Walkerton Clean Water Centre
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Centre de Walkerton pour l'assainissement de l'eau
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Pilot Testing Project Report:

A study to monitor and reduce disinfection by-products in a First Nation's drinking water supply

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Walkerton Clean Water Centre

Research & Technology Department

Disclaimer

Acknowledgments

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Executive Summary

Background and Rationale

A First Nation community is located 350 km northeast of Thunder Bay, Ontario. Their drinking water source comes from 5 blended shoreline wells located near Lake Superior. The water treatment plant starts with pre-ozonation that feeds a dual train slow sand filtration (SSF) plant followed by granular activated carbon (GAC) filtration (Neegan Burnside, 2018). The treatment plant was originally built in 1997 and has undergone routine maintenance including rehabilitation of the wells and some upgrades to various components such as the ozone generators. The water treatment system serves approximately 500 people living on the reserve. Since 2016, the community has seen an increase in chlorinated disinfection by-products (DBPs) with the levels exceeding the maximum acceptable concentration (MAC) for trihalomethanes (THMs) and haloacetic acids (HAAs).

The community is striving to reduce the levels of DBPs to below the Federal Guidelines and has contracted Neegan Burnside Ltd. to provide a long-term solution. The Walkerton Clean Water Centre (WCWC) was asked to provide support for a short-term solution in collaboration with Ontario First Nation Technical Services Corporation (OFNTSC), Neegan Burnside Ltd. and the First Nation operators.

Objectives

The objective of this project was to reduce the concentration of DBPs, specifically THMs and HAAs from the drinking water supply, by reducing the DOC. The project was split into two phases. Phase 1 was to monitor the water quality before and after various treatment stages to determine the feasibility of phase 2. Phase 2 was focused on the removal of DOC using GAC filters. Additionally, the original GAC media and the current GAC media provided from different manufacturers were considered for this pilot.

Approach

The Centre conducted water quality monitoring and analysis of the raw, slow sand filters, GAC filters and treated water. Pending the results of the monitoring phase, a pilot phase would commence to reduce DBPs for the short term.

Key Findings

During the sampling period, the disinfection by-products of the full-scale treatment system consistently exceeded the maximum acceptable concentration for both THMs and HAAs, except in the winter of 2020.

During the sampling period between October 2019 to October 2020:

- The raw water varied from 6 mg/L to 8.5 mg/L DOC, and 40% to 60% UVT, albeit iron fouling likely interfered with the UVT result.
- The ozone residual in the splitter box was inconsistent and often below the target 0.1 mg/L.
- The overall DOC removal by the entire treatment process was approximately 18% but was still above 6 mg/L DOC in the treated.

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1. Introduction

A First Nation community is located 350 km northeast of Thunder Bay, Ontario. Their drinking water source comes from 5 blended shoreline wells located near Lake Superior. The water treatment plant starts with pre-ozonation that feeds a dual train slow sand filtration (SSF) plant followed by granular activated carbon (GAC) filtration (Neegan Burnside, 2018). The treatment plant was originally built in 1997 and has undergone routine maintenance including rehabilitation of the wells and some upgrades to various components such as the ozone generators. The water treatment system serves approximately 500 people living on the reserve. Since 2016, the community has seen an increase in chlorinated disinfection by-products (DBPs) with the levels exceeding the maximum acceptable concentration (MAC) for trihalomethanes (THMs) and haloacetic acids (HAAs).

The community is striving to reduce the levels of DBPs to below the Federal Guidelines and has contracted Neegan Burnside Ltd. to provide a long-term solution. The Walkerton Clean Water Centre (WCWC) was asked to provide support for a short-term solution in collaboration with Ontario First Nation Technical Services Corporation (OFNTSC), Neegan Burnside Ltd. and the First Nation operators.

2. Rationale

Natural Organic Matter (NOM) is a mixture of complex organic materials that vary between sources and geographic locations (Health Canada, 2019). Although NOM does not pose a risk to adverse health effects directly, it is a challenge for many drinking water utilities due to its effects on other health-based standards such as DBPs and water quality characteristics such as colour, taste and odour. Additionally, NOM is highly variable and source water specific when it comes to treatment efficacy, DBP formation potential and limitations in monitoring technologies. Some of the known factors that are responsible for the variation of NOM are the ranges in molecular size, shape, charge, biodegradable half-life, reactivity, and hydrophobic or hydrophilic properties (Health Canada, 2019). As a result, the efficacy of a single treatment is not universal for NOM and may also change seasonally due to natural events like temperature changes, snow melt and precipitation. Consequently, a utility should monitor NOM if possible and may need to adopt multiple treatment strategies to adapt to the changing water conditions (Health Canada, 2019).

