GRAHAM LAKE IMPROVEMENT DISTRICT
REPORT NUMBER:

PILOT PLANT STUDY

CARTRIDGE FILTRATION AND RESIN ORGANICS TRAP

NOVEMBER 15, 2019 CONFIDENTIAL

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FINAL
CONFIDENTIAL

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ABBREVIATIONS

µg/L	Microgram per litre
ACU	Apparent Colour Unit
AO	Aesthetic Objective
CDWQG	Canadian Drinking Water Quality Guidelines
DBP	Disinfection By-Product
GLID	Graham Lake Improvement District
HAA	Haloacetic Acids
MAC	Maxium Allowable Concentrate
mg/L	Miligram per Litre
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
TCU	Total Colour Unit
THM	Trihalomethanes
TOC	Total Organic Carbon
TSS	total suspended solid
UVT	Ultraviolet Transmittance
WTP	Water Treatment Plant

1 INTRODUCTION

The Graham Lake Improvement District (GLID) is located on Denman Island, BC. They are currently operating a small community water supply system that consists primarily of:

A submerged intake screen in Graham Lake with gravity flow through a pipeline to a WTP.

In the WTP the lake water is treated by:

- Inlet mesh strainer followed by,
- Duplex sand media filtration (without coagulation) followed by,
- Duplex UV reactors for UV disinfection followed by,
- Chlorination with sodium hypochlorite followed by,
- 3,200 L chlorine contact tank followed by,
- Chloramination with liquid ammonium sulphate.

The chloraminated water is then discharged into a 20,000 L clear well from where it is supplied to the water distribution network by distribution pumps.

This treatment is not sufficient to meet the *Canadian Drinking Water Quality Guidelines* (CDWQG) for protozoa treatment, turbidity, and colour based on the historical data. In particular, the treated water experiences elevated disinfection byproducts formation (DBPs) and difficulty in maintaining adequate residual chlorine disinfection due to colour and natural organic matter (NOM) present in the lake source water. The treated water also experiences seasonal elevated turbidity from heavy precipitation runoff into the lake. The Improvement District is committed to provide additional treatment to comply with the CDWQG and the BC Surface Water Treatment Objectives (SWTO) through a rigorous evaluation of the best available treatment technologies to meet the particular challenges of this application. Some of these challenges include; remote island location, small community with limited budget, no sewer connection for disposal of filtration residuals, restricted availability of land requiring small WTP footprint, and high variability in flow demand.

1.1 TECHNOLOGY OVERVIEW

Removal of colour and NOM using an ion exchange resin organics trap was identified as a likely candidate process because of its simplicity, small foot-print, low capital cost and possible low operating cost. The resin organics trap system is almost identical to a common water softener using ion-exchange resin beads inside a fiberglass vessel and water-softener salt brine to periodically regenerate the resin beads. The lake water is passed through the vessel containing the resin beads and the colour & NOM are removed by adsorption onto the resin surface. After several days of operation, the resin surface is regenerated by passing a concentrated salt brine solution through the vessel. The chloride ions in the brine displace the organics from the resin surface and release the captured organics into a waste brine stream. In order to realise the low operating cost of this process, it will be necessary to dispose of this waste brine stream to the ocean (or ocean-side septic field). While this process is highly effective at removing colour and NOM, it will not remove any of the turbidity from water.

For turbidity removal, the common treatment approach is to use coagulation (typically aluminium or iron based salts) followed by some form for filtration to remove the coagulated solids. However, this approach usually generates significant volume of coagulant residuals resulting in high disposal costs for this site. Cartridge filtration is a possible option if the source water contains a low concentration of easily filterable solids, and could offer a process solution that would be very simple, have a small footprint, low capital cost and potentially low operating cost. While Graham Lake is known to have low concentration of solids (turbidity typically ~0.7 NTU and always < 3 NTU), there is no information on the filterability of these solids. The probability of turbidity removal by cartridge filtration is low but since pilot testing of small filter cartridges is quick and relatively low cost it was decided to pilot test cartridge filtration to determine if this simple and low cost option could be viable.

1.2 PILOT SYSTEM DESCRIPTION

A pilot treatment system was constructed by John Wiggle for installation at the GLID WTP and was operated by himself and Craig Williams. The pilot consists of:

— Inlet strainer, 1-1/2” wye strainer with 20 mesh (1/32” or 0.8 mm screen)
— 1st Cartridge filter housing, with nominal 2-1/2” diam. X 10” long cartridge
— 2nd Cartridge filter housing, with nominal 2-1/2” diam. X 10” long cartridge
— Ion Exchange resin cartridge, 2” ID x 32” long, contains 1.65 L of Purolite A860 resin
— 3rd Cartridge filter housing, with nominal 2-1/2” diam. X 10” long cartridge

The pilot system has valves, pressure ports, sample taps and flow rotameters used for operating the pilot and collecting the operating data.

The purpose of the pilot inlet strainer was to capture any large solids debris (leaves, sticks, etc.) and provide an easy access clean-out for any such material. The first stage cartridge filter is intended to provide a roughing (coarse) filtration to remove larger solids particles and prolong the run time of the second stage cartridge filter which is intended to remove smaller particles and prolong the run time of the third stage cartridge filter. The third stage cartridge filter is intended to provide 1 micron absolute filtration as a barrier to passage of *Crypto* & *Giardia*. Use of the 1st and 2nd stage cartridge filters to optimize the run time of the 1 micron absolute cartridge filter is included because the 1 micron absolute filters are relatively expensive and cannot be cleaned but instead must be disposed whereas the nominal rated pleated pre-filters are much lower cost and may be cleanable for multiple re-use. The ion exchange column was supplied after the 2nd cartridge filter because it provides fine filtration sufficient for the resin column.

Figure 1 shows the process flow schematic of the pilot system arrangement. Figure 2 is a picture of the pilot system installed in the WTP (note the IX column is removed for storage and flow direction is right-to-left, mirror of the schematic flow direction).

For this pilot operation, the operation of the cartridge filtration and the operation of the IX resin are intended to be independent and have no effect of each other’s performance. The feed water for the IX column is taken from the second stage cartridge filter simply to provide pre-filtration of this water since the IX pilot column cannot be backwashed (the full-scale IX vessels will require and be provided with ability to be backwashed)

