2016

Pilot Study of Water Treatment Technologies for Van Anda Improvement District

PREPARED FOR: VAN ANDA IMPROVEMENT DISTRICT

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TABLE OF CONTENTS

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List of Tables and Figures

Tables

Figures

Executive Summary

This document serves as a comprehensive summary on the development, operation, and results of a water treatment pilot study conducted at Priest Lake, BC, by *RES'EAU-WaterNET* between fall 2015 and spring 2016. The investigation represents a thorough comparative evaluation of several water treatment technologies based upon their performance and practicality for this location. The objective of this unique approach was to successfully pilot various treatment processes that will eventually emulate a full-scale treatment facility. The purpose of this study was to assess and evaluate water treatment technologies to find a feasible and sustainable solution to treat water from Priest Lake to produce clean and safe drinking water.

The pilot plant facility was deployed to Priest Lake in Van Anda Improvement District (VAID) containing several water treatment technologies to improve the community's water quality; filtration, ion exchange, activated carbon and UV disinfection. Specifics of each technology and respective results are provided in detail in chapters 2 and 3. The pilot plant operated from August 29th, 2015 to March 30th, 2016. Water samples were collected before and after each process to monitor water quality parameters and assess the performance of each technology.

Over the course of the pilot study, a series of experiments were conducted with water treatment technologies to investigate their efficacy of treating Priest Lake water. The experiments were performed with individual technologies as well as combinations of different technologies, in order to assess their individual and combined level of treatment. Based on the results, the most promising treatment technologies included; a bag filter and cartridge filters, which reduced turbidity; ion exchange, which provided a high removal of natural organic matter; and UV disinfection, that results in effective inactivation of coliform bacteria and protozoa. Self-cleaning filter showed low reduction of turbidity and had issues leaking during experiments; nonetheless, it is considered beneficial as a pre-filtration stage for the removal of larger particles and debris entering the treatment system (due to unusual weather events). Granular activated carbon showed high removal of natural organic matter only at low flow rates; hence, does not seem to be a feasible solution to fulfil VAID's daily water usage.

As the project progresses, RES'EAU-WaterNET will continue to work with the VAID Water Board of Trustees, further analyse the results, and carry out detailed feasibility assessment to find a sustainable and achievable water treatment solution to provide safe, clean, and aesthetically acceptable quality potable water to the residents of the VAID community.

1.0 Background

Ensuring safe drinking water in small, rural and First Nation communities has been a challenge throughout North America. Conventional solutions and approaches have proven unsuccessful in many of these communities due to the cost and complexity of well-established treatment processes.

RES'EAU-WaterNET is Canada's first and only cross-disciplinary research network devoted exclusively to developing innovative and affordable solutions for providing clean potable water to small, rural and First Nations communities. *RES'EAU-WaterNET* implements a Community Circle approach to understanding and solving issues within these communities. This model takes research programs out of the laboratory and into the real world through incorporating stakeholders' expertise and insight at the earliest stages of the problem-solving process. *RES'EAU-WaterNET* works closely with the communities to understand the limitations and constraints they face to identify research priorities, design, and execute research programs and produce knowledge based reports with the goal of integrating solutions into the drinking water regulations. These approaches are validated by industry so that they can be readily diffused and adopted elsewhere.

1.1 Van Anda Improvement District

Van Anda Improvement District (VAID) is a community located on Texada Island, a northern gulf island in the Georgia Strait. There are approximately 500 residents and 228 connections in VAID. The community has been struggling to provide potable water to their residents resulting in posting several water board advisories for over a decade. Their water treatment system uses chlorine disinfection with no filtration process prior to chlorine disinfection, which does not comply with 4-3-2-1-0 Drinking Water Objectives outlined below. As a result, boil water advisories are posted frequently during the summer months because coliforms are regularly detected in water samples from the distribution system. The five objectives are to have a water treatment system that meets the following criteria:

- ***4*** log (99.99%) inactivation of viruses with a minimum of 0.5 mg/L of free chlorine after 20 minutes
- ***3*** log (99.9%) removal or inactivation of Giardia and Cryptosporidium
- ***2*** treatment processes minimum for all surface water sources
- ***1*** NTU or less for water going into the disinfection process
- ***0*** CFU/100mL for E. coli detected in a sample of treated water

1.1.1 Water Source

The water source for VAID is Priest Lake situated 1 km southwest of the community. The Fish and Wildlife Branch of the Department of Recreation and Conservation conducted a bathymetric survey of Priest Lake on May 23rd, 1970. From the survey, it showed Priest Lake had a surface area of 45 ha and was the basin for the 1,131 ha Priest Lake watershed. Rainfall, runoff, and Van Anda Creek feed the lake. Priest Lake drains to the northeast via Van Anda Creek into the Malapsina Strait. Texada Island's climate has mild wet winters and warm dry summers. Please note, the survey was completed in 1970 and values are subject to change.

The water source assessment conducted by Alluvia Environmental Services, found human activities within the watershed accelerated erosion and increased sediment levels in Priest Lake. These activities include a limestone quarry, forestry and small-scale metal mines. In addition, the assessment concluded, Alder trees, a type of deciduous tree that heavily populates the Priest Lake watershed, are the cause of the natural organic matter (NOM) content found in Priest Lake. Note, no environmental assessments were conducted to confirm these sources during the course of this study. The sediment level and NOM concentration, both affect the water quality of Priest Lake.

Figure 1.1 *VAID's water source, Priest Lake*

Priest Lake is a sensitive natural habitat that supports an array of wildlife. The stickleback, a rare and endangered species of fish, inhabits the lake. Other animals that live in the surrounding area include western painted turtles, beavers, black-tailed deer and over 200 transient species of birds. Beavers and deer are known to host Giardia and Cryptosporidium, increasing the risk of contaminating Priest Lake (Alluvia Environmental Services, 2004). To preserve the natural state of the lake, recreational activities are prohibited.

Priest Lake's water quality has been monitored since the year 2000 to ensure the lake's unique characteristics are maintained. Below are the average values and standard deviations for water quality parameters measured at Priest Lake, for the period between 2014 and 2016.

Water Quality Parameter	Value
Turbidity	0.77 ± 0.66 NTU
Total organic carbon (TOC)	5 ± 1 mg/L
Enterococci	<1 CFU/100mL
E. Coli	5 CFU/100mL
Total coliforms	526 ± 522 CFU/100 mL

Table 1.1 *Priest Lake water quality*

1.1.2 Water Treatment System

VAID's current water treatment system solely relies on chlorine disinfection to treat water from Priest Lake. Water is fed by gravity into a well through an intake line approximately 100 m from shore at the east end of Priest Lake. A strainer, at the end of the line, prevents large debris from entering. Two submersible pumps feed water from the well to the water treatment system where a 12% sodium hypochlorite solution is dosed into the water to eliminate bacteria. The table below shows the water usage for VAID in 2014 and 2015.

Water Usage	Volume[1]
Annual Total	13,000,000 ± 1,600,000 L
Monthly Average	1,100,000 ± 240,000 L
Daily Min.	24,000 ± 330 L
Daily Max.	66,000 ± 8,300 L

Table 1.2 *VAID Water Usage for 2014 and 2015*

As mentioned, the treatment system does not comply with 4-3-2-1-0 Drinking Water Objectives. For a surface water source, a minimum of two water treatment processes are required. This multiple barrier approach ensures the removal of all contaminants. VAID's chlorine disinfection system does not reduce turbidity or remove NOM from Priest Lake water increasing the possibility of disinfection by products (DBPs) forming and reducing the aesthetics of the drinking water.

Figure 1.2 *Water is gravity fed in to a well and pumped to VAID's water treatment system*

[1] Source: VAID Water Board of Trustee

1.1.3 Distribution System

VAID's distribution system consists of a water storage container, elevated above the community in order to maintain water pressure, and an infrastructure network of pipelines to supply water to the residents of VAID. From the treatment system, water is pumped to a 45,000 gallon cedar wood stave storage tank, and then fed by gravity into the distribution system. While water is flowing through the distribution system, NOM is exposed to chlorine for an extended duration. This increases the potential for chlorine to react with NOM and form DBPs. Table 1.3 shows that there are DBPs forming in the water storage tank after water has been disinfected with chlorine.

Trihalomethane	Units	Tank/Inlet	Tank/Outlet
Chloroform	mg/L	0.032	0.094
Bromodichloromethane	mg/L	<0.001	0.003
Dibromochloromethane	mg/L	<0.001	<0.001
Bromoform	mg/L	<0.001	<0.001
Total Trihalomethanes	mg/L	0.032	0.097

Table 1.3 *DBP analysis conducted by Exova on January 11, 2015*

1.1.4 Challenges in a Remote Community

A remote community on an island has several additional challenges to overcome to access clean drinking water that communities accessible by land do not have to face. Texada Island is surrounded by salt water, which isolates the community from all external drinking water resources. They must completely depend on the island to provide water, and on their water treatment system to produce potable water. The island is only accessible by ferry from Powell River or by aircraft from Qualicum Beach. All of the supplies that are transported to the island have an additional transportation cost associated with them, thereby increasing overall costs of operating and maintaining a system. In addition, both these modes of transportation are heavily dependent on the weather. In times of adverse weather conditions, transportation to the island is temporarily shut down. Furthermore, long-term power outages can occur so the community relies on backup generators to supply power to the water treatment system. Being surrounded by water limits the space on the island. The watershed and water source are pristine and sensitive areas. Any accumulation of waste could potentially contaminate VAID's water source. This means any waste produced from water treatment processes must be well contained and transported off the island to be disposed.

1.1.5 Financing and Governance

Efforts have been made to improve the water quality in VAID, yet funding continues to be a major issue. A Water Board of Trustees, comprised of volunteer community members, manage funds received from taxes and allocate them towards projects to operate and maintain the drinking water system. Taxes may be fixed on the basis of parcels (or connections), groups of parcels, values or areas or any combination of these. Tolls are user charges fixed and payable by all land owners in the improvement district to which a service is provided. Taxes are generally used in conjunction with tolls as a method of cost recovery for direct services such as water (British Columbia Ministry of Community Services, 2006). The demographic of the approximately 500 residents in VAID is comprised of mostly senior residents who receive fixed incomes from their pension plans. Since the income most residents receive is fixed, the Water Board of Trustees is unable to increase taxes to raise capital for projects to improve water treatment systems. In addition, VAID is an improvement district, which means under current policies, the community is only able to access government funding through a regional district representative to upgrade the infrastructure for water systems. If the application is successful, both entities and their communities and businesses must agree that ownership of the system will shift to the Regional District. This could actually increase the overall costs of the project and the improvement district would lose the ownership of the water system (BC Chamber of Commerce, 2015). As a results, the Water Board of Trustees rely solely on the funds from taxes and are seeking alternative solutions to reduce the overall cost to improve their water treatment system.

2.0 Water Treatment Pilot Plant Study

RES'EAU-WaterNET researchers and Van Anda Improvement District (VAID) Water Board of Trustees entered into a collaborative effort to develop a systematic approach to find a robust and sustainable water treatment solution. VAID's current water treatment system uses chlorine disinfection to treat their drinking water. The *RES'EAU-WaterNET* team has had a number of opportunities to meet with VAID and proposed a pilot plant study be conducted at Priest Lake. The pilot plant study would evaluate the performance and operation of proven water treatment technologies using Priest Lake's water.

2.1 Objective and Scope of Work

The objective of the project was to evaluate the effectiveness of proven technologies to treat Priest Lake water. Specifically, the objectives of the project were two-fold:

- Demonstrate the performance of the selected technologies to treat Priest Lake water with the use of an on-site water treatment pilot plant
- Use the gathered data during the water treatment pilot study to produce a technical analysis and feasibility of the technologies

2.2 Community Engagement

RES'EAU WaterNET's Community Circle approach aims at addressing the challenges that small, rural and First Nations communities face in the efforts towards safe potable water. It integrates the community stakeholders into every step of the process to involve them in the process, educate them on the importance of potable water and raise awareness of the current issues with their drinking water. Throughout the pilot study *RES'EAU-WaterNET* researchers regularly met with the VAID Water Board of Trustees to inform them of their activities, discuss results from assessments of water treatment technologies and receive input from the community.

Community Circle Affiliation	Name
VAID Water Board of Trustees	Bob Timms
	Karen May
	Walter Gussman
	Terry Hollo
	Mike Craggs
Water Maintenance	Ken Soles
	Doug
Administrator	Heidi Gable
Drinking Water Officer	Dan Glover
BI Pure Water	George Thorpe
	Jim Tam
	Denis Bouchard
RES'EAU-WaterNET	Madjid Mohseni
	Keyvan Maleki
	David Chan
	Megan Wood
	Adrian On

Table 2.1 *Community Circle stakeholders*

Between January and September 2015, *RES'EAU-WaterNET* team held a number of meetings with the VAID Water Board of Trustees to discuss collaborative opportunities, specify project objectives and scopes, and develop plan of activities.

From September 2015 to March 2016, David Chan, a *RES'EAU-WaterNET* research engineer, attended monthly meetings with the Water Board of Trustees to provide updates on activities regarding the pilot plant study, present recent results from experiments and address any concerns from the trustees.

On 20 February 2016, Dr. Madjid Mohseni, Director of *RES'EAU-WaterNET*, and Keyvan Maleki, *RES'EAU-WaterNET*'s Program Director, travelled to VAID to host an open house for the community members of VAID. Dr. Madjid Mohseni gave a presentation to inform the community stakeholders about *RES'EAU-WaterNET*, discussed the pilot study conducted at Priest Lake, shared major findings from the investigated technologies and answered community members' questions. After his presentation, they led a tour of the pilot plant facility to show community members the setup and the technologies investigated.

Figure 2.1 *VAID Water Board of Trustees and RES'EAU-WaterNET initial meeting at Priest Lake*

Figure 2.2 *Walter Gussman, Heidi Gable, and Bob Timms welcome David Chan to VAID*

Figure 2.3 *VAID Open House - Dr. Madjid Mohseni presenting to community stakeholders*

2.3 Water Quality Parameters

There were four main water quality parameters considered to select appropriate water treatment processes suitable for Priest Lake.

- *Particulate content* - solids measured in terms of turbidity, which detects particles that could potentially serve as a surface to harbor microorganisms, protecting them from disinfection and can entrap heavy metals and biocides (Health Canada, 2015). Sediment in a water source occurs from natural erosion such as rainfall, runoff or creeks carrying soil down the natural gradient and collects in a basin.
- *Natural organic matter (NOM)* - found in source water is primarily derived from natural sources (e.g., vegetation, plants, soils, etc.) and measured in terms of total organic carbon (TOC) or dissolved organic carbon (DOC). NOM is the source of aesthetic issues with drinking water as well as a precursor for disinfection by-products. It also reduces the efficacy of disinfection processes, and adds to the energy requirement and cost of disinfection.
- *Disinfection by-products* (DBPs) - are formed from NOM reacting with chlorine and proportionally increases in concentration as DOC concentration increases (Stringfellow, 2009). Haloacetic acids (HAAs) and trihalomethanes (THMs) are two groups of potentially harmful and regulated DBPs (United States Environmental Protection Agency, 2014). Guideline for Canadian Drinking Water Quality (GCDWQ) sets maximum allowable concentration of 80 µg/L and 100 µg/L for HAAs and THMs, respectively (Health Canada, 2015).
- *Total coliforms and E. coli* - Microbial contamination is determined by the presence of *E. coli* which indicates contamination and potential presence of microorganisms capable of causing gastrointestinal illnesses; pathogens in human and animal feces pose the most immediate danger to public health (Health Canada, 2015).

