Biological Filtration Piloting Study at Village of Elk Ridge

Demonstration Project Summary

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Prepared By:

Babak Roshani, PhD, P. Eng.

Scott McKerracher, Engineer-in-Training

Reviewed By:

Dillon Petrucha, P. Eng.

Drop Solutions Inc.
(Drop Water Service)
306-344-1270
service@dropsolutions.ca

BrewNature Inc.
306-716-6551
info@brewnature.ca

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1. Problem Statement

Groundwater is a crucial water resource in the Canadian Prairies. Currently, Saskatchewan is a national leader in economic growth associated with natural resource development and industrial activities. There is a strong demand for securing clean water in a variety of public and industrial sectors. However, groundwater in the Canadian Prairies frequently contains unacceptably high levels of iron, manganese, ammonia, nitrate, arsenic and organic substances, and thus, does not meet drinking water quality standards. Considering future water consumption rates and water infrastructure costs, the development of cost-effective treatment technologies for the removal of contaminants from water has become increasingly urgent in the water treatment industry in the Canadian Prairies.

Various treatment technologies have been employed to enhance potable water quality by removing these inorganic contaminants. In the last two decades, research has focused on individual removal of ammonia, iron, and manganese by biological oxidation from polluted groundwater. However, the combined and simultaneous biological removal of the above contaminants is a difficult task since different conditions are necessary to activate the biological oxidation of each pollutant. Simultaneous biological removal of the above pollutants was studied using two or three treatment stages in order to achieve high removal rates and high-quality potable water that meets or surpasses Canadian Drinking Water standards.

The local groundwater (well water) source at the Village of Elk Ridge, Saskatchewan contains iron, ammonia, and manganese at concentrations higher than the drinking water standards (DWS). The groundwater source contains iron and manganese, at 1.84 and 0.13 mg/L, respectively. Therefore, a combination of a biological filtration process would be a potentially cost-effective option to treat this groundwater for domestic applications. The groundwater also contains a high level of ammonia (0.75 mg/L) which would require a high amount of chlorine to oxidize the ammonia to chloramines if it were not removed in the treatment process. The presence of 0.75 mg/L of ammonia nitrogen in the groundwater may require 6 to 8 mg/L of chlorine to achieve breakpoint chlorination. A high amount of chlorine may result in a high concentration of total chloramines that exceeds the MAC level of 3.0 mg/L set by Health Canada and interferes with the DPD (i.e. N, N-diethyl-p-phenylenediamine) test method for free chlorine. Trihalomethanes (THMs), halogenated acetic acids (HAAs), bromates, chlorates, and chlorides are other concerns associated with a high dosage of chlorine-based disinfectants. By applying biological filtration technology for biological iron, manganese, and ammonia removal from the groundwater, we can produce safe drinking water and considerably reduce the chlorine consumption for disinfection of treated water.

The biological filtration process, a fixed-film biological process, is a specific engineering design that supports the growth of microbial communities capable of metabolizing contaminants through mediating oxidation-reduction reactions. The oxidants (electron acceptors) are normally oxygen, nitrate, perchlorate, sulfate, and iron (III); the reductants (electron donors) include organic matter, trace organic compounds, ammonia, arsenic (III), iron (II), and manganese (II). In a fixed-film biological process, biofilms are developed on the filter media.

A biofilm process mainly consists of two simultaneous steps, substrate diffusion and biological reaction. Electron donors and acceptors diffuse from a bulk fluid into the biofilm and are metabolized by microbial cells. Diffusion profiles are caused to be parabolic by this process. Bio-filtration allows a combination of aerobic biodegradation and physical retention of suspended solids by filtration through the filter bed. The accumulation of a critical mass of micro-organisms, required to bring about the desired reactions, is key to any biological process.

2. Pilot Description

2.1. Pilot Setup

Figure 1: Pilot installation at Village of Elk Ridge.

Drop Water was requested to run a comprehensive pilot study at the Village of Elk Ridge to treat ground water. The 2-gpm pilot skid was provided, including biological filtration system equipment. The biological filtration system has a 2-stage filter vessel array to simulate the operation of the existing system with the required upgrades. This unit is designed to replicate a full-scale system and remove iron, manganese, and ammonia. The piloting study was started in November 2023 and continued until end-March 2024. Through this pilot study, we intended to test the validity of biological filtration as a cost-effective technology for removing iron, manganese, and ammonia at the Village of Elk Ridge. This pilot is specifically designed to perform pilot testing functions and serves as a base on which to further develop new technologies and optimize existing technologies for water treatment.

A pilot-scale biological filtration unit was installed at the Village of Elk Ridge in Saskatchewan. The pilot-scale biological filter consisted of a translucent PVC column, 150 cm high and 12 cm internal diameter. This pilot filter height is typical of a full-scale industrial filter. The height and diameter of the pilot were chosen to ensure enough of the filtrate is available for the bacteria to colonize. The pilot is a scaled-down version of a full biological filtration system, although offers the same filtration capacity for the 2.5 gpm/ft^2 capacity of water. The pilot skid also allows for pressurization of the vessel to closely emulate the conditions inside a full biological filtration system. Air injection is also necessary for the survival of the bacteria in the vessels. Air injection for the pilot skid is supplied by an air compressor that was installed with the pilot skid.

The pilot was running when the full-scale water treatment plant turned on to produce water. The groundwater was pumped directly through the biological filter columns. Ideally, the pilot was to operate 24 hours per day, although the configuration available at the Village of Elk Ridge only allowed for 4-6 hours of operation time, refer to Figure 2 for the graphic of Pilot operational hours. Due to the low run time, the pilot experienced warmer temperatures when not running. The impacts of low runtime and warmer static temperature will be discussed in pilot biofilter performance.

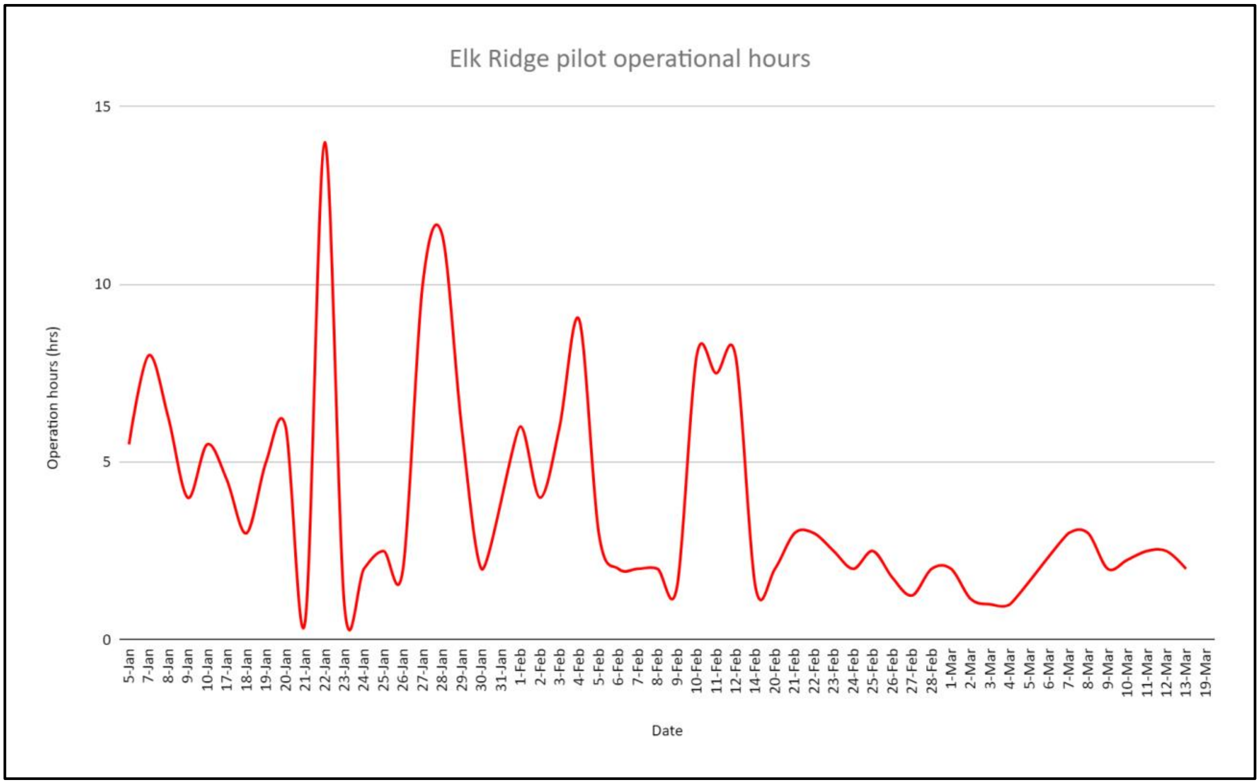

Figure 2: Elk Ridge pilot operational hours.

The groundwater quality parameters and characteristics of the groundwater treated by the biological filtration process are summarized in Table 1.

Table 1: Groundwater quality and treated water by biological filtration at the Village of Elk Ridge.

