UNDERSTANDING AND OPTIMIZING THE PERFORMANCE
OF MUNICIPAL WASTE STABILIZATION PONDS IN THE FAR NORTH

ROB JAMIESON, DALHOUSIE UNIVERSITY

Research conducted 2011-2014

Canadian Water Network

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WHY DID WE DO THIS RESEARCH?

In 2012, Environment Canada introduced national regulations for municipal wastewater treatment systems. The new *Wastewater Systems Effluent Regulations* require that all municipal systems collecting greater than 100 m^3/d of wastewater meet national performance standards, including:

- maximum effluent water quality objectives of 25 mg/L for five-day carbonaceous biochemical oxygen demand ($CBOD_5$)
- 25 mg/L for total suspended solids (TSS)
- 1.25 mg/L for un-ionized ammonia nitrogen (NH_3-N)

Communities in Canada's Far North were granted a grace period during which they are temporarily exempt from the Wastewater Systems Effluent Regulations. This exemption was granted to Nunavut, Northwest Territories, above the 54th parallel in Quebec, and Newfoundland and Labrador, in recognition of the unique challenges associated with wastewater management in Canada's Far North. Typically, passive treatment systems, such as waste stabilization ponds (WSPs), are used in remote, northern communities as they are much easier to operate and maintain. However, until recently, there has been a lack of information on the performance expectations and treatment mechanisms of passive treatment systems in arctic climates. The grace period allowed for research to be conducted on northern systems, in order to inform appropriate standards for treatment and monitoring.

This project (2011-2015) focused on WSPs treating municipal wastewater in artic climates. The primary objectives were to:

- Assess the treatment performance of existing WSPs used in Canada's Far North;
- Determine the influence of environmental, design configuration, and operational factors on treatment performance; and
- Develop recommendations for design improvements for new and existing WSPs operating in the Far North.

The information produced from this research is needed to inform the development of appropriate regulations and design standards that will ensure adequate treatment of wastewater in northern communities.

HOW IS WASTEWATER TYPICALLY MANAGED IN CANADA'S FAR NORTH?

Wastewater management in northern Canada is challenging for many reasons, including extreme cold, permafrost, shortage of skilled operators, short summer seasons (3 months where biological activity occurs) and relatively small population sizes. Many communities are accessible only by sea or air, which renders construction, operation and maintenance of infrastructure costly and difficult. For these reasons, many northern Canadian communities use "passive" treatment technologies that require minimal operational, chemical, and energy inputs.

Figure 1. Overhead photograph of the single cell WSP in Pond Inlet, Nunavut.

Water and wastewater services are usually provided without the use of piped water distribution and sewage collection systems, due to the presence of permafrost. Instead, a truck haulage system is employed, and individual homes are equipped with both a water and wastewater tank. Water deliveries and wastewater pick-ups occur several times per week. Water use in communities serviced by truck haulage systems is approximately three times lower than the Canadian national average and the raw wastewater produced is higher in strength compared to southern Canadian communities.

In the territory of Nunavut, the majority of the 25 communities use passive technologies like WSPs (i.e., sewage lagoons), either exclusively, or in combination with a wetland treatment area. The WSPs are the core component of northern treatment systems, because in many cases they are the sole engineered form of treatment. Only three communities in Nunavut use some form of mechanical treatment, as they have prohibitively high capital and maintenance costs, and intensive requirements for technical supervision and optimization.

WSPs in Nunavut are currently designed as controlled discharge, single-cell retention ponds with storage capacities to accommodate wastewater accumulated over an entire one year period. Wastewater is stored frozen for approximately nine months of the year (October to June), with discharge typically occurring at the end of the three month ice-free period (July to September).

Occasionally, additional WSP cells are incorporated into the design of the treatment systems; these additional cells may be operated in series or parallel. These systems are not equipped with mechanical aeration systems, and rely on algae to introduce oxygen into the system through photosynthetic processes. The design of a WSP to capitalize on the benefits associated with algae growth is well established for more temperate climates, but the applicability of these design guidelines for arctic WSPs has never been assessed.

HOW ARE THESE SYSTEMS PERFORMING?

Field work was conducted on several WSP systems in Nunavut from 2011 to 2014 — Pond Inlet, Clyde River, Kugaaruk, and Grise Fiord. The study sites were chosen to represent a wide geographic range and a diversity of design and operational characteristics. Monitoring focused on characterizing the physical, chemical and biological treatment processes occurring in the WSPs from spring thaw (late June to early July) to the fall decant (late August to early September).

In-situ probes were installed at the start of the summer treatment season. The probes continuously measured and recorded temperature, pH, specific conductivity and dissolved oxygen (DO). These parameters provided an indication of the biogeochemical environment of the WSPs. The oxygen status of the systems (i.e., anaerobic vs facultative vs aerobic) was classified, as this has a large influence on treatment rates.

