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TECHNICAL MEMORANDUM

To:	Lisa Campbell and Cami Apfelbeck, City of Bremerton	**Subject:**	Wells 13 & 14 Iron and Manganese Removal Pilot Testing Results
From:	Alex Mofidi PE, Chris McMeen PE, Al Vetrovs and Michael Hallett, Confluence		
Date:	November 22, 2023	**Project:**	Water Quality Study – Phase 2

The technical data contained in this memorandum were prepared under the supervision of the undersigned whose seal as a professional engineer licensed to practice as such in the State of Washington is affixed below.

CONTENTS

1 EXECUTIVE SUMMARY

Catalytic oxidation and media filtration (filtration) pilot testing for both City of Bremerton (City) Wells 13 and 14 was completed in August 2023 by Confluence Engineering Group LLC (Confluence). Test results showed that manganese was very effectively removed.

All filter medias tested performed well; in terms of material captured (evidenced by material released during backwash), ease of installation, and very modest pressure loss accumulation, Pyrolox Advantage media performed best.

To develop planning level costs for three treatment configurations (Well 13 alone, Well 14 alone, and a treatment plant where the wells are combined) three equipment suppliers were contacted to provide equipment pricing. Cost estimates were compiled comparing a combined treatment facility against individual facilities sited at each well. Cost estimating was completed at the study/feasibility level with an expected range of -25% to +50% (See **Appendix 1**). Cost estimates were generally based on equipment sized for filter loading rates of approximately 10 gpm/ft^2 although pilot testing did indicate excellent performance at 12 gpm/ft^2. These are both considered high-rate filtration, and the ultimate loading rate will be selected during final design.

Costs for the combined treatment facility, including estimates for building and surrounding civil infrastructure, design and administrative costs (25%) and a 30% contingency are shown in **Table 1-1**. Also shown are upper bound (+50%) estimates for the three configurations.

Of note: across the range of vendors and cost uncertainties at this level of project definition, constructing two separate treatment systems may result in approximately 30 - 40% higher overall costs (not including property acquisition, if required).

Table 1-1 Capital Cost Summary

Site Configuration	Cost Estimate Ranges Across Vendors ($M)	Cost Estimate Ranges (+50%) ($M)
Well 13 (460 gpm) with waste recycle	$1.41 - $2.17	$2.12 - $3.25
Well 14 (220 gpm) with waste recycle	$1.14 - $1.77	$1.71 - $2.65
Individual Sites with waste recycle – Combined Cost	$2.56 - $3.94	$3.83 - $5.91
One combined facility, waste recycle (680 gpm)	$1.73 - $2.65	$2.60 - $3.97
One combined facility, sewer connection (680 gpm)	$1.89 - $2.81	$2.84 - $4.22

2 INTRODUCTION AND BACKGROUND

Following an intensive monitoring program, the City engaged Confluence to evaluate iron and manganese removal treatment for Wells 13 & 14. These wells are critical, permanent sources for the City, and the only sources located in East Bremerton, important to supply resiliency. The City chlorinates these wells prior to the distribution system and manganese levels in both wells are above the secondary maximum contaminant level (SMCL) of 0.05 mg/L. These levels result in cumulative deposits in the distribution system that can cause aesthetic or public health concerns.

Wells 13 and 14 are located approximately 1,400 feet apart, as shown in **Figure 2-1**. Well 13 is co-located with Pump Station 16 (PS16) and produces approximately 460 gallons per minute (gpm). It is chlorinated at the wellhead and fills the E398 Zone Reservoir 17/20 complex via a dedicated transmission pipe, splitting at the reservoir site and filling each tank separately from the top.

Well 14 has an operating capacity of approximately 220 gpm and pumps directly into the E240 Zone and to PS 16. It is also chlorinated at the wellhead. Distribution piping carries water from the well in a southerly direction, to PS16, and then continues south to supply the E240 Zone. When both Well 14 and PS16 are operating, flow from both wells is pumped to the E398 Zone Reservoirs 17 & 20.

Confluence completed pilot testing for both Wells 13 and 14 in August 2023. This technical memorandum summarizes pilot testing results and provides screening-level cost estimates for full-scale treatment systems.

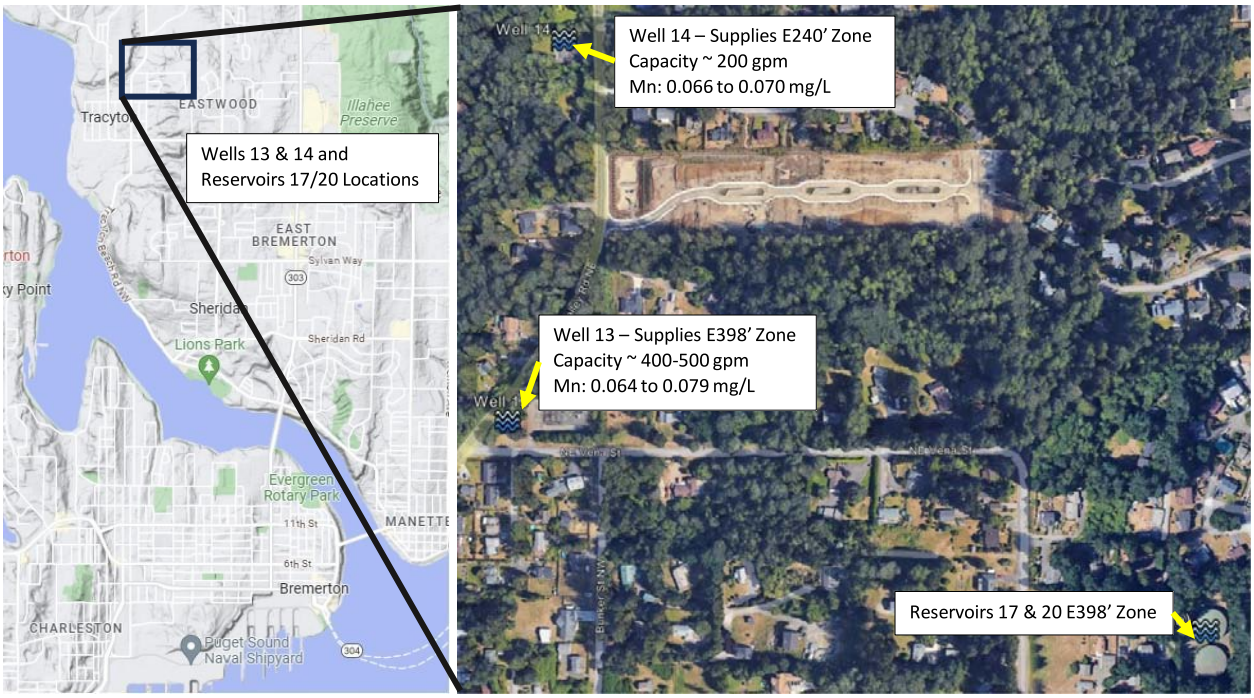

Figure 2-1 Well 13 & Well 14 Location Map

3 SOURCE WATER QUALITY AND FINISHED WATER GOALS

A testing plan was developed for this work (Confluence, August 16, 2023) and referenced the raw water quality and finished-water goals that are summarized below in **Table 3-1**. This information served as a basis for pilot testing the filtration process for removal of iron and manganese. Available data indicates that total iron levels are generally very low in these sources, and the primary contaminant of interest is manganese. It is noted that slightly elevated iron bacteria counts were seen in Well 13 source water. While these bacteria are neither regulated nor harmful to human health, and chlorination as practiced at this source is expected to eliminate the bacteria, higher levels could over time impact well capacity (by fouling the well screen or pump components) and contribute to discoloration issues in the system associated with formation of iron-biofilm on pipe walls and premise plumbing systems. Although not

monitored here, pilot testing for iron and manganese removal in other systems has shown very effective (90-99%) removal of iron bacteria through filtration.