Parameter	Raw Water	SK Guideline
Ammonia-N (mg/L)	0.71	No guideline
Iron (mg/L)	1.84	<0.3
Manganese (mg/L)	0.13	<0.05
TDS (mg/L)	570	<1500
pH	7.96	7-10.5
Total Alkalinity (mg/L $CaCO_3$)	538	<500
Bicarbonate (mg/L)	656	No guideline
Carbonate (mg/L)	<1	No guideline
Hydroxide (mg/L)	<1	No guideline
Total Hardness (mg/L $CaCO_3$)	446	<800
Conductivity (uS/cm)	913	<2300
Calcium (mg/L)	108	No guideline
Magnesium (mg/L)	43	<200
Potassium (mg/L)	3.6	No guideline
Sodium (mg/L)	36	<300

For more information, please see the laboratory reports found in Appendix A

The key items to highlight in the groundwater samples are high levels of

- Iron
- Manganese
- Ammonia

It is expected that the first filter column will remove iron and part of the ammonia and the second filter column is primarily responsible for the removal of manganese, and remaining ammonia. In the first filter iron-oxidizing bacteria and nitrifying-bacteria (nitrification) are selectively enriched. Whereas, in the second filter a combination of nitrifying-bacteria (nitrification) and manganese-oxidizing bacteria are enriched. Depending on the bed height in the filter and the flux rate, there is a possibility there is a possibility to enrich these three groups of bacteria within a single column of a biofilter.

2.2. Design Criteria and Flux Rate

During the pilot operation at Village of Elk Ridge, following parameters in both filters were monitored on day-to-day basis:

- Iron
- Manganese
- Ammonia
- Flow rate
- Air Injection
- Operating Hours

In this pilot study, iron, manganese, and ammonia concentrations in groundwater and biofilter effluents were measured on a daily basis (The details of these results are explained in the below sections). The results of the previous pilot studies indicate that the filtration rate, or hydraulic loading, is the key design parameter for the filtration processes. The micro-organisms are normally present only in the upper layer of the bed, but as the filtration rate is increased the food supply to the bacteria is carried deeper into the medium. Under these conditions the bacteria adapt themselves to living at greater depths, but only to a limited extent. If the flow rate velocity becomes too high a break-through of ammonia, iron and manganese into the effluent may occur. A satisfactory way of assessing the filter depth and the proper filtration rate is to carry out experiments, either in the laboratory or a pilot-plant, filtering the actual groundwater to be treated through media of differing depth. During two months of piloting, the pilot biofilters were operating at a flux rate of 2.5 USgpm/ft^2 or (6 m^3/m^2/h).

2.3. Backwashing Information

The key to long-term operating success of biofilters is proper bed design and adequate bed cleaning during backwashing. Filters with inefficient backwashing tend to accumulate aggregates of sediments in the pores, increasing local velocities and having a potentially negative impact on filtrate efficiency and filter run time. During backwash, the filters are cleaned with water and gentle air scour in order to remove excess micro-organisms and built-up particulates or solids.

Generally, water used in backwashing must be unchlorinated and, in some cases, groundwater sources can be used. Biological filters often run for periods of one week to few months between backwashes, resulting in less wastewater than most other filtration technologies. The backwashing process essentially involves rinsing or flushing the biofilters. The low back wash rates, along with rapid filter ripening following backwash, increase the water production efficiency of the treatment plant. Micro-organisms remain attached to the filter media in the system even after backwashing, which allows the system to run continuously for an indefinite period of time, as long as backwashing is carried out on a regular basis and no biocides or harsh oxidants are introduced.

This pilot study at Elk Ridge resort, to remove iron, manganese, and ammonia from the local groundwater source, was conducted approximately for four months (15 Nov 2023 to 19 March 2024). During the piloting, approximately 28,800 gallons of groundwater was treated through the biofilter columns. And the biofilters were backwashed three times throughout the course of piloting, indicating a very low backwashing rate is required by using a biological filtration system. The biological filtration pilot was backwashed using the raw water. After backwashing, the system was ripened for 20 minutes at the lower flow rate till the turbidity became equal or below 0.1 NTU. Generally, the following parameters should be considered for backwash time and automation of the system:

- Backwash when the differential pressure reaches 5 PSI or accumulative water volume.
- Backwash when there are increasing Fe & Mn levels in the outlet of the filter; and
- Backwash when turbidity equal to or higher than 0.5 NTU.

The biofilter columns at the Elk Ridge were backwashed with a combination of air scour (rate = 0.5 scfm/ft^2) plus water (flow rate = 4-6 US gpm/ft^2). The media in the column experienced 25-30% bed expansion. Backwash water from the first filter which removes iron is orange in colour, whereas the water from the second filter which removes manganese is dark brown.

The Pilot underwent backwashing on three occasions:

- On January 19th, the first backwash of 2.5 gallons per minute (gpm) was conducted on filter one using raw water.
- On February 6th, both vessels underwent backwashing with air scour.
- The filters were reseeded with Leask Colony's backwashed water on February 14th.
- On February 23rd, filter 1 underwent air scour backwashing again.

For the duration of the pilot, the backwash water was captured and analyzed based on the colour from both vessels. Figures 3 and 4 are examples of the backwash water. Figure 3 shows the backwash from the first vessel after three months of operation. The distinct red-brown colour is expected from the first vessel because this colouring usually coincides with iron removal. The backwash water also was fairly opaque signifying lots of removal from the first filter. The red-brown colouring is created when the iron rusts due to the increases in oxygen present in the vessel, the iron then precipitates getting captured in the vessel's media.

Figure 3: Filter 1 backwashed water, February 6th.

The backwash from vessel 2 is consistent with the results found from testing. Figure 4 shows the backwash water from the second vessel after three months of operation. The backwash water was dark brown almost blue, this coloring is consistent with manganese removal. Although different from the backwash water from vessel 1, the vessel 2 backwash water was slightly transparent. Therefore vessel 2 does not have the same removal as vessel 1 was achieving.

Figure 4: Filter 2 backwash water, February 6th.

2.4. Dissolved Oxygen Consumption

Dissolved oxygen (DO) concentration strongly influences the performance of biological processes as it is necessary for micro-organism growth. The minimum dissolved oxygen content in the effluent of Filter 2 should not be allowed to fall below 5 mg/L. By controlling the DO level with sensors in the biological filter, we are able to provide a uniform and stable environment for the microorganisms, which reduces sludge production and energy costs. During biological filtration piloting at the Elk Ridge, the pilot was operating at a water flow rate of 0.3-0.5 USGPM, the air flow rate to the Filter-1 and Filter-2 was 0.035 SCFH and 0.07 SCFH, respectively. This is equal to the air flow of 2 SLPM for Filter-1 and 1 SLPM for Filter-2.

3. Pilot-scale Biofilter Performance

3.1. Iron Removal

Iron concentration in the local groundwater source at the Village of Elk Ridge ranged between 2.21 to 2.41 mg/L during the piloting period. Saskatchewan's guideline for iron in drinking water is ≤0.3 mg/L. The biological filtration pilot has shown conclusive evidence from this study that the iron concentrations in the groundwater can meet drinking water guidelines and can be consistent with biological removal. Time-dependent profiles of iron concentration and its removal efficiency over the two months of piloting are shown in Figures 5, and Figure 6, respectively. As shown in Figure 5 and 6, it is evident that the biological iron removal was rapid and was consistently below the standards over the course of operation, where iron removal efficiency was higher than 99%.

The sharp peak detailed in the figures around February 8th was due to a reconfiguration of the pilot's settings. On February 7th the inlet pressure was increased from 4 psi to 10 psi to test how the pilot operated at different pressures. The pilot was left at this increased pressure for the remainder of the piloting study. The pilot had also undergone an air scour and backwash on February 6th. The combination of the increased inlet pressure and a recent air scour and backwash would have caused the rapid decrease in performance in vessel 1, although vessel 1 responded quickly. The Iron removal in the effluent from vessel 1 returned to normal removal numbers after six days as the system naturally adapted. Throughout the spike, the effluent from vessel 2 maintained 99% iron removal.

