | |
|---|---|
| Building size | 38 ft x 60 ft (slab-on-grade) |
| Tanks | Two in parallel |
| Trains | 2 |
| Diameter | 10 ft |
| Height | 17 ft |
| Orientation | Parallel |
| Resin per Vessel | 393 CF |

| | |
|---|---|
| Vessel Capacity | 785 gpm each (total system capacity 1,570 gpm) |
| Minimum Vessel Flow | 470 gpm |
| Empty Bed Contact Time (EBCT) | 3.7 minutes at design flow of 785 |
| Surface Loading Rate | 9.5 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single resin filter ) + bag filter headloss |
| Expected Life | 1.5 years for PFOA; 4-6 months for shorter chain compounds |
| Backwash | From raw water (cannot accommodate chlorine in finished water) |
| Backwash Rate | 1.5-2 gpm/sf |
| Backwash Flowrate | 118-157 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 4,300-5,700 gallons |
| Additional Equipment | Dual bag filters and dechlorination system |

Refer to ***Figures 10 and 11*** for a conceptual layout.

Refer to the Well #7/8 Resin Option discussion for additional information and considerations regarding the resin tanks, system, and ancillary equipment, as the same system is recommended for Well #2. The new building could be constructed as about a 20 ft high slab-on-grade building, which would house the two resin filters, bag filter system, sodium hypochlorite feed system, caustic feed system and polyphosphate feed system. Raw water from the wells would be fed directly to the resin vessels, followed by the chemical feeds before discharge to the distribution system.

The cost estimate for design and construction of a 38 ft x 60 ft building, installation of the two 10 ft diameter resin filters, each loaded with resin, dechlorination and 5-10 micron bag filtration, in addition to chemical feed systems for sodium hypochlorite, caustic and blended phosphate is **estimated to be about $5.1 Million** (see ***Table 2***).

ECT2 estimates that the resin would need to be changed out about every 1.5 years for PFOA removal, but every 4-6 months for PFBA, at a cost of about $415,000 for the two vessels, plus $8,000-60,000 for resin disposal. This yields a total annual cost of $300,000 if the resin is changed every 1.5 years, based on PFOA removal (not shorter chain compounds, which would result in an annual cost of about $890,000 per year). This cost includes the resin changeout and disposal of the spent resin. It does not include other smaller operational costs such as electricity and heat for the building, chemical costs, bag replacements, additional pumping costs, building maintenance, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $25-30,000 and therefore the **total annual O&M for the addition of resin treatment at Well #2 would be about $330,000** to **$920,000**.

## WELL #3 PFAS TREATMENT FEASIBILITY

Well #3 is located in the central part of Merrimack, off Continental Blvd, near Industrial Drive and south of Well #2. Well #3 has exhibited historic PFOA+PFOS concentrations of approximately 12-30 ppt. The existing facilities at Well #3 include a pump building with a tablet chlorinator and liquid blended phosphate feed system, and a separate lime feed building. The well has an 800 gpm permitted capacity, and has iron and manganese concentrations above the respective SMCLs.

Water Quality:

| | | |
|---|---|---|
| Raw Water: | Alkalinity | approx. 14-22 mg/l |
| | TOC | unknown |
| | pH | 5.5-6 |
| | Iron | 0.05-1.75 mg/l (lower concentrations in recent years) |
| | Manganese | 0.04-0.88 |
| Typical Finished Water: | | |
| | pH | 5.5-6.5 |

Iron and manganese concentrations are above secondary standards and should be removed prior to PFAS treatment by either GAC or resin to avoid fouling of the filters. This will require a greensand filtration system, similar to Wells #7 & 8 (***Figure 12***).

A new building would be constructed adjacent to the existing Well #3 pump house, and would include a Greensand Plus WTP, similar to the existing WTP at Wells #7&8, the new PFAS treatment system, a caustic feed system (bulk storage & day tank) for pH adjustment to replace the existing lime feed system, sodium hypochlorite (bulk storage & day tank) for disinfection, and blended phosphate for corrosion control. For the purposes of this evaluation, we have assumed that bulk sodium hypochlorite would be used for disinfection, but the use of this or calcium hypochlorite tablets can be further evaluated during design.

### Well #3 Iron and Manganese Treatment:

Proposals were solicited from Tonka, Hungerford and Terry and Roberts Filter for iron and manganese treatment using a Greensand Plus filtration system. Tonka and Hungerford and Terry recommended the use of a single horizontal pressure tank, each containing multiple individual filter cells, while Roberts Filter recommended the use of two vertical pressure filters, similar to those at the existing WTP at Wells 7&8.

Tonka Water recommended a Greensand Plus filtration system consisting of the following:

| Greensand Plus Horizontal System Summary | |
|---|---|
| Building size (includes PFAS treatment) | 48 ft x 80 ft (w/ full basement level) |
| Tanks | One (4 Cells) |
| Orientation | Horizontal tank, parallel filter flow |
| Diameter | 10 ft |
| Length | 28 ft |
| Greensands Plus media | 8,550 lbs per cell (34,085 total) |
| Media depth | 45 inches (12 inches anthracite; 18 inches Greensand plus; 3 inches sand; 16 inches graded gravel) |
| Surface Loading Rate | 3.0 gpm/sf (4.0 gpm/sf during single filter cell backwash) |
| Anticipated Headloss | 1-2 psi clean bed/ 7 psi dirty bed |
| Expected Life | 10-15 years |
| Backwash Source | From clearwell |
| Backwash Rate | 3 gpm/sf (air & water backwash) & 10 gpm/sf for re-stratification (water only) |
| Backwash Flowrate | 200 gpm (simul-wash) / 668 gpm (re-stratification) |
| Total Backwash Time | 15 minutes |
| Total Backwash Volume (single cell) | 4,900 gallons per cell; 20,000 gallons total |
| Anticipated Backwash Frequency | unspecified |
| Recommended Feed Water pH | 6.5 to 6.8 |

The recommended system from Hungerford and Terry was similar, but the tank was 10 ft diameter and 20 ft in length, with two (2) filter cells, 4 gpm/sf loading rate, 12 gpm/sf backwash rate for 10 minutes, resulting in 12,000 gallons of backwash water per cell, anticipated backwash frequency between 14 and 20 hours.

Roberts Water Technologies recommended a Greensand Plus filtration system consisting of the following:

| Greensands Plus Vertical System Summary | |
|---|---|
| Tanks | Two |
| Diameter | 12 ft |
| Height | 14.5 ft |
| Orientation | Vertical tanks; Parallel filter flow |
| Greensands Plus per Tank | 19,216.8 lbs. |
| Surface Loading Rate | 7 gpm/sf |
| Anticipated Headloss | Not provided |
| Expected Life | Not provided |
| Backwash Source | From clearwell |
| Backwash Rate | Not provided |

| | |
|---|---|
| Backwash Flowrate | Not provided |
| Total Backwash Time | Not provided |
| Total Backwash Volume (single cell) | Not provided |

Alternatively, three (3) ten (10) foot diameter tanks could be used, but the cost of that system is higher.

The cost of the iron and manganese treatment system is included with the cost opinions for each of the PFAS treatment options (GAC & Resin) below (see ***Table 3***).

**Well #3 GAC Option**

We received a proposal from Calgon for Well #3. They recommend the following using their bituminous based coal, Filtrasorb 400, granular activated carbon. The recommended system consists of the following:

| GAC System Summary | |
|---|---|
| Building size (includes Greensand treatment) | 48 ft x 80 ft (w/basement level) |
| Tanks | One |
| Trains | 1 |
| Diameter | 12 ft |
| Height | 26 ft |
| Orientation | NA |
| GAC per Vessel | 40,000 lbs |
| Vessel capacity | 1,000 gpm maintain min10 min EBCT |
| Empty Bed Contact Time (EBCT) | 11 minutes with Calgon F400 |
| Surface Loading Rate | 7 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single filter train) |
| Expected Life | 2+ years |
| Backwash | From clearwell |
| Backwash Rate | 8.5 – 12 gpm (with lower ramp-up/ramp-down rate) |
| Backwash Flowrate | 960 - 1350 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 16,500 – 47,500 gallons |

Refer to ***Figure 13*** for a conceptual layout.

Alternatively, two 10 ft diameter units could be installed, each with 20,000 lbs of GAC and an approximate height of 22 ft. The 10 ft vessels would have an EBCT of about 11 minutes, loading rate of 3.5 gpm/sf, and backwash flowrate of 670-940 gpm (at an average rate of 8.5-12 gpm/sf). With a backwash time of 36 minutes, this would generate about 11,500-33,000 gallons of backwash water.

Refer to the Well #7/8 GAC Option discussion for additional information and considerations regarding the GAC tanks and system, as a similar system is recommended for Well #3 (single tank vs dual tanks). The new building could be constructed with a basement/sump, to reduce the wall height of the building to about 20 ft, or a 30 ft high slab-on-grade building could be constructed (***Figure 14 and 15***).

The cost estimate for design and construction of a new 48 ft x 80 ft building, including iron and manganese treatment, installation of the single 12 ft diameter GAC filter loaded with 40,000 lbs of carbon, new sodium hypochlorite, caustic and blended phosphate systems, and replacement of the well pump is **estimated to be about $6.9 Million** (see ***Table 3***).

At an estimated change-out rate of one year, and a cost of $1.50-$3.00/lb from different GAC vendors, a cost of about $60,000 -$120,000 per change-out per vessel is anticipated. This equates to a total annual cost of $60,000-$120,000 for media replacement. This cost includes the carbon changeout and disposal of the spent carbon. This does not include other operational costs such as power and heat for the building, chemical costs, additional pumping costs, building maintenance, and operation of an iron and manganese WTP, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $60-65,000 and therefore the **total annual O&M cost for the addition of Fe-Mn and GAC at Well #3 would be $120,000-185,000**.

### Well #3 Resin Option

The following was recommended by ECT2:

| Resin System Summary | |
|---|---|
| Building size | 48 ft x 80 ft (w/ basement for Fe/Mn and slab-on-grade for resin portion) |
| Tanks | One |
| Trains | 1 |
| Diameter | 10 ft |
| Height | 17 ft |
| Orientation | NA |
| Resin per Vessel | 393 CF |
| Vessel Capacity | 785 gpm |
| Minimum Vessel Flow | 470 gpm |
| Empty Bed Contact Time (EBCT) | 3.7 minutes at design flow of 785 |
| Surface Loading Rate | 10.2 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single resin filter ) + bag filter headloss |
| Expected Life | 1.5 years for PFOA; 4-6 months for shorter chain compounds |
| Backwash | From raw water (cannot accommodate chlorine in finished water) |
| Backwash Rate | 1.5-2 gpm/sf |

| | |
|---|---|
| Backwash Flowrate | 118-157 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 4,300-5,700 gallons |
| Additional Equipment | Dual bag filters and dechlorination system |

Refer to ***Figures 16 and 17*** for a conceptual layout.

Refer to the Well #7/8 Resin Option discussion for additional information and considerations regarding the resin tanks, system, and ancillary equipment, as the same system is recommended for Well #3, just with a single vessel. Since the new building will also house the iron and manganese treatment process, that part of the building would likely be constructed with a clearwell and recycle tanks below, with the iron and manganese filtration units and the resin units constructed on the grade level, with approximately a 20 ft ceiling height. The new building would house the iron and manganese filters, two resin filters, bag filter system, dechlorination system sodium hypochlorite feed system, caustic feed system and blended phosphate feed system. Filtered water from the Greensand Plus filters would need to be dechlorinated, similar to that described for the Well #7/8 site. Alternatively, a different media could be evaluated for the iron and manganese treatment that would not require an oxidant.

The cost estimate for design and construction of a 48 ft x 80 ft building containing the iron and manganese treatment process, one 10 ft diameter resin vessel loaded with resin, dechlorination and 5-10 micron bag filtration, in addition to chemical feed systems for sodium hypochlorite, caustic and blended phosphate is **estimated to be about $7.4 Million** (see ***Table 3***).

ECT2 estimates that the resin would need to be changed out about every 1.5 years for PFOA removal, but every 4-6 months for PFBA, at a cost of about $250,000 for the vessel, plus $4,000-30,000 for resin disposal. This yields a total annual cost of about $180,000 if the resin is changed every 1.5 years, based on PFOA removal (not shorter chain compounds, which would result in an annual cost of about $540,000 per year). This cost includes the resin changeout and disposal of the spent resin. It does not include other operational costs such as power or heating for the building, chemical costs, bag replacements, additional pumping costs, building maintenance, operation of the iron and manganese WTP, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $65-70,000 and therefore the **total annual O&M for the addition of Fe-Mn and resin treatment at Well #3 would be about $250,000** to **$610,000**.

## WELL #2/3 COMBINED WTP EVALUATION

Since Well #2 and #3 are both located in the central part of Town, an option for a combined Water Treatment Plant (WTP) was evaluated. The design capacity for a combined Well #2 & 3 WTP would be 2,300 gpm (1,500 from Well #2 and 800 gpm from Well #3) and could be located on the south eastern portion of the Well #2 lot (map 3/lot C-76), adjacent to the existing MVD garage, or at any other location along the connecting water main (see ***Figure 18***). As previously noted, Well #2 is currently pumped at no more than 1,100 gpm, but for the purposes of this design, we have planned for the full permitted capacity.

The possibility of using blending of the two wells in lieu of iron and manganese treatment for the Well #3 water has not been evaluated at this time. For the purposes of this evaluation, we have assumed that iron and manganese treatment would be provided, the same as described previously in the Well #3 treatment options.

The new building would include the new iron, manganese and PFAS treatment systems, in addition to caustic feed (bulk storage & day tank) for pH adjustment, sodium hypochlorite (bulk storage & day tank) for disinfection, and blended phosphate for corrosion control. Well #3 water would be treated for iron and manganese, as previously discussed. Combining the PFAS treatment of Well #2 and the iron, manganese and PFAS treatment of Well #3 in to a single facility would require new water mains between Wells 2&3 (approximately a mile long) and the new centrally located treatment plant, as well as pump upgrades at both wells. The additional construction costs associated with the new water mains may be offset some by savings by eliminating duplicate processing equipment at two separate facilities. These cost savings include: 1) constructing only one facility, 2) not having to perform site enhancements at both Wells 2&3 for buildings and infrastructure to accommodate bulk chemical deliveries, 3) economies of scale with HVAC and electrical systems, generator, etc. and 4) long term operational and maintenance cost savings from operating just a single facility.

Additional value could also be incorporated through housing a much-needed backup booster pump system for the MVD High Pressure Zone (HPZ) and adding space to accommodate the current MVD offices as MVD has been contemplating new office space at this location for some time. However, costs for these additions (booster pump system and administrative space) have not been included in this cost evaluation.