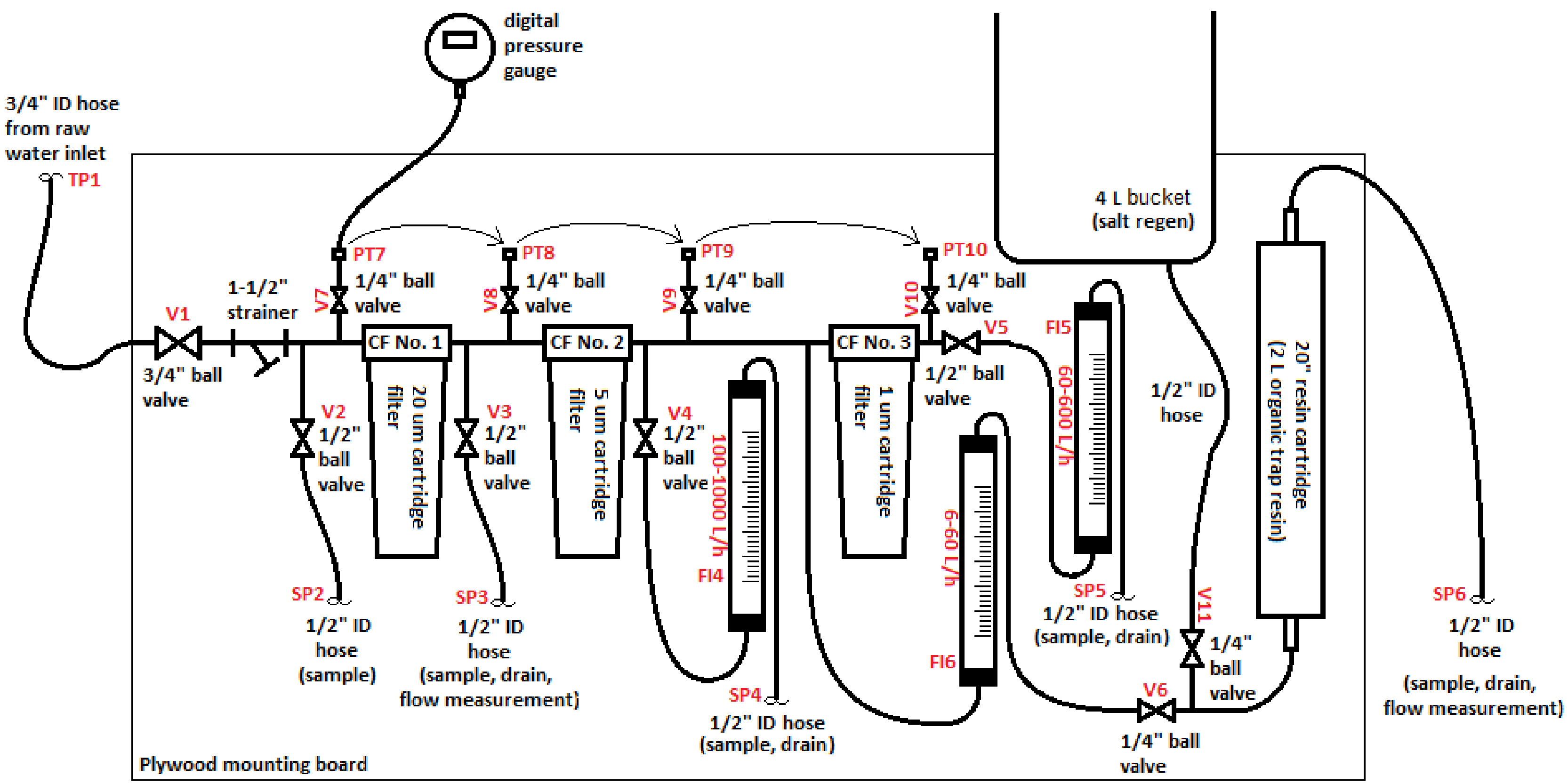

Fig. 1 - Pilot System Arrangement

Figure 1: Pilot System Arrangement

Figure 2: Pilot System Installed in GLID WTP (with IX Column removed for storage)

1.1 OBJECTIVES OF PILOT SYSTEM

The Primary Objectives of the pilot study were to determine:

- Suitability of cartridge filtration to remove turbidity from the Graham Lake source water.
- Suitability of 1 micron absolute cartridge filtration on Graham Lake source water (as a barrier to *Cryptosporidium* and *Giardia* oocysts).
- To determine the applicable run times for cartridge filters (to evaluate the full scale WTP filter cartridges replacement costs).
- To confirm if the cartridge pre-filters can be washed and reused several times (to economize on filter cartridges replacement cost).
- To confirm the applicable cartridge filters filtration rate (to evaluate the full scale WTP number of cartridge filters).
- To confirm anticipated operation of the ion exchange resin; colour and organics removal, run time between regenerations, and effectiveness of regeneration.

— To characterize, through lab analysis, the ion exchange regeneration waste stream to determine if it may be suitable for direct disposal to the sea (or to sea-side septic field).

The cartridge filters are staged so that they can be used to characterise the nature of the Graham Lake source water turbidity such as the particle size distribution and filterability of different particle sizes in the water.

2 PILOT SYSTEM STUDY

The pilot system was installed into the GLID WTP and operation started on the morning of Jan 16, 2019. The initial configuration used a 20 micron nominal pleated cartridge filter followed by a 5 micron nominal pleated cartridge filter flowed by the IX column and 1 micron absolute pleated cartridge filter. The pleated cartridge filters provide surface filtration allowing for the 20 micron and 5 micron nominal cartridge filters to be washed and reused several times for potential savings in the operating costs of a full scale WTP. The cartridge filters where set to run at a fixed flow rate with occasional valve adjustments to keep them at their set flow as they become fouled with solids. The pressure drop through the cartridge filters was recorded to monitor the rate at which they become fouled and determine their applicable capacity for Graham Lake water filtration. The turbidity and colour from each cartridge filter stage was monitored to determine the effectiveness of each filter at removing turbidity (suspended solids). The colour was monitored to confirm that there was no colour removal by cartridge filtration. The cartridge filters were replaced when they were deemed to have reached their solids removal capacity and different types of cartridge filters were tested to try to optimize the system performance (pleated surface filtration vs string-wound depth filtration at various filter micron ratings).

The IX column was run from the pre-filtered water to provide sediment free feed water to the column. The column flow was set to a fixed rate and the treated water from the column was monitored to confirm the organics removal, applicable treatment volume between regenerations, and effectiveness of each regeneration. After the final IX column treatment run, the final regeneration waste brine water was collected, sampled and analysed for the waste water parameters that are applicable to possible permitting for discharge to the ocean.

2.1 CARTRIDGE FILTRATION PILOT RESULTS

2.1.1 20 MICRON NOMINAL PLEATED CARTRIDGE

The pilot system was first operated with a 20 micron nominal pleated cartridge filter in the first stage (CF1) from 16/01/2019 through 28/01/2019. During this operation, the cartridge filter was found to have no measurable increase in pressure drop (no plugging), it did appear to become very dirty (dark brown colour) and the filtered water turbidity increased after passing through it that progressively got worse over time. The absence of any plugging or fouling of this filter is indication that it was not capturing and retaining any significant amount of suspended solids material from the water indicating that the suspended solids are generally smaller than 20 micron in size. The very dirty appearance of dark-brown colour, uniformly covering the filter surface suggests that this dirt is likely organic matter (corroborated by the Raw Water TOC=25 mg/L vs DOC=4.9 mg/L results in Table 8 of this report). The increase in turbidity through the filter also suggests that some particles may break-up into smaller particles as they were forced through the filter pores by the flowing water. This also suggests the larger particles may be soft (decaying) organic matter. The dirty cartridge when removed had a strong 'musty' odour and was easily cleaned with chlorinated water. The 20 micron pleated cartridge filter results are shown in Table 1 below and indicate that there is no benefit to use this type of filter cartridge for pre-filtration of the Graham Lake water supply.

Table 1: 20 Micron Pleated Cartridge Filter (CF1) & 5 Micron Pleated Cartridge Filter (CF2) Results

