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Performance of municipal waste stabilization ponds in the Canadian Arctic

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ABSTRACT

The majority of small remote communities in the Canadian arctic territory of Nunavut utilize waste stabilization ponds (WSPs) for municipal wastewater treatment because of their relatively low capital and operational costs, and minimal complexity. New national effluent quality regulations have been implemented in Canada, but not yet applied to Canada's Arctic due to uncertainty related to the performance of current wastewater treatment systems. Waste stabilization pond (WSP) treatment performance is impacted by community water use, pond design, and climate. The greatest challenge arctic communities experience when using passive wastewater treatment technologies is the constraints imposed by the extreme climate, which is characterized as having long cold winters with short cool summers that can be solar intense. The removal of carbonaceous biochemical oxygen demand ($CBOD_5$), total suspended solids (TSS), and ammonia–nitrogen were measured during the summer treatment period (late June until early September) from 2011 to 2014 in the WSP systems of four Nunavut communities; Pond Inlet, Clyde River, Grise Fiord and Kugaaruk. Monitoring results showed that WSPs in their current single cell design can achieve greater than 80% removal of $CBOD_5$ and TSS but were challenged to produce effluent quality that meets secondary wastewater treatment standards (<25 mg/l $CBOD_5$ and TSS). This study points to the need for revisions of design guidelines for facultative WSPs in the Arctic, as current systems are anaerobic and do not contain sufficient dissolved oxygen required to consistently support aerobic biological treatment processes.

1. Introduction

Nunavut is an arctic territory consisting of all the land mass of northeastern Canada above 60°N and the regional islands. Nunavut has a small but widely distributed population with 32,000 inhabitants spread across 25 communities and over 2 million square kilometers; communities are extremely remote with no connecting roads making transportation of goods and labor expensive (Government of Canada, 2005). The population of hamlets in Nunavut ranges from 130 to 2800 with median and average populations of 1000 and 1200 people, respectively (Government of Nunavut, 2014). The arctic climate is characterized by long cold winters and short solar intense summers. Lakes and ponds remain frozen until late June or early July and begin to freeze in mid-September. All of Nunavut experiences continuous permafrost. Communities in Nunavut have average air temperatures below zero for all months except for the summer (June, July, August and, depending on location, September) when temperatures rise into the single digits (Environment Canada, 2014).

Simple infrastructure solutions tend to be preferred in the Canadian Arctic due to the environmental, financial and logistical constraints. In 21 of 25 hamlets in Nunavut the entire community is on trucked water and wastewater service, with residences and buildings receiving drinking water and sewage pick-ups every 2–3 days depending on the service schedule and water use (Nunavut Water Board, 2014). It should be noted that raw sewage tends to be more concentrated in communities on trucked water systems as the decreased accessibility to water significantly lowers water use (90 l/person/day) when compared to the Canadian national average of 274 l/person/day (Smith, 1986).

Wastewater treatment systems in the territory are required to meet territorial effluent quality criteria of 180 mg/l, total suspended solids (TSS) and 120 mg/l biochemical oxygen demand (BOD_5) (Nunavut Water Board, 2014). New national standards for municipal wastewater systems have recently been implemented for southern regions of Canada, with all municipal systems

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producing greater than 100 m^3/d having to meet effluent quality criteria of 25 mg/l TSS, 25 mg/l carbonaceous BOD_5, and 1.25 mg/l un-ionized ammonia (Government of Canada, 2012). These regulations have yet to be applied to northern Canada due to the limited knowledge of the performance of existing systems.

Currently, wastewater systems in northern Canada are designed according to specifications outlined in the *Cold Climate Utilities Manual* (Smith, 1986) with additional guidelines for sizing and constructing WSPs in the Arctic (Heinke et al., 1991). In most Nunavut communities, one year detention WSPs have been designed as controlled discharge storage ponds, sized to hold 365 days of wastewater generation, as discharge during the winter is challenging and effluent quality is expected to be poor due to limited biological activity. These systems were mostly designed to act as facultative pond systems, with operating water depths between 1.5 and 2.5 m. However, some WSPs are deeper (3–6 m), as the system design may have been constrained by topography and geology. The effluent from arctic WSPs is typically discharged in late summer or early fall just prior to freeze-up, allowing for approximately 60 days of wastewater treatment during the ice-free summer season. The available OLR recommendation for facultative WSPs operating in cold climates is 11–22 kg BOD_5/ha/d (USEPA, 1983) in order to promote aerobic treatment environments. Aerobic biological processes are generally desirable in municipal wastewater treatment because they produce a better effluent quality, are less temperature sensitive, and have a shorter start-up time in comparison to anaerobic processes (Chan et al., 2009).

