Assessment of Water Quality Impacts in Marine Environments Receiving Municipal Wastewater Effluent Discharges in Nunavut

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List of Abbreviations

%	Percent
°C	Degree Celsius
µS	Micro Siemen
APHA	American Public Health Association
B.C.MoE	British Columbia Ministry of the Environment
$CBOD_5$	Five-Day Carbonaceous Biochemical Oxygen Demand
CCME	Canadian Council of Ministers of the Environment
CEQG	Canadian Environmental Quality Guideline
CFU/100mL	Colony Forming Units per 100 mL
CGS	Community and Government Services
cm	Centimetre
CWRS	Centre for Water Resources Studies
d	Day
DFO	Department of Fisheries and Oceans
DO	Dissolved Oxygen
E	East
E. coli	*Escherichia coli*
e.g.	*Exempli gratia*
EC	Environment Canada
EDO	Effluent Discharge Objective
EQO	Environmental Quality Objective
ERA	Environmental Risk Assessment
et al.	*Et alii*
etc.	*Et cetera*
GN	Government of Nunavut
GPS	Global Positioning System
HC	Health Canada
hr	Hour
HT	High Tide

i.e.	*Id est*
IMZ	Initial Mixing Zone
IT	Incoming Tide
L	Litre
LT	Low Tide
m	Metre
m^3	Metres Cubed
mg	Milligram
mL	Millilitre
mm	Millimetre
MoEE	Ontario Ministry of Environment and Climate Change
MPN/100mL	Most Probable Number per 100 mL
MWWE	Municipal Wastewater Effluent
N	North
NE	North-East
NH_3-N	Un-Ionized Ammonia Nitrogen
NPS	National Performance Standards
NU	Nunavut
NWT	Northwest Territories
NWTWB	Northwest Territories Water Board
OT	Outgoing Tide
Pop.	Population
RTK	Real-Time Kinematic
RWT	Rhodamine WT
s	Second
TAN	Total Ammonia Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency

W	West
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 document summarizes the findings of water quality impact assessments in receiving water environments downstream of municipal wastewater treatment facilities in three hamlets in Nunavut. The summary was prepared by the Centre for Water Resources Studies (CWRS) at Dalhousie University in collaboration with the Community and Government Services (CGS) department of the Government of Nunavut (GN). This summary is a deliverable of a research contract on municipal wastewater infrastructure in Nunavut funded by the GN and granted to CWRS.

The majority of the twenty-five hamlets in Nunavut discharge primary treated municipal wastewater into marine receiving environments. Typically, there is some recognition of the assimilative capacity of the receiving environment by regulatory bodies in establishing discharge criteria. Specifically, the assimilative capacity is the ability of the receiving environment to buffer the impacts of wastewater discharges and mitigate negative environmental impacts. This may involve the establishment of initial mixing zones within which particular water quality criteria are applied and must be met. In Canada, the Canadian Council of Ministers of the Environment (CCME) has proposed an Environmental Risk Assessment (ERA) approach for characterizing risk associated with effluent discharges. At the time of this study, it was not known how the ERA approach should be modified for the unique conditions in Northern Canada. This study was undertaken to assess the water quality impacts of wastewater effluent discharges into marine arctic receiving environments. The various factors which affect the water quality impacts upon discharge into the receiving environment were identified. Ultimately, this will help inform the ERA approach specifically for Nunavut.

Three study sites with marine receiving environments were selected: Pangnirtung, Kugaaruk, and Pond Inlet, Nunavut. Fieldwork was conducted during the summer treatment season in 2013. Dye tracer tests were conducted at each of the study sites, which involved injection of a non-reactive dye into the discharge stream and monitoring the dispersion over time in the receiving waters. Plume boundaries were delineated for various different tidal regimes to develop an understanding of the spatial extent of the wastewater plume before substantial dilution occurs. Water quality samples were collected based on the plume distribution during the tracer tests. Various standard water quality parameters were assessed such as total suspended solids, total ammonia nitrogen, and fecal indicator bacteria.

Results of the tracer tests and water quality analysis showed that Kugaaruk had the most favorable receiving water quality of the study sites. Notably, Kugaaruk had most favorable quality of effluent discharging into the receiving environment. Pangnirtung had varying water quality results depending on the tidal regime. For instance, during low tides the intertidal zone became exposed and very little dilution was observed. There is risk associated with exposed intertidal discharge areas, such as in Pangnirtung, due to the increased risk of human contact with effluent.

