Proposed Revisions to Regulatory Criteria for Risk Assessment of Municipal Wastewater Treatment Systems in Nunavut

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List of Abbreviations

%	Percent
◦C	Degrees Celsius
$CBOD_5$	Five-Day Carbonaceous Biochemical Oxygen Demand
$CBOD_A$	Average Carbonaceous Biochemical Oxygen Demand
CCME	Canadian Council of Ministers of the Environment
CGS	Community and Government Services
CWRS	Centre for Water Resources Studies
d	Day
e.g.	*Exempli gratia*
EC	Environment Canada
et al.	*Et alii*
etc.	*Et cetera*
GN	Government of Nunavut
i.e.	*Id est*
L	Litre
Ltd.	Limited
m	Metre
m^3	Cubic Metre
mg	Milligram
MWWE	Municipal Wastewater Effluent
n	Sample Size
NH_3-N	Un-ionized Ammonia Nitrogen
NPS	National Performance Standards
NS	Nova Scotia

NU	Nunavut
Pop.	Population
s	Second
SS_A	Average Suspended Solids
TRC	Total Residual Chlorine
TSS	Total Suspended Solids
WSER	Wastewater Systems Effluent Regulations
WSP	Wastewater Stabilization Pond
WTA	Wetland Treatment Area
WTAC	Wastewater Treatment Advisory Committee
WWTP	Wastewater Treatment Plant

Executive Summary

This report presents a proposed approach for conducting semi-quantitative risk assessments of municipal wastewater treatment facilities in Nunavut. First, the environmental risk assessment approach that is currently contained within Environment Canada's Wastewater Systems Effluent Regulations (WSER) was reviewed in the context of its applicability to Nunavut. Based on research conducted by Dalhousie University, and other researchers, over the past 8 years, the risk factor categories and weighting schemes were then adjusted to better represent Nunavut wastewater systems.

Based on this analysis, the WSER risk factor related to total residual chlorine levels was removed, while the risk criteria related to facility size and un-ionized ammonia concentrations were retained without alteration. Several risk criteria were retained but altered; these included the separation of environmental and human health risk criteria into two categories, and the revision of the receiving environment characteristics criteria. Another major revision included the replacement of the CBOD5/TSS effluent concentration criteria with a risk weighting scheme based on the type of treatment system. New criteria were also added to the assessment framework to specifically account for the potential for humans to interact with effluent once it is discharged to terrestrial and aquatic environments. This included new criteria related to timing and frequency of discharges, uses of land and water systems surrounding the effluent release locations, and the level of community education and consultation regarding the wastewater management system.

The risk assessment process generates a numerical risk score with a maximum value of 200, which represent the highest level of risk. Proposed timelines for system upgrades based on risk score were also developed and are presented in the table below.

Risk level	Risk characterization	Timeline for upgrades
< 50	Low	30 years
50 – 100	Low to medium	20 years
100 – 150	Medium to high	15 years
150 – 200	High	10 years

Preface

In 2012, National Performance Standards (NPS) were introduced by Environment Canada (EC) to harmonize the nation-wide treatment requirements for municipal wastewater (Government of Canada, 2012, CCME 2009). The EC Wastewater Systems Effluent Regulations (WSER) stipulate that all wastewater treatment facilities with effluent capacities of 100 m^3/d or greater must comply with discharge quality objectives of 25 mg/L for $CBOD_5$ and TSS, and 1.25 mg/L for NH_3-N. In. The resulting research is meant to inform the development of regulations specifically for the Northern provinces and territories.

This document has been written by the Centre for Water Resources Studies (CWRS) at Dalhousie University. The Community and Government Services (CGS) department of the Government of Nunavut (GN) awarded funding to CWRS to conduct site-specific research programs at the sites described within this document. The site-specific studies took place during the summer treatment seasons from 2011 to 2016.

1.0 Introduction

1.1 Purpose

The method described in the WSER for risk assessment and timelines for upgrades of systems is not currently applicable to systems located in the Far North. This report will assess the applicability of the existing method for risk assessment of the systems in the Far North. Proposed revisions to the existing risk assessment methodology are founded on research findings that have been produced from the northern wastewater treatment research program conducted by the Centre for Water Resources Studies (CWRS) at Dalhousie University from 2011 to 2016 and funded by the Community and Government Services (CGS) department of the Government of Nunavut (GN). In particular, the proposed changes specifically address the unique differences associated with wastewater treatment in northern Canada in comparison to southern Canada.

1.2 Regulatory framework

In 2009, the Canadian Council of Ministers of the Environment (CCME) introduced the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* (CCME, 2009). The Strategy was subsequently adopted by Environment Canada in the form of the Wastewater Systems Effluent Regulations (WSER) that require minimum treatment requirements in the form of National Performance Standards (NPS) for all facilities producing greater than 100 m^3/d of effluent (Government of Canada, 2012). In recognition of the unique challenges associated with wastewater treatment in Canada's Northern provinces and territories, a grace period was granted to the Northwest Territories, Nunavut, and above the 54^{th} parallel in Quebec and Newfoundland and Labrador, to facilitate research on northern treatment facilities. Therefore the WSER does not currently apply to systems in the Far North. Interim requirements for facilities in the Far North are to continue to apply existing territorial and provincial effluent quality, compliance, monitoring and reporting requirements (CCME, 2009).

