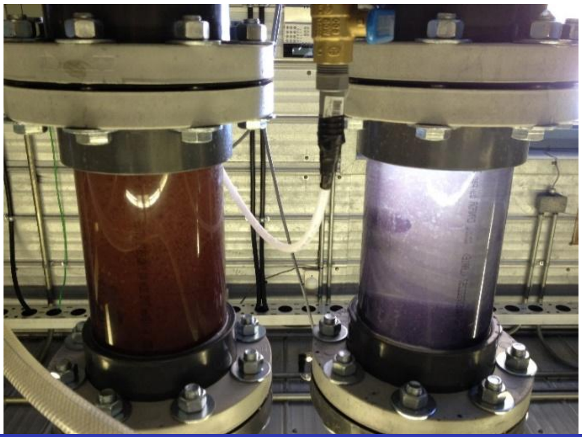


Abstract

Delco Water provided a novel water treatment system for producing municipal drinking water in the small community of Montana First Nation, Alberta, Canada. The water treatment strategy includes the installation of Delco $BioF_x$ biological filters (biofilters) along with a Delco $HYDRA_{MAX}$™ reverse osmosis and nanofiltration membrane skid. Compared to conventional methods, biological treatment is an easy system to operate without using any chemicals, and it significantly reduces operating costs.

The source water at Montana First Nation is brackish well water, high in iron and manganese. The raw water also contains dissolved organic carbon and ammonia. After over five months of operation, Delco Water's custom-designed water treatment equipment has produced a consistent product water quality which far surpasses Canadian Drinking Water Guidelines, while using minimal chemicals. The Delco $BioF_x$ biofilters operate effectively with the cold temperatures of the source water at Montana First Nation, typical of central Canada groundwater. While competing biological water treatment systems may remove iron adequately, they struggle to remove manganese and ammonia. At Montana First Nation, the Delco $BioF_x$ removal of manganese and ammonia has been exceptional. The biofilters remove nearly 100% of the iron and manganese and over 86% of the ammonia. Furthermore, the biofilters operate at steady state, with no indication of changing operating conditions, from operating cycle to operating cycle.

The biofilters are an excellent fit as pretreatment for reverse osmosis and nanofiltration membranes. The biofilters remove iron and manganese which can cause fouling in the membranes. During the past five months, the performance of the Delco $HYDRA_{MAX}$™ reverse osmosis and nanofiltration skid at Montana First Nation has been consistent and steady, and the membranes are showing no need of cleaning. As a result of fewer cleaning cycles, membranes last longer between replacement, reducing operating costs. The Delco $HYDRA_{MAX}$™ skid removes any remaining ammonia, dissolved organic carbon, metals, and majority of dissolved salts, producing a water which is pleasant-tasting, and aesthetically appealing. There is on-line monitoring and control of many variables of the biological treatment and reverse osmosis/nanofiltration equipment, which helps to optimize operation. The sophisticated automation, as well as the infrequency of biofilter backwash cycles, makes the system very operator-friendly.

Introduction

January 19, 2017 marked the grand opening of a new municipal water treatment plant at Montana First Nation, Alberta. The water treatment is comprised of Delco BioF$_x$ biological filters along with a Delco HYDRA$_{MAX}$™ reverse osmosis and nanofiltration skid. The system is cost-effective and straightforward to operate. The biological filters (biofilters) themselves require no chemicals, and are an environmentally-friendly technology when compared to conventional methods.

***Figure 1*: Pilot Testing of Biological Filters**

Although the concepts of biological water treatment are not new, there have been few examples of its use for municipal drinking water treatment in central Canada. Water temperature is a particular concern. Biological water treatment excels at room temperature but typical groundwater temperatures are as low as 5^o Celsius during the winter months in central Canada.

As with other new technologies, there are concerns with the complexity and functionality of biological treatment; there is a worry that the operation of biological treatment may be unpredictable and potential problems difficult to troubleshoot.

Delco Water took on these challenges and invested in several years of research and development into the biological treatment of ground water in central Canada. The result is a highly effective, cold-adapted, biological process. Unlike existing technologies, the Delco BioFx technology allows for the simultaneous removal of iron, manganese and ammonia at cold temperatures. Factors leading to Delco Water's success include long-term pilot testing at the water treatment plants of several Saskatchewan communities, and Delco Water's expertise in process automation.

