Development of Effective Drinking Water Treatment Processes for Small Communities with Extremely Poor Quality Water on the Canadian Prairie

Hans Peterson
Safe Drinking Water Foundation, 912 Idylwyld Drive, Saskatoon, SK S7L OZ6, Canada, Email: hans.peterson@yahoo.com

Robert Pratt
George Gordon First Nation, Box 443, Punnichy, SK SOA 3CO, Canada, Email: gordonwaterkeeper@yahoo.com

Roberta Neapetung
Yellow Quill First Nation, Box 37, Yellow Quill, SK SOA 3AO, Canada, Email: yellowquill@xplornet.com

Anthony Steinhauer
Saddle Lake Cree Nation, Box 97, Saddle Lake, AB TOA 3TO, Canada, Email: projheal@hotmail.com

Abstract

Microbially and chemically poor quality surface and ground water sources are frequently used for the production of drinking water by rural communities across Canada and indeed internationally. Canadian cities, in contrast, generally obtain drinking water from high quality source waters yet provide far more extensive treatment than rural water treatment plants when the opposite needs to be true. This realization has prompted the development of drinking water treatment processes based on biological removal of compounds that can either be energy or nutrient sources for bacteria, which are followed by reverse osmosis treatment of the water. This process is allowing small water treatment plants to cost-effectively produce superior quality drinking water from marginal water sources that previously could not be used for drinking water.

Introduction

The Canadian prairie is semi-arid, and while cities are located near large rivers, most rural communities rely on local surface and groundwater supplies. Some communities, for example, Saddle Lake Cree Nation, have been developed around natural lakes, while others have excavated holes in the ground (dugouts) to trap mainly water from the snowmelt in the spring. There are more than 100,000 dugouts on the Canadian prairie. The drainage basins for these dugouts and hypereutrophic lakes are generally >80% agricultural, with high levels of nutrients and other agricultural compounds ending up in the water. With evaporation losses of around one metre every summer, compounds in the water, such as dissolved organics, concentrate making it a challenge to treat in the water plant. Associated with these shallow reservoirs are heavy algal and weed growth further degrading the quality of the stored water. Is then ground water any better?

Unfortunately, a large part of the Canadian prairie in pre-historic times was an inland sea, and when the sea retracted it left vast deposits of salt behind resulting in brackish well water. One province, Saskatchewan, has indeed increased its Drinking Water Quality Guideline Value for Total Dissolved Solids (TDS) to 1,500 mg TDS/L in contrast to everywhere else in the world where this number is 500 mg/L. While TDS is an aesthetic objective, accompanying these high levels of TDS are frequently high levels of organics, iron, manganese, ammonium, and arsenic, also presenting water treatment challenges. It is especially troubling that the guideline level for arsenic has gone from 50 micrograms/L to 25 and now to 10 when it actually needs to be below 5 (Kapaj et al. 2006).

Here we show examples of rural surface and ground water, as well as their treatment. We then describe a project that has successfully tackled the poor quality by developing an integrated biological and Reverse Osmosis (RO) treatment system that produces exceptionally high quality drinking water. The continued development of this process in several aboriginal communities has resulted in improved treatment efficiencies, while at the same time, costs have decreased to make the process less expensive (while producing better quality water) than conventional + RO treatment.

There are hundreds of rural communities facing huge challenges to make their drinking water safe. We use Yellow Quill First Nation as an example of one such community, located about 300 km northeast of Saskatoon. Yellow Quill has had one of the longest boil-water-advisories in Canada, put in place in 1995, and it could not be lifted with the existing surface water source and water treatment equipment.

Yellow Quill and Other Water Treatments

The quality of Yellow Quill's raw water source is compared with Saskatoon's and also bottles of the waters themselves (Fig. 1).

