GREYWATER TREATMENT AND REUSE IN NORTHERN BUILDINGS AND COMMUNITIES – RESULTS FROM A DEMONSTRATION PROJECT

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Abstract

Greywater is wastewater from activities like showering, bathing, or laundry. Compared to blackwater (sewage), greywater is less contaminated as it does not include wastewater from toilets, urinals, kitchen sinks, and dishwashers. In many regions of the world where water is not plentiful, people reuse greywater for toilet flushing, irrigation, laundry, and cleaning. Various plumbing and building codes include standards that ensure the safety of using treated greywater for various purposes.

Generally, Nunavut does not have a shortage of water, but it is costly. Especially for small communities with no piped distribution systems, the high cost of water is related to the delivery of water by truck to individual homes and businesses, and the removal of sewage from these buildings by truck. As a result, Nunavut uses less water per person than other parts of Canada. Greywater reuse in northern buildings and communities would reduce the amount of wastewater generated and allow more truck-delivered, potable water to be reserved for activities that truly require this quality, such as drinking, food preparation, and bathing.

This project studied the potential to treat and reuse greywater in northern communities using a new greywater treatment system designed for the North. The new system was installed in a triplex residence of the Canadian High Arctic Research Station in Cambridge Bay, Nunavut. During the demonstration project, the greywater system was able to meet the requirements of a widely adopted standard for greywater. This paper discusses the treated water quality and cost per cubic metre (m^3) as well as presents the results from a survey of community residents and business owners regarding their perspectives on greywater treatment and reuse.

Introduction

Cambridge Bay is a hamlet located on Victoria Island in the Kitikmeot Region of Nunavut, Canada. In 2016, the population was 1,716, with the majority of residents being Indigenous (Inuit) (Statistics Canada, 2016). Due to permafrost and the harsh climate in the North, piped-water-distribution systems (underground or above ground) and wastewater-collection systems are

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extremely costly and impractical. In most Nunavut communities, trucks deliver potable water and collect wastewater from homes and businesses that are equipped with separate water- and sewage-holding tanks. Potable water is generated from treated surface water and wastewater is disposed of in a nearby sewage lagoon. These truck services are provided for a fee by the Hamlet, with different rates for residential and commercial customers which include significant Nunavut Government subsidies. These subsidies are necessary since the cost of water services in Nunavut is more than 10 times the average $ 5 per m^3 cost of water and wastewater services in other Canadian regions. Residential per capita water use in Nunavut is typically around 100 litres per day (L/day), approximately one third of the Canadian average (Daley et al., 2014), and the cost of unsubsidized diesel-generated electricity is approximately 5 to 10 times higher than in other Canadian regions.

Greywater (GW) from bathing and laundry activities typically represents about 50% of potable water consumption (Mortillaro, 2016). Treating and storing GW in a separate tank allows it to be used in applications that do not require potable water (i.e., toilet flushing and laundry). This approach would reduce water costs and reserve clean water for those applications that truly require potable quality (drinking, cooking, and bathing). GW reuse also decreases the per capita volume of potable water required and the volume of sewage generated. In northern communities, GW reuse could ease the load on potable water treatment facilities and truck delivery services that may be operating near capacity in some communities. Commercial water users may be especially interested in GW reuse, given that their water cost is four times more than the rate for residential customers even with the government subsidy. Treatment and reuse of GW is of high interest in many regions of North America due to water shortages resulting from drought or a mismatch between water availability and domestic, agricultural, and industrial needs. However, GW treatment and reuse has rarely been considered for the North because of various technical, practical, and social challenges.

A novel GW treatment system was developed and tested for a six-month period prior to this demonstration project (Poirier and Pristavita, 2017). To assess its suitability for treating GW in northern settings, the system was transported to Cambridge Bay in November 2018 and installed in a triplex residence (Figure 1) at the Canadian High Arctic Research Station (CHARS). A survey of northern residents and business owners was also carried out to obtain their perspectives on GW treatment and reuse.

Description of the greywater treatment system

Figure 1: Triplex residence at the CHARS where the greywater system was installed.

The GW treatment system, presented in Figure 2, is approximately the size of a refrigerator. For this demonstration project, the system was installed in the multi-occupancy CHARS triplex building, which can house up to 24 people, with eight people in each of the three residences. This system is suitable for processing all of the GW generated in the triplex, based on its treatment capacity (1 440 L/day), the typical building occupancy, and the measured water usage rates of the building's high-efficiency fixtures that generate GW (showers and clothes washing machines).