Finally, Pond Inlet had minimal mixing and dispersion at times during the study period which resulted in elevated concentrations of effluent transported long distances from the discharge location (> 330 m in some cases).

In particular there were some key factors that were identified which affect the water quality impacts associated with wastewater discharges into the receiving environments. These factors consisted of the ambient characteristics of the receiving environment, discharge rates, timing of the discharges, water quality of the effluent, and receiving water uses. There was little to no near-field mixing due to the low energy discharges and therefore most of the plume characteristics were dictated by the ambient conditions of the receiving waters. This is important because discharges during unfavorable ambient conditions may be avoided with simple and practical management techniques such as submerged diffuser pipes, or strategically timed discharges. The timing of the discharges were important as the ambient tidal and current conditions in most cases were influential factors for the behavior of the effluent plume. The formation of an ERA framework for Nunavut should acknowledge these unique factors which affect the site-specific risk for each community.

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 which collect greater than 100 m^3/d 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 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 54th parallel in Quebec and Newfoundland and Labrador, to facilitate research on northern treatment facilities. 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 2014. One aspect of the project was focused on environmental risk assessments of the receiving environments. Two separate yet related studies that were conducted in association with the receiving environment risk assessments. These included an assessment of the benthic invertebrate communities and a water quality assessment of the receiving environments downstream of municipal wastewater treatment facilities in Nunavut.

Research findings from the benthic invertebrate studies are presented under a separate cover titled: *"Assessment of arctic community wastewater impacts on marine benthic invertebrates*" by CWRS (2015), which was submitted to the GN. The results from the water quality assessment of the receiving environment are presented within this report. Overall, the two separate studies on the receiving environments were complimentary in their findings. Impacts to the benthic communities correlated well with the observed water quality results presented within this report, as expected.

The work presented herein is ultimately meant to inform the formation of a framework for environmental risk assessment of municipal wastewater systems in Nunavut. There are unique differences in the Far North that should be considered within the standardized framework used to assess overall human and environmental risks associated with MWWE discharges and to specify regulatory discharge criteria.

1.0 Introduction

1.1 Purpose

The purpose of this report is to assess the water quality impacts associated with municipal wastewater effluent (MWWE) discharges into receiving environments throughout Nunavut. The different types of discharge scenarios will be introduced and their implications for water quality described. This information provides a methodology for water quality assessment of the receiving environments.

These studies provide comprehensive assessments of the water quality impacts for a selection of key systems that are typical of the majority of Nunavut's hamlets. These findings will be used to extrapolate the overall receiving water quality associated with MWWE discharges in Nunavut. Furthermore, territorial governments may use the methodologies described herein to conduct future studies on receiving water environments.

1.2 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 (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 low 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.

Municipal wastewater treatment in Nunavut consists of a combination of methods. There are twenty-five hamlets located in Nunavut, of which sixteen use a wastewater stabilization pond (WSP), or an un-engineered lake lagoon, in combination with a tundra wetland treatment area (WTA). There are also a few hamlets that directly discharge untreated effluent into WTAs, natural ponds, and marine receiving environments. The WSPs can have a scheduled decant with a mechanical pump, 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).

1.3 Receiving water characteristics

Due to the variety of wastewater treatment facilities, and the influential effect 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 focus of this study is on discharges to marine waters, which represents the majority of MWWE discharge scenarios in Nunavut. In order to understand the factors affecting the mixing and dispersion conditions in marine environments, the following set of variables should be considered: differences in densities between the discharge and ambient environment, stratification of the receiving water body, wind speed and direction, speed and direction of the ambient currents, and tidal effects.

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 – 140 m^3/day, in line with reported estimates related to wastewater production for trucked water delivery and wastewater collection (i.e., 90 L/person/day; Heinke, 1991). 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). These communities are thus on the low end of MWWE producers in the country (Heinke, 1991; Daley, 2014).

Some of the communities manually pump effluent (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).

1.4 Regulations

1.4.1 *Initial mixing zones*

The assimilative capacity of the environment is typically considered when forming regulations governing MWWE discharges. This assimilative capacity is the ability of the receiving environment to buffer the impacts of wastewater discharges and mitigate negative impacts. Required discharge quality criteria are set in many jurisdictions, which are maximum concentrations of key pollutants in the MWWE. When setting regulations for required discharge quality criteria, the assimilative capacity is acknowledged by defining a zone surrounding the discharge location where modified water quality criteria are applied. This zone is typically referred to as an Initial Mixing Zone (IMZ), which is a defined area surrounding a discharge location, within which initial mixing of the effluent discharge occurs. IMZ dimensions have typically been set using a cross sectional area, surface area, or radius/width measurement (USEPA, 1984).