Table 3-1 Well 13 and 14 raw water quality and recommended post-treatment goals

Parameter	Well 13 Values	Well 14 Values	Routine Goal	Goal Not to Exceed
Iron bacteria (No./L)	600 to 3,100	20 to 84	≤500	1000
Iron, total (mg/L)	ND to 0.04	ND	≤0.05	0.20
Manganese, total (mg/L)	0.064 to 0.079	0.066 to 0.070	≤0.015	0.03
Total organic carbon (mg/L)	0.3 to 0.4	0.3 to 0.4	<1	1
Turbidity (NTU)	NA	NA	≤0.3	1

NA = Not analyzed
Data for Well 13 and 14 are based on monitoring conducted from May through August 2021.

4 PILOT TESTING

Pilot testing was conducted with the Confluence portable pilot filter skid and associated equipment. The equipment and testing approach is described below.

4.1 Pilot Testing Equipment

The pilot skid, shown at Bremerton's Well 14 in **Figure 4-1**, is manufactured on a frame of welded aluminum and incorporates two 6-inch, clear PVC columns with flanged height extensions. Equipment included all necessary flow meters, totalizers, control valves, pressure gauges, sample ports, chemical storage and metering systems, and backwash capabilities to complete testing at both sites.

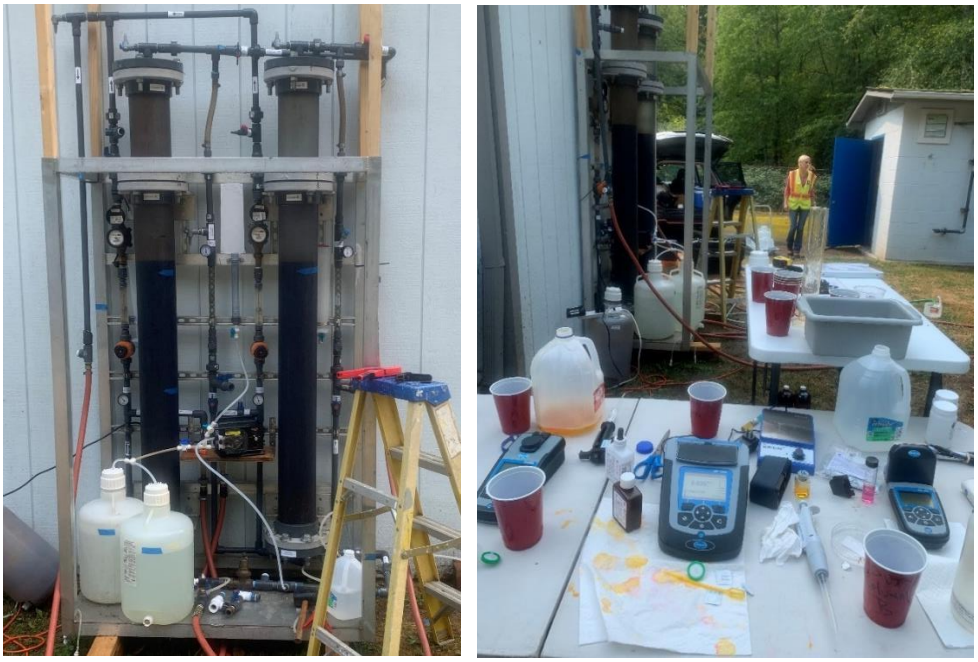

Figure 4-1 Pilot filter test rig and field analysis equipment at Bremerton's Well 14

The sites were prepared so that all field sampling could be completed on-site. Each site supplied raw water to the test skid with a 0.75-inch hose-bib connection and 120v power supply to operate equipment. Following the pilot filter, water was collected in a 250-gallon plastic stock tank with de-chlorination pucks to allow sufficient contact time prior to disposal to a local storm drain.

4.2 Pilot Testing Approach

Pilot testing (with some limited bench-scale testing) was conducted at Wells 13 & 14 using three media configurations shown in **Table 4-1**. It has not yet been determined if the two wells will eventually be combined, or if treatment will be implemented at each site. Pilot testing was carried out at each of the two sites. Water quality profiles for the two wellswells are very similar, and results are applicable whether treating the wells individually or as combined sources.

To maximize efficiency of testing, and because of the similarity of the two sources, two media configurations were tested at Well 14 first. The configuration deemed to be best performing was continued at Well 13, and a third media configuration was then tested.

Raw water in all tests was continuously fed 6.5% sodium hypochlorite at a dose between 1.3 and 1.5 mg/L (as Cl_2). Chlorine reaction and loss ranged from 0.10 to 0.15 mg/L across all filters.

Table 4-1 Filter media designs for pilot testing

Parameter	Pyrolox Advantage	GreensandPlus™ with Anthracite	Anthracite
Top Media	NA	Anthracite	NA
Depth (inch)	-	20	-
Effective Size, ES (mm)	-	1.0	-
Uniformity Coefficient, UC	-	1.5	-
Specific Gravity, SG	-	1.6	-
Bottom Media	Pyrolox Advantage	GreensandPlus™	Anthracite
Depth (inch)	36	16	36
Effective Size, ES (mm)	0.56	0.34	1
Uniformity Coefficient, UC	1.5	<1.6	<1.5
Specific Gravity, SG	2.7	2.4	1.6
Total L/d	1,600	1,700	900

NA = Not applicable

ES = 10th percentile media grain diameter

UC = Ratio of the 60th percentile media grain diameter to the ES

L/d = Ratio of media depth to ES

SG = Ratio of density of media to the density of water, dimensionless

Support media included 2-inches of garnet (#8/12 mesh, ES = 1.85 mm, SG = 4.0 to 4.1) over 2-inches of pea stone (0.25- to 0.5-inch diameter), over 4-inches of course gravel (0.5- to 1.0-inch diameter).

Testing was conducted as follows:

1. Iterative, short-duration tests were completed to evaluate the impact of filter loading rate (FLR) on filter effluent water quality[1] to establish the target FLR for an extended-duration test. FLR reflects the amount of water flow (gpm) passing through 1 square foot of media area; the higher the acceptable FLR, the less media required for a given source flow rate, and the less cost of the treatment system. While higher FLR values allow reduced filter and media sizing, they can come at the cost of more rapid headloss build-up, and potentially greater backwash frequency. Testing started at a FLR of 10 gallons per minute per square foot of filter area (gpm/ft^2) and was increased to test the efficacy of 12 gpm/ ft^2.
2. Extended duration tests were conducted at a filter run time up to 48 hours to investigate treatment performance, headloss development, and characterize backwash residuals.
3. Bench-scale testing was completed to evaluate chlorine demand and decay (CDD) for raw and finished water (following filtration). CDD tests were conducted at a hold time of up to seven days.

To provide representative water quality to the pilot equipment, each well was operated continuously throughout testing. Wells were started at least 24 hours prior to each test run and pumped at their normal flow rate into the distribution system. Untreated water was supplied to the pilot filter columns via a side stream flow.