1.3 Dalhousie University Northern wastewater research program

The CWRS at Dalhousie University conducted a research program on wastewater treatment infrastructure in Nunavut, Canada from 2011 to 2016. The research program was a collaborative effort with, and funded by, the CGS department of the GN. Prior to the commencement of this research program, there was limited knowledge in the literature in regards to the treatment performance of wastewater treatment facilities in Canada's Far North. Inherent risks with wastewater treatment in Northern Canadian communities was not quantified. This research was conducted with the primary objectives to gain information on the current performance, and the environmental and human health risks associated with these systems, as well as identification of design improvements. Ultimately, this research is meant to inform the development of appropriate wastewater treatment standards for the North (Hayward et al., 2014).

There were multiple components of the research program that consisted of the following focus areas:

- Treatment performance assessment of wastewater stabilization ponds and tundra wetland treatment areas.
- Formulation of best practices for northern wastewater treatment design and operation.
- Human health risk assessment associated with the wastewater treatment systems.
- Environmental risk assessment of the receiving water environments downstream of wastewater discharges.

Site-specific studies on various components of the research program were conducted in the communities of Kugaaruk, Coral Harbour, Pond Inlet, Pangnirtung, Clyde River, and Grise Fiord (Figure 1).

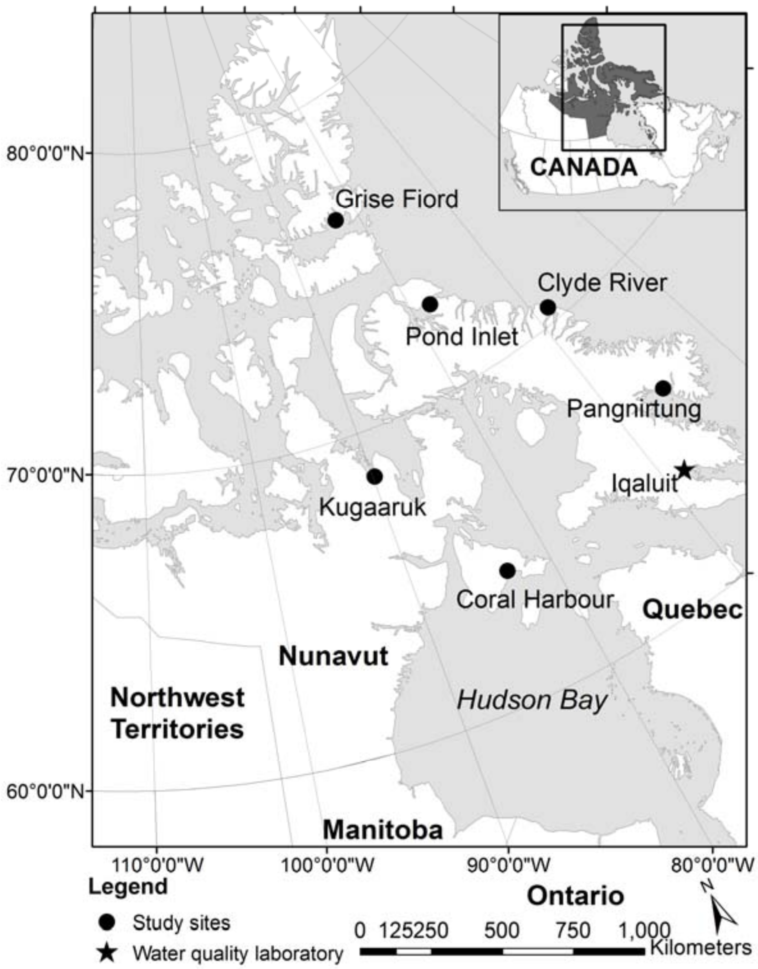

FIGURE 1. SITE LOCATOR MAP FOR THE DALHOUSIE NORTHERN WASTEWATER RESEARCH PROGRAM IN NUNAVUT.

Fieldwork was conducted exclusively in the summer months from June to September. Qualitative studies were conducted which involved community consultations throughout the year. The study sites were selected to include different geographic localities to ensure that the climatic variability across Nunavut was well represented. Other justifications for the site selection included the assessment of a range of types of facilities.

1.4 Wastewater treatment in Nunavut

Conventional wastewater treatment plants (WWTPs) have repeatedly been cited as an inappropriate option for many remote and relatively small communities. The prohibitively high capital and maintenance costs, and intensive requirement for technical supervision and optimization, renders mechanical treatment plants a less favorable choice for most communities in Nunavut when the land space is available (Yates et al., 2012; Krkosek et al., 2012; Hayward et al., 2014; Chouinard et al., 2014).

As a result, passive methods of municipal wastewater treatment tend to be the most successful in Nunavut due to the minimal operation and maintenance requirements. In most communities, passive treatment of wastewater in Nunavut occurs during a three to four month period spanning from the spring freshet in June to the freeze-up in September. This period is termed the treatment season.

There are a variety of types of wastewater treatment systems in Nunavut as per Figure 2. A combination approach consisting of a wastewater stabilization pond, or an un-engineered lake lagoon, followed by a tundra wetland treatment area, is the most common configuration. There are also a few hamlets that directly discharge untreated effluent into WTAs, natural ponds, and marine receiving environments. The WSPs either have a scheduled decant or passively discharge effluent into the receiving environment during the treatment season. There are only three hamlets that use mechanical WWTPs in Nunavut (Johnson et al., 2014).