From these water quality parameters, it was determined that the potential of DBPS forming as a result of the TOC were major factors to consider when selecting new water treatment technologies, as the other water quality parameters were in an acceptable range. From August 2015 to March 2016, the raw water quality was consistent and comparable to historical data.

2.4 Mobile Water Treatment System

The pilot plant contained a number of technologies to assess their effectiveness of treating the water from Priest Lake. There were four main treatment technologies investigated during this pilot study including filtration, ion exchange, activated carbon and UV disinfection. They were contained in a 6 m trailer, shown in Figure 2.4 *Mobile pilot* Figure 2.4, parked next to the water treatment facility for Priest Lake, BC. A CentriPro M05412-01 submersible pump was placed in the well to feed the pilot plant through a 1-inch clear reinforced PVC hose. The submersible pump's maximum feed flow rate for the pilot was approximately 46.7 L/min. As an initial barrier, the water passed through a basket strainer first to remove any large debris. The flow path of the water through the pilot plant could be manipulated to determine different treatment technologies' ability individually and in combination with other treatment processes. The piping throughout the pilot was comprised of PVC Sched. 80.

Figure 2.4 *Mobile pilot plant parked near Priest Lake*

2.5 Filtration

Filtration technologies were assesed individually and in combination to determine the effectiveness of each filter configuration at removing larger particles from Priest Lake water reducing turbidity. The technologies that were assessed included a self-cleaning filter, bag filter and cartridge filters. The self-cleaning filter used a 25 μm stainless steel screen to filter the water and could periodically be backwashed to remove the accumulated debris from the screen. The bag filter technology that was investigated was a 5 μm polypropylene needle felt and monofilament mesh filter bag held in a FLV serives filter vessel. The following cartridge filters made by Calypso Blue contained in two Big Blue housings were assessed; 5 µm nominal cartrdige filter, 1 µm nominal cartridge filter, and 1 µm absolute cartridge filter. Note, a filter with a *nominal* rating is capable of removing up to 90% of the stated particle size compared to an *absolute* rating which is able to remove close to 100% of a given particle size under laboratory conditions. The apparatus allowed filters to be tested individualy or in series. After the basket strainer, the seqeunce of filter technologies was a 25 µm self-cleaning filter, followed by a bag filter and finally two housings for cartridge filters in parallel.

Figure 2.5 *Filtration system in the pilot plant*

2.6 Ion Exchange

The ion exchange process uses Purolite A860 resin to remove NOM from Priest Lake water. NOM is the source of aesthetic issues and a known precursor for DBPs. Two fiberglass vessels, with a 12” diameter x 49” height, each contained a packed bed of resins. Water Specialist 1” Control Valve Series Model: WS1CS valves mounted on the vessels controlled the system’s two stages of operation; treatment and regeneration. An external vessel known as a Saturator was used to contain sodium chloride pellets and dissolve them in water over an extended period to produce a high concentration sodium chloride (salt) solution to inject into the feed stream of the ion exchange process during regeneration.

In the treatment stage of operation, raw water flowed into the annular space of the vessel, passed through the packed bed of regenerated resins, and treated water flowed into the effluent stream. Regenerated resins have chloride ions on the surface. When NOM was in excess in the raw water, chloride ions on the surface of the resins exchanged with NOM ions. Once the surfaces of the resins were saturated, NOM could not absorb onto the resins and broke through the packed bed. The point when NOM removal begins to decrease is known as Breakthrough.

Regeneration is the process of rinsing resins, saturated with NOM, with a salt solution to remove NOM from the surface of the resins and exchange them with chloride ions from the salt solution. In the regeneration stage of operation, automated control valves changed the flow path through four stages. The resins were backwashed, where water was flowed counter-currently through the bed of resins, to expand the bed creating more space between resins. A salt solution flowed down the annular space of the vessel into the spaces where chloride ions diffused and exchanged with NOM on the resins' surface. After passing through the bed of resins, the salt solution containing NOM. Resins were rinsed to remove any remaining salt solution. The system was backwashed again to expand the bed and then finally rinsed with raw water. During the regeneration stage of operation, the effluent was discharged to an external tank and was treated off site.

Figure 2.6 *Ion exchange reactor where the raw water is mixed with the resin*

2.7 Activated Carbon

Activated carbon was investigated during the pilot study to assess its ability to remove NOM from Priest Lake water. As mentioned, NOM is a precursor to DBPs and must be removed prior to chlorine disinfection. The activated carbon block was a HARMSCO WB WaterBetter Carbon Block Cartridge made from coconut shell. There were two types of granular activated carbon assessed, Filtrasorb 300 and Filtrasorb 400. The granular carbon was contained in a canister that inserts into the cartridge housing. Prior to tests, the activated carbon was rinsed several times with distilled water to remove fine activated carbon grains. During the experiments, water flowed upwards through the canister and contaminants were captured in the activated carbon pores. Treated water continued through the packed bed to the effluent stream. The volume of water that is treated by the activated carbon determines the breakthrough point. This occurs when the activated carbon cartridge has become saturated and the concentration of NOM in the effluent stream begins to increase.

Figure 2.7 *Refillable granular activated carbon cartridge (Left) & housing for activated carbon cartridge (Right)*

2.8 UV Disinfection

An amalgam UV disinfection system was investigated to assess its ability to inactivate coliforms in the Priest Lake water. Coupling UV disinfection with chlorination is advantageous because it inactivates bacteria, reduces chlorine concentration required for disinfection, and prevents regrowth potentials of microbes within the distribution system. The technology evaluated was a VIQUA - UVMAX E4 system. It is comprised of two parts; a UV chamber to house the sleeve and UV lamp and a controller to regulate the system. The glass sleeve serves as a protective barrier between water and the UV lamp which inserts into the sleeve. The controller has three functions; providing power to the UV lamp from a power supply, tracking the remaining operating time for the UV lamp and raising alarms if there was an error with the system. During the UV disinfection process, water flowed into the annular space between the sleeve of the lamp and the outer chamber. Water was exposed to ultraviolet light from the UV lamp with a wavelength of 254 nm. The energy from the light causes the DNA in a bacterial cell to mutate preventing it from replicating and contaminating the water. UV dosage is dependent on the intensity of the UV lamp and the flow rate of water. A minimum UV dosage of 40 mJ/cm^2 is typically used to ensure all coliforms are inactivated.

PATHOGENIC BACTERIA	
E. coli	6.6 mJ/cm^2
PATHOGENIC VIRUSES	
Poliovirus	7 mJ/cm^2
Hepatitis A	8 mJ/cm^2
PROTOZOAN CYSTS	
Giardia lamblia	10 mJ/cm^2
Cryptosporidium	$<$10 mJ/cm^2

Table 2.2 *UV dose requirements for up to 4-log (99.99%) inactivation of micro organisms*

Figure 2.8 *Housing for activated carbon cartridges*

2.9 Electrocoagulation

Electrocoagulation, a novel electrochemical technology, was investigated to assess its ability to remove NOM from Priest Lake water. Sean McBeath, a graduate student at UBC, designed a flow-through reactor, seeking to find an alternative method to the traditional addition of coagulant, known as chemical coagulation. He has conducted extensive experiments in the laboratory at UBC and required larger volumes of water containing NOM to evaluate the process at higher flow rates. VAID is the first place electrocoagulation has been tested, as a continuous process, at the pilot scale.

The electrocoagulation apparatus isolates specific parameters to determine their effectiveness at NOM removal. The following parameters were varied; metal loading, current density and inter-electrode gap. Untreated water was fed into the process via a Masterflex I/P Precision Process drive with high performance head 650 rpm peristaltic pump. It flowed through a baffle to minimize localized flow over the electrode surface. It then flowed between the electrodes, and exited over an additional baffle. An electrical current was applied using an external DC power source (Keithley 2260B-30-72 720W), connected to the electrodes causing the iron electrode dissolution of iron cations. A coagulation reaction occurred between iron cations and hydroxide anions synthesized at the cathodes, by reduction of water, forming coagulant species which then interact with NOM forming flocs that were removed downstream with a 5 µm bag filter.

Figure 2.9 *Electrocoagulation chemical cell (Left) & Complete electrocoagulation process (Right)*

2.10 Sampling

Water samples were collected from the pilot plant facility and delivered to BC Center for Disease Control (BCCDC), the University of Laval and the University of British Columbia (UBC) for analysis. Samples were collected using sterile bottles coated with dechlorinating agent (for microbiological analysis) and laboratory-grade bottles (for physiochemical analysis). Samples were transported in coolers with ice packs and taken to the corresponding university for analysis. Samples were analyzed within 24 hours when microbiological analyses were conducted.

Samples were taken from raw Priest Lake water, and effluent water (treated) from the various treatment processes (eg. post filtration, ion exchange, activated carbon and UV disinfection). Parameters measured were: pH, turbidity, ultraviolet transmittance, dissolved organic carbon (DOC), total coliforms, *E. coli*, and disinfection by-products (DBPs). All of the physicochemical water quality analyses were conducted following Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Microbiological analysis (total fecal coliforms and *E. coli*) was conducted following the EPA Method 1604, which detected total fecal coliforms and *E. coli* in 24 hours (APHA, 2012). DBPs (THM and HAA) were detected according to a modified US-EPA 552.2 method (APHA, 2012).

2.11 Challenges associated with activities

As with all fieldwork, a variety of unforeseen challenges were expected when executing such a highly technical work with limited resources. The challenges associated with running the pilot plant were regularly quickly resolved to ensure that results were not compromised. Often the challenges were associated with the automation of the pilot system and were not indicators of the applicability of the treatment processes.

A number of challenges were encountered when conducting the pilot study. Poor weather conditions caused accessibility issues to the site. Mechanical challenges were also encountered when the pilot plant facility was operational. Resins leaked from the vessel of the ion exchange process during regeneration into the discharge line feeding into the external tank several times during the study. This issue was resolved by installing screens at the top and bottom of the vessel. Turbidity increased from the feed stream of the 25 µm self-cleaning filter. Performing a diagnostic check led to the discovery of a dent in the stainless steel screen, this prevented the cleaning mechanism from functioning properly. After reassembling the filter, it leaked several times before sealing properly. Fouling occurred in a granular activated carbon cartridge resulting in a decreased flow rate. Changing the cartridge to a new type and using a V-slot ball valve to better control the flow rate enabled experiments to continue.

3.0 Results and Discussion

In this chapter, we present the results and findings related to the performance of each technology and the implications associated with such results on the overall treatment process.

3.1 Filtration

3.1.1 Filtration - Initial Filtration Test

Initial filtration tests were conducted to determine turbidity reduction of filtration process on August 25th, 26th and 31st, 2015. The tests consisted of isolating individual filtration processes and running combinations of the filters in series to assess which combination of filters was the most effective at removing suspended particles from the raw lake water. Each experiment was one hour in duration with a flow rate of 17 L/min. Samples were taken pre and post filtration at the beginning and end of each experiment. Turbidity and UV transmittance were measured on site and dissolved organic carbon (DOC) was measured at the University of British Columbia. The filters that were investigated were a 25 µm self-cleaning filter (SCF), a 5 µm bag filter (BF), and a 1 µm cartridge filter (CF) and a 5 µm CF that are in parallel.

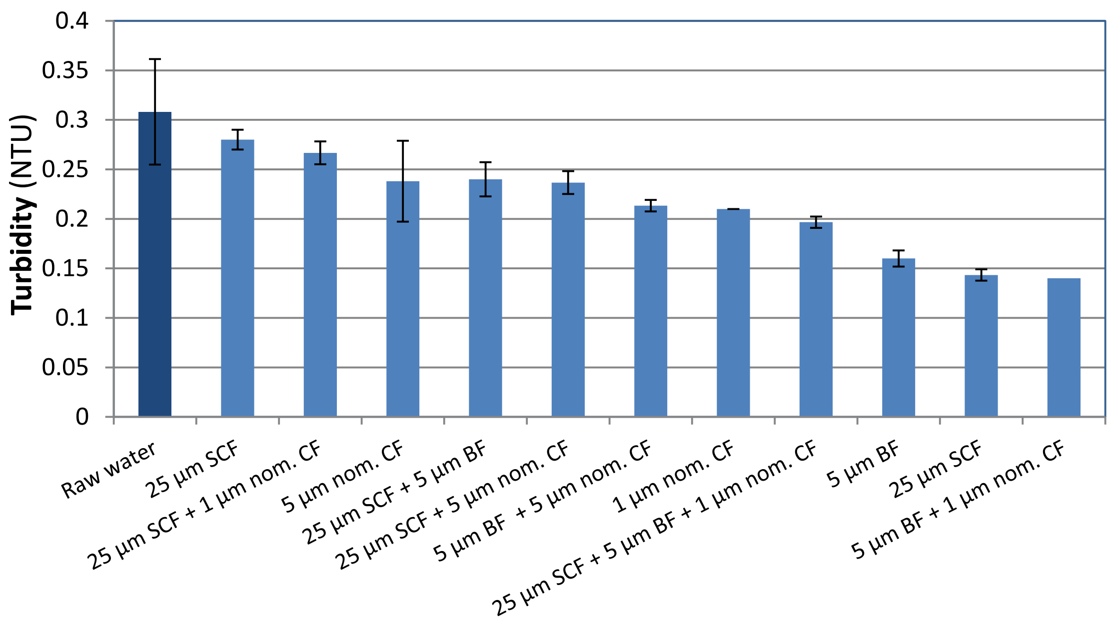

Figure 3.1 *Turbidity results for initial filtration experiment*

As shown in *Figure 3.1 (as well as earlier in Table 1.1)*, Priest Lake water contains very low turbidity and relatively high dissolved organic (DOC) content. The results of the filtration tests (*Figure 3.1*), from August 25th, 26th and 31st, indicate that the 25 µm SCF did not reduce turbidity compared to the 5 µm BF, 1 µm CF and 5 µm CF which all reduced turbidity to very small extent. It should be noted with such low turbidity in the raw water, one would not expect significant reduction of turbidity anyway. Also, as expected none of the filters provided significant reduction of the dissolved organic carbon concentration.

3.1.2 Filtration - Second Filtration Test

The second filtration test was conducted on December 15th, 2015 to determine its ability to reduce turbidity. As a pre-treatment, combinations of filters were used to remove larger particles from the raw water. Each filter combination was tested for 10 minutes and each test had a duplicate run at a flow rate of 45 L/min. Samples were taken downstream of the filters after each test. Turbidity was measured on site.