CF1						CF2					
20 um NOM						5 um NOM					
Date Time	**Q (LPM)**	**SP2 (NTU)**	**SP3 (NTU)**	**V (L)**	**DP (psi)**	**Date Time**	**Q (LPM)**	**SP3 (NTU)**	**SP4 (NTU)**	**V (L)**	**DP (psi)**
16/01/2019 9:02	14.10			0	0.50	16/01/2019 9:02	14.10			0	0.70
16/01/2019 9:10	14.10			113	0.50	16/01/2019 9:10	14.10			113	0.70
16/01/2019 9:50	14.10			677	0.78	16/01/2019 9:50	14.10			677	0.46
16/01/2019 10:45	14.10			1452	0.73						
16/01/2019 10:50	14.10			1523	0.73	16/01/2019 10:50	14.10	2.01	1.81	1523	0.57
16/01/2019 11:12	14.10	1.87	2.01	1833	0.69	16/01/2019 11:40	14.10			2228	0.35
16/01/2019 11:40	14.10			2228	0.64	16/01/2019 13:17	13.70	1.98	1.80	3576	0.37
16/01/2019 13:17	13.70	1.87	1.98	3576	0.67	16/01/2019 14:30	14.00			4587	0.51
16/01/2019 14:30	14.00			4587	0.51	16/01/2019 19:09	13.94			8485	0.48
16/01/2019 19:09	13.94	1.91		8485	0.55	17/01/2019 9:01	12.19		1.82	19355	0.36
17/01/2019 9:01	12.19	2.38		19355	0.56	17/01/2019 10:00	13.98			20127	0.62
17/01/2019 10:21	13.98			20401	0.60	17/01/2019 10:21	13.98			20420	0.55
17/01/2019 13:27	11.00			22724	0.48	17/01/2019 13:27	11.00			22743	0.42
17/01/2019 21:00	11.00	2.00	1.94	27707	0.48	17/01/2019 21:00	11.00	1.94	1.89	27726	0.34
18/01/2019 9:00	10.95	2.31	3.60	35607	0.42	18/01/2019 9:00	10.95	3.60	2.11	35627	0.37
18/01/2019 21:00	10.74	2.35	3.30	43414	0.34	18/01/2019 21:00	10.74	3.30	2.55	43433	0.67
18/01/2019 21:37	10.94			43815	0.57	18/01/2019 21:37	10.94			43834	0.48
19/01/2019 9:00	10.80	1.92	1.80	51238	0.49	19/01/2019 9:00	10.80	1.80	1.76	51258	0.36
19/01/2019 9:18	10.80			51432	0.02	19/01/2019 9:18	10.80			51453	0.70
19/01/2019 9:56	11.20			51850	0.31	19/01/2019 9:56	11.20			51871	0.44
19/01/2019 13:47	11.05			54420	0.43	19/01/2019 13:47	11.05			54441	0.77
19/01/2019 20:49	10.95	1.98	2.19	59061	0.46	19/01/2019 20:49	10.95	2.19	1.87	59082	0.64
20/01/2019 9:08	10.95	1.85	3.79	67151	0.53	20/01/2019 9:08	10.95	3.79	1.99	67172	0.76
Average		**2.04**	**2.58**								
Replace 20 um NOM											
20/01/2019 10:13	10.95			0	0.38	20/01/2019 10:13	10.95			67883	0.51
20/01/2019 20:53	10.90	1.84	2.78	6990	0.32	20/01/2019 20:53	10.90	2.78	1.73	74874	0.89
20/01/2019 21:07	11.15			7145	0.42	20/01/2019 21:07	11.15			75028	0.85
21/01/2019 9:10	10.60	1.90	1.93	15006	0.51	21/01/2019 9:10	10.60	1.93	1.85	82889	0.87
21/01/2019 9:23	10.89			15145	1.21	21/01/2019 9:23	10.89			83029	0.86
21/01/2019 21:00	10.89	1.92	2.30	22736	0.43	21/01/2019 21:00	10.89	2.30	2.02	90619	1.18
22/01/2019 9:05	10.79	1.91	3.44	30595	0.22	22/01/2019 9:05	10.79	3.44	1.82	98478	1.27
22/01/2019 20:02	10.59	2.06	2.59	37618	0.34	22/01/2019 20:02	10.59	2.59	2.14	105501	1.32
22/01/2019 9:00	10.58	2.07	2.66	30612	0.47	23/01/2019 9:00	10.58	2.66	2.09	113734	1.56
23/01/2019 9:20	11.00			46362	0.45	23/01/2019 9:20	11.00			113950	1.52
23/01/2019 20:30	10.35	1.85	2.25	53514	0.34	23/01/2019 20:30	10.35	2.25	2.27	121102	1.82
24/01/2019 9:05	9.50	1.71	1.93	61008	0.30	24/01/2019 9:05	9.50	1.93	1.67	128596	1.98
24/01/2019 20:40	9.22	1.72	1.79	67511	0.43	24/01/2019 20:40	9.22	1.79	1.62	135099	1.35
25/01/2019 9:16	9.09	1.78	3.97	74429	0.50	25/01/2019 9:16	9.09	3.97	2.56	142017	2.28
Average		**1.88**	**2.56**				Average	**2.57**	**1.97**		

From 25/01/2019 through 28/01/2019, CF1 cartridge was replaced with the washed 20 micron pleated cartridge and was allowed to run down to a low flow rate (as a result of full plugging of the CF3 filter discussed later in this report). It was found that even at greatly reduced flow rate, there was no improvement in turbidity through the 20 micron filter suggesting that the solids passing through are likely highly shear sensitive (easily broken down into smaller particles).

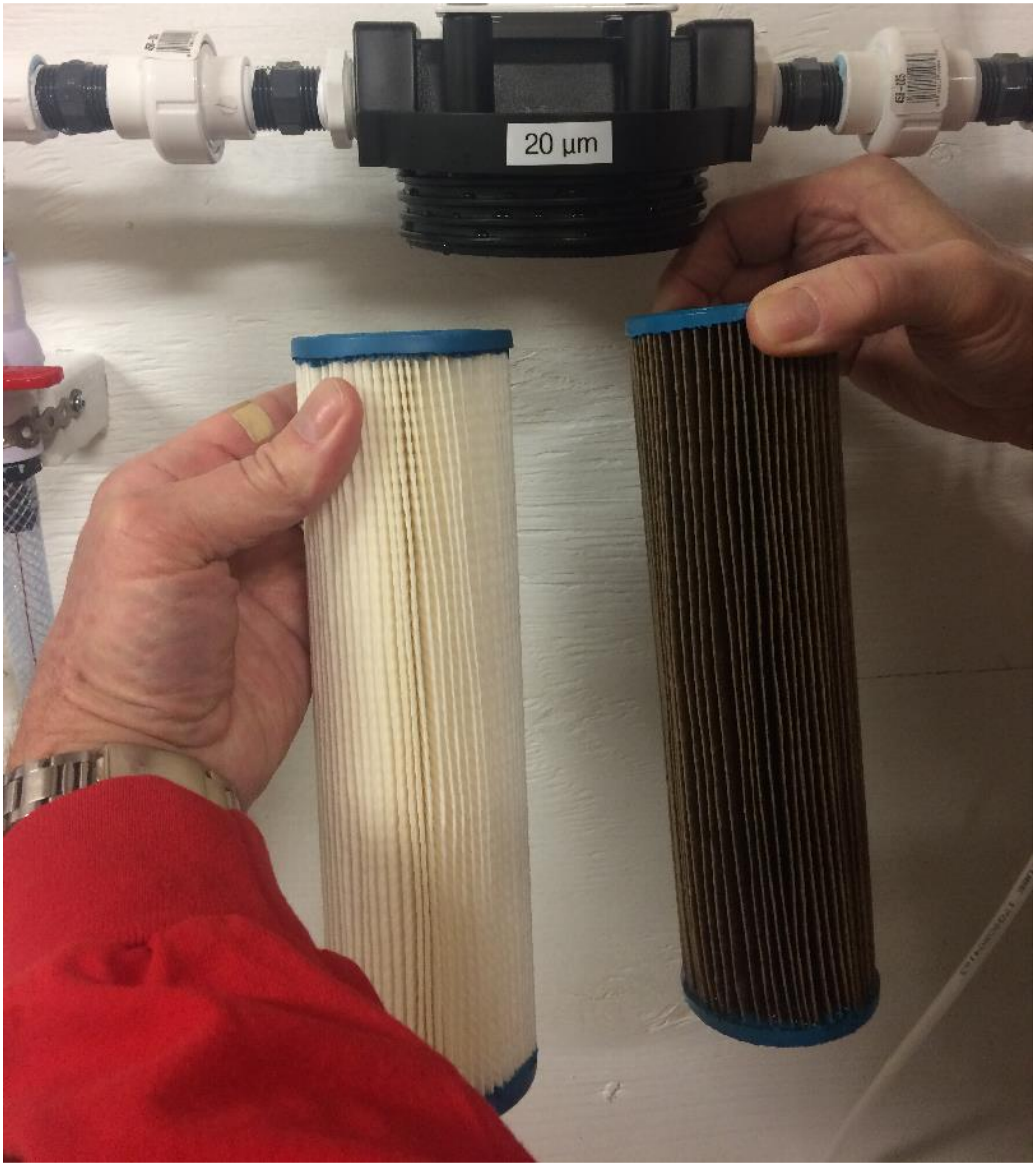

Figure 3: 20 Micron Cartridge (clean vs dirty)

2.1.2 5 MICRON NOMINAL PLEATED CARTRIDGE

The initial pilot operation was with a 5 micron nominal pleated cartridge filter in the second stage (CF2) from 16/01/2019 through 25/01/2019. During this operation, this cartridge filter was found to have only a very gradual increase in pressure drop (minimal plugging), and appeared to become dirty (dark brown colour) but much less so than the 20 micron. This cartridge presented a consistent but marginal reduction in turbidity. The minor plugging or fouling and marginal turbidity removal of this filter is indication that it was not capturing and retaining any significant amount of suspended solids material from the water suggesting that most of the suspended solids are smaller than 5 micron in size. The 5 micron pleated cartridge filter results are shown with the 20 micron cartridge results in Table 1 above and indicate that there is no benefit to use of this type of filter cartridge for pre-filtration of the Graham Lake water supply.