Background

Montana First Nation is a community with over 650 residents, approximately 100 km south of Edmonton (Figure 2). Water is piped directly to band buildings, a school and several homes (Heyden-Kaye, 2017). Prior to 2016, the community relied on greensand filtration and chlorine for disinfection of brackish well water. The pre-2016 treated water exceeded the Canadian Drinking Water Guidelines recommended levels of total dissolved solids (TDS), iron, manganese, and certain dissolved salts. Also, the amount of trihalomethanes (THM's) was uncomfortably close to the recommended limit. THMs are the by-products of chlorination of water that contains natural organic matter. High dissolved organic carbon levels in the Montana groundwater were likely responsible for the high THM's.

Water treatment for communities in central Canada is more complex than one would imagine, and cookie-cutter solutions are seldom ideal. There are various constrictions which make it difficult to find a water treatment strategy which meets the needs and wants of a given community.

***Figure 2*: Map showing location of Montana First Nation (https://www.google.ca/maps/)**

One challenge is the size of the community. They may not have the budget for the capital investment required of certain technologies or may not be able to afford high operating costs for chemicals, materials and labour. The size and location of community may also limit the capacity to keep the water treatment operation staffed, to monitor equipment and to carry on daily operations. Thus while a particular conventional water treatment technology may be successful in cities, it can fail in smaller municipalities if it is too labour-intensive.

Another challenge is that the water demand and the composition of raw water available for drinking water varies drastically from community to community. Source water may be brackish groundwater, shallow well water influenced by surface water, or lake water with treated wastewater discharging to it. As a result, tailor-made water treatment options are often required.

In Alberta, Saskatchewan, and Manitoba, 23%, 43% and 30% of the population, respectively, relies on groundwater as a water resource (Environment Canada, 2013). Greensand filtration is a conventional method, often employed in central Canada, to remove iron and manganese from groundwater. For very small communities, this technology may not be appropriate. Some installations require frequent backwashing, sometimes more than once per day. Chemical addition of potassium permanganate or chlorine compounds is usually required, which adds operating costs. Unfortunately, greensand filtration does not remove ammonia which would require a high amount of chlorine to oxidize ammonia to chloramines. The presence of 1 mg/L of ammonia nitrogen in raw water may require 8 to 10 mg/L of chlorine to achieve breakpoint chlorination.

Chlorine compounds alone may be used to treat contaminants in groundwater. However Trihalomethanes (THMs), halogenated acetic acids (HAAs), bromates, chlorates, and chlorides are other concerns associated with high dosage of chlorine-based disinfectants. THM's and HAA's have demonstrated carcinogenic activity in laboratory animals. In addition to higher operating costs from chemical usage, there are safety issues in handling chlorine chemicals.

Membrane treatment by reverse osmosis or nanofiltration can be used to remove many metals, salts and dissolved organic carbons. However, high levels of iron and manganese will lead to fouling of the membranes, requiring labour and chemicals to clean the membranes more frequently. In addition, membranes will have to be replaced more often, further adding to operating costs.

Delco Water was solicited to devise a custom water treatment strategy for Montana First Nation, delivering 4 L/s of treated water. Delco Water provided treatment by Delco BioF$_x$ biological filters followed by a two train Delco HYDRA$_{MAX}^{TM}$ Nanofiltration/Reverse Osmosis skid (Figure 3).

***Figure 3*: Delco Water biofilters and reverse osmosis/nanofiltration skid at Montana First Nation**

Theory

Biological filtration for water treatment takes advantage of naturally-occurring bacteria and micro-organisms in surface and groundwater.

There are multiple species of iron-oxidizing, manganese-oxidizing and nitrifying bacteria which will facilitate chemical and biological reactions of iron, manganese and ammonia. Many of these thrive under aerobic conditions, which means the bacteria utilize oxygen dissolved in the water. In biological filters for water treatment, these bacteria are encouraged to grow, retained on the surface of a solid medium. Figure 4 shows a pilot-scale biofilter filled with media. Biofilms develop around the particles of the support media.

***Figure 4*: Pilot-scale biofilter filled with media**

In aerobic biological water treatment, oxygen is dissolved into the water to create aerobic conditions. Oxidation reduction potential (ORP), dissolved oxygen (DO), and pH of the water affect the removal efficiency of contaminants. These parameters need to be monitored in the water into and out of the biological bed.