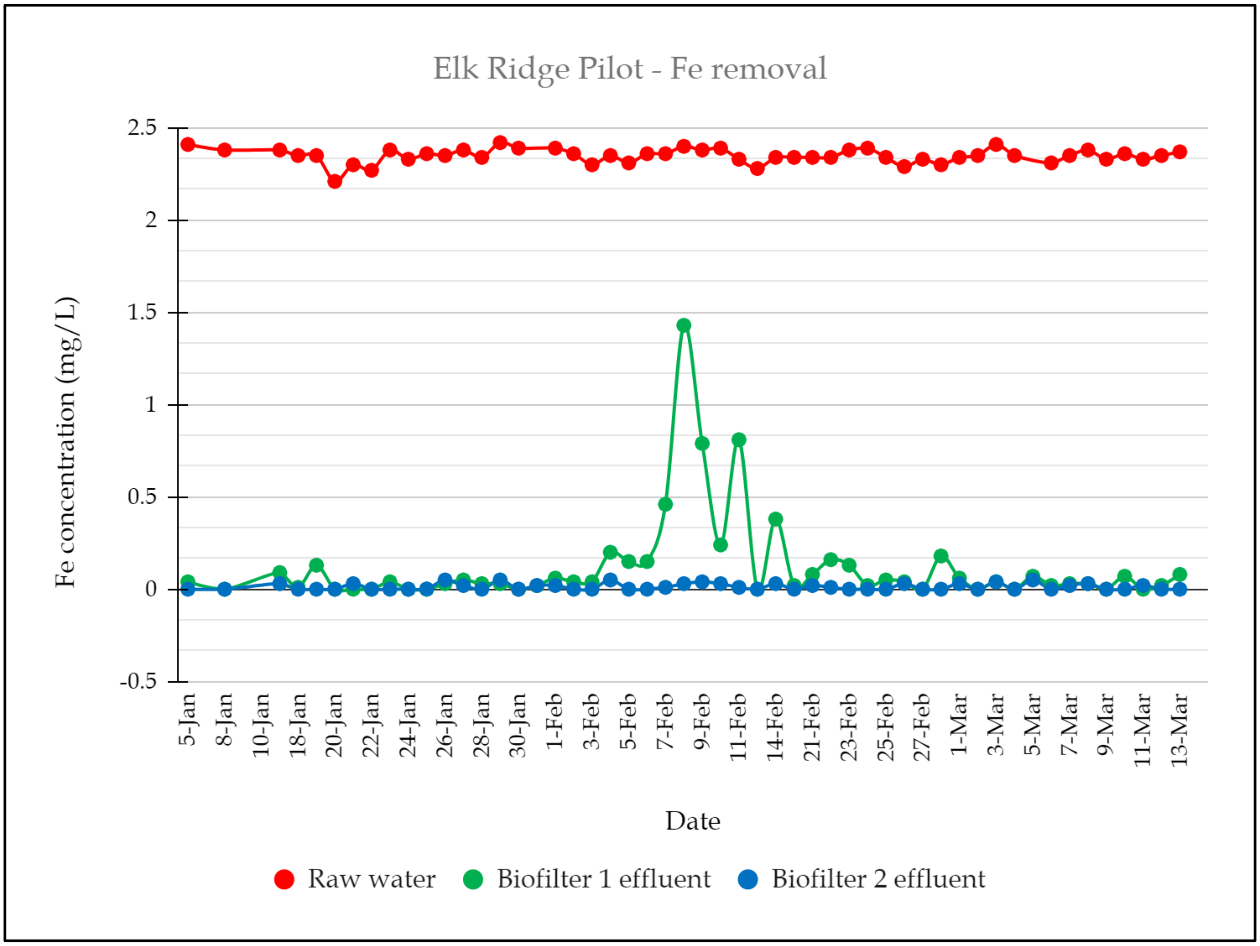

Figure 5: Profile of iron (Fe) concentration in the groundwater, Bio-1, and Bio-2 outlet for the Village of Elk Ridge.

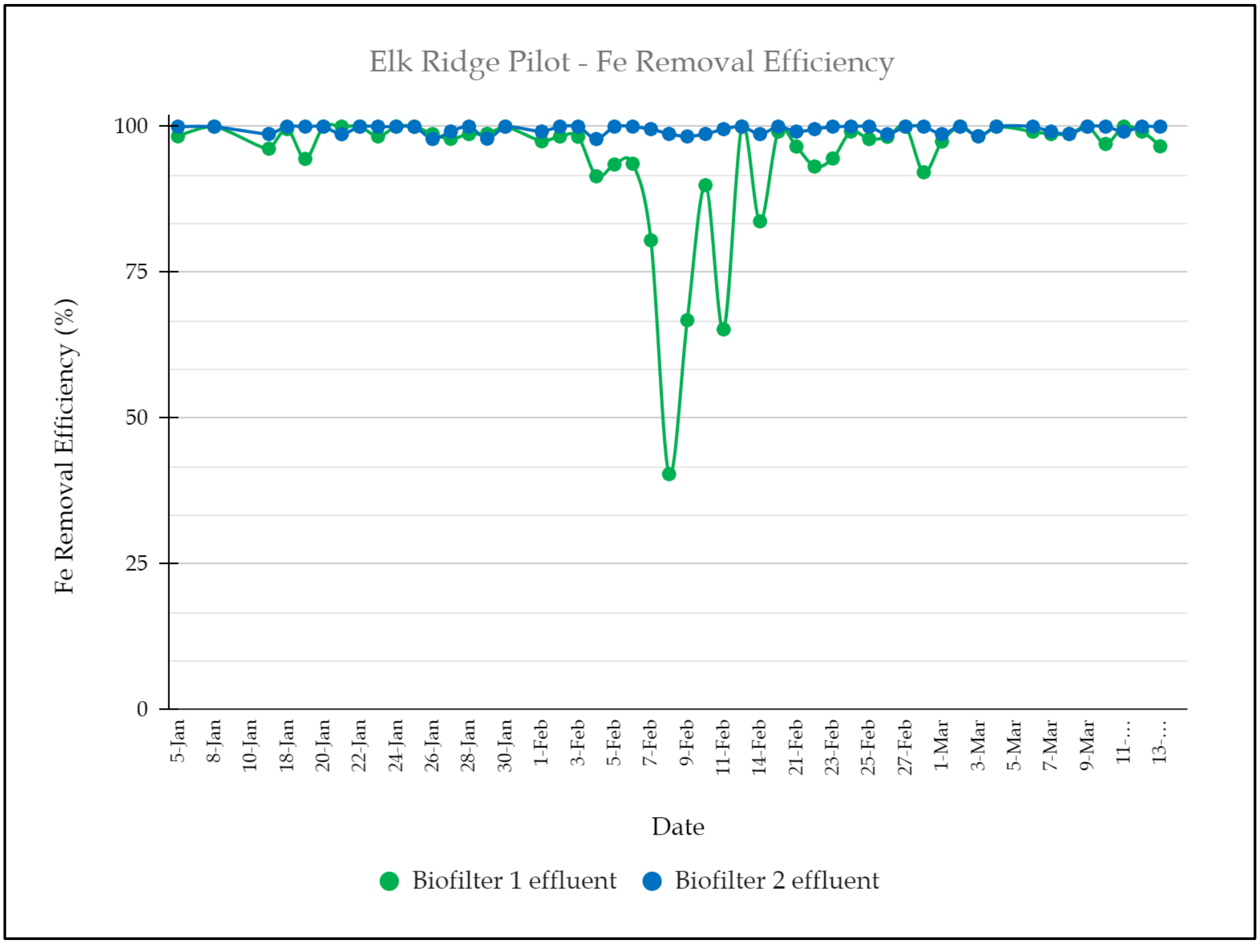

Figure 6: Profile of iron (Fe) removal efficiency in the Bio-1 outlet and Bio-2 outlet for the* Village of Elk Ridge*.

3.2. Manganese Removal

In this pilot study, along with iron, the potential of manganese removal by biological filtration was investigated. Manganese concentration in the local groundwater source at the Village of Elk Ridge varied between 0.029 to 0.123 mg/L during the duration of the pilot. Saskatchewan guideline for manganese in drinking water is ≤0.05 mg/L. For the given manganese concentration in local groundwater source, the biological filtration system had shown commendable performance in the biofilter effluent from the start of the pilot till around February 14th. After this date, we see a breakdown of the manganese removal shown in figure 7. In the early phases of biofilter operation, manganese removal was mainly promoted in the Filter-2 of the pilot.

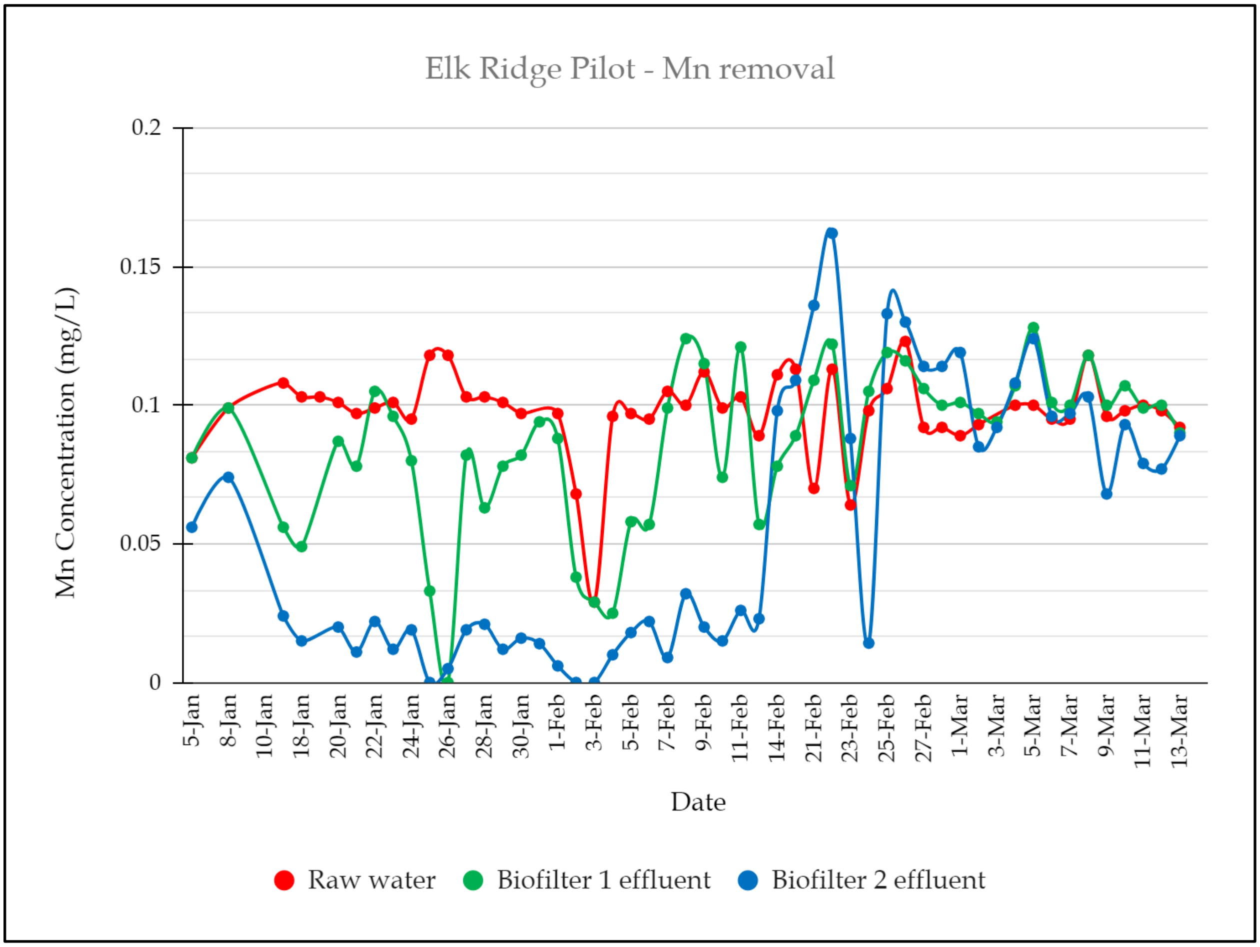

Figure 7: Profile of manganese (Mn) concentration in the groundwater, Bio-1, and Bio-2 outlet over the Pilot at the Village of Elk Ridge.