Three media configurations were tested; these included:

- Monomedia installation of a high manganese dioxide (MnO_2) content coated silica sand (Pyrolox Advantage)
- A lower manganese oxide content MnO_2-coated silica sand (commercially available as GreensandPlus™) with an anthracite cap to improve particulate capture
- An anthracite-only column

As treatment performance and backwashing can vary by media type, media options were tested side-by-side in two, parallel columns. Tests started at Well 14 with the dual media GreensandPlus™ with anthracite, and the monomedia Pyrolox Advantage. Subsequently, GreensandPlus™ with anthracite was replaced with Anthracite monomedia and was tested together with Pyrolox Advantage at Well 13.

All media used in testing was prepared in advance by soaking in a potassium permanganate solution. Media was thoroughly backwashed to remove chemicals prior to testing. During testing, each media configuration was backwashed at between 13 to 22 gpm/ft^2 with a target bed expansion of 40% for a total duration of 10 minutes. The pilot filter operations, sampling approach, and data collection activities for both filtration and backwash characterization tests are described in the pilot testing plan (Confluence, August 16, 2023). Briefly, the following is a description of the parameters sent to an external laboratory for analysis along with the analytical method used and their method detection limit (MDL):

- Alkalinity, total (mg/L as $CaCO_3$), Standard Method (SM) 2320B, MDL = 1 mg/L
- Ammonia, total (mg/L NH_3-N), EPA 350.1, MDL – 0.10 mg/L

[1] Short-duration tests were used to determine whether a given filter loading rate provided suitable time for manganese adsorption/oxidation kinetics and suitable filterability of oxidized inorganic precipitates.

- Calcium, total (mg/L-CA), EPA 200.7, MDL = 0.2 mg/L
- Dissolved solids, total (mg/L), SM 2540 C, MDL = 10 mg/L
- Iron, total (mg/L-Fe), EPA 200.8, MDL = 0.1 mg/L
- Manganese, total and soluble (mg/L-Mn), EPA 200.8, MDL = 0.01 mg/L
- Organic carbon, total (mg/L), SM 5310 C, MDL = 0.1 mg/L
- Silica, dissolved reactive (mg/L-SiO_2), EPA 200.7, MDL = 1 mg/L
- Suspended solids, total (mg/L), SM 2540 D, MDL = 1 mg/L

5 PILOT TESTING RESULTS

Water quality, headloss, backwash, and chlorine demand results from pilot testing are provided below.

5.1 Filtration Performance

Well 14 was tested first, followed by Well 13.

Table 5-1 summarizes data collected from pilot testing for parameters that have established goal values shown above in **Table 3-1**. These data are either single sample results or, when available, average values across the filter run along with the data minimum and maximum (range). At the time of testing, raw water temperature for both wells was 10°C, alkalinity ranged from 73 to 90 mg/L as $CaCO_3$, and silica was 28 mg/L and did not change through treatment.

Table 5-1 Water quality conditions observed during pilot testing with reference to Table 3-1 goals

Parameter	Condition	Well 14 FLR = 12 gpm/ft²	Well 13 FLR = 12 gpm/ft²
pH (units)	Raw Water	8.5	8.3
	GreensandPlus™ + Anthracite	8.3	NT
No goal	Pyrolox Advantage	8.4	8.3
	Anthracite	NT	8.3
Iron, total (mg/L)	Raw Water	<0.10*	<0.10*
	GreensandPlus™ + Anthracite	All <0.010	NT
	Pyrolox Advantage	<0.10*	All <0.010
Goal ≤0.20 mg/L	Anthracite	NT	All <0.010
Manganese, total (mg/L)	Raw Water	0.08*	0.09*
	GreensandPlus™ + Anthracite	0.008 (0.001-0.016) F	NT
	Pyrolox Advantage	0.011 (0.005-0.028) F	0.005 (0.003-0.008) F
Goal ≤0.03 mg/L	Anthracite	NT	0.009 (0.006-0.012) F
Total Organic Carbon, TOC (mg/L)	Raw Water	1.2*	0.6*
	GreensandPlus™ + Anthracite	0.8*	NT
	Pyrolox Advantage	0.3*	0.3*
Goal ≤1 mg/L	Anthracite	NT	0.3*
Turbidity (NTU)	Raw Water	0.12*	0.21*
	GreensandPlus™ + Anthracite	0.02*	NT
	Pyrolox Advantage	0.12*	0.12 (0.09-0.23)
Goal ≤1 NTU	Anthracite	NT	0.10 (0.08-0.12)

Data as average and range from multiple samples collected at least one hour apart.

F = Field measurement result shown (all laboratory samples were reported as not detected; <0.01 mg/L)

NT Not tested * Single sample result.

Water quality results indicate that the filtration treatment process operating at 10 – 12 gpm/ft^2 is effective at removing the targeted contaminants from both Well 13 and 14, and with any of the filter medias tested. All filtered water values collected during the extended filter run tests were within the established treatment goals. Overall, results are consistent with performance of the catalytic oxidation and filtration process in similar groundwater treatment applications.

All finished water laboratory results for manganese were reported as "Non-Detect", so results summarize manganese information using field measurements. Field manganese measurements at these very low levels are not as accurate as laboratory measurements, and in past Confluence studies, generally over-report manganese levels when compared to laboratory results. Field measurements are provided here to provide supplemental information since all laboratory measurements in filtered water for all media returned results that were below the laboratory reporting limit (<0.01 mg/L).

Filter runs were monitored for between two to three days at both wells and filter headloss was recorded as testing progressed. Headloss profile data for both wells are shown in **Figure 5-1** (Well 14, tested with Pyrolox Advantage and GreendsandPlus™ + Anthracite) and **Figure 5-2** (Well 13, tested with Pyrolox Advantage and Anthracite monomedia). The headloss accumulation is presented as a function of Unit Filter Run Volumes (UFRVs) treated. The UFRV is calculated by dividing the water produced (gallons) by the surface area of the filter (ft^2) for the period of interest (generally between backwashes). It is calculated equivalently by multiplying the loading rate (i.e., 12 gpm/ft^2) times the period of interest.

In many filtration applications, UFRV values exceeding 12,000 gal/ft^2 are considered to demonstrate efficient filtration operation (no requirement for excessive backwashing frequency). The UFRVs achieved here are substantially greater than this level.

Filter headloss accumulation profiles were calculated for each filter run. This allowed for extrapolation of filter run times through curve fit equations. This extrapolation is only an estimate for illustrative purposes, but does indicate that filter runs of several days or more of run time could occur with all media types, though this is not generally best operating practice. Observations from headloss accumulation curves shown in **Figure 5-1** and **Figure 5-2** are:

- For all tests, terminal headloss was never achieved in the available test period, indicating that filter runs could have been extended for possibly several days longer without exceeding the allowable headloss of 8 psi.
- The most rapid headloss accumulation was observed at Well 14 with GreensandPlus™ media. This is not unexpected since this media has the smallest grain size, and had the highest initial (clean bed) headloss.
- The Anthracite only media, much coarser in size, accumulated almost no headloss in Well 13 tests, while still providing excellent removal.
- Headloss accumulation for Pyrolox Advantage media was generally similar at both well sites, and very low.
- In this relatively clean groundwater application, testing indicates highly efficient performance, and accumulation of headloss across the filters is unlikely to trigger backwash or be a significant operational constraint.