A critical parameter in the design of biological filters is the flux rate through the bed. Flux needs to be adjusted to allow sufficient time for contaminant removal. Contaminant removal must be balanced with the reality that larger fluxes result in smaller footprints and lower equipment costs.

Periodic backwashing of a biofilter helps to remove suspended solids physically retained in the bed, as well as dead bacteria and excessive biofilm growth. Additionally, air scour helps to loosen up media particles. Agglomeration of particles may lead to flow channelling, and inefficient contaminant removal.

Methods

Delco Water used a scientific approach to develop a biological water treatment process. Following benchtop studies, Delco embarked on extensive pilot testing of biological water treatment at various locations in Saskatchewan. Pilot equipment was installed in the water treatment plants of communities which were dependent on brackish well water.

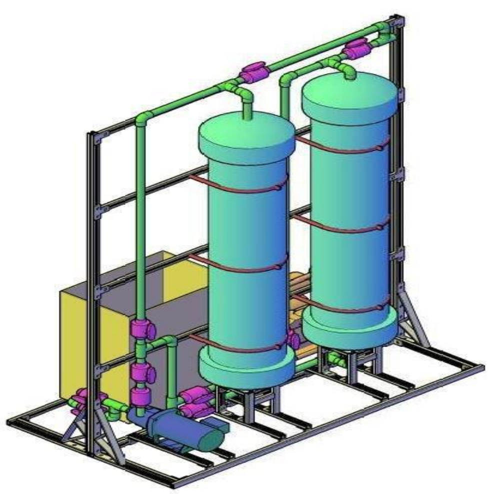


***Figure 5*: Pilot-scale biofilter skid schematic**

For the purposes of pilot testing, multimedia biological filtration beds were constructed of plexi-glass. The pilot test skid includes two filter beds which may be operated in series or parallel (see Figure 5). Raw well water was fed to the pilot biofilters, and oxygen injection was varied to each biofilter. In general, biofilters were run in series such that iron removal occurred primarily in the first biofilter, and manganese and ammonia removal occurred in both biofilters.

While Delco Water's pilot testing resulted in high removal of iron, manganese and ammonia, it was possible that only physical retention and filtration of contaminants took place. An objective of further research was to confirm whether biological treatment of contaminants occurred. Testing was completed to characterize bacteria on the biological filter media.

Samples of the media from the pilot scale biofilters at the Langham, Saskatchewan water treatment plant were analyzed by Scanning Electron Microscopy, with energy dispersive X-ray (SEM/EDX). A control sample of media, which was not used in a biofilter, was also analyzed.

Other investigations into the biological activity in the biofilters included genetic sequencing. Tests were completed on backwash water collected from each full-scale biofilter at the new Montana Water Treatment Plant. DNA extraction and genetic sequencing was performed by Contango Strategies Ltd on the samples.

Start-up of both full-scale biofilters at the Montana First Nation water treatment plant took place on August 16, 2016. Two biofilters were installed in series. The water began feeding the reverse osmosis/nanofiltration skid on November 3, 2016 and by the end of December, 2016, water produced by the Delco equipment was supplied to the community.

***Figure 6*: Pilot-scale biofilter skid**

As part of regular operations at the water treatment plant, samples of the raw water, and filtrate water from each biofilter were periodically taken and tested for iron and manganese concentrations, by a Hach DR900 benchtop colorimeter. Several samples were also tested for ammonia, nitrite and nitrate using a Hach DR 3900 benchtop spectrophotometer.

In addition to this testing, samples of the raw water, Biofilter 1 filtrate and Biofilter 2 filtrate were taken on October 18, 2016, and November 24, 2016 and analyzed by KaizenLab, Calgary, and Exova, Edmonton.

Delco Water provided extensive automation of the biological treatment and reverse osmosis/ nanofiltration processes at the new water treatment plant in Montana First Nation. The biofilters and membrane skid have many mechanically-actuated valves, including automated flow control valves. As well, there is online monitoring of temperature, flow, pressure, ORP, pH, dissolved oxygen, and turbidity into and out of each biofilter. Automation sequences were designed for the biofilters to control normal operation, start-up, backwash, air scour, and flushing to waste.