2.1.3 1 MICRON NOMINAL SPUN-WOUND DEPTH CARTRIDGE

After discovery that the 20 micron and 5 micron cartridge filters were ineffective at retaining captured solids, they were replaced with 1 micron nominal depth filtration cartridges (spun-wound polypropylene). The second stage cartridge (CF2) was replaced first and run with the cleaned 20 micron cartridge in CF1 from 25/01/2019 through 28/01/2019 in front of CF2. As indicated in Table 2 below, during this run the 1 micron nominal depth cartridge had no measurable increase in pressure drop and only marginal reduction of turbidity (similar results as the 5 micron cartridge).

Table 2: 20 Micron Pleated Cartridge Filter (CF1) with 1 Micron Depth Cartridge Filter (CF2) Results

CF1							CF2					
Cleaned 20 um NOM							New 1 um NOM					
Date Time	Q (LPM)	SP2 (NTU)	SP3 (NTU)	V (L)	DP (psi)		Date Time	Q (LPM)	SP3 (NTU)	SP4 (NTU)	V (L)	DP (psi)
25/01/2019 10:07	8.00			0			25/01/2019 10:07	8.00			0	0.00
25/01/2019 10:54	7.94	2.06	1.84	375	0.17		25/01/2019 10:54	7.94	1.84	1.59	375	0.29
25/01/2019 14:05	8.12	1.76	2.97	1908	0.28		25/01/2019 14:05	8.12	2.97	1.58	1908	0.22
25/01/2019 14:17	8.10			2006			25/01/2019 14:17	8.10			2006	0.00
25/01/2019 19:04	7.91	1.66	2.27	4302	0.31		25/01/2019 19:04	7.91	2.27	1.52	4302	0.10
25/01/2019 21:30	7.50			5426	0.14		25/01/2019 22:03	7.50	2.23	1.79	5680	0.20
25/01/2019 22:03	7.50	1.61	2.23	5674	0.10		26/01/2019 9:24	7.50	2.94	1.73	10786	0.26
26/01/2019 9:24	7.50	1.71	2.94	10779	0.02		26/01/2019 10:09	8.10			11137	0.00
26/01/2019 20:40	8.20	1.76	1.84	16083	0.18		26/01/2019 20:40	6.70	1.84	1.67	15803	0.29
27/01/2019 9:10	5.35	1.53	2.83	21160	0.26		27/01/2019 9:10	5.35	2.83	1.62	20318	0.08
27/01/2019 21:00	4.19	1.82	1.96	24545	0.16		27/01/2019 21:00	4.19	1.96	1.77	23703	0.15
28/01/2019 9:04	3.61	1.69	2.66	27369	0.14		28/01/2019 9:04	3.61	2.66	1.40	26527	0.09
Average		**1.73**	**2.39**					Average	**2.39**	**1.63**		

As can be seen in Figure 4 below, the 1 micron depth filtration cartridge started to become dirty, collecting some dark material on its outer surface while Figure 5 shows that it appears to have rather consistent dirt penetration through the depth of the cartridge.

Figure 4: 1 Micron Depth Cartridge Surface (28/01/2019)

Figure 5: 1 Micron Depth Cartridge Dirt Penetration (28/01/2019)

Table 3 shows the results from 28/01/2019 through 30/01/2019 where the CF1 and CF2 cartridges were run at high flow rate with 1 micron absolute depth filtration cartridges in both filter housings. At this high flow rate it was found that the first stage filter (CF1) showed a moderate rate of increasing pressure drop (plugging) indicating that it was capturing some solids but it still resulted in an increase in turbidity suggesting larger particles break-up and passage similar to the 20 micron cartridge. The second stage (CF2) 1 micron depth cartridge had no measurable plugging and moderate turbidity removal similar to the results of the 5 micron cartridge. This indicates that the turbidity is from particles primarily smaller than 1 micron size. Figures 6 and 7 below shows the dirty 1 micron nominal depth cartridges taken from the first stage (CF1) and second stage (CF2) filters (respectively). The dark brown dirt on the outside surface of the first stage filter appears to be indicative of organic matter.

Table 3: 1 Micron Depth Cartridge Filter (CF1) with 1 Micron Depth Cartridge Filter (CF2) Results

CF1						CF2					
Used 1 um NOM						New 1 um NOM					
Date Time	**Q (LPM)**	**SP2 (NTU)**	**SP3 (NTU)**	**V (L)**	**DP (psi)**	**Date Time**	**Q (LPM)**	**SP3 (NTU)**	**SP4 (NTU)**	**V (L)**	**DP (psi)**
28/01/2019 10:35	8.10			0	0.26	28/01/2019 10:35	8.10			0	0.38
28/01/2019 13:46	8.13			1549	0.29	28/01/2019 13:46	8.13			1549	0.11
28/01/2019 13:56	8.10			1631	0.29	28/01/2019 13:56	8.10			1631	0.00
28/01/2019 14:00	8.00	1.65	2.03	1663	0.34	28/01/2019 14:00	8.10	2.03	1.49	1663	0.00
28/01/2019 20:44	8.00	1.66	4.36	4895	0.34	28/01/2019 20:44	8.00	4.36	2.24	4915	0.22
29/01/2019 9:10	7.39			10635	0.82	29/01/2019 9:10	7.39			10656	0.02
29/01/2019 9:18	8.00	<--- Re-adjust		10697	0.77	29/01/2019 9:18	8.00			10717	0.20
29/01/2019 9:30	8.00	1.67	2.51	10793	0.78	29/01/2019 9:30	8.00	2.51	1.41	10813	0.00
29/01/2019 20:50	6.89	1.75	1.61	15855	1.11	29/01/2019 20:50	6.89	1.61	1.53	15876	0.14
29/01/2019 21:42	7.89			16240	1.14	29/01/2019 21:42	7.89			16260	0.00
30/01/2019 9:14	7.89	1.79	1.57	21700	1.57	30/01/2019 9:14	7.89	1.57		21720	-0.01
Average		**1.70**	**2.42**			Average		**2.42**	**1.67**		

Figure 6: 1 Micron Depth Cartridge Surface (from CF1, 30/01/2019)

Figure 7: 1 Micron Depth Cartridge Surface (from CF2, 30/10/2019)

From 30/01/2019 through 02/02/2019 the pilot was again operated using 1 micron depth filtration cartridges in both the first stage (CF1) and second stage (CF2) filters, however this time they were run at a significantly reduced filtration flow rate. As seen in Table 4 below, the increase in pressure drop (plugging) of the filters could not be determined at this low flow rate but it was found that there was no significant change in turbidity through both stages indicating that there is minimal capture of the suspended solids that are generally smaller than 1 micron in size.

Table 4: 1 Micron Depth Cartridge Filter (CF1) with 1 Micron Depth Cartridge Filter (CF2) Results

CF1							CF2					
Used 1 um NOM							New 1 um NOM					
Date Time	**Q (LPM)**	**SP2 (NTU)**	**SP3 (NTU)**	**V (L)**	**DP (psi)**		**Date Time**	**Q (LPM)**	**SP3 (NTU)**	**SP4 (NTU)**	**V (L)**	**DP (psi)**
30/01/2019 9:50	2.30	2.12	2.24	0	-0.03		30/01/2019 9:50	2.30	2.24	1.72	0	-0.07
30/01/2019 14:30	2.29	1.63	1.51	641	-0.04		30/01/2019 14:30	2.29	1.51	1.76	641	-0.23
30/01/2019 21:00	2.28	1.50	1.46	1530	0.07		30/01/2019 21:00	2.28	1.46	1.39	1530	0.31
30/01/2019 21:15	2.40			1565	0.08		30/01/2019 21:15	2.40			1565	0.00
31/01/2019 9:00	2.35	1.55	1.45	3238	0.37		31/01/2019 9:00	2.35	1.45	1.29	3238	-0.25
31/01/2019 20:50	2.29	1.50	1.69	4884	-0.18		31/01/2019 20:50	2.29	1.69	1.47	4884	0.18
31/01/2019 9:40	2.16	1.49	1.58	3393	0.31		31/01/2019 9:40	2.16	1.58	2.00	3393	-0.04
1/02/2019 10:00	2.40			6722	0.32		1/02/2019 10:00	2.40			6722	0.00
1/02/2019 20:30	2.25	1.77	1.85	8186	0.32		1/02/2019 20:30	2.25	1.85	1.78	8186	-0.13
2/02/2019 9:15	1.95	1.64	1.51	9791	0.34		2/02/2019 9:15	1.95	1.51	1.44	9791	0.25
Average		**1.65**	**1.66**					Average	**1.66**	**1.61**		

2.1.4 0.5 MICRON NOMINAL STRING-WOUND DEPTH CARTRIDGE

From 02/02/2019 through 11/02/2019 the first and second stage filters were run using 0.5 micron nominal depth filtration cartridges (string wound polypropylene). From 02/02/2019 through 06/02/2019 they were run at high flow rate and the first stage filter (CF1) did not exhibit any increase in turbidity (same as the 20 micron or 1 micron depth filtration cartridges at similar flow rate) and only developed a very gradual increase in pressure drop (plugging), while the second stage filter (CF2) provided a marginal reduction in turbidity and only very slight increase in pressure drop. Figures 8, 9 and 10 below show the dirt build-up in the CF1 filter during this run, while CF2 remained quite clear indicating that these filters are effective at capturing the organic solids material while any dissolved organic matter is able to freely pass through them.