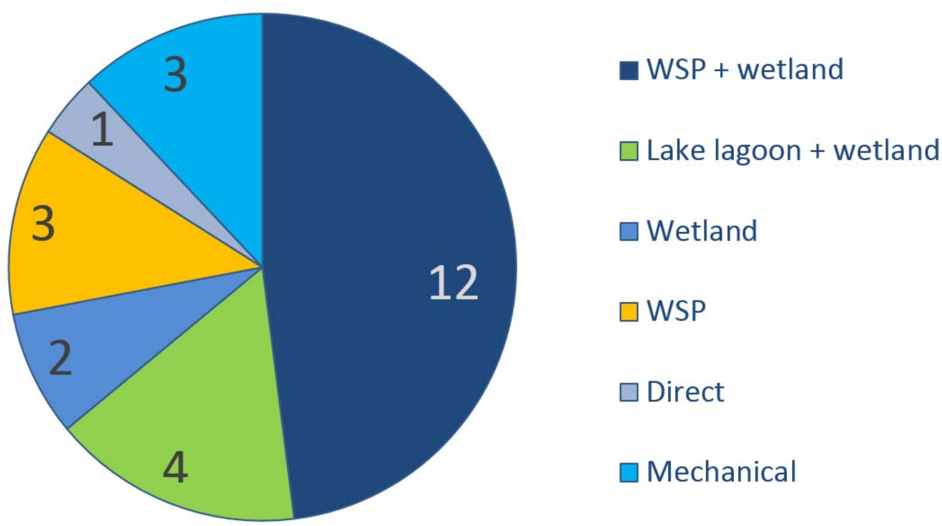

FIGURE 2. TYPES OF WASTEWATER TREATMENT SYSTEMS IN NUNAVUT.

1.5 Receiving water characteristics

Due to the variety of wastewater treatment facilities, and the influence of the local geography and climatic conditions, the MWWE discharges vary in water quality, magnitude, and timing. As well, the characteristics of the receiving environment vary from site to site (i.e., marine, freshwater, tidal, currents, wind, WTA buffer, etc.). These differences between sites directly relate to the water quality impacts associated with the MWWE discharges.

The majority of communities in Nunavut are small in size with populations ranging from 130 to 2800, with median and average populations of 1000 and 1200 people, respectively (Government of Nunavut, 2014). Water uses in Nunavut's communities range from approximately 13 – 225 m^3/d, in line with reported estimates related to wastewater production for trucked water delivery and wastewater collection (i.e., 90 L/person/day; Heinke, 1991). The only exception is Iqaluit, where as a result of higher population of 6700 people, approximately 1500 m^3/d of wastewater is produced. Water consumption values are on average three times less than the national average (e.g., 110 L/capita/day in Nunavut vs. 329 L/capita/day overall in Canada). Thus, these communities are on the low end of MWWE producers in the country (Heinke, 1991; Daley, 2014a).

Some of the communities manually pump effluent into receiving environments (e.g., decant), at scheduled times near the end of the treatment season, or on an as-need basis (i.e., a few days to weeks intervals). Whereas, the three communities that use mechanical treatment plants have near-continuous discharge throughout the year. A few communities have systems that continuously exfiltrate effluent during the treatment season only. Many of the communities (i.e., > 16) obtain a primary level of effluent treatment. Therefore, the majority of the receiving environments downstream of wastewater facilities in Nunavut are subject to very small and intermittent (CCME, 2009) MWWE discharges of primary treated wastewater (e.g., <100 to <500 m^3/d).

1.6 WSER risk criteria

According to the WSER, there are timelines for upgrades to facilities based on their respective assessed level of risks (Government of Canada, 2012). Timelines for upgrades are based on the level of risk associated with the wastewater treatment facilities. Five criteria are used to assess the risk associated with each wastewater treatment system consisting of: facility size (i.e., flow); $CBOD_5$/TSS average concentrations; total residual chlorine; un-ionized ammonia nitrogen; and type of receiving environment. Numeric values are assigned based on the amount of risk associated with each criteria. The level of risk corresponds with the numeric point value assigned (i.e., low points equate to lower risks and high points equate to higher risks). Table 1 lists the types of risk classifications with the criterions for the WSER that are applicable to southern wastewater treatment facilities.

TABLE 1. RISK CRITERIA FROM THE WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Criteria	Description		Points
Facility size (flow)	Average daily volume of effluent, expressed in m^3, deposited during the period of 12 consecutive months.	>100 and ≤ 500	5
		>500 and ≤ 2 500	10
		>2 500 and ≤ 17 500	15
		>17 500 and ≤ 50 000	25
		>50 000	35
CBOD5/TSS (average)	The average carbonaceous biochemical oxygen demand ($CBOD_A$) due to the quantity of CBOD matter in the effluent and the average concentration of suspended solids (SS_A) in the effluent, both expressed in mg/L, during the period of 12 consecutive months.	$(CBOD_A + SS_A)/5$	Points as per formula in column 2
Total residual chlorine (TRC)		Average concentration of total residual chlorine in the effluent deposited via the final discharge point is > 0.02 mg/L	10
		Effluent is not dechlorinated before it is deposited	10
Un-ionized ammonia nitrogen (NH_3-N)	The maximum concentration of un-ionized ammonia, expressed in mg/L as nitrogen (N), in the effluent deposited during the period of 12 consecutive months	≥ 1.25 at 15°C ± 1°C	20

TABLE 1. (CONT'D) RISK CRITERIA FROM THE WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Criteria	Description		Points
Type of receiving environment or affected use	Water where effluent is deposited via the final discharge point (highest value that applies)	Open marine waters	5
		Marine port waters	10
		Lake, natural wetland, reservoir, estuary, enclosed bay	20
		Watercourse with bulk flow ratio > 100	15
		Watercourse with bulk flow ratio ≥ 10 and ≤ 100	20
		Watercourse with bulk flow ratio <10	25
		Shellfish harvesting area within 500 m of the point of entry where effluent is deposited in the water via the final discharge point	20

The risk associated with each facility is assessed by determining the representative number of points for each risk criteria. All of the points from each risk criteria are summed to determine a total risk number for each facility. Table 2 outlines the timelines for system upgrades based on summed risk from each risk criteria.