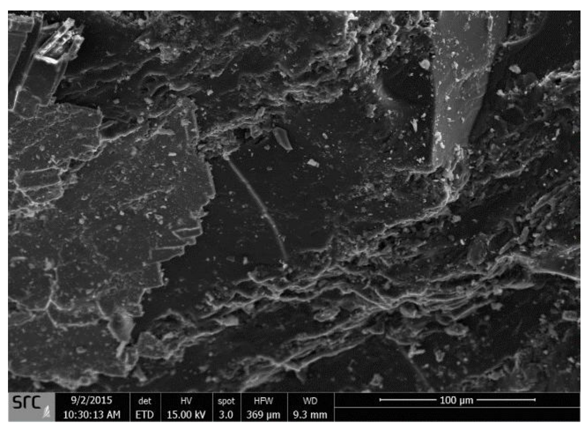
On the Delco Water reverse osmosis/nanofiltration skid at Montana First Nation, variable frequency drives, automated valves and online instruments allow membrane cleaning cycles, start-up and shutdown sequences to run automatically.

In addition, online instrumentation on the biofilters and membrane skid provides information on biofilter and membrane performance. These parameters are presented in the following sections.

Results

Characterization of microbial growth in biofilters

The following research supports the premise that biological treatment of iron, manganese and ammonia does in fact occur in the biofilters.



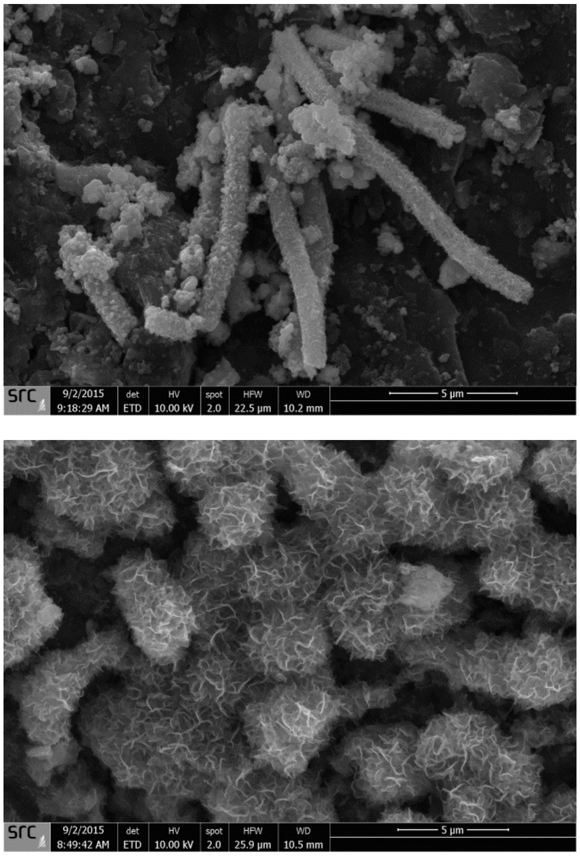


***Figure 7*: SEM/EDX images of (a) fresh media (b) Biofilter 1 media (c) Biofilter 2 media during Langham, SK, Pilot-scale biofilter testing**

The results of the SEM/EDX analysis on unused media, and media in biofilters 1 and 2 from pilot testing are illustrated in Figure 7. These indicate distinctly different types of microbial growth in the two biofilters.