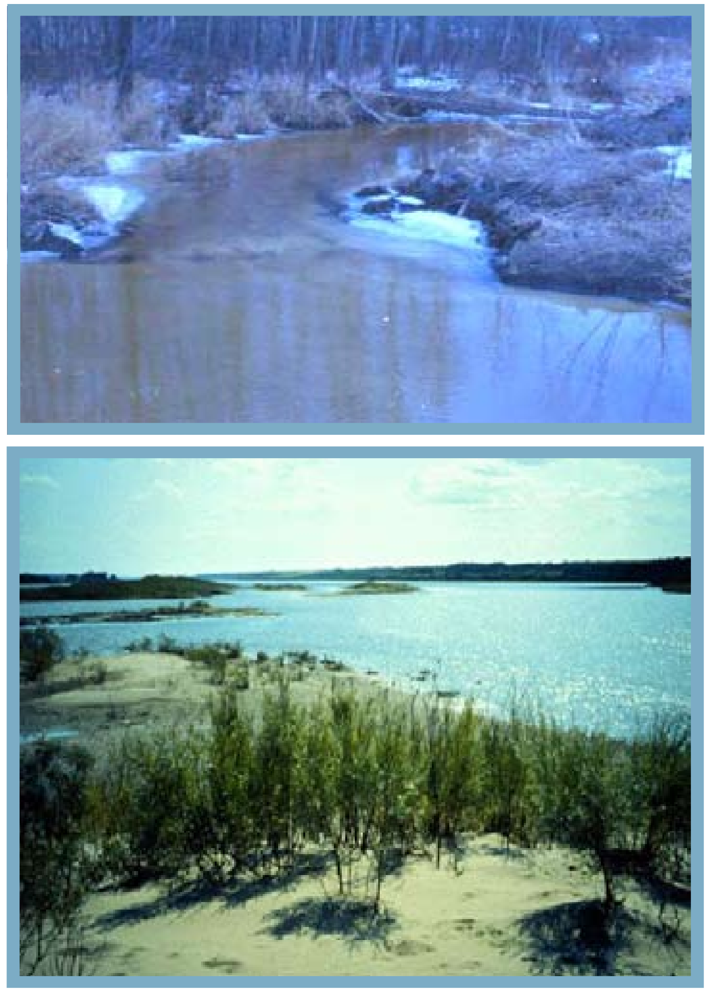

Fig. 1. *Yellow Quill raw water source (upper horizontal) contaminated by wastewater lagoon discharge; Saskatoon raw water source. South Saskatchewan River (lower horizontal) originating from the Rocky Mountains.*

The small Yellow Quill Water Treatment Plant housed one direct filtration unit (addition of coagulant, upflow clarifier, and a downflow rapid sand filter), which was incapable of producing water safe for human consumption. High levels of organics produced unacceptably high levels of trihalomethanes (THMs), and the package treatment plant was also incapable

Yellow Quill raw water (left bottle) and Saskatoon raw water (right bottle).