Time-dependent profiles of manganese concentration and its removal efficiency in the biofilter effluent over the two months of piloting were depicted in Figure 7, and Figure 8, respectively. Manganese concentration in the filter 2 outlet met SK standard after 15 days of operation and held under the 0.05 mg/L for 26 days.

The fluctuation in manganese concentration can be attributed in part to inconsistent operational hours. The variability in operation affects the bacterial population within the vessels, as warmer temperatures facilitate increased bacterial growth. This fluctuation in bacterial population may account for the inconsistencies observed from the beginning of the pilot study through mid-February. Subsequently, a significant reduction in pilot operation hours, as illustrated in Figure 2, resulted in inconsistent manganese removal.

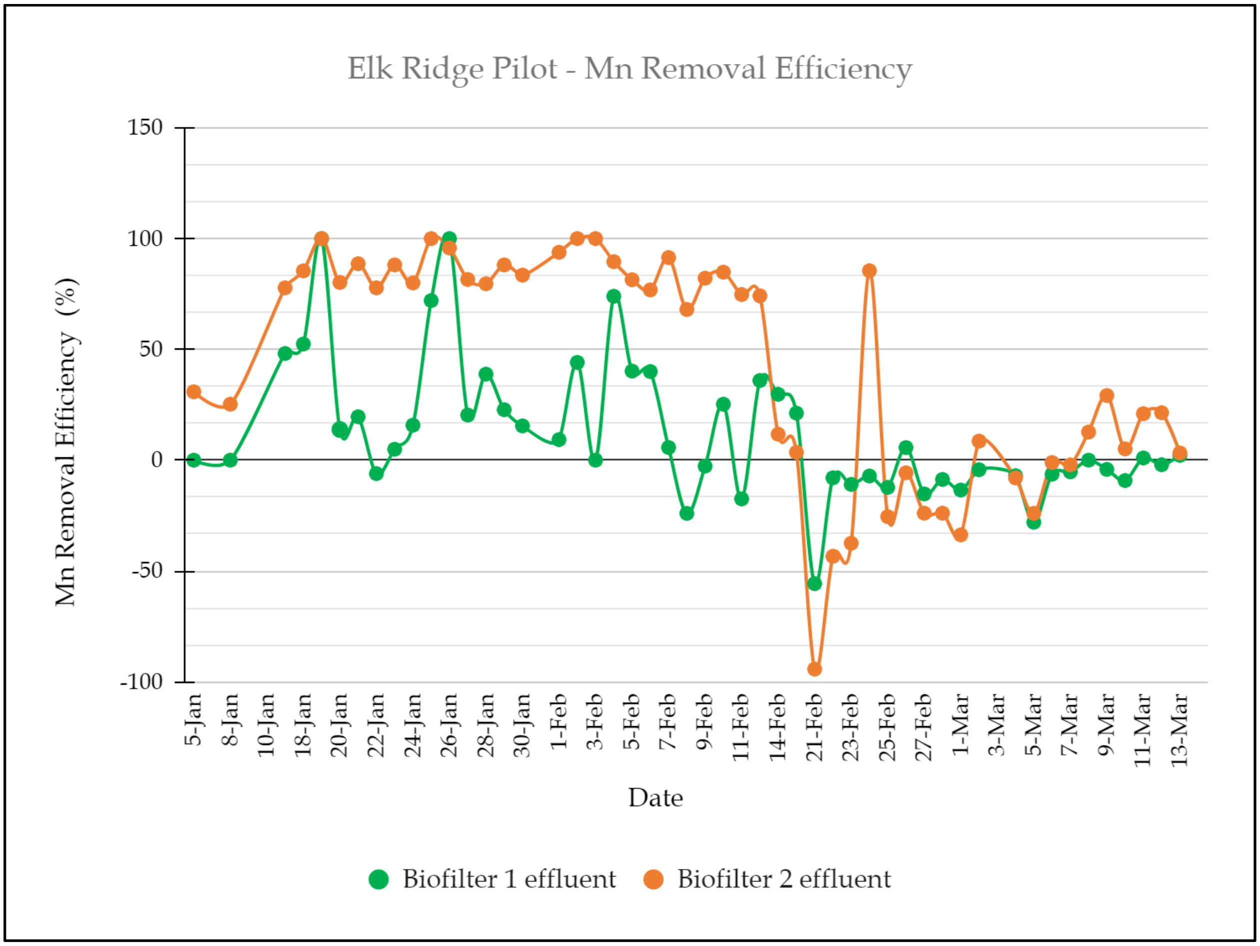

Figure 8: Profile of manganese (Mn) removal efficiency in the bio-1, and bio-2 outlet over the Pilot at the Village of Elk Ridge.

As depicted in Figure 8, during the initial stages of piloting, the manganese levels in the groundwater remained relatively constant. Throughout this phase, the Filter-2 effluent consistently exhibited an average removal rate of 81% for manganese. It is not believed that the operational times had a strong correlation with removal percentages, refer to section 3.4 for more analysis on operational times. After February 14, it is believed the void spaces in the filter media became filled with precipitated manganese. The precipitated manganese would then be added to the filtered water as it runs, leading to a negative removal efficiency of manganese leading to poor pilot performance from February 14th to the conclusion of the pilot. It is believed that this precipitation could be avoided in a full-scale biological filtration system. Typically, biological filtration is employed for manganese removal once ammonia has been removed prior. Based on the findings of this pilot project and previous pilots, the manganese would be able to be removed by a biological filtration system. The subsequent section on ammonia removal will elucidate why biological removal of ammonia was not achievable.

3.3. Ammonia Removal

3.3.1. Biological Ammonia Removal

Biological ammonia removal by bacteria needs very specific environmental conditions. To promote conditions for biological ammonia removal in a water/wastewater treatment process of a plant, an understanding of the processes and careful control of process conditions are required. Untreated groundwater can contain nitrogen in the form of organic nitrogen, ammonia (NH_3-N). Ammonia removal in biological filters involves oxidation of ammonia contained in the water to nitrate (NO_3-N) by nitrifying bacteria. This process is called nitrification. Nitrification is the two-step biological oxidation of ammonia (NH_3-N) to nitrate (NO_3-N). The oxidation is performed by aerobic autotrophic bacteria frequently called nitrifiers. The predominant species that are commonly encountered in water treatment plants for nitrification belong to genera *Nitrospira*, *Nitrobacters,* and *Nitrosomonas*. Equations describing the oxidation of NH_3-N to NO_2^--N and oxidation of NO_2^--N to NO_3^--N are presented as follows:

$$2NH_4^+ + 3O_2 \text{ -----> } 2NO_2^- + 2H_2O + 4H^+ + \text{New Cells}$$

$$2NO_2^- + O2 \quad \text{-----> } 2NO_3^- + \text{New Cells}$$

Nitrification occurs only under aerobic conditions, so dissolved oxygen must be available to the bacteria in the treatment process. It requires approximately 4.6 kg of oxygen for every kg of ammonia converted to nitrate by the bacteria. Temperature, pH, and alkalinity are other factors which impact biological nitrification. Alkalinity is consumed at a rate of approximately 7.14 kg per kg of ammonia nitrified. During nitrification, this alkalinity reduction causes the pH of the water to drop. The rate of nitrification is dependent on pH, temperature and the water components. The optimum pH for nitrification is approximately 8.4. The rate of nitrification drops off rapidly at pH levels of less than 7.0. There is also a significant drop in nitrification rates at temperatures less than 15°C.

3.3.2. Ammonia Removal at Village of Elk Ridge Pilot

In addition to iron and manganese, biological filtration pilots at the Village of Elk Ridge have also shown poor and sporadic removal of ammonia through biological processes. Ammonia concentration in the local groundwater source at the Village of Elk Ridge ranged mainly between 0.60 to 0.92 mg/L throughout the pilot. Although there is no guideline for ammonia in drinking water, Saskatchewan Water Security Agency developed an operational guideline of ≤0.1 mg/L to minimize chlorine consumption. Within a few days of operation, the biological filtration pilot has shown complete removal of ammonia from groundwater source by biological process and has met process guidelines. Although this removal was short-lived because a couple days later there was minimal removal. The inconsistencies continued throughout the pilot's duration.

