ATTAWAPISKAT FIRST NATION

FYNE Membrane Pilot System Study

High Level Results

The FYNE Membrane pilot study increased our understanding of the:

- *raw water quality from the present community water source (Intake Lake)*
- *impact of variable raw water quality on membrane performance and treated water quality*
- *impact of biofilm (microbiological contamination) formation on membranes and high iron/manganese concentrations in the raw water, with respect to membrane flux, treated water quality and reliability of monitoring instrumentation*
- *the challenges of operating water treatment systems in compliance with the drinking water regulations in a remote community*

Project Context

The Attawapiskat First Nation is a fly-in remote community of approximately 2,000 people located 12 km inland from the James Bay coast. The community's drinking water is obtained from a shallow inland slough (Intake Lake) surrounded by low-lying wetlands.

The Class III chemically assisted conventional filtration plant is not able to consistently produce drinking water that meets the Drinking Water Standards and Guidelines (Ontario and Canada).

For many years disinfection by-products including Trihalomethane (THM) values have consistently exceeded the guideline values and therefore Health Canada issued an advisory notice to the residents in 2007 recommending that residents reduce their exposure to THMs by not drinking the "tap water" and reducing shower times.

While the community would like to change their water source to the Attawapiskat River, construction of a new river intake is very capital intensive (> $20 million) so Aboriginal Affairs Northern Development Canada (AANDC) recommended an interim solution of upgrading or replacing the water filtration/treatment system to produce treated water that will comply with the drinking water regulations.

Challenge

A review of existing water treatment plant processes, raw water quality, and current treated water quality suggested that even a fully optimized plant operation would not be able to remove sufficient organics to prevent exceedances in THM levels, particularly in light of the highly variable raw water quality throughout the year. As such, the community is looking at alternative processes and technologies to address this drinking water concern.

There are numerous challenges in finding suitable processes and technologies for upgrading and operating a water system in Attawapiskat including:

- very poor raw water source,
- limited financial resources (capital and operations)
- limited access to skilled water operators,
- longer delivery times for materials, supplies or parts
- high transportation costs
- limited internet communications for SCADA troubleshooting and transferring data (lower speed internet)

From a treatment technology perspective, the primary challenge is to reduce the Natural Organic Material (NOM) in the raw water which is characterized by high Dissolved Organic Carbon (15 to 24 mg/L), high colour (50 to 125 True Colour Units (TCU) and low Ultraviolet Transmittance (UVT) (12% to 30%). In addition, other parameters that complicate the filtration process that were found to be present in the raw water include: elevated Iron (3.5 mg/L), Manganese (0.37 mg/L) and Sodium (30 mg/L) during the winter period from January to April, Bromide (0.27 mg/L) and iron bacteria and sulfate reducing bacteria.

Ultraviolet light disinfection followed by chlorination (5 minute contact time) and then chloramination was investigated and considered; however preliminary results indicated it would be difficult to operate and to ensure proper UV disinfection with filtered water UVT less than 80%.

Ozonation for disinfection is not recommended for water containing Bromide as there is the potential to form Bromate (a carcinogen). Ion Exchange or MIEX treatment to reduce NOM could potentially work; however these processes would likely increase the already elevated sodium level in the drinking water. Installation of post filtration Granular Activated Carbon (GAC) units could reduce THMs in the treated water; however the operational costs of regenerating and replacing the media was thought to be very high.

Project Goals/Objectives

The Attawapiskat First Nation was advised by Genivar/WSP (and First Nations Engineering Services Ltd) that the most efficient process in the long term to reduce formation of THMs was to reduce the NOM in the raw water by filtration. Therefore, the goal of this project was to pilot a filtration/treatment process that:

- did not require chemicals or pre-treatment processes,
- could produce drinking water that would consistently meet all the present and anticipated future drinking water quality standards and guidelines in Ontario and Canada,

- could meet the drinking water Protocols (Canada) and Regulations (Ontario) with respect to filtration system design, integrity testing and primary and secondary disinfection requirements.
- was simple to operate with limited operator skill and equipment, and
- had a low operating cost.