TABLE 2. RISK LEVEL AND TIMELINES FOR SYSTEM UPGRADES UNDER WSER (GOVERNMENT OF CANADA, 2012).

Risk level	Points	Timeline for upgrades
Low	<50	25 years
Medium	>50 and < 70	15 years
High	>70	5 years

1.7 Previous assessments

In 2011, an assessment of the WSER risk classification methodology in the context of Northern Canada was conducted by Hutchinson Environmental Sciences Ltd. for the CCME (Hutchinson Environmental Sciences Ltd., 2011). Proposed modifications to the risk criteria recommended in their assessment included revisions to the (i) types of receiving environments; (ii) the addition of types of human uses of the land surrounding the discharge points, and (iii) the consideration for the socioeconomic capacity of the regions (Hutchinson Environmental Services Ltd., 2011). Table 3 summarizes the changes to the risk classification proposed by Hutchinson Environmental Services Ltd.

TABLE 3. PROPOSED CHANGES TO THE WSER RISK CRITERIA BY HUTCHINSON ENVIRONMENTAL SERVICES LTD. (2011).

Risk category	Criteria	Points
Receiving environment type	Open marine	5
	Large lake	10
	Enclosed bay, marine estuary	10
	Large river (MacKenzie or Slave)	10
	Small river, stream or lake	15
	Wetland, fish habitat	15
	Wetland, no fish habitat	10
Human use	Discharge to accessible wetland or vegetated area, no warning signage	15
	Discharge to accessible wetland or vegetated area, warning signage	5
	Discharge to within 100 m of beach or wharf, no warning signage	15
	Discharge to within 100 m of a beach or wharf, warning signage	5
	Drinking water source within 500 m on lake or downstream on river	25
	Shellfish harvesting within 500 m	20
Socioeconomic capacity	Nordicity index classification of "mid north"	10
	Nordicity index classification of "far north"	15
	Nordicity index classification of "extreme north"	20

Table 3 (Hutchinson Environmental Services Ltd., 2011) proposed changes in relation to the receiving environment type. These changes were to separate the risks posed to human and environmental health. This would place the shellfish harvesting activity under a new risk category titled "human use." The use of bulk flow to infer assimilation capacity of watercourses was removed and replaced with the two river types (small and large) and two wetland types (fish bearing and non-fish bearing). A new risk category to describe the human use of the receiving environment was proposed to account for receiving environments where there may be a greater risk of human contact with the effluent. In addition, another new risk category was proposed which addressed the socio-economic capacity of the region where the wastewater treatment system was located based on the Nordicity Index. The Nordicity Index was conceived by Hamelin (1975), and it assigns three major regions for northern Canada, consisting of the: middle, far and extreme north. Various factors were taken into account to formulate the Nordicity Index which include climate, ice cover, vegetation, transportation, population and economic activity.

This report proposes a similar review of the applicability of the WSER for systems operating in the Far North. However, the review provided herein has been formulated based on the research findings produced from the Dalhousie northern wastewater treatment research program conducted between 2011 and 2016 in Nunavut. Based on the research findings, some of the recommendations herein are similar to those proposed in Hutchinson Environmental Services Ltd. (2011); however, some differ significantly.

2.0 Proposed revisions

2.1 Criteria to retain or discard

This section of the report addresses each risk criteria from the WSER (Government of Canada, 2012) with respect to the unique context of Nunavut. The risk criteria that were assessed include: facility size (i.e., flow); $CBOD_5$/TSS average; total residual chlorine, un-ionized ammonia nitrogen; and type of receiving environment or affected use. In addition, other new criteria are proposed that have been identified to be uniquely applicable to wastewater treatment systems in Nunavut. Justification is provided within this section for either maintaining, revising or establishment of new criteria for each of the risk criteria.

2.1.1 *Facility size (flow)*

Table 4 shows the risk criteria associated with the size of facility according to the WSER (Government of Canada, 2012). Many of the 25 communities in Nunavut are classified as very small (≤ 500 m^3/d) according to the CCME Strategy (CCME, 2008). Therefore when compared to the southern standard, most of the communities would be assigned 5 points for receiving environment risk assessments.

TABLE 4. FACILITY SIZE (FLOW) RISK CRITERIA ACCORDING TO WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Risk criteria	Description	Flow (m^3/day)	Points
Facility size (flow)	Average daily volume of effluent, expressed in m^3, deposited during the period of 12 consecutive months.	>100 and ≤ 500	5
		>500 and ≤ 2 500	10
		>2 500 and ≤ 17 500	15
		>17 500 and ≤ 50 000	25
		>50 000	35

In comparison to the magnitudes of flow in Table 4 according to the WSER, many of Nunavut's 25 communities fall into the lowest risk range of between 100 and ≤ 500 m^3/d, which has an assigned numeric value of 5 points. Krumhansl et al. (2014) observed that there was a direct relationship between the size of the community and the scale of environmental impact in the receiving environment. Therefore this criteria is important to adequately account for communities that are larger in population such as Iqaluit. It is recommended that this criteria be retained for the risk assessment framework in Nunavut.

2.1.2 *Total residual chlorine*

Total residual chlorine is a risk criterion in the WSER (Government of Canada, 2012; CCME, 2008). Chlorination is sometimes used as a final step in the treatment process in some large southern Canadian WWTPs. Total residual chlorine is not relevant for the treatment systems in Nunavut because chlorine is not used as a final treatment step. This is in due part to not having to meet stringent bacterial effluent discharge objectives. Therefore, it is recommended that this criteria not be used to assess risk in the context of Nunavut's treatment systems.

