Pilot Testing Project Report:

Red Rock Indian Band

A study to reduce disinfection by-products in a community's drinking water supply

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Walkerton Clean Water Centre

Research & Technology Institute

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Executive Summary

Background

The Red Rock Indian Band (RRIB) is an Ojibwe First Nation Community located in Northwestern Ontario, Canada. During the 2018 reporting year, two sampling locations used for quantifying disinfection by-products (DBPs), specifically trihalomethanes (THMs) and haloacetic acids (HAAs), were identified as containing results above the limits set out by the Guidelines for Canadian Drinking Water Quality (GCDWQ) and the Ontario Drinking Water Standards, Objectives and Guidelines (ODWSOG). The maximum acceptable concentrations (MAC) of THMs and HAAs are 100 µg/L and 80 µg/L respectively, as they are presumed carcinogens. Lake Helen surface water is dosed with ~ 10 mg/L of the coagulant SternPac and filtered through a 0.04 µm membrane filter. Chlorine is dosed after filtration and the treated water travels through a 500 m^3 multi-chamber clearwell tank to achieve primary disinfection and a final chlorine residual of approximately 0.7 mg/L. Water detention time for the system has been estimated at 9 days in the clearwell and around 1 day in the distribution system.

Objectives

The objectives of the project were to reduce the concentration of DBPs, specifically THMs and HAAs from the Community's drinking water supply with coagulation prior to membrane filtration; post membrane granular activated carbon filtration; and control of treated water detention times. To address DBP water quality, the target was to lower the treated DOC concentration to < 3 mg/L, below the aesthetic objective (AO) of 5 mg/L in the ODWSOG (MECP, 2006). Through use of various online and grab sampling techniques, prepare a DOC and UV absorbance (UVa) model to subsequently estimate the DBP formation in real-time from online UVa readings.

Approach

The Centre initially conducted bench scale jar tests to determine the optimal coagulant and dose for organic removal. Two pilot scale granular activated carbon (GAC) filters were installed in parallel at the water treatment plant WTP following membrane filtration. The Centre installed monitoring equipment on the RAW, post membrane filtration, and post GAC filtration along with for water quality and treatment performance relative to DBPs.

Key Findings

The jar test results determined:

- SternPac performed more effectively than the other coagulant at removing turbidity and DOC for the existing water treatment process.
- DOC could be reduced beyond the recommended maximum target dose of 10 mg/L
- A reduced contact time was effective at reducing the amount of DBPs in the simulated distribution system

The pilot test results determined that:

- Bituminous GAC filtration post membrane filtration was the most effective at reducing DBPs in the simulated distribution system.
- UVa can be used to

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1. Introduction

The Red Rock Indian Band (RRIB) is an Ojibwe First Nation Community located in Northwestern Ontario, Canada. Currently, there are 109 houses on the Lake Helen Reserve being serviced with treated drinking water and septic systems. According to the study produced by Hamilton in 2016, approximately 320 people rely on the RRIB water treatment plant, which uses Lake Helen as the source water, to supply safe and aesthetically pleasing drinking water.

Community sampling is conducted on a regular basis by drinking water Operators in conjunction with Health Canada on the reserve. Two sampling locations used for quantifying disinfection by-products (DBPs), specifically trihalomethanes (THMs) and haloacetic acids (HAAs), were identified in 2018 as containing results above the limits set out by the Guidelines for Canadian Drinking Water Quality (GCDWQ) and the Ontario Drinking Water Standards, Objectives and Guidelines (ODWSOG). The maximum acceptable concentrations (MAC) of THMs and HAAs are 100 µg/L and 80 µg/L, respectively, based on an annual rolling quarterly average. In 2018, Health Canada results showed the annual average DBP's of THMs to be 117 µg/L and HAAs to be 99.3 µg/L.

The Community's water treatment plant has an average daily flow rate of approximately 55 m^3. Incoming raw water is dosed with the coagulant SternPac and filtered through a 0.04 µm membrane filter. The plant doses SternPac at a rate ~ 10 mg/L, as recommended by the membrane manufacturer to prevent a reduction in flux, increased backwashing, and potential irreversible fouling (Hamilton, 2016). Following filtration, chlorine is dosed and the treated water travels through a 500 m^3 multi-chamber clearwell tank to achieve primary disinfection and a final chlorine residual of ~ 0.7 mg/L. Water detention time for the system has been estimated at 9 days in the clearwell and around 1 day in the distribution system.

2. Objectives

The objectives of the project were to reduce the concentration of DBPs, specifically THMs and HAAs from the Community's drinking water supply with the following strategies.

- Coagulation prior to membrane filtration
- Post membrane granular activated carbon filtration

- Control of treated water detention times

To address DBP water quality, the target was to lower the treated DOC concentration to < 3 mg/L, below the aesthetic objective (AO) of 5 mg/L in the ODWSOG (MECP, 2006). Through use of various online and grab sampling techniques, prepare a DOC and UV absorbance (UVa) model to subsequently estimate the DBP formation in real-time from online UVa readings.

3. Methods

The project was split into two phases to address different potential areas of improvement in the treatment process. Phase 1 included bench-scale jar testing and filtration to assess the effectiveness of selected coagulants and their doses at removing DOC from Lake Helen source water. A simulated distribution system – disinfection by-product (SDS-DBP) test was conducted to analyze the effect of dose, coagulant and detention time on THM and HAA formation. Phase 2 included pilot scale testing of a pressure vessel GAC media post-membrane treatment system to analyze their effectiveness for DOC removal prior to chlorination.

3.1. Phase 1: Bench Scale Study

Bench scale testing was conducted to understand the effects of coagulation in relation to the surface water quality. Lake Helen was sampled and measured for selected water quality parameters, including specific ultra-violet absorbance (SUVA) and was put through a series of formulated jar tests to represent the Lake Helen Water Treatment Plant process flow. The results were compared with the expected results from SUVA. A ferric trichloride (FerriPlus) was used to determine if the current poly aluminum chloride (SternPac) provided better performance than alternative options for this specific case.