Results from the pilot investigations were to provide performance and operational data that will assist the Attawapiskat community in making an informed decision about proceeding to full scale implementation using this technology.

The pilot system objectives or performance criteria could be summarized as follows:

- Confirm the choice of membrane (ES404 or AFC30) that will produce treated water which will meet the target levels of Colour, THM, HAA_5, Iron, Manganese, Turbidity, Dissolved Organic Carbon and Ultraviolet Transmittance parameters.
- Confirm the relationship between pressure and design flux for 2 different membranes
- Determine the optimal design parameters, including flux rates, cleaning cycles, cleaning solutions, projected membrane life span and power requirements
- Establish if foam ball cleaning will maintain the performance of the membranes over the test period or if additional chemical cleaning is required
- Confirm whether the piloted membrane flux is consistent with published specifications for the final membrane of choice at recoveries of at least 80%
- Confirm the robustness and reliability of the technology through all four seasons
- Assess the manpower requirements (time and skill) to run the FYNE system
- Confirm effectiveness of the post filtration limestone contactor
- Evaluate waste stream volume and quality to evaluate waste disposal options and requirements.

Water quality and operational data will be analyzed to determine the appropriateness of this technology for both treatment objectives and community needs.

Solution

Aboriginal Affairs Northern Development Canada (AANDC) and the Ontario First Nations Technical Services Corporation (OFNTSC) technical services departments recommended that Attawapiskat First Nation pilot the FYNE membrane nano-filtration system. The FYNE membrane process was selected over other membrane technologies based on the following unique features:

- nano-filtration membranes are designed to remove dissolved organics,
- the process typically does not require pre- or post-treatment or the use of chemicals in the treatment process,
- the wastewater generated under normal operations does not contain chemicals and therefore is more likely to meet wastewater disposal criteria,
- the system is simple to operate with relatively few moving parts.

Aboriginal Affairs Northern Development Canada had committed funding towards 2 months of piloting the FYNE membrane system; however with the financial support from the Ontario Ministry of Environment and Climate Change’s (MOECC) Showcasing Water Innovation Program, piloting could be completed over a 12 month period allowing for the capture of operational performance data from all 4 seasons. The MOECC also contributed expertise from their Drinking Water Approvals Branch engineers to the project team.

Attawapiskat First Nation retained the services of WSP Canada Inc. (WSP) to coordinate the pilot program, analyze the data and complete the reports. Northern Waterworks Inc. is the water operating authority for the water system in Attawapiskat and they were retained to provide on-site technical support to the local Attawapiskat First Nation water operators. Feherty and Associates Ltd. provided overall project management services for Attawapiskat.

Pilot System Description and Configuration

The FYNE membrane Pilot System supplied to Attawapiskat was manufactured and distributed by Membrane Specialist LLC of Hamilton, Ohio, USA. The FYNE membrane technology originated in Scotland and was developed to treat water high in colour and dissolved organic humic and fluvic acids that create disinfection by-products when chlorinated.

