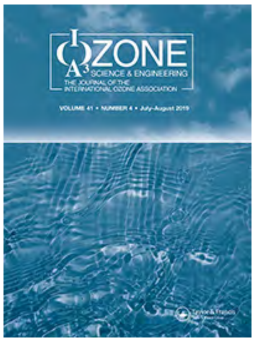

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Ozone Application for Arsenic and Manganese Treatment at the City of White Rock, BC, Canada

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ABSTRACT
The City of White Rock purchased the water utility on October 30, 2015, from EPCOR Utilities Inc. The City of White Rock's water utility provides safe and clean drinking water to its residents. The drinking water is obtained from the Sunnyside Uplands Aquifer. To ensure water supplied is of the highest quality, the City collaborated with the RES'EAU-WaterNET, to conduct research to evaluate and identify technologies that are capable of providing a significant reduction of arsenic and manganese, to improve water quality. The City submitted a grant application to the Clean Water and Wastewater Fund (CWWF) for the construction of a water treatment plant to reduce arsenic and manganese in drinking water. The Government of Canada and the Province of British Columbia provided funding from the Clean Water and Wastewater Fund (CWWF) to the City of White Rock for the "Arsenic and Manganese Water Treatment Project. The City awarded a contract for the Design Build for a Water Treatment Plant to provide a major reduction in arsenic and manganese in drinking water. The Design Build project utilized the scientific findings from the research conducted. The construction of the plant started in March 2018, and the project is expected to be completed by March 2019.

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Ozone; arsenic; manganese; oxidation; ground water

Introduction

The City of White Rock purchased the water utility on October 30, 2015, from EPCOR Utilities Inc. Since taking ownership of the water utility, the City has continued to maintain the importance of quality assurance and has taken steps to ensure providing clean water to the residents. The drinking water is obtained from the Sunnyside Uplands Aquifer and seven wells located throughout the City. The utility serves a population of approximately 20,000 people.

The quality of drinking water is of the utmost importance to the City, which is why regular water testing is conducted, and the city has taken steps to build a water treatment plant to remove arsenic and manganese, hired in-house experts and consultants who have extensive experience. The City applied for infrastructure grants funding programs by the provincial and federal governments, which is not available to private organizations. The Government of Canada and the Province of British Columbia provided funding from the Clean Water and Wastewater Fund (CWWFA) to the City of White Rock for the "Arsenic and Manganese Water Treatment Project No. C40174".

Arsenic and manganese in water

Arsenic is a natural element that is present in Earth's crust. It is often found naturally in groundwater, through erosion and weathering of soils, minerals, and ores. Arsenic presence in the environment may come mainly via drinking water which could pause a serious threat to human health. Sources of drinking water are mainly from surface water or ground depending on the availability. Higher arsenic concentrations are usually present in groundwater.

Arsenic occurs in the environment in different oxidation states, however, naturally occurring in water supplies is mostly inorganic arsenic, as arsenite As(III) or pentavalent arsenate As(V) (Smedley and Kinniburgh 2001).

Arsenic is one of the many chemicals for which Health Canada has set guidelines. The guideline has been established at 0.010 mg/L (10 µg/L) and will continue to be reviewed to reflect new treatment methods and new information on health risks as they become available. The guideline is based on lifetime exposure to arsenic from drinking water and takes into consideration the ability to measure arsenic and to remove it from drinking water supplies (Health Canada 2006).

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/bose.

The Guidelines for Canadian Drinking Water Quality include an aesthetic objective for manganese in drinking water with a value of 0.05 mg/L (50 µg/L). The presence of manganese in drinking water supplies may be objectionable for a number of reasons. At higher concentrations, manganese could have an impact in causing stains on laundry and leaves deposits on supply pipes in distribution system and in residential plumbing that may cause objectionable tasting water. The presence of manganese in water may lead to the accumulation of microbial growths in the distribution system. Even at concentrations below 0.05 mg/L, manganese may form coatings on water distribution pipes that may slough off as black precipitates (Health Canada 1987).

Health Canada started a consultation process in 2016 to update the drinking water guideline for Manganese. The effects observed in children are consistent with the neurological effects reported in the key animal studies used to establish the proposed MAC. A maximum acceptable concentration (MAC) of 0.1 mg/L (100 µg/L) is proposed for total manganese in drinking water. An aesthetic objective (AO) of 0.02 mg/L (20 µg/L) is also proposed for total manganese in drinking water. A non-cancer endpoint was chosen for this assessment as available studies are not adequate to support a link between manganese and cancer (www.canada.ca/en/health-canada/programs/consultation-manganese-drinking-water.html) (Health Canada 2016).