The GW treatment system is based on electrochemistry and does not require chemical addition (challenging for northern communities) or use biological treatment, filters, or membranes

Figure 2: Greywater treatment system that was installed in the triplex residence.

(which are generally high maintenance). The core of the system is a patented electrocoagulation (EC) reactor; this is followed by a novel turbidity removal unit, a final polishing stage, and a disinfection unit. The EC is used to remove most of the GW Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS). The remaining COD, BOD and TSS are then further reduced by the turbidity removal unit and the final polishing stage. The disinfection unit provides an oxidant residual so that treated GW can be safely stored prior to use for flushing toilets or laundry. The treatment performance is not affected by the presence of cleaning or personal care products in the GW.

The GW treatment system generates all that is required for treatment in-situ and has on/off capability, making it practical for northern applications and intermittent usage. The system has low maintenance requirements; depending on usage, the EC electrodes need to be replaced approximately once every three months (a 15-minute procedure) and the polishing and disinfection units require refreshing several times per year. The automated system operates without operator attendance and starts and stops automatically depending on the availability of GW. The system can also be remotely monitored and be programmed to operate during selected time periods.

Installation of the greywater treatment system

During an initial site visit in July 2017, it was concluded that the mechanical room of the triplex building did not have sufficient space to install the GW treatment system. The site visit also identified another issue affecting the demonstration project: shower GW and the effluent from the toilets (referred to as blackwater or BW) were commingled in the bathroom piping leaving all triplex bathrooms. The inclusion of any BW in the GW means that the entire stream becomes BW and is no longer suitable for treatment as GW. Northern buildings are typically built on piles due to permafrost, which can make it challenging to harvest GW separately from BW since there is no opportunity to access piping in a basement.

After considering various options, the GW treatment system was installed in the second-floor laundry room of one of the triplex residences to treat laundry and shower/bath GW from a single residence rather than the entire triplex. Laundry GW is usually easy to harvest since the washing machine pump directs GW to an above-the-floor standpipe drain. To collect shower/bath GW, a novel device[1] was developed that inserts into the bathtub drain, in order to avoid accessing piping under the ceramic floor. In order to distribute the load on the second floor, the system control cabinet was installed in the laundry room, and the stacked collection tanks for untreated and treated GW were

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[1] *Patent protection for the device is currently being sought and therefore no further details about the device are presented here.*

Figure 3: Laundry room and bathroom layout in the triplex residence.

installed in the bathroom. Each collection tank had a storage capacity of 100 L and was designed to overflow to the bathtub drain. A commercial water bank unit (WaterLoo, 2018) serving as a reservoir for treated GW was installed on top of the toilet tank underneath the lid. The laundry room, adjacent to the bathroom, had an open storage area (Figure 3) just the right size to install the GW treatment system.

GW from the washing machine and shower/bath was collected in the untreated GW tank. Treated GW was disinfected in the collection tank using an electrochemical approach (without any chemicals). The treated GW was used for toilet flushing. Potable water remained connected to the toilet in case there was a lack of treated GW for flushing. The flow control system of the toilet tank provides an air gap between potable water and GW in the toilet tank as required by various plumbing regulations. Figure 4 presents the various components of the GW treatment and reuse installation. All minor plumbing and electrical modifications were expertly carried out by a local contractor (Jago Services Inc.).

Analysis of greywater treatment

For decentralized GW treatment, NSF/ANSI 350: *Onsite Residential and Commercial Water Reuse* Treatment describes the required criteria for water reuse systems. The standard has now been adopted by international plumbing and building codes and was used to assess the performance of the GW treatment system. The treatment requirements for residential (≤5 678 L/day) and commercial (>5 678 L/day) applications are presented in Table 1.

Samples of triplex potable (tap) water, untreated GW, and treated GW were collected and characterized. Source water from the lake near Cambridge Bay used to create potable water for the Hamlet was also sampled and characterized. The quality of the potable water was of interest because it serves as the base into which detergents, soaps, shampoo, personal care products, oils, and dirt are added by the activities of the triplex residents. This combination creates the GW to be treated. Since local laboratory services for sample analysis were not available, analytical equipment was purchased and shipped to CHARS. The equipment was installed temporarily (Figure 5) in the CHARS FMB since the main research building was not yet officially opened. The analytical equipment was selected based on ease of operation, portability, and usage of environmentally friendly reagents that do not result in hazardous materials after testing. The equipment included:

- a Mantech PeCOD analyzer for measurement of COD;
- a VELP 6 Position System and Incubator for BOD;
- a Hach 2100Q Turbidity Meter for measurement of suspended particles; and

- an Assy SL1000 Parallel Portable Analyzer for measurement of pH, Conductivity, Hardness and Chlorine.