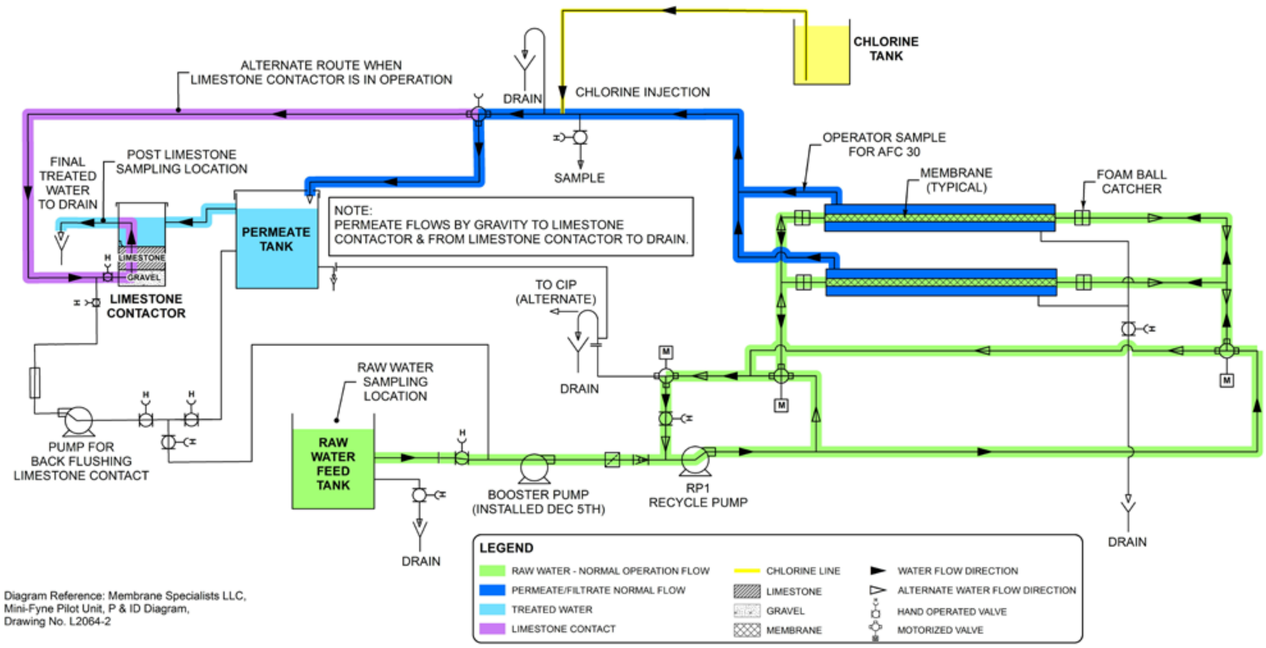
There are numerous installations in the smaller remote communities of Scotland where skilled labour is harder to find or labour is costly. There are a number of FYNE membrane installations in the USA, primarily in Alaska, with less than 5 installations in Canada. At the time of piloting the plant there were no FYNE membrane facilities in operation in Ontario. Since then, a full-scale FYNE membrane plant is scheduled for construction in 2014/15 at the Serpent River First Nation located between Sault Ste. Marie and Sudbury Ontario.

The pilot system was installed in the community water treatment plant and was configured to draw water from the raw water supply piping which filled a small tank.

FYNE Membrane Pilot System Setup in former Ozonation Room in WTP

Under normal operations, raw water from the tank was pumped through 2 - 900 mm long membrane modules that contained 72 – 12 mm diameter AFC 30 polymide film nano-filtration tubular membranes. The filtered/permeate water collected in the module and then flowed into a permeate tank.

A limestone contactor tank containing crushed limestone was installed after the membrane filtration system and was used only when the manganese and iron concentrations were elevated. Sodium hypochlorite was injected into the filtrate prior to the limestone contactor to assist in precipitating iron and manganese within the limestone contactor. Filtrate then passed up through a bed of limestone before overflowing to an open drain.



Pilot System Process Flow - Normal Operations

During the foam ball cleaning cycle, the direction of flow of the raw water in the module is reversed. This causes the foam ball to pass through each of the 72 membrane tubes inside the module, cleaning the inside surface of the membrane while at the same time discharging the concentrated raw water and drawing fresh raw water into the recirculation loop.

Periodic washing of the membranes with suitable cleaning agents is required anywhere from 2 to 4 month intervals depending on the raw water quality. A low pH solution (acetic acid) is circulated through the membranes under pressure to remove foulant from within the membranes. After the membranes have been chemically cleaned, raw water is pumped as per the normal operation; however the filtrate is drained to waste.