Table 1. Bench Scale Sampling and Laboratory Analysis

Parameters	Method	Instruments
Turbidity	Nephelometric	Hach 2100P
Alkalinity	Method 10280 (LR)	SL1000
UVa	Method 10054	Real UV254
DOC	Persulphate- UV oxidation	Sievers 5310C Laboratory TOC
pH	Method 8156	Hach HQ40D/ PHC301
Aluminum	Method 8012	Hach 3900
Iron	Method 8008	HACH 3900

An untreated sample was analyzed in duplicate by WCWC staff at the beginning of the experiment to determine the water quality using the parameters, instruments and methods listed in Table 1. Samples were filtered with a 0.45 µm Polyethersulfone (PES) filter prior to analysis.

A jar testing procedure, adapted from AWWA (2011) and tailored to the process flow of the Lake Helen Water Treatment Plant, was used to simulate the coagulation (rapid mixing), flocculation (gentile agitation), and filtration stages of treatment. A 'Phipps & Bird' six jar tester was filled with 2 L volumes and mechanical paddle stirrers simulated the rapid mixing and flocculation stages. Sample water was mixed rapidly at 150 rpm for 1 min, followed by 20 rpm for 15 min to simulate flocculation, then sampled and filtered with a 1 µm pre-filter and 0.45 µm PES filter to mimic system conditions. Table 2 lists the selected coagulants and summarizes information about each chemical. Jar tests were performed on the raw water using SternPac provided by the utility and a Ferriplus provided by a manufacturer.

Table 2. Selected Coagulants for Jar Tests

Coagulant	Chemical Formula	% Active Ingredient	Physical & Chemical Properties	Name
SternPac	Not available	18%	Clear or amber liquid S.G 1.26	Aluminum Chloride Hydroxide Sulfate
FerriPlus	$FeCl_3$	-	Dark red brown liquid	Iron trichloride

Adapted from manufacturers SDS and Technical Spec Sheets

Two jar tests were performed on the raw water using SternPac and Ferric Chloride and their optimum doses were compared with the water characteristics of the treated-unchlorinated water collected from the Lake Helen Water Treatment Plant.

A SDS-DBP test, adapted from *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 2017), was completed to understand how chlorine contact time impacts the formation of DBPs for this drinking water supply. Water samples were collected from both the Lake Helen Water Treatment Plant as treated-unchlorinated; and from the jar tests conducted previously (Figure 1). The treated-unchlorinated water from the plant was compared to the water treated in the jar tests using the membrane manufacturers recommended dosage and the optimum dosage of SternPac and FerriPlus. Samples were collected in 250 mL amber glass bottles, pretreated to be chlorine demand free. The water samples were dosed with ~ 2.5 mg/L of chlorine and immediately measured for free chlorine and pH, then stored at room temperature and kept in the dark. After the designated detention time, at intervals of 6 days, 8 days and 10 days, the free chlorine and pH were measured before samples were shipped to an external lab for DBP analysis.