TABLE 5. TOTAL RESIDUAL CHLORINE RISK CRITERIA ACCORDING TO WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Risk criteria	Description	Points
Total residual chlorine (TRC)	Average concentration of total residual chlorine in the effluent deposited via the final discharge point is > 0.02 mg/L.	10
	Effluent is not dechlorinated before it is deposited.	10

2.1.3 *Un-ionized ammonia nitrogen*

Under the WSER, the regulatory effluent discharge quality objective for un-ionized ammonia nitrogen is specified as 1.25 mg/L for NH_3-N (Table 6). This parameter is also of concern for Nunavut due to the potential for deleterious effects on aquatic life in the receiving environment. In some rare cases, the pH in the WSPs was reported to be greater than 10 in Nunavut (Ragush et al., 2015). In these cases, the total ammonia nitrogen would favor the un-ionized ammonia form (Ragush et al., 2015). Furthermore, there were instances where un-ionized ammonia concentrations in the effluent discharging into the receiving environment were reported as 1.52 mg/L for NH_3-N (n = 7) in Pond Inlet (CWRS, 2015a). It is recommended that the un-ionized ammonia nitrogen be retained as a risk criteria due to the noted instances of elevated NH_3-N concentrations in the WSPs and in effluent discharging to the receiving environment.

TABLE 6. UN-IONIZED AMMONIA NITROGEN RISK CRITERIA ACCORDING TO THE WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Risk criteria	Description	Metric	Points
Un-ionized ammonia nitrogen (NH_3-N)	The maximum concentration of un-ionized ammonia, expressed in mg/L as nitrogen (N), in the effluent deposited during the period of 12 consecutive months	≥ 1.25 at 15°C ± 1°C	20

2.2 Proposed revisions to criteria

2.2.1 *Average $CBOD_5$ and TSS*

The average concentrations of $CBOD_5$ and TSS are taken into account within the risk criteria of the WSER as shown in Table 7. This risk criteria is developed from average concentrations of both the $CBOD_5$ and TSS measured in the effluent discharging into the receiving environment. A modified version of this risk criteria is recommended to account for differences between southern and northern treatment systems. It is recommended that the type of treatment system be used to assess risk associated with treatment facilities instead of concentration of $CBOD_5$ and TSS.

TABLE 7. AVERAGE $CBOD_5$/TSS AVERAGE RISK CRITERIA ACCORDING TO WSER (GOVERNMENT OF CANADA, 2012; CCME, 2008).

Risk criteria	Description	Metric	Points
Average $CBOD_5$/TSS	The average carbonaceous biochemical oxygen demand ($CBOD_A$) due to the quantity of CBOD matter in the effluent and the average concentration of suspended solids (SS_A) in the effluent, both expressed in mg/L, during the period of 12 consecutive months.	$(CBOD_A + SS_A)/5$	Points as per formula in column 2

2.2.1.1 *Applicability of effluent discharge objectives*

Northern systems are challenged to meet stringent effluent discharge objectives. Currently, southern systems must meet 25/25 mg/L for $CBOD_5$ and TSS under the NPS. Applying this type of stringent treatment requirement is impractical and not well suited to the realities and challenges of treatment systems in Nunavut. As part of the Dalhousie Northern wastewater research studies, Ragush et al. (2015) observed that the WSPs can achieve greater than 80% removal of $CBOD_5$ and TSS; however, they could not meet the 25/25 southern standard, particularly in regards to removal of organic matter. Hayward et al. (2014) and Yates et al. (2012) demonstrated that tundra wetland treatment areas improved the effluent quality to below or close to the 25/25 mg/L treatment objectives in most cases. As was demonstrated in CWRS (2015b), there are no design standards in place to predict treatment of the wetland treatment areas; therefore 25/25 mg/L for $CBOD_5$ and TSS is not consistently attained for all systems, because in some cases the external hydrologic influences are not adequately controlled.

2.2.1.2 *Risk dependency on type of treatment system*

The results of the receiving water quality studies summarized in CWRS (2015c) showed that the type of treatment system in use was an important factor influencing the scale of water quality impacts in the receiving environment. For example, the average effluent quality discharging from the mechanical treatment plant in Pangnirtung was 104/253 mg/L for $CBOD_5$ and TSS respectively;

the single-cell WSP in Pond Inlet had average concentrations of 47/77 mg/L for $CBOD_5$ and TSS respectively; while, the WSP and wetland treatment area combination in Kugaaruk had the most favorable effluent quality of 12/3 mg/L for $CBOD_5$ and TSS, respectively. Within CWRS (2015c), the water quality of the discharging effluent was identified as an important factor that affects the severity of the water quality impacts in the receiving environment. Effluent water quality was noted to be dependent on the type of treatment facility in use at the site. The highest quality effluent and most localized water quality impacts in the receiving environment was observed in Kugaaruk; where both a WSP and wetland treatment area are used to treat wastewater. Treatment performance results for the WSP studies were summarized in CWRS (2015a), within which it was suggested that multi-cell WSPs (passive secondary treatment) would improve the effluent water quality compared to single-cell WSPs (passive primary treatment), thereby reducing associated risks with the discharge.

The primary mechanical treatment plant in Pangnirtung was observed to have poor effluent water quality as a result of being undersized (CWRS, 2015c). Authors such as Hayward et al. (2014), Jensen et al. (2013), and Yates et al. (2012) have cited mechanical treatment plants as less favorable than passive treatment systems for northern communities where passive systems are feasible to use. This is because there are challenges with optimization, requirements for technical supervision, training and retention of operators, and high capital costs associated with mechanical systems. Mechanical treatment plants are not practical solutions for many communities because they require technical optimization and operator input that is unsustainable in many Northern communities. Likewise, as part of the benthic invertebrate study by Krumhansl et al. (2014), the mechanical treatment plant in Iqaluit (screening pre-treatment only) was shown to result in significant negative impacts (i.e., sediment anoxia) to the receiving environment up to 550 m from the discharge point.