Each system was sampled at the start and end of the treatment season. Raw wastewater samples were collected directly from the trucks discharging into the WSPs, and from multiple locations within the WSPs. After collection, the samples were transported in chilled coolers by aircraft to analytical laboratories in Iqaluit or Yellowknife. Due to the remote geographic location of Grise Fiord, a temporary on-site laboratory space was established to analyze samples. The samples were analyzed for $CBOD_5$, TSS, *Escherichia coli (E. coli)*, total ammonia nitrogen (TAN), NH_3-N, and total phosphorus (TP). Additional samples were collected for identification and enumeration of algae species in the WSPs, and for detection of several pathogenic bacteria.

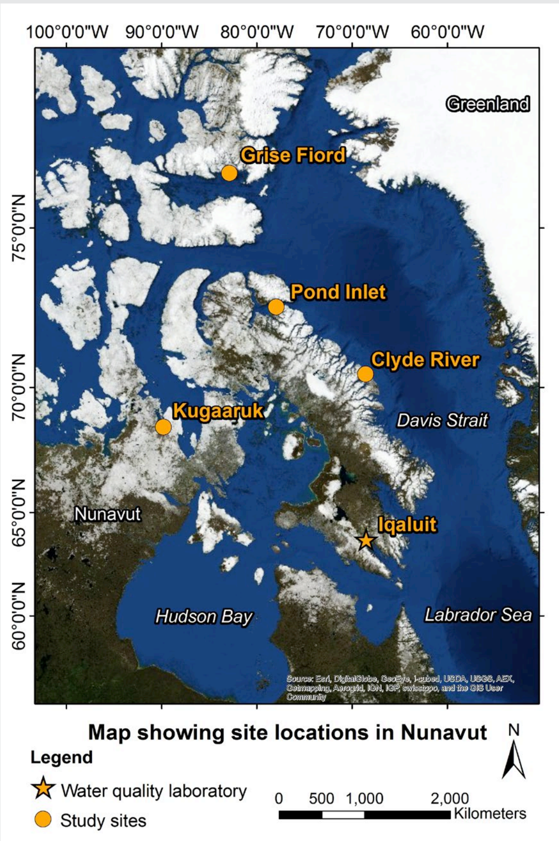

Figure 2. Study sites in Nunavut

Our research indicated that single-cell WSPs effectively remove TSS, but experience difficulties reducing $CBOD_5$, bacteria and nutrient concentrations to levels consistent with the performance standards for secondary wastewater treatment as specified in the WSER . Treatment performance was affected by many factors, including organic loading rates, raw wastewater quality, algae populations, water depth, climate, and maintenance and operation.

In most cases, the WSPs were anaerobic, even if they were designed to produce a facultative environment. The absence of large algae populations, and therefore oxygen, indicated that the design standards for WSPs adopted from southern regions are not appropriate for northern systems. In these extreme climatic conditions, biological treatment processes are constrained to relatively short time periods (approximately 60 days), where average air temperatures are less than 10ºC. This results in slow growth rates of algae and bacteria. Based on the treatment rate constants that we observed, wastewater would have to be held and treated for three summer treatment seasons in order to meet the WSER performance standards for $CBOD_5$.

The operating water depth was an important factor in the treatment performance. The shallow ponds promoted biological activity, albeit at a slow rate, which resulted in improved $CBOD_5$ removal, whereas the deep ponds promoted settling of solids, and lower TSS concentrations. With respect to nutrients, the removal of nitrogen was poor to moderate, with some level of treatment occurring only in the shallow ponds. Un-ionized ammonia concentrations were generally below 1.25 mg/L NH_3-N due to the near-neutral pH.

PARAMETER	SHALLOW (< 2.5 M)	DEEP (> 2.5 M)
$CBOD_5$ (mg/L)	80 – 120	120 – 160
TSS (mg/L)	50 – 100	25 – 50
TAN (% removal)	10 – 25	0
NH_3-N (mg/L)	< 1.25	< 1.25

Table 1. Summary of expected effluent quality from WSPs currently used in Nunavut.

Figure 3. Photograph showing collection of samples from the WSP in Pond Inlet, Nunavut

Phosphorus removal efficiencies were highly variable, ranging from 24% to 76%, with the highest removal occurring in a system that had algae growth present (Grise Fiord). Sludge samples were collected from several of the WSPs, and analyzed for various phosphorus forms in an attempt to identify specific mechanisms of phosphorus treatment. This analysis confirmed that biological mechanisms (i.e., assimilation by algae) were largely responsible for the phosphorus removal in these systems.