## Combined Well #2/3 Combined GAC Option

The same iron and manganese treatment system previously described for Well #3 would be incorporated in the combined WTP. The GAC system for PFAS treatment would include the following:

| GAC System Summary | |
|---|---|
| Building size | 48 ft x 100 ft (w/ full basement level) |
| Tanks | Three in parallel |
| Trains | 3 |
| Diameter | 12 ft |
| Height | 26 ft |
| Orientation | Parallel |
| GAC per Vessel | 40,000 lbs |
| Vessel Capacity | 1,000 gpm each (total system capacity 3,000 gpm) to maintain min10 min EBCT |
| Empty Bed Contact Time (EBCT) | 11.5-13.5 min |
| Surface Loading Rate | 6.8 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single filter train) |
| Expected Life | 2+ years |
| Backwash Source | From clearwell |

| | |
|---|---|
| Backwash Rate | 8.5 – 12 gpm/sf (with lower ramp-up/ramp-down rate) |
| Backwash Flowrate | 960 - 1350 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 16,500-,47,500 gallons |

Refer to ***Figures 19 and 20*** for a conceptual layout.

Refer to the previous Well # 2 and #3 GAC Options discussion for additional information and considerations regarding the GAC tanks and system.

The cost estimate for design and construction of a new 48 ft x 100 ft building, including an iron and manganese treatment system, three 12 ft diameter GAC filters, each loaded with 40,000 lbs of carbon, new sodium hypochlorite, caustic and blended phosphate systems, replacement of the well pumps, connecting water mains is **estimated to be about $10.9 Million** (see ***Table 4)***.

At an estimated change-out rate of one year, and a cost of $1.50-$3.00/lb from different GAC vendors, a cost of about $60,000 -$120,000 per change-out per vessel is anticipated. This equates to an annual cost of about **$180,000 to $360,000.** This cost includes carbon changeout and disposal of the spent carbon. This does not include other operational costs such as power and heat for the building, chemical costs, additional pumping costs, building maintenance, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $60-65,000 and therefore the **total annual O&M cost for the addition of Fe-Mn and GAC at Wells #2/3 would be $240,000-425,000.**

## Combined Well #2/3 Combined Resin Option

The following resin treatment system was recommended by ECT2:

| Resin System Summary | |
|---|---|
| Building size | 48 ft x 100 ft (w/partial basement level for Fe/Mn, slab-on-grade for resin portion) |
| Tanks | Three in parallel |
| Trains | 1 |
| Diameter | 10 ft |
| Height | 17 ft |
| Orientation | Parallel |
| Resin per Vessel | 393 CF |
| Vessel Capacity | 785 gpm each (total system capacity 2,355 gpm) |
| Minimum Vessel Flow | 470 gpm |
| Empty Bed Contact Time (EBCT) | 3.8 minutes at design flow of 785 gpm |
| Surface Loading Rate | 9.8 gpm/sf |
| Anticipated Headloss | 10-12 psi (for single resin filter ) + bag filter headloss |
| Expected Life | 1.5 years for PFOA; 4-6 months for shorter chain compounds |

| | |
|---|---|
| Backwash Source | From raw water (cannot accommodate chlorine in the finished water) |
| Backwash Rate | 1.5-2 gpm/sf |
| Backwash Flowrate | 118-157 gpm |
| Total Backwash Time | 36 minutes |
| Total Backwash Volume (single vessel) | 4,300-5,700 gallons |
| Additional Equipment | Dual bag filters and de-chlorination system |

Refer to ***Figures 21 and 22*** for a conceptual layout.

The new building construction would be similar to that previously described for the Well #3 resin option.

The cost estimate for design and construction of a 48 ft x 100 ft building containing the iron and manganese treatment process, three 10 ft diameter resin vessels loaded with resin, dechlorination, 5-10 micron bag filtration, chemical feed systems for sodium hypochlorite, caustic and blended phosphate, and connecting water mains is **estimated to be about $12.2 Million** (see ***Table 4***).

ECT2 estimates that the resin would need to be changed out about every 1.5 years for PFOA removal, but every 4-6 months for PFBA. We assumed a cost of about $620,000 for the resin, plus $12,000-90,000 for resin disposal, yielding a total annual cost of about $450,000 if the resin is changed every 1.5 years, based on PFOA removal (not shorter chain compounds, which would result in an annual cost of about $1.35 Million per year**.** This cost includes the resin changeout and disposal of the spent resin. It does not include other operational costs such as power or heating for the building, chemical costs, additional pumping costs, building maintenance, etc. For the purposes of this evaluation, we have assumed that these additional costs might be in the range of $65-70,000 and therefore the **total annual O&M for the addition of Fe-Mn and resin treatment at Wells #2/3 would be about $520,000** to **$1,400,000**.

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## COST SUMMARY AND CONCLUSIONS

Below is a summary of the costs presented herein:

| Location | Building size | PFAS Treatment | Cost (Capital/O&M) |
|---|---|---|---|
| Wells #7/8 (PFAS addition) | 34'x48' w/ basement | GAC – Two 12 ft vessels | $3.6 Million<br>$130,000-255,000/yr |
| | 34'x48' slab-on-grade | Resin – Two 10 ft vessels | $4.4 Million<br>$320,000-910,000/yr |
| | | | |
| Well #2 (New PFAS Building) | 32'x60' w/ basement | GAC – Two 12 ft vessels | $4.3 Million<br>$140,000-265,000/yr |
| | 32'x60' slab-on-grade | Resin – Two 10 ft vessels | $5.1 Million<br>$330,000-920,000/yr |
| | | | |
| Well #3 (New Fe/Mn and PFAS Bldg) | 48'x80' w/ full basement | GAC – One 12 ft vessel | $6.9 Million<br>$120,000-185,000/yr |
| | 48'x80' w/ partial basement (Fe/Mn), partial slab-on-grade (resin) | Resin – One 10 ft vessel | $7.4 Million<br>$250,000-610,000/yr |
| | | | |
| Wells #2/3 (New Fe/Mn and PFAS Bldg) | 48'x100' w/ full basement | GAC–Three 12 ft vessels | $10.9 Million<br>$240,000-425,000/yr |
| | 48'x80' w/ partial basement (Fe/Mn), partial slab-on-grade (resin) | Resin–Three 10 ft vessels | $12.2 Million<br>$520,000-$1.40 Mil/yr |

Although not included in the costs presented in this study, a combined facility at Wells #2/3 would provide the opportunity to incorporate a booster pump station for the high-pressure zone, as well as new administration space at the facility. These 'extra' features were not included in this evaluation, but present an added benefit to the combined Well #2/3 facility, over separate facilities.

As previously discussed, regulatory requirements are currently under review in New Hampshire, and may change in early 2019. There are currently only two compounds regulated. It is expected that the number regulated compounds will increase to four in early 2019, and MCLs for the two existing regulated compounds could change. In addition, changes are anticipated to occur in the future as more research and studies are conducted on these compounds.

This study is based on single vessel treatment (lead vessels only), since removal of PFAS at this time is not required by regulation. Space has been allocated in the proposed building footprints for the addition of lag vessels, should regulatory requirements become a factor in the future, or if polishing treatment is necessary to remove trace compounds.

Several options exist for each site, which may produce different results. Although GAC is predicted to have a slightly longer life to bed change-out (approximately 2 years compared to 1.5 years for resin), and is less expensive, there is substantially more GAC material used in each bed, as evident from the tank size discussed previously. In addition, previous studies have indicated that GAC may not be as successful in removing short chain compounds. If these short chain compounds need to be removed, then the use of resin somewhere in the process (either for primary, or 'polishing' should be considered. Examples of short chain compounds include PFBA, PFBS, PFHpA, PFHxA and PFPeA. Some of these compounds have been identified in very low concentrations (typically 2 ppt or less, a few up to 5 ppt) in the wells. If the goal is to remove the higher concentration compounds, like PFOA, which has been identified in concentrations about 20 ppt in the wells, then GAC may be a more cost-effective option.

Where iron and manganese treatment is necessary (Wells #3 and #7/8), additional processes are needed to accommodate resin due to the oxidants necessary in the iron and manganese treatment process. For the purposes of this evaluation, we have assumed chemical dechlorination would be used. Particularly for these sites, it may be more advantageous to use GAC for treatment. If removal of smaller chain compounds is necessary, and not accomplished by the GAC, a resin filter could be used as a lag or polishing filter, allowing the GAC to remove any oxidants, as well as longer chain compounds, thereby saving the capacity of the resin for those shorter chain compounds, and extending its life as much as possible.

DES is investigating the possibility that pumping of Wells 7&8 is contributing to an increase in PFAS concentrations downstream in Pennichuck Brook. While neither UE nor EGGI feel that there is technical data to support this possibility, this investigation should be closely monitored by MVD as there could be serious consequences on the use of these wells if DES determines that their use is causing surface water quality issues.

The cost of constructing a single combined plant to treat water from Wells #2 and #3 is presented as slightly less than single plants at each site, even with the cost of additional water main. There are several other advantages to combining facilities at one location. First, the possibility of blending the water to eliminate the need for iron and manganese treatment could be evaluated. Having a combined facility would also allow the addition of other improvements (not included in this evaluation), such as a booster pump station and new administrative office space to be included into a single space. There also may be operational savings in having heating, electrical, chemical feed equipment in a single location.

## NEXT STEPS/RECOMMENDATIONS

To continue to plan for PFAS treatment, we recommend the following:

- Advance a preliminary design phase for treatment at Wells #7 and #8 and a combined facility at Wells #2 and #3. Proceeding with preliminary design will allow the project to be better defined including:
    - Field investigations
    - Piloting for resin or GAC, Rapid Small Scale Column Testing (RSSCT) for GAC, or desk-top evaluations for media selection
    - Confirmation of treatment goals (regulatory or local preference)
    - 30% design preparation for site and building
    - Updates on costs

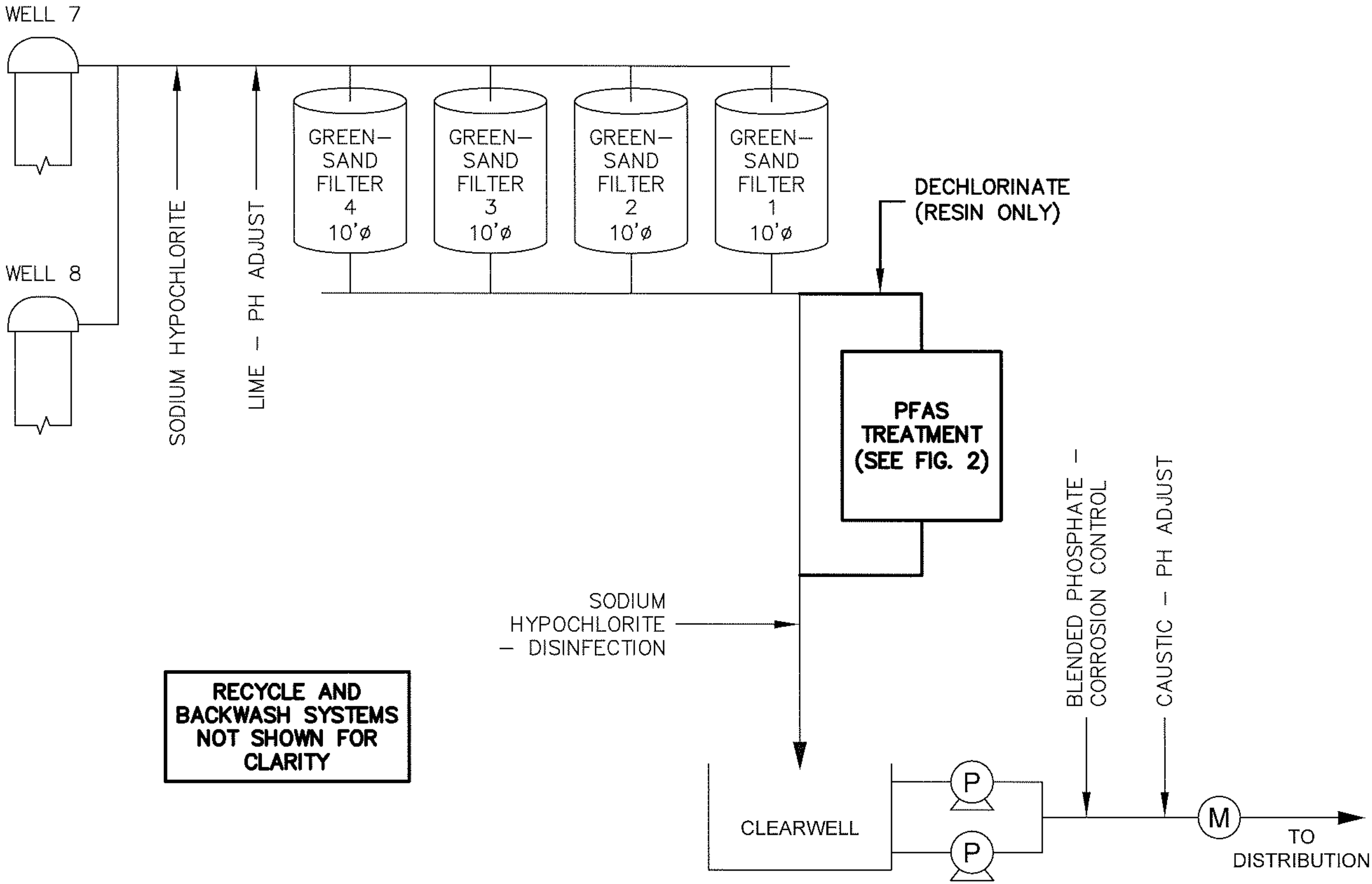
- Funding and financing options

- Advance preliminary design of the booster pump system for the high-pressure zone and new administrative space, as part of the combined facility at Wells #2 and #3.
- While preliminary design is ongoing, work with NHDES to understand what future regulatory limits might look like so they can be met and incorporated into final design.
- Stay abreast of DES's investigation into the increase of PFAS concentrations in Pennichuck Brook to see if their conclusions have any impact on the use of Wells 7&8.
- Update MVD's CIP to incorporate PFAS treatment into the financial plan along with other infrastructure needs.
- If MVD continues to desire to plan for PFAS treatment, we recommend a budget for preliminary design of $300,000.
- Depending on funding availability, preliminary design could begin as soon as spring/summer 2019
- Advance a preliminary design