DBPs are formed when certain organics are present in water and react with chemical disinfectants, such as chlorine (MECP, 2006). The common chlorinated DBPs are THMs and HAAs, which are regulated at 100 µg/L and 80 µg/L MAC, respectively, due to their presumed carcinogenic effects (Health Canada, 2017). Although the composition of natural organic matter (NOM) is very complex, it is commonly detected by measuring total organic carbon (TOC) and dissolved organic carbon (DOC), usually with grab samples. A useful surrogate of DOC is ultraviolet (UV) absorbance (254 nm) as it can be monitored continuously and because a portion of organics absorb UV light. Although UV absorbance (UVa) is typically associated with organics, the scale and unit from 0- 2.0 cm^{-1} is not easily comprehended. UVa was converted to UV transmittance (UVT) for the purposes of this study because it is easier to visualize a scale of 0-100%.

Generally, the preferred approach to reduce DBPs is by reducing the concentration of NOM in the treated water before the addition of chlorine. Reducing NOM in the treated water will also improve the taste, odour, and colour, while decreasing the chlorine demand and biological regrowth in the distribution system. To reduce NOM in the treated water, the level of performance for each treatment component should be evaluated in the water treatment plant. The performance of the various stages of the slow sand treatment are dependent on one another and rely on previous stages to cumulatively provide enough performance. For example, the slow sand filter uses microbes to reduce NOM, but does not function effectively unless an ozone residual is achieved to oxidize complex NOM into a useable food source for the microbes; and the roughing filter must quench the residual ozone to prevent it from damaging the microbes. The granular activated carbon (GAC) filter can further reduce some DOC effectively, if the DOC has been oxidized and reduced by the previous stages of treatment. If there are disruptions to the performance or inconsistencies in the stages of treatment, then a cascading effect of decreasing performance can be expected.

The Centre was asked to pilot GAC filtration after slow sand filtration; however, this was conditional that the other stages of treatment demonstrated consistent performance for an extended period. The Centre proposed to support the community with monitoring the various stages of treatment for DOC, UVa, and ozone residual. If the recommended ozone residual could be maintained before the roughing filter and the slow sand filter responded to the operation, then the Centre would pilot two GAC filter medias after slow sand filtration.

3. Objectives

The objective of this project was to reduce the concentration of DBPs, specifically THMs and HAAs from the drinking water supply, by reducing the DOC. The project was split into two phases. Phase 1 was to monitor the water quality before and after various treatment stages to determine the feasibility of phase 2. Phase 2 was focused on the removal of DOC using GAC filters. Additionally, the original GAC media and the current GAC media provided from different manufacturers were considered for this pilot.

4. Methods

4.1 Phase 1

The raw, slow sand filter 1 (SSF1), slow sand filter 2 (SSF2), granular activated carbon 1 (GAC1) and granular activated carbon 2 (GAC2) water was sampled initially for iron and manganese, DOC, and UVa. Samples were taken at each location approximately every other month for DOC and UVa, and several times a week for UVa, both online and grab samples. The splitter box was sampled daily for ozone residual, and the percentage dose of ozone was periodically recorded. All grab samples and recordings were taken by operations staff and the data was compiled by WCWC staff.

4.2 Phase 2

Once the water treatment plant demonstrated a consistent ozone residual within engineer specifications from the splitter box, two GAC filters would be tested after the SSFs. The filters would be sampled for DOC, UVa/ UVT removal. The filter effluents would also be subject to a simulated distribution system (SDS) DBP test, that was consistent with the distribution system detention time of 6 days and compared with the full scale GAC filters. The original GAC media would be compared to the current GAC media and allowed to run side by side for several months to monitor performance.