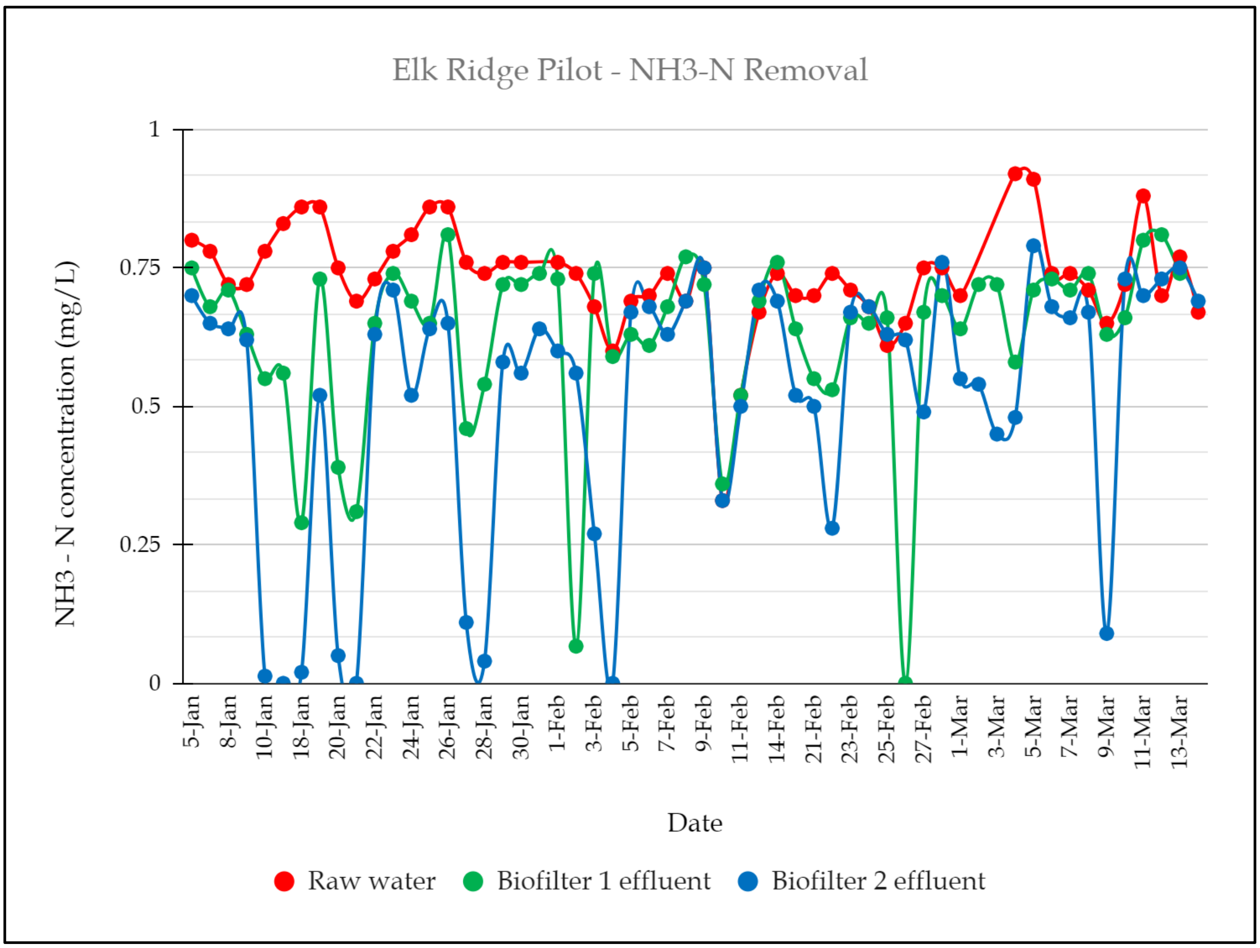

Figure 9: Profile of ammonia-N (NH_3-N) concentration in the groundwater, Filter-1 and Filter-2 outlet over the Pilot at the Village of Elk Ridge.

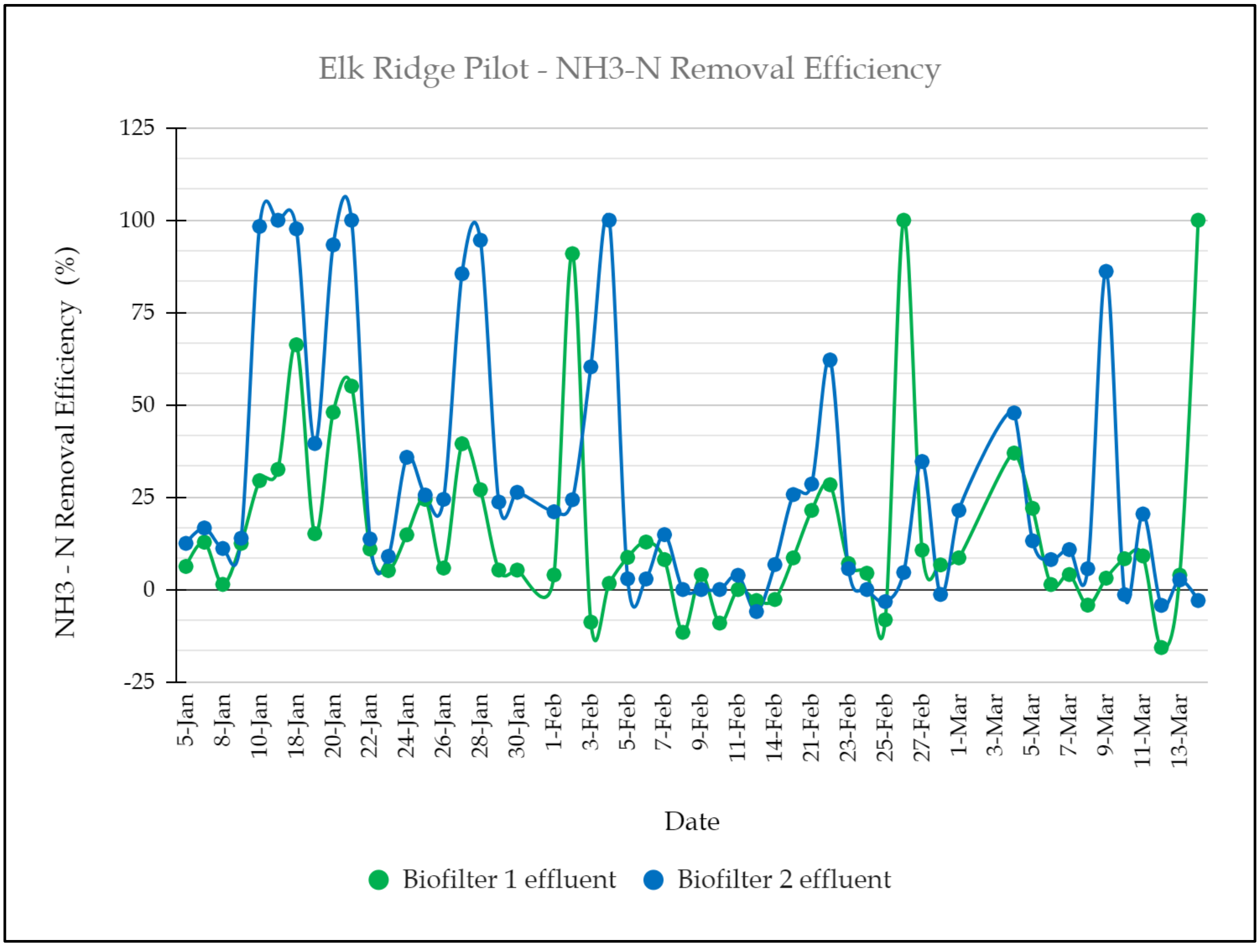

Figure 10: Profile of ammonia-N (NH_3-N) removal efficiency in the Filter-1, and Filter-2 outlet over the Pilot at the Village of Elk Ridge.

Figure 11 illustrates the operational hours of the pilot in red, measured on the left vertical axis, alongside the percentage of ammonia removal in orange, measured on the right vertical axis. This figure offers valuable insights into the relationship between operational time and ammonia removal. A noticeable trend from the graph suggests that extended operational periods, followed by shorter intervals of activity, result in higher percentages of ammonia removal due to increased bacteria count in the vessels. For instance, on January 22, the pilot was operational for 14 hours, followed by less than 3 hours of operation over the next four days. This pattern led to a substantial increase in ammonia removal on January 26th and 27th.

The trend continues from January 28th to February 3rd, where a large operation time followed by decreased activity sees a spike in ammonia removal. An explanation for this trend could be low nitrifying bacteria in the raw water. For example, when the pilot is run for long amounts of time, the vessels can build up nitrifying bacteria and their food source. Then, when the pilot is run for less time, the bacteria are given a chance to bolster populations in a warmer environment leading to more ammonia removal. For every 10°C the total micro-organism population doubles. The increased bacteria would lead to a small unsustainable peak of ammonia removal as seen in figure 10.