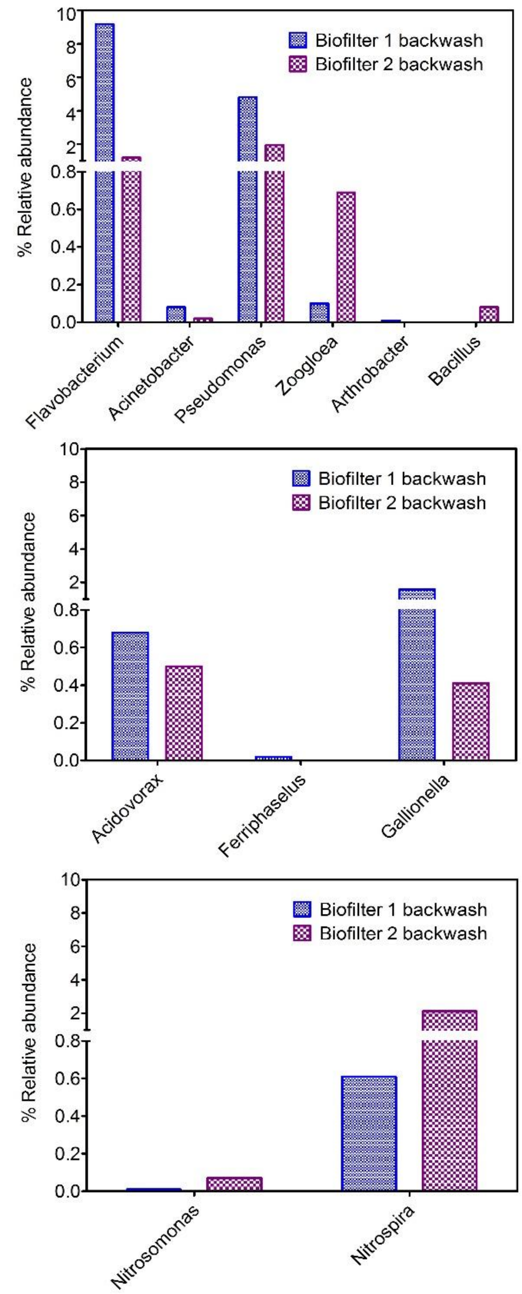


***Figure 8*: Bacteria species identified by genetic sequencing of backwash water from full-scale biofilters, Montana FN Water treatment plant, Oct. 18, 2016 (a) Iron Oxidizing bacteria (b) Manganese Oxidizing bacteria (c) Nitrifying bacteria.**

In the image from biofilter 1, the rods are likely iron oxidizing bacteria. In the sample from biofilter 2, there appears to be kidney-shaped manganese oxidizing bacteria cells.

DNA sequencing of microbes gathered from the backwash water of biofilters 1 and 2 at the new Montana First Nation water treatment plant, confirm the presence of iron-oxidizing manganese-oxidizing and nitrifying bacteria in both biofilters (Figure 8).

Contaminant Removal in Biofilters

Figure 9 illustrates the removal efficiency of iron and manganese from the raw water by two biofilters in series, at the Montana water treatment plant. The graph shows contaminant removals from initial start-up through eight months of operation. Iron is easily removed, and quickly 100% removal efficiency is achieved. Whereas with manganese, there is an onset of microbial activity, an acclimation period, followed by steady state, with nearly 100% removal efficiency. Removal efficiency is the concentration of the contaminant removed by two biofilters in series as a percentage of raw water concentration

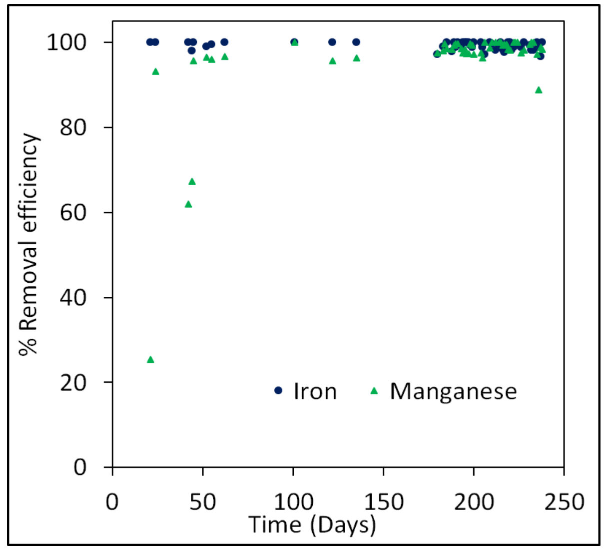


***Figure 9*: Contaminant removal efficiency in biofilters at Montana FN water treatment plant, starting August 16, 2016.**

Data on the removal of nitrogen compounds is summarized in Table 1. This table suggests that nitrifying bacteria takes several weeks to establish. The removal efficiency of the ammonia across both biofilters increases to 65% in November.