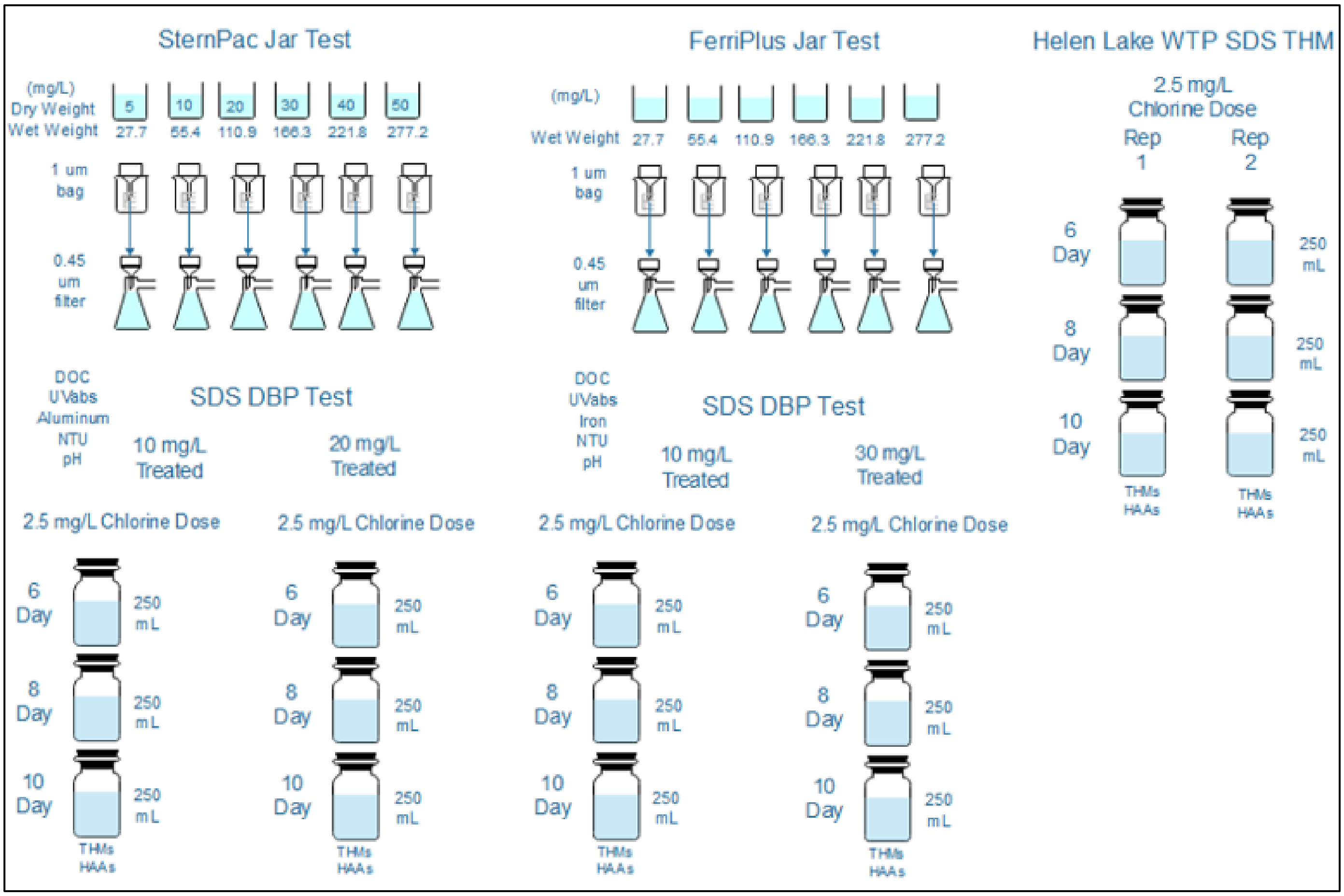


Figure 1. Bench Scale Process Flow

3.2. Phase 2: Pilot Scale Study

The solid arrows in Figure 2 indicate the process flow of the full-scale system, and the dashed arrows indicate the monitoring equipment and pilot system that was added. The full-scale membrane water treatment plant was designed for rated capacity of 500 m^3/ day, with the current demand being ~ 50 m^3/ day. A diaphragm style chemical metering pump doses SternPac directly into the raw water pipe which then passes through a static mixer. The flow is controlled with a butterfly valve (FCV) that opens during membrane permeate cycle and closes during the membrane back-pulse cycle. The three membrane filters rotate operation with one duty and two standbys due to the demand of the system in comparison to the designed capacity. The filter effluent is then chlorinated in a contact chamber before entering a 500 m^3 clearwell.

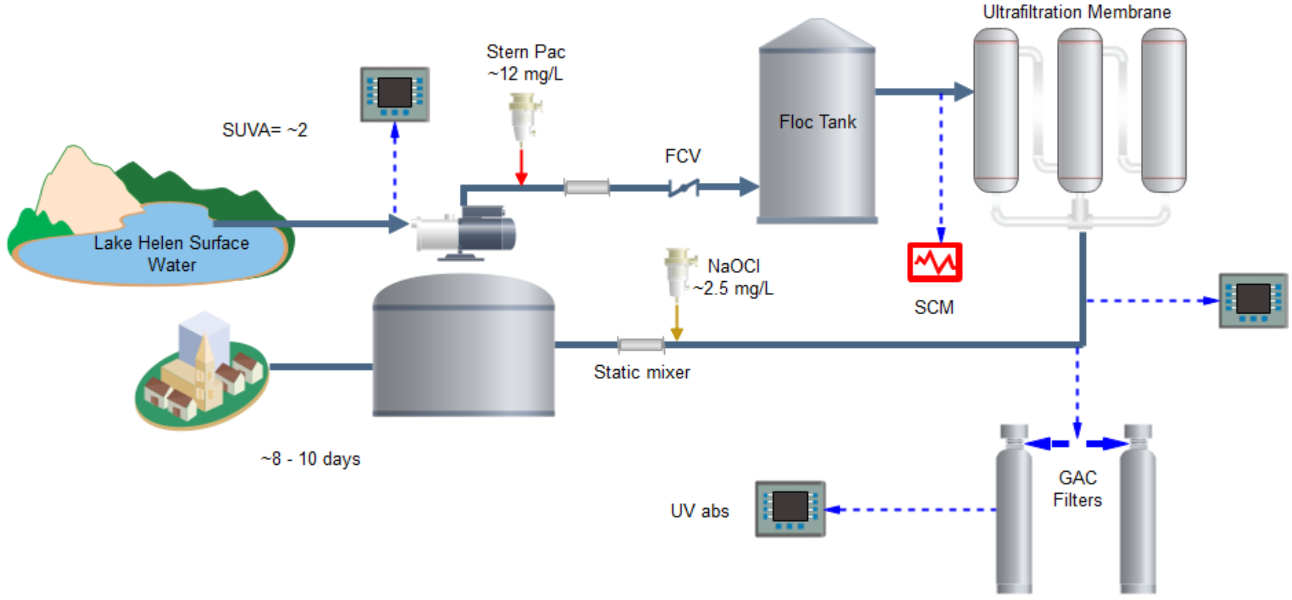


Figure 2. Water Treatment Plant and Pilot Process Flow

The first UVa monitor was set up on a raw water sample port to monitor changes to absorbance as a surrogate measurement of DOC. Another UVa monitor was set up on the membrane permeate water to determine the performance of each filter during its operation. Lastly, UVa was sampled manually during operation of the pilot system. A streaming current monitor (SCM) was placed at the closest sample port after coagulation to monitor water quality changes from the baseline value established during normal operation.

Two pressure vessel GAC filters were installed in parallel post-membrane filtration and monitored for performance over a 4-month period. The media installed was a common bituminous (GAC1) and coconut coir (GAC2) carbon to determine the better performing media for the source. The inlet to the pilot system was installed on sample ports on the effluent side of the membrane filters and drained into a tank with an air gap. A shallow well pump supplied water to the GAC filters with equal flow using a rotameter and globe valve on the discharge side of the filters. The filters were programmed to automatically backwash once per week. The raw, membrane, and GAC filtered water were monitored for changes in UV_{254} and DOC. A SDS-DBP test was completed monthly on the finished WTP effluent and each GAC filter.

4. Results and Discussion

4.1. Phase 1: Bench Scale Study

4.1.1. Raw Water Characteristics

Table 3. Lake Helen Raw Water Characteristics.