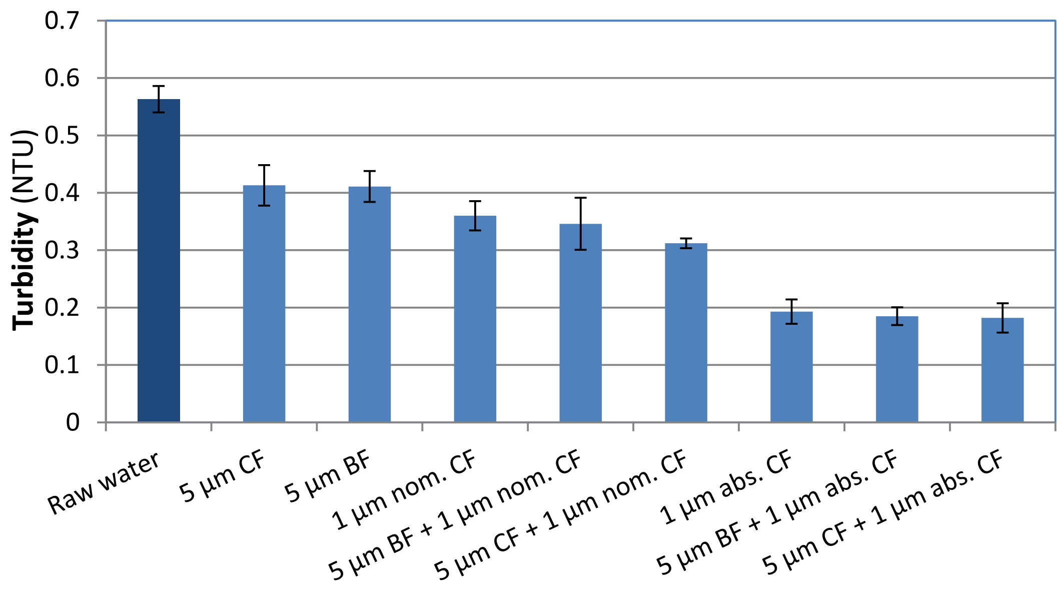

Figure 3.2 *Turbidity results for second filtration experiment*

Figure 3.2 shows turbidity of the raw water from Priest Lake and filtered water after each filter combination. The filter combinations are in order, from left to right, from lowest reduction in turbidity to the highest reduction in turbidity. The 5 µm BF and 5 µm CF performed relatively similarly, reducing turbidity by 0.15 NTU. The 1 µm nominal CF by itself or downstream of the 5 µm BF or the 5 µm CF reduced turbidity by 0.20 NTU. The 1 µm absolute CF, by itself or downstream of the 5 µm BF or 5 µm CF, reduced turbidity the most by approximately 0.40 NTU.

3.2 Ion Exchange

3.2.1 Ion Exchange - Initial Organic Removal Experiment

The initial organic removal experiment was conducted with fully regenerated resins, on November 19th, 2015 to assess the maximum capacity of the ion exchange process to remove NOM from the Priest Lake raw water. As a pre-treatment, the 25 µm SCF was used to remove larger particles from the raw water. The experiment was conducted for 7 hours at a feed pressure of 32 psi and a flow rate of 7.4 L/min. Over the course of the experiment, 3,100 L of water was treated by the ion exchange process.

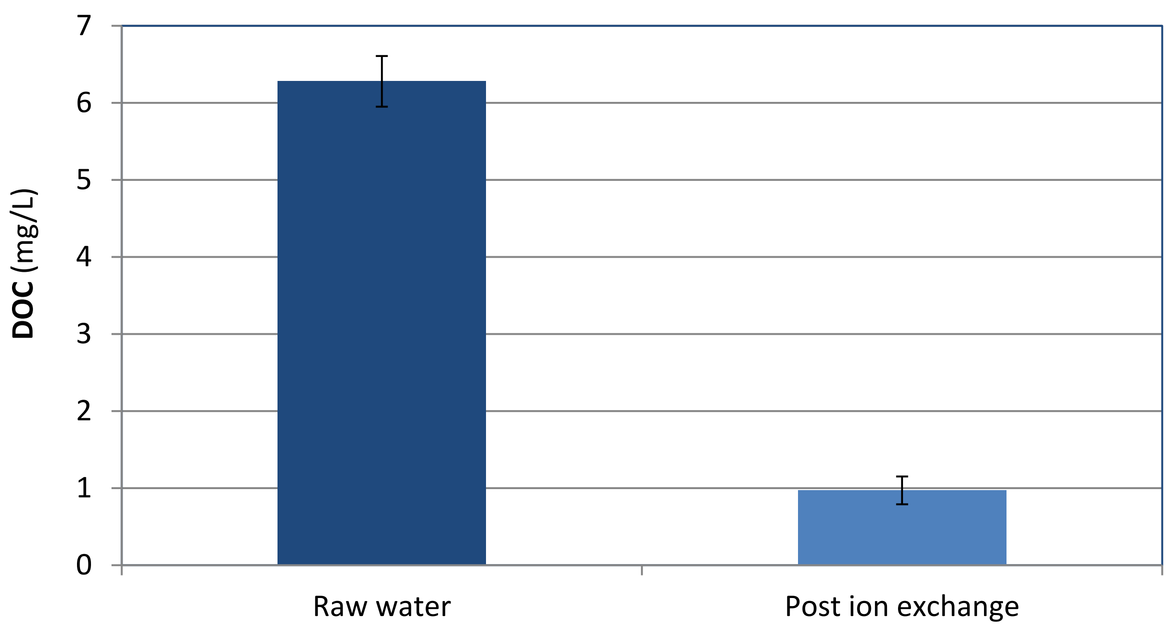

Figure 3.3 *DOC results for initial organic removal experiment with ion exchange process*

Figure 3.3 shows the dissolved organic carbon, DOC, of the raw water stream and the ion exchange treated water. The results show clearly that the ion exchange process is able to effectively remove NOM from the Priest Lake raw water, with an organic removal of 84%. This level of treatment will bring the quality of the water to the level suitable for effective and safe application of UV and chlorine as disinfection processes.

3.2.2 Ion Exchange - Breakthrough Experiment

A full-cycle breakthrough experiment was conducted on the ion exchange process from November 23rd, 2015 to December 3rd, 2015. The objective of this test was to determine the extent and level of treatment achieved through the ion exchange process before the resins become saturated and require regeneration. The experiment was conducted for 40 hours at a flow rate of 20.3 L/min and a feed pressure of 35 psi. A nominal 1 µm CF was used as pre-treatment to remove larger particles from untreated water. The increased flow rate (compared to the initial test) was used to better represent the actual operation of the system, and also to push the system to the limit in terms of performance. During this experiment, 48,720 L of water was treated by the ion exchange treatment system.

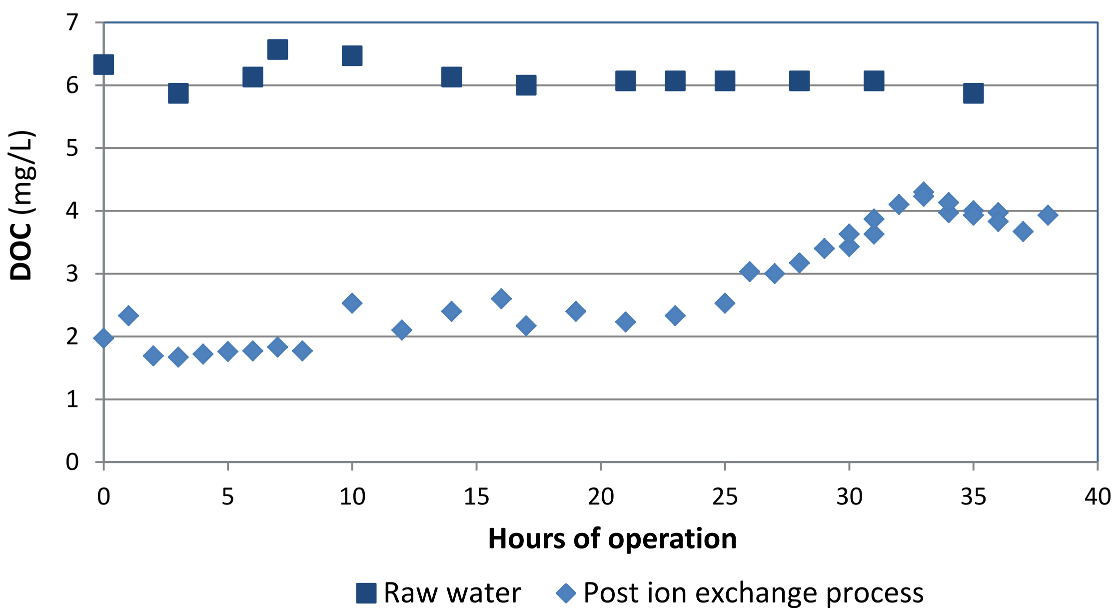

Figure 3.4 *DOC results for breakthrough experiment with ion exchange process*

Figure 3.4 shows the DOC results for raw water and treated water after ion exchange process, over the course of the experiment. Initially, the ion exchange process began the experiment with an organic removal of 70% for over 10 hours of operation (treating approximately 10,000 L of raw water), and gradually decreased to an organic removal 33% after 40 hours of operation (this remained the same for another several hours). For the results shown in *Figure 3.4*, the ion exchange process begins to show signs of breakthrough after 25 hours, or after treating approximately 30,000 L of water. At this point, the system would likely require regeneration.

3.2.3 Ion Exchange - Replicate Breakthrough Experiment

A second full-cycle breakthrough experiment was conducted with the ion exchange process from December 14th to December 18th, 2015 to replicate the first breakthrough test and confirm the level of treatment before the resins become saturated. The experiment was conducted for 37 hours at a flow rate of 20.3 L/min and a feed pressure of 34 psi. A 1 μm nominal CF was used as a pre-treatment to remove larger particles from the water. During the experiment, 43,300 L of water was treated.

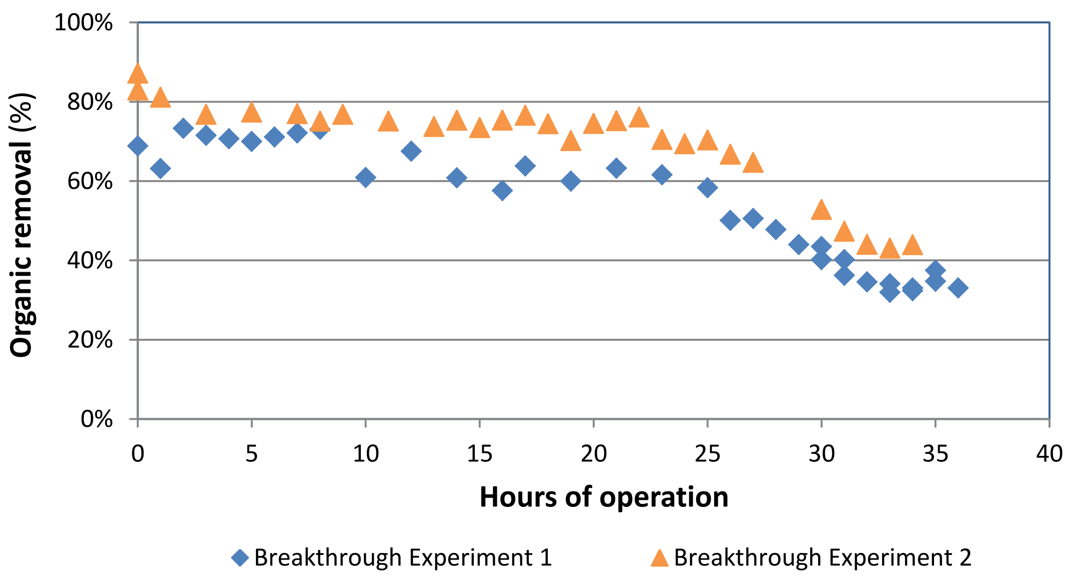

Figure 3.5 *Percent of organic removal of both breakthrough experiments conducted with ion exchange process*

Figure 3.5 shows the percent of organic removal from the first and second breakthrough experiments. During the second breakthrough experiment, for approximately 25 hours of operation (treating about 30,000 L of water), the ion exchange process had an organic removal of greater than 70%. At 25 hours of operation, there were signs of breakthrough and the organic removal gradually reduced to 43%. The ion exchange process performed similarly during the two breakthrough experiments showing signs of breakthrough at approximately 25 hours of operation. The results show the repeatability of the ion exchange process and its robustness in removing NOM, and improving the quality of water for downstream disinfection with UV and/or chlorine.

3.2.4 Ion Exchange - Reduction of Disinfection By-products

An experiment was conducted on 16 February 2016 to quantify the efficacy of the ion exchange process at reducing the formation of disinfection by-products (DBPs). The ion exchange process was operated for 10 hours at a flow rate of 20.2 L/min with a 5 µm CF as pre-treatment. Samples were collected from the following locations; raw water, post ion exchange process, post UV disinfection, post ion exchange process in series with UV disinfection and 8 sample sites in VAID. Samples from the community were collected in vials containing dechlorinating agent to prevent chlorine from further reacting with NOM. Samples collected from the VAID distributions system (8 sites in total) and the pilot plant were analyzed for disinfection by-products (DBPs) and disinfection by-product formation potentials (DBPfps), respectively. For the DBPfp analysis, samples containing NOM (Raw water and post UV disinfection) were dosed with 3 mg/L of chlorine and samples with NOM removed (post ion exchange process and post ion exchange process in series with UV disinfection) were dosed with 1 mg/L of chlorine. After a retention time of 5 hours, samples were analyzed for DBPfps. All the DBP analyses (ie, DBPs and DBPfps) were conducted at Laval University (a partner institution within the *RES'EAU-WaterNET* program).

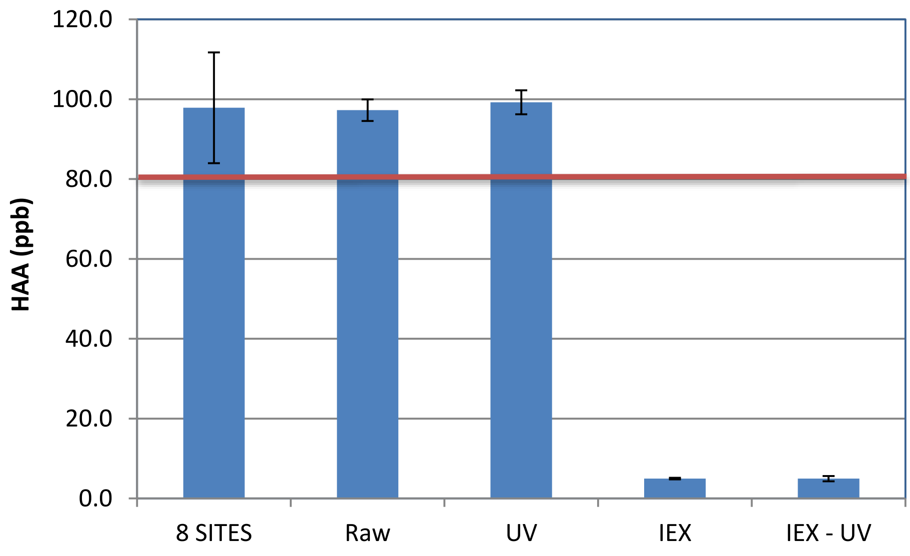

Figure 3.6 *HAA results for experiment with ion exchange process*

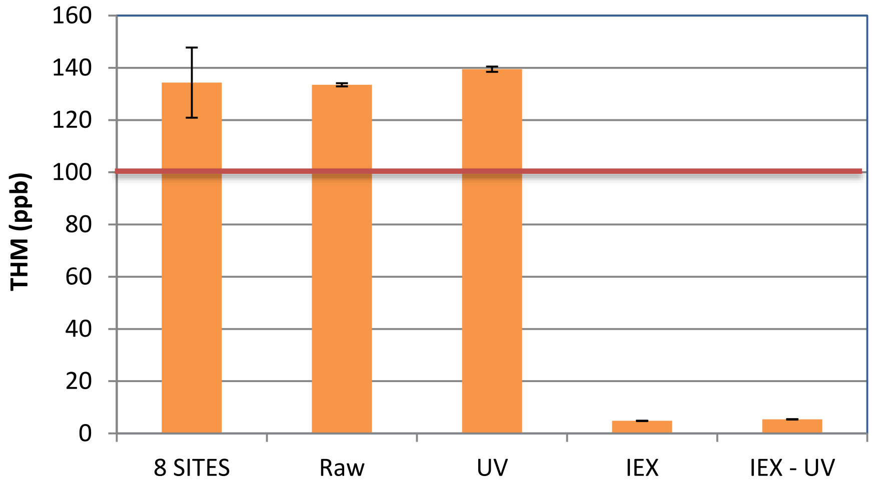

Figure 3.7 *THM results for experiment with ion exchange process*

Figure 3.6 and Figure 3.7 show HAA and THM results of the samples collected from the experiment to quantify the ion exchange process' reduction of DBPs. From the results it shows the current concentration in VAID's drinking water is well above Health Canada's maximum allowance of 80 µg/L HAAs and 100 µg/L THMs. The ion exchange process reduced both, HAAs and THMs, by over 100 µg/L. These results confirm the ion exchange process was capable of significantly reducing DBPs.