Table 1: Ammonia Removal in Biofilters at Montana First Nation Water Treatment Plant

Parameter	Raw Water	Biofilter 1 Filtrate	Biofilter 2 Filtrate	Raw Water	Biofilter 1 Filtrate	Biofilter 2 Filtrate	Raw Water	Biofilter 1 Filtrate	Biofilter 2 Filtrate
Sample date	09/06/16	09/06/16	09/06/16	10/17/16	10/17/16	10/17/16	11/25/16	11/25/16	11/25/16
NH3-N (mg/L)	0.336	0.321	.301	0.44	0.23	0.06	0.38	0.183	0.10
NH3-N removal	---	---	10%	---	---	86%	---	---	73%
NO2-N (mg/L)	0.005	0.005	0.005	0.005	0.079	0.043	0.005	0.005	0.005
NO3-N (mg/L)	0.01	0.16	0.21	0.01	0.294	0.350	0.01	0.16	0.21

Table 2 presents the results of complete water analyses, of water into and out of biofilters, as well as the reverse osmosis/ nanofiltration membrane permeate. While biofilters take out the iron, manganese and majority of ammonia, the membranes remove remaining ammonia, arsenic, dissolved organic compounds, and a great deal of the total dissolved solids (TDS).

Table 2: Performance of Biofilters and RO/NF at Montana First Nation Water Treatment Plant

Parameter	Raw Water	Raw Water	Biofilter 1 Filtrate	Biofilter 1 Filtrate	Biofilter 2 Filtrate	Biofilter 2 Filtrate	RO/NF Permeate	Can. Drinking Water Guidelines
Sample Date	10/18/16	11/24/16	10/18/16	11/24/16	10/18/16	11/24/16	11/24/16	
pH	7.7	7.73	7.6	7.6	7.6	7.6	6.75	6.5-8.5
Fe (mg/L)	1.8	1.85	0.01	<0.05	0.012	<0.05	<0.05	<0.3
Mn (mg/L)	0.898	0.884	0.76	0.4532	0.006	<0.005	<0.005	<0.05
Ammonium (mg/L)	0.44	0.38	0.23	0.183	0.06	0.108	<0.025	<0.1
DOC (mg/L)		7.8		8.2		8.3	<0.5	NA*
Hardness (mg/L)	618	652	600	643	599	647	46	80-100
Calcium (mg/L)	167	166	162	172	161	175	14.2	NA
Magnesium (mg/L)	49	52	48	51	48	52	2.8	NA
Chloride (mg/L)	359	323	329	324	312	321	70.5	<250
Bicarbonate (mg/L)	515	526	519	533	522	528	80	Na
Sulphate (mg/L)	78	80.4	79	78.9	80	79.3	<0.9	<500
TDS (mg/L)	1072	1040	1027	1040	1010	1040	182	<500
Turbidity (NTU)	10.2	20.4	<0.1	0.6	0.1	0.3	0.4	
Arsenic (µg/L)	2.8	2.9	1.0	1.0	0.9	0.8	<0.2	<10

Where RO/NF is Reverse osmosis/nanofiltration membrane skid

Biofilter Operating Conditions

Figure 10: **Differential Pressure in Biofilter 1 and 2, new Montana First Nation Water Treatment Plant.**

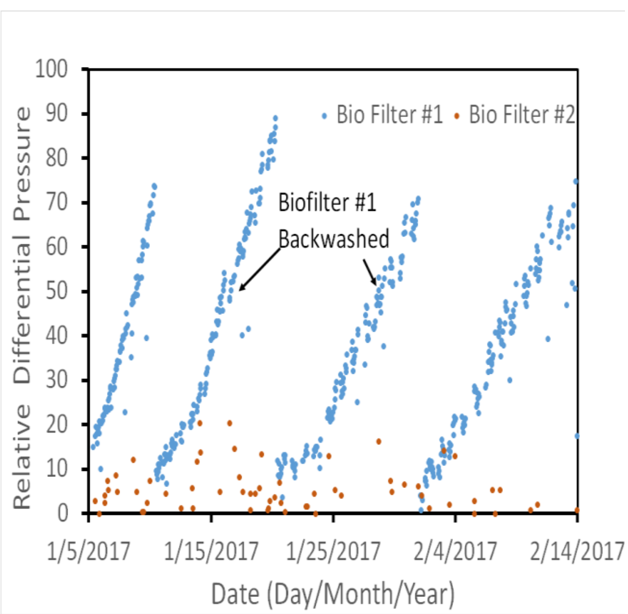


Figure 10 shows the relative differential pressure across Biofilters 1 and 2 at the Montana First Nation water treatment plant, over seven weeks of operation. In Biofilter 1 there is a steady increase in differential pressure between backwash sequences. Biofilter 1 is backwashed every 7 to 12 days. Backwashing is effective at reducing differential pressure. There is no noticeable build-up of differential pressure in Biofilter 2, and it has only been backwashed once in the past four months. The purpose of backwashing Biofilter 2 is to remove dead microbial cells.