City of white rock water system

As part of its acquisition and operation of the water utility, the City is under mandate by the Fraser Health Authority to implement a secondary form of water disinfection. The work is necessary to treat the water supply and upgrade critical infrastructure in the White Rock system and is a part of the City's commitment to implement the Total Water Quality Management (TWQM) Project.

In August 2010 E. coli contamination was confirmed at the Merklin reservoir and a boil water advisory was issued for the entire City. Fraser Health instructed that secondary disinfection of the entire water distribution system. Currently, chloramination is provided as the secondary disinfectant to the distribution system in White Rock.

The water quality analysis for the water supply from the seven wells at the City of White Rock, Figure 1, indicated an elevated naturally occurring arsenic and manganese at different concentrations, Figures 2–3.

The City of White Rock collaborated with RES'EAU-WaterNET, a research program funded by the Natural Sciences and Engineering Research Council (NSERC) and partnerships with 26 public and private organizations.

The RES'EAU-WaterNET Mobile Water Treatment Pilot Plant was utilized to conduct testing of various combinations of technologies to identify a sustainable and robust water treatment system capable of removing

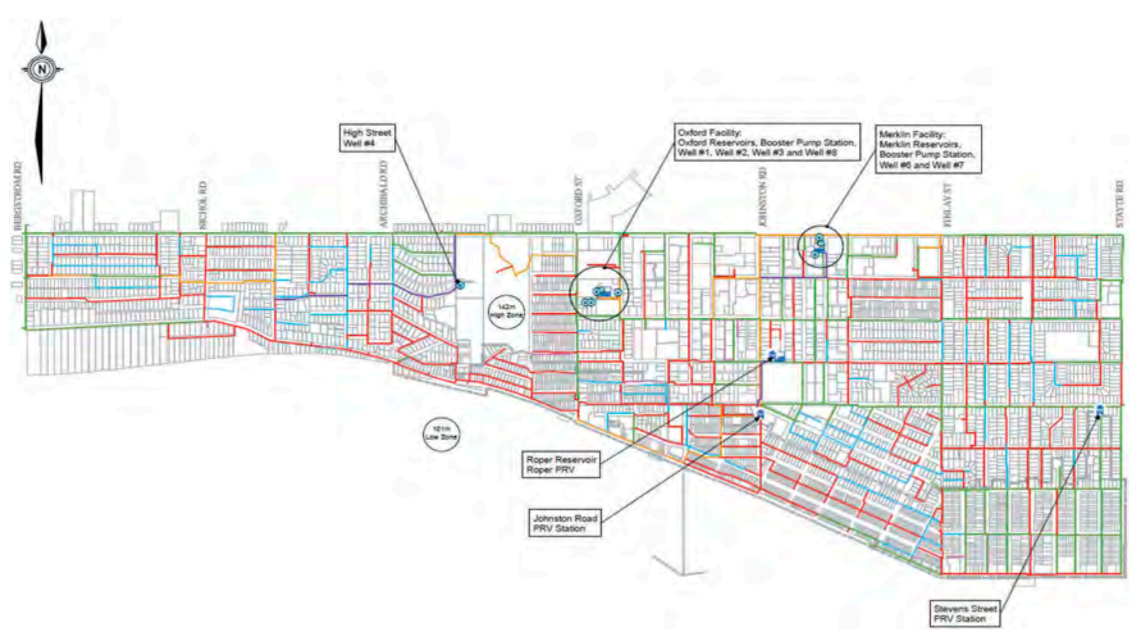

Figure 1. City of white rock water system.

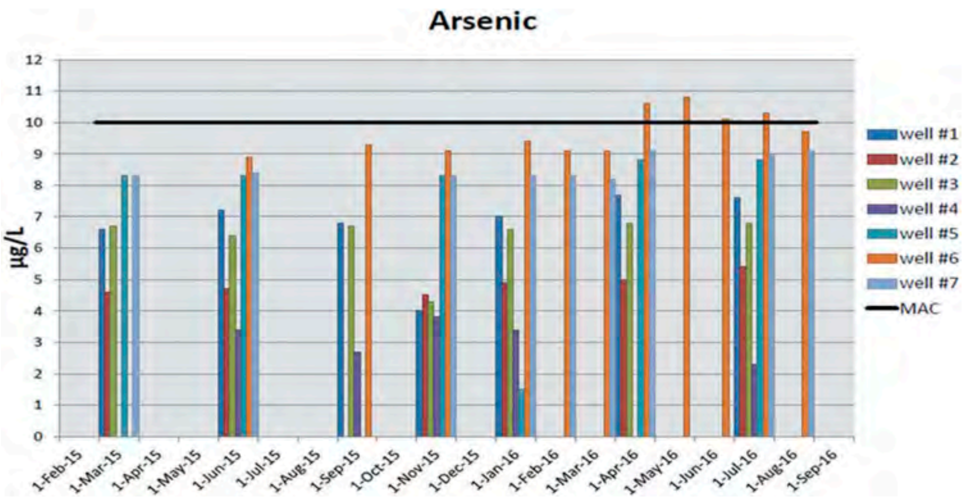

Figure 2. Arsenic concentrations for wells1–7, 2015–2016.