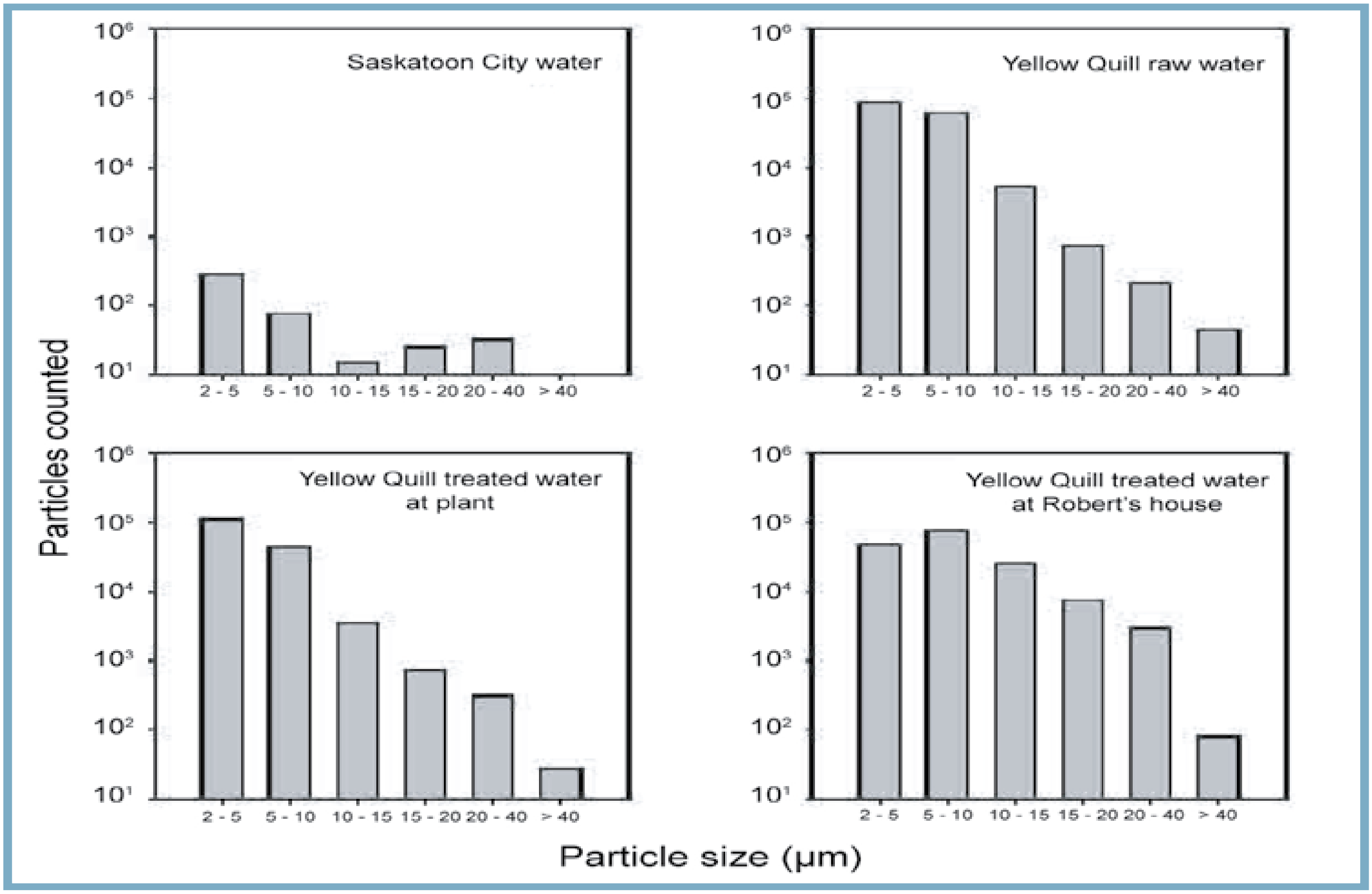

***Fig. 2**. Particle size distributions for Saskatoon city water and that of Yellow Quill First Nation.*

of removing the heavy particle load it experienced most of the time.

Water quality in terms of particle size and abundance of treated water at Yellow Quill is compared with that for the city of Saskatoon (Fig. 2). While Saskatoon's distributed water has a total particle count of less than 50 particles/mL, Yellow Quill treated water values both at the treatment plant and in the distribution system were in excess of 20,000 particles/mL. Particle count is not regularly used to determine acceptability of drinking water in aboriginal communities, but where it is used by larger cities, the requirement is to produce particle levels <50 or <100 per mL.

The problem for Yellow Quill and many other rural communities is the exceedingly poor water quality sources that they have to treat. This is combined with fewer resources to treat the water in terms of treatment equipment, people, and financial support. Simple water treatment processes are frequently used, such as at Yellow Quill, treating water within minutes, while cities using far superior quality raw water have many more processes that are continually optimized. While Yellow Quill was supposed to treat its water within five minutes, Saskatoon takes up to two hours, and Calgary (treating even better water than Saskatoon) takes up to six hours to complete its treatment. Only by using small subsets of the Canadian Drinking Water Quality Guidelines can regulatory authorities claim that the treated water is "safe." Perception, unfortunately, is not reality. There is a great need to address the use of inferior quality water sources for human consumption as many communities simply don't have the luxury to pick and choose their water source. Limnologists trained in water quality areas are needed to better help manage and protect water sources that are going to be used for drinking water.