5. Results and Discussion

5.1 Phase 1 Water Quality Monitoring

Grab sample results of the five wells for iron, manganese, and TOC from 1997 were available and compared with samples from 2018. The results are found in Table 5.1. On average, the iron, manganese and TOC were above the aesthetic objectives (AO) in both sets of samples. Iron and manganese remained relatively unchanged, but the TOC was 2 mg/L higher in 2018 compared to 1997. The caveat of this comparison is that only two grab samples were available with no confirmation of the sampling dates, as seasonal changes could potentially explain this variation. The raw water DOC appeared to represent the entire TOC in the water quality results reported in the 2018 Water Feasibility Study (Neegan Burnside, 2018); therefore, the TOC and DOC were approximately equal and considered interchangeable.

Table 5.1. Well Water Raw Grab Samples

Wells	Fe (mg/L)			Mn (mg/L)			TOC (mg/L)		
	AO	1997	2018	AO	1997	2018	AO	1997	2018
W1	0.3	0.3	0.252	0.05	0.03	0.040	5	1.7	8.5
W2		1.2	2.01		0.1	0.098		8.3	11.8
W3		1.3	0.363		0.1	0.0754		7.8	4.42
W4		0.5	0.79		0.15	0.0577		5.4	7.0
W5		0.6	0.408		0.05	0.0394		7.3	8.4
Avg.		0.78	0.77		0.086	0.0621		6.1	8.0

AO: aesthetic objective (Health Canada, 2017); 1997 results provided by operations staff; 2018 results provided by Neegan Burnside

DBP results were taken at the furthest site in the distribution system from the water treatment plant, as these would likely represent the worst-case conditions. The quarterly samples associated with the approximate season were recorded in Table 5.2 and indicate that most of the samples were above the MAC for both THMs and HAAs. The colder months had lower DBPs likely due to a combination of lower temperatures and the composition of DOC.

Table 5.2. Distribution System Disinfection By-product Results

Disinfection By-products (DBPs)					
Year	Parameter (µg/L)	Winter (1-3)	Spring (4-6)	Summer (7-9)	Fall (10-12)
2017	THM	124	162	177	124
	HAA	126	177	127	197
2018	THM	61.2	93.8	120	92.7
	HAA	61.5	237	125	125
2019	THM	89.8	139	108	133
	HAA	141	155	119	160
2020	THM	69.5	140	171	
	HAA	87.5	125	167	
Maximum acceptable concentration (MAC): THM = 100 (µg/L); HAA = 80 (µg/L)					

Figure 5.1**Error! Reference source not found.** shows seasonal DOC results from grab samples in 2019 and 2020, in the raw water (five blended wells) and after various stages of treatment. The raw water DOC was recorded as low as 6.36 mg/L in November of 2019 but was greater than 8.2 mg/L in all other seasons.