2.2.1.3 Recommended revisions

Consideration for the type of treatment system is recommended in place of specific prescriptive effluent discharge objectives (i.e., 25/25 mg/L for $CBOD_5$ and TSS). This alternative assigns the risk associated with effluent quality to the type of treatment system, whereby eliminating the impractical requirement to obtain treatment objectives. Table 8 lists the types of treatment systems that may be employed in Nunavut either currently, or in the future, and their assigned risk values.

Passive secondary treatment was associated with the lowest risk value because effluent discharging from this type of facility undergoes treatment of solids and organics, and has limited reliance on operator interaction. While, active (mechanical) secondary treatment was also classified as low risk due to removal of both solids and organics; however, the risk was increased slightly due to the requirement for technical supervision, and difficulties associated with maintenance. Moderate risk was assigned to passive and active primary treatment, with 15 and 20 points respectively. Passive primary treatment was allocated a slightly lower risk value than active primary treatment because there is less reliance on technical input and decreased tendency to require mechanical maintenance with passive treatment. Screening pre-treatment was assigned a high risk value based on findings by Krumhansl et al. (2014) and CWRS (2015d). Direct discharge (direct discharge or outfalls) are assigned the highest risk value, because there is no treatment and effluent quality is raw in strength, which poses the greatest risk to the receiving environment and human health.

TABLE 8. RECOMMENDED REVISIONS TO WSER WATER QUALITY RISK CRITERIA IN RELATION TO THE TREATMENT SYSTEM TYPE.

Risk criteria	Description	Points
Treatment system type	Secondary treatment (passive)	5
	Secondary treatment (active)	10
	Primary treatment passive (WSP only)	15
	Primary treatment active (WWTP only)	20
	Screening pre-treatment only	25
	Direct discharge (outfall)	35

2.2.2 *Type of receiving environment or affected use*

Table 9 summarizes the type of receiving environment or affected use risk criteria under the WSER. Studies on the receiving water environments in Nunavut summarized in CWRS (2015c) demonstrated that the type of receiving environment is important to consider in risk assessment. The criteria listed in Table 9 are appropriate for the systems in Nunavut; however, there are some suggested revisions to account for inherent differences between southern Canada and Nunavut. These proposed revisions include the consideration for the ambient currents and tidal cycles, as well as, separating the human health and environmental risk aspects within this category.

TABLE 9. TYPE OF RECEIVING ENVIRONMENT OR AFFECTED USE RISK CRITERIA ACCORDING TO THE WSER (GOVERNMENT OF CANADA, 2012).

Criteria	Description		Points
Type of receiving environment or affected use	Water where effluent is deposited via the final discharge point (highest value that applies)	Open marine waters	5
		Marine port waters	10
		Lake, natural wetland, reservoir, estuary, enclosed bay	20
		Watercourse with bulk flow ratio > 100	15

TABLE 9. (CONT'D) TYPE OF RECEIVING ENVIRONMENT OR AFFECTED USE RISK CRITERIA ACCORDING TO THE WSER (GOVERNMENT OF CANADA, 2012).

Criteria	Description		Points
		Watercourse with bulk flow ratio ≥ 10 and ≤ 100	20
		Watercourse with bulk flow ratio <10	25
		Shellfish harvesting area within 500 m of the point of entry where effluent is deposited in the water via the final discharge point	20

The CWRS (2015c) studied the water quality impacts from MWWE at three different marine receiving water sites in Nunavut. Results from the CWRS (2015d) study showed that the ambient conditions are important determinants for the extent of the water quality impacts in the receiving environment. The ambient currents were especially important because the discharge energies of the effluent were relatively low compared to larger scale plants in southern Canada. For instance, the periodically strong ambient currents (e.g., 0.17 – 0.25 m/s) in Pond Inlet led to the long range transport of the minimally diluted effluent plume for distance of over 330 m from the discharge point (CWRS, 2015c).

Another important factor that influenced the scale of water quality impact was the presence of exposed intertidal flats. In CWRS (2015c), the Pangnirtung study site was observed to have poor effluent quality (e.g., 16mg/L for TSS; 200 MPN/100mL for *E. coli*; and 7.5 mg/L for TAN) at a distance of 150 m from the discharge point. Pangnirtung had a continuously discharging WWTP that had a periodically exposed tidal flats on low and outgoing tides. Likewise, significant effects to the benthic invertebrate communities were observed up to 225 m from the discharge point in Pangnirtung (Krumhansl et al., 2014). Therefore the presence of exposed intertidal zones should be considered for risk assessment of treatment facilities in Nunavut.

2.2.2.1 Recommended revisions

Human health risks are considered specifically in the type of receiving environment criteria in Table 10 from the WSER. It is recommended that factors affecting human health risks be separated from the type of receiving environments risk criteria. The reason for separating this is to distinguish between risks related to direct human activities and natural factors associated with the type of receiving environment. The shellfish harvesting and port use was separated from this criteria and will be considered in a new proposed criteria that specifically considers human health risks. Consideration for the ambient conditions and the presence of exposed intertidal zones in the receiving environment are also proposed as per Table 10. The bulk flow ratio is recommended to be removed, as no communities in Nunavut discharge to rivers.

TABLE 10. RECOMMENDED REVISIONS TO WSER WATER QUALITY RISK CRITERIA IN RELATION TO THE TYPE OF RECEIVING ENVIRONMENT OR AFFECTED USE.