Parameter	Measurement	OG/ AO
Turbidity (NTU)	0.55	5
DOC (mg/L)	7.46	5
UV_{254} abs (cm^{-1})	0.151	-
pH	6.68	6.5 - 8.5
Alkalinity (mg/L)	47.2	30 - 500
Dissolved Aluminum (mg/L)	0.013	0.1
Dissolved Iron (mg/L)	0.06	0.3
SUVA	2.02	-

Grab sampling of the Lake Helen raw water intake occurred on March 14th, 2019 and the results were measured on March 19th, 2019. The water was below the AO for turbidity, aluminum, and iron, but above the AO for DOC (Table 3). The water was within the Ontario operational guideline range for pH and alkalinity. SUVA was calculated at 2.0. SUVA is a relationship between the measurement of DOC and UVa, and acts as an operational indicator of the organic composition and provides the expected DOC removal using the coagulant aluminum sulphate (alum) (Edzwald and Tobiason 1999). The SUVA value obtained from the raw water DOC and UVa estimates the composition and the expected percentage of DOC removal (Table 4). The formula for SUVA is described below.

$$SUVA = \frac{UV\ abs\ (cm^{-1})}{DOC\ (\frac{mg}{L})}\ X\ \frac{100\ cm}{1\ m}$$

Table 4. Guidelines for Organic Composition and DOC removal with coagulation

SUVA	Composition	Coagulation Removal	DOC Removal
≥ 4	Mostly aquatic humic Hydrophobic, high MW	Good	≥ 50%
2 – 4	Mixture of humics and non- humics	Fair – Good	25 – 50%
≤ 2	Mostly non-humics, hydrophilic, low MW	Poor DOC	≤ 25%

(Adapted from Edzwald and Tobiason 1999).

It is expected that the composition of organics in Lake Helen are mostly non-humic, hydrophilic compounds of low molecular weight based on the SUVA calculated value. In this case, the expected DOC removal is ~ 25% when using alum and conventional treatment as hydrophilic compounds have a tendency to remain dissolved in water. SternPac typically yields better results in comparison to alum; however, when poor DOC removal is expected from coagulation, enhanced coagulation is not often recommended as an optimal solution for the removal of organics.

4.1.2. Jar Tests

Overall, SternPac performed better than the Ferric Chloride regardless of the concentration of the dose when considering all the parameters tested. The apparent optimal dose for SternPac fell between 15 - 20 mg/L as it had the lowest DOC (Figure 4) and aluminum residual. Additionally, the turbidity (Figure 3) and UVa (Table 5) reached the point of diminishing return around the apparent optimum.