Figure 8: CF1, 2 & 3 (06/02/2019)

Figure 9: CF 1 (06/02/2019)

Figure 10: CF 1 (06/02/2019)

New 0.5 micron depth cartridge filters were installed and run from 06/02/2019 through 11/02/2019 at their maximum design filtration flow rate and were found to have the same performance as compared to their previous lower flow rate run. Table 5 below shows the results of these two filter runs showing a high filtration volume and high achievable filtration flow rate but only very slight reduction in turbidity.

Table 5: 0.5 Micron Depth Cartridge Filter (CF1) & 0.5 Micron Depth Cartridge Filter (CF2) Results

CF1							CF2					
New 0.5 um NOM							New 0.5 um NOM					
Date Time	**Q (LPM)**	**SP2 (NTU)**	**SP3 (NTU)**	**V (L)**	**DP (psi)**		**Date Time**	**Q (LPM)**	**SP3 (NTU)**	**SP4 (NTU)**	**V (L)**	**DP (psi)**
2/02/2019 10:00	7.90	1.57	1.65	0	0.30		2/02/2019 10:00	7.90	1.65	1.51	0	0.53
2/02/2019 20:45	7.60	1.73	1.61	4999	0.73		2/02/2019 20:45	7.60	1.61	1.53	4999	0.55
3/02/2019 9:00	7.70	1.59	1.59	10620	0.79		3/02/2019 9:00	7.70	1.59	1.53	10620	0.67
3/02/2019 21:05	7.54	1.60	1.78	16142	0.77		3/02/2019 21:05	7.54	1.78	1.52	16142	0.97
4/02/2019 9:10	7.49	1.63	1.53	21589	1.21		4/02/2019 9:10	7.49	1.53	1.44	21589	0.85
5/02/2019 8:55	7.34	1.67	1.76	32148	1.53		5/02/2019 8:55	7.34	1.76	1.49	32148	0.98
5/02/2019 9:40	7.70			32486	1.55		5/02/2019 9:40	7.70			32486	0.98
5/02/2019 20:20	7.55	1.80	1.71	37365	1.91		5/02/2019 20:20	7.55	1.71	1.49	37365	1.03
6/02/2019 9:00	7.10	1.71	1.59	42928	2.04		6/02/2019 9:00	7.10	1.59	1.48	42928	1.07
6/02/2019 9:30	7.40			43145	2.07		6/02/2019 9:30	7.40			43145	1.06
6/02/2019 20:00	7.09	1.71	1.64	47708	2.66		6/02/2019 20:00	7.09	1.64	1.66	47708	0.91
Average		**1.67**	**1.65**					Average	**1.65**	**1.52**		
New 0.5 um NOM							New 0.5 um NOM					
Date Time	**Q (LPM)**	**SP2 (NTU)**	**SP3 (NTU)**	**V (L)**	**DP (psi)**		**Date Time**	**Q (LPM)**	**SP3 (NTU)**	**SP4 (NTU)**	**V (L)**	**DP (psi)**
6/02/2019 21:05	13.81	1.76	1.61	0	1.32		6/02/2019 21:05	13.81	1.61	1.58	0	0.93
7/02/2019 9:10	13.51	1.58	1.66	9900	1.65		7/02/2019 9:10	13.51	1.66	1.48	9900	1.10
7/02/2019 20:50	13.20	1.73	1.61	19247	1.74		7/02/2019 20:50	13.20	1.61	1.60	19247	1.21
8/02/2019 9:00	12.40	1.58	1.59	28589	2.00		8/02/2019 9:00	12.40	1.59	1.45	28589	1.24
8/02/2019 11:22	13.50			30427	2.26		8/02/2019 11:22	13.50			30427	1.32
8/02/2019 11:35	13.39	1.14		30602	2.25		8/02/2019 11:35	13.39			30602	1.22
8/02/2019 20:20	13.39	1.72	1.61	37632	2.63		8/02/2019 20:20	13.39	1.61	1.41	37632	1.01
9/02/2019 9:05	12.67	1.44	1.43	47600	3.31		9/02/2019 9:05	12.67	1.43	1.47	47600	1.37
9/02/2019 9:45	13.40			48121	3.35		9/02/2019 9:45	13.40			48121	1.37
9/02/2019 20:30	12.69	1.65	1.52	56534	4.07		9/02/2019 20:30	12.69	1.52	1.42	56534	1.29
10/02/2019 9:10	11.87			65866	4.61		10/02/2019 9:10	11.87			65866	1.20
10/02/2019 9:25	13.50	1.65	1.94	66057	4.64		10/02/2019 9:25	13.50	1.94	1.53	66057	1.20
11/02/2019 8:50	11.47			83591	7.42		11/02/2019 8:50	11.47			83591	1.41
11/02/2019 9:10	13.50	1.75	1.58	83841	#####		11/02/2019 9:10	13.50	1.58	1.59	83841	1.41
Average		**1.60**	**1.62**					Average	**1.62**	**1.50**		

2.1.5 1 MICRON ABSOLUTE SURFACE FILTRATION CARTRIDGE

The entire pilot operation was performed with 1 micron absolute pleated (surface filtration) cartridge filters in the third stage (CF3). The intent of the 1 micron absolute filtration is to provide a barrier to prevent passage of particles larger than *Cryptosporidium* or *Giardia* oocysts which are known to be larger than 3 micron in size. The 1 micron absolute filtration would provide confidence that no oocysts could evade the following UV disinfection while being shielded (coated in solids).

A total of ten (10) 1 micron absolute cartridge filters where used during the pilot testing. Each filter cartridge was allowed to run until maximum pressure drop was reached and its flow rate could not be maintained by further opening its discharge valve (i.e. it reached terminal filter plugging). Figure 11 below shows the results of each of the 1 micron absolute filter runs identifying the different types of cartridge pre-filtration applied in CF1 and CF2 during each run. The plots indicate the 1 micron absolute filter pressure drop (plugging) VS the cumulative volume of water filtered through it. The plots in Figure 11 provides clear indication of the relative ability of the different types of pre-filters to provide protection for the expensive 1 micron absolute filters from premature plugging and extend its filtration run volume.

There were four (4) runs of 1 micron absolute filter performed using the 20 micron filter in CF1 and 5 micron filter in CF2. One run was done at high filtration flow rate of about 5 LPM while the other three were done at reduced flow rate of about 2 LPM, showing no significant difference in performance based on the filtration flow rate. All four of these runs showed consistent results with fairly rapid filter plugging reaching about 10 psid after filtering only about 5500 to 6000 L of water.

There was one (1) run of 1 micron absolute filter performed with the 20 micron filter in CF1 and 1 micron nominal depth filtration cartridge in CF2 resulting in moderately improved filtration capacity of the 1 micron absolute filter to about 8000 L filtrate at 10 psid.

There were two (2) runs performed with the 1 micron nominal depth filtration cartridge in both CF1 and CF2 resulting in a marginal further increase in filtration capacity of the 1 micron absolute filter to about 9000 L filtrate at 10 psid. (Note: the green plot line was run at high filtration flow rate of about 5 LPM and the brown plot line at low flow rate of about 2 LPM which presented one erroneous value at about 4000 L volume).