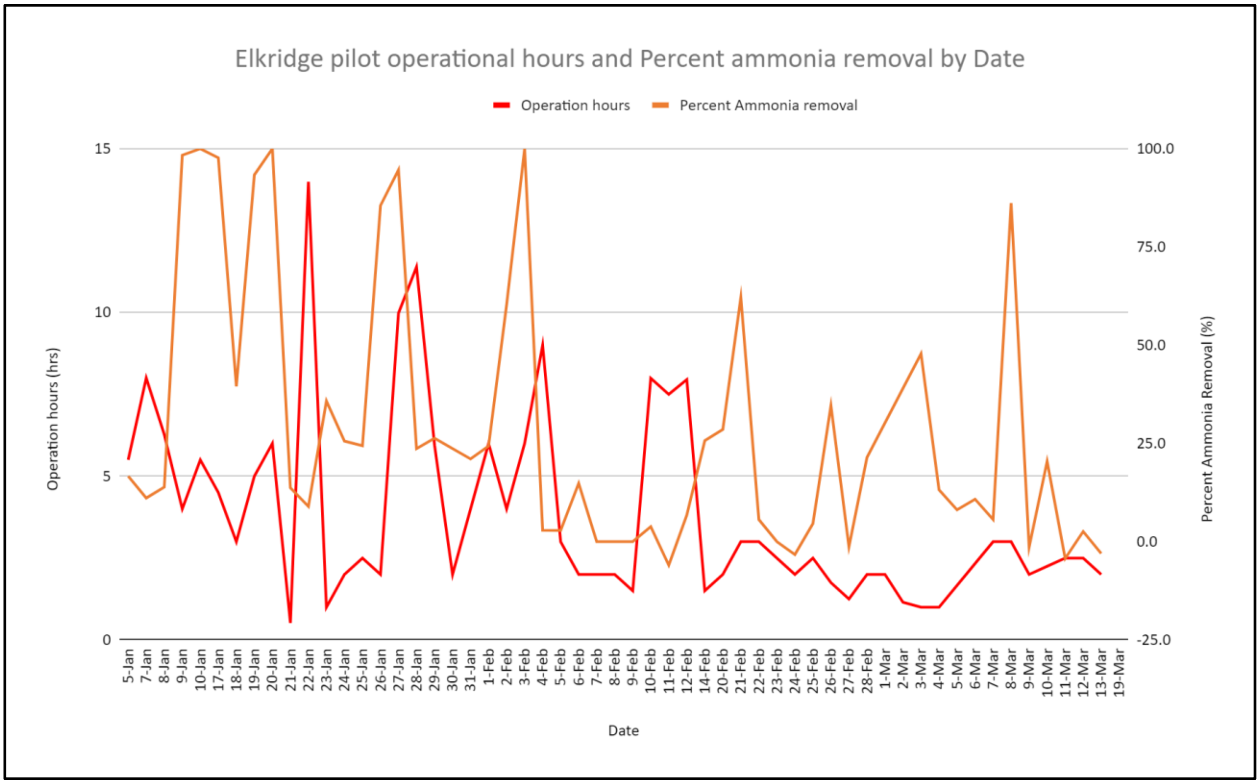

Figure 11: Elk Ridge pilot operation vs percent ammonia removal.

After conducting over three months of piloting at Elk Ridge and comparing it with previous piloting efforts in various locations, we made a significant observation regarding the depth of the well water. At Elk Ridge, the well water depth is exceptionally deep, averaging around 360 feet. This contrasts with our prior successful piloting experiences, where the well water depth typically did not exceed 200 feet. This variance in depth led us to speculate about the reason for the low indigenous nitrifying bacteria crucial for promoting ammonia removal.

Upon seeding the biofilter, we initially observed promising results in ammonia removal. However, this efficiency declined after a few days, which we attribute to an insufficient number of indigenous bacteria at such depths to maintain sufficient ammonia removal. Additionally, Elk Ridge's location within a federally protected area limits activities like farming and animal husbandry, which are typically sources of live organisms and bacteria in the soil. Which could also affect the amounts of nitrifying bacteria present in the well water. Consequently, the biological filtration system's efficacy is compromised due to the scarcity of these essential organisms.

We conclude that biological filtration systems are more feasible when fed from shallow wells rather than excessively deep ones like those found at Elk Ridge because of the higher likelihood of sufficient nitrifying bacteria. This insight underscores the importance of considering environmental factors, such as well depth and surrounding land use, when implementing such filtration systems for effective ammonia removal. It is possible to complete an HPCs test to validate low amounts of nitrifying bacteria. Heterotrophic plate counts (HPCs) are commonly used to assess the general microbiological quality of drinking water.

3.4. Correlation between Operational time and Percent removal

Due to the inconsistent run time of the pilot, it is necessary to analyse the correlation between pilot run time and the removal of manganese and ammonia from the water to ensure proper recommendations are made. Correlation is a statistical measurement of the relationship between two variables. The analysis will be done using a scatter plot graph with trend lines indicating possible correlations. The correlation coefficient value or r value will also be calculated throughout analysis. r value can range from 1 for a strong positive correlation meaning an increase of one variable leads to an increase of the other variable, to -1 a strong negative correlation where an increase of one variable leads to a decrease in the other. An r value of 0 indicates no correlation, meaning the variables do not have a relationship with each other. For this analysis the relationship between operational run time and percent removal will be calculated. A strong relationship, an r value close to 1, would mean the longer the pilot is run the better the removal percentage. No correlation or an r value close to 0 would mean that the operational time does not have a relationship with the removal percentage.

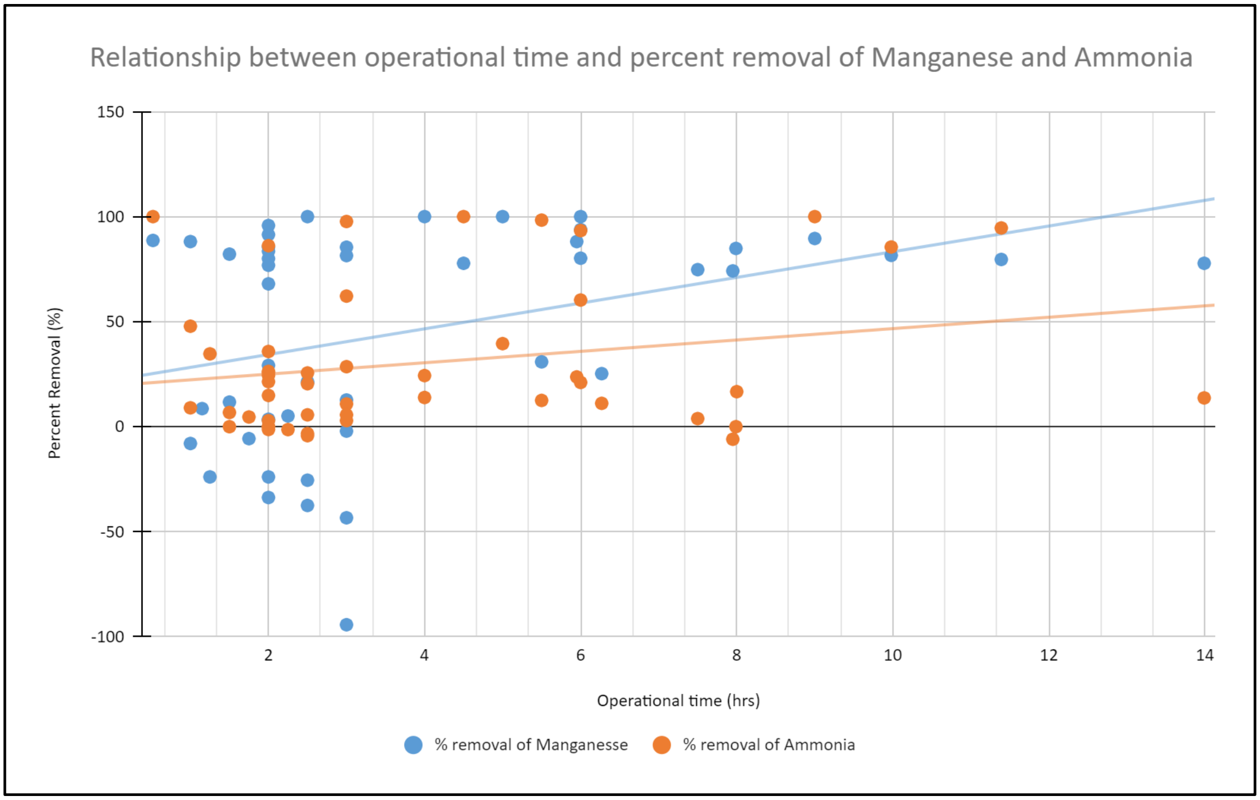

Figure 12: Relationship between operational time and percent removal of Manganese and Ammonia

The figure above displays the relationship between the Operational time of the pilot and the percent removal of manganese and ammonia. The left axis is for percent removal while the horizontal is for the operational hours of the pilot. The percent removal of manganese is displayed in blue, while ammonia is in orange. The linear slope is depicted for both relationships. Manganese removal has a higher slope than ammonia removal which indicates a stronger relationship between operational time and manganese removal than operational time and ammonia removal. Both slopes are positive, representing more operational time would lead to more percent removal. To determine the strength of the relationship the equation pictured below will be used where r_{xy} is the correlation coefficient, X_i is the x variable values, $\overline{\mathbf{X}}$ is the mean value of the x variables, y_i is the y variable values, and

$\bar{y}$ is the mean of the y variables.

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}$$

Figure 13: Equation for calculating the correlation coefficient

The equation used over the data set correlation coefficient can be calculated for both relationships. The value for the relationship between the operational time and percent removal of manganese was calculated to be r = 0.36, therefore the relationship can be described as a weak relationship. The values of the relationship between operational time and the percent ammonia removal was calculated to be r = 0.24, therefore the relationship can be described as weak as well bordering on very weak/ no association. (These determinations were based on a table from Boston universities educational website, and the table will be included in the appendix) While both correlation coefficients are positive slopes, due to their low value operational time would not be the leading factor in affecting percent removal for both manganese and ammonia. Therefore, it is accurate to describe operational time as not having significant enough effect on percent removal of manganese and ammonia to invalidate our piloting project. It is still believed that low bacteria present in the raw water has the largest impact on the pilots poor inconsistent removal of Ammonia from the water.

4. Conclusions and Recommendations

The analysis reveals that Filter-1 effectively eliminates iron, while Filter-2 encountered challenges in removing both ammonia and manganese. Iron and manganese concentrations consistently adhered to drinking water and process standards. Conversely, the biofilter proved ineffective in removing ammonia due to the potentially low amounts of indigenous bacteria in the well water and the inconsistent operation of the pilot. In summary, the pilot study at the Elk Ridge WTP reveals conclusions in the following areas:

- Iron concentrations in the local groundwater source were effectively reduced by over 99% through biological filtration, all achieved without the need for chemical additives.
- Manganese concentrations in the groundwater underwent a reduction of over 80% via biological treatment, although the consistency of this reduction varied.
- Biological filtration resulted in an average 28% decrease in ammonia concentrations within the groundwater.
- Despite a prolonged acclimation period during the biological filtration pilot aimed at removing ammonia from the given groundwater source, the potential for a low number of indigenous bacteria and inconsistent operation hindered the ability to achieve full ammonia removal.
- A next step could be to ensure that the absence of nitrification bacteria is confirmed to eliminate it as a cause, then comp the pilot with more consistent run times and possibly add a third stage.
- The use biological filtration as primary treatment system to effectively eliminate iron and manganese, is possible and it is recommended that breakpoint chlorination for ammonia removal be employed at the outlet of the final biofilter to ensure targets are achieved. The main advantage of a biological filtration system will be less backwashing of the filters compared to greensand filters. Typical backwash requirements for the first biofilter is every two weeks and the second biofilter is every three months, comparing the greensand filters that must be backwashed every second day.