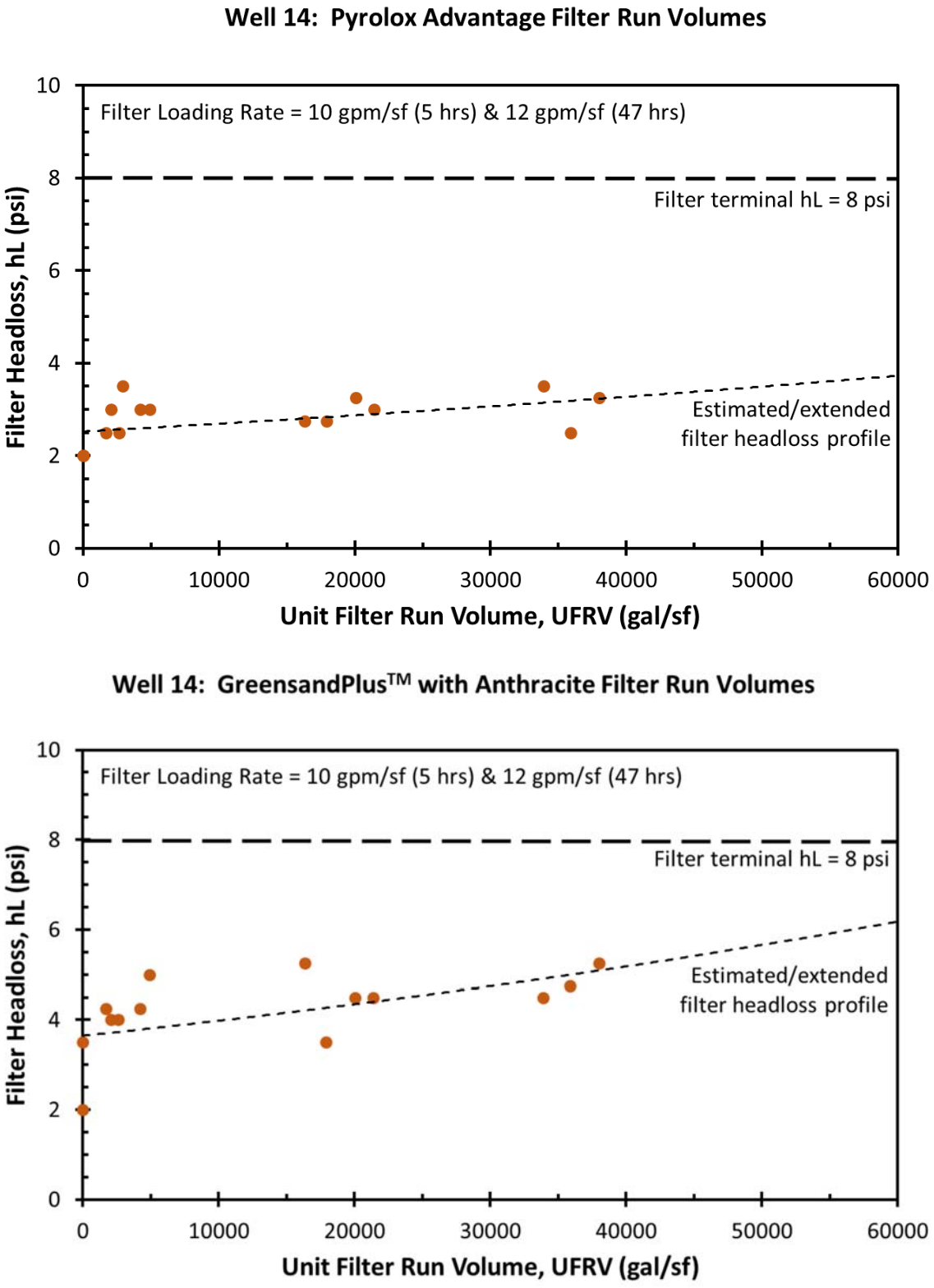

Figure 5-1 **Filter headloss data and estimated headloss profile curves for Well 14 testing at 10 & 12 gpm/ft² (curve fit equations estimate filter headloss based on calculated UFRV)**

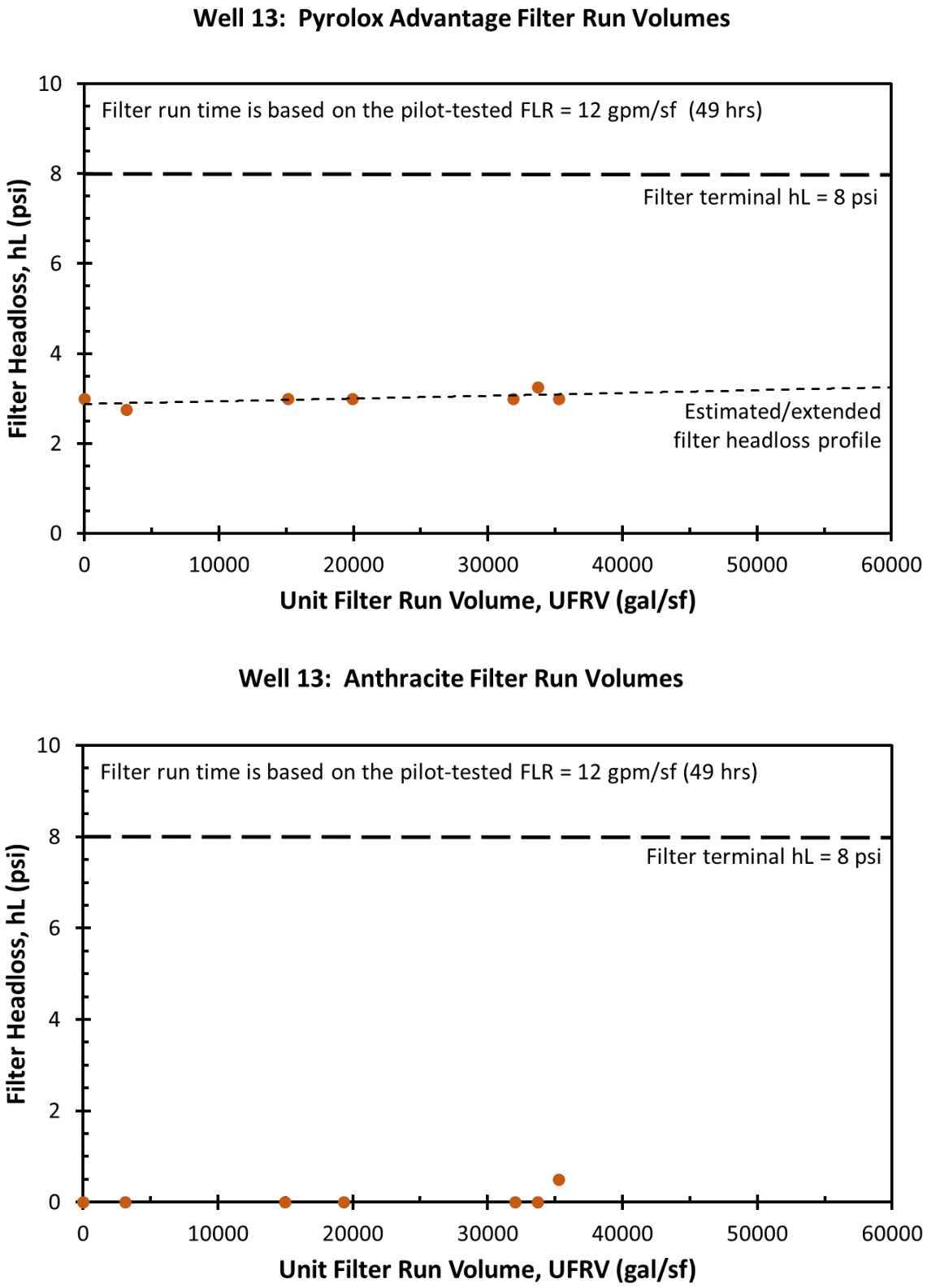

Figure 5-2 **Filter headloss data and estimated headloss profile curves for Well 13 testing at 12 gpm/ ft^2 (curve fit equations estimate filter headloss based on calculated UFRV)**

5.2 Backwash Residuals Estimating and Characterization

The filtration process requires that filters are periodically backwashed to remove accumulated solids, metals, and bacteria in the media bed. This backwash operation, along with the potential filter-to-waste (rinse) cycle at the start of the ensuing filter run, produces liquid residuals that must be addressed. Utilities generally take one of two approaches with these residuals:

- Option 1 – Discharge the entire, composite residuals volume to the sanitary sewer system, if available; or,
- Option 2 – Capture backwash flows in a backwash storage tank, provide gravity settling of solids, and recycle clarified supernatant to the head of the filter plant at a relatively low rate (<10% of the total plant flow). Periodic removal of sludge solids must be performed.