Finally there were three (3) runs with the 0.5 micron nominal depth filtration cartridges in both CF1 and CF2, one run at reduced flow rate of about 2 LPM and two at high flow rate of about 5 LPM. These runs resulted in the best protection for the 1 micron absolute filter (i.e. highest filtration volume achieved at about 12000 L or more at 10 psid).

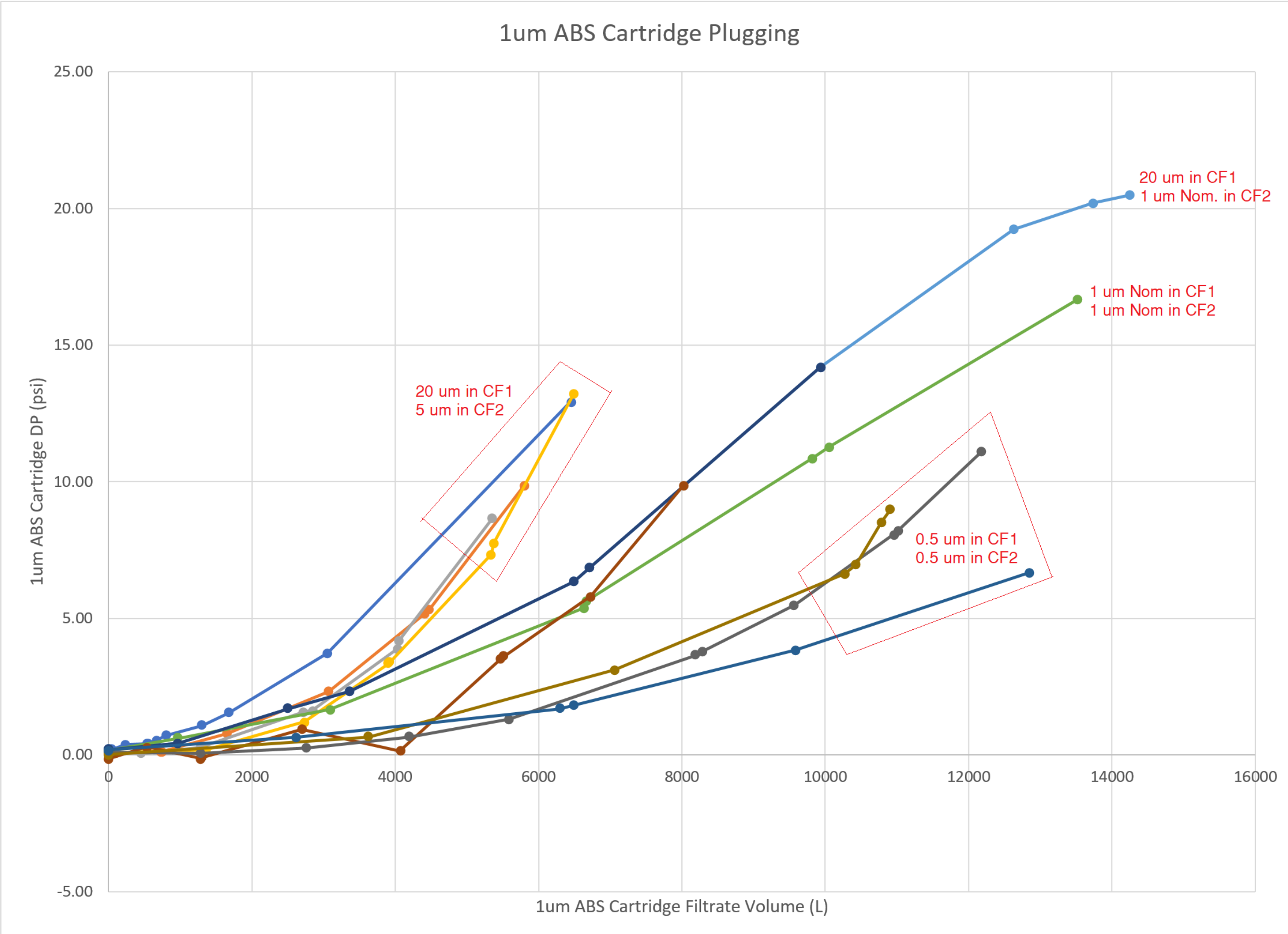

Figure 11: 1 Micron absolute cartridge filter plugging VS volume of water filtered

Table 6 below shows the average turbidity measurements taken across the 1 micron absolute filters during each of their filter runs. During operation using the 20 micron and 5 micron pre-filters, the 1 micron absolute filters were found to have the highest turbidity removal (from 30% to 42%) which agrees with their resultant corresponding shorter run length (faster plugging), because more solids were passing through the pre-filters filters as compared to using the 0.5 micron nominal depth filtration cartridges in CF1 and CF2. For this run, the 1 micron absolute filters experienced the lowest turbidity removal (from 19% to 30%) with corresponding longest run time. However, the important result from the operations of the cartridge filtration piloting is that regardless of the cartridge filter types and pore size used, the cartridge filtration was unable to reduce the water turbidity to below about 1.1 to 1.2 NTU, indicting that the source of the turbidity is appreciably due to solids particles that are smaller than 0.5 micron in size.

Table 6: 1 Micron Absolute Cartridge Filter (CF3) Turbidity Removal Results

DATE & TIME	SP4 AVG (NTU)	SP5 AVG (NTU)	% TURB. REDUCTION
CF1 = 20 um pleated, CF2 = 5 um pleated			
16/01/2019 9:02 to 17/01/2019 9:01	**1.81**	**1.27**	30
17/01/2019 10:00 to 19/01/2019 9:18	**2.08**	**1.26**	39
19/01/2019 9:56 to 21/01/2019 9:10	**1.86**	**1.28**	31
21/01/2019 9:23 to 25/01/2019 9:16	**2.02**	**1.18**	42
CF1 = 20 um pleated, CF2 = 1 um depth			
25/01/2019 10:54 to 28/01/2019 9:04	**1.63**	**1.21**	26
CF1 = 1 um depth, CF2 = 1 um depth			
28/01/2019 10:35 to 30/01/2019 9:14	**1.67**	**1.17**	30
30/01/2019 9:50 to 2/02/2019 9:15	**1.61**	**1.11**	31
CF1 = 0.5 um depth, CF2 = 0.5 um depth			
2/02/2019 10:00 to 6/02/2019 20:00	**1.52**	**1.23**	19
6/02/2019 21:05 to 8/02/2019 11:22	**1.53**	**1.24**	19
8/02/2019 11:35 to 10/02/2019 9:10	**1.43**	**1.15**	20
10/02/2019 9:25 to 13/02/2019 20:24	**1.57**	**1.10**	30
13/02/2019 21:00 to 15/02/2019 9:30	**1.44**	**1.15**	20

2.1.6 CARTRIDGE FILTRATION EFFECTS ON OTHER PARAMETERS

The cartridge filtration pilot results showed no change in the water pH passing through the filter cartridges as expected. There was a slight increase in apparent colour of the water passing through the 20 micron filter which agrees with its corresponding increase in turbidity due to possible break-up of organic particles. The 1 micron absolute cartridge filters provided a consistent slight reduction in apparent colour suggesting there was some small amount of organics solids removed, however, there was no appreciable change in the UVT or dissolved organics measurements, indicating that the cartridge filters did not retain any dissolved organics as expected. Figure 12 shows the dirty 1 micron absolute cartridge filter removed after its run ending on 21/01/2019 with a clean replacement filter next to it.

Figure 12: Dirty vs clean 1 micron absolute cartridge filter after run ending 21/01/2019

2.2 ION EXCHANGE RESIN PILOT RESULTS

The ion exchange resin was operated throughout the pilot testing period using water pre-filtered by cartridge filtration through CF1 and CF2. During piloting the IX resin was regenerated with brine salt solution four times (for a total of 4 water treatment runs). The IX resin was not expected to provide any significant reduction in turbidity as the water channel open path between the resin beads is orders of magnitude larger than the micron pore size of the cartridge filters. Individual measurements of the inlet to outlet turbidity through the IX column had a very high degree of variability (from +50% to -50% removal) with no apparent pattern over each IX run. However, the overall averages of the IX column inlet to outlet turbidity presents a fairly consistent and slight improvement in turbidity which could possibly be attributed to some small amount of charged solids particles adhering to the oppositely charged resin surface.