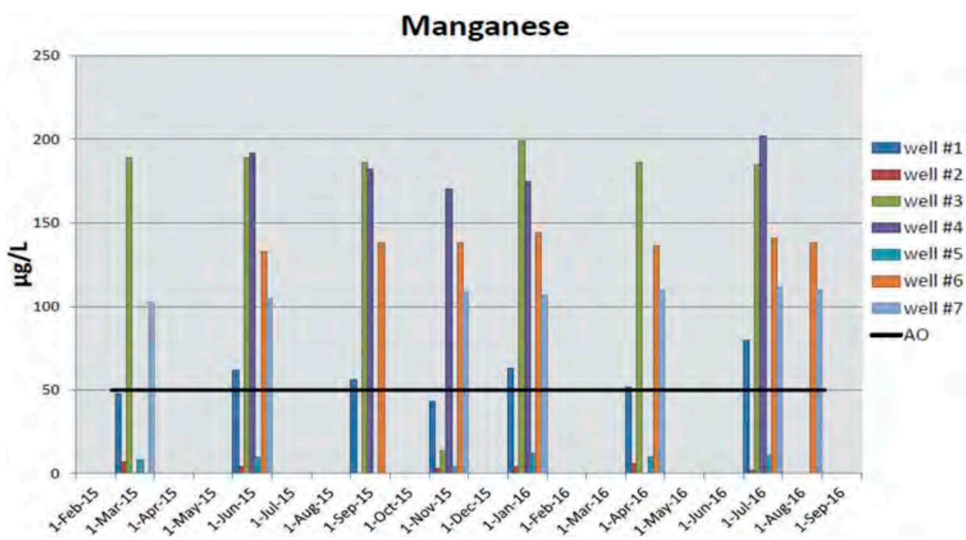

Figure 3. 2015 manganese concentrations for wells 1–7, 2015–2016.

naturally occurring arsenic and manganese from the groundwater sources. The mobile facilities allowed for faster, more accurate and more cost-effective assessment of potential technologies than traditional methods.

The objectives of the research focused on the evaluation of several treatment technologies, including technologies already available commercially such as filtration/oxidation, adsorption, biological filtration, and pre-oxidation with ozone. Pilot testing included the most promising technologies to evaluate their viabilities, both in terms of performance and economics. The pilot work conducted in close collaboration with the staff of the City of White Rock and involved RES'EAU's partners who have extensive experience with groundwater treatment and quality.

The study was conducted from using the mobile pilot plant facility that consisted of two treatment trains that involved oxidation, filtration and adsorption stages. The source water was taken from wells 6 and 7 with levels of manganese and arsenic are 130–140 µg/L and 7–10 µg/L, respectively.

The two predominant inorganic arsenic species found in drinking waters are As(III) and As(V). As(III) is commonly associated with ground waters while As(V) is associated with surface waters. The efficiency of arsenic removal from a drinking water supply is dependent on the oxidation state of the arsenic because the removal technology is often based on ion exchange or iron co-precipitation (EPA 2006).

Arsenic speciation analysis was conducted to establish the knowledge about the As(III) and As(V) concentrations and evaluate if there is a difference in these concentrations at different times of the year. Samples were analyzed by ALS Canada Ltd., Burnaby, British Columbia, CA, Figure 4.