Option 2 improves overall filter plant water recovery percentage and allows the opportunity of installing a filter plant on a site without a sanitary sewer connection, but this option does require additional infrastructure and footprint. It is understood that a sanitary sewer connection is currently not provided to the Wells 13 and 14 locations. A recent sewer line extension to serve the Shadowhawk development passes in front of Well 14, and terminates approximately 700 feet north of Well 13. Given current uncertainty about whether connection to sanitary sewer will be included with the project, data was collected during pilot testing to evaluate Option 2.

Filter backwash turbidity profiles were collected to inform the effective length of backwash and for filter backwash composite settleability (to determine design characteristics for settling tanks). At the end of each long-term filter run, each individual filter was backwashed at a flowrate sufficient to achieve approximately 40% expansion. To achieve this, the following flowrates (and backwash loading rates) were used for each media configuration:

- GreensandPlus^{TM} + Anthracite – 2.5 gpm (12.7 gpm/ ft^2)
- Pyrolox advantage – 3.5 gpm (17.8 gpm/ ft^2)
- 100% Anthracite – 4.25 gpm (21.6 gpm/ ft^2)

Figure 5-3 summarizes turbidity grab samples collected every 15 seconds during backwash of each filter media. For each media, estimated completion of the filter backwash (where the bed is effectively clean and turbidity is no longer significantly declining) occurs at approximately 5-6 minutes of backwash. This duration may extend up to 10 minutes if longer filter run times occur in the full-scale filters.

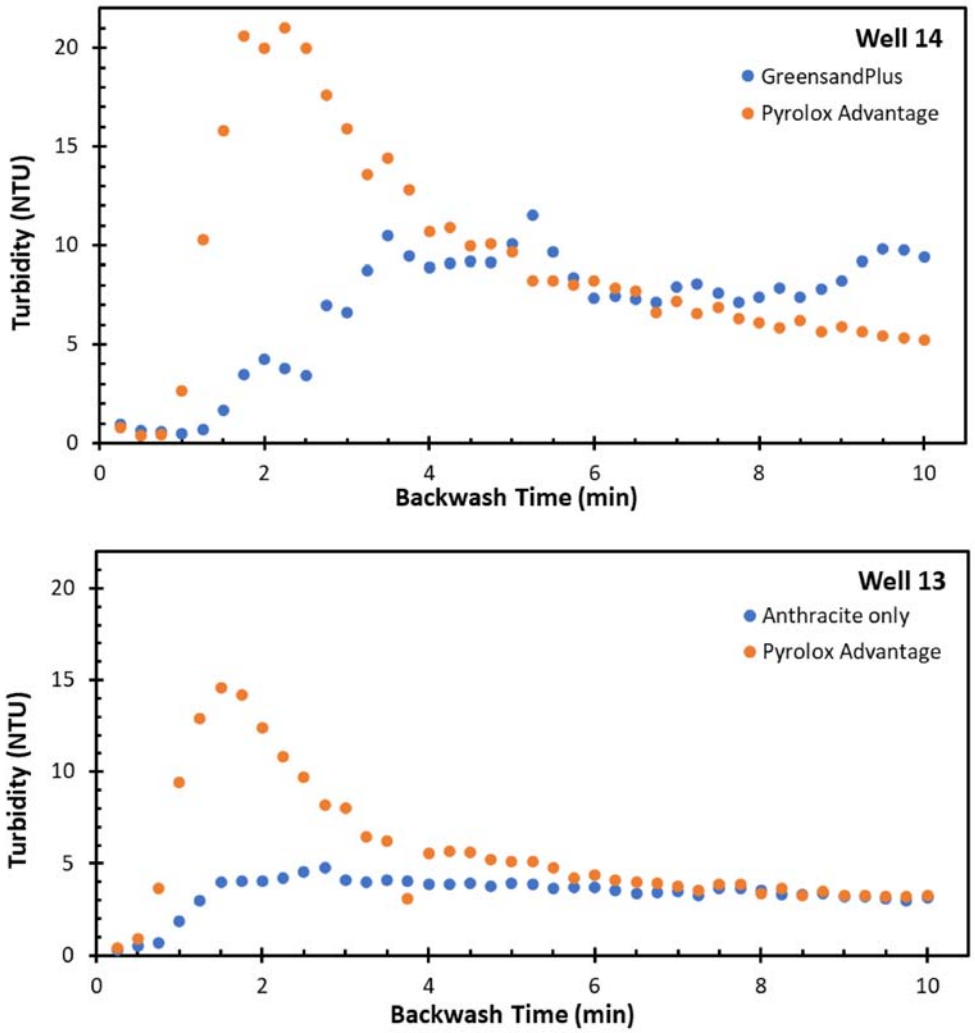

Figure 5-3 **Filter backwash turbidity profile data collected during Well 14 and 13 testing**

Table 5-2 summarizes composite and settled backwash water quality characteristics. This data summarizes settling performance of the backwash, characterizing water quality that will be returned to the head of the filters following settling. For the 2- to 3-day filter runs, only a low-level of material had accumulated onto filter media, ranging from ND to 4 mg/L TSS, 0.3 to 1.6 mg/L Mn, and 0.21 to 0.53 mg/L Fe for all composite backwash samples.

Settled materials from each backwash were measured and no discernable amount of material was able to be quantified (<0.5 mL solids / liter of backwash water) from any of the runs. Based on all the information collected during piloting, it is expected that the filtration run at both wells could have continued significantly longer. With a longer filter run (higher UFRV), metals/solids concentrations in the backwash composite volume would increase proportionately, yielding a corresponding increase in settleable solids. Under this scenario, the settled fraction for the various constituents would also likely increase due to flocculation effects from the higher composite concentration, which would in turn further increase the settleable solids.

Table 5-2 Filter backwash composite and settled water quality

Well, Media Type, and Sample Identification	TSS (mg/L)	Manganese (mg/L)	Iron (mg/L)
Well 14 GreensandPlus™			
Composite backwash	3.0	0.62	0.24
12 hr-settled supernatant	<1	0.16	0.12
24 hr-settled supernatant	<1	0.22	0.15
Well 14 Pyrolox Advantage			
Composite backwash	4.0	1.6	0.53
12 hr-settled supernatant	1.5	0.49	0.33
24 hr-settled supernatant	<1	0.39	0.25
Well 13 Anthracite only			
Composite backwash	<1	0.48	0.22
12 hr-settled supernatant	<1	0.08	<0.1
24 hr-settled supernatant	<1	0.08	<0.1
Well 13 Pyrolox Advantage			
Composite backwash	2.0	0.27	0.21
12 hr-settled supernatant	<1	0.14	0.18
24 hr-settled supernatant	<1	0.13	<0.1

Values shown as "<" were below the laboratory reporting level as shown.