Table 3 shows the backwash volumes compared to biofilter throughput.

Table 3: Backwash Volumes at Montana First Nation for a typical backwash cycle

	Biofilter 1	Biofilter 2
Backwash volume (m3)	6.8	4.3
Biofilter throughput (m3)	1,017	12,380
Time between backwashes (days)	8	97

Figure 11 indicates that steady state operation is achieved in the biofilters. The most important point to note is that these parameters return to a steady state very quickly following backwash of biofilter 1, and performance is maintained over time.

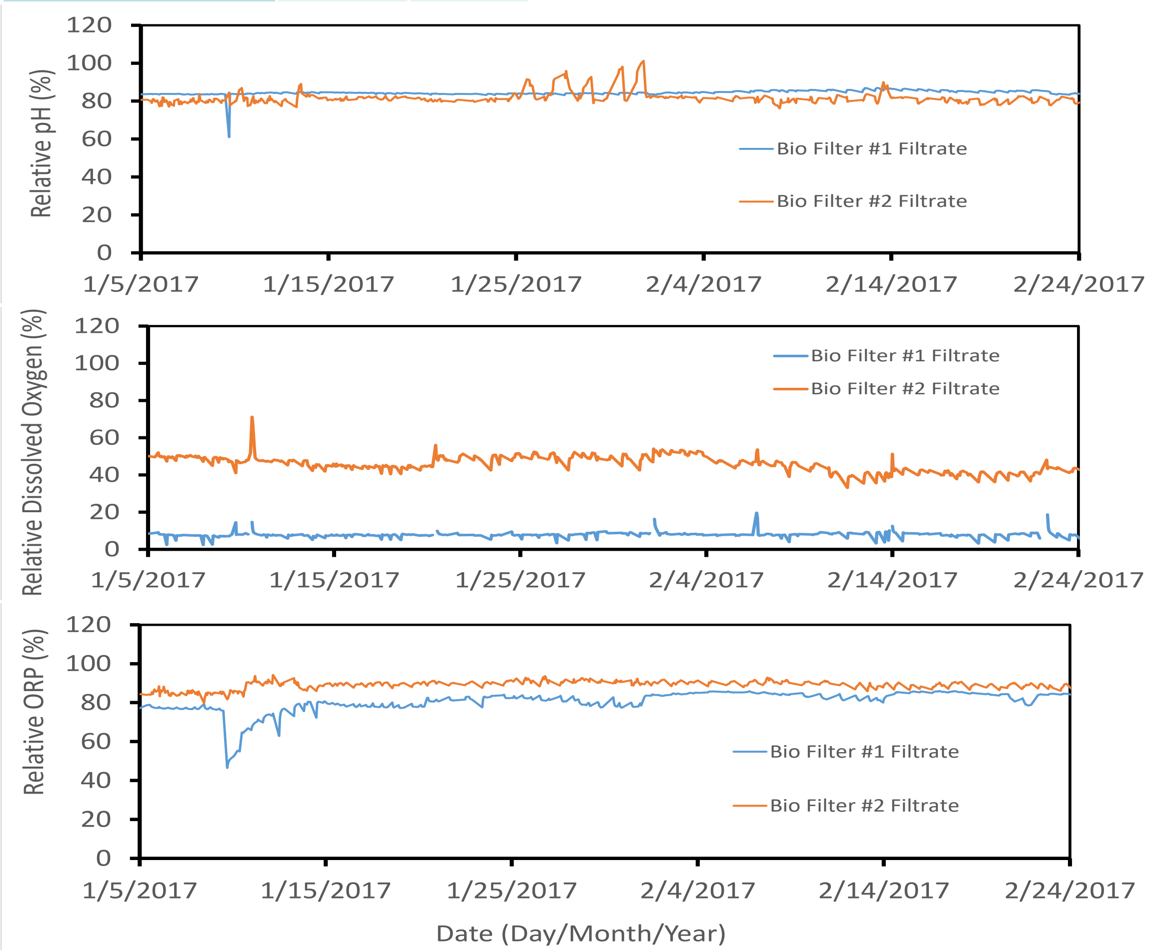


Figure 11: **Relative pH, dissolved oxygen, and ORP in biofilter filtrate at Montana First Nation Water Treatment Plant.**

Reverse Osmosis/Nanofiltration Performance

There is no evidence of precipitates from the biofilters interfering with the reverse osmosis/ nanofiltration membranes. Furthermore, there is no indication of biofouling occurring on the membranes as a result of the biological activity in the biofilters.