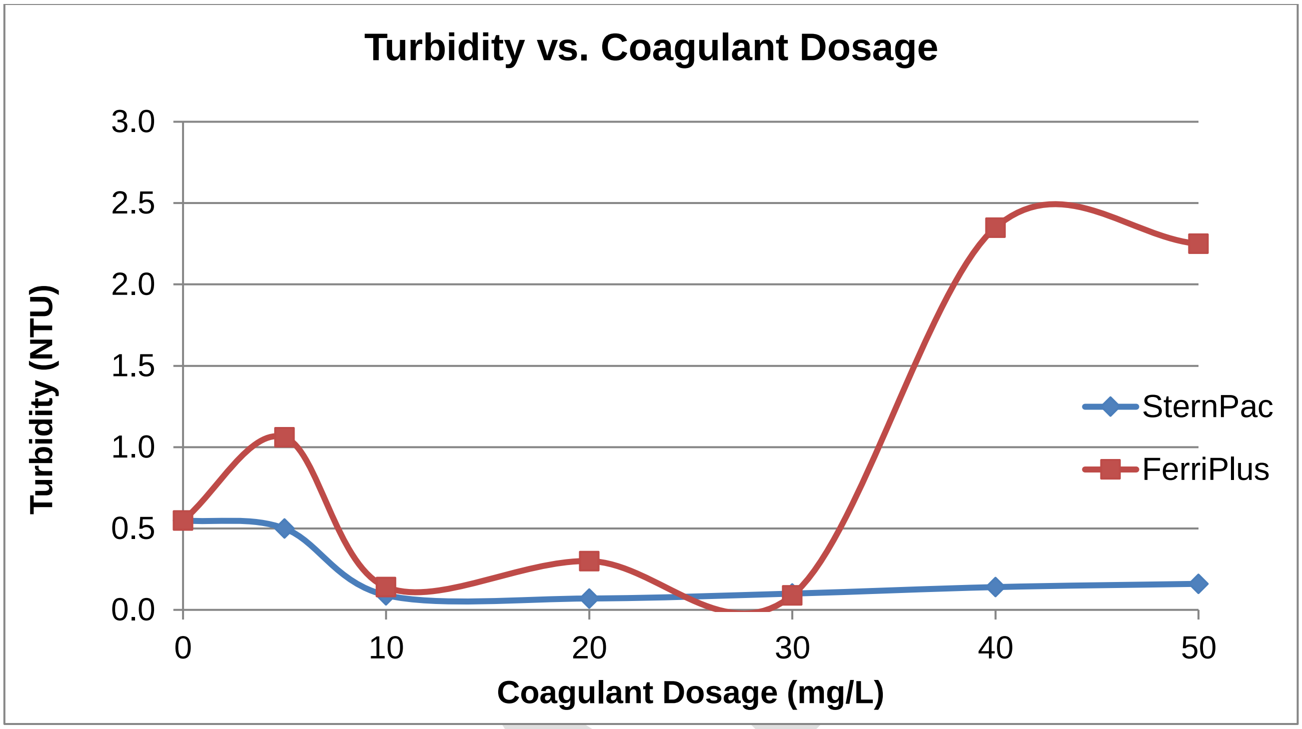


Figure 3. Turbidity vs Coagulant Dose

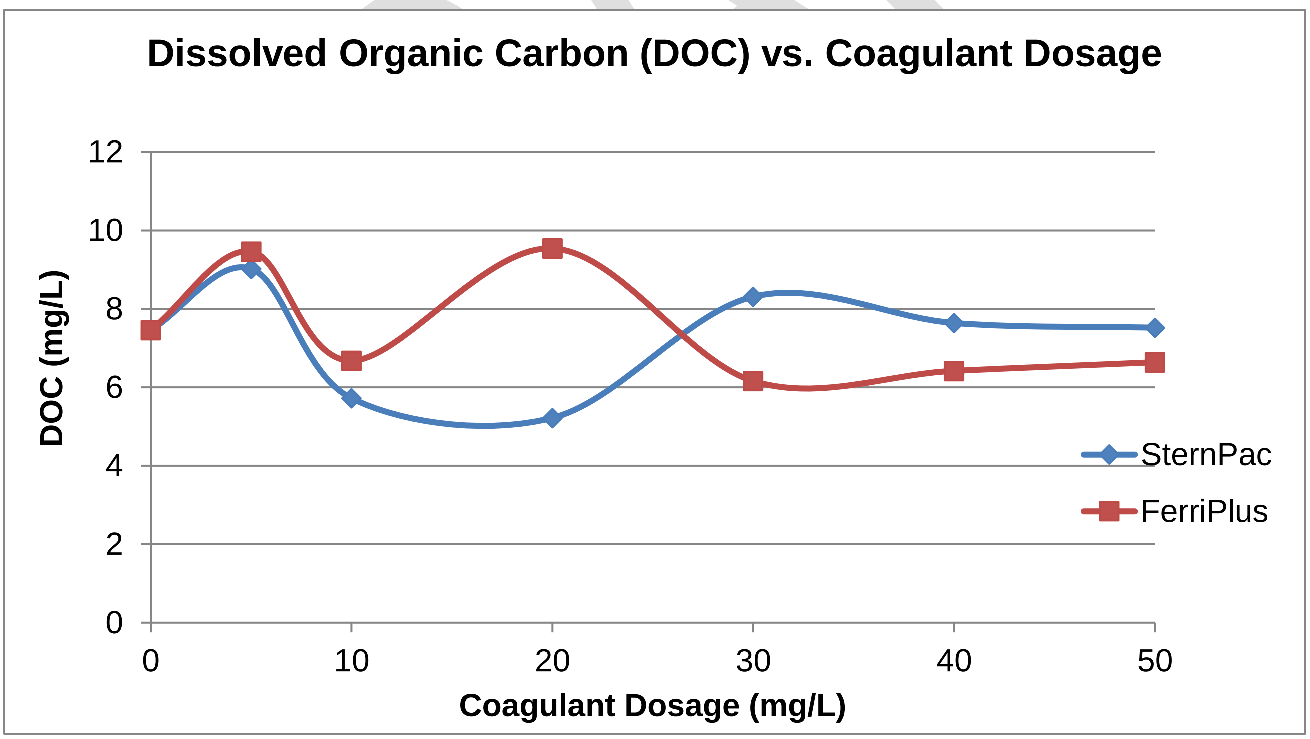


Figure 4. DOC vs Coagulant Dose

Table 5. Jar Test Comparison of Water Characteristics

Parameter	Raw	WTP	SternPac	Ferric Chloride
Coagulant Dosage (mg/L) DW	0	14	20	10
Turbidity (NTU)	0.55	0.10	0.07	0.14
DOC (mg/L)	7.46	3.02	5.22	6.68
UVa (cm^{-1})	0.151	0.044	0.041	0.050
pH	6.68	6.15	6.89	6.52
Dissolved Aluminum (mg/L)	0.013	0.018	0.012	-
Dissolved iron (mg/L)	0.060	-	-	0.11
Filter pore (µm)	-	0.04	0.45	0.45

Table 5 summarizes the results from the jar tests and compares them to the WTP performance. The DOC removal at the Lake Helen WTP was 60 %, which is much greater than the expected ~ 25% DOC removal from the SUVA calculation. There was 30% DOC removal using 20 mg/L of SternPac with a 0.45 µm filter, suggesting that ~ 2 mg/L of the DOC was dissolved, hydrophilic, and between 0.04 and 0.45 µm in size.

SDS DBP tests were completed on the treated water from the jar tests for the maximum dose recommended by the membrane manufacturer and the apparent optimum dose based on the results for SternPac and FerriPlus coagulants (Table 6). It was found that FerriPlus produced less disinfection by-products compared to SternPac for the same coagulant doses; and the apparent optimum dose of 30 mg/L produced less DBPs compared to the maximum recommended dose of 10 mg/L. At the time of sampling, the WTP was operating at 14 mg/L which was above the maximum of 10 mg/L but below the apparent optimum from the jar test.

Table 6. Effects of Detention Times on SDS DBP Tests

Sources	Coagulant Dose	Time (days)	HAA (µg/L)	THM (µg/L)
			Rep 1	Rep 1
Lake Helen WTP	14 mg/L	6	49	94
		8	53	106
		10	48	113
Jar Test SternPac	10 mg/L	6	63	125
		8	59	135
		10	67	131
	20 mg/L	6	42	75
		8	44	95
		10	40	97
Jar Test FerriPlus	10 mg/L	6	49	81
		8	50	95
		10	50	105
	30 mg/L	6	33	42
		8	35	52
		10	35	52

[1] On January 1, 2020, O. Reg. 169/03, Schedule 2 is to be amended by adding a MAC for HAA

[2] Expressed as a running annual average of quarterly results

Figure 5 shows duplicate results of various estimated detention times and the effect on DBP formation of the WTP treated water. The results show that the DBP formation increased with detention time; where 6 days was below the MAC and 8 and 10 days were above the MAC for THMs.