Typical Membranes and foam ball

The piloted system was outfitted with the following instrumentation:

- flowmeter - to record permeate flow
- pressure sensor – at inlet and outlet of membranes
- temperature sensor – raw water sensor
- turbidity meters – laser turbidity meters capable of recording turbidity in milli-NTU on the raw and filtered water lines at one to five second intervals.

Pilot System Operations and Monitoring

The Pilot System was commissioned in May 2012 and operations started in June 2012 and continued until the system was decommissioned at the end of May 2013. During that period, the Pilot System supplier conducted 5 site visits for troubleshooting, equipment repairs/adjustments and membrane chemical cleaning.

Continuous on-line data logging of flow, pressure, temperature and turbidity by the Pilot System instrumentation facilitated the calculation of membrane flux and turbidity monitoring for compliance with the regulations.

The local water operators conducted routine/daily field sampling and analysis for pH, colour, UVT, Turbidity and Iron and Manganese of the raw, filtered and post limestone contactor water. Water samples were collected monthly for off-site laboratory analysis for metals, general water chemistry, bacteriological parameters, disinfection by-product formation potential (THM and HAA_5) and in the spring, iron bacteria and sulfate reducing bacteria.

Minimal Pilot System operational duties were completed by the local operators other than sampling and adjusting the pressure and chlorine dose settings from time to time. The membrane supplier was able to make minor adjustments remotely via the PLC which was connected to the internet; however the slow and sporadic operation of the internet connection limited the amount of remote oversight and data downloading capability by the membrane supplier.

<u>Operational Challenges</u>

There were numerous operational issues and challenges encountered during piloting of the FYNE membrane system. Many of the problems and issues encountered were exaggerated and reduced the amount of reliable data that could be collected due to limitations with quick access to the site by the membrane supplier for troubleshooting and repairs (required travel from the USA to Attawapiskat). As such, there were periods of time (months) where the operational data recorded and logged was determined to be questionable.

Following is a brief summary of some of the operational issues/events that occurred during the 12 month piloting period:

- The original configuration of raw water supply to the Pilot System resulted in long residence time of the raw water in the tank which increased the water temperature causing bacteria to grow, seeding the membranes and turbidity meters with bio-film. The raw water supply was reconfigured in March 2013 to allow for a continuous supply of fresh raw water that could be supplied to the Pilot System.
- The membrane supplier had to experiment with the membrane chemical cleaning procedures, the choice of chemicals, water temperature and time required for membranes to “soak” in solution, to fully restore the membrane flux to original conditions. Given the sensitivity of the membranes to oxidants including hydrogen peroxide, chlorine and low or high pH, the choice of chemicals to remove the foulants and disinfect the membranes was very limited. It was found that during the fall and winter period, chemical cleaning of the membranes should be completed more frequently

(every 3 to 5 weeks) than what actually occurred (every 8 weeks) to maintain membrane flux within the target range of 12 to 14 L/m^2/hr.

- The Pilot System was originally configured to pilot 2 types of membranes (ES 404 and AFC 30). After it was determined that the ES404 was not able to meet the water quality objectives the ES404 module was sealed off from the system. Shortly after that, complications with the pump and flow meter and flow meter transmitter were encountered. These problems occurred between October 2012 and February 2013 until the flow meter was replaced, a new booster pump installed and the system recalibrated.
- During the period from November 2012 to January 2013, there were also a number of power outages and power surges that resulted in the Pilot System shutting down (requiring manual startup) and the loss of data and the reconfiguration of the data logger.
- The limestone contactor process flow was reconfigured from a pumped system to flow by gravity which eliminated the problems associated with pumping and kinked hoses restricting flow to the limestone contactor. The chlorine feed pump dosing was not properly configured to maintain a proper dose rate.
- The excessive growth of biofilm, HPC bacteria and iron related and sulfate reducing bacteria caused significant fouling of the membranes and turbidity meters. Biofilm fouling of the turbidity meter sensors was thought to be the primary reason for the turbidity spikes logged, as immediately after the turbidity meter was cleaned, the turbidity levels returned to expected values.