A search for better quality source waters around Yellow Quill was not successful, as the only source that could be used was nearly a hundred kilometres from the community. Improving the treatment of the surface water supply was considered, but the small creek from which Yellow Quill pumped its water to a constructed reservoir was highly unreliable, with years of no flow. Discharge of an upstream sewage lagoon into the small creek was also of great concern. Calls for the upstream community to discontinue discharging its effluents into the watershed of the creek (the wastewater could have been used for irrigation) were unsuccessful, leaving Yellow Quill's Water Project Team to look at other alternatives.

When the original surface water treatment plant was constructed, ground water had been discounted because of its poor quality. However, in contrast to the surface water, it was available in ample quantity. Yellow Quill's ground water is similar to many other such sources on the Canadian prairie, being naturally contaminated with arsenic, high levels of sulphate, ammonium or nitrate, calcium, magnesium, as well as organic matter (Peterson et al. 2006; Peterson and Sketchell 2003). These typically brackish water sources (TDS levels >1000 mg/L) are supplying both potable (with Saskatchewan's altered guideline for TDS) and non-potable water requirements for many rural communities.

Unfortunately, rural communities frequently use treatment methods that simply cannot render these poor quality water sources safe for human consumption from either a chemical or microbial standpoint. Indeed, it is possible that >90% of native drinking water treatment plants may not be able to produce drinking water that meets the current Canadian Drinking Water Quality Guidelines. The federal government and engineering companies providing water treatment equipment and drinking water treatment advice need to implement more effective water treatment processes and testing must be carried out to ensure that safe drinking water is actually produced. The treatment methods applied to these exceedingly poor quality water sources have even failed on better quality water sources in large communities, where also the technical and financial constraints were not as limited as in most rural communities (Mouchet 1992).

The federal government agency responsible for aboriginal people in Canada, Department of Indian and Northern Affairs Canada (INAC), is relying on engineering companies to design and construct water treatment systems. However, the dilemma for Canada's aboriginal communities is that INAC is not requiring that the treated water meets all of the Canadian Drinking Water Quality Guidelines. Instead INAC relies on Health Canada's bare bones assessments of drinking water safety (10% of the total guidelines) total and free chlorine, *Escherichia coli*, coliforms and nitrate. To meet four of these five parameters, water treatment plants are not necessary, only chlorine is. While Health Canada every two years or so make more extensive analyses, these are generally not used by INAC to assess treatment plant efficiencies and, indeed, this information is not always communicated to INAC.

Currently, it therefore is feasible for engineering companies to design inadequate treatment systems and INAC simply has no ability to make the appropriate drinking water safety assessments. If this does not change soon, there is an urgent need to establish a different mechanism to ensure the full implementation of the Canadian Drinking Water Quality Guidelines in every aboriginal community in Canada. One also needs to remember that current European and U.S. regulations are considerably more stringent than the Canadian Drinking Water Quality Guidelines and as more is learned about chemical and microbial contaminants, drinking water guidelines around the world are becoming more stringent.

There are INAC people, however, that have realized the extent of the problems and are trying to put things right. The Saskatchewan regional office of INAC has pioneered advances in drinking water treatment processes for several years, with some failing and others succeeding. INAC officers realized that both chemical and microbial issues need to be addressed before the drinking water supply can be considered safe, and started in 2001 to apply RO membrane treatment to render brackish ground water suitable for human consumption. This also included a few misguided attempts to just get the chemistry right, forgetting about microbial threats and constructing water treatment plants where RO water is "blended" with pre-treated water. This practice is enabling the construction of inferior treatment plants as the fall-back of simply adding more "blend water" can disguise RO treatment problems and provides no microbial protection. While frequently ignored by the federal government, viral and bacterial issues pertaining to ground water must be addressed in the future (Peterson 2001).