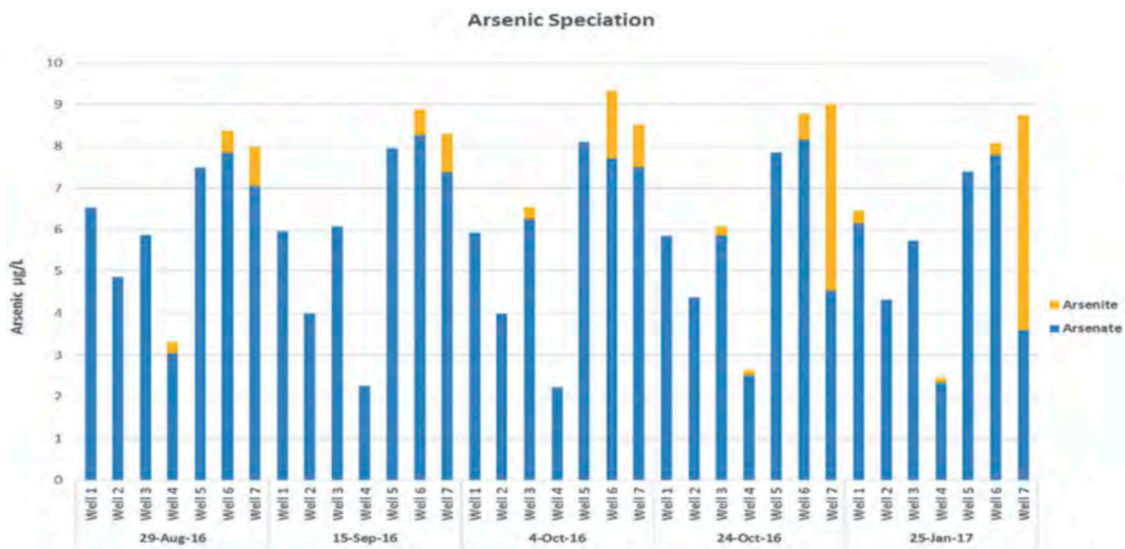

Figure 4. Arsenic speciation results for different wells.

The research evaluated the efficacy of different filter media for the removal of arsenic and manganese and the impact of ozone as pre-oxidant on the oxidation of arsenic, as shown in Figures 5–6.

After completion of the pilot plant study and analysis of the collected data, a report was prepared that included all the treatment processes considered in the experimental project. The report is available on the website www.whiterockcity.ca. (Res'eau-WaterNet 2017).

The findings of the research provided an important guidance for the consultants to select the required technologies for the water treatment plant.

Water treatment plant for the removal of arsenic and manganese

The Fraser Health Authority (FHA) advised that the City of White Rock Water that; should arsenic and manganese levels move above Health Canada's Guideline for Drinking Water Quality (GCDWQ), or should the GCDWQ deem manganese a health criteria, a treatment system must be operational on or before December 31, 2018 (Fraser Health 2017).

Shortly after the acquisition of the water utility, the City confirmed that levels of arsenic in two out of seven wells were higher than Health Canada's maximum allowable level on limited occasions. The City took immediate steps to address water quality issues and plan for the design and construction of a water treatment plant for arsenic and manganese removal.

The City submitted grant applications towards arsenic and manganese treatment processes, under Canada's and the Province's Clean Waste Water Fund (CWWF).

In March 2017, the City of White Rock received \$11.79 million in grant funding from the Government

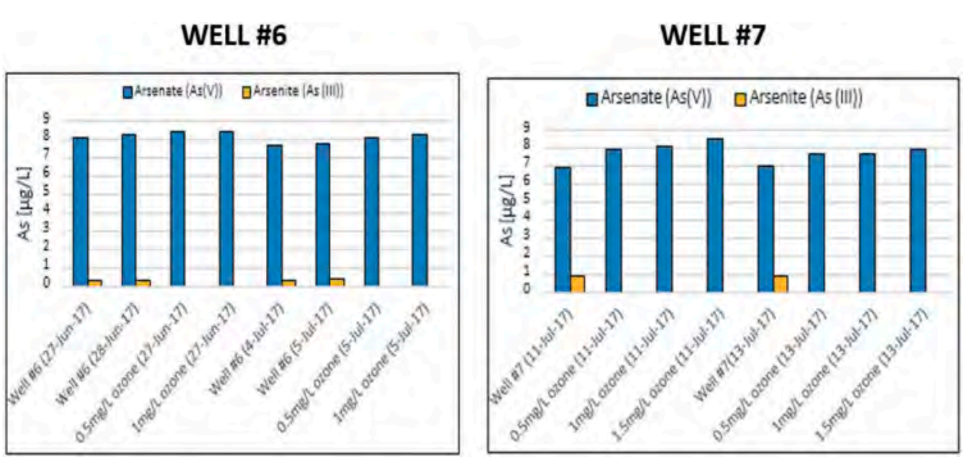

Figure 5. Oxidation of arsenic from wells #6 & #7 at 0.5 and 1.50 mg/L ozone dosage.

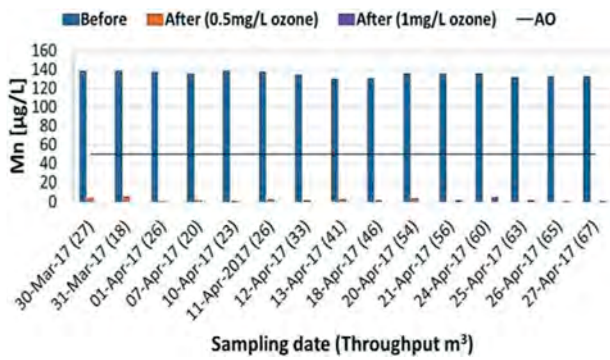

Figure 6. Manganese concentrations before and after GreensandPlus at different sampling dates; values in the brackets represent the cumulative throughput volume of the water.

of Canada and Government of British Columbia. The funding would go towards the City's $14.2 million arsenic and manganese treatment process to address the City's water quality and ensure a healthier community.