Fouled internals of Turbidity Meter

Piloting Results

Membrane Specialists downloaded and compiled the piloting data which was reviewed and analyzed by WSP. The local water operators and Northern Waterworks Inc. provided onsite operational observations which were valuable in assessing the overall performance of the FYNE Membrane process.

A summary of the FYNE Membrane pilot study results and experience is provided relative to the original project goals as follows:

<u>Water Quality</u>

- During the period from December 2012 to May 2013 when only the AFC30 nano-filtration membrane was piloted (after the ES404 membrane was removed), the AFC30 membrane did an excellent job of removing the Natural Organic Material (as measured by DOC, Colour and UVT) to well below Pilot Study Target Objectives which were at or below the Canadian and Ontario Drinking Water Standard guidelines. The maximum expected THMs anticipated to form in the FYNE membrane filtered water was determined to be less than 50 ug/L (THM formation potential test), compared to the target threshold of 80 ug/L.
- Results of the monthly laboratory analysis of the membrane filtered water indicated the majority of the parameters analyzed were well below the Drinking Water Standards with the exception of iron and manganese which occasionally exceeded the 0.3 mg/L and 0.05 mg/L standards and

sodium which was in the 20 mg/L range during the winter period (essentially the same as the raw water which is at the Drinking Water Standard intermediate threshold).

- The removal efficiency of the AFC30 membrane for selected parameters is as follows:
  - UVT 330%
  - DOC 95%
  - Colour 99%
  - Iron 73%
  - Managanese 55%
  - Sodium 11%
  - THM & HAA_5 FP 98%
- The membranes on their own were not able to reduce the iron and manganese levels to comply with the Drinking Water Standard without pre- or post-treatment process. The post-limestone contactor significantly reduced the iron and manganese concentrations to below the Drinking Water Standards; however sodium levels remained essentially the same, as expected.

<u>Membrane Flux</u>

- The AFC30 membrane design flux was determined to be 14 litres/sq.m/hour.
- Factors impacting the membrane flux included: reduced efficacy of the foam ball cleaning process, elevated iron and Managanese concentrations above 2.5 mg/L and 0.1 mg/L respectively, increased microbiological growth/biofilm on the membranes, DOC concentrations above 20 mg/L.
- Given that most of the above impacts occurred simultaneously, it was difficult to accurately determine the impacts of each of the parameters individually on membrane flux.
- The AFC30 membrane were found to operate between 78% and 82% recovery

<u>Membrane Cleaning</u>

- The unique foam ball cleaning system was able to significantly delay the need for membrane chemical cleaning. While a scenario of no foam ball cleaning cycles was not trialed, under the more severe winter water quality period, the foam balls wore down significantly in a matter of weeks compared to months during the summer period.
- During the winter period (poorest water quality), replacement of the foam balls should be completed every 2 to 3 weeks and a chemical clean every 3 to 5 weeks due to the significant iron/manganese and biofilm accumulation on the membranes resulting in premature fouling of the membranes.
- There was no significant observed change in membrane flux immediately before and after the foam ball clean. Since the foam ball clean is scheduled to be completed every 40 to 55 minutes of operation, the foam ball cleaning process is considered a preventative/on-going cleaning process to ensure the membranes remain clean rather than waiting until the flux drops and then initiate the foam ball clean.
- The frequency for chemically cleaning the membranes was significantly higher than what the membrane supplier anticipated. In addition, the type of chemicals, pH level and the need for a hot chemical membrane soak overnight changed from season to season.
- The pilot study determined that the foam balls would need to be replaced 10 times per year and a membrane chemical clean would need to be completed approximately 7 times per year. This

is approximately twice the frequency of "normal" cleaning cycles which is anticipated to potentially reduce the life span of the membranes by 50%.