Polypropylene pre-filter cartridges, with a nominal filtration of 5 µm, are installed after the biofilters, and upstream of the reverse osmosis/ nanofiltration skid. These cartridges have remained clean. In addition, end caps on the membrane vessels were removed for inspection on XXXXXX and there was no evidence of discolouration, biofouling or precipitates reaching the membranes.

Figures 12 and 13 illustrate the performance of the membrane skid. Variations in normalized permeate flow or conductivity of the permeate may indicate that a membrane cleaning is required. Thus far, normalized permeate flow and permeate conductivity have been steady and membrane cleaning has not been required.

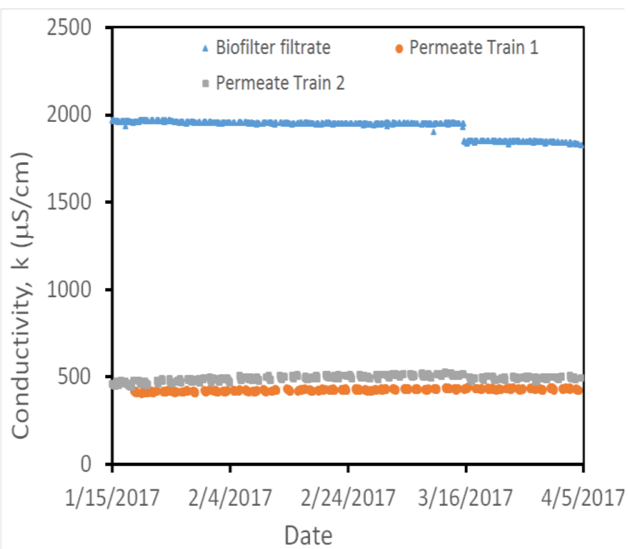


Figure 12: **Conductivity into and out of reverse osmosis/nanofiltration skid at Montana First Nation Water Treatment Plant.**

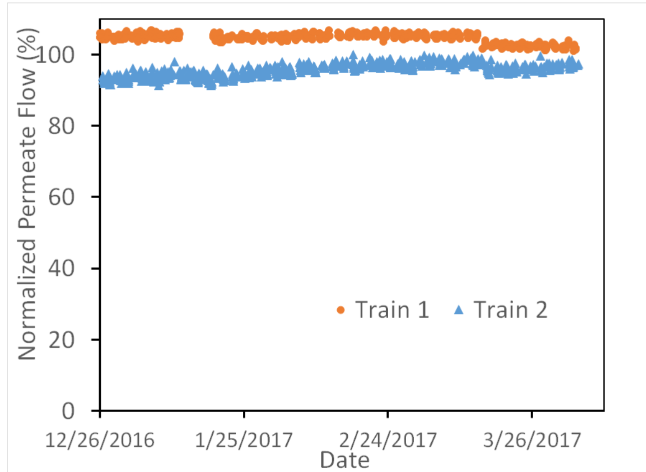


Figure 13: **Normalized permeate flow of reverse osmosis/nanofiltration skid at Montana First Nation Water Treatment Plant.**

Conclusions

When used in conjunction with reverse osmosis and nanofiltration treatment, biological filtration at Montana First Nation has proved very successful. As pre-treatment, the biofilters reduces the risk of fouling of the membranes with iron and manganese oxides. As a result it increases the efficiency and life expectancy of the membranes.

When compared to greensand filtration, biofilters eliminate the use of chemicals, and require much fewer backwashes. Thus, chemical handling risks and operating costs are reduced.

The Delco biofilters combined with a HYDRA$_{MAX}$^{TM} membrane skid removes dissolved organic carbon, metals, and the majority of dissolved salts, producing a water which is pleasant-tasting, and aesthetically appealing.

Automation of the water treatment equipment is a key component of the success of the Montana Water Treatment Plant. Operating parameters are monitored, and system performance is controlled effectively.

Figure 14: **Biofilter at Montana First Nation Water Treatment Plant**

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