3.3 Electrocoagulation

From October 6th - 8th, 2015, pilot-scale electrocoagulation tests were conducted at Priest Lake in VAID. A variety of experiments were conducted in order to investigate the effectiveness of electrocoagulation to remove natural organic matter (NOM) from Priest Lake raw water. Experiments varied the amount of metal coagulant dosed into the water (28-66 mg/L), the current density (1-20 mA/cm^2) applied on the electrodes and the inter-electrode gap (1, 3 and 10 mm), which is the spacing between the electrode plates. All the experiments were conducted at a flowrate of 10 L/min, the final target capacity of the scale-up project.

On site, all samples were analyzed for their ultraviolet transmittance, where a greater percentage correlates to water containing less organic contaminants. Upon returning to UBC, all samples were once again analyzed for UV-absorbance at 254 nm (UV-Abs-254), where a decreasing absorbance correlates to a decrease in NOM. Additionally, samples were analyzed using high performance size exclusion chromatography (HPSEC), which will quantitatively analyze the decrease in NOM using absorbances. Moreover, HPSEC will allow one to see which sized particles are being removed in order to determine whether the technology predominantly removes some particles more so than others do. Finally, samples were analyzed for dissolved organic carbon content, to give an exact measurement of NOM in the water.

3.3.1 Electrocoagulation - Metal Loading Experiment

A metal loading experiment was conducted with the electrocoagulation process to determine the efficacy of metal loading at removing NOM. An electrical current was applied using an external DC power source connected to the electrodes causing the iron electrode dissolution of iron cations. A coagulation reaction occurred between iron cations and hydroxide anions synthesized at the cathodes, by reduction of water, forming coagulant species which then interact with NOM forming flocs that were removed downstream with a 5 µm BF. During the experiment, the flow rate was 10 L/min and the current density ranged from 7.35 mA/cm^2 to 17.47 mA/cm^2.

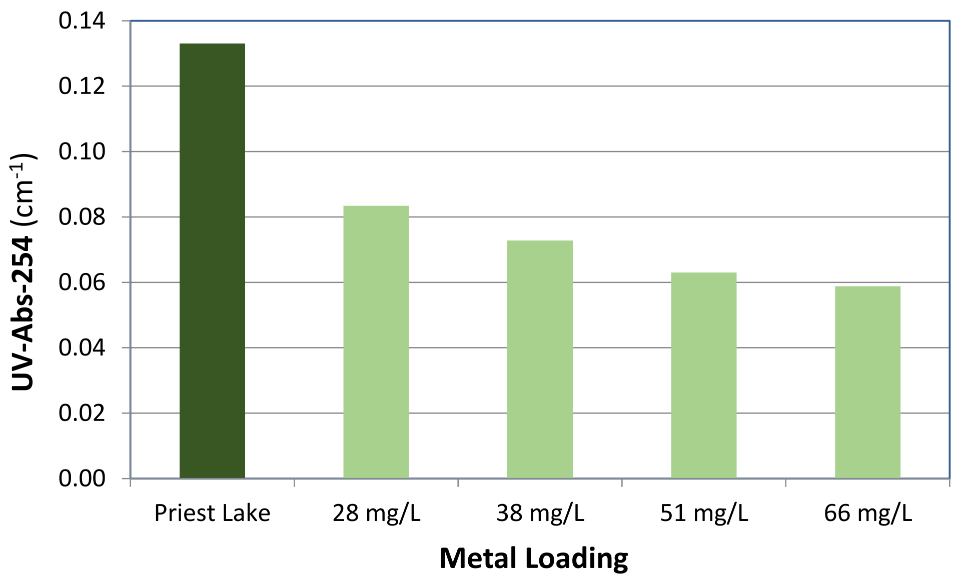

Figure 3.8 *UV-Abs-254 results for four-cell experiments with a 1 mm inter-electrode gap*

In *Figure 3.7* above, it can be seen that a general trend of decreasing UV-Abs-254 was observed with an increase in metal loading. These results agree with lab-scale experiments previously performed at UBC. At the highest metal loadings, reductions greater than 50% were achieved; suggesting electrocoagulation gives adequate removal of absorbance and may be a viable alternate to traditional chemical coagulation.

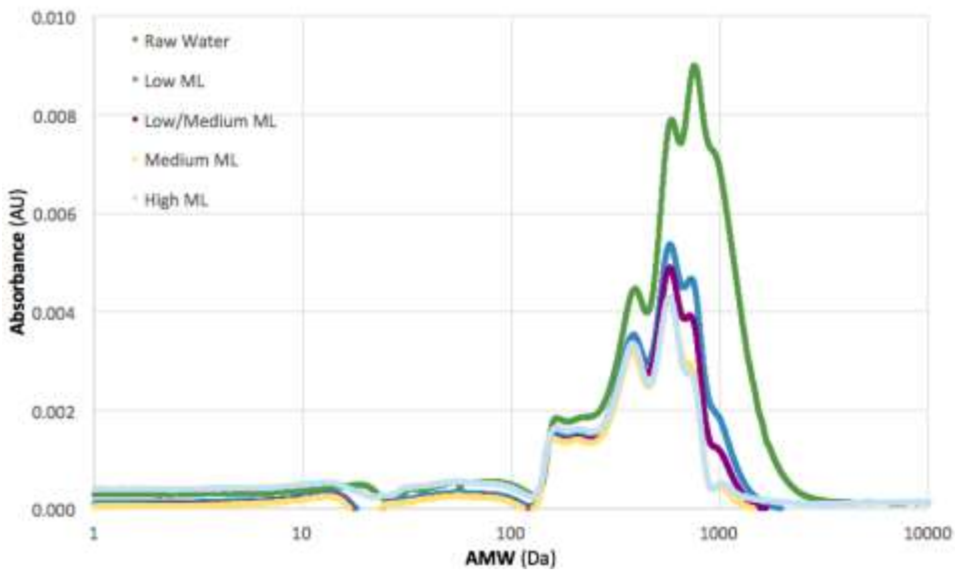

Figure 3.9 *HPSEC results for four-cell experiments with a 1 mm inter-electrode gap*

Figure 3.8 shows a plot generated through HPSEC analysis. Once again, a decrease in absorbance is seen with increasing metal loading (ML). For all experiments, substantial reductions for all molecular sizes were observed, with no removal preference for larger particles over smaller particles.

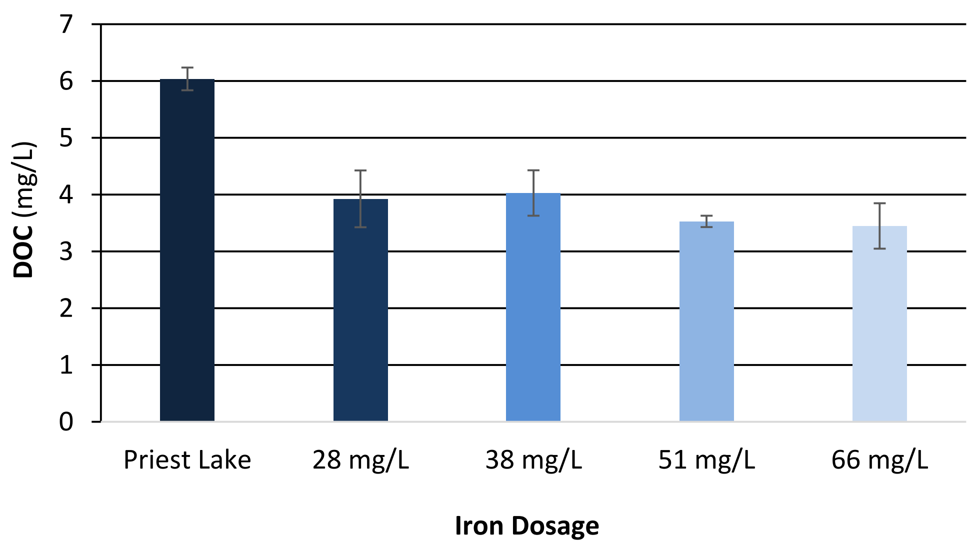

Figure 3.10 *DOC results for four-cell experiments with a 1 mm inter-electrode gap*

Figure 3.9 shows the DOC results for four-cell experiments with a 1 mm inter-electrode gap. The results show as the coagulant dosage increased from 28 mg/L to 66 mg/L, the DOC decreased from 3.9 mg/L to 3.4 mg/L. This is equivalent to an organic removal of approximately

43%. These results show somewhat a similar trend to the UVT results. As the metal loading increased, the DOC removal increased.

3.3.2 Electrocoagulation – Inter-Electrode Gap Experiment

The inter-electrode gap (spacing between the iron electrodes) was varied to assess the effectiveness of NOM removal. A 5 µm BF downstream of the electrocoagulation process was used to collect flocs that formed. The flow rate was 10 L/min and the current density ranged from 7.35 mA/cm^2 to 17.47 mA/cm^2.

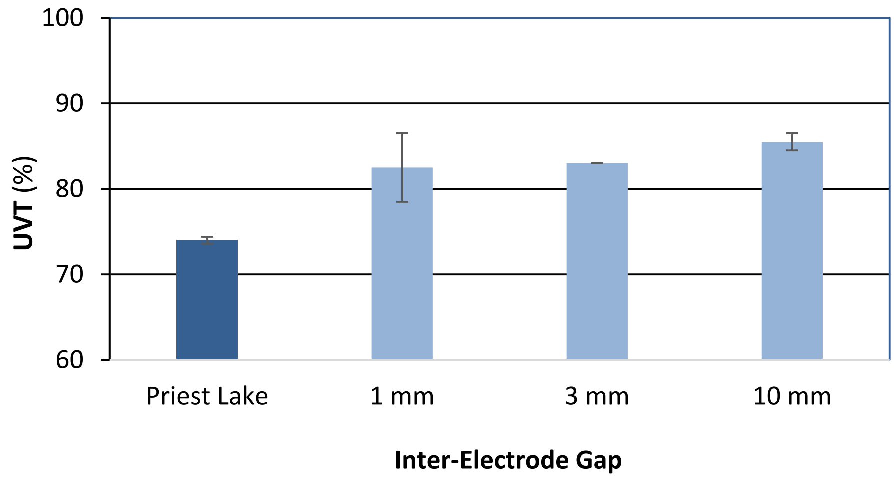

Figure 3.11 *UV-Trans-254 results for four-cell experiments varying inter-electrode gap*

Figure 3.10 shows the UVT of the treated water during the inter-electrode gap experiment. The results show as the spacing between the electrodes increased from 1 mm to 10 mm the UVT was between 82.5% and 85.5%. This indicates the inter-electrode gap does not affect the removal of NOM relatively.

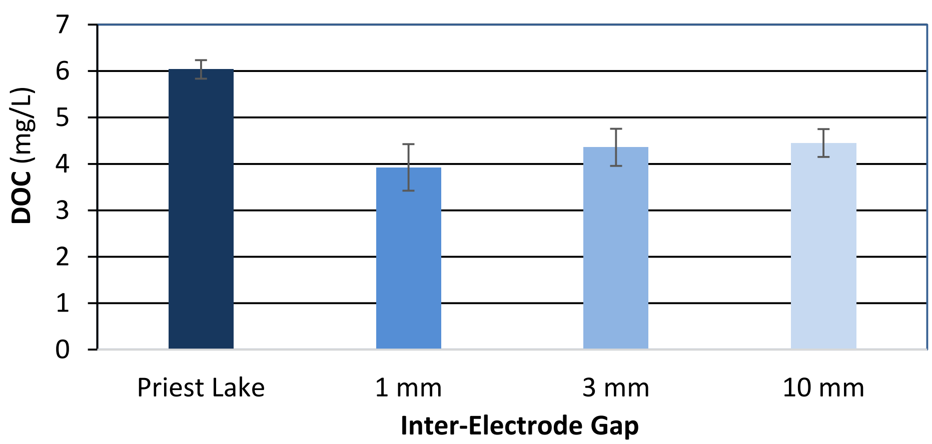

Figure 3.12 *DOC results for four-cell experiments varying inter-electrode gap*

Figure 3.11 shows the DOC results of the treated water over the course of the inter-electrode gap experiment. The results show as the inter-electrode gap increased from 1 mm to 10 mm the NOM removal increased from 3.9 mg/L to 4.5 mg/L. As the inter-electrode gap increased the removal of NOM decreased. An organic removal of less than 50% was maintained over the course of this experiment.

3.4 Activated Carbon

3.4.1 Activated Carbon - Activated Carbon Cartridge Breakthrough Experiment

A breakthrough test was conducted with an activated carbon cartridge on September 15th and 16th. The activated carbon cartridge was tested by itself to measure its removal of NOM over the course of two days. The experiment was conducted for 8 hours each day. Samples were taken upstream and downstream of the activated carbon cartridge hourly to measure turbidity and UV transmittance on site. The pilot system was operating at a flow rate of 16 L/min throughout the course of the test.

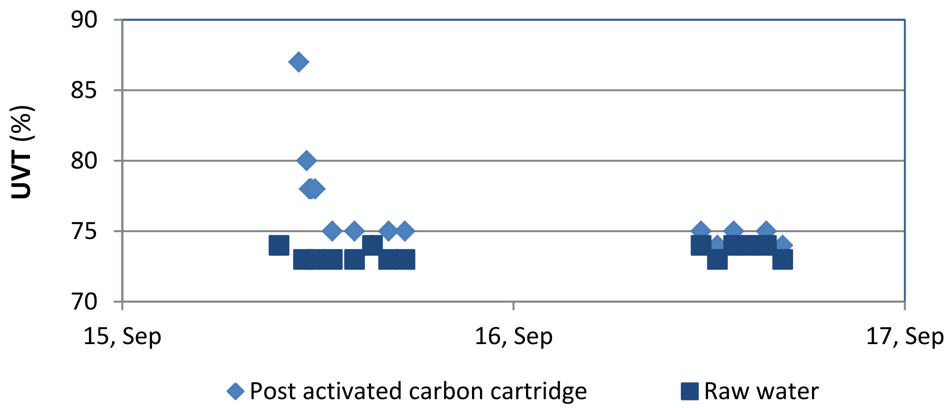

Figure 3.13 *UV-Trans-254 results for activated carbon cartridge*

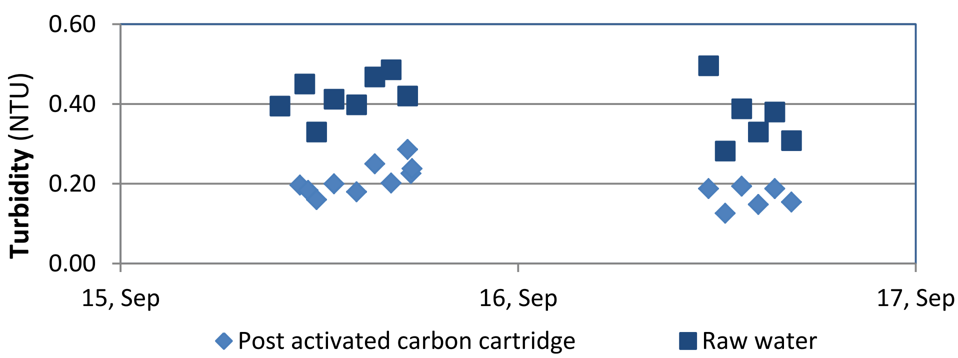

Figure 3.14 *Turbidity results for activated carbon cartridge*

As shown above in *Figure 3.13* and *Figure 3.14*, Priest Lake water contains very low turbidity and relatively high dissolved organic carbon (DOC) content. The UV transmittance after the activated carbon cartridge, from September 15th to September 16th, showed signs of breakthrough within two hours and turbidity was marginally decreased. To possibly increase the time before breakthrough occurs, the flow rate could be reduced to maximize the activated carbon cartridge's retention time.