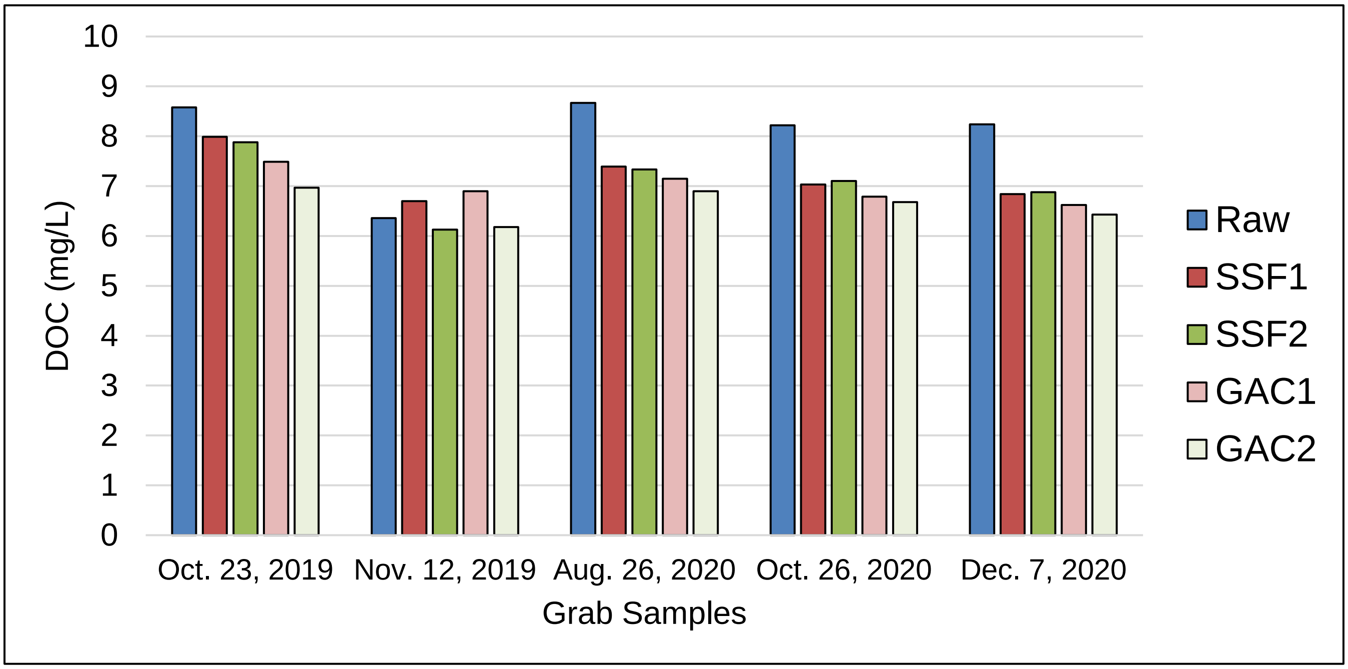

Figure 5.1. DOC Water Quality and Treatment Performance

The slow sand filters SSF1 and SSF2 performed similarly, reducing the DOC on average 10% and 11%, respectively. These results are consistent with the lower end of performance from a review of several conventional (without ozone) SSF plants removing between 5 and 40% of DOC (Graham, 1999). When evaluating water treatment plants with the combination of ozone and SSF, reductions as high as 18% and up to 50% were reported treating 2.0 - 8.2 mg/L of DOC at an ozone dose range of 0.2 - 1.0 mg O_3/mg TOC (Seger and Rothman, 1996; Dempsey and Fu, 1994) as cited by Graham (1999). The slow sand filter was designed to operate with an ozone residual of 0.1 – 0.5 mg/L in the splitter box (MS filter), before the roughing filter to ensure that the larger, less biodegradable organic compounds could be oxidized into smaller, more easily metabolized compounds (EPA, 2011). Grab samples at the splitter box were reported from October 2019 to October 2020 to confirm if the plant was meeting the target ozone residual before the roughing filter (Figure 5.2). The results indicate many of the ozone residual samples were below the minimum target and relatively inconsistent. This suggests the majority of DOC in the raw water consisted of large, less biodegradable organic compounds and were not effectively oxidized based on the lower than desired ozone residual and DOC removal.

Furthermore, the GAC1 and GAC2 filters contributed an average DOC removal of 3% and 6% respectively after slow sand filtration (Figure 5.1). GAC1 and GAC2 had the best performance in October of 2019, when the removal was 6% and 12% respectively. GAC2 had twice the removal of GAC1, likely because the media in GAC2 was replaced more recently than the media in GAC1. By November 12th, 2019, the filters were again performing very similarly, and lower than expected with respect to DOC reduction.

Continuous UV absorbance (converted and displayed as transmittance) was used as a surrogate for DOC and installed on sample lines from the raw water, SSF1 and GAC1. The purpose was to monitor the relative DOC treatment performance in real-time; however, issues with the raw and GAC1 monitors were experienced. The raw sample line showed significant iron fouling after a few weeks even with the automatic cleaning system set to maximum dosing and frequency. The GAC1 monitor experienced technical issues that were not resolvable on-site; therefore, the raw and GAC1 online UVT were omitted from the data set. The online SSF1 was used from December 11th, 2019 until August 26th, 2020 and grab samples for UVT were taken from June 18th, 2020 until October 22nd, 2020. The (grab) raw water UVT was 52% on average and about 20% lower than the slow sand filter effluent (Figure 5.2). The large difference in the UVT can be explained by a 2 mg/L reduction in DOC and iron interference. The continuous SSF1 averaged 71% UVT and was highest in the winter of 2019 - 2020, when the DOC and DBPs were the lowest. The SSF1 and GAC1 UVT results were not expected to have iron interference, as the slow sand filter effluent was below the detection limit for iron. The grab SSF1 and GAC1 UVT averaged 69% and 71%, respectively and was consistent with the DOC results that suggests the GAC filters are exhausted.