The design of the water treatment plant

Kerr Wood Leidal Associates (KWL) were retained to provide cost evaluations for three options for design and construction of water treatment plant(s). The options were as follows:

- Option 1: One water treatment plant at the Oxford site; without connect to well#4 (well#4 is about 1 km west of the Oxford site).
- Option 2: Two water treatment plants, one at Merklin site and another at Oxford site; and
- Option 3: One water treatment plant covering all the above-referenced wells in addition to connecting existing well # 4 to the water treatment plant located at the Oxford site.

The seven (7) wells water quality have different levels of Ammonia, Iron, Manganese and Arsenic. The goal is to have a water treatment system that is capable of providing a significant reduction for arsenic and manganese. Currently wells 1, 2, 3 and 8 supply water to the Oxford reservoir and wells 6 and 7 supply water to the Merklin reservoir. The existing secondary disinfection systems at both pumping stations will be used for the water treatment plant effluent secondary disinfection.

In order to accommodate the water treatment units, the selection of a pre-engineered building (an insulated steel frame building) was considered for 1 or 2 water treatment plants. The building would include the area for the filter units and accessories and modest areas for office, chemical storage, building ventilation, electrical control room, and lab.

Under each option, additional pipework would be required to deliver the water from the well pump discharge lines to the treatment plant and back after the treatment processes to the water reservoirs located at Merklin and Oxford sites. The pipework was included, as required for all the options in the budget for connecting the well discharge headers to the treatment plants and from the treatment plants to the reservoirs at Oxford and Merklin sites.

The evaluation results favored in the selection of Option 3, to have "One Water Treatment Plant" located at the Oxford Pumping Station Site with the connection of Well #4 to the plant, for the following reasons:

(1) The difference in water quality between the two sites (Merklin and Oxford) would require a different treatment operation setup on each site to deal with the different water quality parameters (ammonia, iron, manganese, and arsenic) if two water treatment plants are considered. Blending the water from the seven wells, providing the treatment processes required and having the same water quality pumped from the two pumping stations would be a better engineering, operational and cost-effective approach.
(2) The available space at the Merklin Pumping Station is less than 30% of the available space at the Oxford pumping station.
(3) The estimated Capital cost difference associated with building one plant at Oxford, and connecting Well 4 to Oxford, which is necessary in any case, is estimated to be $964,000 less than building two plants (one at Oxford and another at Merklin).
(4) The Operation and Maintenance Cost for one plant at the Oxford (including connection to Well 4 – Option 3) is estimated to be $422,000 less than for two plants.

A request for proposals the (RFP) for a Design Build for a Water Treatment Plant for the Removal of Arsenic and Manganese was posted. Colliers Project Leaders was contracted by the City of White Rock to assume the responsibility of the project management until project completion. Detailed technical evaluation to the submitted proposals was conducted by the staff of the City of White Rock, KWL and Colliers Project Leaders.

A unanimous decision to select NAC Constructors Ltd./Associated Engineering team was based on the technical evaluation by the technical evaluation committee (City of White Rock, KWL & Colliers Project Leaders). The financial proposals were reviewed independently after the technical review was completed. The NAC Constructors Ltd./Associated Engineering Ltd team were selected based on both the technical and financial proposal submissions.

Based upon the outcome of the review teams' analysis, it was recommended that the City select the NAC Constructors Ltd. and Associated Engineering Ltd team as the successful Proponent.

The recommendation was presented to the City Council at its meeting on November 6, 2017. The City Council awarded NAC Constructors Ltd. the contract for the Design Build of the Water Treatment Plant.

Water treatment processes and technologies design

Water treatment objectives

The White Rock Water Treatment Plant is designed to treat the City's existing groundwater supplies to remove naturally occurring manganese and arsenic to ensure that an improved drinking water quality is supplied to the residents that meets the guidelines and aesthetic objectives. The plant is built next to the Oxford Pumping Station of the City of White Rock, Figure 1. The water treatment plant process is multi-stage and includes the following key treatment components:

- Pre-Oxidation with ozone for arsenic and manganese in the raw water supply.
- Removal of manganese using Greensand Plus media filters.
- Removal of arsenic using Bayoxide E33 media filters.

The treatment objectives of the White Rock WTP are to deliver drinking water meeting the following operational targets:

• Mn < 0.02 mg/L

• As < 0.002 mg/L (95% of time, 0.005 mg/L for 5% of operation)

All other water quality parameters shall meet the objectives of the Guidelines for Canadian Drinking Water Quality (GCDWQ).