5.3 Chlorine Demand and Decay

To determine if filtration provided any impact on chlorine demand and decay (CDD), testing was conducted in chlorine-demand-free glassware to compare raw water CDD rates to those observed after filtration. **Table 5-3** summarizes all test results, observed across a 7-day storage period and resulting in a consistent chlorine demand of approximately 0.3 mg/L. These results indicate that filtration will not markedly change CDD from either well, given that background values are already relatively low.

Table 5-3 7-day chlorine demand for raw and treated water

Condition	7-Day Total Chlorine Demand (mg/L)
Well 14	
Raw / Unfiltered	0.3
After GreensandPlus™	0.3
After Pyrolox Advantage	0.3
Well 13	
Raw / Unfiltered	0.2
After Anthracite	0.3
After Pyrolox Advantage	0.3

6 SCREENING-LEVEL COST ESTIMATES

Cost estimating for the Well 13 and 14 treatment facilities are "Study/Feasibility" level estimates as defined by the Association for the Advancement of Cost Engineering (AACE) International Recommended Practice No. 18R-97 (2005). In general, this level of estimate can range from -50% to +100% of the base estimate (i.e., 0.5x to 2x base costs). However, because vendors were directly solicited for equipment costs, essentially improving the cost estimates, the cost summary ranges provided herein might be considered more in a range of -25% to +50% (i.e., 0.75x to 1.5x the estimates).

A current and significant unknown impact on cost estimates and the overall cost of construction is the lasting impact from disruption to global supply chains. Because there may be some lasting supply chain unknowns, cost estimates were prepared with specified contingencies, and are shown with potential upper bound of cost + 50%. A summary of the estimated total project costs and estimated ranges are presented below.

Estimated costs, expressed in 2023 dollars, are based upon historical data, past project data, and correspondence with vendors and contractors. Costs include sales tax at 9.2%; legal, engineering, and administrative costs at 25%; and a 30% project contingency. Costs do not include land acquisition in the form of either purchase or easements.

As Well 14 currently discharges to the E240 Zone, and the new plant would be in the E398 Zone, it is assumed that the pump and motor would be replaced (likely with a 50 hp pump and motor). Major electrical upgrades at Well 14 are not included in this estimate and will need to be assessed if the pump motor is increased from 25 hp to 50 hp. Detailed design may also identify other pumping configurations that are more efficient. It is possible that additional land will need to be acquired or an easement obtained from Puget Sound Energy for this combined facility at Well 13 (costs not included in estimate).

Table 6-1 shows a summary of study/feasibility cost estimates for a single combined treatment facility, and individual facilities installed at both Wells 14 and 13. To illustrate potential continuity with other projects, Confluence has obtained as-built costs for four other filtration facilities in the pacific northwest (one in British Columbia and three in the Seattle region). The Bremerton study/feasibility-level cost estimates are plotted against these other facilities and shown in **Figure 6-1**.

Details assumed for each of the cost estimates (for individual wells and the combined facility) are provided in **Appendix 1**. Media supplied with each Vendor system may or may not be proprietary and was interpreted to be able to provide results similar to Pyrolox Advantage. A media selection other than one of those tested in this work may require additional validation testing.

Table 6-1 Range of study-level capital cost estimates based on equipment and facility site development

Site Configuration		Low-Cost Estimate (-25%) ($M)	Cost Estimate ($M)	High-Cost Estimate (+50%) ($M)
One combined facility with waste recycle (680 gpm)				
	Vendor A	$1.99	**$2.65**	$3.97
	Vendor B	$1.30	**$1.73**	$2.60
	Vendor C	$1.81	**$2.41**	$3.61
One combined facility with sewer connection (680 gpm)				
	Vendor A	$2.11	**$2.81**	$4.22
	Vendor B	$1.42	**$1.89**	$2.84
	Vendor C	$1.93	**$2.57**	$3.86
Treatment at Well 13 (460 gpm)				
	Vendor A	$1.63	**$2.17**	$3.25
	Vendor B	$1.06	**$1.41**	$2.12
	Vendor C	$1.57	**$2.01**	$3.15
Treatment at Well 14 (220 gpm)				
	Vendor A	$1.33	**$1.77**	$2.65
	Vendor B	$0.86	**$1.14**	$1.71
	Vendor C	$1.19	**$1.59**	$2.38

Estimates are for capital costs only. Costs include general site preparation, development, and yard piping; building with HVAC; process equipment, site finish work, 9.2% tax, 25% legal engineering and admin fees, and 30% contingency. All prep work, building sizing, yard piping, and finish work costs are estimated at a study/feasibility level and should be confirmed prior to finalizing City planning budgets.