These IMZs are defined by the regulatory body, and represent the spatial boundary where environmental water quality criteria must be met. In this approach, the definition of appropriate IMZs and end-of-pipe wastewater discharge quality criteria must consider the overall assimilative capacity of the downstream environment. This ensures that irreversible damages to these environments do not occur. When setting IMZ parameters, it is critical to minimize the risk of long-term environmental impacts to aquatic life and the ecosystem, and ensure the health and safety of humans in the vicinity (MoEE, 1994; CCME, 2008).

As a result of the variable nature of receiving environments, the definition of appropriate IMZs is best determined on a site-specific basis. However, this is not always feasible, as the cost of completing such studies can be prohibitive. In addition, several legacy treatment plants exist that would not have completed such a study, and would require approval renewal or upgrades, in order to meet updated provincial/territorial water quality criteria. There is not a one size fits all solution for defining the IMZ requirements.

It should be noted that IMZs are not an alternative to the implementation of minimum treatment requirements at the last point of engineered control. IMZs established across Canada aim to be as minimal in size as possible, while still accomplishing the goals of providing a reasonable 'buffer' zone for dilution and mixing processes to occur. In addition, several regulatory agencies have stated that IMZs are only to apply for 'conventional' pollutants, and not to be applied to pollutants defined as hazardous substances that may be acutely toxic (MoEE, 1994; CCME, 2008). In Nunavut, the conventional pollutants of concern are total suspended solids (TSS), five-day carbonaceous biochemical oxygen demand ($CBOD_5$), total nitrogen (TN), total ammonia nitrogen (TAN), total phosphorus (TP), and *Escherichia coli* (*E. coli*)

In Canada, it is up to the individual provincial/territorial regulatory bodies to define the IMZs that are used. Therefore regulatory decisions must be made in determining what level of both acute and chronic toxicity can be accepted in a particular receiving water. In doing so, efforts also must be made to ensure that all combinations of concentrations of pollutants, discharge magnitudes, and environmental conditions are assessed for worst case scenarios.

1.4.2 *CCME Canada-wide strategy*

Effluent Discharge Objectives (EDOs) are the maximum concentrations of key parameters in wastewater to be met at the point of discharge. A standardized methodology for developing EDOs for discharges from municipal wastewater treatment facilities has been created as part of the Canadian Council of Ministers of the Environment (CCME) *Canada-wide Strategy for the management of municipal wastewater effluent* (CCME, 2009). The framework for the environmental risk assessment (ERA) approach, which includes development of EDOs is illustrated in Figure 1 (CCME, 2009).

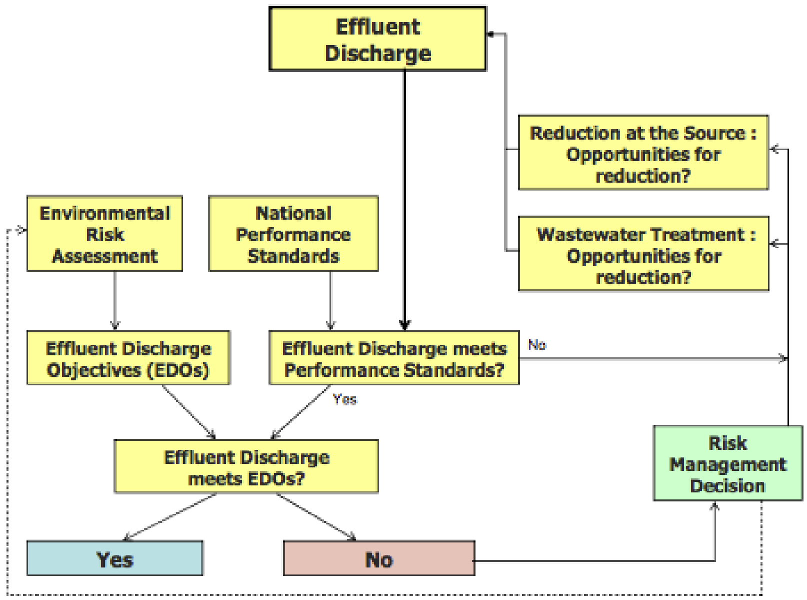


FIGURE 1. ENVIRONMENTAL RISK MANAGEMENT FRAMEWORK (SOURCE: CCME, 2008).