5. Acknowledgements

Drop Water would like to thank **Mr. Russel and Ms. Terri** for their assistance in measuring water parameters during the pilot study at the Elk Ridge WTP.

APPENDIX
Laboratory Results and Daily Log sheet and Correlation Coefficient table

Daily Monitoring of Biofilters @ Elk Ridge WTP

Elk Ridge Weekly Log	Friday	Sat	Sun	Mon	Tuesday	Wed.
Date	Jan 5	Jan 6	Jan 7	Jan 8	Jan 9	Jan 10
Raw Water						
Operating (hr)	5.5		8 hrs	6.27	4.00	5.5
Iron (mg/L)	2.41			2.39		
Manganese (mg/L)	.081			.099		
NH3-N (mg/L)	.80		.78	.72	.72	.78
Outlet Filter 1						
Iron (mg/L)	.04			0.00		
Manganese (mg/L)	.081			.099 ~~.099~~		
NH3-N (mg/L)	.75		.68	.71 ~~.099~~	.63	1st .53 / 2nd .55
Inlet Press. (PSI)	.2		5	5	5	0
Outlet Press. (PSI)	3		5	5	5	0
Outlet Filter 2						
Iron (mg/L)	0.00			0.00		
Manganese (mg/L)	.056			.074		
NH3-N (mg/L)	.70		.65	.64	.62	0.00 / 2nd .015
Inlet Press. (PSI)	4		5	4	5	0
Outlet Press. (PSI)	4		5	4	4	0
Air Scour (Bio 1 or 2)						
Backwashing (Bio 1 or 2)						

Comments:

.34/m

Daily Monitoring of Biofilters @ Elk Ridge WTP							
Elk Ridge Weekly Log	Wed	Thur	Frid	Sat	Sun	Mon	Tues
Date	Jan 17	18	19	20	21	22	23 (Startup)
Raw Water							
Operating (hr)	4.5	3	5	6	.52	13.99	(Sun) / 1hr
Iron (mg/L)	2.38	2.35	2.35	2.21	2.30	~~13.99~~ 2.22	2.38
Manganese (mg/L)	.108	.103	.103	.101	.097	.099	.101
NH3-N (mg/L)	.83	.86	.86	.75	.69	.73	(.78) / .78
Outlet Filter 1							
Iron (mg/L)	.09	.01	.13	.00	.00	.00	.04
Manganese (mg/L)	.056	.049		.087	.078	.105	.096
NH3-N (mg/L)	.56	.29	.73	.39	.31	.65	(.41) / .74
Inlet Press. (PSI)	2	2	8	2	2	5	5
Outlet Press. (PSI)	2	2	8	2	2	7	5
Outlet Filter 2							
Iron (mg/L)	.03	.00	.00	.00	.03	.00	.00
Manganese (mg/L)	.024	.015		.020	.011	.022	.012
NH3-N (mg/L)	.00	.02	.52	.05	.00	.63	(.01) / .71
Inlet Press. (PSI)	2	2	7	2	2	5	5
Outlet Press. (PSI)	2	2	6	2	2	5	5
Air Scour (Bio 1 or 2)							
Backwashing (Bio 1 or 2)			#1 - 5 59gal				

Comments:

Taken 5 min well on Warm

run from Colder wat

Daily Monitoring of Biofilters @ Elk Ridge WTP

Elk Ridge Weekly Log	Wed	Thur	Fri	SAT	SUN	Mon
Date	Jan 24	25	26	27	28	29
Raw Water						
Operating (hr)	2 hrs cold	2.5	2	9.98	11.39	5.95
Iron (mg/L)	2.33	2.36	2.35	2.38	2.34	2.42
Manganese (mg/L)	.095	.118	.118	.108	.103	.101
NH3-N (mg/L)	.81	.86	.86	.76	.74	.76
Outlet Filter 1	—	—	—	—	—	—
Iron (mg/L)	.00	.00	.03	.05	.03	.03
Manganese (mg/L)	.080	.033	.000	.082	.063	.078
NH3-N (mg/L)	.69	.65	.81	.46	.54	.72
Inlet Press. (PSI)	4	3	4	2	2	2
Outlet Press. (PSI)	4	3	4	2	2	4
Outlet Filter 2	—	—	—	—	—	—
Iron (mg/L)	.00	.001	.05	.02	.00	.05
Manganese (mg/L)	.019	.000	.005	.019	.021	.012
NH3-N (mg/L)	.52	.64	.65	.11	.04	.58
Inlet Press. (PSI)	4	3	5	2	2	2
Outlet Press. (PSI)	4	3	5	2	2	4
Air Scour (Bio 1 or 2)	—	—	—	—	—	—
Backwashing (Bio 1 or 2)	—	—	—	—	—	—

Comments: cold to test

Daily Monitoring of Biofilters @ Elk Ridge WTP

Elk Ridge Weekly Log	Tue	Wed	Thurs	Fri	Sat	Sun
Date	Jan 30	31	Feb 1	Feb 2	Feb 3	Feb 4
Raw Water						
Operating (hr)	2 hrs		6	4	6	(bus all 9) ran well 45 min - 1 hr
Iron (mg/L)	2.39		2.39	2.36	2.30	2.35
Manganese (mg/L)	.097		.097	.068	.028	.096
NH3-N (mg/L)	.76		.76	.74	.68	.60
Outlet Filter 1						
Iron (mg/L)	.00	.02	.06	.04	.04	.20
Manganese (mg/L)	.082	.094	.088	.038	.029	.025
NH3-N (mg/L)	.72	.74	.73	.67	.74	.59
Inlet Press. (PSI)	4	6	10	8	9	5
Outlet Press. (PSI)	5	6	10	10	9	6
Outlet Filter 2						
Iron (mg/L)	.00	.02	.02	.00	.00	.05
Manganese (mg/L)	.016	.014	.006	.000	---	.010
NH3-N (mg/L)	.56	.64	.60	.56	.27	.00
Inlet Press. (PSI)	5	5	10	7	9	5
Outlet Press. (PSI)	5	6	10	9	9	6
Air Scour (Bio 1 or 2)						
Backwashing (Bio 1 or 2)						

Comments:

Jan 31 - Increase output pressure to 10 lbs Increase Filter 2 Air to 2 [illegible]

did mang 2x same results

Daily Monitoring of Biofilters @ Elk Ridge WTP

Elk Ridge Weekly Log	Feb						
Date	5	6	7	8	9	10	11
Raw Water							
Operating (hr)	3 act/run	2 hrs 10 AM	2 hrs	2 hrs	1.5 hrs	2.99 (1.5) Hr	7.5 (1 Hr
Iron (mg/L)	2.31	2.36	2.36	2.40	2.38	2.39	2.33
Manganese (mg/L)	.097	.095	.105	.100	.112	.099	.103
NH3-N (mg/L)	.69	.70	.74	.69	.75	.33	.52
Outlet Filter 1							
Iron (mg/L)	.15	15	.46	1.43	.79	.24	.01
Manganese (mg/L)	.058	.057	.099	~~.100~~ .124	.115	.074	.121
NH3-N (mg/L)	.63	.61	.68	.77	.72	.36	.52
Inlet Press. (PSI)	5	4	10	12	13	8	16
Outlet Press. (PSI)	7	5	10	11	12	8	16
Outlet Filter 2							
Iron (mg/L)	.00	.00	.01	.03	.04	.03	.01
Manganese (mg/L)	.018	.022	.009	.032	.020	.015	.026
NH3-N (mg/L)	.67	.68	.63	.69	.75	.33	.50
Inlet Press. (PSI)	5	4	10	10	10	7	13
Outlet Press. (PSI)	7	5	10	10	10	8	14
Air Scour (Bio 1 or 2)	—	yes @ 2:30 pm	—				
Backwashing (Bio 1 or 2)	—	yes	—				

Comments:

very cold
well ran long 3hr

Filter 1 has air when openning to sample
Redid mang
raw .100
filter1 .124

Elk Ridge Weekly Log						
Date	Feb 12	13	14	20	21	22
Raw Water	3		1.5			
Operating (hr)	7.95			2	3	3
Iron (mg/L)	2.28		2.34	2.34	2.34	2.34
Manganese (mg/L)	.089		.111	.113	.070	.113
NH3-N (mg/L)	.67		.74	.70	.70	.74
Outlet Filter 1						
Iron (mg/L)	0.00		.38	.02	.08	.16
Manganese (mg/L)	.057		.078	.039	.109	.122
NH3-N (mg/L)	.69		.76	.64	.55	.53
Inlet Press. (PSI)	9	16	16	10	7	12
Outlet Press. (PSI)	9	15	15	12	10	13
Outlet Filter 2						
Iron (mg/L)	0.00		.03	.00	.02	.01
Manganese (mg/L)	.023		.098	.109	.136	.162
NH3-N (mg/L)	.71		.69	.52	.50	.28
Inlet Press. (PSI)	9	15	15	10	7	12
Outlet Press. (PSI)	8	15	15	11	8	12
Air Scour (Bio 1 or 2)						#1
Backwashing (Bio 1 or 2)						#1