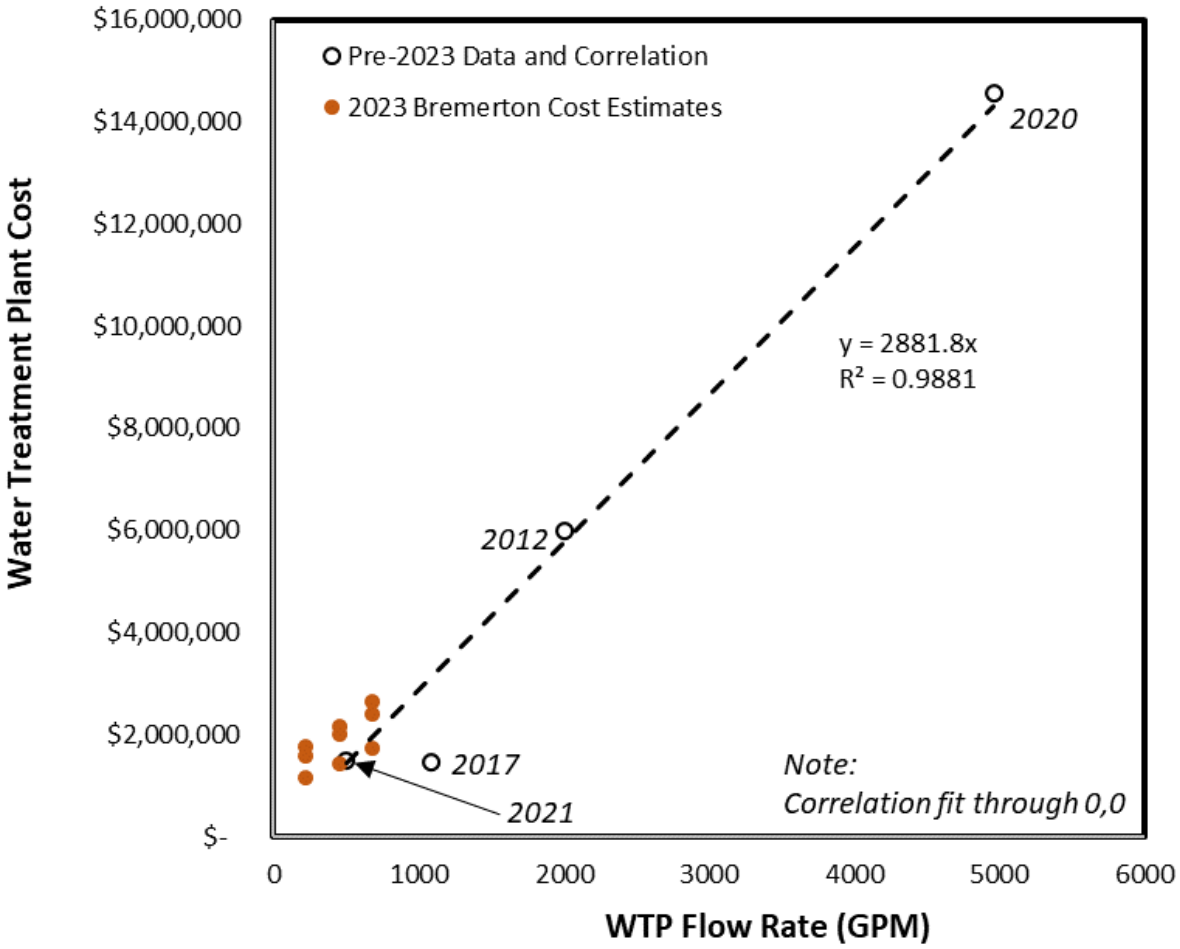

Figure 6-1 **Comparing Bremerton capital cost data against capital cost data from four Pacific Northwest filtration facilities completed between 2012 and 2021 (pre-2023 costs were escalated to 2nd quarter 2023 dollars using the Turner Building Cost Index for non-residential building construction)**

APPENDIX 1 – COST ESTIMATE SUPPORTING INFORMATION

(See following pages)

Cost estimate for Combined treatment of both wells w/Recycle

(Vendor A - Pureflow, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$690,000	$690,000
2	Installation of filtration system	1	LS	$103,500	$103,500
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Backwash reclamation system & pumping	1	LS	$180,000	$180,000
5	Chlorine storage and feed tank, pumping, piping		Incl.		$0
6	Building (foundation, walls, rooms)	800	SF	$350	$280,000
7	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
8	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
9	Treatment building HVAC	1	LS	$15,000	$15,000
10	Miscellaneous yard piping	1	LS	$10,000	$10,000
11	Concrete sidewalks	168	SF	$20	$3,360
12	Site paving	200	SF	$150	$30,000
13	Security fencing	200	LF	$50	$10,000
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$5,000	$5,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$1,000	$1,000
19	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,612,860
	Sales Tax			9.2%	$148,383
	Legal, engineering, and administrative			25%	$403,215
	Contingency			30%	$483,858
	Total				$2,648,316
	Range, low (-25%)				$1,986,237
	Range, high (+50%)				$3,972,474

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Combined treatment of both wells w/ Sewer

(Vendor A - Pureflow, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$690,000	$690,000
2	Installation of filtration system	1	LS	$103,500	$103,500
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Sewer connection fees	1	EA	$140,000	$140,000
5	Sanitary sewer extension line	700	LF	$200	$140,000
6	Chlorine storage and feed tank, pumping, piping		Incl.		$0
7	Building (foundation, walls, rooms)	800	SF	$350	$280,000
8	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
9	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
10	Treatment building HVAC	1	LS	$15,000	$15,000
11	Miscellaneous yard piping	1	LS	$10,000	$10,000
12	Concrete sidewalks	168	SF	$20	$3,360
13	Site paving	200	SF	$150	$30,000
14	Security fencing	200	LF	$50	$10,000
15	Security gate	1	EA	$5,000	$5,000
16	Site surface restoration	1	LS	$5,000	$5,000
17	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
18	Miscellaneous signage	1	LS	$1,000	$1,000
19	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,712,860
	Sales Tax			9.2%	$157,583
	Legal, engineering, and administrative			25%	$428,215
	Contingency			30%	$513,858
	Total				$2,812,516
	Range, low (-25%)				$2,109,387
	Range, high (+50%)				$4,218,774

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 13 w/Recycle

(Vendor A - Pureflow, 2023) 460 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$575,000	$575,000
2	Installation of filtration system	1	LS	$86,250	$86,250
3	Backwash supply tank and associated systems	1	LS	$140,000	$140,000
4	Backwash reclamation system & pumping	1	LS	$158,000	$158,000
5	Chlorine storage and feed tank, pumping, piping		Incl.		$0
6	Building (foundation, walls, rooms)	600	SF	$350	$210,000
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$10,000	$10,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	150	SF	$20	$3,000
12	Site paving	150	SF	$150	$22,500
13	Security fencing	150	LF	$50	$7,500
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$1,322,550
	Sales Tax			9.2%	$121,675
	Legal, engineering, and administrative			25%	$330,638
	Contingency			30%	$396,765
	Total				$2,171,627
	Range, low (-25%)				$1,628,720
	Range, high (+50%)				$3,257,441

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 14 w/Recycle

(Vendor A - Pureflow, 2023) 220 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$465,000	$465,000
2	Installation of filtration system	1	LS	$69,750	$69,750
3	Backwash supply tank and associated systems	1	LS	$94,500	$94,500
4	Backwash reclamation system & pumping	1	LS	$144,750	$144,750
5	Chlorine storage and feed tank, pumping, piping		Incl.		$0
6	Building (foundation, walls, rooms)	450	SF	$350	$157,500
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$8,000	$8,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	126	SF	$20	$2,520
12	Site paving	125	SF	$150	$18,750
13	Security fencing	125	LF	$50	$6,250
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$1,077,320
	Sales Tax			9.2%	$99,113
	Legal, engineering, and administrative			25%	$269,330
	Contingency			30%	$323,196
	Total				$1,768,959
	Range, low (-25%)				$1,326,720
	Range, high (+50%)				$2,653,439

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Combined treatment of both wells w/Recycle

(Vendor B - ATEC, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$190,000	$190,000
2	Installation of filtration system	1	LS	$28,500	$28,500
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Backwash reclamation system & pumping	1	LS	$180,000	$180,000
5	Chlorine storage and feed tank, pumping, piping	1	EA	$16,000	$16,000
6	Building (foundation, walls, rooms)	800	SF	$350	$280,000
7	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
8	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
9	Treatment building HVAC	1	LS	$15,000	$15,000
10	Miscellaneous yard piping	1	LS	$10,000	$10,000
11	Concrete sidewalks	168	SF	$20	$3,360
12	Site paving	200	SF	$150	$30,000
13	Security fencing	200	LF	$50	$10,000
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$5,000	$5,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$1,000	$1,000
18	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,053,860
	Sales Tax			9.2%	$96,955
	Legal, engineering, and administrative			25%	$263,465
	Contingency			30%	$316,158
	Total				$1,730,438
	Range, low (-25%)				$1,297,829
	Range, high (+50%)				$2,595,657

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Combined treatment of both wells w/ Sewer

(Vendor B - ATEC, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$190,000	$190,000
2	Installation of filtration system	1	LS	$28,500	$28,500
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Sewer connection fees	1	EA	$140,000	$140,000
5	Sanitary sewer extension line	700	LF	$200	$140,000
6	Chlorine storage and feed tank, pumping, piping	1	EA	$16,000	$16,000
7	Building (foundation, walls, rooms)	800	SF	$350	$280,000
8	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
9	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
10	Treatment building HVAC	1	LS	$15,000	$15,000
11	Miscellaneous yard piping	1	LS	$10,000	$10,000
12	Concrete sidewalks	168	SF	$20	$3,360
13	Site paving	200	SF	$150	$30,000
14	Security fencing	200	LF	$50	$10,000
15	Security gate	1	EA	$5,000	$5,000
16	Site surface restoration	1	LS	$5,000	$5,000
17	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
18	Miscellaneous signage	1	LS	$1,000	$1,000
19	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,153,860
	Sales Tax			9.2%	$106,155
	Legal, engineering, and administrative			25%	$288,465
	Contingency			30%	$346,158
	Total				$1,894,638
	Range, low (-25%)				$1,420,979
	Range, high (+50%)				$2,841,957