Table 7: IX column averaged turbidity results

DATE & TIME	SP4 AVG (NTU)	SP5 AVG (NTU)	% TURB. REDUCTION
New IX resin first run			
16/01/2019 13:17 to 25/01/2019 9:16	**1.98**	**1.67**	16
Regenerated IX resin with brine			
25/01/2019 10:54 to 8/02/2019 11:22	**1.59**	**1.42**	11
Regenerated IX resin with brine			
8/02/2019 11:35 to 15/02/2019 9:30	**1.49**	**1.30**	13
Regenerated IX resin with brine			
15/02/2019 17:30 to 22/02/2019 8:10	**1.41**	**1.27**	10

The UV transmittance of the water entering and leaving the IX column was measured and recorded at regular intervals. The UVT provides an indication of the level of dissolved organics in water because the organics will cause the water to absorb UV light of 254 nm wavelength. Water containing a low concentration of organics will have higher UVT measurements. Figure 13 shows a plot of the % UVT of the water entering the IX column and the water leaving the IX for the four IX column runs between its regenerations.

The IX column influent water showed consistent measurements with a slight general improvement from about 58% UVT at the start of the piloting to about 61% UVT by the end of the piloting. This slight improvement in the influent UVT is likely due to natural variation in the Graham Lake source water concentration and/or type of organics and is not expected to have any impact on the IX piloting results.

The results of the IX column treated effluent water generally shows the expected trend where there is very high UVT (ie. organics removal) immediately after starting its run after regeneration (or new media), followed by reducing rate of decline in UVT as the run continues (i.e. as the IX media becomes more loaded with the organics being removed).

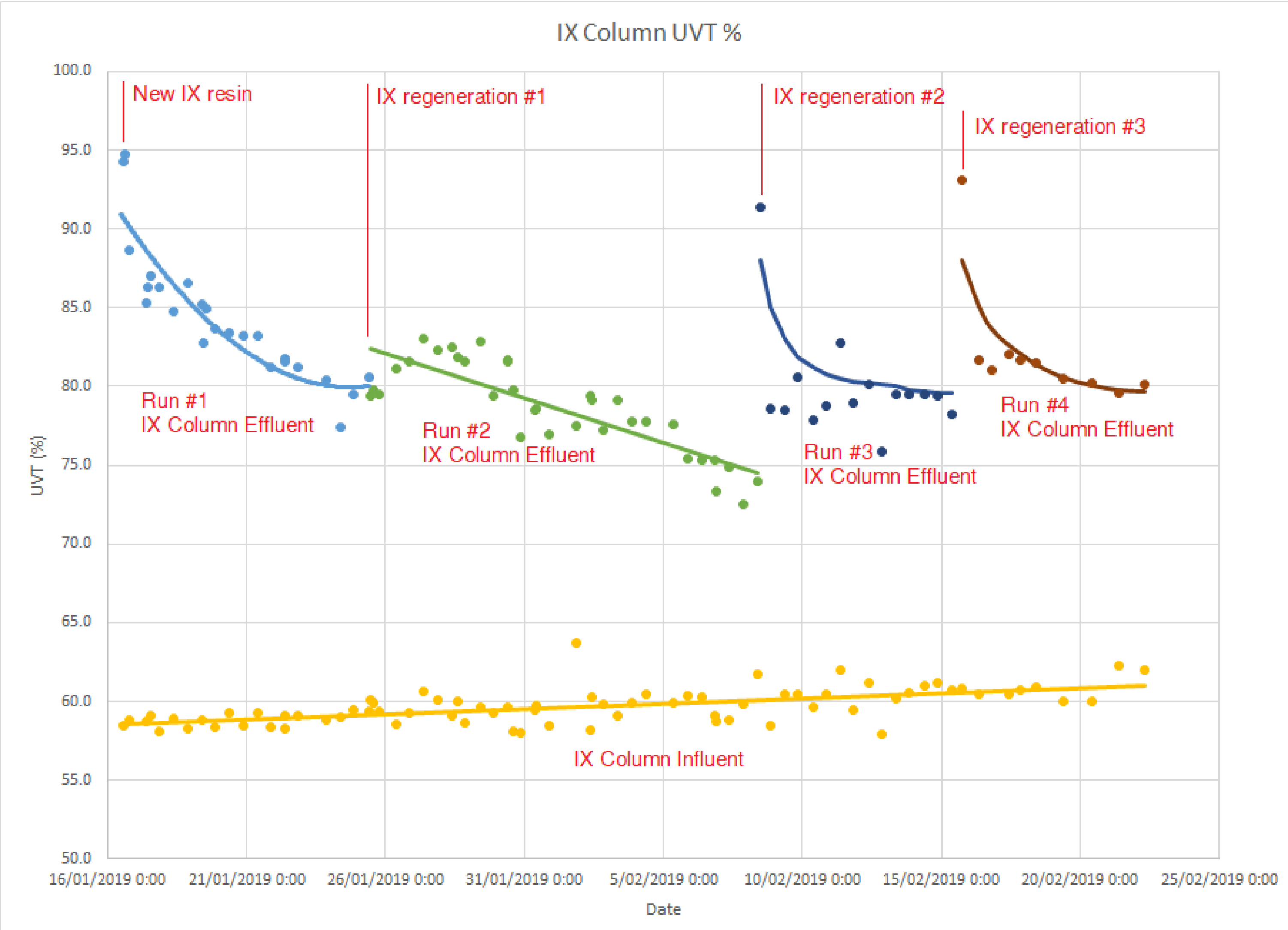

Figure 13: IX column influent and effluent water UVT VS pilot running time

One exception to this trend is the second run which appears to follow a more linear drop in discharge UVT. A possible reason for this difference is that the 1st and 2nd IX column runs were allowed to continue for longer than the IX resin's design treatment capacity (and thus degrading the organics removal from the 2nd run). The anticipated treatment capacity of the IX column for the Graham Lake source water is estimated to be about 4,000 L whereas the volume treated during the four pilot runs were; run #1 = 5270 L, run #2 = 7680 L, run #3 = 4010 L and run #4 = 3760 L. The 3rd and 4th run were shortened and represented the expected IX performance for its discharge UVT. In all cases the IX column treated water had UVT greater than the 70% value required for validation of UV disinfection, and for runs #1, #3 and #4 had treated UVT values generally greater than about 80%, suggesting good organics removal.

During each of the IX column runs, the pH of the treated effluent was found to follow the expected trend as shown in Figure 14 below. Immediately after regeneration, the IX column effluent has a significant drop in pH as the IX resin readily adsorbs both organics as well as alkalinity ions. As the run progresses, the effluent pH increases as the resin becomes loaded with organics and alkalinity. And nearing the end of each IX column run, the pH of the effluent actually exceeds the influent water pH due to the affinity of the resin for organics which results in the resin releasing some of the alkalinity as the previously adsorbed alkalinity gets exchanged with the more readily adsorbed organic molecules. A slight general increase in the influent pH is likely due to natural variation in the Graham Lake source water and correlates well with the corresponding general increase in the source water UVT over the pilot operation period.

The decrease in IX column pH is expected to result in a corresponding increase in the treated water corrosion potential and will need to be addressed in a full scale WTP system. Corrosion control could be easily provided by pH correction using a simple calcite contactor or by dosing of caustic soda or a liquid hydrated lime suspension.

Water samples were taken to compare laboratory analysis of drinking water parameters from the Graham Lake source water and the IX column treated water at two separate times. The first sample time (16/01/2019 at about 2 pm) provides results of the IX performance after about only two hours into its first run (i.e. new IX media, newly regenerated), and the second sample time (20/02/2019 at about 9 am) provides results of the IX performance after about 2/3 of the way through its run #4. Table 8 below shows the results of some of the parameters of interest for these two sample times.

For the primary intention of removal of colour and organics, the newly regenerated IX provided very high levels of organics removal with the IX treated water having colour and organics below the laboratory's detection limits. After 2/3 of the IX columns fourth run, the treated water still had organics removal of nearly 70%. Of interest to note is the newly regenerated IX had aggressive removal of alkalinity, bicarbonate, sulphate, nitrate and some metals by replacing those ions with exchange of chloride ions from the resin surface. However, after 2/3 of its run, removal of alkalinity, bicarbonate and metals are not nearly as predominate with much lower increase in chloride.