Criteria	Description		Points
Type of receiving environment or affected use	Water where effluent is deposited via the final discharge point (highest value that applies)	Open marine waters low current (< 0.1 m/s)	5
		Open marine waters strong current (≥ 0.1 m/s)	25
		Exposed marine intertidal zone	25
		Lake, natural wetland, reservoir, estuary, enclosed bay	20

2.3 Proposed new risk criteria

2.3.1 *Frequency and timing of discharge*

2.3.1.1 Benthic invertebrate impacts

Benthic invertebrate studies in the receiving environments were conducted as part of the Dalhousie northern wastewater research program in the communities of: Kugaaruk, Pond Inlet, Grise Fiord, Pangnirtung, and Iqaluit. As part of this work, Krumhansl et al. (2014) found that there were minimal impacts to benthic communities in four out of five study communities. Impacts were observed at linear distances of less than 225 m from the discharge point of the effluent in all communities which had a populations of less than 2000 people. Table 11 summarizes the scale of impacts for each of the study sites by Krumhansl et al. (2014). Generally, it was suggested that the total volume and duration of the effluent discharge were the most important factors influencing the amount of environmental impact in the receiving environment. Continuous year-round discharge facilities such as Pangnirtung and Iqaluit had larger linear distances of impacts than decanted facilities. While, the larger community of Iqaluit was observed to have significant negative environmental impacts over 500 m from the point of discharge. These findings suggested that communities of populations of less than 2000 people currently have adequate treatment systems to minimize environmental impacts to the receiving environments (Krumhansl et al., 2014).

TABLE 11. SUMMARY OF DISTANCE OF SIGNIFICANT ENVIRONMENTAL IMPACTS TO BENTHIC INVERTEBRATES IN THE RECEIVING ENVIRONMENTS FROM KRUMHANSL ET AL. (2014).

Community	Pop.	Average daily flow (m^3/d)[a]	Treatment type	Discharge type	Receiving environment	Linear distance of significant environmental impacts from discharge point
Kugaaruk	771	70	WSP and wetland	Decant (2 – 3 weeks)	Small marine bay	70 – 100
Pond Inlet	1549	225	WSP	Decant (2 – 3 weeks)	Open marine	0 – 75
Grise Fiord	130	12	WSP and wetland	Decant (~ 1 week)	Fiord (marine)	20 – 150
Pangnirtung	1425	128	Mechanical treatment (activated sludge)	Continuous year-round	Fiord (marine)	75 – 225
Iqaluit	6699	1513	Preliminary treatment (bulk solids removal)	Continuous year-round	Large bay (marine)	580

[a]Value obtained by dividing annual wastewater production estimates into daily flow rates. Kugaaruk, Pond Inlet and Grise Fiord have higher daily flows due to short discharge timeframe.

2.3.1.2 Recommended risk criteria

The frequency and timing of the discharge was found to be significant for the risk associated with wastewater discharges (Krumhansl et al., 2014). Krumhansl et al. (2014) suggested that long duration discharges throughout the year had more significant environmental impacts on the receiving water environment. Therefore continuous discharge facilities are weighted higher in points than decanted facilities. Additionally, findings in regards to tundra wetland treatment areas in Nunavut by Hayward et al. (2014), suggested that end of season decants are preferable over start of treatment season decants, in terms of final effluent water quality discharging to receiving environments. These findings were corroborated by the treatment performance studies on WSPs conducted by Ragush et al. (2015). Generally, Ragush et al. (2015) observed improved effluent water quality over the course of the treatment season in WSPs. Hayward et al. (2014) also observed that steady and controlled discharges produced higher quality effluent than variable discharges.

Therefore new risk criteria are recommended in Table 12 to address the frequency and timing of discharge. The lowest risk was assigned to those systems that discharge effluent at the end of the treatment season in a controlled flow decant. This was ranked as the lowest risk discharge because the discharge is intermittent and the water quality has likely improved over the course of the treatment season prior to discharge. Continuous and steady discharges over the course of the treatment season was ranked as slightly higher in risk because the cumulative impact onto the receiving environment would be greater. Systems that discharge continuous variable flow rates over the treatment season are ranked as higher risk than steady-flow systems because these have greater impact on the receiving environment water quality and benthic invertebrates. The systems with the highest risk were those that decant at the start of the treatment season because the wastewater has not gone through a treatment season. Likewise, those that discharge on a continuous year-round basis are also ranked as the highest in risk, due to cumulative impacts on the receiving environment.

TABLE 12. PROPOSED NEW CRITERIA OF FREQUENCY AND TIMING OF DISCHARGE.

Risk criteria	Description	Classification	Points
Frequency and timing of discharge	Decanted systems are those which are manually discharged typically with a pump and generator.	End of season decant (August -October)	5
	Continuous discharges are those from mechanical treatment plants, passive exfiltration structures and subsurface discharge.	Continuous steady (June – October)	10
		Continuous variable (June –October)	20
		Start of season decant (June-July)	25
	Steady indicates maximum flow fluctuations of ± 50 m^3/d.	Continuous year-round	25

2.3.2 *Surrounding land and water uses*

The surrounding land and water uses in the vicinity of the wastewater treatment systems are important considerations to assess the human health risk associated with receiving water environments. The exposure pathways of pathogens to humans in Inuit communities are illustrated in Figure 3 by Daley et al. (2014b). Interactions between humans and the environment have varying levels of associated risk in terms of pathogen exposure. The land and water use activities influence the likelihood of transmission of pathogens to humans.

FIGURE 3. POTENTIAL WASTEWATER EFFLUENT EXPOSURE PATHWAYS IN INUIT COMMUNITIES (DALEY ET AL., 2014B).