# APPENDIX 1

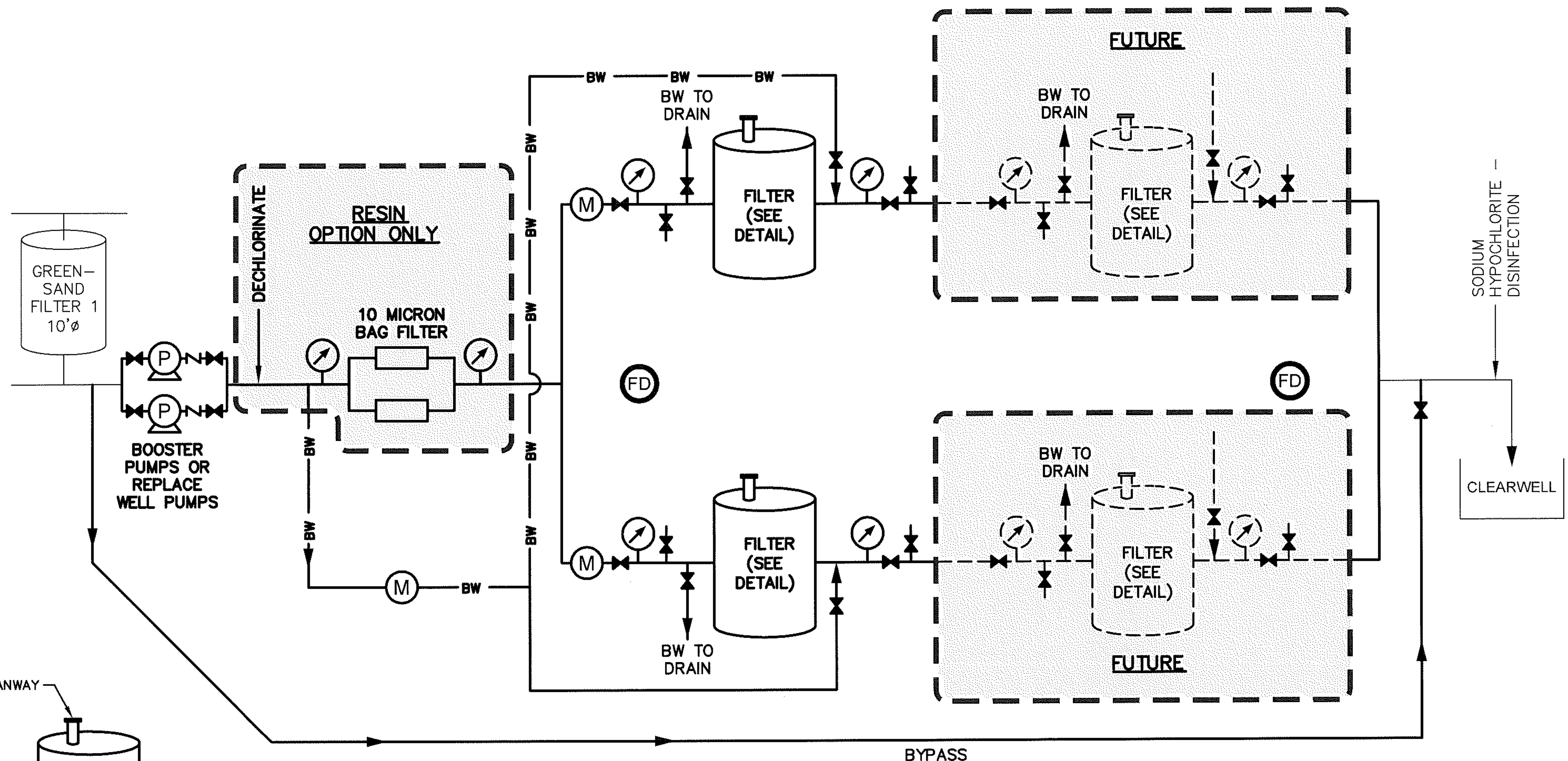
# FIGURES

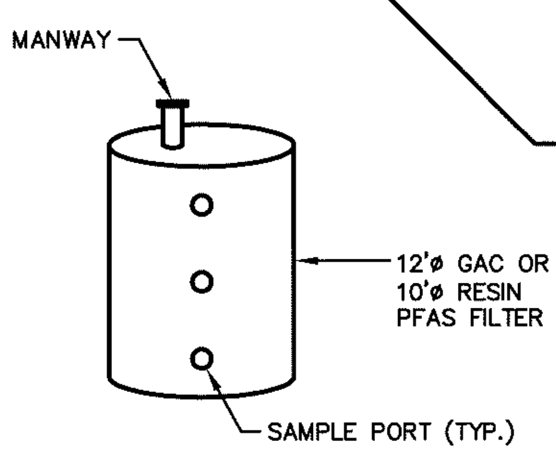
## APPENDIX 1 – FIGURES




| DATE | UNDERWOOD engineers | PROPOSED PFAS TREATMENT | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | WELLS 7 & 8<br>MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | 1 |
| PROJECT 2345 | | | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS 7-8.dwg, 12/14/2018 1:02:24 PM



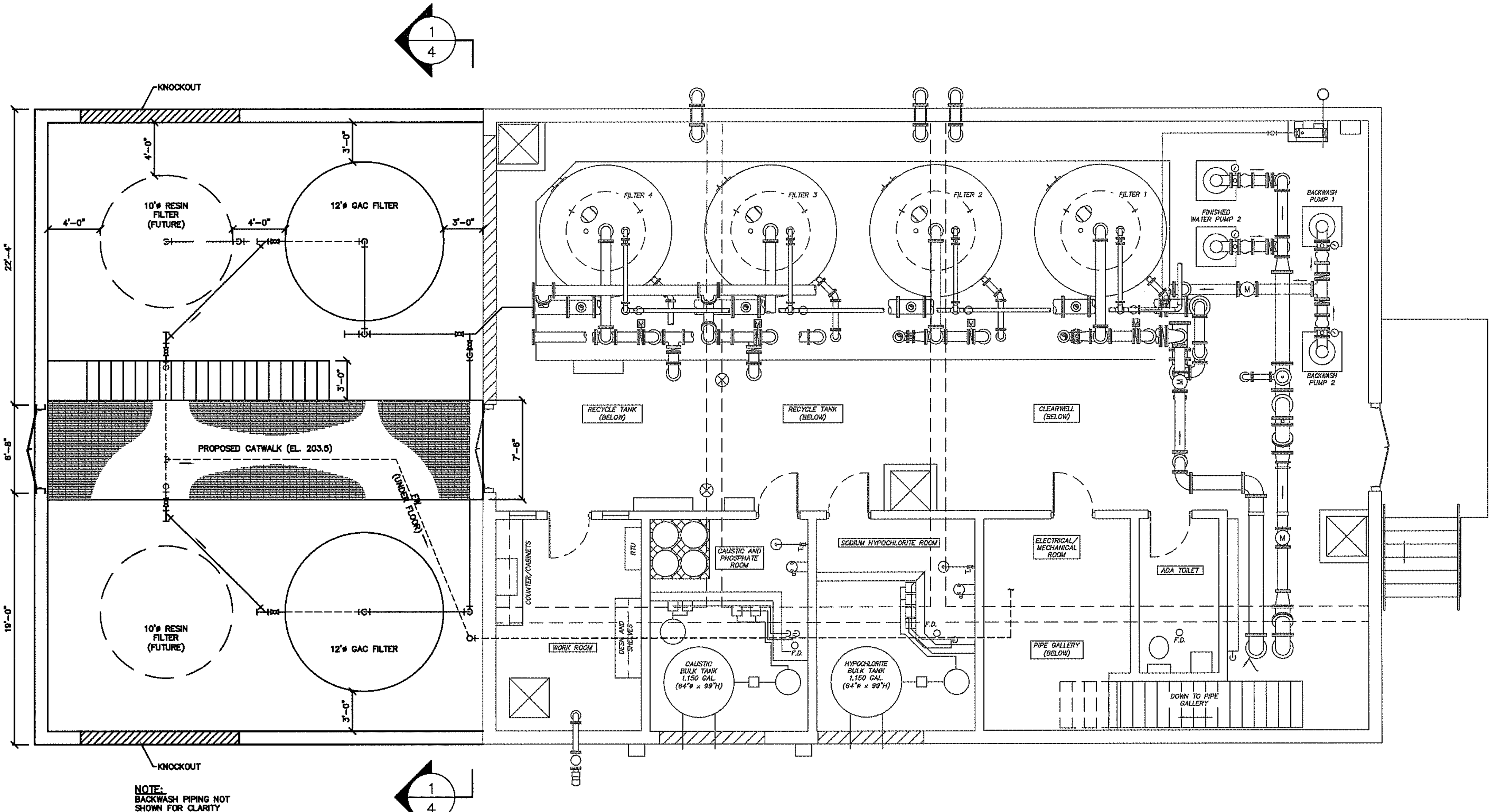




**FILTER DETAIL**
NOT TO SCALE

**LEGEND**

| | | | |
|---|---|---|---|
| (symbol) | PRESSURE TRANSMITTER | (symbol) | SAMPLE TAP |
| (M) | FLOW METER | (FD) | FLOOR DRAIN |
| —BW— | BACKWASH | (P) | PUMP |
| (symbol) | BUTTERFLY VALVE | (symbol) | CHECK VALVE |

| DATE | | PROPOSED PFAS TREATMENT SCHEMATIC WELLS 7 & 8 | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | MERRIMACK VILLAGE DISTRICT | 2 |
| PROJECT 2345 | 99 North State Street, Concord, N.H. 03301 Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |



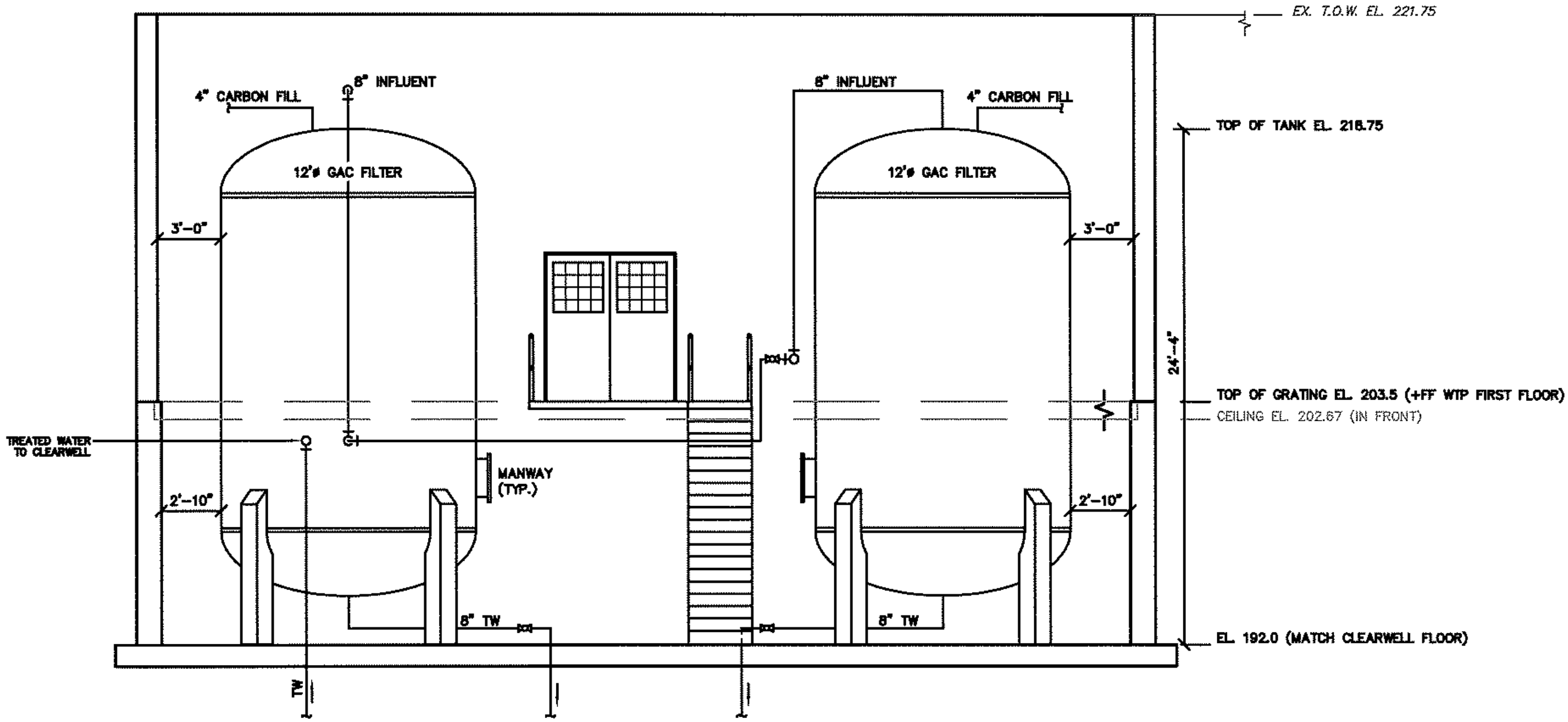

GAC OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | GAC PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | | WELLS 7 & 8 | 3 |
| PROJECT | 99 North State Street, Concord, N.H. 03301 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |




## 1/3 GAC PFAS TREATMENT OPTION

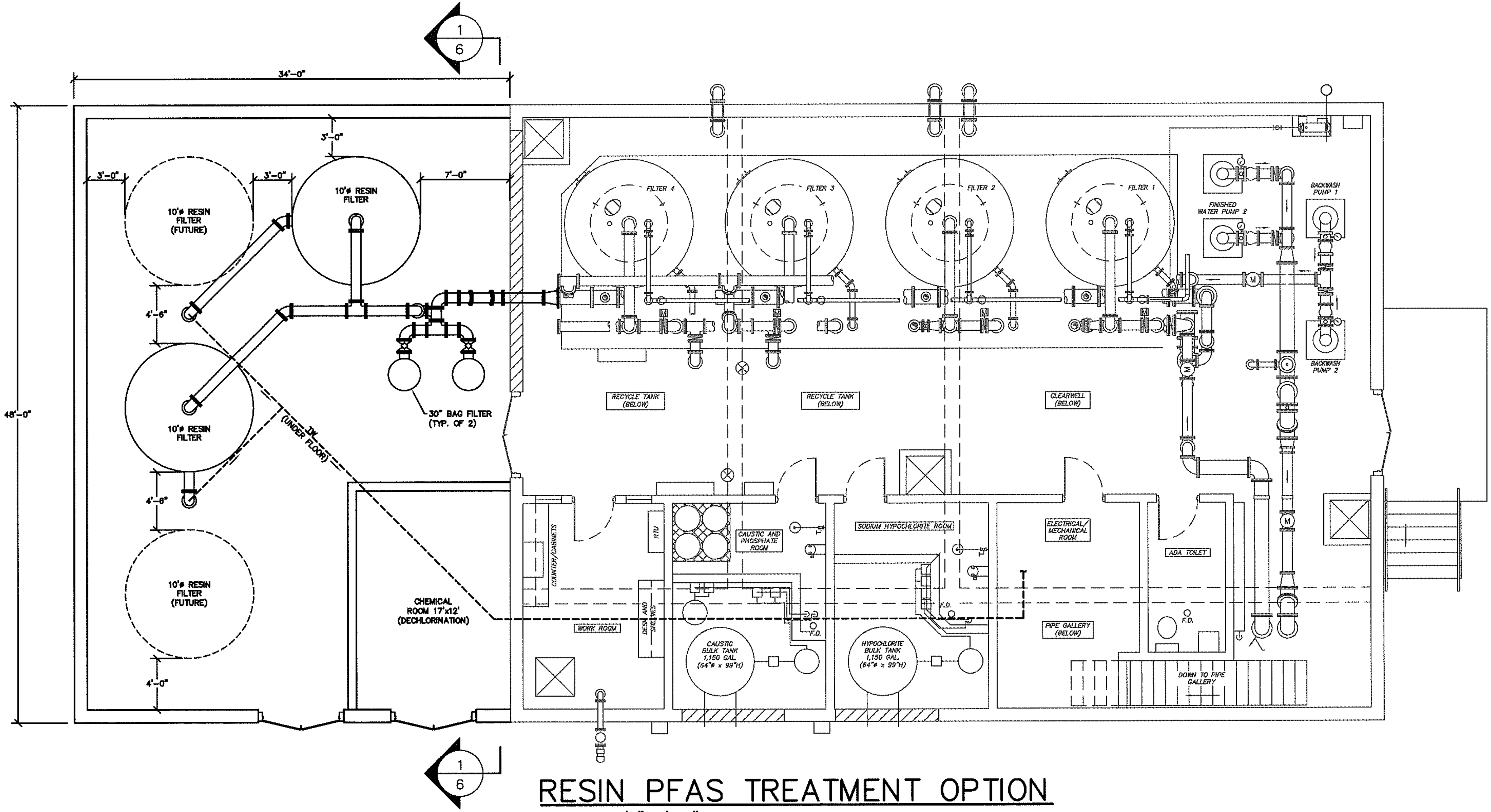
SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | GAC PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELLS 7 & 8 | 4 |
| PROJECT | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS 7-8.dwg, 12/14/2018 2:17:48 PM