Membrane Condition Assessment

- Unfortunately a detailed inspection/verification of the integrity of the membranes was not part of the original scope of the project and therefore was not completed. Laboratory sample concentrations for Dissolved Organic Carbon (DOC) (measuring DOC removal efficiency) at the beginning and end of the piloting period were very similar and the very low laser turbidity readings at the end of the piloting period along with the high UVT readings all suggest the likelihood of a breach in the membranes during the piloting period is considered very low.

Regulatory Compliance

- The FYNE membrane system on its own cannot reduce the iron, manganese or sodium levels of filtered water to meet the Drinking Water Standards without the need for pre- and/or post-treatment processes. Sodium concentrations of the filtered water are at the 20 mg/L range which is the intermediate threshold in the Drinking Water Standards. Apart from Reverse Osmosis, there are limited treatment processes that can further reduce sodium concentrations in water.
- If the FYNE membrane system is required to claim 2+ log reduction credits for Cryptosporidium oocysts in a treatment process, it must comply with the performance criteria set out in the Ontario MOECC "Procedure for Disinfection of Drinking Water in Ontario" regulations. If however the FYNE membrane process is used primarily for removal of DOC and other chemical parameters and not microbiological parameters (disinfection processes), the FYNE membrane process would not need to comply with the performance criteria set out in the disinfection regulations.
- Results from the piloting experience indicated the FYNE membrane could not fully and consistently comply with the disinfection performance criteria of:
    - filtered water turbidity being less than or equal to 0.1 NTU in 99% of the measurements recorded each month, and
    - monitoring integrity of the membranes by continuous particle counting or equivalent procedures to ensure filtered water turbidity requirements are met at all times.
- The operational challenges (biofilm growth on the turbidity meter sensors) are believed to have largely contributed to the elevated turbidity readings above 0.1 NTU.
- Integrity testing of the FYNE membrane process had been an on-going issue during the piloting study as the FYNE process does not allow the membranes to implement pressure decay measurements. The Ontario MOECC met with the membrane supplier to discuss alternate acceptable membrane integrity testing protocols but the membrane supplier did not pursue this any further with the MOECC. As such, the membrane integrity issue remained unresolved at the end of the project.

Ease of Operation and Maintenance

- Under normal operations, the membrane system does not require the use of chemicals so the operators do not have to manage/oversee chemical dosing as part of the treatment process (other than during the winter period for operation of the limestone contactor for enhanced iron and manganese removal).

- Day to day operation of the Pilot System was straight forward and there was minimal to no operator time required. The Pilot System produced water without much oversight except for mechanical troubleshooting, reconfiguration of the raw water feed system and membrane chemical cleaning periods. More routine maintenance (instrument cleaning and calibration) would have been beneficial to receiving more usable and reliable turbidity data.
- For considerable periods of time from September 2012 to February 2013, the pilot system experienced numerous equipment breakdowns (recirculation pump and chlorine pump) and monitoring instrumentation (flow meter and turbidity meter) problems which resulted in the collection of unreliable operational data. During the period from February 2013 to early April 2013, the membranes fouled quickly requiring more frequent chemical cleans.
- In most cases, neglect by the operators to maintain the system did not result in the production of inferior water quality, but rather a reduction in water production, potential unreliable turbidity readings and the increased potential for the stagnant water in the membranes to become biologically unstable resulting in significant biofilm growth throughout the membrane system. These conditions required extensive work to disinfect and sanitize the system before placing the pilot system into service.