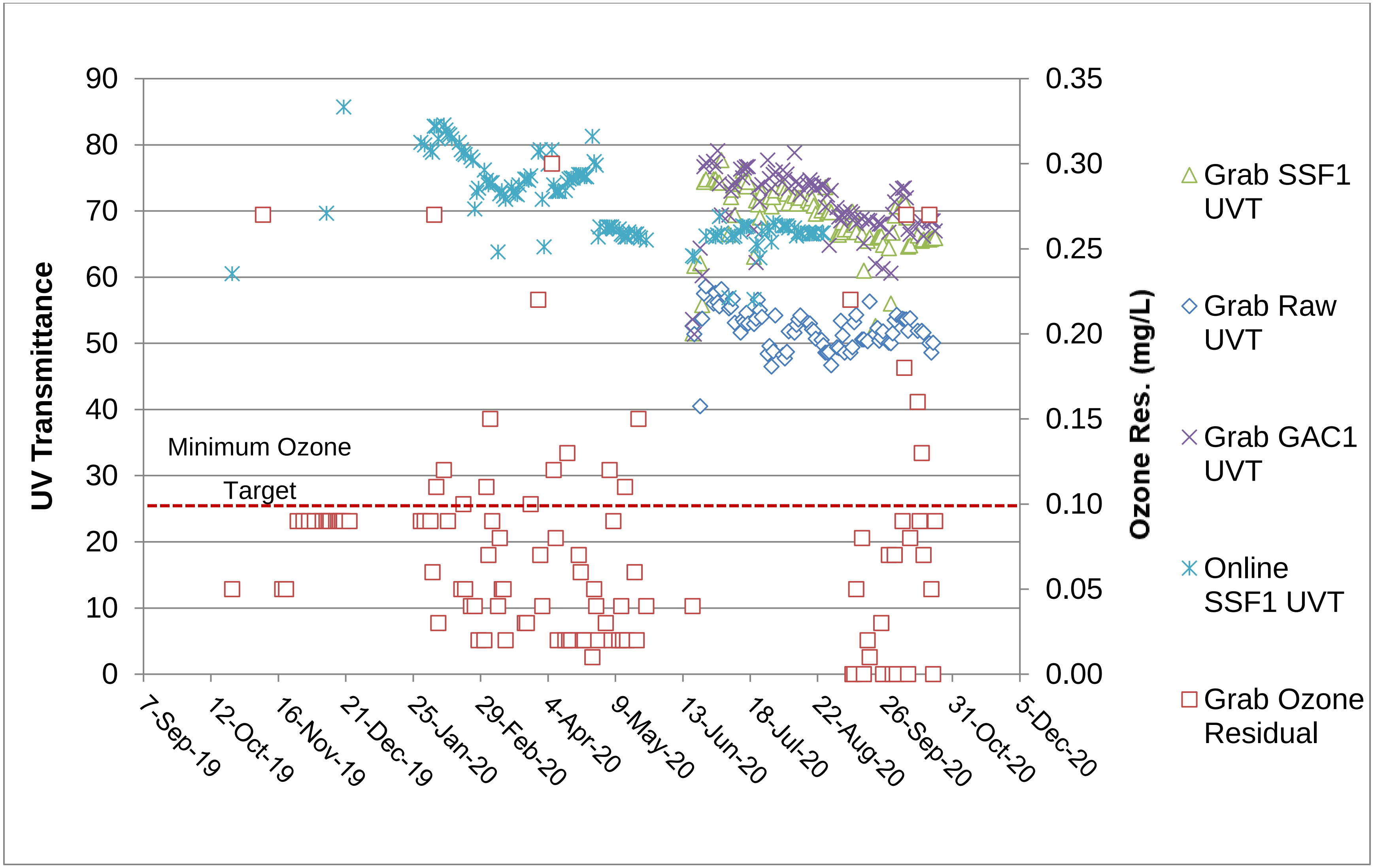

Figure 5.2. Ozone Residual and UV Transmittance

6. Conclusions

During the sampling period, the disinfection by-products of the full-scale treatment system consistently exceeded the maximum acceptable concentration for both THMs and HAAs, except for one result in the winter of 2020.