# RESIN PFAS TREATMENT OPTION

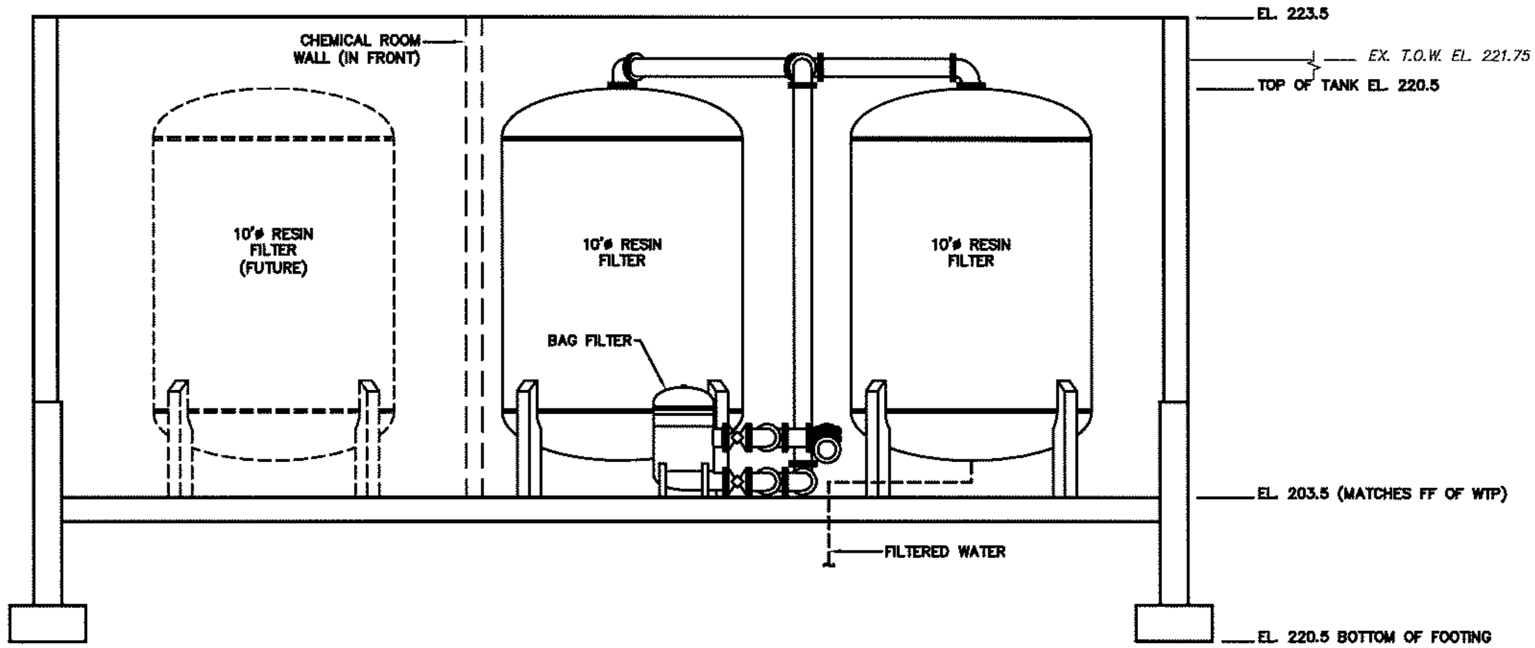
SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | RESIN PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 Tel. 603-230-9898 Fax. 603-230-9899 | WELLS 7 & 8 | 5 |
| PROJECT | | MERRIMACK VILLAGE DISTRICT | |
| 2345 | | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS 7-8.dwg, 12/14/2018 1:24:22 PM




# 1/5 RESIN PFAS TREATMENT OPTION

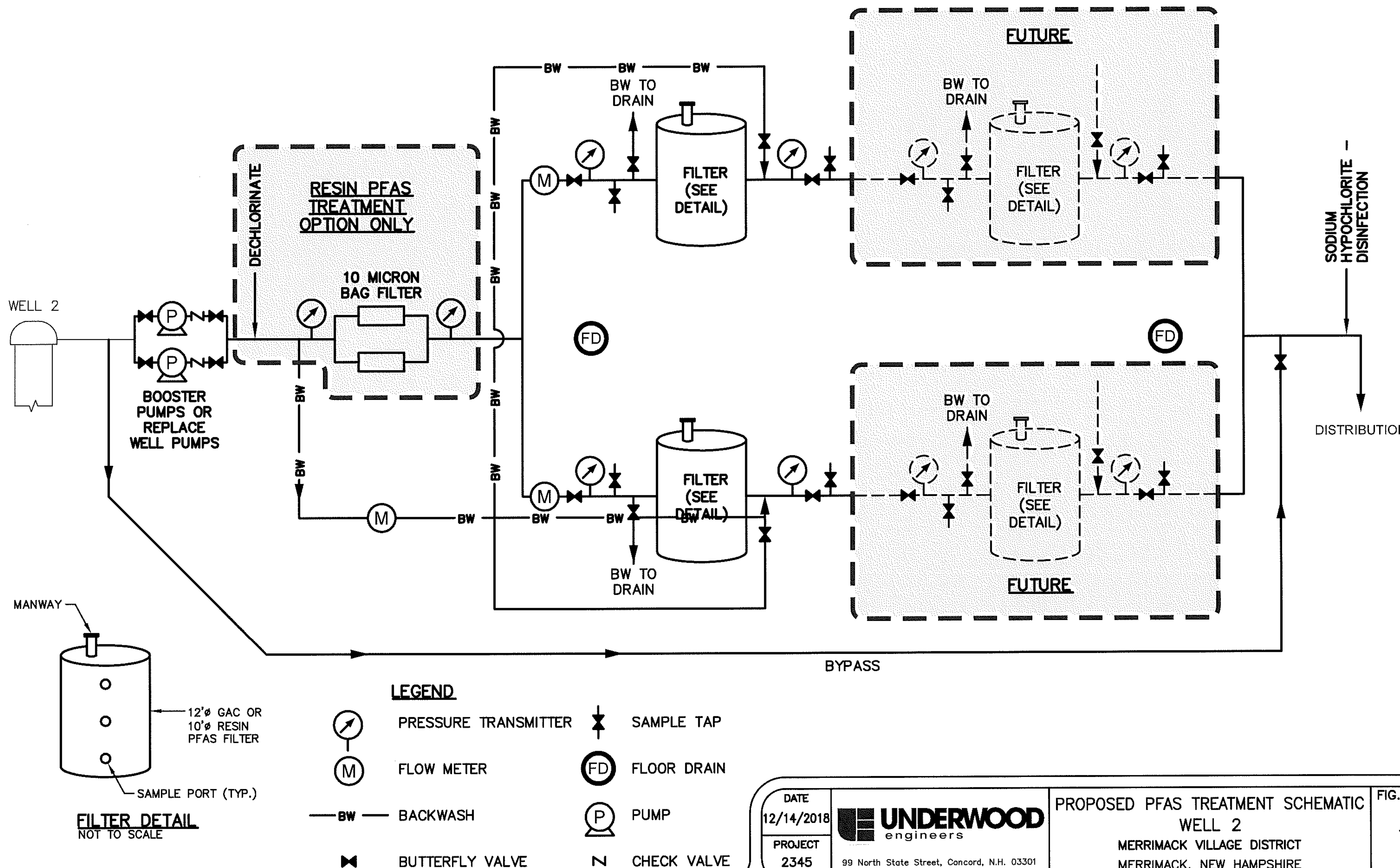
SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

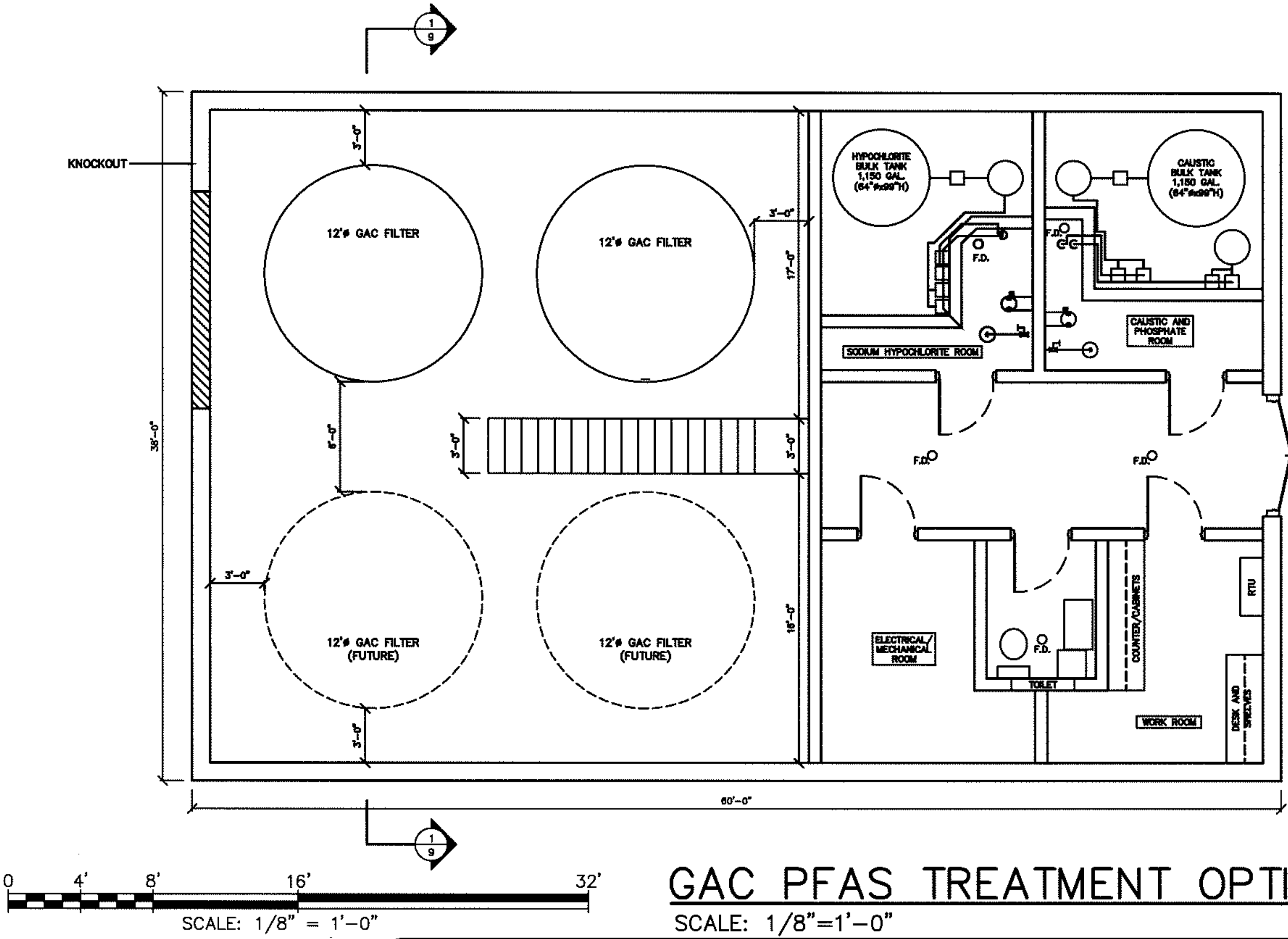
| DATE | UNDERWOOD engineers | RESIN PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELLS 7 & 8 | 6 |
| PROJECT 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS 7-8.dwg, 12/14/2018 2:21:57 PM




| DATE | | PROPOSED PFAS TREATMENT SCHEMATIC | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 2 | 7 |
| PROJECT | 99 North State Street, Concord, N.H. 03301 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 2.dwg. 12/14/2018 2:24:53 PM