Table 8: IX Column Feed Water and Treated Water Laboratory Analysis Results

GLID Pilot Results		16/01/2019	16/01/2019		20/02/2019	20/02/2019
Parameter	**Units**	Raw Water	IX Effluent		Raw Water	IX Effluent
True Colour	Col.Unit	35.6	<5.0		31.2	18.1
UV Transmittance (at 254nm)	%T/cm	59.7	97.4		61.6	80.6
Dissolved Organic Carbon (C)	mg/L	4.9	<0.50		4.8	1.5
Total Organic Carbon (C)	mg/L	25	<0.50			
Total Aluminum (Al)	ug/L	128	66.6		122	123
Total Asenic (As)	ug/L	0.16	<0.10		0.14	<0.10
Total Copper (Cu)	ug/L	0.65	<0.50		0.67	<0.50
Total Iron	ug/L	215	61		203	161
Total Hardness (CaCO3)	mg/L	16.7	15.7		16.4	16.0
Nitrate (N)	mg/L	0.37	<0.020		0.329	0.069
Alkalinity (Total as CaCO3)	mg/L	14.5	<1.0		15.2	13
Bicarbonate (HCO3)	mg/L	17.7	<1.0		18.6	15.9
Disolved Sulphate (SO4)	mg/L	1.7	<1.0		1.5	<1.0
Disolved Chloride (Cl)	mg/L	8.6	26		8.1	13
Total Dissolved Solids	mg/L	56	68		50	48
Total Calcium (Ca)	mg/L	4.32	3.95		4.27	4.13

THM formation potential and chlorine demand were tested for the second sample (2/3 of run #4) with results of total THMs = 210 µg/L and chlorine demand = 2.2 mg/L. The THM potential is greater than the drinking water limit of 100 ug/L because the formation potential uses a high initial chlorine dose of 9.3 mg/L and a long reaction time of 7 days to maximise the possible formation of THMs. These values are however indicative of typical water quality that should not result in the formation of disinfection by-products exceeding the drinking water guideline limits in the Improvement District’s water supply system.

2.2.1 ION EXCHANGE REGENERATION WASTE BRINE CHARACTERIZATION

Comments on the IX process waste brine suitability for direct discharge to the ocean will be provided by Madrone as a separate report and must be included in the consideration of its economic viability. Low cost disposal of the waste brine produced during IX regeneration will be a significant factor in the life cycle cost for this process.

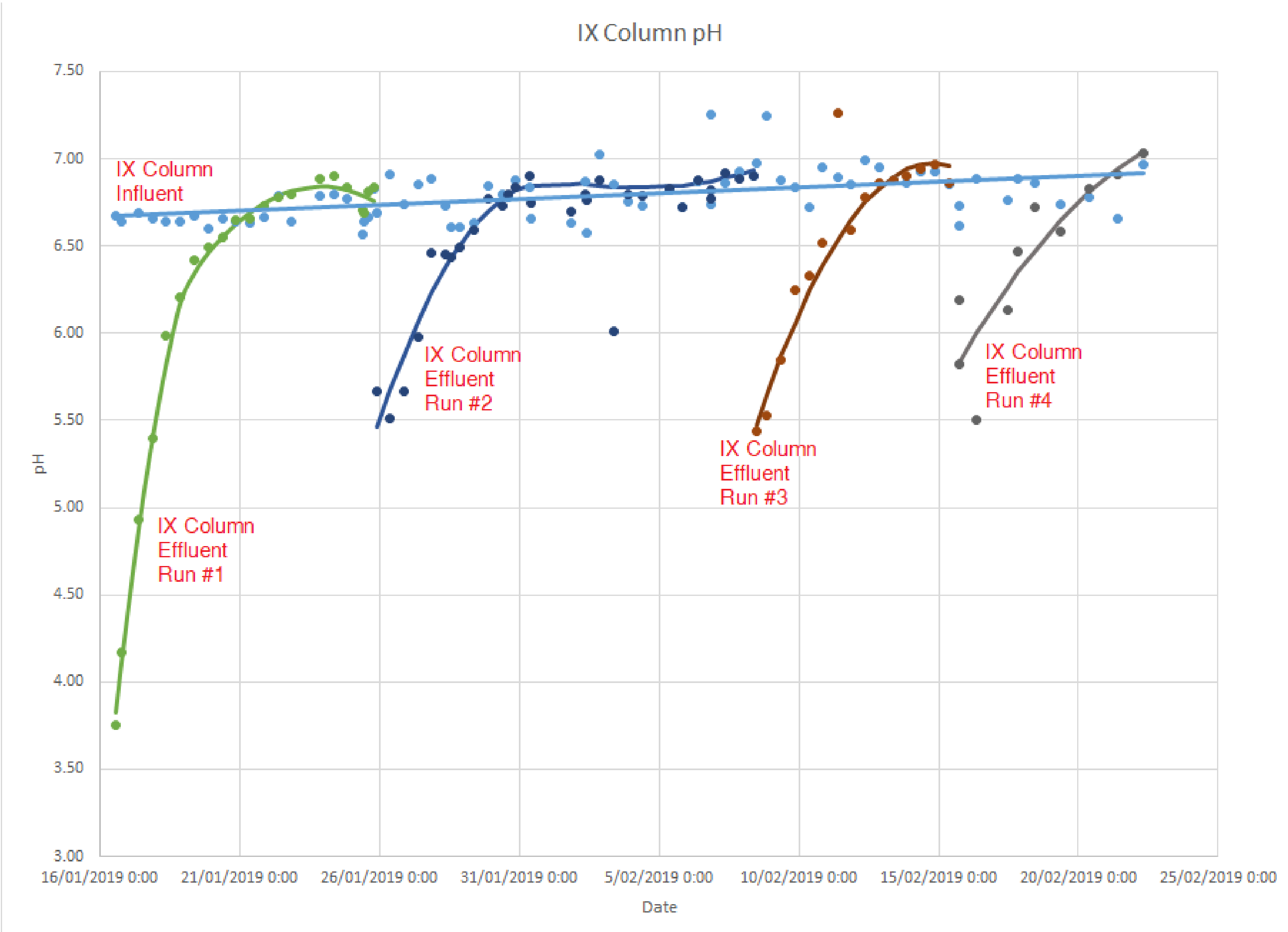

Figure 14: IX column influent and effluent pH VS pilot running time

Figure 15: Waste regeneration brine after IX column run #1 (25/01/2019)

2.3 GLID PILOT CONCLUSIONS

2.3.1 CARTRIDGE FILTRATION

Cartridge filtration of the Graham Lake source water was found to be unable to reduce the water turbidity to below the drinking water guideline of 1.0 NTU, without the use of an excessively large number of filters, which would increase operating costs to beyond what GLID could afford. VIHA may accept a somewhat higher turbidity using cartridge filtration if a 1 micron absolute filtration could be applied to provide a barrier to *Cryptosporidium* and *gGiardia*, but this would have to be explored.

Re-usable (washable) 20 micron and/or 5 micron pleated cartridge filters were ineffective as prefiltration for 1 micron absolute cartridge filters. They were readily washable but did not prevent passage of fine suspended solids that rapidly plugged the 1 micron absolute filters.

Prefiltration of the water using low cost disposable 0.5 micron nominal depth filtration cartridges only provided moderate protection of the 1 micron absolute filters, doubling the 1 micron service life over the washable pre-filters, but did not provide a sufficiently long service life needed for economical use.

Based on the pilot results, the anticipated cartridge filter replacement cost for a GLID full scale WTP is expected to be in the order of $30,000 to $50,000 per year.

2.3.2 ION EXCHANGE ORGANICS REMOVAL

The pilot IX column operated as anticipated providing performance consistent with standard system design for this process. As anticipated, the IX column did not provide any significant reduction in turbidity but did provide good removal of colour and organics and greatly reduced formation of disinfection by-products. The salt regeneration of the IX media followed the expected frequency and salt consumption but the characterization of the waste brine will need to be confirmed by Madrone regarding its suitability for disposal to the sea.

Based on the pilot results, the anticipated salt consumption cost for a GLID full scale WTP is expected to be in the order of $2000 per year.