Due to electrical connection issues, the VELP equipment could not be used in the FMB and consequently no BOD measurements were made. Generally, the COD to BOD ratio varies between 2 and 3; a value of 2.5 was used to estimate BOD, based on results previously obtained by the authors during other GW projects.

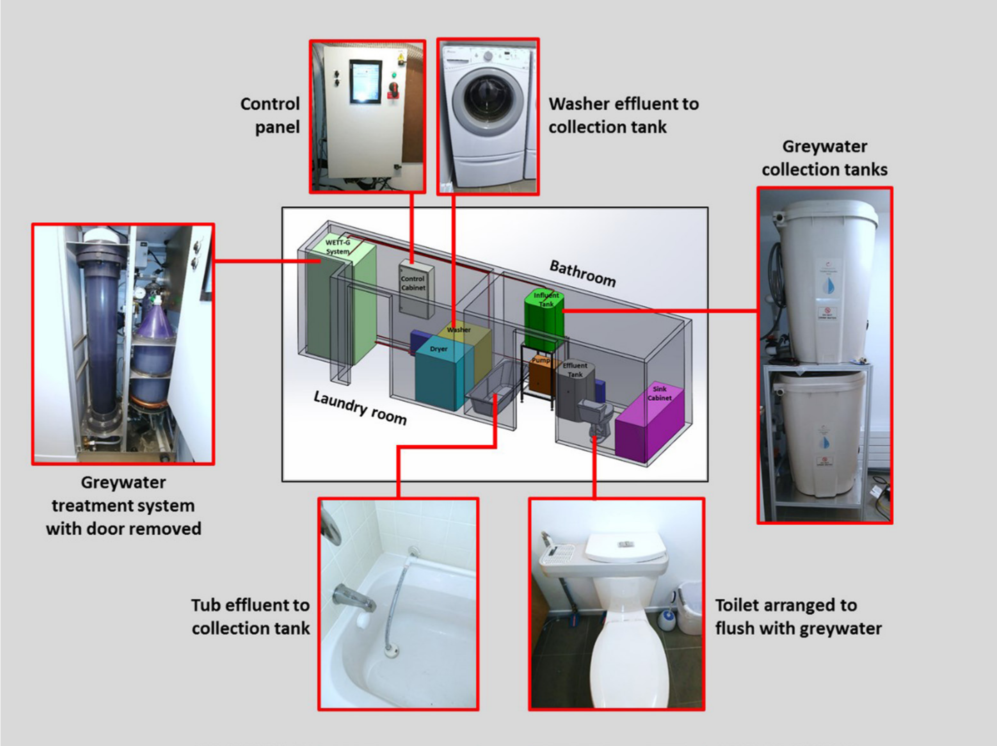

Figure 4: Greywater treatment and reuse system components and their location in the laundry room and bathroom.

Table 1: NSF/ANSI 350 greywater treatment requirements for residential (Class R) and commercial (Class C) reuse.

		Class R		Class C	
Parameter	Units	Overall Test Average	Single sample maximum	Overall Test Average	Single sample maximum
CBOD[5]	(mg/L)	10	25	10	25
TSS	(mg/L)	10	30	10	30
Turbidity	(NTU)	5	10	2	5
E.coli[2]	(MPN/100 mL)	14	240	2.2	200
pH	(SU)	6 - 9	NA[1]	6 - 9	NA
Storage vessel disinfection	(mg/L)[3]	≥0.5 - ≤2.5	NA	≥0.5 - ≤2.5	NA
Color		MR[4]	NA	MR	NA
Odor		Non-offensive	NA	Non-offensive	NA
Oily film and foam		Non-detectable	Non-detectable	Non-detectable	Non-detectable
Energy consumption		MR	NA	MR	NA

[1] NA = Not applicable

[2] Calculated as geometric mean

[3] As chlorine. Other disinfectants can be used.

[4] MR = Measured and reported only

[5] CBOD = Carbonaceous Biochemical Oxygen Demand (mg/L)

Figure 5: Analytical equipment temporarily installed in the CHARS Facilities and Maintenance Building (FMB).