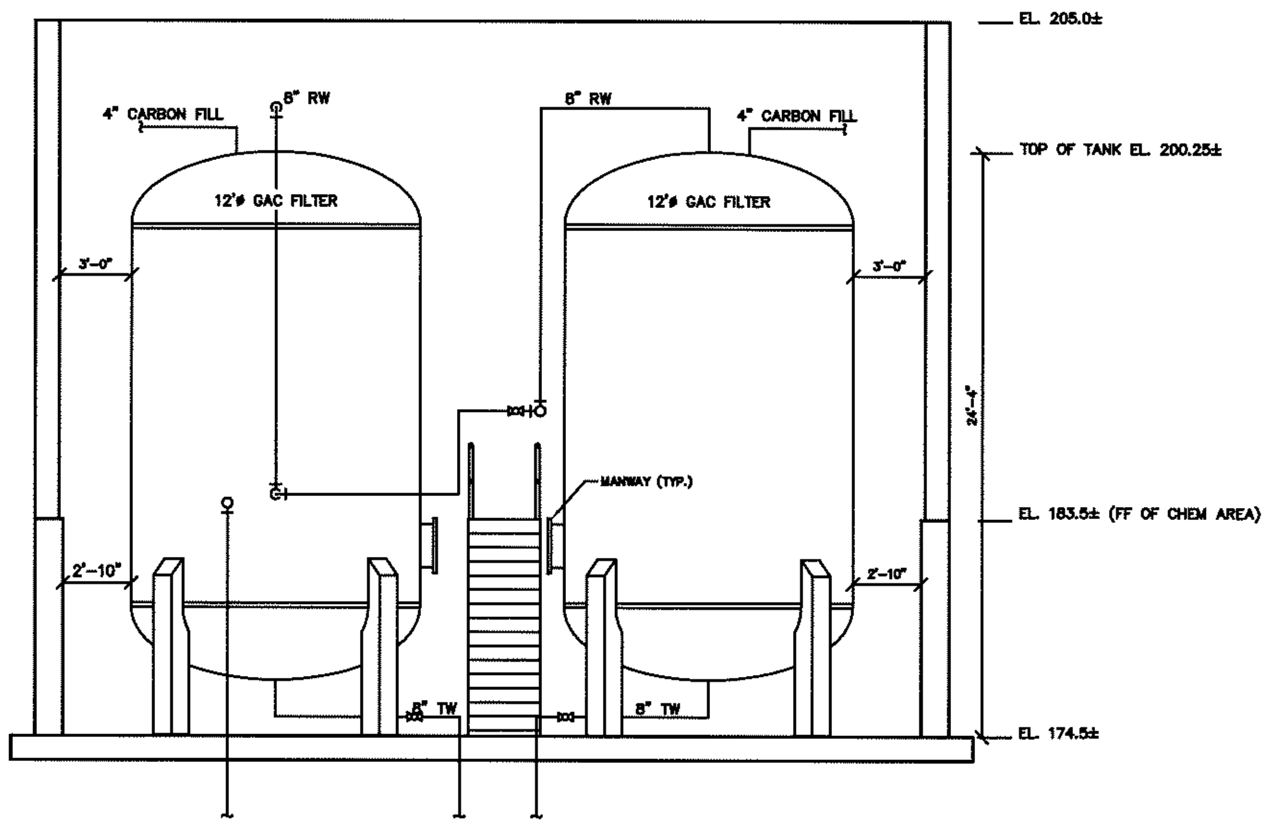



# GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

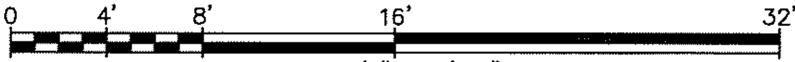
| DATE | UNDERWOOD engineers | GAC PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 2 | 8 |
| PROJECT 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 2.dwg, fig 8, 12/14/2018 1:28:21 PM, amr

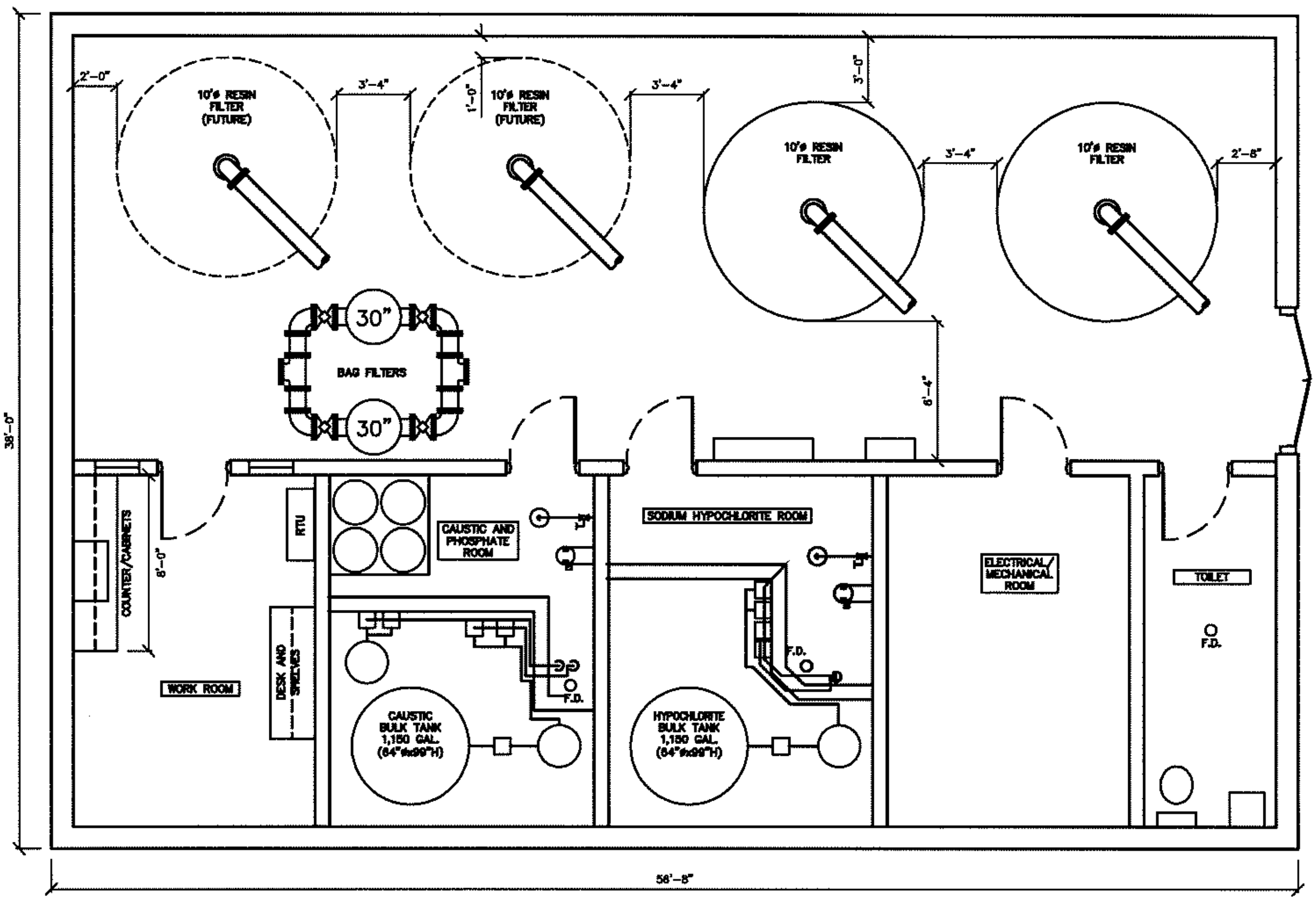



# GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"




| | | | |
|---|---|---|---|
| DATE 12/14/2018 | UNDERWOOD engineers<br>99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | GAC PFAS TREATMENT OPTION – ELEVATION<br>WELL 2<br>MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | FIG. 9 |
| PROJECT 2345 | | | |

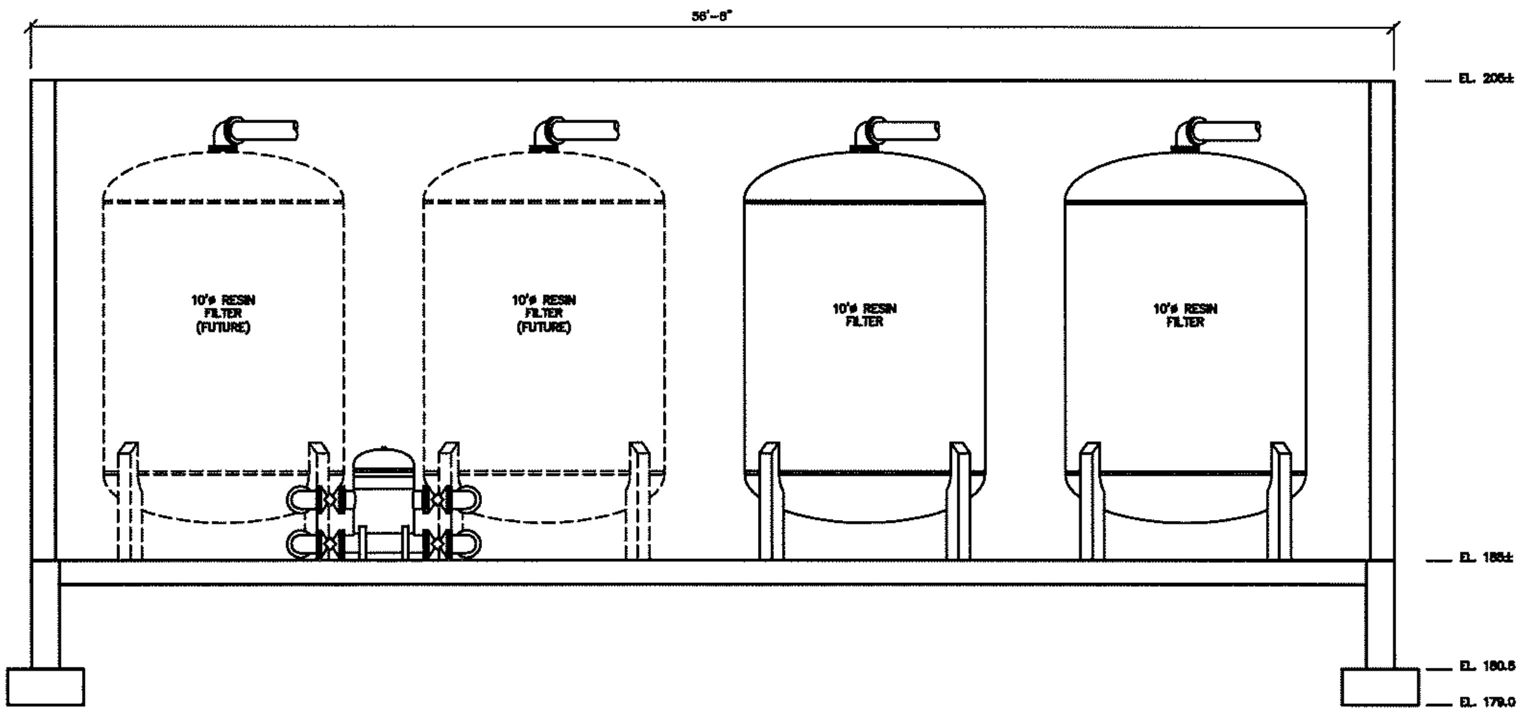



# RESIN PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

| DATE | | RESIN PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 2 | 10 |
| PROJECT | 99 North State Street, Concord, N.H. 03301 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 2.dwg, 12/14/2018 3:18:30 PM




# RESIN PFAS TREATMENT OPTION

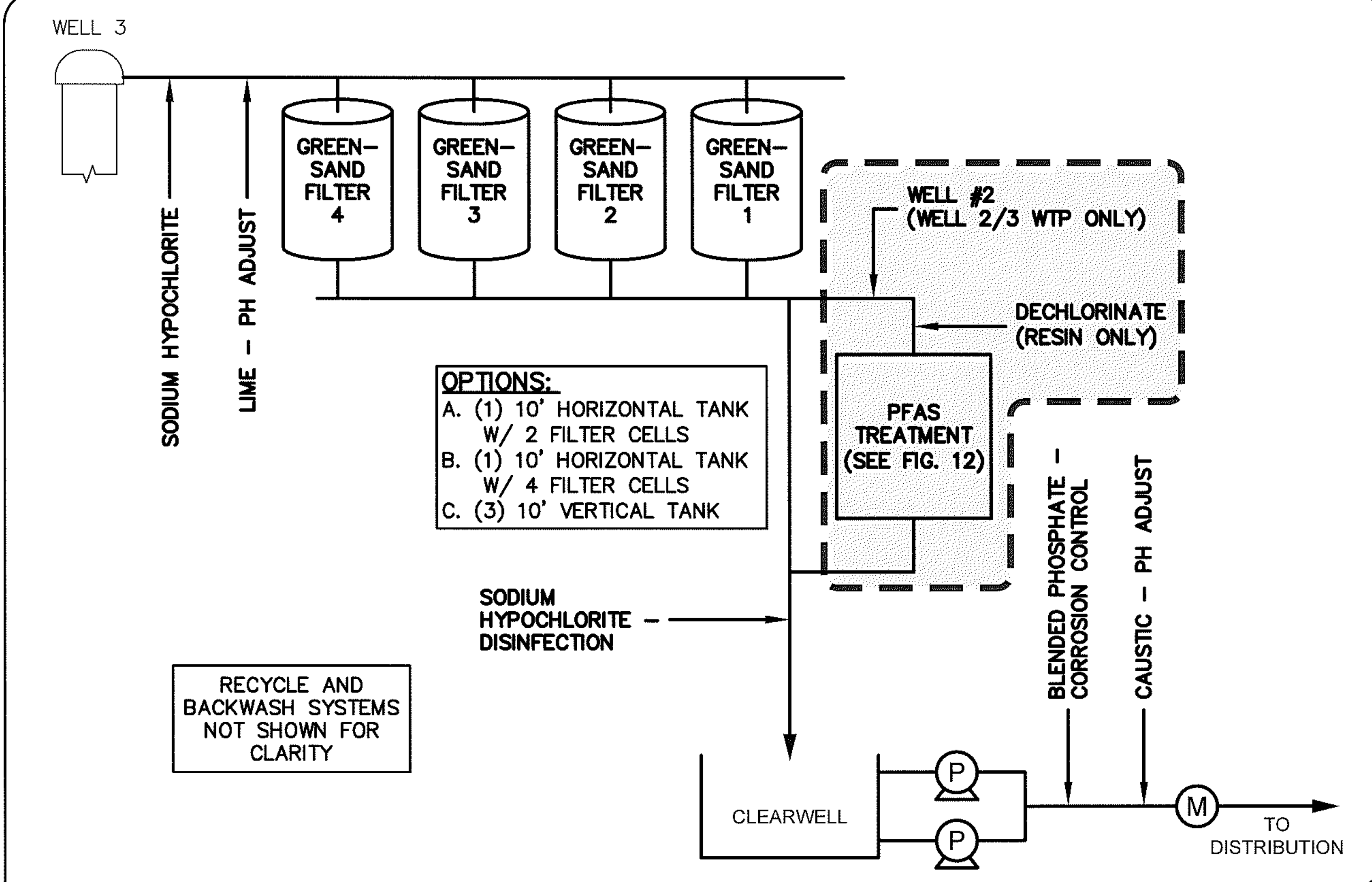
SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