3.4.2 Activated Carbon - Granular Activated Carbon Breakthrough Experiment

Three breakthrough experiments were conducted with a granular activated carbon from March 21st to 23rd. The granular activated carbon cartridge was tested to determine the level and extent of NOM removal. There were two types of GAC evaluated, Filtrasorb 300 and Filtrasorb 400. Two replicate experiments were conducted with Filtrasorb 300 and an additional experiment was conducted with Filtrasorb 400. The duration of the experiments, were 5 to 10 hours and were all conducted at a flow rate of approximately 0.75 L/min. Samples were taken upstream and downstream of the granular activated carbon cartridge hourly to measure turbidity, UV transmittance, temperature and pH on site and DOC at UBC.

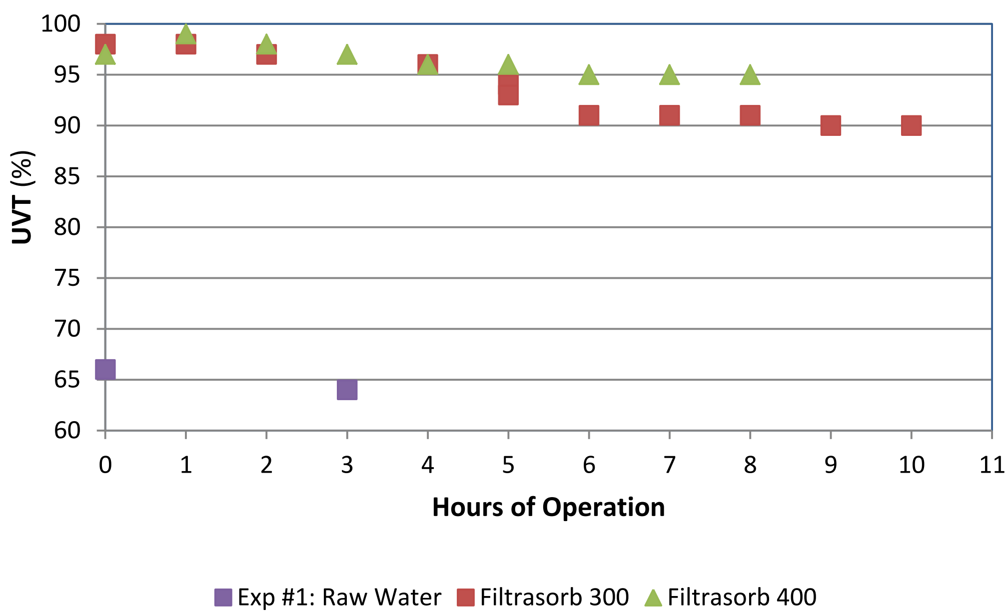

Figure 3.15 *UV-Trans-254 results for granular activated carbon experiments*

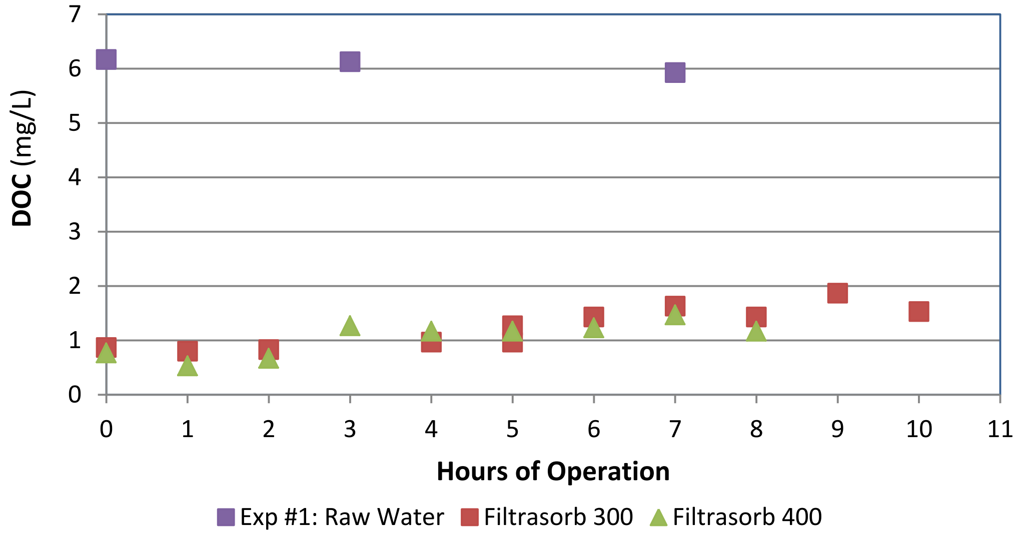

Figure 3.16 *DOC results for granular activated carbon experiments*

From the results in *Figure 3.15* and *Figure 3.16*, it shows that granular activated carbon was effective at removing NOM at a flow rate of 0.75 L/min. The increased retention time within the GAC canister provided more time for NOM to diffuse into the pores of the GAC removing it from Priest Lake raw water. The results from both types of GAC showed the UV transmittance was above 90% and the DOC was below 2 mg/L for the duration of the experiment. Turbidity was marginally decreased over the course of the experiments. Further studies need to be conducted for a longer duration to determine the NOM removal capacity for activated carbon.

3.5 UV Disinfection

3.5.1 UV Disinfection - Initial Coliform Inactivation Experiment

A series of experiments were conducted with a standard amalgam UV system on October 1st, 2015 to determine its effectiveness at inactivating coliforms in Priest Lake water. The tests were comprised of a combination of filtration processes to pre-treat water prior to UV disinfection. Each test was performed for one hour. Samples were taken upstream and downstream of the UV disinfection process after 45 minutes and were analyzed at the BC Centre for Disease Control for total coliform counts. The pilot system was operating at 3 L/min during the course of these experiments.

Processes	Raw Water Total Coliforms (CFU/100mL)	Post UV Disinfection Total Coliforms (CFU/100mL)
25 µm SCF + UV disinfection	1772.8	0
25 µm SCF + UV disinfection	910.05	0
25 µm SCF + 1 µm CF + UV disinfection	576.1	0
25 µm SCF + 1 µm CF + UV disinfection	1353.5	0
25 µm SCF + 5 µm CF + UV disinfection	1130.5	0
25 µm SCF + 5 µm CF + UV disinfection	625.6	0

* Total coliform values are the average of two tests run

Table 3.1 *Coliform counts from UV initial coliform inactivation experiment*

From the data collected, shown above in *Table 3.1*, Priest Lake contains a relatively high concentration of total coliform. After the UV disinfection system, the results from October 1st, 2015 showed there were no coliforms detected for all of the filtration combinations coupled with the UV disinfection system. However, it is known that the flow rate affects the UV disinfection process and needs to be further investigated in order to determine the efficacy of total coliform deactivation.

3.5.2 UV Disinfection - Coliform Inactivation Experiment with a UV Dosage of 50 mJ/cm^2

The coliform inactivation test was conducted with an amalgam UV system on December 15th, 2015 to determine its ability to disinfect the water (i.e., inactivate E. coli) at an approximate UV dosage of 50 mJ/cm^2. As a pre-treatment, combinations of filters were used to remove larger particles from the raw water. Each filter combination was tested for 10 minutes, each test had a duplicate run. Samples were taken from downstream of the UV system after each test. Turbidity was measured on-site and the presence of total coliforms and E. coli was measured at BC Centre for Disease Control (BCCDC).

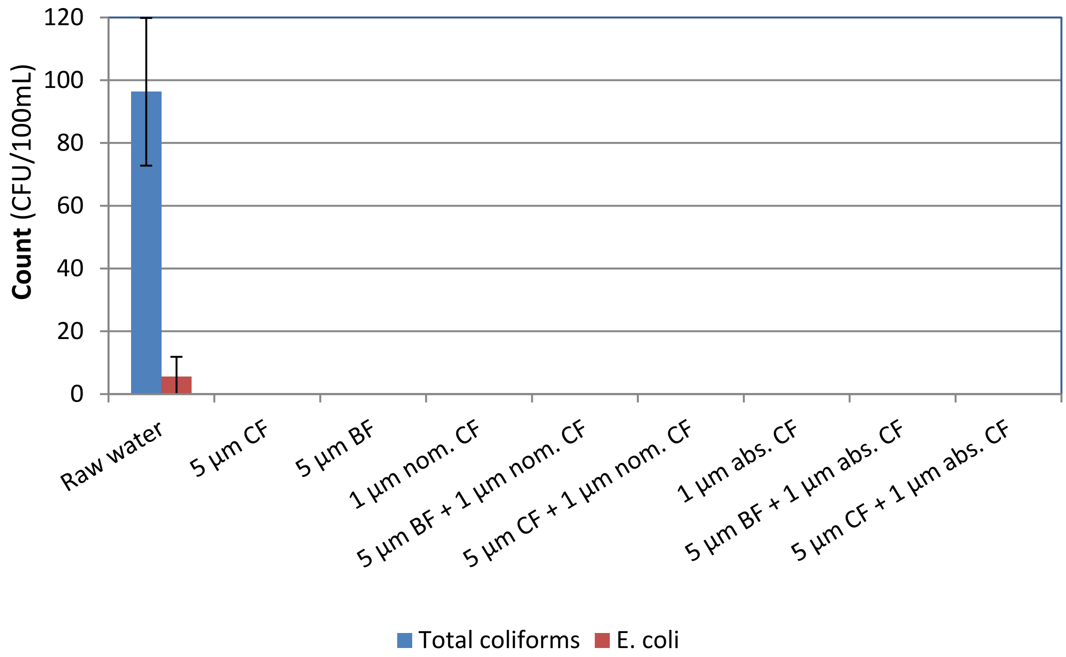

Figure 3.16 *Coliform count results from coliform inactivation experiment with a UV dosage of 50 mJ/cm^2*

Figure 3.16 shows the total coliform and E. coli counts for the raw water and treated water after UV disinfection. From the data collected, the UV system was able to inactivate all of the coliforms at a UV dose of 50 mJ/cm^2. Further investigation will focus on assessing the performance of the UV at lower dosage.

3.5.3 UV Disinfection - Coliform Inactivation Experiment with a UV Dosage of 50 mJ/cm^2 and 40 mJ/cm^2

The coliform inactivation test was conducted with an amalgam UV system on March 22nd, 2016 to determine its ability to disinfect the water (i.e., inactivate E. coli) at an approximate UV dosage of 50 mJ/cm^2 and 40 mJ/cm^2. As a pre-treatment, combinations of filters were used to remove larger particles from the raw water. Each filter combination was tested for 10 minutes, each test had a duplicate run. Samples were taken from downstream of the UV system after each test. Turbidity was measured on site and the presence of total coliforms and E. coli was measured at BC Centre for Disease Control (BCCDC).

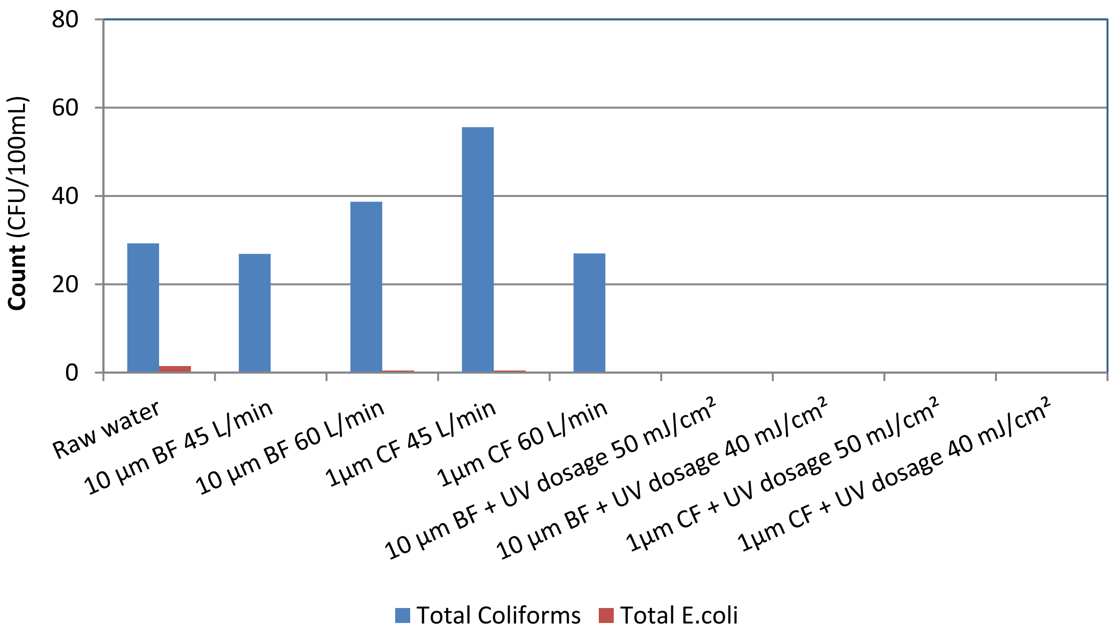

Figure 3.17 *Coliform count results from coliform inactivation experiment with a UV dosage of 50 mJ/cm^2 and 40 mJ/cm^2*

Figure 3.17 shows the total coliform and E. coli counts for the raw water and treated water after UV disinfection. From the data collected, the UV system was able to inactivate all of the coliforms at a UV dose of 50 mJ/cm^2 and 40 mJ/cm^2.

4.0 Operating Cost Estimates

The operating and maintenance costs asssociated with a potential water treatment plant (WTP) with the viable processes was estimated (based on the pilot plant data) to assess the financial impact to the community of VAID. The technologies considered in this cost analysis included a 5 micron bag filter, ion exchange, UV disinfection and chlorine disinfection.

Based on VAID's approximate current population of 550 people and 228 connections as well as the 2015 and 2014 water usage, the theoretical average daily water flow was estimated to be 124,000 L (32,700 US gal). Increasing the operating time of the pump to 22 hours would reduce the required treatment rate and reduce the size of the treatment equipment needed. Incorporating these considerations, the theoretical treatment rate would be 94 L/min (26.4 US gal/min).

WTP operating and maintenance	Annual cost
Bag filters	$100.00
Salt and brine disposal	$22,000.00
UV lamps	$300.00
Chlorine	$2,000.00

Table 4.1 Water treatment processes maintenance costs

Some of the main operating and maintenance costs associated with a full scale WTP include tasks such as replacing bag filters, regenerating resins in the ion exchange, replacing UV lamps and purchasing chlorine. These would of course exclude the cost associated with the personnel and operator wages. Bag filters were assumed to be replaced on average every 3 months. The major operating costs associated with the ion exchange process are to produce and dispose of the brine solution used to regenerate resins. The estimated number of regenerations each year is 1,500. The annual cost for sodium chloride required to produce the brine solution for the regenerations is $11,000.00. Disposal fees for a service company to remove the brine solution after regeneration, approximately 16 services each year, are approximately $11,000.00. This assumes there is a storage tank on site to maximize the capacity of the septic services and minimize service fees. UV lamps need to be replaced on an annual basis. Containers of chlorine are purchased periodically to maintain a chlorine concentration of 2 mg/L.