George Gordon First Nation, with arsenic levels above 70 micrograms/L in its raw water, was not able to decrease those concentrations to safe levels with the manganese greensand filtration process it was using. In 2001, RO membranes were installed. However, both chemical and microbial fouling became apparent, and despite frequent cleanings, the membranes became permanently fouled after just over one year. The next set was fouled within eight months. Microbial and chemical analysis of the fouled membrane showed that extensive biofouling was accompanied by the accumulation of a string of different compounds covering the white membrane with a brown layer of fouling material (Fig. 3). Microorganisms, including manganese oxidizing bacteria, were present in the biofilms that covered the membranes.

Fig. 3. *A cut open reverse osmosis membrane fouled by manganese oxidizing bacteria leaving a brown coating on top of a bright white membrane sheet. From the George Gordon First Nation water treatment system.*

One alternative to solving the above problems with treating challenging water supplies is to obtain better quality water through supply pipelines, but the scarcity of good quality water and long transport distances can make this very expensive. For example, bringing better quality water to Yellow Quill required the construction of 100 km of pipelines, with its associated $8 million in construction and material costs. The realization that many communities were struggling to produce good quality drinking water sparked the development of water treatment processes that could effectively deal with existing water sources.

The Yellow Quill Pilot Study

A 20 month pilot study was initiated at Yellow Quill First Nation. Conventional water treatment technologies, such as manganese greensand, were tested along with advanced technologies, such as ozone and biological filtration. A test water supply of 200 L/min was supplied directly from the well into the pilot study trailer (Fig. 4). Inside this trailer, raw water was distributed to several different treatment processes. Different combinations of treatment were tested using both pressurized and gravity filtration systems. Conventional water treatment processes, including manganese greensand, failed to remove both iron and manganese. While ozone removed some contaminants, the filtration run lengths were short and the floc difficult to contain. Better success was obtained

Fig. 4. *The pilot water quality trailer (outside top and inside bottom) used by Yellow Quill First Nation to test raw water treatment processes.*

with the biological filtration trials, and the work started centering on using different types of material including granular activated carbon and expanded clay for the attachment of bacteria. In the end, we were able to develop a highly effective biological treatment process integrated with RO membranes.

The Full-Scale Yellow Quill Treatment Plant

The material used for the attachment of microbes in the full-scale water treatment plant was Filtralite expanded clay supplied by the Maxit Group from Norway (Fig. 5).

Fig. 5. Upper: Expanded clay material (Filtralite) with size similar to coarse coffee grounds. Lower: Electron microscope photograph showing bacterial clusters on the expanded clay material.

Operational data for the full-scale plant are shown for biological treatment and membrane treatment (Table 1). These data were collected before a series of design modifications were carried out, resulting in complete ammonium oxidation and greater arsenic removal by the biological process. In addition, the RO treated water is currently running through a calcium and magnesium mineral bed raising treated water calcium and magnesium levels to produce a healthy as well as a safe drinking water. The distributed water has no detectable trihalmethanes or heterotrophic bacteria, and chlorine residuals at the treatment plant do not deteriorate in the distribution system.

Table 1. Operational Data from the Yellow Quill Water Treatment Plant

Mainly Biological Removal (full-scale plant)

Substance	Raw	BioTreated	Membrane Treated
Iron (mg/L)	9.0	0.03	0.007
Arsenic (μg/L)	21	6	<0.4
Ammonium-N (mg/L)	3.7	1.9	0.05
Phosphorus (mg/L)	0.17	<0.01	<0.01
Turbidity (NTU)	100	0.19	0.09

Mainly Membrane Removal (full-scale plant)

Substance	Raw	BioTreated	Membrane Treated
TDS (mg/L)	1858	1850	17
Calcium (mg/L)	280	250	0.2
Magnesium (mg/L)	120	98	<0.1
Silicon (mg/L)	12.7	12.2	0.16
DOC (mg/L)	10.0	8.1	<0.2
Manganese (mg/L)	0.25	0.24	<0.001
Nitrate-N (mg/L)	<0.01	2.0	0.36