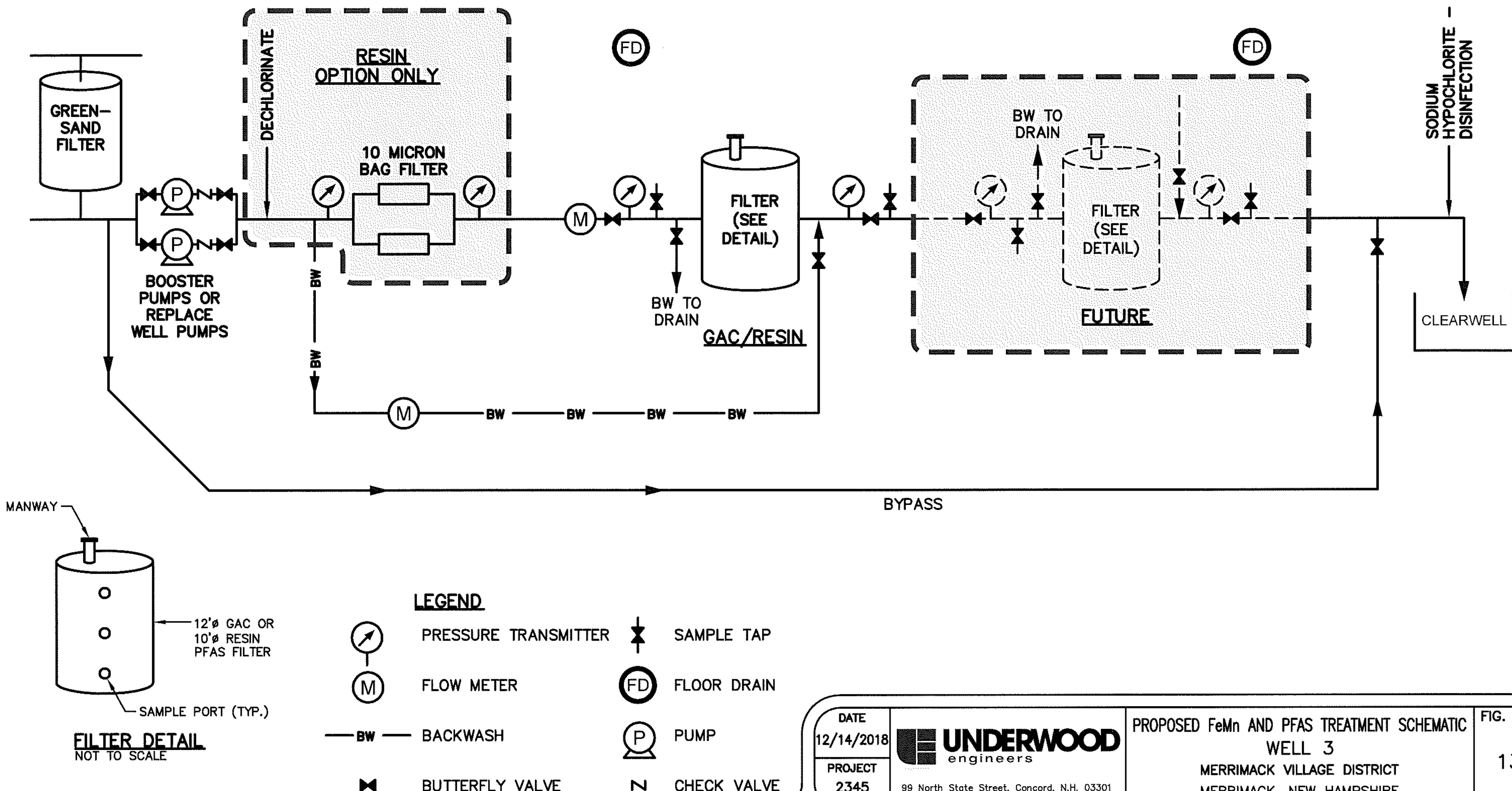
SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | RESIN PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 2 | 11 |
| PROJECT 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 2.dwg, 12/14/2018 3:43:41 PM

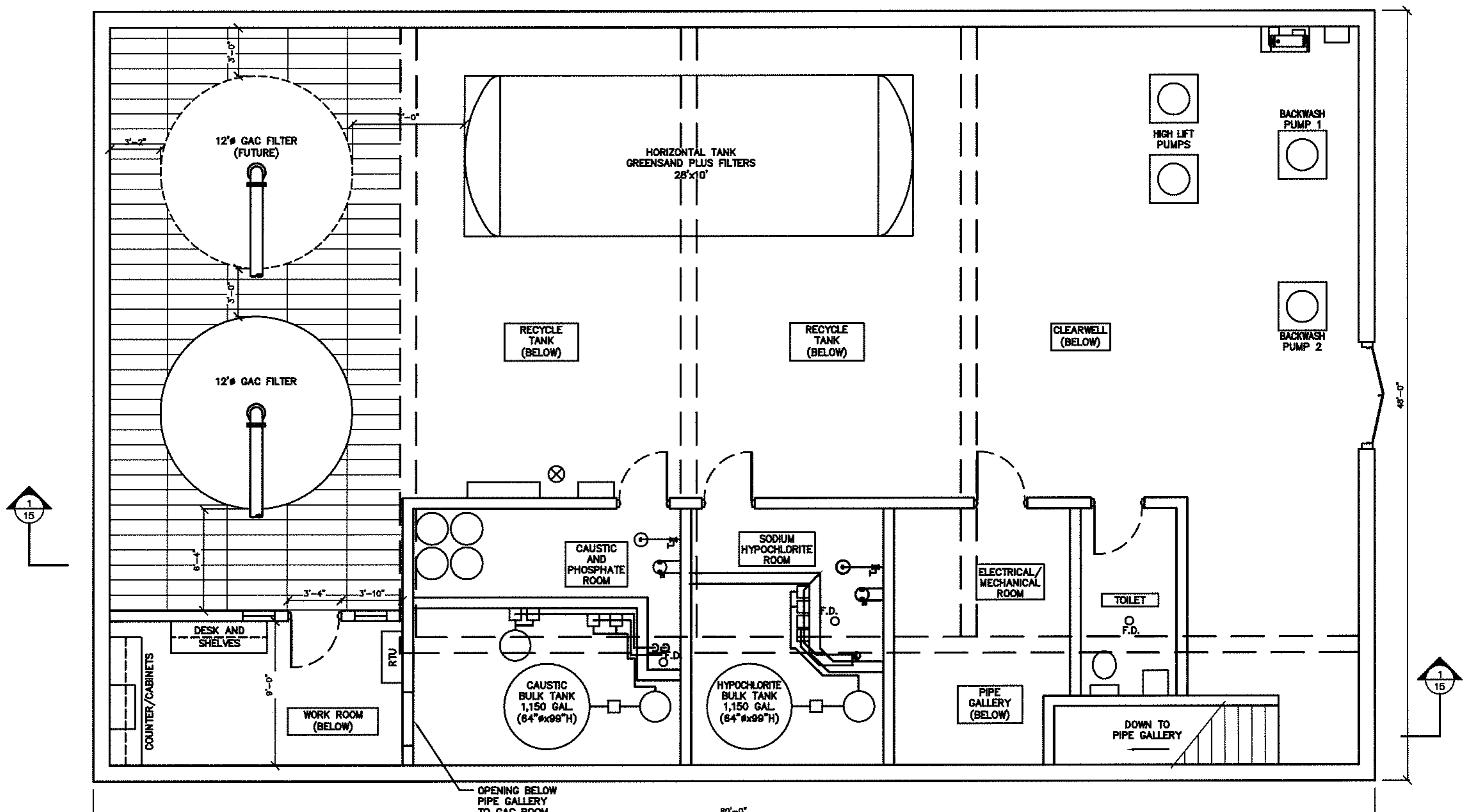



| DATE | UNDERWOOD engineers | PROPOSED FeMn AND PFAS TREATMENT | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 3 AND/OR WELL 2/3 WTP | 12 |
| PROJECT 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |




| DATE | | PROPOSED FeMn AND PFAS TREATMENT SCHEMATIC | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 3 | 13 |
| PROJECT 2345 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 3.dwg, fig 13, 12/14/2018 12:27:14 PM, amr



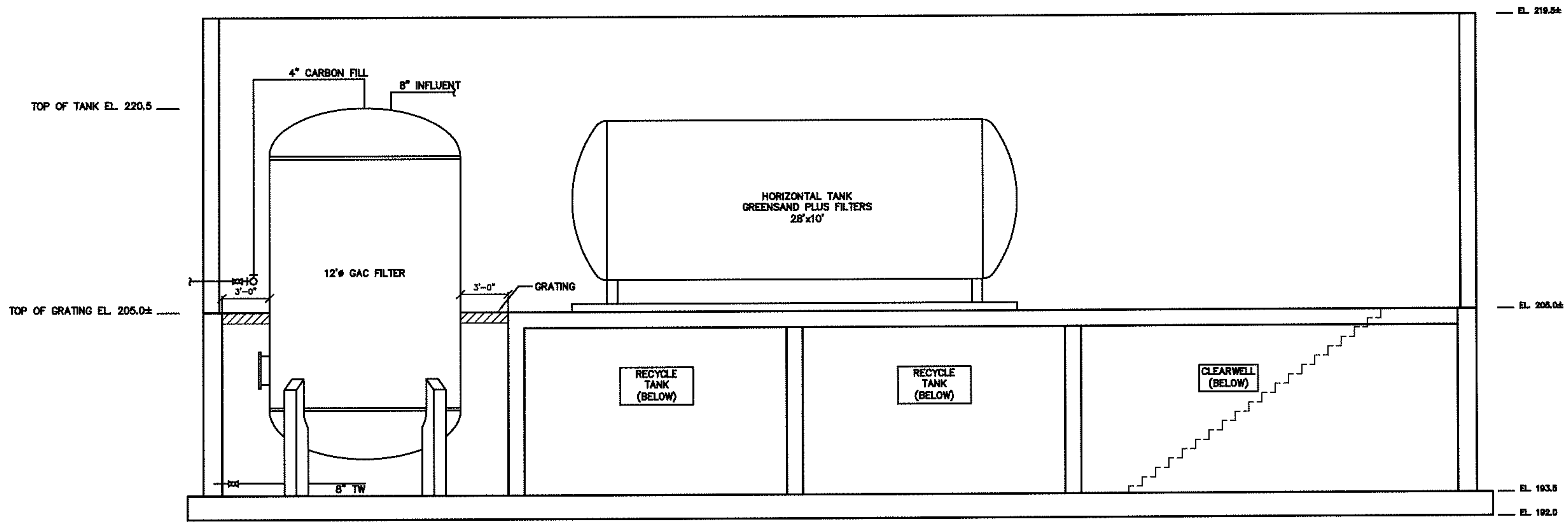

# GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

| DATE | | FeMn AND GAC PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 3 | 14 |
| PROJECT 2345 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | |

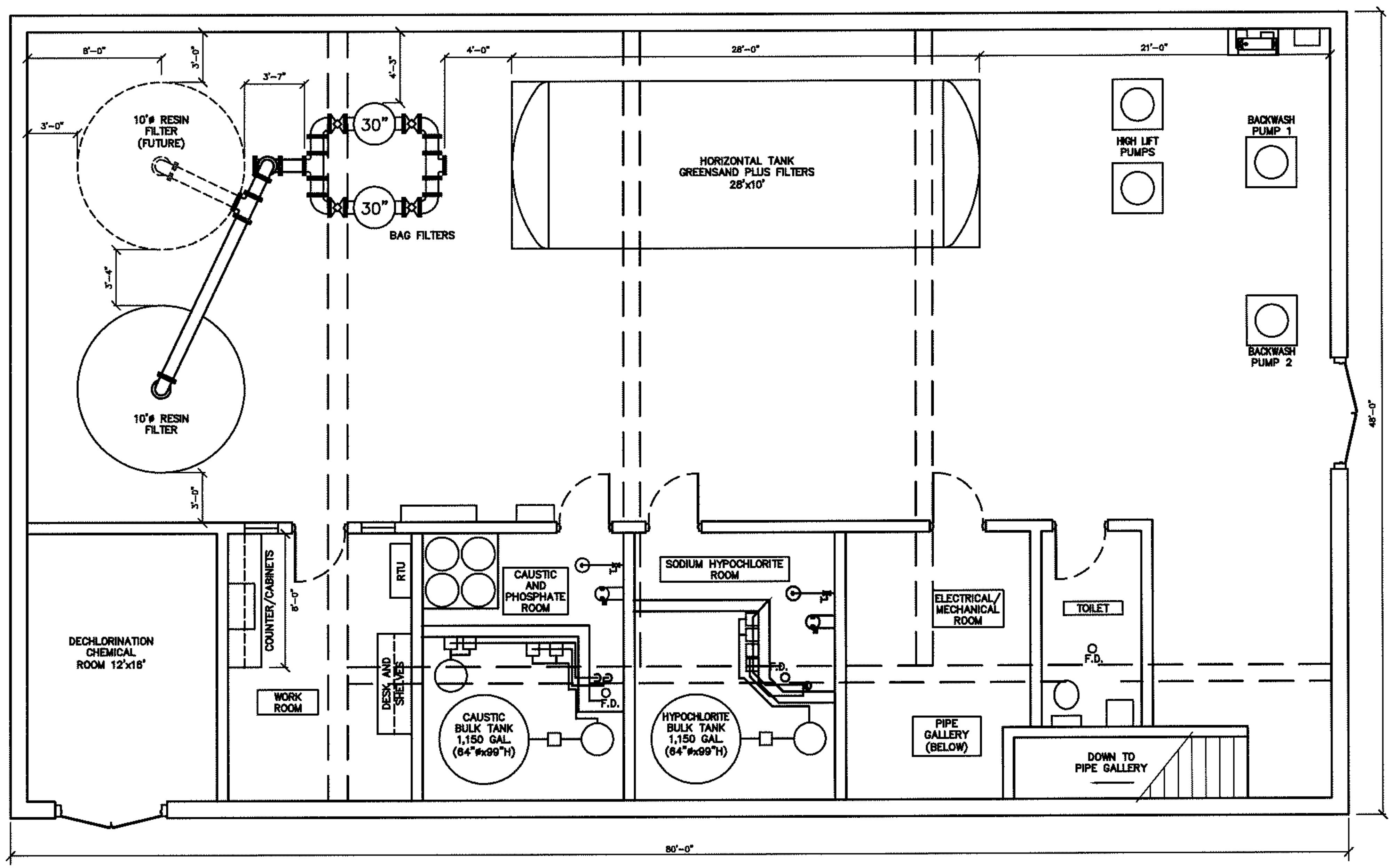



## GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'
SCALE: 1/8" = 1'-0"

| DATE | | FeMn AND GAC PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 3 | 15 |
| PROJECT | | MERRIMACK VILLAGE DISTRICT | |
| 2345 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |



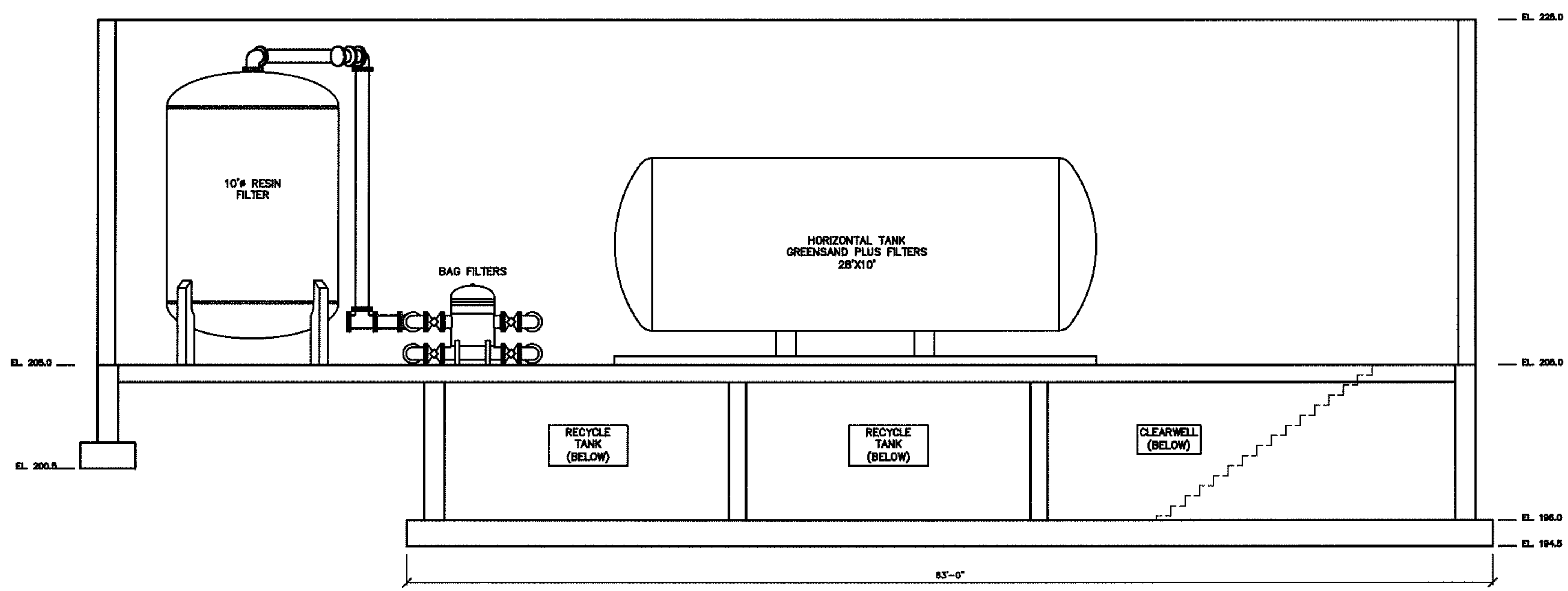

# RESIN PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | FeMn AND RESIN PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 3 | 16 |
| PROJECT | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | | MERRIMACK, NEW HAMPSHIRE | |




## RESIN PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

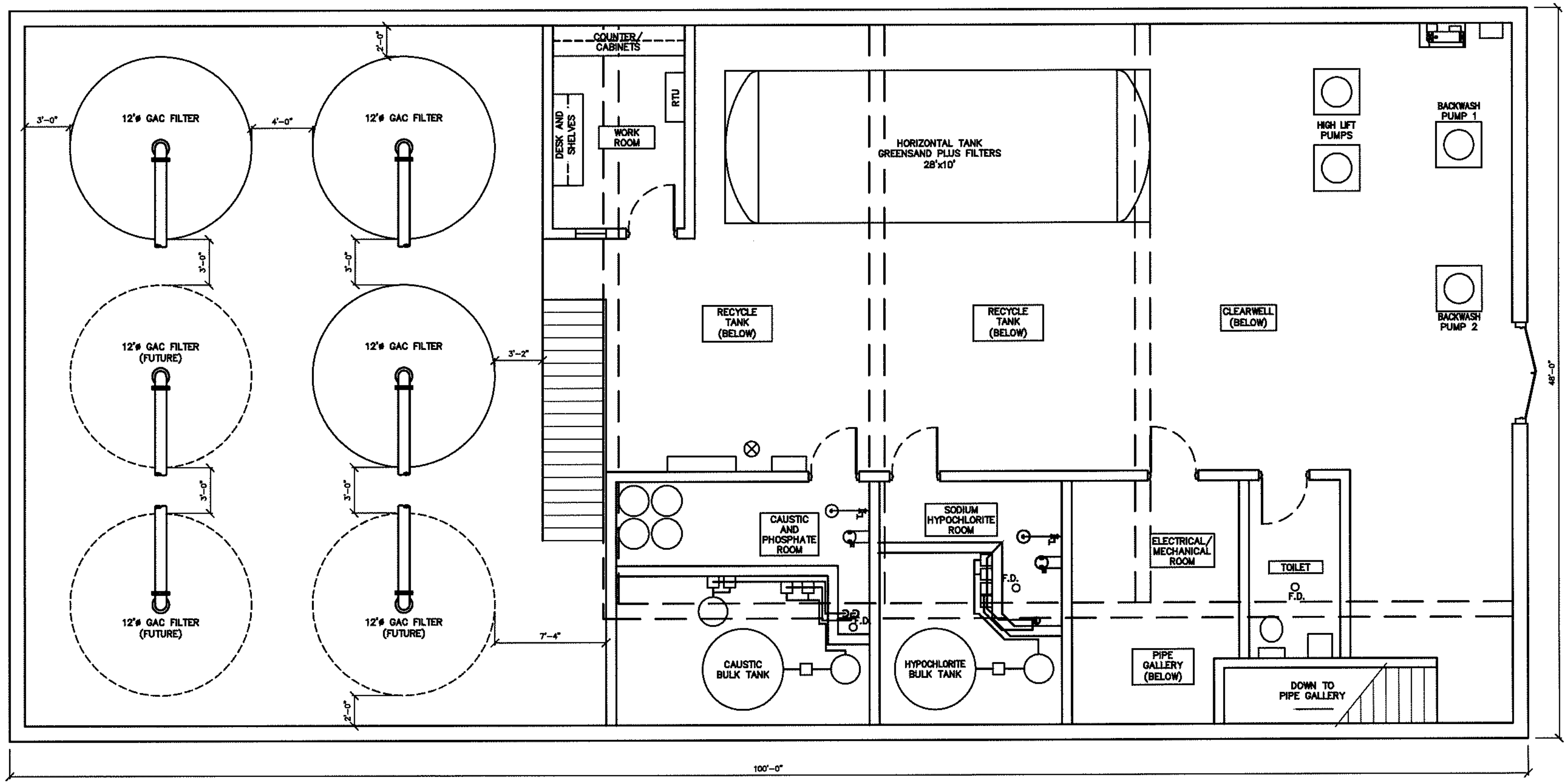
SCALE: 1/8" = 1'-0"

| DATE | | | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | FeMn AND RESIN PFAS TREATMENT OPTION – ELEVATION<br>WELL 3<br>MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | 17 |
| PROJECT<br>2345 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | | |


SCALE: NOTE TO SCALE

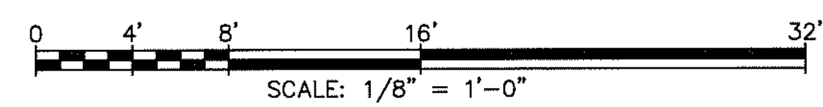
| DATE | UNDERWOOD engineers | PROPOSED WATERMAIN INTERCONNECTION | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 2/3 WTP | 18 |
| PROJECT | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL 3.dwg, 12/14/2018 1:45:23 PM

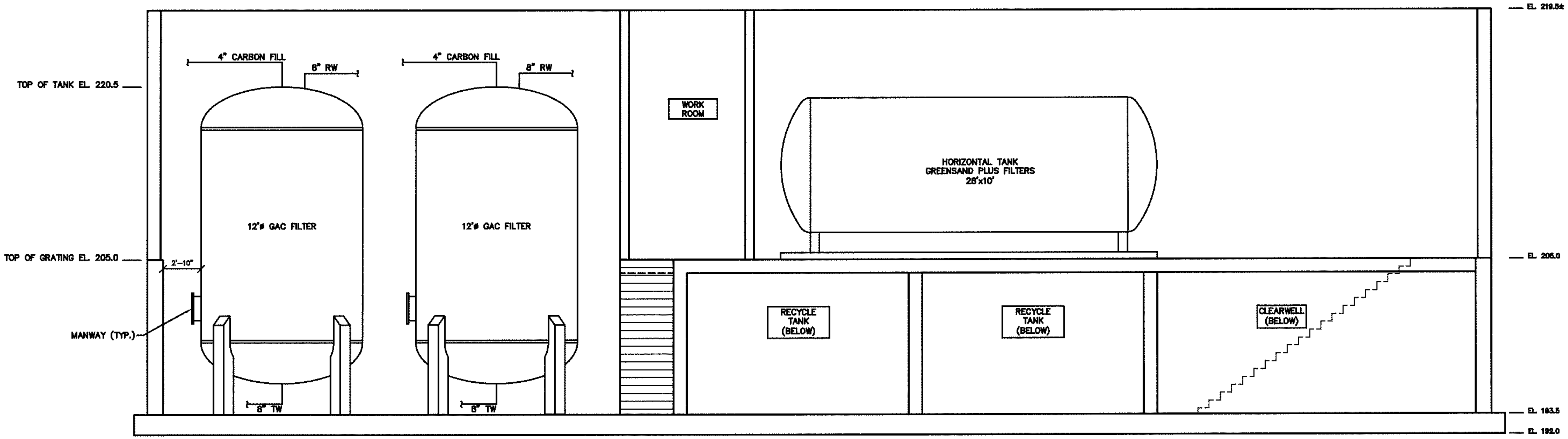



# GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"




| DATE | UNDERWOOD engineers | FeMn AND GAC PFAS TREATMENT OPTION – PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301<br>Tel. 603-230-9898 Fax. 603-230-9899 | WELL 2/3 WTP<br>MERRIMACK VILLAGE DISTRICT<br>MERRIMACK, NEW HAMPSHIRE | 19 |
| PROJECT 2345 | | | |



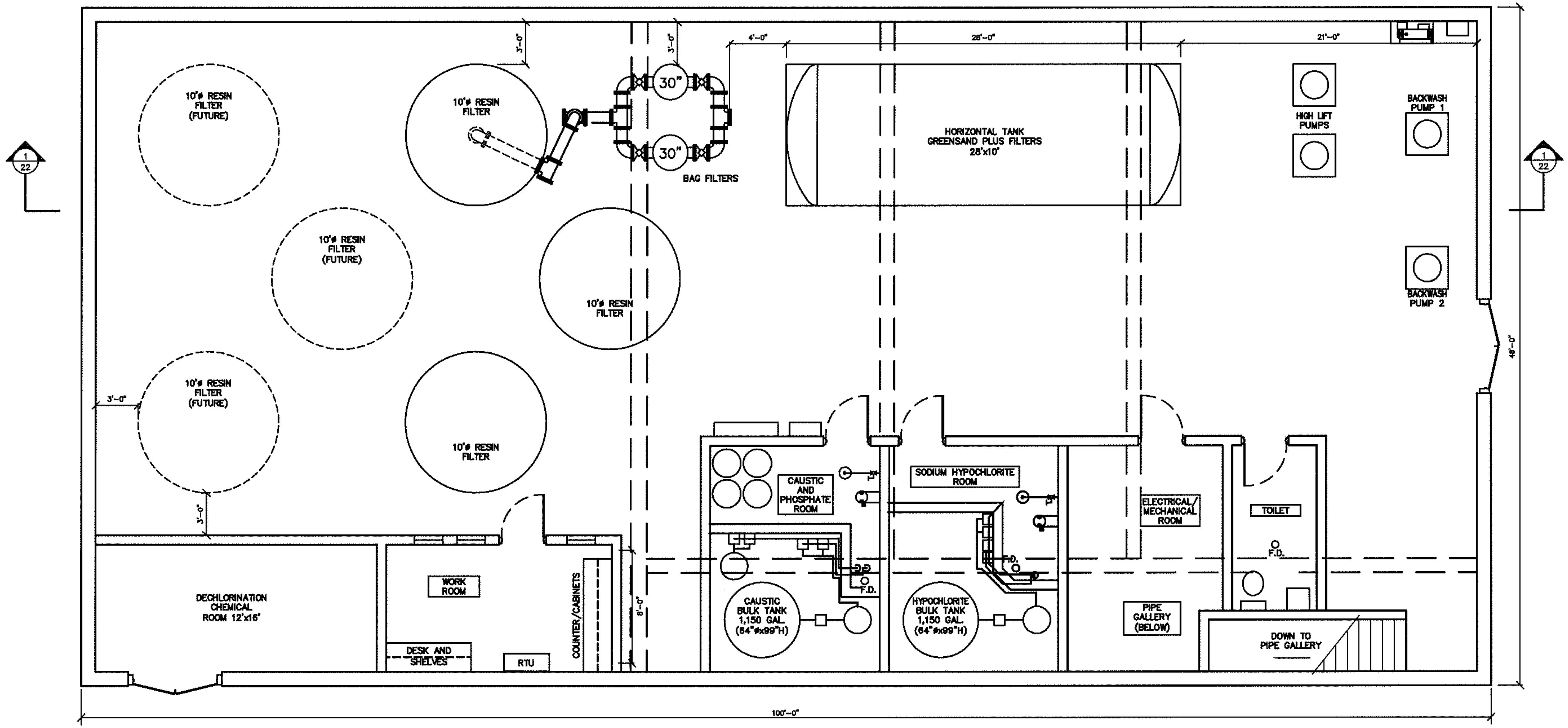

# GAC PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'
SCALE: 1/8" = 1'-0"

| DATE | UNDERWOOD engineers | FeMn AND GAC PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | 99 North State Street, Concord, N.H. 03301 | WELL 2/3 WTP | 20 |
| PROJECT | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL COMB.dwg, fig 20, 12/14/2018 1:36:36 PM, amr