<u>Capital and Operating Costs</u>

- The capital cost to retrofit the existing water treatment plant with a 1,600 m^3/day (maximum day demand) FYNE membrane system was estimated to amount to $12.2 Million with an annual operation and maintenance cost of $535,000/year.
- The cost to supply membranes only was estimated to be $4 Million and the projected cost to replace the membranes was estimated to amount to $700,000 to $1.4 Million depending on whether all the membranes would need to be replaced. The membrane supplier anticipated the membranes would need to be replaced at least every 5 years given the raw water quality and frequency of membrane clean cycles.
- The operational cost per cubic metre of water produced was estimated to be $1.83 with electricity being the largest single component of the cost at $0.86/$m^3$ followed by labour at $0.65/$m^3$.
- Over the long term, the operation and recapitalization costs are very sensitive to the price of electricity and membrane life. Interestingly, the present cost of chemicals for the operation of the conventional chemical filtration plant is approximately equivalent to the projected cost of electricity for operation of the FYNE membrane system.

Next Steps

Based on the 12 month FYNE membrane piloting experience, the project team came to the conclusion that implementing a stand-alone full-scale FYNE membrane system in the Attawapiskat First Nation as was originally contemplated, was not in the best interest of the Attawapiskat First Nation, for the following reasons:

1. The Pilot System could not successfully demonstrate that it could meet the performance requirements and criteria (filtered water turbidity consistently below 0.1 NTU and integrity testing of the membranes) to obtain the pathogen removal credits outlined in the Ontario legislation and standards.
2. The operational challenges (equipment breakdown, biofilm formation in the filtered water

components and the resulting complications, etc.) were significant enough to question whether a full-scale plant could overcome these issues.

3. The high Iron and Manganese concentrations along with biologically unstable raw and filtered water during the winter period resulted in significant and premature fouling of the membranes, which required more frequent chemical cleaning of the membranes to maintain production. As a result it is anticipated that the membranes may only have a maximum life span of 5 years which will be an ongoing significant cost to the community.
4. Uncertainty relating to the availability of local (in Ontario) reliable FYNE membrane technical support for the membrane system was a concern to the community.

Since the FYNE membrane system piloting experience did not yield encouraging results to proceed with the project, in the short term, the community is now looking at optimizing the present water filtration system by replacing the filter media, repairing the air scour blower and considering implementing corrosion control measures to minimize problems in the distribution and household piping. These measures will not eliminate the THM problems resulting from high organics in water, but will provide the best quality of treated water possible until such time as the water treatment plant is upgraded or replaced. In the medium term, the community will be pursuing developing a new water source (Attawapiskat River) and revisiting and exploring alternative filtration/treatment technologies and processes to improve the treated water quality.

Application to Ontario Communities

The FYNE Membrane technology outfitted with AFC 30 nano-filtration membranes proved to be capable of removing up to 99% of the organics from the raw water without chemicals and pre- treatment processes. In communities where organics removal is the primary filtration objective, where iron or manganese concentrations are less than 2 mg/L and 0.1mg/L respectively, and where disinfection credits are not required by the filtration system, the FYNE technology may perform well as a stand-alone filtration system or in combination with other treatment processes where the above raw water quality parameters are exceeded.

This piloting experience reinforced the need to complete piloting through all four seasons where raw water sources are variable through the year and/or have complex chemistry. Had the piloting program stopped within 3 or 4 months of starting, the community may have come to a different conclusion.

As a result of this pilot project Aboriginal Affairs Northern Development Canada, the Ontario First Nations Technical Service Corporation, Mushkegowuk Tribal Council and the Ontario Ministry of Environment and Climate Change are more aware of the technical and operational complexities of selecting appropriate water treatment technologies that comply with drinking water regulations in remote and northern communities.

This project has also highlighted the lessons learned from piloting a filtration system in Attawapiskat so that when future treatment processes are piloted, the piloting program can be more effectively implemented.

The Attawapiskat First Nation benefited from the Showcasing Water Innovation funding program by enabling Attawapiskat to properly assess and evaluate the FYNE membrane technology which was recommended to them by technical and funding agencies, under actual site conditions. Without this significant financial assistance to pilot the FYNE membrane plant for a 12 month period, the community may still be looking to secure funding to implement the pilot program or may have proceeded with implementing a full scale FYNE membrane facility in their community based on only a 2 month piloting experience.

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