Power usage	Annual cost
10 HP pump	$7,500.00
UV disinfection	$300.00
Chlorine disinfection	$300.00
Miscellaneous (heating and lighting)	$2,600.00
Total	$10,700.00

Table 4.2 Costs for water treatment processes power usage

A majority of power usage in the water treament plant will be consumed by the 10 HP feed pumps. In addition, other processes consuming power include UV disinfection, chlorine injection pumps and heating and lighting for the facility. Below are the estimated costs for the annual power usage for each process. Rates were based on BC Hydro's small general service rate of $0.1116 per kWh.

As indicated earlier, in estimating the operation and maintenance cost of the running the treatment system, we did not consider the wage and salary of the water operator. It is expected that there will be a need for 2 hours per day of a water operator time for inspections and operation of the treatment system to ensure it is operating well and to address any issues are resolved in timely manner.

Operating and maintenance summary	**Approximate Annual cost**
Bag filter	$100.00
Ion exchange process	$22,000.00
UV disinfection	$200.00
Chlorine disinfection	$2,000.00
Power usage	$10,700.00
Total operation and maintenance	$35,000.00
Cost per connection	$159.00

Table 4.4 Summary of WTP estimated operating and maintenance costs

Considering some of the main operational and maintenance costs associated with a potential water treatment plant a total annual cost of approximately $34,000 could be expected. Once again, this does not include the cost associated with hiring and retaining a water operator.

5.0 Conclusions and Future Works

This report summarizes a pilot water treatment study, which was a collaboration between Van Anda Improvement District (VAID) Water Board of Trustees, RES'EAU-WaterNET, the University of British Columbia, BI Pure Water, and Laval University. The overall goal of the study was to assess a number of water treatment processes and determine the most sustainable and feasible solution for treating Priest Lake's water. The study was conducted from August 2015 to March 2016 using a pilot plant facility that contained filtration, ion exchange, electrocoagulation, activated carbon and UV disinfection processes for the purposes of improving the overall water quality. Priest Lake's water quality is unique and requires a specific water treatment system to treat the water and provide potable water. The approximate characteristics of Priest Lake's water quality include; turbidity of 0.77 NTU, DOC of 6 mg/L, total coliforms and E. Coli count of 5 CFU/100mL.

Several filtration technologies were tested to assess their ability to remove large particles from Priest Lake water that could interfere with downstream treatment processes and affect the aesthetics of the drinking water. Each of the technologies was evaluated independently and in series to determine the optimal combination. The technologies that were investigated include a 25 µm self-cleaning filter (SCF), 5 µm bag filter (BF), 5 µm cartridge filter (CF), 1 µm nom. CF, and 1 µm abs. CF. From the results the 25 µm SCF was not able to reduce turbidity and had issues with leaks during the pilot study. The 5 µm BF and 5 µm CF performed relatively similar to one another, reducing turbidity by 0.15 NTU. The 1 µm nom. CF by itself or downstream of the 5 µm BF or the 5 µm CF reduced turbidity by 0.20 NTU. The 1 µm abs. CF, by itself or downstream of the 5 µm BF or 5 µm CF, reduced turbidity the most by approximately 0.40 NTU. In addition, the CF and BF systems were the easiest to use and maintain making them very operator friendly and reliable systems. From the results, the BF or CF would be a robust and effective filtration solution to maintain a low turbidity.

Preliminary results from the ion exchange process showed that it has potential at being a viable solution. A series of experiments were conducted with it to determine the level and extent of NOM removal. The results from replicate breakthrough experiments with a flow rate of 20 L/min showed significant removal of NOM, leading to the significant reductions in the formation potential of THMs and HAAs after the ion exchange process. While very effective at removing NOM and improving the overall quality of the water, this process is the one requiring significant operating and maintenance cost, as it involves regeneration of resins and disposal of the spent brine solution used for regeneration.

Experiments were conducted for the first time with electrocoagulation at the pilot-scale. The following parameters were investigated to assess their impact on NOM removal; metal loading (28-66 mg/L), current density (1-20 mA/cm^2), and inter-electrode gap (1, 3 and 10 mm). All of the tests were conducted at a flow rate of 10 L/min. Results from the electrocoagulation experiments indicated the metal loading had an organic removal of 43% with no preference to larger or smaller NOM particles and the inter-electrode gap had an organic removal below 50%. These results show electrocoagulation could be a potential solution in the future but further studies must be conducted to improve its removal of NOM for large-scale projects. More importantly, further work is required to determine the long term efficacy and performance of the electrocoagulation process. For this reason, electrocoagulation is not recommended for full scale installation at VAID.

Several activated carbon technologies, an activated carbon cartridge block and two types of granular activated carbon, were assessed to determine their ability to remove NOM from Priest Lake raw water. The results from the first breakthrough experiment conducted with an activated carbon cartridge block at 16 L/min showed immediate signs of breakthrough. The UV transmittance began at 87% and decreased to 75% within two hours. To further confirm the results, several experiments were conducted systematically reducing the flow rate to as low as 2.5 L/min and continued to show early signs of breakthrough. The second series of breakthrough experiments were conducted with two types of granular activated carbon, Filtrasorb 300 and Filtrasorb 400, at a lower flow rate of 0.75 L/min to assess their efficacy of removing NOM. Both types of granular activated carbon had UV transmittance results above 90% and DOC results below 2 mg/L for over 7 hours (over 300 L of water treated). These results indicated activated carbon was capable of removing NOM at low flow rates. Because VAID's minimum daily water usage is 24,000 L, this technology would not be feasible to serve the community because it would require a significant amount of time or a substantial quantity of GAC to treat enough water to meet their daily needs. This technology may be more applicable for very small-scale applications such as point of entry or point of use.

UV disinfection experiments were conducted to investigate the level of inactivation of coliforms with respect to UV dosage. This was achieved by progressively decreasing the UV dosage. An initial experiment was conducted at a flow rate of 3 L/min then increased the flow rate to 45 L/min and 60 L/min equivalent to a UV dosage of 50 mJ/cm^2 and 40 mJ/cm^2, respectively. The results from all of the experiments resulted in reducing the coliform counts to below detection level in the UV treated Priest Lake water. Note that UV dose of 40 mJ/cm^2 is the US EPA recommended dose for surface water disinfection, ensuring inactivation of bacteria and protozoa, as well as many of viruses. Coupling this system with chlorine disinfection would provide effective inactivation of all potential pathogens (including adenovirus) and protect against contamination in the distribution system.

In conclusion, several treatment processes were tested at Priest Lake to assess their efficacy at treating raw water. From the data collected, the potential viable technologies include bag filter and cartridge filters to reduce turbidity, ion exchange for removal of NOM and UV disinfection to inactivate coliforms. In addition, chlorine disinfection should be included as a secondary disinfection process and to maintain residual in the distribution system. These technologies showed promising repeatable results as well as being easy to operate and maintain. A very high level cost analysis was performed to estimate the costs associated with operating and maintaining a water treatment plant with these technologies. The estimated annual cost to operate and maintain a water treatment plant (without considering the operator wage and salary), that incorporates these technologies, was estimated to be approximately $35,000.00. This equates to about $160.00 per connection each year.

The lessons learned during the pilot plant study were the value of the interactions with the VAID Water Board of Trustees and the community. The support provided by the VAID Water Board of Trustees, specifically from Heidi Gable and Ken Soles were incredibly valuable. They helped facilitate all of the activities to engage the community, provided support when there were operational issues and limited resources and ensured researchers were safe while on site. The value of engaging the community was highlighted over the series of events that were held. It provided a platform to raise the community's awareness, help them understand the water treatment issues and build support to move a water treatment solution forward.

Going forward, VAID now has this additional data to incorporate into their decision on which technology to move forward. *RES'EAU-WaterNET*, BI Pure Water, the University of British Columbia, and Laval University will continue to collaborate with VAID's Water Board of Trustees to find the most sustainable and feasible solution for their water treatment system's upgrade. This will allow them to provide safe, clean and aesthetically acceptable quality potable water to the residents of Priest Lake.

6.0 References

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7.0 Appendix

Filtration:

Experiment:	Filtration - Initial Filtration Experiment
Date:	August 25th, 26th and 31st, 2015
Research Scientist:	David Chan
Processes online:	Filtration
Experiment description:	The tests consisted of isolating individual filtration processes and running combinations of the filters in series to assess which combination of filters was the most effective at removing suspended particles from the raw (lake) water. Each experiment was one hour with a flow rate of 17 L/min. Samples were taken pre and post filtration at the beginning and end of each experiment. Turbidity and UV transmittance were measured on site and dissolved organic carbon (DOC) was measured at the University of British Columbia. The filters that were investigated were a 25 µm self-cleaning filter (SCF), a 5 µm bag filter (BF), and a 1 µm cartridge filter (CF) and a 5 µm CF that are in parallel.

Filtration Process	Raw Water	Effluent	Raw Water	Effluent
	Turbidity (NTU)		DOC (mg/L)	
25 µm Self-Cleaning Filter	0.27	0.28	5.91	5.88
5µm Bag Filter	0.19	0.16	5.91	6.34
1 µm nominal Cartridge Filter	0.28	0.21	6.11	6.2
5 µm Cartridge Filter	0.28	0.24	6.11	6.03
25 µm Self-Cleaning Filter + 5 µm Bag Filter	0.36	0.24	6.26	6.11
25 µm Self-Cleaning Filter + 1 µm Cartridge Filter	0.32	0.27	6.4	6.31
25 µm Self-Cleaning Filter + 5 µm Cartridge Filter	0.36	0.24	6.33	5.81
5 micron Bag Filter + 1 µm Cartridge Filter	0.32	0.14	6.4	5.75
5 µm Bag Filter + 5 µm Cartridge Filter	0.29	0.21	6.4	6.19
25 µm Self-Cleaning Filter + 5 µm Bag Filter + 1 µm Cartridge Filter	0.36	0.2	4.94	5.12
25 µm Self-Cleaning Filter + 5 µm Bag Filter + 5 µm Cartridge Filter	0.36	0.14	5.29	5.41

Experiment:	Filtration - Second Filtration Experiment
Date:	December 15th, 2015
Research Scientist:	David Chan
Processes online:	Filtration
Experiment description:	The tests consisted of isolating individual filtration processes and running combinations of the filters in series to assess which combination of filters was the most effective at removing suspended particles from the raw (lake) water. As a pre-treatment, combinations of filters were used to remove larger particles from the raw water. Each filter combination was tested for 10 minutes at a flow rate of 45 L/min and each test had a duplicate run. Samples were taken from downstream of filters after each test. Turbidity was measured on site.Turbidity and UV transmittance were measured on site and dissolved organic carbon (DOC) was measured at the University of British Columbia. The filters that were investigated were a 25 µm self-cleaning filter (SCF), a 5 µm bag filter (BF), and a 1 µm cartridge filter (CF) and a 5 µm CF that are in parallel.

			Analyzed at VAID	
			Turbidity (NTU)	
Date	Time	Filters online	Raw water	Post filter series + UVMAX
8/12/2015	6:50 AM	1 µm nominal cartridge filter		
8/12/2015	7:07 AM	5 µm bag filter		
8/12/2015	7:27 AM	5 µm cartridge filter		
8/12/2015	7:47 AM	5 µm bag filter + 1 µm nominal cartridge filter		
8/12/2015	8:07 AM	1 µm absolute cartridge filter		
8/12/2015	8:27 AM	5 µm bag filter + 1 µm absolute cartridge filter		
15/12/2015	6:21 AM	5 µm bag filter		0.392
15/12/2015	6:35 AM	5 µm cartridge filter		0.438
15/12/2015	6:45 AM	1 µm nominal cartridge filter		0.342
15/12/2015	6:55 AM	5 µm bag filter + 1 µm nominal cartridge filter		0.378
15/12/2015	7:05 AM	5 µm cartridge filter + 1 µm nominal cartridge filter		0.318
15/12/2015	7:15 AM	5 µm bag filter		0.426
15/12/2015	7:25 AM	5 µm cartridge filter		0.388
15/12/2015	7:35 AM	1 µm nominal cartridge filter	0.54	0.378
15/12/2015	7:45 AM	5 µm bag filter + 1 µm nominal cartridge filter		0.314
15/12/2015	7:55 AM	5 µm cartridge filter + 1 µm nominal cartridge filter		0.306
15/12/2015	8:10 AM	1 µm absolute cartridge filter		0.208
15/12/2015	8:20 AM	5 µm bag filter + 1 µm absolute cartridge filter		0.196
15/12/2015	8:30 AM	5 µm cartridge filter + 1 µm absolute cartridge filter		0.2
15/12/2015	8:40 AM	1 µm absolute cartridge filter		0.178
15/12/2015	8:50 AM	5 µm bag filter + 1 µm absolute cartridge filter		0.174
15/12/2015	9:00 AM	5 µm cartridge filter + 1 µm absolute cartridge filter	0.586	0.164

Ion Exchange:

Experiment:	Ion Exchange - Breakthrough Experiment
Date:	November 30, 2015 to December 7, 2015
Research Scientist:	David Chan
Processes online:	Ion Exchange IE221
Experiment description:	The Ion Exchange Saturation Test is to determine the length of time it takes to saturate the resin in the ion exchange process. To do this, the ion exchange process was operated with a flow rate of 20.5 L/min and feed pressure of 35 psi. The data was collected by taking raw water samples every three hours and hourly samples after the ion exchange process to show the removal with respect to time. The pilot configuration for this experiment had the raw water feeding the 1 micron cartridge filter as a pretreatment and then into the ion exchange process. The samples' UVT, turbidty, and pH were measured on site and the DOC and IC were measured at UBC. The temperature, pressure and flowrate values were taken from inline instruments.