Daley et al. (2014b) indicated that there is a strong interrelatedness between human activities and the risk of exposure to pathogens. Therefore, it is recommended that individual human activities associated with the land and water surrounding the effluent discharge points should be considered as part of the risk assessments of the receiving environments. Table 14 recommends a suite of activities to be considered that affect the risk to human health of users of the receiving environment. Community consultation will likely be required to inform this risk criteria based on local uses of the land and water.

TABLE 13. PROPOSED NEW CRITERIA OF SURROUNDING LAND AND WATER USES.

Risk criteria	Activities	Points
Surrounding land and water uses	Commercial shipping (<500 m)	5
	Recreational boating (<100 m)	10
	ATV and/or snowmobile (<100 m)	10
	Mining and/or craving rock collection (<100 m)	15
	Walking (<100 m)	15
	Fishing (<100 m)	20
	Hunting and harvesting (<100 m)	20
	Swimming (<500 m)	25
	Drinking water collection (<500 m)	30
	Shellfish harvesting (<500 m)	30

2.3.3 *Community education and engagement*

A complimentary component of the human health risk criteria is community education and engagement. This new proposed criteria is intended to address the risk mitigation techniques that can be implemented to reduce the human health risks associated with effluent discharges to receiving environments. Table 15 describes the interactive measures within the community that can be implemented to reduce the risks to human health. The consultation is intended to inform the aforementioned surrounding land and water uses risk criteria. Consultation with the community would be used to gauge the types of activities taking place in the vicinity of the receiving environment. Risk can be reduced with the installation of signage near the discharge point of the effluent. This would be useful to alert users of the area of the presence of effluent. Simple community education tools such as posters and brochures in the hamlet offices and Hunters and Trappers Association offices may also help to reduce risk of human contact with wastewater. As well, communication of proper game preparation practices may help avoid food contamination with pathogens.

TABLE 14. PROPOSED NEW CRITERIA OF COMMUNITY EDUCATION AND ENGAGEMENT.

Risk criteria	Interactive measures	Points
Community education and engagement	No posters in hamlet and Hunters and Trappers offices showing location of discharges	10
	No communication of proper waterfowl and game handling at Hunters and Trappers offices	15
	No consultation on radio and in-person	25
	No signage near outfall area	30

3.0 Implementation

3.1 Risk calculation

The risk calculated for each community can be used to determine priorities for system upgrades as shown in Table 16. It is recommended that the systems with the lowest risk have values below 50. These low risk systems would have the longest recommended timeline for upgrades of 30 years. Low to medium risk levels would range from 50 to 100, and the recommended timeline for upgrades would be 20 years. Risk levels ranging from 100 to 150 are characterized as medium to high risk systems, and are recommended to have upgrades completed within a 15 year horizon. The highest risk systems have levels from 150 to 200, and it is recommended that they take priority, and undergo upgrades within the next 10 years.

TABLE 15. SUGGESTED TIMELINE FOR SYSTEM UPGRADES BASED ON RISK CHARACTERIZATION.

Risk level	Risk characterization	Timeline for upgrades
< 50	Low	30 years
50 – 100	Low to medium	20 years
100 – 150	Medium to high	15 years
150 – 200	High	10 years

3.2 Risk mitigation techniques

It is important to note that there are opportunities to easily decrease the risk value of each community to some degree at a relatively low cost. For instance some of the risk levels can be changed simply by operational and community engagement activities. These small operational and community engagement changes can in some cases delay the urgency of system upgrades. Operational changes could include:

- controlling variable effluent discharges to create steady discharges (i.e., lose up to 10 points); and
- decanting at the end of the treatment season instead of the start (i.e., lose up to 20 points).

Additional points can be lost by engaging in community education activities which lowers the overall risk of the systems. These activities provide an opportunity to refine the surrounding land use category as well. Community education changes consist of:

- engaging the community with information about the direction and extent of wastewater flow areas with in-person and/or radio sessions (i.e., lose up to 25 points);
- distributing posters and/or brochures for the hamlet and Hunter's and Trapper's Association offices (i.e., lose up to 25 points); and

- installation of permanent signage at the outfall area and warning of the dangers of interaction with MWWE (i.e., lose up to 30 points).

4.0 Conclusions

In conclusion, based on the findings from the Dalhousie University Northern Wastewater research program, revisions are recommended for the WSER risk criteria in order to accurately assess wastewater treatment systems in Nunavut. These proposed recommendations to the WSER consist of criteria to be retained or removed, to be revised, and new criteria, summarized as follows.

1. **Recommended criteria to be retained or discarded.**
    - WSER risk criteria of facility size (flow) and un-ionized ammonia nitrogen (NH_3-N) are recommended to be retained as is.
    - Total residual chlorine is recommended to be discarded from the risk criteria.
2. **Recommended revisions to criteria.**
    - The type of treatment systems, and associated level of treatment expected, are recommended to be used to assess the risk instead of the concentration based metric ($CBOD_5$/TSS).
    - The risk criteria for the type of receiving environment are recommended be revised to represent conditions observed in Nunavut (i.e., ambient current conditions, exposed intertidal zones).
    - Human activities are recommended to be removed from the type of receiving environment criteria to be considered separately in a new criteria.
3. **Recommended new criteria.**
    - New criteria which considers the frequency and timing of discharges are recommended (i.e., steady vs. variable discharge rates, continuous vs. decanted discharges).
    - New criteria which considers surrounding land and water uses by human activities are recommended (i.e., commercial shipping, recreational boating, hunting, harvesting etc.)
    - New criteria which considers the risk reducing merit of community education and engagement, such as consultation, and signage, are recommended.

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