The PeCOD Analyzer was selected due to its unique capabilities and suitability for this project. As compared to conventional COD measurement, PeCOD does not require potassium dichromate and mercury, which cannot be transported on planes and results in the generation of hazardous waste. Unlike the conventional COD measurement, which requires two hours and is primarily for contaminated wastewater, the PeCOD Analyzer requires only 10 minutes per measurement and is suitable for drinking water (or other relatively clean streams, such as treated GW). The PeCOD is also able to measure low levels of Natural Organic Matter (NOM) which is a critical variable in drinking water treatment, especially in northern communities, and offers a 0.7 milligram per litre (mg/L) COD detection limit.

Greywater treatment performance

The results of the assessment show that the GW treatment system met the NSF/ANSI 350 standard for GW reuse presented in Table 1. Figure 6 presents the results obtained during the GW treatment demonstration for various parameters (pH, conductivity, hardness, COD, turbidity, and total chlorine). The results are grouped into four sets of data; each set includes values for untreated and treated GW. Set 1 GW consists of laundry water plus potable water to which detergent and shampoo were added. Sets 2 and 3 GW have an equal number of laundry loads and showers taken. Set 4 GW has twice as many laundry loads as number of showers taken, and it can be seen that this results in the most concentrated GW based on COD. Set 1 and Set 4 also include data for potable water in the triplex residence.