Ozone pre-oxidation

Research has shown that the application of ozone for water treatment processes can enhance the ability to remove many emerging contaminants (Jasim et al. 2006; Rahman et al. 2010) and reduce disinfectant by-products (Borikar, Jasim, and Mohsini 2015; Irabelli, Jasim, and Biswas 2008). Ozone, a strong oxidant, is very effective in the oxidation of organic and Inorganic compounds more effectively than chlorine (Fong 1998; Langlais and Brink 1991).

Arsenic present in groundwater in As(III) form needs to be oxidized to As(V). To have an optimum removal of As(III) which is neutrally charged, it should be oxidized to As(V) which is negatively charged. The use of a strong oxidant is an important factor to achieve arsenic removal.

Strong chemical oxidants oxidize As(III) very rapidly (Ghurye and Clifford 2001, 2004), thus contact time generally is not a critical factor for optimizing arsenic removal. The simple oxidation reactions between ozone and arsenic, and manganese are as follows (EPA 2001):

$$O_3 + H_3AsO_3 = H_2AsO_4^{-} + O_2 + H^{+} \text{ (@ pH 6.5)}$$

$$O3 + H_3AsO_3 = HAsO_4^{2-} + O_2 + 2H^{+} \text{ (@ pH 8.5)}$$

$$O_3 + H_2O + Mn^{2+} = MnO_2(s) + 2H^{+} + O_2$$

Manganese and arsenic removal

Manganese removal in groundwater supplies has been practiced for many decades. Technology approaches are mature, and improvements in treatment efficiency have been only incremental.

The focus on arsenic removal technologies has been increasing due to more emerging evidence of concerns over human exposure risks of arsenic that led to changes of guidelines for arsenic in drinking water. Knowledge of raw water quality is an important factor in the selection of the technology and processes to remove certain organic or inorganic compounds that might interfere in achieving the targeted effluent water quality.

The City of White Rock's groundwater has elevated, naturally occurring arsenic and manganese. The research conducted by the City of White Rock and RES'EAU-WaterNet showed that the use of ozone as a pre-oxidant, followed by greensand and adsorption filter media for the removal of manganese and arsenic, respectively, is effective for groundwater sources like White Rock's water supply. NAC/Associated Engineering Team chose filtration using Greensand Plus media for manganese reduction, and AdEdge E33 adsorption media, for arsenic polishing to achieve the low target levels required by the City. The use of ozone for pre-oxidation of the arsenic and manganese prior to the two-stage process; filtration and adsorption process was included in the design due to the facts that:

- Many arsenic removal technologies are more effective at removing the pentavalent form of arsenic, arsenate, As(V) than arsenite, As(III).
- Therefore, many treatment systems include a pre-oxidation step to convert Arsenite, As(III) to Arsenate As(V).
- Ozone can achieve 100% oxidation of As(III) to As(V), Figure 5.
- Oxidation alone does not remove arsenic from solution, and must be coupled with a removal process such as coagulation, adsorption or ion exchange.
- Manganese removal was very effective using ozone followed by Greensand Plus, Figure 6.

Ozone system

The ozone treatment process at the White Rock WTP is targeting the oxidation of Mn and As for downstream removal by filtration and adsorption. The system is designed to provide up to 1 mg/L of ozone dose for up to 15 MLD of water to treat. The design of the White Rock Water Treatment Plant includes a pre-oxidation with ozone injected via sidestream injection; the concentrated ozonated water is injected into the raw water through an in-line mixer to oxidize metals in raw water.

On-site generated ozone gas will be used to pre-oxidize the arsenic and manganese in the raw water. The ozone will convert the arsenite form As(III) to the arsenate form As(V). It will also convert Mn(II) to Mn(IV). Both oxidized forms are more readily removable in downstream filtration and adsorption processes.

The ozone system supplied by SUEZ Water Treatment Solutions, Inc., USA, includes two parallel trains of oxygen and ozone production with 100% redundancy in active equipment, followed by two parallel 50% trains of ozone injection system (Mazzei Injector Co., USA) through the application of ozone into two side streams of water pumped from the mainstream line. Undissolved ozone is removed at the side stream level through centrifugal degassing and destroyed back to oxygen through two 100% redundant ozone destruct units. The ozone system is controlled through a main ozone control panel where inputs will be provided by the operator.

The ozone system is comprised of the following main equipment:

Oxygen generator system

Pressure Swing Adsorption (PSA) Oxygen Generation Equipment 2 × 2.8 scfm (2 x 4.76 m^3/h) O2 @ 95% concentration (AIRSEP-Chart Industries). Common to the two (2) parallel oxygen generation lines is one (1) common 60 Gal vertical oxygen gas receiver followed by two (2) redundant parallel particles filters and a dew point analyzer.