Feed Pressure (psi)	Pressure In 1 µm cartridge filter (psi)	Pressure In Ion Exchange (psi)	Pressure Out Ion Exchange (psi)	Temperature (degrees C)	Flow rate FT401 (L/min)
40	36	35	28	10	20.3

Height of Resin	Diameter of Ion Exchange Vessel	Volume (L)
38	12	70.4

		Analyzed at VAID UVT (%)		Analyzed at UBC UVT (%)		Anlyzed at UBC DOC (mg/L)		Analyzed at VAID Turbidity (NTU)			Analyzed at UBC Turbidity (NTU)		Analyzed at VAID pH		Analyzed at UBC Chlorine (ppm)	
	Hours of operation	Raw water	Post ion exchange	Raw water	Post ion exchange	Raw water	Post ion exchange	Raw water	Post 1 µm cartridge filter	Post ion exchange	Raw water	Post ion exchange	Raw water	Post ion exchange	Raw water	Post ion exchange
30/11/2015 11:00	0			84.61	96.85	6.33	1.97				0.35	0.19				115.10
30/11/2015 12:00	1	73	99		96.51		2.33	0.326	0.222	0.142			7.37	5.11		
30/11/2015 13:00	2				97.07		1.69					0.14		5.13		
30/11/2015 14:00	3		98	73.70	96.74	5.87	1.67	0.292	0.16	0.124	0.37	0.16	7.12	5.72		
30/11/2015 15:00	4	73	98		96.83		1.72	0.232	0.166	0.11		0.18	7.21	6.19		99.75
30/11/2015 16:00	5	75	98		96.53		1.76	0.316	0.224	0.178		0.16	7.29	6.45		108.46
30/11/2015 17:00	6	75	98	73.73	96.48	6.13	1.77	0.342	0.234	0.148	0.37	0.18	7.30	6.88		
30/11/2015 18:00	7															
1/12/2015 10:00	7	75	98	73.35	97.03	6.57	1.83	0.292	0.24	0.12	0.37		7.33	6.66	6.71	81.57
1/12/2015 11:00	8	74	98		96.84		1.77	0.26	0.214	0.138		0.18	7.31	6.82		78.31
1/12/2015 12:00	9	74	98					0.314	0.144	0.112			7.33	6.87		
1/12/2015 13:00	10	74	98	73.19	96.84	6.47	2.53	0.308	0.166	0.11	0.36	0.22	7.33	6.96	6.79	65.58
1/12/2015 15:00	12	74	98		96.38		2.1	0.278	0.14	0.128		0.16	7.38	7.04		51.41
1/12/2015 17:00	14	73	98	73.90	96.19	6.13	2.4	0.326	0.182	0.118	0.34	0.19	7.35	7.15	6.73	39.68
1/12/2015 19:00	16	75	98		96.35		2.6	0.336	0.182	0.128		0.18	7.35	7.24		31.74
1/12/2015 20:00	17															

2/12/2015 9:00	17	75	98	74.67	96.26	6	2.17	0.396	0.178	0.144	0.56	0.27	7.31	7.27	7.06	29.33
2/12/2015 11:00	19	75	98		96.32		2.4	0.298	0.128	0.096		0.17	7.38	7.34		24.03
2/12/2015 13:00	21	74	98	73.52	96.51	6.07	2.23	0.336	0.18	0.142	0.35	0.21	7.40	7.42	6.83	16.14
2/12/2015 15:00	23	75	98		96.69	6.07	2.33	0.374	0.226	0.2		0.19	7.45	7.60		13.63
2/12/2015 17:00	25	74	97	74.42	95.93	6.07	2.53	0.338	0.176	0.138	0.36	0.23	7.45	7.90	7.10	12.51
2/12/2015 18:00	26	74	96		95.17		3.03	0.31	0.226	0.23		0.21	7.48	8.18		10.62
2/12/2015 19:00	27	74	96		94.31		3	0.274	0.246	0.236		0.19	7.56	8.59		10.24
2/12/2015 20:00	28															
3/12/2015 11:00	28	75	95	73.89	94.34	6.07	3.17	0.314	0.288	0.214	0.38	0.23	7.37	8.60	4.77	10.24
3/12/2015 12:00	29	75	96		94.02		3.4	0.354	0.274	0.264		0.20	7.41	8.59		9.58
3/12/2015 13:00	30	74	94		93.23		3.43	0.34	0.25	0.174		0.23				8.37
3/12/2015 13:30	30				92.38		3.63					0.26				8.37
3/12/2015 14:00	31	74	93		92.09		3.63	0.32	0.196	0.172		0.41	7.42	8.82	6.99	9.29
3/12/2015 14:30	31			73.96	91.72	6.07	3.87				0.28					8.28
3/12/2015 15:00	32				88.33		4.1									
3/12/2015 16:00	33	74	92		90.40		4.3	0.388	0.27	0.168		0.19	7.46	8.54		7.54
3/12/2015 16:30	33				90.66		4.23					0.32				7.26
3/12/2015 17:00	34		92		89.89		3.97	0.314	0.196	0.16		0.20	7.46	8.54		6.99
3/12/2015 17:30	34				90.94		4.13					0.20				7.11
3/12/2015 18:00	35				91.08		4	0.294	0.25	0.204		0.20	7.41	8.40	7.23	6.95
3/12/2015 18:30	35			74.96	91.39	5.87	3.93				0.39	0.22				6.93
3/12/2015 19:00	36		92		91.73		3.97	0.286	0.252	0.168		0.20	7.52	8.41		7.00
3/12/2015 19:30	36				91.60		3.83					0.20				6.86
3/12/2015 20:00	37		92		91.80		3.67	0.43	0.224	0.168		0.24	7.43	8.13		
3/12/2015 21:00	38		92		91.91		3.93	0.342	0.24	0.164		0.22	7.41	7.94		8.54
3/12/2015 22:00	39															6.85
7/12/2015 15:00	39	71	92					0.682	0.426	0.3			7.40	7.64		
7/12/2015 17:00	41	71	93					0.618	0.386	0.294			7.39	7.46		
7/12/2015 19:00	43	71	94					0.644	0.436	0.338			7.42	7.47		

Experiment:	Ion Exchange - Replicate Breakthrough Experiment
Date:	December 14, 2015 to December 18, 2015
Research Scientist:	David Chan
Processes online:	Ion Exchange IE221
Sample sites:	Raw water port, post 1 micron cartridge filter and post IE221
Experiment description:	The Ion Exchange Breakthrough Test is to validate the extent and level of treatment in the ion excha nge process before the resins become saturated and need to be regenerated found during the first b reakthrough experiment. The ion exchange process was operated at the same conditions with a flow rate of 20.5 L/min and and feed pressure of 35 psi. The data was collected by taking raw water sampl es every three hours and hourly samples after the ion exchange process to show the removal of orga nic matter with respect to time. The pilot configuration for this experiment had the raw water feedin g the 1 micron cartridge filter as a pretreatment and then into the ion exchange process. The sample s' UVT, turbidty, and pH were measured on site and the DOC and IC were measured at UBC. The tem perature, pressure and flowrate values were taken from inline instruments.

Feed Pressure (psi)	Pressure In 1 micron cartridge filter (psi)	Pressure In Process (psi)	Temperature (degrees C)	Flow rate FT401 (L/min)
40	36	35	10	20.4

Height of Resin	Diameter of Ion Exchange Vessel	Volume (L)
37	12	68.57

		Analyzed at VAID		Analyzed at UBC		Analyzed at UBC		Analyzed at VAID			Analyzed at UBC		Analyzed at VAID	
		UVT (%)		UVT (%)		DOC (mg/L)		Turbidity (NTU)			Turbidity (NTU)		pH	
	Hours of operation	Raw water	Post ion exchange	Raw water	Post ion exchange	Raw water	Post ion exchange	Raw water	Post 1 µm cartridge filter	Post ion exchange	Raw water	Post ion exchange	Raw water	Post ion exchange
14/12/2015 12:00	0			69.94		5.45					0.704			
14/12/2015 13:00	0	70	98		98.65		0.70	0.574	0.422	0.39		0.088	7.51	5.84
14/12/2015 13:30	0				98.42		0.93					0.25		
14/12/2015 14:00	1	70	99		98.13		1.03	0.56	0.436	0.294		0.256	7.18	5.77
14/12/2015 15:00	2													
14/12/2015 16:00	3		98	69.86	97.33	5.34	1.24	0.502	0.392	0.298	0.558	0.202	7.33	5.76
14/12/2015 17:00	4													
14/12/2015 18:00	5	71	98		97.16		1.21	0.522	0.31	0.244		0.14	7.26	5.74
14/12/2015 19:00	6													
14/12/2015 20:00	7	70	98	69.82	96.96	5.45	1.26	0.55	0.322	0.264	0.524		7.24	6.22
14/12/2015 21:00	8													
15/12/2015 12:30	8	70	97	69.95	96.79	5.32	1.32	0.586	0.35	0.278	0.502	0.178	7.3	6.32
15/12/2015 13:30	9	70	98		96.82		1.23	0.546	0.396	0.24		0.172		6.66
15/12/2015 14:30	10	70	98					0.66	0.324	0.272			7.4	6.63
15/12/2015 15:30	11			69.47	96.33	5.33	1.33				0.45	0.194		
15/12/2015 16:30	12	70	98										7.33	6.77
15/12/2015 17:30	13				96.40		1.40					0.14		

15/12/2015 18:30	14	70	98					0.538	0.316	0.255			7.32	6.92
16/12/2015 11:00	14	70	98	69.83	96.60	5.21	1.29	0.56	0.368	0.324	0.456	0.156	7.39	6.91
16/12/2015 12:00	15		98				1.38							
16/12/2015 13:00	16	70	97		96.62		1.28	0.504	0.34	0.236		0.168	7.26	6.95
16/12/2015 14:00	17	70	97	69.87	96.47	5.34	1.25	0.566	0.32	0.26	0.508	0.148	7.28	7.11
16/12/2015 15:00	18		97		96.61		1.36					0.148		
16/12/2015 16:00	19		97		96.53		1.59	0.556	0.312	0.254		0.116	7.33	7.17
16/12/2015 17:00	20		97	69.58	96.27	5.15	1.31				0.432	0.176		
16/12/2015 18:00	21		97		96.08		1.28	0.502	0.262	0.22		0.164	7.38	
16/12/2015 19:00	22		97		96.77		1.23					0.156		
16/12/2015 20:00	23		96		96.41		1.52	0.516	0.288	0.264		0.134	7.4	7.38
16/12/2015 21:00	24		96		96.28		1.58					0.142		
16/12/2015 22:00	25													
17/12/2015 11:00	25		97		96.65		1.36	0.526	0.38	0.296		0.218		7.44
17/12/2015 12:00	26		96		96.55		1.37					0.176	7.39	
17/12/2015 13:00	27	70	96		96.22		1.41	0.482	0.362	0.322		0.18	7.4	7.58
17/12/2015 14:00	28		96	69.73	95.99	5.15	1.52				0.438	0.212		
17/12/2015 15:00	29	70	95		95.29		1.71	0.508	0.342	0.244			7.42	8.26
17/12/2015 16:00	30		95		94.77		1.82							
17/12/2015 17:00	31	69	95		94.63		27.77	0.54	0.33	0.23			7.41	8.63
17/12/2015 18:00	32		94		93.77		7.16							
17/12/2015 19:00	33	70	93		92.86		2.43	0.504	0.35	0.23			7.44	8.83
17/12/2015 20:00	34			69.75	91.73	5.12	2.70				0.25			
17/12/2015 21:00	35				91.12		2.87							
17/12/2015 22:00	36				91.00		2.92							
17/12/2015 23:00	37				90.98		2.87							

RES'EAU WATERNET

Rapport d'analyse -Analytical Report	
# Rapport	**AHA-001-MEGAN**
Projet	**Megan Wood_UBC**
Type d'eau	**Treated water and raw water and simulations**
Paramètre	**Acides Haloacétiques**
Unités:	µg/L ou ppb
LQ:	<1 ppb
incertitudes:	± 25% déterminée selon protocole du CEAEQ
Méthode:	GC-ECD, EPA 552.3 avec Modification par la CREPUL
Note:	Laboratoire non accrédité

Chaire de recherche en eau potable de l'Université Laval

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Commentaires:

Résultats Acides Haloacétiques

Nb	Projet	Date d'entrée	Date d'analyse	Sequence	Éch.	**MCAA** LQ<1,0 ppb	**MBAA** LQ<1,0 ppb	**DCAA** LQ<1,0 ppb	**TCAA** LQ<1,0 ppb / LQ<2,0 ppb	**BCAA** LQ<1,0 ppb	**DBAA** LQ<1,0 ppb
4	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-1-DUP	3.1	0.0	40.4	53.2	1.2	0.0
5	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-1	3.1	0.0	40.2	52.3	1.1	0.0
6	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-2	3.2	0.0	38.3	49.1	1.1	0.0
7	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-3	3.0	0.0	45.2	67.8	1.3	0.0
8	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-4	2.7	0.0	39.5	53.7	1.1	0.0
9	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-5	2.9	0.0	34.3	62.0	0.0	0.0
10	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-6	3.1	0.0	42.9	61.2	1.3	0.0
11	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-7	1.7	0.0	17.5	47.7	0.0	0.0
12	Megan Wood_UBC	19/02/2016	19/02/2016	charny013	SITE-8	3.2	0.0	41.4	59.1	1.2	0.0
13	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	RAW-A-DUP	3.9	0.0	43.7	48.1	1.1	0.0
14	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	RAW-A	3.9	0.0	43.5	49.3	1.1	0.0
15	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	RAW-B	3.6	0.0	43.8	48.3	1.3	0.0
16	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	RAW-C	3.8	0.0	43.8	43.0	1.3	0.0
17	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	UV-A	3.8	0.0	44.3	51.9	1.4	0.0
18	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	UV-B	3.6	0.0	42.7	48.2	1.3	0.0
19	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	UV-C	3.7	0.0	44.3	51.3	1.4	0.0
20	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-A	1.3	0.0	1.8	1.8	0.0	0.0
21	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-B	1.3	0.0	1.9	1.6	0.0	0.0
22	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-C	1.5	0.0	1.9	1.8	0.0	0.0
23	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-UV-A	1.2	0.0	2.1	2.1	0.0	0.0
24	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-UV-B	1.4	0.0	2.0	2.0	0.0	0.0
25	Megan Wood_UBC	19/02/2016	1/03/2016	megan001	IEX-UV-C	0.0	0.0	2.1	2.1	0.0	0.0

Rapport d'analyse -Analytical Report	
# Rapport	**THM-001_MEGAN**
Projet	**Megan Wood**
Type d'eau	**Treated water and raw water and simulations**
Paramètre	**Trihalométhanes**
Unités:	µg/L ou ppb
LQ:	<3 ppb (TCM, DBCM) et < 2ppb (BDCM, TBM)
incertitudes:	± 25% déterminée selon protocole du CEAEQ
Méthode:	GC-MS (IT) Varian avec fibre SPME 100 µm PDMS
Note:	Laboratoire non accrédité

Chaire de recherche en eau potable de l'Université Laval

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Commentaires:

Nbr. d'éch.	Projet	Date d'entrée	Date d'analyse	Sequence	Éch.	**TCM** LQ <3 ppb	**BDCM** LQ <2ppb	**DBCM** LQ <3 ppb	**TBM** LQ <2 ppb
1	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-1	114	4	0	0
2	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-2	108	4	0	0
3	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-3	135	4	0	0
4	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-4	131	5	0	0
5	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-5	132	4	0	0
6	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-6	133	4	0	0
7	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-7	150	6	0	0
8	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	SITE-8	134	5	0	0
9	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	RAW-A	128	5	0	0
10	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	RAW-B	129	5	0	0
11	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	RAW-C	128	5	0	0
12	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	UV-A	134	5	0	0
13	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	UV-B	134	5	0	0
14	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	UV-C	136	4	0	0
15	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-A	5	0	0	0
16	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-B	5	0	0	0
17	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-C	5	0	0	0
18	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-UV-A	5	0	0	0
19	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-UV-B	5	0	0	0
20	Megan Wood	19/02/2016	25/02/2016	20160225_VQ	IEX-UV-C	5	0	0	0

Activated Carbon:

Experiment:	Activated Carbon - Activated Carbon Cartridge Breakthrough Experiment
Date:	September 15, 2015 and September 16, 2015
Research Scientist:	David Chan
Processes online:	Activated Carbon
Sample sites:	Raw water port, post 1 micron cartridge filter and post IE221
Experiment description:	A breakthrough test was conducted with an activated carbon cartridge on September 15th and 16th. The activated carbon cartridge was tested by itself to measure its removal of NOM over the course of two days. The experiment was conducted for 8 hours each day. Samples were taken upstream and downstream of the activated carbon cartridge hourly to measure turbidity and UV transmittance on site. The pilot system was operating at a flow rate of 16 L/min throughout the course of the test.