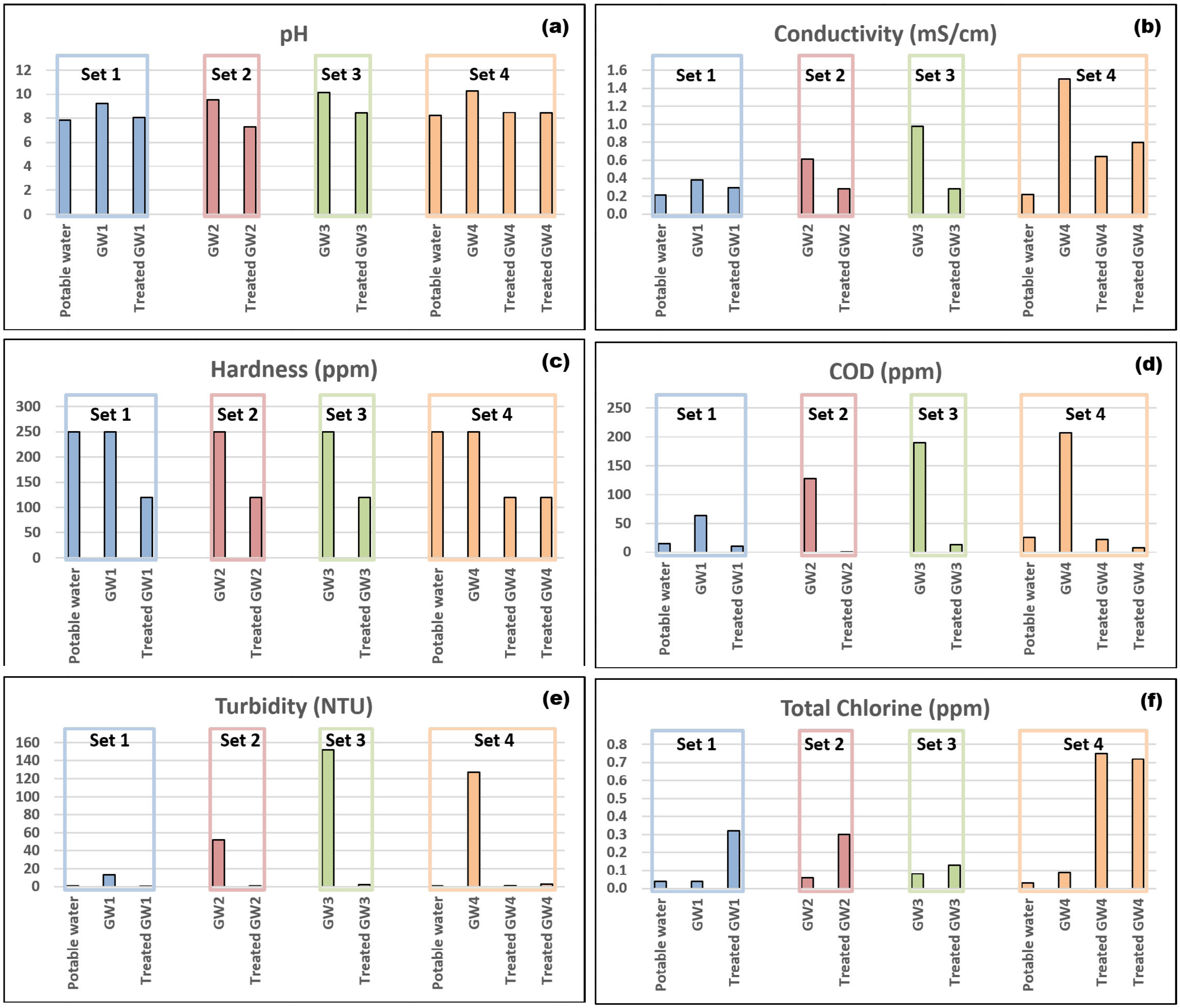

Figure 6: Analytical results for a) pH, b) conductivity, c) hardness, d) COD, e) turbidity, and f) total chlorine.

All water samples had a pH that was slightly basic and a conductivity varying between 0.2 millisiemens per centimeter (m^S/cm) and 1.5 m^S/cm. Untreated GW had the highest pH and conductivity values (Figure 6a and 6b). While the hardness values classify the potable water and the untreated GW as hard water, the GW treatment was effective in significantly lowering the hardness (Figure 6c).

Regarding COD (Figure 6d), non-negligible amounts (up to 25 parts-per-million (ppm)) of oxidizable material were present in the potable water samples collected. This indicates the presence of contaminants that were not removed by the potable water treatment plant (or that were introduced in the potable water distribution system). Surface water used to make the potable water was found to have similar COD values (data not shown). It is assumed that the COD is due primarily to NOM that is not removed during the potable water treatment process. These are fairly high levels of COD for potable water, which ideally should have zero/negligible COD, and indicate that the BOD values (based on the COD to BOD ratio of 2.5) are close to the treatment requirements

Figure 7: Untreated and treated GW samples obtained during the demonstration.

Figure 8: Toilet tank before (top) and after cleaning and flushing with treated greywater (bottom).

in Table 1 even before potable water is used for showering or laundry and becomes untreated GW. The COD values for the untreated GW samples varied between 126 ppm and 207 ppm (depending on the ratio of shower to laundry water, with laundry water having a greater COD contribution). The COD values were reduced to a range from 0.86 ppm to 22 ppm, with an average of 10 ppm after treatment. The treated GW COD values correspond to BOD values ranging from 0.34 ppm to 8.8 ppm, with an average of 4.3 ppm. As far as COD is concerned, the treated GW was as pure as or purer than the potable water available to triplex residents.

The turbidity (Figure 6e) of the potable water was negligible. The turbidity of the untreated GW varied between 13.5 Nephelometric Turbidity Units (NTU) and 152 NTU, and this was reduced to below 2 NTU for all treated GW effluents. The chlorine measurements (Figure 6f) indicated a very slight (<0.05 ppm) chlorine residual in the potable water (although none was detected in samples taken during previous visits) and in the untreated GW samples (between 0.04 ppm and 0.09 ppm). Potable water typically has 1-2 ppm of chlorine residual to prevent contamination. The treated GW had between 0. 3ppm and 0.75 ppm of residual chlorine, which is ideal. A chlorine residual indicates that a sufficient amount of chlorine was available to inactivate bacteria and some viruses that cause disease, and that the water is protected from recontamination during storage. Figure 7 presents a photograph of the untreated and treated GW. The significant improvement in the quality of the water can be noted.

The triplex residence toilet tank was cleaned of all deposits and biofilm, and treated GW was used for toilet flushing. The treated GW had no impact on the toilet tank or flush mechanism; the water in the tank was clear and no deposits were observed (Figure 8). This was as expected since — previous work (Poirier and Pristavita, 2017) showed that a toilet flushed for up to six-months with the disinfected GW produced by the GW treatment system did not develop any biofilm or deposits.

Economics of greywater treatment in northern applications

Since the GW treatment system is electrochemical, the conductivity of the GW has an impact on the power consumption. Using an average value of 1 m^S/cm for the GW conductivity, as measured during the demonstration, the power consumption of the treatment system was 0.5 kilowatt (kW). The average cost of electricity in Canada is $ 0.129/kW per hour (kWh) (Government of Canada National Energy Board, 2017). The Nunavut Government subsidizes electricity for residents of private dwelling units including homeowners, and small businesses with gross revenues less than $ 2 million per year. The subsidized rate is slightly more than $ 0.30/kWh; social housing tenants pay a highly subsidized rate of only $ 0.06/kWh (Nunatsiaq News, 2018).