The effectiveness of WSPs for the treatment of municipal wastewater has been demonstrated in temperate climates (Finney and Middlebrooks, 1980; Shilton, 2005; Barjenbruch and Erler, 2005) and there are a number of guidance manuals for their design and operation (e.g., USEPA, 1983). The use of WSP technology for wastewater treatment in arctic regions, however, is poorly understood, and it is unclear if design practices used in southern jurisdictions are applicable. The climate of arctic regions likely poses the greatest constraint on treatment performance, but the influent wastewater quality, and operational regime (e.g., single cell treatment, controlled annual decant) will also influence effluent quality.

There is a paucity of published research concerning the performance of one year detention, single cell WSPs in the Arctic. There is also limited understanding of how these systems function during the summer treatment season with respect to the level of oxygenation and treatment kinetics. The overall goal of this study was to assess the performance of four municipal WSPs in the Canadian Arctic. Specific objectives of the research were to: (i) characterize the biogeochemical (e.g., pH, dissolved oxygen, temperature), environmental (e.g., degree days above 0 °C, pond dimensions) and operational (e.g., daily loading rates) factors of arctic WSP systems and the potential for aerobic treatment, and (ii) determine the treatment performance and range of effluent quality from a one year detention arctic WSP. This paper focuses on the removal of $CBOD_5$, TSS, and ammonia-nitrogen, as these are the parameters that will be regulated under the Canadian municipal wastewater regulations (Government of Canada, 2012).

2. Methods

2.1. Study sites

All four communities in this study have trucked drinking water and wastewater systems, and represent a broad geographical distribution of communities as shown in Fig. 1. The studied systems are also representative of WSP designs across Nunavut. Table 1 provides an overview of the location, population and

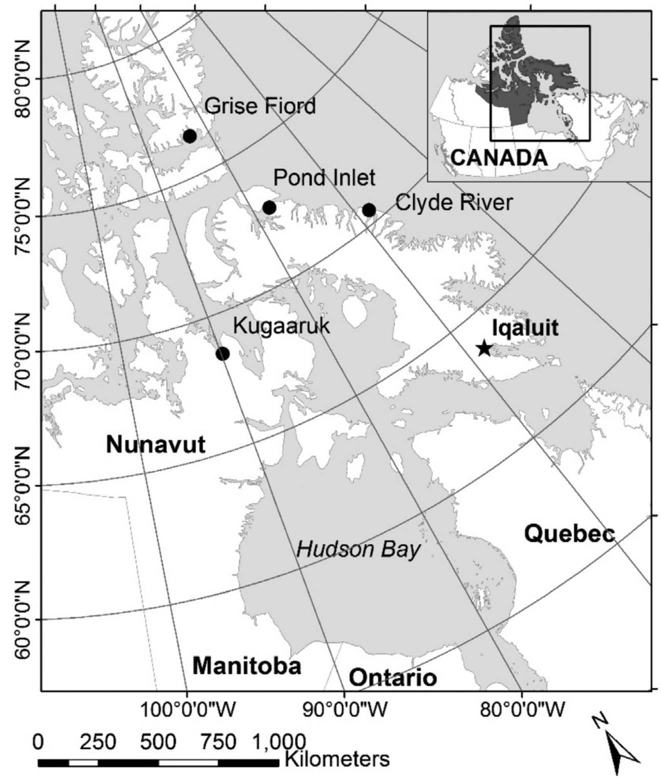

Fig. 1. Map of geographical locations of study communities.

climate (degree days) for each of the study communities while Table 2 provides general information on WSP design and operation conditions at each site. Degree days above 0 and 5 °C (as annual averages [1981–2010] for the ambient air temperature) are provided in Table 1 as they aid in describing the arctic climate's imposed limitations for biological treatment as it pertains to temperature and climatic variability across the arctic region. Included in Table 2 is organic loading rates (OLRs) of the systems, as determined by the influent organic carbon content per a unit area per a time ($CBOD_5$/ha/d). The operation of each WSP is briefly discussed in the following section.

2.1.1. Pond Inlet

Pond Inlet's WSP is a single cell system constructed in 2005. The WSP was designed to be a facultative pond with an average depth of 1.9 m during the summer, but there are areas of the pond that are deeper (e.g., near the middle a depth of 3.2 m was measured). The surface area during the summer is approximately 4 ha and the estimated volume of the pond is 80,000 m^3. The WSP is decanted annually between early September and early October over a period of 3 weeks. Wastewater is pumped over the berm of the WSP and then flows in a channel (500 m) before ending in the marine environment (eclipse sound).

In the fall of 2010 the WSP was emptied for an inspection of the HDPE liner and was offline until the spring of 2011. Wastewater was sent to an alternative disposal site from the fall 2010 to late spring 2011 at which time the WSP began to receive wastewater again.

2.1.2. Kugaaruk

Kugaaruk has a single cell WSP, with an additional small decant cell located between the main cell and a tundra treatment wetland. Kugaaruk's WSP is a deeper system with an operating depth of 5.4 m. From mid to late summer, wastewater effluent is pumped from the main cell into the decant cell. The water from the decant