Ozone generator/PSU

Two (2) ozone generators each capable of producing 33 lb/day of ozone at 10% with a cooling water temperature of up to 25 °C are installed (SUEZ Water Treatment Solutions, Inc., USA). Each generator has been sized to supply a dose of up to 1 mg/L of ozone at a maximum plant flow rate of 15 MLD.

Ozone injection system

To provide a rapid mix of the produced ozone into the raw groundwater, a side-stream injection was considered. Two (2) Mazzei ozone injection skids are installed (Mazzei Injector Company, USA). Each skid will respond to 50% of the total ozone generation capacity. This corresponds to 17.5 lbs/day of 10% wt. ozone for each skid.

The side-stream system includes injection booster pumps drawing raw water, venturi ejectors to draw ozone into the side-stream flow and static mixers to super-saturate the raw water with ozone. Prior to re-introduction of the side-stream flow into the ozone pipe reactor, any residual ozone gas will be collected using gas separation units and directing the ozone off-gas to thermal destruct units.

Using the sidestream method of ozone mixing and off-gas collection, it is likely there will be little additional ozone off-gas within the pipeline contactor.

A dissolved ozone monitor is provided to measure dissolved ozone concentrations at two locations downstream of the Pipeline Flash Reactor. The contact time at the Flash Reactor at a maximum design flow rate of 15 ML/D will be 1 min. The concentration of dissolved ozone collected from this monitor will be used to ensure that the filters downstream will not be exposed to high ozone concentrations.

Each ozone injection skid is sized to inject 50% of the capacity of ozone in parallel. Motive water pumps operate at constant regime. The gas flow control valve operates based on feedback from the gas flow control valve to accommodate for set ozone gas flow rate (NAC/Associated Engineering 2018).

Ozone destruct system

Two (2) thermal ozone destruct units are installed downstream the gas outlet. Each ozone destruct unit is sized to accommodate 100% of the design ozone generation capacity.

The ozone destructs unit will be to maintain an operating temperature of 350 ºC. A small controller based on an internal temperature switch will modulate the temperature of the unit.

A low concentration ozone monitor installed downstream of the common outlet of the ozone destruct units will monitor the concentration ozone in the gas rejected outside. The maximum allowable concentration reading will be 0.08 ppmv of ozone.

Ambient ozone monitors

Two ambient ozone monitors are located at the ozone system room and the hallway where the Mazzei injectors are installed. The analyzers will initiate the first alarm at 0.1 ppmv, and at 0.3 ppmv, the ozone generator operation will be turned off. The ozone room is provided with industrial air extractors with operation to be initiated at ambient ozone concentration of 0.1ppmv.

Greensand plus

Greensand Plus filter media (AdeEdge Water Technologies) was selected for removing manganese from groundwater supplies of the City of White Rock (Sunnyside Aquifer). Greensand Plus manganese dioxide coated surface acts as a catalyst in the oxidation-reduction reaction of manganese. The silica sand core of Greensand Plus allows it to withstand waters low concentrations in silica, TDS, and hardness without breakdown. Greensand Plus is effective at higher operating temperatures and higher differential pressures than standard manganese greensand. Greensand Plus has the WQA Gold Seal Certification for compliance with NSF/ANSI 61 (AdEdge 2018). Two (2) pressure filter vessels supplied by AdEdge will be operating in parallel mode, Figures 7–8.

The newly designed and built water treatment plant will utilize a Supervisory Control and Data Acquisition (SCADA) for the daily operation, control and data acquisition for all the water treatment processes. The existing SCADA for the two pumping stations (Oxford and Merklin) will be integrated into the water treatment