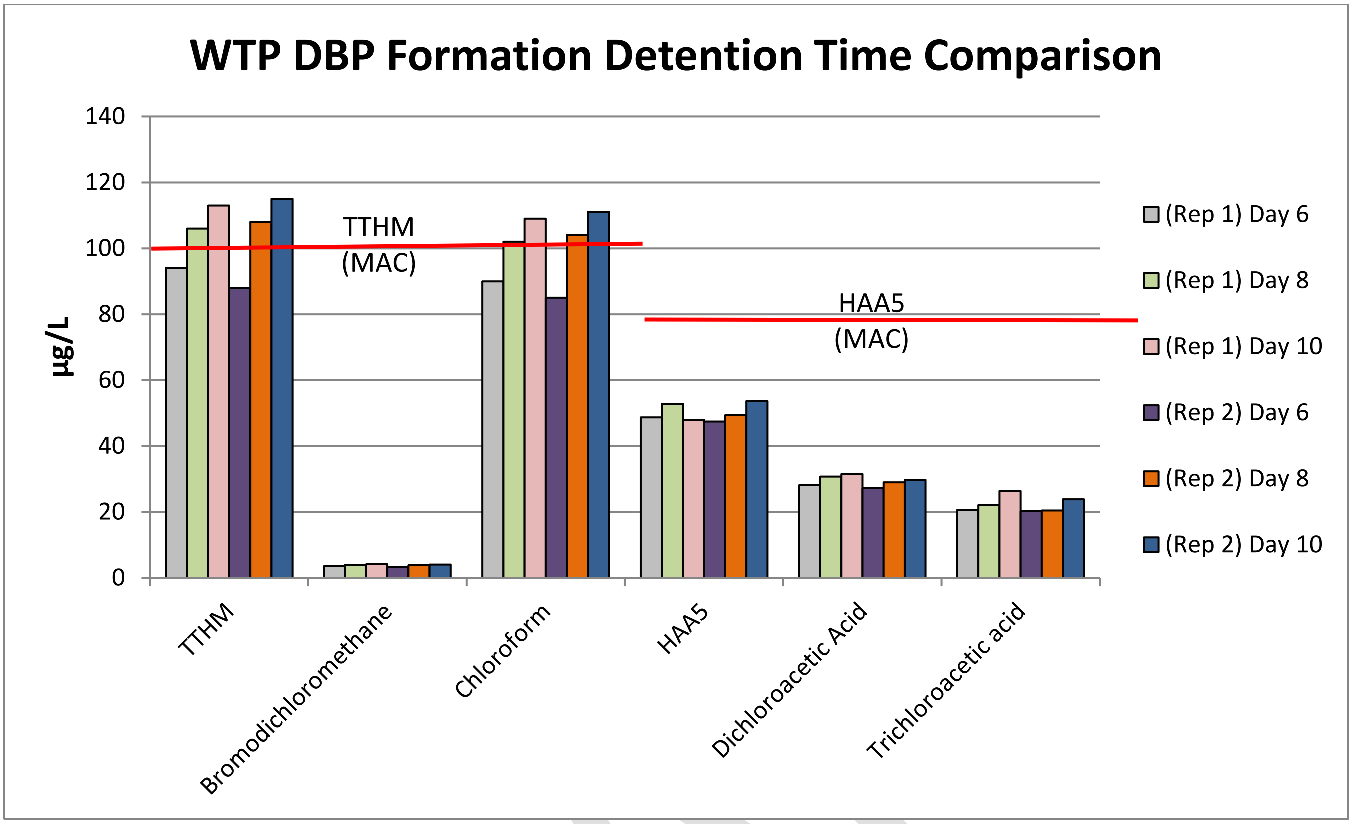


Figure 5. Effects of Detention Times on WTP Effluent SDS DBP Formation

4.2. Phase 2: Pilot Scale Study

The Raw, WTP and GAC filters were monitored for UVa frequently, and monthly grab samples (Table 7) were taken for SDS DBP tests over a 4-month period from August 20th to December 10th, 2019. The grab sample SDS DBP tests estimated the WTP THM and HAA results were near or above the respective MACs during the sampling period. The WTP DOC levels were > 3.0 mg/L and UVa was > 0.05 cm^{-1} during the sampling period.

The recommended empty bed contact time for the GAC media filters was 10 min for best performance. The bituminous (GAC1) and coconut (GAC2) activated carbon filters were run intermittently at 7 min empty bed contact time to estimate peak capacity performance. The THMs and HAAs were below their respective MACs in all GAC1 grab samples; the DOC was < 2.0 mg/L and the UVa was ~ 0.030 cm^{1}. The GAC2 filter performed similarly and was also below the MACs for THMs and HAAs, but had slightly higher DBPs, DOC (~ 2.5 mg/L) and UVa (~ 0.04 cm^{-1}).

Table 7. Pilot Grab Sample SDS-DBP Results

Date	Sample	DOC (mg/L)	UVa (cm^{1})	Cl_2 Dose (mg/L)	Immediate Cl_2 Residual (mg/L)	8 Day Cl_2 Residual (mg/L)	THM µg/L	HAA µg/L
	WTP	3.3	0.048	2.94	2.56	0.06	122	66.2
Aug. 20,	GAC1	1.34	0.013	2.94	2.80	1.55	55	27.9
	GAC2	1.24	0.017	2.94	2.76	1.22	63	30
Oct. 8	Raw	5.74	0.134	-	-	-	-	-
	WTP	3.22	0.051	2.94	2.76	0.35	108	77.4
	GAC1	-	-	-	-	-	-	-
	GAC2	1.68	0.026	2.94	2.82	1.15	68.1	40
Nov. 6	Raw	5.92	0.151	-	-	-	-	-
	WTP	3.54	0.061	3.03	2.42	0.06	148	77.2
	GAC1	1.82	0.028	3.03	2.52	1.24	75.4	43.7
	GAC2	2.3	0.026	3.03	2.54	1.13	87.8	54.6
Dec. 10	Raw	5.82	0.142	-	-	-	-	-
	WTP	3.52	0.056	2.94	2.49	0.33	107	80.4
	GAC1	1.96	0.030	2.94	2.55	1.31	75	45.8
	GAC2	2.54	0.039	2.94	2.16	1.03	85	49.6

The results from the grab sample SDS DBP tests in Table 7 were applied to a quadratic polynomial to best fit the relationship between DOC and UVa for the water system. The equation and R^2 value of 0.9881 can be found in Figure 6. The model was used to predict the amount of DOC using UVa, and subsequently the potential formation of DBPs. The UVa was frequently monitored continuously as a surrogate for DOC; and was input into the quadratic equation (Figure 6) to estimate the level of DOC during the pilot study. From the December 10th grab sample of the GAC2 (coconut) filter, it can be estimated that ~ 0.04 cm^{-1} would equal ~ 2.5 mg/L of DOC and would produce ~ 85 µg/L and ~ 50 µg/L of THMs and HAAs respectively with a chlorine dose of ~ 3.0 mg/L and final chlorine residual of ~ 1.0 mg/L; therefore, ≤ 0.04 cm^{-1} could be considered a water quality target as a rule of thumb, labelled by the red line (Figure 6).