During the sampling period between October 2019 to October 2020, the monitoring showed:

- The raw water varied from approximately 6.4 mg/L to 8.7 mg/L DOC, and 40% to 60% UVT, albeit iron fouling likely interfered with the UVT result.
- The ozone residual in the splitter box was inconsistent and often below the target 0.10 mg/L.
- The overall DOC removal by the entire treatment process was approximately 18% but the DOC was still above 6 mg/L in the treated water.

7. References

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8. Appendix- A

Table 8.1. Raw Data for Figure 5.1

Date	DOC (mg/L) Data					
	Raw	SSF1	SSF2	GAC1	GAC2	Treated
Oct. 23, 2019	8.58	8.0	7.88	7.49	6.97	-
Nov. 12, 2019	6.36	6.7	6.13	6.9	6.18	-
Aug. 26, 2020	8.67	7.39	7.34	7.15	6.90	7.00
Oct. 26, 2020	8.22	7.03	7.10	6.79	6.68	6.71
Dec. 7, 2020	8.24	6.84	6.88	6.62	6.43	6.44

9. Appendix- B

Table 9.1. Raw Data for Figure 5.2

Date	Raw			Splitter Box	SSF1			GAC1
	Online UVa	Calculated Raw UVT	Grab UVT	Ozone Residual	Online SSF1 UVa	Calculated UVT	Grab UVT	Grab UVT
23-Oct-19	0.238	58		0.05	0.218	61		
8-Nov-19				0.27				
18-Nov-19				0.05				
20-Nov-19				0.05				
26-Nov-19				0.09				
29-Nov-19				0.09				
2-Dec-19				0.09				
5-Dec-19				0.09				
9-Dec-19				0.09				
9-Dec-19				0.09				
11-Dec-19	0.230	59		0.09	0.157	70		
12-Dec-19				0.09				
13-Dec-19				0.09				
16-Dec-19				0.09				
17-Dec-19				0.09				
18-Dec-19				0.09				
19-Dec-19				0.09				
20-Dec-19	0.340	46		0.09	0.067	86		
23-Dec-19				0.09				
29-Jan-20	0.430	37		0.09	0.095	80		
31-Jan-20	0.427	37		0.09	0.097	90		
3-Feb-20	0.468	34		0.09	0.101	79		
4-Feb-20	0.461	35		0.06	0.103	79		
5-Feb-20	0.463	34		0.27	0.082	83		
6-Feb-20	0.467	34		0.11	0.082	83		
7-Feb-20	0.472	34		0.03	0.092	81		
10-Feb-20	0.463	34		0.12	0.081	83		
11-Feb-20	0.447	36			0.085	82		
12-Feb-20	0.482	33		0.09	0.088	82		
13-Feb-20	0.472	34			0.089	81		
14-Feb-20	0.488	33			0.092	81		
18-Feb-20	0.497	32			0.095	80		
19-Feb-20	0.499	32		0.05	0.101	79		
20-Feb-20	0.496	32		0.10	0.104	79		
21-Feb-20	0.501	32		0.05	0.105	79		