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 13 w/Recycle

(Vendor B - ATEC, 2023) 460 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$115,000	$115,000
2	Installation of filtration system	1	LS	$17,250	$17,250
3	Backwash supply tank and associated systems	1	LS	$140,000	$140,000
4	Backwash reclamation system & pumping	1	LS	$158,000	$158,000
5	Chlorine storage and feed tank, pumping, piping	1	EA	$15,000	$15,000
6	Building (foundation, walls, rooms)	750	SF	$350	$262,500
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$10,000	$10,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	162	SF	$20	$3,240
12	Site paving	150	SF	$150	$22,500
13	Security fencing	150	LF	$50	$7,500
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$861,290
	Sales Tax			9.2%	$79,239
	Legal, engineering, and administrative			25%	$215,323
	Contingency			30%	$258,387
	Total				$1,414,238
	Range, low (-25%)				$1,060,679
	Range, high (+50%)				$2,121,357

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 14 w/Recycle

(Vendor B - ATEC, 2023) 220 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$90,000	$90,000
2	Installation of filtration system	1	LS	$13,500	$13,500
3	Backwash supply tank and associated systems	1	LS	$94,500	$94,500
4	Backwash reclamation system & pumping	1	LS	$144,750	$144,750
5	Chlorine storage and feed tank, pumping, piping	1	EA	$14,000	$14,000
6	Building (foundation, walls, rooms)	550	SF	$350	$192,500
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$8,000	$8,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	144	SF	$20	$2,880
12	Site paving	125	SF	$150	$18,750
13	Security fencing	125	LF	$50	$6,250
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$695,430
	Sales Tax			9.2%	$63,980
	Legal, engineering, and administrative			25%	$173,858
	Contingency			30%	$208,629
	Total				$1,141,896
	Range, low (-25%)				$856,422
	Range, high (+50%)				$1,712,844

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Combined treatment of both wells w/Recycle

(Vendor C -TONKA, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$488,000	$488,000
2	Installation of filtration system	1	LS	$73,200	$73,200
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Backwash reclamation system & pumping	1	LS	$180,000	$180,000
5	Chlorine storage and feed tank, pumping, piping	1	EA	$16,000	$16,000
6	Building (foundation, walls, rooms)	1000	SF	$350	$350,000
7	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
8	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
9	Treatment building HVAC	1	LS	$15,000	$15,000
10	Miscellaneous yard piping	1	LS	$10,000	$10,000
11	Concrete sidewalks	192	SF	$20	$3,840
12	Site paving	200	SF	$150	$30,000
13	Security fencing	200	LF	$50	$10,000
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$5,000	$5,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$1,000	$1,000
18	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,467,040
	Sales Tax			9.2%	$134,968
	Legal, engineering, and administrative			25%	$366,760
	Contingency			30%	$440,112
	Total				$2,408,880
	Range, low (-25%)				$1,806,660
	Range, high (+50%)				$3,613,320

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Combined treatment of both wells w/ Sewer

(Vendor C - TONKA, 2023) 680 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$488,000	$488,000
2	Installation of filtration system	1	LS	$73,200	$73,200
3	Backwash supply tank and associated systems	1	LS	$155,000	$155,000
4	Sewer connection fees	1	EA	$140,000	$140,000
5	Sanitary sewer extension line	700	LF	$200	$140,000
6	Chlorine storage and feed tank, pumping, piping	1	EA	$16,000	$16,000
7	Building (foundation, walls, rooms)	1000	SF	$350	$350,000
8	Clearing, grubbing, and grading	1	LS	$10,000	$10,000
9	Treatment building electrical, I&C, and chem feed	1	LS	$30,000	$30,000
10	Treatment building HVAC	1	LS	$15,000	$15,000
11	Miscellaneous yard piping	1	LS	$10,000	$10,000
12	Concrete sidewalks	192	SF	$20	$3,840
13	Site paving	200	SF	$150	$30,000
14	Security fencing	200	LF	$50	$10,000
15	Security gate	1	EA	$5,000	$5,000
16	Site surface restoration	1	LS	$5,000	$5,000
17	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
18	Miscellaneous signage	1	LS	$1,000	$1,000
19	New Submersible Pump & Motor - Well 14	1	LS	$20,000	$20,000
	Subtotal				$1,567,040
	Sales Tax			9.2%	$144,168
	Legal, engineering, and administrative			25%	$391,760
	Contingency			30%	$470,112
	Total				$2,573,080
	Range, low (-25%)				$1,929,810
	Range, high (+50%)				$3,859,620

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 13 w/Recycle

(Vendor C - TONKA, 2023) 460 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$415,000	$415,000
2	Installation of filtration system	1	LS	$62,250	$62,250
3	Backwash supply tank and associated systems	1	LS	$140,000	$140,000
4	Backwash reclamation system & pumping	1	LS	$158,000	$158,000
5	Chlorine storage and feed tank, pumping, piping	1	EA	$15,000	$15,000
6	Building (foundation, walls, rooms)	800	SF	$350	$280,000
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$10,000	$10,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	168	SF	$20	$3,360
12	Site paving	150	SF	$150	$22,500
13	Security fencing	150	LF	$50	$7,500
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$1,223,910
	Sales Tax			9.2%	$112,600
	Legal, engineering, and administrative			25%	$305,978
	Contingency			30%	$367,173
	Total				$2,009,660
	Range, low (-25%)				$1,507,245
	Range, high (+50%)				$3,014,490

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing

Cost estimate for Well 14 w/Recycle

(Vendor C - TONKA, 2023) 220 gpm flow rate

Item	Description	Quantity	Units	Unit Price	Total Price
1	Filtration system	1	LS	$313,000	$313,000
2	Installation of filtration system	1	LS	$46,950	$46,950
3	Backwash supply tank and associated systems	1	LS	$94,500	$94,500
4	Backwash reclamation system & pumping	1	LS	$144,750	$144,750
5	Chlorine storage and feed tank, pumping, piping	1	EA	$14,000	$14,000
6	Building (foundation, walls, rooms)	600	SF	$350	$210,000
7	Clearing, grubbing, and grading	1	LS	$7,500	$7,500
8	Treatment building electrical, I&C, and chem feed	1	LS	$20,000	$20,000
9	Treatment building HVAC	1	LS	$8,000	$8,000
10	Miscellaneous yard piping	1	LS	$8,000	$8,000
11	Concrete sidewalks	150	SF	$20	$3,000
12	Site paving	125	SF	$150	$18,750
13	Security fencing	125	LF	$50	$6,250
14	Security gate	1	EA	$5,000	$5,000
15	Site surface restoration	1	LS	$4,000	$4,000
16	Power upgrades, site electrical & Telemetry	1	LS	$65,000	$65,000
17	Miscellaneous signage	1	LS	$800	$800
	Subtotal				$969,500
	Sales Tax			9.2%	$89,194
	Legal, engineering, and administrative			25%	$242,375
	Contingency			30%	$290,850
	Total				$1,591,919
	Range, low (-25%)				$1,193,939
	Range, high (+50%)				$2,387,879

EA = Each, SF = Square feet, LF = Linear foot, LS = Lump sum, Incl. = included in other provided pricing