Compared with conventional treatment of groundwater, mainly manganese greensand for similar types of water, the amount of backwash water required for the fully developed biological treatment system is 20 times less. Even ahead of the membranes, all of the ammonium is oxidized to nitrate (after modifications to the original plant), and most of the arsenic and other bio-available material (bio-available-DOC, etc.) are also removed. After biological filtration, the water is biologically stable resulting in low biological fouling, of the reverse osmosis membranes. The Yellow Quill water treatment plant has been providing high quality drinking water for three years (Fig. 6). Our experience with membrane cleaning is quite limited as there is very little fouling/scaling and only one membrane cleaning has been carried out so far. The developed process has now been implemented in two other water treatment plants, George Gordon and Pasqua First Nations.

Fig. 6. *Upper: full scale biological filters; lower: reverse osmosis treatment unit at the Yellow Quill First Nation water treatment plant.*

This process is dealing not only with poor quality water but also with water temperatures for ground water sources as low as 6 °C. The process is robust, requiring few operator interventions. It is also highly cost-effective due to extremely low chemical use (no chemical additions for the biological treatment process and low levels of antiscalant for the membrane process with final disinfection carried out with low levels of chlorine). The process uses inexpensive and long-lasting filtration material. In addition, the plants operate 24 hours per day for weeks before backwashing or any other direct operator intervention is required. Switching from manganese greensand + RO to the Integrated Biological and RO Process has been estimated to save the George Gordon First Nation $100,000 per year mainly in decreased RO membrane replacements, decreased use of chemicals and process water. A similar integrated biological and reverse osmosis treatment process is currently being developed for the exceedingly poor quality surface water (DOC, 25 mg/L) at Saddle Lake Cree Nation in Alberta. It is simply not feasible to allow large levels of DOC in the distributed drinking water when chlorine is used as a disinfectant (Peterson et al. 1993). It is also not possible to use pre-oxidation strategies to produce high quality drinking water from poor quality surface water sources (Peterson et al. 1995).

Concluding Remarks

The Integrated Biological and RO Membrane Process was developed in pilot form and then scaled up to deal with the communities' entire water needs. Engineers took the pilot data and did the necessary magnifications. When government agencies finally realize that the production of truly safe drinking water is less expensive than allowing small rural drinking water treatment plants to become "Centers for Disease Creation," then biological limnologists must become involved to ensure that we can take advantage of microbial green power and limit the use of chemistry. Understanding and implementing biological drinking water treatment solutions are areas where engineers are often uncomfortable, and need additional scientific support; such support also improves the comfort level of both the community and the federal government. These developments are, of course, not limited to aboriginal communities, but also are suited to other rural drinking water treatment plants. They also offer an economic and better quality alternative to rural drinking water pipelines, which can suffer from slime problems caused by bacterial growth in long distribution system pipes.

Indeed, water to be distributed in long pipelines should be biologically stable (microbial nutrient and energy sources removed) to reduce this problem. The removal philosophy used in the developed process, therefore, is quite different from that used in conventional water treatment plants. Conventional treatment removes some compounds, but leaves many microbial nutrient and energy sources intact. Indeed, any oxidative treatments, such as ozonation, chlorination, etc., increase the quantity of biologically available organic material. Also, conventional treatment relies on inactivation of disease-causing microbes, as bacteria and viruses cannot be effectively removed. This means that conventionally treated water is prone to build-up of microbial slimes in the distribution system and when drinking conventionally treated water, we also consume large quantities of "inactivated" microbes. The realization, however, is growing that many microbes cannot be effectively inactivated, and their removal is desired.

The removal of microbes as well as microbial nutrients and energy sources, therefore, may become a future requirement to produce truly safe drinking water. It, therefore, is quite likely that biological filtration will become not only a future "nicety" in drinking water treatment, but an essential part of advanced water treatment technologies in Canada and around the world.

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