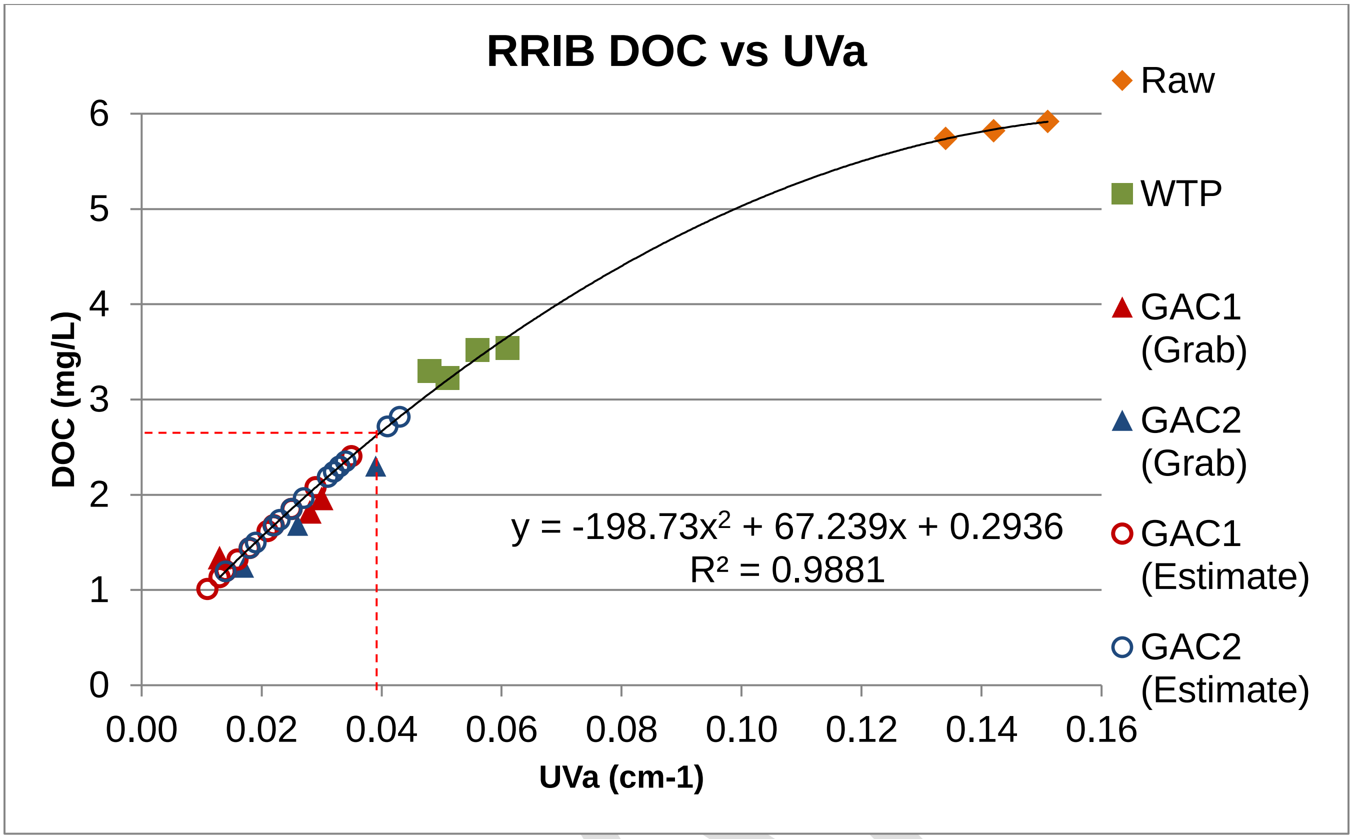
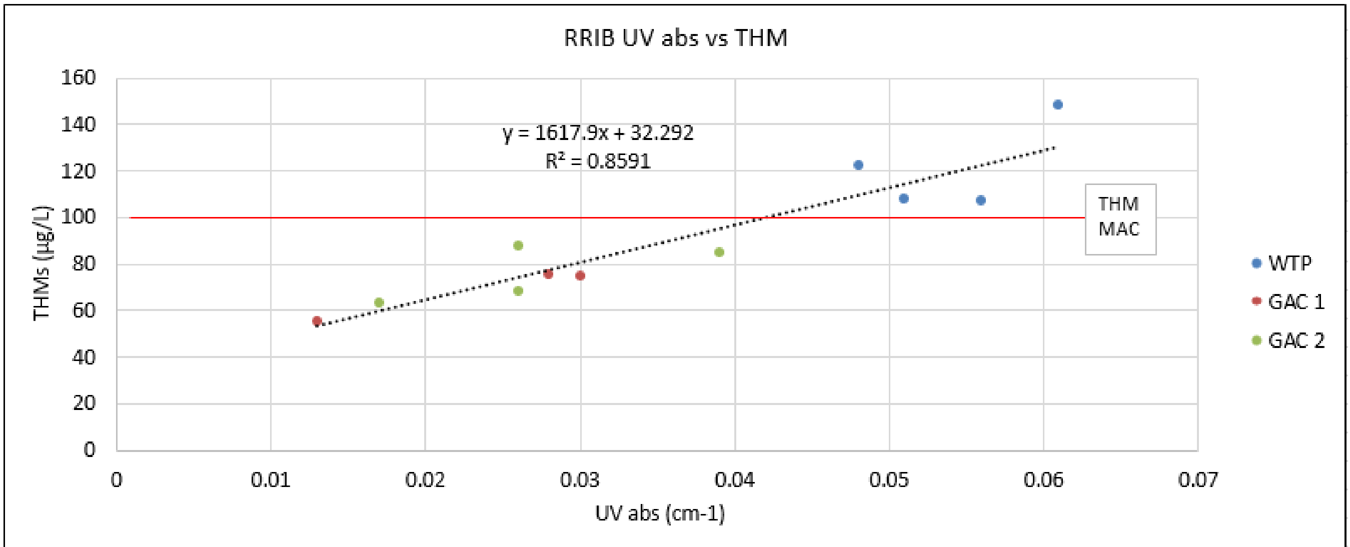


Figure 6. Estimating DOC using UVa Model

Using the quadratic model, it is estimated that two readings from GAC2 (coconut) filter were > 0.04 cm^{1} during the pilot operation. It is estimated that grab samples would have likely measured above the target rule of thumb for DOC; subsequently, it would be expected that the DBPs would be approaching the MAC for THMs, based on the grab samples previously conducted.