# RESIN PFAS TREATMENT OPTION

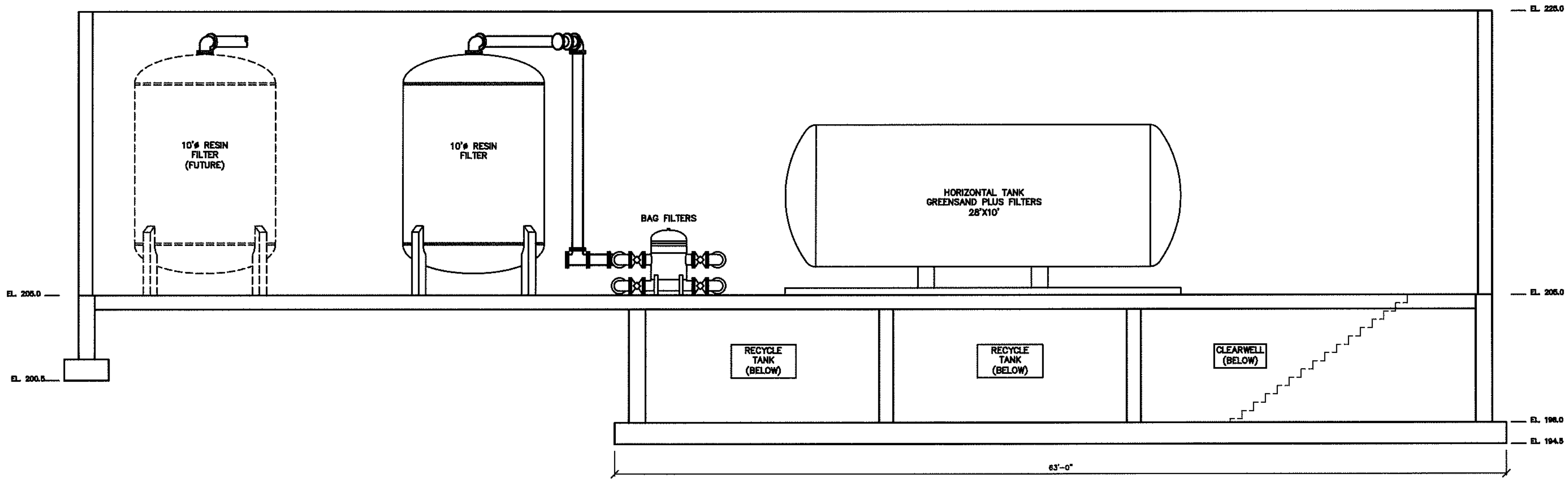
SCALE: 1/8"=1'-0"

0 4' 8' 16' 32'

SCALE: 1/8" = 1'-0"

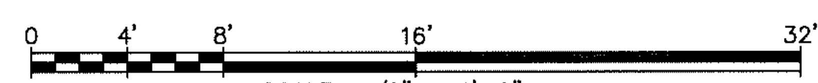
| DATE | | FeMn AND RESIN PFAS TREATMENT OPTION - PLAN | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 2/3 WTP | 21 |
| PROJECT | 99 North State Street, Concord, N.H. 03301 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |

M:\Real Numbers\MERRIMACK\2345 Wells 3, 7 & 8\c3d\FIGS WELL COMB.dwg, 12/14/2018 2:25:51 PM




# RESIN PFAS TREATMENT OPTION

SCALE: 1/8"=1'-0"




| DATE | | FeMn AND RESIN PFAS TREATMENT OPTION – ELEVATION | FIG. |
|---|---|---|---|
| 12/14/2018 | UNDERWOOD engineers | WELL 2/3 WTP | 22 |
| PROJECT | 99 North State Street, Concord, N.H. 03301 | MERRIMACK VILLAGE DISTRICT | |
| 2345 | Tel. 603-230-9898 Fax. 603-230-9899 | MERRIMACK, NEW HAMPSHIRE | |

# APPENDIX 2

# COST OPINIONS

# Table 1

## PFAS Treatment Summary - Wells 7/8 GAC
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| GAC treatment for Wells 7/8 - Construction | LS | $ 1,909,000 | 1 | $ 1,909,000 | |
| General Requirements (11.5% of Construction Cost) | LS | $224,700 | 1 | $ 224,700 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $97,700 | 1 | $ 97,700 | |
| | | | | | |
| ***Subtotal*** | | | | *$2,276,400* | |
| *Contractor Overhead & Profit (8%)* | | | | *$182,100* | |
| *Contingency (20% of construction)* | | | | *$455,300* | |
| ***Total Probable Construction Cost*** | | | | ***$2,913,800*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$2,910,000** |
| Engineering (25%) | | | | $728,500 | |
| Total Project Cost | | | | **$3,642,000** | |

## PFAS Treatment Summary - Wells 7/8 Resin
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| Resin treatment for Wells 7/8 - Construction | LS | $ 2,321,200 | 1 | $ 2,321,200 | |
| General Requirements (11.5% of Construction Cost) | LS | $272,100 | 1 | $ 272,100 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $118,300 | 1 | $ 118,300 | |
| | | | | | |
| ***Subtotal*** | | | | *$2,756,600* | |
| *Contractor Overhead & Profit (8%)* | | | | *$220,500* | |
| *Contingency (20% of construction)* | | | | *$551,300* | |
| ***Total Probable Construction Cost*** | | | | ***$3,528,400*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$3,530,000** |
| Engineering (25%) | | | | $882,100 | |
| Total Project Cost | | | | **$4,411,000** | |

## Table 1

**Assumptions:**

- Cost based on the 2016 90% design Opinion of Cost for the Well #7/8 Fe and Mn water treatment plant (project #1769) and tabulated bid prices (2016) for the WTP. Items with a significant difference were updated.
- Costs were escalated from 2016 to 2018 using ENRs 2016 – 10,338 (yrly avg.) and 2018 –11,124.46 (Aug.).
- Assumed building size is 34'x48'with CMU construction attached to the existing Fe and Mn WTP at Wells 7&8 on the previously stabilized soil area. The GAC option would have a depressed slab area for GAC tanks at a similar depth of the existing clearwell and recycle tanks. Resin option would be slab on grade. Overall building height for both options, the addition would be about two feet greater than the existing building to limit snow drift load on the existing structure.
- Assumed single PFAS treatment trains with space for additional future lag tanks (should treatment become regulatory). Structural roof design provisions would be made for future filter installation.

## Table 2

### PFAS Treatment Summary - Well 2 GAC
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| GAC treatment for Well 2 - Construction | LS | $ 2,272,500 | 1 | $ 2,272,500 | |
| General Requirements (11.5% of Construction Cost) | LS | $266,500 | 1 | $ 266,500 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $115,900 | 1 | $ 115,900 | |
| ***Subtotal*** | | | | *$2,699,900* | |
| *Contractor Overhead & Profit (8%)* | | | | *$216,000* | |
| *Contingency (20% of construction)* | | | | *$540,000* | |
| ***Total Probable Construction Cost*** | | | | ***$3,455,900*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$3,460,000** |
| Engineering (25%) | | | | $864,000 | |
| Total Project Cost | | | | **$4,320,000** | |

### PFAS Treatment Summary - Well 2 Resin
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| Resin treatment for Well 2 - Construction | LS | $ 2,691,700 | 1 | $ 2,691,700 | |
| General Requirements (11.5% of Construction Cost) | LS | $314,700 | 1 | $ 314,700 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $136,800 | 1 | $ 136,800 | |
| ***Subtotal*** | | | | *$3,188,200* | |
| *Contractor Overhead & Profit (8%)* | | | | *$255,100* | |
| *Contingency (20% of construction)* | | | | *$637,600* | |
| ***Total Probable Construction Cost*** | | | | ***$4,080,900*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$4,080,000** |
| Engineering (25%) | | | | $1,020,200 | |
| Total Project Cost | | | | **$5,101,000** | |

## Table 2

**Assumptions:**

- Cost based on the 2016 90% design Opinion of Cost for the Well #7/8 Fe and Mn water treatment plant (project #1769), and tabulated bid prices (2016) for the WTP. Items with a significant difference were updated.
- Costs were escalated from 2016 to 2018 using ENRs 2016 – 10,338 (yrly avg.) and 2018 –11,124.46 (Aug.).
- Assumed building size is 38'x60'with CMU construction located at or near the current Well #2 building. Two types of systems are being considered for the removal of PFAS, Granular Activated Carbon (GAC) and Resin. The GAC option would have a depressed slab area for GAC tanks, to reduce overall building height. Resin option would be slab on grade. Overall building wall height for either option would be about 20 feet.
- Current prices for equipment and systems were used where available.
- Assumed single PFAS treatment trains with space for additional future lag tanks (should treatment become regulatory). Structural roof design provisions would be made for future filter installation.

# Table 3

## Fe,Mn & PFAS Treatment Summary - Well 3 GAC
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| GAC treatment for Well 3 - Construction | LS | $ 1,001,844 | 1 | $ 1,001,800 | |
| Fe Mn treatment for Well 3 - Construction | LS | $ 2,670,698 | 1 | $ 2,670,700 | |
| General Requirements (11.5% of Construction Cost) | LS | $427,500 | 1 | $ 427,500 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $185,900 | 1 | $ 185,900 | |
| | | | | | |
| ***Subtotal*** | | | | *$4,330,900* | |
| *Contractor Overhead & Profit (8%)* | | | | *$346,500* | |
| *Contingency (20% of construction)* | | | | *$866,200* | |
| ***Total Probable Construction Cost*** | | | | ***$5,543,600*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$5,540,000** |
| Engineering (25%) | | | | $1,385,900 | |
| Total Project Cost | | | | **$6,930,000** | |

## Fe,Mn & PFAS Treatment Summary - Well 3 Resin
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| Resin treatment for Well 3 - Construction | LS | $ 1,270,594 | 1 | $ 1,270,600 | |
| Fe Mn treatment for Well 3 - Construction | LS | $ 2,670,698 | 1 | $ 2,670,700 | |
| General Requirements (11.5% of Construction Cost) | LS | $458,400 | 1 | $ 458,400 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $199,300 | 1 | $ 199,300 | |
| | | | | | |
| ***Subtotal*** | | | | *$4,644,000* | |
| *Contractor Overhead & Profit (8%)* | | | | *$371,500* | |
| *Contingency (20% of construction)* | | | | *$928,800* | |
| ***Total Probable Construction Cost*** | | | | ***$5,944,300*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$5,940,000** |
| Engineering (25%) | | | | $1,486,100 | |
| Total Project Cost | | | | **$7,430,000** | |

## Table 3

**Assumptions:**

- Cost based on the 2016 90% design Opinion of Cost for the Well #7/8 Fe and Mn water treatment plant (project #1769), and tabulated bid prices (2016) for the WTP. Items with a significant difference were updated.
- Building piping was estimated using similar projects.
- Costs were escalated from 2016 to 2018 using ENRs 2016 – 10,338 (yrly avg.) and 2018 –11,124.46 (Aug.).
- Assumed building size is 48'x80'with CMU construction located at or near the current Well #3 building with clearwell and recycle tanks. The GAC option would have a depressed slab area for GAC tanks to match the clearwell and recycle tanks, floor elevation (below the operating floor). This would also reduce the overall building height. The Resin portion of the building would be slab on grade with the clearwell and recycle tanks below grade below the Fe/Mn filters. Overall building wall height for either option would be about 20 feet.
- Site work also includes infiltration lagoons for the Fe and Mn treatment.
- Current prices for equipment and systems were used where available.
- Assumed single PFAS treatment trains with space for additional future lag tanks (should treatment become regulatory). Structural roof design provisions would be made for future filter installation.
- PFAS and Fe Mn building costs separated on a square footage basis. The Fe Mn was assumed to be 75% of the total cost while PFAS was 25%. The basis for this split was the fact that Fe Mn treatment would require recycle tanks, clearwell and infiltration lagoons and the PFAS treatment would require a smaller footprint based on total flow rate. This is a rough separation of cost and should not be used for construction costs estimates.

## Table 4

### Fe, Mn & PFAS Treatment Summary - Well 2&3 WTP GAC
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| GAC treatment for Well 2/3 WTP - Construction | LS | $ 1,877,508 | 1 | $ 1,877,500 | |
| Fe Mn treatment for Well 2/3 WTP - Construction | LS | $ 2,676,451 | 1 | $ 2,676,500 | |
| 12" Watermain Well 2 to Well 3 | LS | $ 1,300,000 | 1 | $ 1,300,000 | |
| General Requirements (11.5% of Construction Cost) | LS | $678,400 | 1 | $ 678,400 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $230,000 | 1 | $ 230,000 | |
| | | | | | |
| ***Subtotal*** | | | | *$6,807,400* | |
| *Contractor Overhead & Profit (8%)* | | | | *$544,600* | |
| *Contingency (20% of construction)* | | | | *$1,361,500* | |
| ***Total Probable Construction Cost*** | | | | ***$8,713,500*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$8,710,000** |
| Engineering (25%) | | | | $2,178,400 | |
| Total Project Cost | | | | **$ 10,892,000** | |

### Fe, Mn & PFAS Treatment Summary - Well 2&3 WTP Resin
### Preliminary Engineer's Opinion of Probable Construction Cost
### Merrimack Village District
2018

| CAPITAL COSTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Unit** | **Unit Price** | **Quantity** | **Extended Total** | |
| ACT or Pilot Testing | ALLOW | $40,000 | 1 | $ 40,000 | |
| Sampling/Testing | ALLOW | $ 5,000 | 1 | $ 5,000 | |
| Resin treatment for Well 2/3 WTP - Construction | LS | $ 2,683,758 | 1 | $ 2,683,800 | |
| Fe Mn treatment for Well 2/3 WTP - Construction | LS | $ 2,676,451 | 1 | $ 2,676,500 | |
| 12" Watermain Well 2 to Well 3 | LS | $ 1,300,000 | 1 | $ 1,300,000 | |
| General Requirements (11.5% of Construction Cost) | LS | $621,600 | 1 | $ 621,600 | |
| Mobilization/demobilization (5% of Construction Cost) | LS | $270,300 | 1 | $ 270,300 | |
| | | | | | |
| ***Subtotal*** | | | | *$7,597,200* | |
| *Contractor Overhead & Profit (8%)* | | | | *$607,800* | |
| *Contingency (20% of construction)* | | | | *$1,519,400* | |
| ***Total Probable Construction Cost*** | | | | ***$9,724,400*** | |
| **Total Construction (rounded to nearest $10,000)** | | | | | **$9,720,000** |
| Engineering (25%) | | | | $2,431,100 | |
| Total Project Cost | | | | **$12,156,000** | |

# Table 4

**Assumptions:**

- Cost based on the 2016 90% design Opinion of Cost for the Well #7/8 Fe and Mn water treatment plant (project #1769), and tabulated bid prices (2016) for the WTP. Items with a significant difference were updated.
- Costs were escalated from 2016 to 2018 using ENRs 2016 – 10,338 (yrly avg.) and 2018 –11,124.46 (Aug.).
- Assumed building size is 48'x100'with CMU construction, located at or near the old Well 1 building/ garage area with clearwell and recycle tanks. Two types of systems are being considered for the removal of PFAS, Granular Activated Carbon (GAC) and Resin. The GAC option would have a depressed slab area for GAC tanks to match the clearwell and recycle tanks, floor elevation. This would reduce the overall building height. The Resin portion of the building would be slab on grade with the clearwell and recycle tanks under the Fe/Mn filters below grade. Overall building wall height for either option would be about 20 feet.
- Water would be pumped through a new water main from Wells 2 &3 to a central location for treatment.
- Current prices for equipment and systems were used where available.
- Assumed single PFAS treatment trains with space for additional future lag tanks (should treatment become regulatory). Structural roof design provisions would be made for future filter installation.
- PFAS and Fe Mn building costs separated on a square footage basis. The Fe Mn was assumed to be 70% of the total cost while PFAS was 30%. The basis for this split was the fact that Fe Mn treatment would require recycle tanks, clearwell and infiltration lagoons and the PFAS treatment would require a smaller footprint based on total flow rate. This is a rough separation of cost and should not be used for construction costs estimates.