	Raw Water Turbidity (NTU)	Post Activated Carbon Turbidity (NTU)	Raw Water UVT (%)	Post Activated Carbon UVT (%)	Feed Pressure (psi)	Pressure In Process (psi)	Pressure Out Process (psi)	Raw Water pH	Post pH	Temperature (degrees C)	Flow rate FT101 (L/min)	Flow rate FT401 (L/min)
15/09/2015 9:37	0.40		74		54			8.09		14.5	19.8	
15/09/2015 10:50		0.20		87		50	46		8.80	16.0		16.3
15/09/2015 11:07	0.45		73					8.19		16.0		
15/09/2015 11:19		0.18		80		49	46					
15/09/2015 11:29				78					8.48			
15/09/2015 11:37				78								
15/09/2015 11:50	0.33	0.16	73	78	54	49	46	8.14	8.35	16.5	18.9	
15/09/2015 12:53	0.41	0.20	73	75	53.5	49	45.8	8.10	8.22	17.0	19.1	16.1
15/09/2015 14:15	0.40	0.18	73	75	54	48	45	8.08	8.15	17.5	19.3	16.1
15/09/2015 15:21	0.47	0.25	74	74	53	49	45	8.10	8.14	17.5	19.3	16.0
15/09/2015 16:20	0.49	0.20	73	75	54	49	44.5	8.10	8.16	17.0	19.1	16.0
15/09/2015 17:20	0.42	0.29	73	75	53.5	49	44	8.09	8.11	17.0	19.1	15.9
15/09/2015 17:32		0.23										
15/09/2015 17:36		0.24										
16/09/2015 11:30	0.50	0.19	74.00	75.00	54.00	50.00	44.00	8.14	8.21	15.00	19.10	16.00
16/09/2015 12:30	0.28	0.13	73.00	74.00	54.00	49.00	44.00	8.14	8.17	16.00	19.00	16.00
16/09/2015 13:30	0.39	0.19	74.00	75.00	54.00	49.00	44.00	8.12	8.14	16.00	19.10	16.00
16/09/2015 14:30	0.33	0.15	74.00	74.00	54.00	49.00	44.00	8.12		16.00	19.10	15.90
16/09/2015 15:30	0.38	0.19	74.00	75.00	54.00	49.00	43.00	8.12		16.50	18.90	16.00
16/09/2015 16:30	0.31	0.15	73.00	74.00	54.00	49.00	42.00	8.12	8.16	16.50	18.80	15.90

Experiment:	Activated Carbon - Granular Activated Carbon Breakthrough Experiment
Date:	March 21st, 2016 to March 23rd, 2016
Research Scientist:	David Chan
Processes online:	Activated Carbon
Experiment description:	Three breakthrough experiments were conducted with a granular activated carbon from March 21st to 23rd. The granular activated carbon cartridge was tested to determine the level and extent of NOM removal. There were two types of GAC evaluated, Filtrasorb 300 and Filtrasorb 400. Two replicate experiments were conducted with Filtrasorb 300 and an additional experiment was conducted with Filtrasorb 400. The duration of the experiments, were 5 to 10 hours and were all conducted at a flow rate of approximately 0.75 L/min. Samples were taken upstream and downstream of the granular activated carbon cartridge hourly to measure turbidity, UV transmittance, temperature and pH on site and DOC at UBC.

	Sample Description	DOC	UVT (%)	Turbidity (NTU)	pH	Temperature	Pressure	Flowrate
2:00 PM 21/03/2016	Exp #1: Raw Water	6.17	66	0.68		16	44	0.75
5:00 PM 21/03/2016	Exp #1: Raw Water	6.13	64					
9:00 PM 21/03/2016	Exp #1: Raw Water	5.93				14.1		
12:30 PM 22/03/2016	Exp #1: Raw Water	6.07		0.818	7.35	15	43	
5:00 PM 22/03/2016	Exp #1: Raw Water	6.43		0.702				0.77
10:00 PM 23/03/2016	Exp #3: Raw Water	6.37	64	0.7575	7.7	14	42	
2:00 PM 23/03/2016	Exp #3: Raw Water	6.23	64	0.624	7.7	14	42	
2:30 PM 21/03/2016	Exp #1: GAC	0.87	98	0.584		19	44	0.76
3:30 PM 21/03/2016	Exp #1: GAC	0.8	98	0.514				0.767
4:30 PM 21/03/2016	Exp #1: GAC	0.83	97	0.466				0.74
6:00 PM 21/03/2016	Exp #1: GAC	0.97	96					
7:00 PM 21/03/2016	Exp #1: GAC	0.97	94			18		0.741
7:41 PM 21/03/2016	Exp #1: GAC	1.27	93		8.98	16.2		
8:10 PM 21/03/2016	Exp #1: GAC	1.43	91					
9:00 PM 21/03/2016	Exp #1: GAC	1.63	91		8.78			
12:30 PM 22/03/2016	Exp #1: GAC	1.43	91	0.464	8.5	18	43	0.75
1:30 PM 22/03/2016	Exp #1: GAC	1.87	90					
2:30 PM 22/03/2016	Exp #1: GAC	1.53	90					
5:45 PM 22/03/2016	Exp #2: GAC	0.63	98	0.622	9.77	19		
6:45 PM 22/03/2016	Exp #2: GAC	0.7	98					
7:45 PM 22/03/2016	Exp #2: GAC	0.57	97					
8:45 PM 22/03/2016	Exp #2: GAC	1	96		9.33			0.7
9:45 PM 22/03/2016	Exp #2: GAC	0.87	94		9.24			
10:45 PM 22/03/2016	Exp #2: GAC	1.07	94		9.07			
2:00 PM 23/03/2016	Exp #3: GAC	0.77	97		10.1	14	41	0.71
3:00 PM 23/03/2016	Exp #3: GAC	0.53	99	0.46				
4:00 PM 23/03/2016	Exp #3: GAC	0.67	98		9.83			
5:00 PM 23/03/2016	Exp #3: GAC	1.27	97		9.65			
6:00 PM 23/03/2016	Exp #3: GAC	1.17	96	0.916	9.44	16	35	
7:00 PM 23/03/2016	Exp #3: GAC	1.17	96		9.29			
8:00 PM 23/03/2016	Exp #3: GAC	1.23	95		9.18		24	0.63

9:00 PM 23/03/2016	Exp #3: GAC	1.47	95		9.12			
10:00 PM 23/03/2016	Exp #3: GAC	1.17	95	0.348	9	17	14	

UV Disinfection:

Experiment:	UV Disinfection - Initial Coliform Inactivation Experiment
Date:	October 1st, 2015
Research Scientist:	David Chan
Experiment description:	The UV Disinfection test was to determine the extent of deactivation of total and fecal coliforms with the UV disinfection process with different combinations of filters. The process was conducted at a flow rate of 3 L/min. The data was collected by taking raw water samples at the beginning and at the end of the experiment and after the UV disinfection process. A combination of filters were used as pretreatment including a self-cleaning filter, 1 µm cartridge filter and 5 µm cartridge filter. The samples' UVT, turbidity, and pH were measured on site and the DOC and IC were measured at UBC. The presence of total coliforms and E. coli was measured at BC Centre for Disease Control (BCCDC).

	Processes online	Raw Water Total Coliforms (CFU/100mL)	Post UVMAX Total Coliforms (CFU/100mL)	Raw Water Total E. Coli (CFU/100mL)	Post UVMAX Total E. Coli (CFU/100mL)	Raw Water UVT (%)	Post UVMAX UVT (%)	Raw Water Turbidity (NTU)	Post Turbidity (NTU)	Feed Pressure (psi)	Pressure In Process (psi)	Pressure Out Process (psi)	Tempe rature (degre es C)	Flow rate (L/mi n)
1/10/2015 15:00	25 µm self-cleaning filter + UVMAX	1341.425	0	0	0	74	76	0.29725	0.295	36	33	30	17	3.1
1/10/2015 16:15	25 µm self-cleaning filter + 1 µm cartridge filter + UVMAX	964.8	0	0	0	74	76	0.326	0.235	36	33	30	17	2.9
1/10/2015 18:00	25 µm self-cleaning filter + 5 µm cartridge filter + UVMAX	878.05	0	0	0	74	76	0.298	0.268	36	33	30	17	3.0

Experiment:	UV Disinfection - Coliform Inactivation Experiment with a UV Dosage of 50 mJ/cm^2
Date:	December 8th and December 15th, 2015
Research Scientist:	David Chan
Experiment description:	The UV Disinfection test was to determine the extent of deactivation of total and fecal coliforms with the UV disinfection process with different combinations of filters. The process was conducted at a flow rate of 46.7 L/min. The data was collected by taking raw water samples at the beginning and at the end of the experiment and after the UV disinfection process. A combination of filter were used as pretreatment to remove larger particles. The samples' UVT, turbidity, and pH were measured on site and the DOC and IC were measured at UBC. The presence of total coliforms and E. coli was measured at BC Centre for Disease Control (BCCDC).

			Raw water					
Date	Time	Filters online	Total Coliforms	Raw Dilution 1/10	Average Total coliforms	Total E. coli	Raw Dilution 1/10	Average Total Coliforms
8/12/2015	6:50 AM	1 µm nom cartridge filter	130.9		126.45	5.2		5.2
8/12/2015	7:07 AM	5 µm bag filter						
8/12/2015	7:27 AM	5 µm cartridge filter						
8/12/2015	7:47 AM	5 µm bag filter + 1 µm nom cartridge filter						
8/12/2015	8:07 AM	1 µm abs cartridge filter						
8/12/2015	8:27 AM	5 µm bag filter + 1 µm abs cartridge filter	272.3		216.2	5.2		5.2
15/12/2015	6:21 AM	5 µm bag filter	121.1	85.0	103.05	< 1	< 1	< 1
15/12/2015	6:35 AM	5 µm cartridge filter						
15/12/2015	6:45 AM	1 µm nom cartridge filter						
15/12/2015	6:55 AM	5 µm bag filter + 1 µm nom cartridge filter						
15/12/2015	7:05 AM	5 µm cartridge filter + 1 µm nom cartridge filter						
15/12/2015	7:15 AM	5 µm bag filter						
15/12/2015	7:25 AM	5 µm cartridge filter						
15/12/2015	7:35 AM	1 µm nom cartridge filter						
15/12/2015	7:45 AM	5 µm bag filter + 1 µm nom cartridge filter						
15/12/2015	7:55 AM	5 µm cartridge filter + 1 µm nom cartridge filter						
15/12/2015	8:10 AM	1 µm abs cartridge filter						
15/12/2015	8:20 AM	5 µm bag filter + 1 µm abs cartridge filter						
15/12/2015	8:30 AM	5 µm cartridge filter + 1 µm abs cartridge filter						
15/12/2015	8:40 AM	1 µm abs cartridge filter						
15/12/2015	8:50 AM	5 µm bag filter + 1 µm abs cartridge filter						
15/12/2015	9:00 AM	5 µm cartridge filter + 1 µm abs cartridge filter	71.5	41.0	56.25	1.0	10.0	5.5

			Post filtration				Post UV disinfection			
Date	Time	Filters online	Total Coliforms	Average Total coliforms	Total E. coli	Average Total Coliforms	Total Coliforms	Average Total coliforms	Total E. coli	Average Total Coliforms
8/12/2015	6:50 AM	1 µm nominal cartridge filter								
8/12/2015	7:07 AM	5 µm bag filter					0		0	
8/12/2015	7:27 AM	5 µm cartridge filter	228.2		6.3					
8/12/2015	7:47 AM	5 µm bag filter + 1 µm nominal cartridge filter	129.1		3.1		0		0	
8/12/2015	8:07 AM	1 µm absolute cartridge filter	70.3		6.3		0		0	
8/12/2015	8:27 AM	5 µm bag filter + 1 µm absolute cartridge filter					0		0	
15/12/2015	6:21 AM	5 µm bag filter					0		0	
15/12/2015	6:35 AM	5 µm cartridge filter					0		0	
15/12/2015	6:45 AM	1 µm nominal cartridge filter					0		0	
15/12/2015	6:55 AM	5 µm bag filter + 1 µm nominal cartridge filter					0		0	
15/12/2015	7:05 AM	5 µm cartridge filter + 1 µm nominal cartridge filter					0		0	
15/12/2015	7:15 AM	5 µm bag filter					0		0	
15/12/2015	7:25 AM	5 µm cartridge filter					0		0	
15/12/2015	7:35 AM	1 µm nominal cartridge filter					0		0	
15/12/2015	7:45 AM	5 µm bag filter + 1 µm nominal cartridge filter					0		0	
15/12/2015	7:55 AM	5 µm cartridge filter + 1 µm nominal cartridge filter					0		0	
15/12/2015	8:10 AM	1 µm absolute cartridge filter					0		0	
15/12/2015	8:20 AM	5 µm bag filter + 1 µm absolute cartridge filter					0		0	
15/12/2015	8:30 AM	5 µm cartridge filter + 1 µm absolute cartridge filter					0		0	
15/12/2015	8:40 AM	1 µm absolute cartridge filter					0		0	
15/12/2015	8:50 AM	5 µm bag filter + 1 µm absolute cartridge filter					0		0	
15/12/2015	9:00 AM	5 µm cartridge filter + 1 µm absolute cartridge filter					0		0	

Experiment:	UV Disinfection - Coliform Inactivation Experiment with a UV Dosage of 50 mJ/cm^2 and 40 mJ/cm^2
Date:	March 22nd, 2016
Research Scientist:	David Chan
Experiment description:	The coliform inactivation test was conducted with an amalgam UV system on March 22nd, 2016 to determine its ability to disinfect the water (i.e., inactivate E. coli) at an approximate UV dosage of 50 mJ/cm^2 and 40 mJ/cm^2. As pre-treatment, combinations of filters were used to remove larger particles from the raw water. Each filter combination was tested for 10 minutes, each test had a duplicate run. Samples were taken from downstream of the UV system after each test. Turbidity was measured on site and the presence of total coliforms and E. coli was measured at BC Centre for Disease Control (BCCDC).

SampleID	Time	Dilution	#Big wells/49	#Small Wells/48	Total Coliforms CFU/100ml	Average Total Coliforms CFU/100mL	#Big wells/49	#Small Wells/48	Total E.coli CFU/100ml	Average Total Coliforms CFU/100mL
VAID Raw	7:00	1	23	4	35.5	35.5	2	0	2	2
VAID Raw 1/10	7:00	1	0	0	<10		0	0	<10	
VAID Raw	8:00	1	18	1	23.1	23.1	0	0	<1	<1
VAID Raw 1/10	8:00	1	1	0	10		0	0	<10	
10 µm BF 45L/min	7:15	1	19	3	27.2	27.2	0	0	<1	<1
10 µm BF 60L/min	7:25	1	28	1	41	41	1	0	1	1
10 µm BF 60L/min	7:40	1	25	2	36.4	36.4	0	0	<1	<1
10 µm BF 45L/min	7:45	1	17	5	26.6	26.6	0	0	<1	<1
1µm CF 45L/min	7:35	1	38	5	77.1	77.1	1	0	1	1
1µm CF 45L/min	7:50	1	23	3	34.1	34.1	0	0	<1	<1
1µm CF 60L/min	7:30	1	20	2	27.5	27.5	0	0	<1	<1
1µm CF 60L/min	7:55	1	21	0	26.5	26.5	0	0	<1	<1
10 µm BF + UV 45L/min	7:15	1	0	0	<1	<1	0	0	<1	<1
10 µm BF + UV 60L/min	7:25	1	0	0	<1	<1	0	0	<1	<1
10 µm BF + UV 60L/min	7:40	1	0	0	<1	<1	0	0	<1	<1
10 µm BF + UV 45L/min	7:45	1	0	0	<1	<1	0	0	<1	<1
1 µm CF + UV 45L/min	7:35	1	0	0	<1	<1	0	0	<1	<1
1 µm CF + UV 45L/min	7:50	1	0	0	<1	<1	0	0	<1	<1
1 µm CF + UV 60L/min	7:30	1	0	0	<1	<1	0	0	<1	<1
1 µm CF + UV 60L/min	7:55	1	0	0	<1	<1	0	0	<1	<1