Based on the results obtained, the GW treatment system produces treated GW at a cost of $ 6.80/ m^3 using a subsidized electricity rate of $ 0.32/kWh. Electricity and consumable electrodes each account for about 40% of the treated GW cost. This cost compares favorably with the Cambridge Bay cost of unsubsidized water (economic rate of $75/m^3) and the cost of subsidized water for commercial customers ($ 23/m^3), and is comparable to the highly subsidized cost of water for non-commercial customers ($ 6/m^3) (Hamlet of Cambridge Bay NU, n.d.). Assuming that approximately 50% of the water consumption in northern residential buildings is due to showers/bathing/laundry, the treatment and reuse of GW would result in a 35% savings in operating costs for water for commercial customers if all of the treated GW could be used for toilet flushing and laundry. Alternatively, a GW treatment system may also result in a decreased environmental impact and other benefits due to reduced volume of wastewater produced. It may allow users to effectively increase their per capita water availability by reserving their allotment of potable water for activities that require it (food preparation, drinking, showering/bathing) and using treated GW for toilet flushing and laundry. These aspects may be of greater importance than monthly water cost savings for northern regions or when water is scarce; it is difficult to put a value on these aspects.

Studies frequently attempt to estimate the payback period for GW treatment systems based on the savings made, even if these are not the only benefits derived. Generally, this type of analysis has shown that for systems offering a high level of treatment and able to meet plumbing and building code standards, payback periods are long (many years) for individual homes, but may be more reasonable for multi-occupancy buildings. This is because the capital cost per m^3 of GW treated decreases significantly with increasing treatment capacity. In northern regions, due to the very high cost of water, payback period is reduced and estimates need to be made on a case by case basis. A much simpler and lower-cost GW reuse approach is being conceptualized for northern single-family homes that have limited space and require a rapid payback. An alternative to the GW treatment system for multi-occupancy buildings, this approach will be described in a subsequent publication.

Community considerations

A detailed survey was prepared to gather information from northern residents regarding their satisfaction with the quality and quantity of potable water available, and their understanding and perspectives on GW treatment and reuse. The survey was conducted on a confidential basis to identify any pain points that exist with regards to water, and to gauge the acceptability of GW treatment and reuse. Only some of the results are presented here. Survey respondents do not constitute a representative subset of the community but rather those who were willing or available to participate. All 20 respondents were from Cambridge Bay; 85% were college or university educated, 80% were female, 75% were Inuit, 50% were aged 18-29 years, 25% were aged 30-49 years, and 25% were aged 50 or more years. As for occupation, 25% were employed, 65% were students and 10% were business owners. Regarding their type of dwelling, 45% lived in multi-occupancy buildings, 40% lived in a single-family home, and 15% lived in an apartment or condo. Truck delivery of potable water occurred 3 or 4 times per week for 65% of the respondents.

In general, respondents felt that the cost of water was acceptable (70%); many (60%) were unaware or not certain that the Nunavut Government subsidizes the cost of water. Regarding GW, 65% knew what this was and 65% would consider reusing GW. Respondents were asked what would most motivate them to reuse GW; the top 2 reasons were to have more potable water, and environmental reasons. However, some respondents were worried that such a practice would not be safe (40%), would require too much space (15%), would be complicated/expensive (25%) or felt uncertain as to how to proceed (15%). The survey indicates that respondents are open to the possibility of using treated GW to derive various benefits.

Conclusions

An electrochemical automated GW treatment system that does not require chemical addition or include maintenance-intensive components was installed in a northern multi-occupancy building (triplex residence at CHARS in Cambridge Bay, Nunavut). It was found that the local potable water had significant values of COD (up to 25 ppm) even before it was converted to GW through use in laundry or bathing activities (although turbidity was negligible). It was assumed that the COD was related to NOM contained in the lake water used to make the potable water, since the lake water had similar values of COD. The GW treatment system was able to produce treated GW that had lower values of COD than the potable water, even though NOM is challenging to remove. The treated GW parameters met the required levels specified in the NSF/ANSI 350 standard, and produced treated GW at a cost that was significantly lower than the Cambridge Bay cost of unsubsidized water and subsidized water for commercial customers. The GW treatment system may be of interest to commercial enterprises such as hotels and inns, multi-occupancy buildings, and the Nunavut Government which contributes large amounts in subsidies so that its customers can have an affordable cost of water. Treating and reusing GW can also lead to reduced discharge of wastewater and increased per capita availability of potable water. A detailed survey carried out with local residents and business owners indicated that respondents were open to the possibility of using treated GW to derive various benefits.

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