Two graphs were created using the results from the grab samples to illustrate the relationship between THMs vs DOC and UVa (Figure 7). The general trend for both relationships indicated they had a similar slope and R^2 value, meaning either DOC or UVa could be used as an indicator for water quality to estimate the expected DBP formation in the treated water. As previously discussed, if the UVa is approximately ≤ 0.04 cm^{-1} or the DOC is ≤ 2.5 mg/L, than it is estimated that the THMs would likely be below the MAC for 8 days of contact time with ~ 3 mg/L of chlorine dosed. Additionally, when the DOC and UVa are lower, the chlorine demand also decreases over the detention time, meaning less chlorine will likely be needed to maintain desired chlorine residuals in the distribution system.



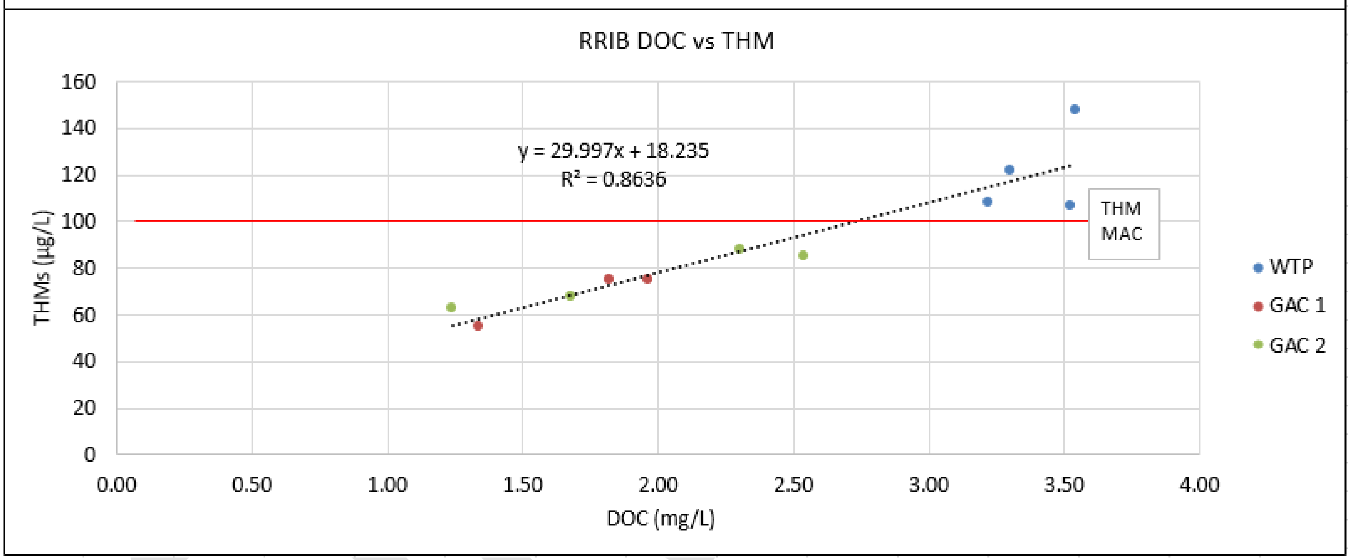


Figure 7. THMs vs UVa; and DOC

5. Conclusions

SternPac performed more effectively than the other coagulant at removing turbidity and DOC for the existing water treatment process. The WTP coagulation and filtration process performed better for DOC removal than what could be produced on the bench scale level; however, the jar test indicated that DBPs were lower in samples that had 20 mg/L of coagulant despite having higher DOC values. The results from the jar tests indicate increasing the coagulant dose up to 20 mg/L may help to reduce organics and DBPs; however, the design of the plant restricts the coagulant dose to ~ 10 mg/L to prevent membrane fouling. Consultation with the manufacturer regarding increasing the coagulant dose beyond the recommended maximum should be conducted prior to changing operations.

The low SUVA value in the raw water source indicated that seasonal changes in the DOC may not be represented well by changes in the UVa because a large portion of the DOC in this source water did not absorb UV light. Despite the low SUVA relationship, a quadratic model using UVa and DOC was fit with a high R^2 value using water quality grab sample results to monitor and estimate the potential to form DBPs based on the real-time UVa monitoring. A target UVa value was established to predict in real-time, the estimated DBP concentration in the distribution system.

GAC post membrane filtration was effective at reducing the amount of DOC in the treated water at estimated peak capacity, ultimately reducing the formation of DBPs in the simulated distribution system. The bituminous GAC filter performed better than the coconut GAC filter as it reduced the DOC by ~ 0.6 mg/L more after around four months of operation. The life expectancy of the GAC filters was undetermined in this study.

An additional strategy conducted in this study determined that reducing the detention time of the treated water in the distribution system could also be an effective measure to reduce DBP formation in the system. If operationally feasible, reducing the retention time between 6 and 8 days would help reduce the DBPs.

DBPs were reduced by adjusting the coagulant dose to target DOC, adding GAC filtration after membrane filtration, and reducing the detention time in the distribution system. Regular sampling of the UVa was an important monitoring tool to indicate water quality and treatment performance in real-time.

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