24-Feb-20	0.512	31		0.04	0.107	78		
25-Feb-20	0.509	31			0.11	78		
26-Feb-20	0.571	27		0.04	0.153	70		
27-Feb-20	0.576	27			0.138	73		
28-Feb-20	0.543	29		0.02	0.134	73		
2-Mar-20	0.510	31		0.02	0.118	76		
3-Mar-20	0.518	30		0.11	0.127	75		
4-Mar-20	0.525	30		0.07	0.131	74		
5-Mar-20	0.528	30		0.15	0.129	74		
6-Mar-20	0.544	29		0.09	0.129	74		
9-Mar-20	0.531	29		0.04	0.195	64		
10-Mar-20	0.543	29		0.08	0.139	73		
11-Mar-20	0.541	29		0.05	0.136	73		
12-Mar-20	0.539	29		0.05	0.141	72		
13-Mar-20	0.561	27		0.02	0.144	72		
16-Mar-20	0.585	26			0.133	74		
17-Mar-20	0.605	25			0.138	73		
18-Mar-20	0.616	24			0.139	73		
19-Mar-20	0.612	24			0.14	72		
20-Mar-20	0.612	24			0.131	74		
23-Mar-20	0.640	23		0.03	0.126	75		
24-Mar-20	0.645	23		0.03	0.126	75		
25-Mar-20	0.648	22			0.127	75		
26-Mar-20	0.663	22		0.10	0.123	75		
30-Mar-20	0.694	20		0.22	0.103	79		
31-Mar-20	0.690	20		0.07	0.101	79		
1-Apr-20	0.739	18		0.04	0.144	72		
2-Apr-20	0.754	18			0.190	65		
4-Apr-20	0.754	18			0.113	77		
6-Apr-20	0.790	16		0.30	0.101	79		
7-Apr-20	0.709	20		0.12	0.131	74		
8-Apr-20	0.727	19		0.08	0.137	73		
9-Apr-20	0.730	19		0.02	0.137	73		
10-Apr-20	0.747	18			0.137	73		
13-Apr-20	0.763	17		0.02	0.136	73		
14-Apr-20	0.778	17		0.13	0.129	74		
15-Apr-20	0.799	16		0.02	0.126	75		
16-Apr-20	0.795	16		0.02	0.125	75		
17-Apr-20	0.805	16			0.125	75		
20-Apr-20	0.836	15		0.07	0.122	76		
21-Apr-20	0.842	14		0.06	0.122	76		
22-Apr-20	0.851	14		0.02	0.122	76		

23-Apr-20	0.867	14		0.02	0.124	75		
24-Apr-20	0.870	13			0.124	75		
27-Apr-20	0.912	12		0.01	0.09	81		
28-Apr-20	2.000	1		0.05	0.111	77		
29-Apr-20	2.000	1		0.04	0.114	77		
30-Apr-20	2.000	1		0.02	0.18	66		
1-May-20	2.000	1			0.17	68		
4-May-20	2.000	1		0.03	0.172	67		
5-May-20	2.000	1			0.17	68		
6-May-20	2.000	1		0.12	0.17	68		
7-May-20	2.000	1		0.02	0.17	68		
8-May-20	2.000	1		0.09	0.172	67		
11-May-20	2.000	1		0.02	0.172	67		
12-May-20	2.000	1		0.04	0.177	67		
13-May-20	2.000	1		0.02	0.178	66		
14-May-20	2.000	1		0.11	0.18	66		
15-May-20	2.000	1		0.02	0.18	66		
16-May-20	2.000	1			0.175	67		
19-May-20	2.000	1		0.06	0.177	67		
20-May-20	2.000	1		0.02	0.177	67		
21-May-20	2.000	1		0.15	0.18	66		
22-May-20	2.000	1			0.181	66		
25-May-20	2.000	1		0.04	0.183	66		
18-Jun-20	0.911	12	52.6	0.04	0.199	63	51.5	53.6
19-Jun-20	2.000	1	51.4		0.2	63	61.7	51.4
22-Jun-20			40.5				62.1	64.4
23-Jun-20			53.7				55.8	60.2
24-Jun-20			57.5				74.4	76.7
25-Jun-20	2.000		58.6		0.179	66	74.8	77.3
29-Jun-20	2.000		56		0.179	66	74.8	77.5
30-Jun-20	2.000		57.6		0.18	66	74.8	76.7
01-Jul-20	2.000		56.2		0.178	66	74.3	79.1
02-Jul-20	2.000		55.6		0.16	69	74.3	74.1
03-Jul-20	2.000		58.2		0.176	67	77.7	69.4
07-Jul-20	2.000		55.3		0.245	57	66.5	69.4
08-Jul-20	2.000		55.5		0.178	66	72.1	73
09-Jul-20	2.000		56.7		0.18	66	73.2	73.8
10-Jul-20	2.000		53.1		0.179	66	69.4	74.4
13-Jul-20	2.000		51.6		0.175	67	74.1	76.3
14-Jul-20	2.000		53.6		0.169	68	76.1	75
15-Jul-20	2.000		53.2		0.17	68	74.6	76.5
16-Jul-20	2.000		54.6		0.17	68	73.7	76.7