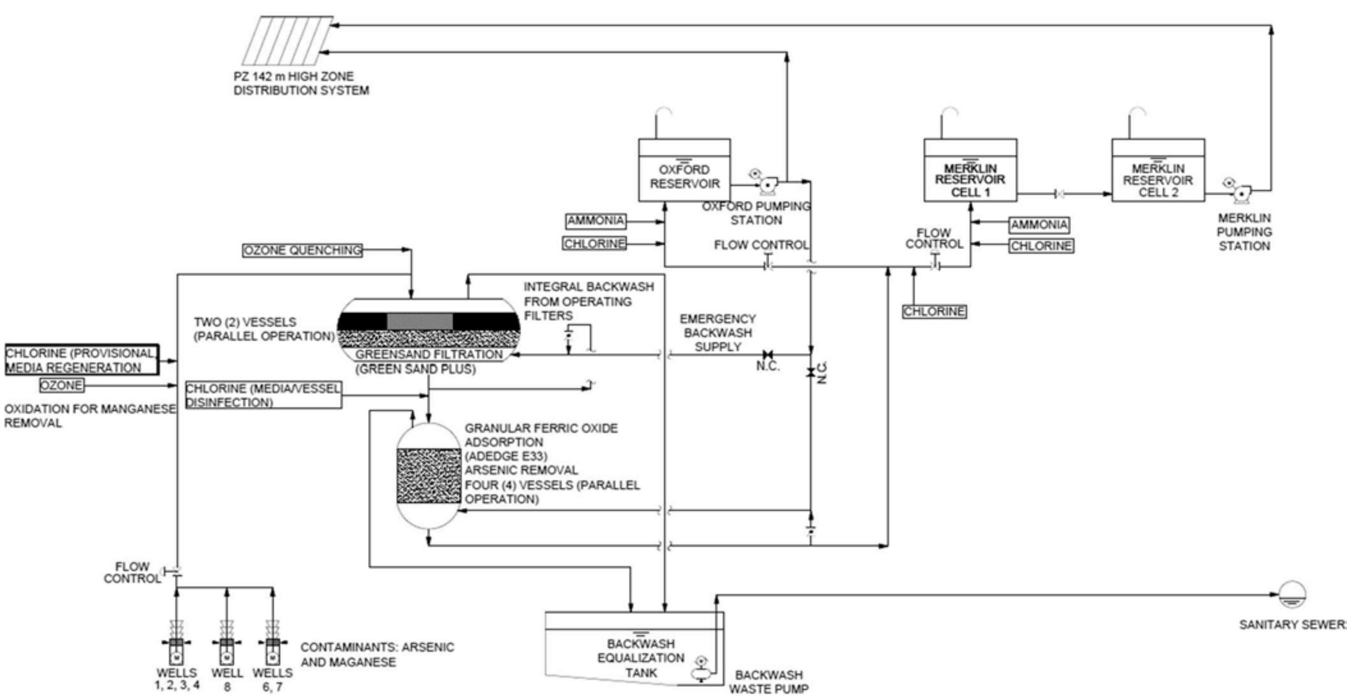

Figure 7. Water treatment processes.

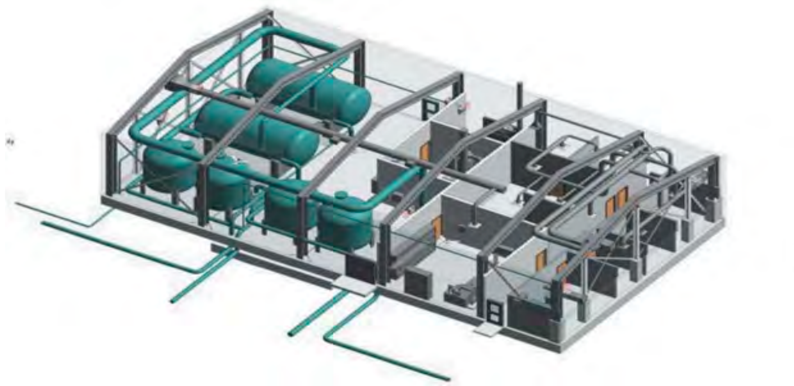

Figure 8. 3D layout of the water treatment processes.

plant SCADA to have a central operation and control at the water treatment plant Control Room (AdEdge 2018).

Bayoxide E33 granular ferric oxide media

Bayoxide E33 was selected for Arsenic removal (AdEdge Water Technologies) following the research conducted by the City of White Rock and the Res'eau-WaterNet. The E33 media would provide significant reduction of total arsenic, including both arsenic (III) and arsenic (V).

It is also effective in reducing other heavy metals such as lead, antimony, and others. Developed in the mid-nineties, this ferric oxide-based product has been successfully used in hundreds of installations around the globe (AdEdge 2018). Four (4) pressure contactor vessels supplied by AdEdge will be operating in parallel, Figures 7–8.

Conclusions

The importance of investment to build and upgrade water treatment plants is a strategic factor in ensuring long sustainability planning for water systems infrastructure. This project is an example of successful collaboration of governments, and municipal water systems with academic institutes, and a key in planning for sustainable urban growth. The grant funding from CWWF program from the Government of Canada and Government of British Columbia provided a significant support to deliver a successful Design Build Project arsenic and manganese treatment process to address the City's water quality and ensure a healthier community. The improvement of water quality for the City of White Rock will have a significant importance for the residents of the municipality.

Acknowledgments

The authors would like to acknowledge the support from the City of White Rock. The authors would like to acknowledge the funding support provided by Government of Canada and the Government of British Columbia for providing funding for the project from the Clean Water and Wastewater Fund (CWWF). The Design Build of the Water Treatment Plant to remove arsenic and manganese to <2 μg/L and <20 μg/L, respectively, will provide a significant improvement for the water quality provided to the public.

Funding

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