Comments:

Feb 16
Scott added Bio
to filter 1+2
restart 20

BackWash #1 - 22nd

@ Elk Ridge WTP

Elk Ridge Weekly Log						
Date Feb	23	24	25	26	27	28
Raw Water						
Operating (hr)	2½	2hrs	2.5hr	1.75	1.25	2.0
Iron (mg/L)	2.38	2.39	2.34	2.29	2.33	2.3
Manganese (mg/L)	.064	.098	.106	.123	.092	.092
NH3-N (mg/L)	.71	.68	.61	.65	.75	.75
Outlet Filter 1						
Iron (mg/L)	.13	.02	.05	.04	.00	.18
Manganese (mg/L)	.071	.105	.119	.116	.106	.100
NH3-N (mg/L)	.66	.65	.66	+++	.67	.70
Inlet Press. (PSI)	14	12	9	9	4-5	5
Outlet Press. (PSI)	14	10	11	11	6	6
Outlet Filter 2						
Iron (mg/L)	.00	.00	.00	.03	.00	.00
Manganese (mg/L)	.088	.142	.133	.130	.114	.114
NH3-N (mg/L)	.67	.68	.63	.62	.49	.76
Inlet Press. (PSI)	11	10	10	9	5	5
Outlet Press. (PSI)	11	10	10	10	6	6
Air Scour (Bio 1 or 2)	—	—	—	—	—	
Backwashing (Bio 1 or 2)	—	—	—	—	—	

Comments:

took 2 pails out of filter 1 as per Mr B.

ran bio 2 hrs. evening 6:30 - 8:30

[redacted] ran

ran 30 min AM

…@ Elk Ridge WTP

Elk Ridge Weekly Log						
Date	Mar 1	Mar 2	Mar 3	4	5	6
Raw Water						
Operating (hr)	2	1.15	1	—		
Iron (mg/L)	2.34	2.35	2.41	2.35	—	~~.095~~ 2.31
Manganese (mg/L)	.089	.093	—	.100	.100	.095
NH3-N (mg/L)	.70	—	—	.92	.91	.74
Outlet Filter 1				—		
Iron (mg/L)	.06	.00	.04	.06	.07	.02
Manganese (mg/L)	.101	.097	.094	.107	.128	.101
NH3-N (mg/L)	.64	.72	.72	.58	.71	.73
Inlet Press. (PSI)	9	5	5	9	12	9
Outlet Press. (PSI)	10	5	6	11	15	10
Outlet Filter 2				—		
Iron (mg/L)	.03	.00	.04	.06	.05	.00
Manganese (mg/L)	.119	.085	.092	.108	.124	.096
NH3-N (mg/L)	.55	.54	.45	.48	.79	.68
Inlet Press. (PSI)	8	5	5	9	10	10
Outlet Press. (PSI)	9	5	5	10	12	10
Air Scour (Bio 1 or 2)						
Backwashing (Bio 1 or 2)						

Comments:

…ters @ Elk Ridge WTP

Elk Ridge Weekly Log						
Date	Mar 7/24	Mar 8	9	10	11	12
Raw Water						
Operating (hr)	3	3	2	2.25	2½	2.5
Iron (mg/L)	2.35	2.38	2.33	2.36	2.33	2.35
Manganese (mg/L)	.095	.118	.096	.098	.100	.98
NH3-N (mg/L)	.74	.71	.65	.72	.88	.70
Outlet Filter 1			—			
Iron (mg/L)	.03	.03	.00	.07	.00	.02
Manganese (mg/L)	.100	.118	.100	.107	.099	.100
NH3-N (mg/L)	.71	.74	.63	.66	.80	.81
Inlet Press. (PSI)	9	10	8	12	11	10
Outlet Press. (PSI)	10	11	10	14	12	10
Outlet Filter 2			—			
Iron (mg/L)	.02	.03	.00	.00	.02	.00
Manganese (mg/L)	.097	.103	.068	.93	.079	.077
NH3-N (mg/L)	.66	.67	.09	.73	.70	.73
Inlet Press. (PSI)	8	8	8	11	11	11
Outlet Press. (PSI)	10	10	10	14	14	10
Air Scour (Bio 1 or 2)			—			
Backwashing (Bio 1 or 2)	[signature]	[signature]	[signature]	[signature]	[signature]	

Comments:

Date	Mar 13	Mar 19				
Raw Water						
Operating (hr)	2					
Iron (mg/L)	2.37					
Manganese (mg/L)	.092					
NH3-N (mg/L)	.77	.67				
Outlet Filter 1						
Iron (mg/L)	.08					
Manganese (mg/L)	.090					
NH3-N (mg/L)	.74					
Inlet Press. (PSI)	15					
Outlet Press. (PSI)	15					
Outlet Filter 2						
Iron (mg/L)	.00					
Manganese (mg/L)	.089					
NH3-N (mg/L)	.75	.69				
Inlet Press. (PSI)	15					
Outlet Press. (PSI)	15					
Air Scour (Bio 1 or 2)	/					
Backwashing (Bio 1 or 2)	/					

Comments:

ELK RIDGE UTILITY LTD. - WATER QUALITY DATA

Source		PW7-2014	PW6-2011	PW6-2011	OBS PW5-2000	Sask / Canada Municipal Treated Water AO and MAC
Developed Aquifer		Un-named Aquifer	Un-named Aquifer	Un-named Aquifer	Un-named Aquifer	
Location		Elk Ridge Utility Ltd.	Elk Ridge Utility Ltd.	Elk Ridge Utility Ltd.	Elk Ridge Utility Ltd.	
Lab and Sample No.		SRC	SRC	Sask Disease Control	Sask Disease Control	
		29643	32460	1053954	1042983	
Date Sampled		Sep-17-14	22-Sep-11	22-May-14	Apr-2-13	
Well Completion Depth (metres)		101.50	100.81	100.81	N/A	
Major Constituents						
Bicarbonate, HCO_3	mg/L	656	619	608	608	no criteria
Calcium, *Ca*	mg/L	108	105	109	111	no criteria
Carbonate, CO_3	mg/L	<1	<1	0	0	no criteria
Chloride, *Cl*	mg/L	3	4	14.8	13.5	250
Hydroxide, *OH*	mg/L	<1	<1	0	0	no criteria
P. Alkalinity	mg/L	<1	<1	0	0	no criteria
Magnesium, *Mg*	mg/L	43	40	43	43	200
Potassium, *K*	mg/L	3.6	4.3	5	5	no criteria
Sodium, *Na*	mg/L	36	37	47	48	300 / 200
Sulphate, SO_4	mg/L	23	20	21	19	500
Sum of Ions (calc.)	mg/L	874	829			1500
Total Alkalinity	mg/L	538	507	498	498	500
Total Hardness	mg/L	446	426	449	454	800 / 200
Nutrients/Organics						
Ammonia, as N	mg/L	0.71	0.64			no criteria
Nitrate, NO_3	mg/L	<0.04	<0.04	<0.2	<0.2	45
Organic Carbon, *Total*	mg/L	7.2	8.5			no criteria
Organic Carbon, *Dissolved*	mg/L	7	8.5			no criteria
Trace Constituents						
Cyanide, total	ug/L					200
Fluoride, *F*	mg/L	0.21	0.22	0.21	0.4	1.5
Mercury, Hg	ug/L					1.0
Phosphorous, *P*	mg/L					no criteria
Selenium, *Se*	mg/L	<0.0001	<0.0001	<0.00096		0.01
Trace Metals						
Aluminum, *Al*	mg/L	0.16	<0.0005	<0.00214		no criteria
Arsenic, *As*	ug/L	27.0	23	1.4		25 / 10
Barium, *Ba*	mg/L	0.16	0.16	0.129		1.0
Boron, *Bo*	mg/L	0.13	0.12	0.1		
Cadmium, *Cd*	mg/L	<0.00002	<0.00001	<0.00056		0.005
Chromium, *Cr*	mg/L	<0.0005	<0.0005	0.0003		0.05
Copper, Cu	mg/L	0.0012	<0.0002	0.238		1
Iron, *Fe*	mg/L	1.84	1.88	<0.1	<0.1	0.3
Lead, *Pb*	mg/L	0.0004	<0.0001	0.9		0.01
Manganese, *Mn*	mg/L	0.13	0.084	<0.01	<0.01	0.05
Zinc, *Zn*	mg/L	0.0041	<0.0005	0.0851		5
Physical Properties						
Total Dissolved Solids, *TDS*	mg/L	570	546	848	848	1500 / 500
Total Suspended Solids, *TSS*	mg/L		<1			no criteria
Turbidity	NTU		0.1			no criteria
Sp. Conductivity	uS/cm	913	901	919	908	no criteria
pH of Water	pH units	7.96	7.7	7.6	7.6	6.5 - 9.0
Radiochemicals						
Uranium, *total*	ug/L	0.8	<0.0005	0.0006		20

Legend	
MAC - Maximum Acceptable Concentration	Exceeded Sask or Federal AO
AO - Aesthetic Objective	Exceeded Sask or Federal MAC
< Not detected at the concentration stated	

Correlation Coefficient (r)	Description (Rough Guideline)
+1.0	Perfect positive + association
+0.8 to 1.0	Very strong + association
+0.6 to 0.8	Strong + association
+0.4 to 0.6	Moderate + association
+0.2 to 0.4	Weak + association
0.0 to +0.2	Very weak + or no association
0.0 to -0.2	Very weak - or no association
-0.2 to – 0.4	Weak - association
-0.4 to -0.6	Moderate - association
-0.6 to -0.8	Strong - association
-0.8 to -1.0	Very strong - association
-1.0	Perfect negative association