17-Jul-20	2.000		53		0.169	68	74.4	76.7
20-Jul-20	2.000		52.9		0.247	57	63.1	67.2
21-Jul-20	2.000		53.7		0.187	65	71.6	62.2
22-Jul-20	2.000		56.6		0.189	65	71	73.6
23-Jul-20	2.000		55		0.201	63	69	71.4
24-Jul-20	2.000		54		0.174	67	72.8	74
27-Jul-20	2.000		48.4		0.171	67		77.7
28-Jul-20	2.000		49.6		0.173	67	72.2	74.9
29-Jul-20	2.000		46.5		0.185	65	70.7	73.4
30-Jul-20	2.000		48.8		0.166	68	72.1	75.5
31-Jul-20	2.000		54.2		0.168	68	73.1	75.9
04-Aug-20	2.000		48.2		0.169	68	73.7	76.2
05-Aug-20	2.000		47.7		0.169	68	73	74.8
06-Aug-20	2.000		48.7		0.169	68	72.6	75.6
07-Aug-20	2.000		51.8		0.171	67	71.2	73.4
10-Aug-20	2.000		51.6		0.171	67	72.3	78.8
11-Aug-20	2.000		52.8		0.179	66	71.1	74.5
12-Aug-20	2.000		53.6		0.175	67	72	74
13-Aug-20	2.000		54.2		0.176	67	72	72.5
14-Aug-20	2.000				0.177	67		
17-Aug-20	2.000		53.1		0.176	67	71.6	74
18-Aug-20	2.000		53		0.177	67	71.2	74.7
19-Aug-20	2.000		52.1		0.177	67	71.9	74.2
20-Aug-20	2.000		51.9		0.177	67	70.8	73.7
21-Aug-20	2.000		50.7		0.175	67	69.6	73.3
24-Aug-20	2.000		50.5		0.176	67	70.1	73.9
25-Aug-20	2.000		49.7		0.176	67	70.7	73.9
26-Aug-20			48.6				73.6	70.6
27-Aug-20			48.6				69.8	72.4
28-Aug-20			48.7				70.1	64.8
29-Aug-20			46.7				69.8	73.1
01-Sep-20			49.4				66.5	70.5
02-Sep-20			49.3				66.4	69.1
03-Sep-20			53.4				66.8	68.5
04-Sep-20			51.2				68.3	69.3
05-Sep-20			48.6				67.2	69.9
8-Sep-20			48.6	0.22			67.2	69.9
9-Sep-20			49.4	0.02			69.9	69.6
10-Sep-20			53.2	0.02			67.9	68.9
11-Sep-20			54.3	0.05			66.8	68.1
14-Sep-20			50.6	0.08			66.4	68.8
15-Sep-20			50.6	0.02			61	65.1

17-Sep-20			50.3	0.02			65.5	68.6
18-Sep-20			56.3	0.01			66	68.5
21-Sep-20			51.4				52.6	62
22-Sep-20			52.3				66	68.3
23-Sep-20			50.4				66.1	68
24-Sep-20			50.9	0.03			66.2	68
25-Sep-20			51.8	0.02			64.9	61.3
28-Sep-20			50.1	0.07			64.4	66.8
29-Sep-20			50				56	60.6
30-Sep-20			51.5	0.02			66.7	69.5
1-Oct-20			53.5	0.07			69.3	71.4
2-Oct-20			54.3	0.02			70.7	73
5-Oct-20			53.7	0.09			71.2	73.4
6-Oct-20			53.6	0.18			71.4	73.5
7-Oct-20			53.6	0.27			69	72
8-Oct-20			51.9	0.02			64.6	67.2
9-Oct-20			53.8	0.08			64.8	66.5
13-Oct-20			51.9	0.16			66.3	68.2
14-Oct-20				0.09				
15-Oct-20			51.9	0.13			65.5	68.4
16-Oct-20			51.6	0.07			65.7	66.2
19-Oct-20			50	0.27			65.7	68.7
20-Oct-20			48.6	0.05			65.8	68.5
21-Oct-20			50.1	0.02			65.9	68.5
22-Oct-20				0.09			65.9	67

Notes:

Values from online or manual instrumentation were used for calculated values.

Values in red font were omitted from the plotted data. Raw values were influenced by iron fouling, and SSF1 required calibration and maintenance. Error between SSF1 online and manual grab samples was 7.2% in 36 samples.