With respect to the removal of enteric microorganisms, current WSP designs generally achieve 1- 2 log removal efficiencies of indicator organisms (*E .coli*). Several pathogenic bacteria species (*campylobacter, salmonella*) were still present in effluent at the end of the summer treatment season in the systems studied.

HOW CAN TREATMENT BE IMPROVED?

ENHANCED ALGAE GROWTH

A series of experiments were conducted involving bench scale WSP models operating under closely controlled climate (temperature and light) and organic loading conditions. Synthetic wastewater was manufactured in the lab to closely mimic the wastewater of northern WSPs. The model WSPs were housed in a climate-controlled cold room and subjected to banks of LED lights to mimic arctic irradiance.

Bacteria and algae recovered from arctic WSPs were added to the columns to provide biological seed populations. A factorial analysis was used to assess how temperature, irradiance, initial carbon concentration and daily organic loading rate affected algae populations, dissolved oxygen levels and $CBOD_5$ removal. The experiments demonstrated that algae growth are the critical link to improving treatment with arctic WSPs.

Model WSPs that possessed high initial organic carbon concentrations at the start of the treatment season and high daily organic loading rates (typical of current WSPs) had little algae growth, anaerobic conditions and poor $CBOD_5$ removal. When the initial organic carbon concentrations and organic loading rates were lowered, algae populations flourished, the systems were aerobic, and $CBOD_5$ concentrations approached 25 mg/L within a 40-day treatment window. As expected, temperature strongly affected biological processes, with less treatment at lower temperatures (5ºC). Therefore, the design of new systems should be resilient enough to provide treatment in all climatic conditions.

Figure 4. Photograph of the WSP in Grise Fiord, Nunavut, the northernmost community in Canada.

FIXED FILM BIOLOGICAL TREATMENT

It is well known that fixed film biological treatment systems are more efficient for wastewater treatment due to enhanced contact between microorganisms and wastewater constituents. One simple approach for incorporating this type of treatment mechanism into a northern WSP design is to place a geotextile filter within, or on the surface of a permeable berm of the WSP. After the spring thaw, effluent in the WSP would exfiltrate through the geotextile and berm at a controlled rate. The effluent would be treated by physical and biological processes as it flowed through the geotextile, and there would be no need for mechanical pumping systems to decant the WSP.

The major question about this approach is whether an adequate biofilm can form on the geotextile within the temperature and time constraints of an arctic summer. A series of test cells were constructed to mimic a granular berm lined with a geotextile and housed in a climate controlled cold room to simulate temperature conditions experienced in the arctic. Primary treated municipal wastewater was then applied to the columns at controlled rates. The effluent water quality and the hydraulic conductivity of the geotextile were measured at regular intervals.

Results indicated that it is possible to form a biomat on the geotextile during a 3-month period at temperatures typically seen in arctic communities (2 – 10ºC). The formation of a biomat provides the benefits of fixed-film biological treatment on the surface of the geotextile and filtration of the exfiltrating wastewater. Significant differences in water quality improvements for TSS and BOD_5 were observed with the use of the geotextiles, compared to the control columns (no geotextiles). This study shows promising results for improving WSP design by incorporating alternative passive treatment technologies.

WHAT DO THESE FINDINGS MEAN FOR WASTEWATER MANAGEMENT IN THE FAR NORTH?

Current WSP systems used for municipal wastewater management in the Far North can provide reliable primary treatment. Biological treatment processes are occurring within some of these systems, but at very slow rates.

Design approaches for northern WSPs will need to be refined in order to facilitate increased levels of biological treatment that meet secondary treatment standards specified in the WSER. Current designs are not able to consistently facilitate algae growth, which means these systems possess negligible concentrations of dissolved oxygen.

Elevated levels of $CBOD_5$ present in current WSPs at the onset of the summer treatment season limit algae growth, resulting in anaerobic conditions and reduced $CBOD_5$ treatment rates.

- To address this issue, future WSP systems should be designed as multi-cell systems. The first cell should be a deep (< 4 m) anaerobic pond, sized to accommodate wastewater generated during the dormant season, from October to June. Effluent from this cell could then be decanted into shallow (< 1.5 m) facultative cells during the summer treatment season.
- Geotextiles should also be installed on specifically designed exfiltrating berms in facultative cells, to provide for solids removal and additional biological treatment prior to discharge.

This project demonstrated that adequately sized and designed WSPs can potentially meet secondary treatment standards for $CBOD_5$ as specified by the national performance standards in the WSER (<25 mg/L), even under adverse arctic conditions, when temperatures are as low as 5ºC during the summer treatment period. Pilot scale studies should be designed and implemented in arctic communities to test these recommended design improvements.

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