These EDOs are set through determining appropriate Environmental Quality Objectives (EQOs), which are to be met at the boundary of the defined IMZ. EQOs are usually established as the Canadian Environmental Quality Guidelines (CEQGs) in conjunction, or replaced by, any related provincial or territorial water quality guidelines (CCME, 2009). The intent of the EQOs is to define the upper limits for concentrations of substances of concern within a receiving water body.

The benefits to incorporating an environmental-risk based approach to developing MWWE discharge criteria is that site specific inputs are considered, and as such, tailored solutions related to risks to human and ecosystem health can be developed. This approach has the potential to be more cost-effective by allowing for focus to be placed on discharge scenarios with significant environmental risk, while still allowing for discharges with minimal predicted risk for impacts to be managed with an appropriate level of treatment and financial commitment. Under the CCME *Strategy*, southern facilities for wastewater treatment and discharge must use an ERA approach in defining appropriate EDOs to be met for each facility (CCME, 2009).

1.4.3 *Northern Canadian context*

The *Guidelines for the discharge of treated municipal wastewater in the Northwest Territories* document (NWTWB, 1992) is used for guidance on wastewater discharges in Nunavut and the Northwest Territories (NWT). There are additional considerations for the criteria set by the Department of Fisheries and Oceans (DFO), which includes provisions for any discharge parameters that could be defined as 'acutely lethal' (NWTWB, 1992).

Within this document, the IMZ concept is applied, allowing for modified water quality criteria to be set within an area defined by the receiving water body. The following applies for marine discharges (NWTWB, 1992) such that IMZs in NWT are:

- An area bounded by up to 100 m surrounding the discharge location;
- Not occupying more than one-third of the cross-sectional area of a waterbody around a discharge point; and
- Not intruding on any drinking water intakes, shellfish beds, recreational areas, and biologically sensitive areas.

Water quality objectives are specified for outside the IMZ in terms of dissolved oxygen, residual chlorine, nutrients, coliforms, toxicity, and suspended solids (NWTWB, 1992). It should be noted that these are the minimum criteria to be applied – it is further outlined that more stringent criteria can be applied at the discretion of the Water Board and/or DFO on a case by case basis, including the addition of supplementary parameters to be met.

Due to the variability between community water uses, effluent qualities, and receiving water environments, the document states that final considerations will be made by the Water Board itself when considering any license. In addition, many of the considerations in the document (e.g., calculations of dilution) relate only to wastewater discharges to freshwater or estuaries (e.g., rivers, lakes, estuaries). When considering marine discharges, untreated discharges are permitted if floatables are removed, and the discharge is free of larger particles. There are additional guidelines related to the impacts that wastewater discharges may have on commercial or recreational endeavors, such as fisheries, shellfish harvesting, and other hunting/gathering activities.

One of the key considerations of the NWTWB document is the need for flexibility when defining municipal wastewater discharge criteria. This is due to the variability observed between northern communities, as water quality may differ greatly according to populations, industry, and geographic locations. In addition, due to the large overall land area these communities occupy, there are diverse receiving water environments, with varying background concentrations of many of the parameters of interest. As such, there are considerations for the background levels of these parameters when assigning discharge criteria.

1.5 Effluent dispersion and mixing processes

When wastewater is discharged into receiving water environments, a wastewater plume is typically formed. This plume exists due to the differences between the characteristics of the wastewater and the ambient receiving waters, particularly differences in their densities. The ambient conditions represent the natural conditions of the receiving water before the discharge of effluent. As typical wastewater discharges are less dense than the marine receiving waters, discharges are often positively buoyant. When wastewater is discharged at a subsurface location (i.e., at depth), the plume typically entrains and mixes with the ambient water as it rises, to either a level of neutral buoyancy, or the surface of the receiving waters. When wastewater is discharged at surface, the wastewater acts as a buoyant surface jet in the receiving water environment (US EPA, 1985; Jones et al., 1996). The MWWE discharge scenarios typically observed in Nunavut involve these surface discharges, and are the focus of this research. Examples of typical buoyant jet discharge plumes are given in Figure 2.

U_a is the ambient velocity of the receiving waters

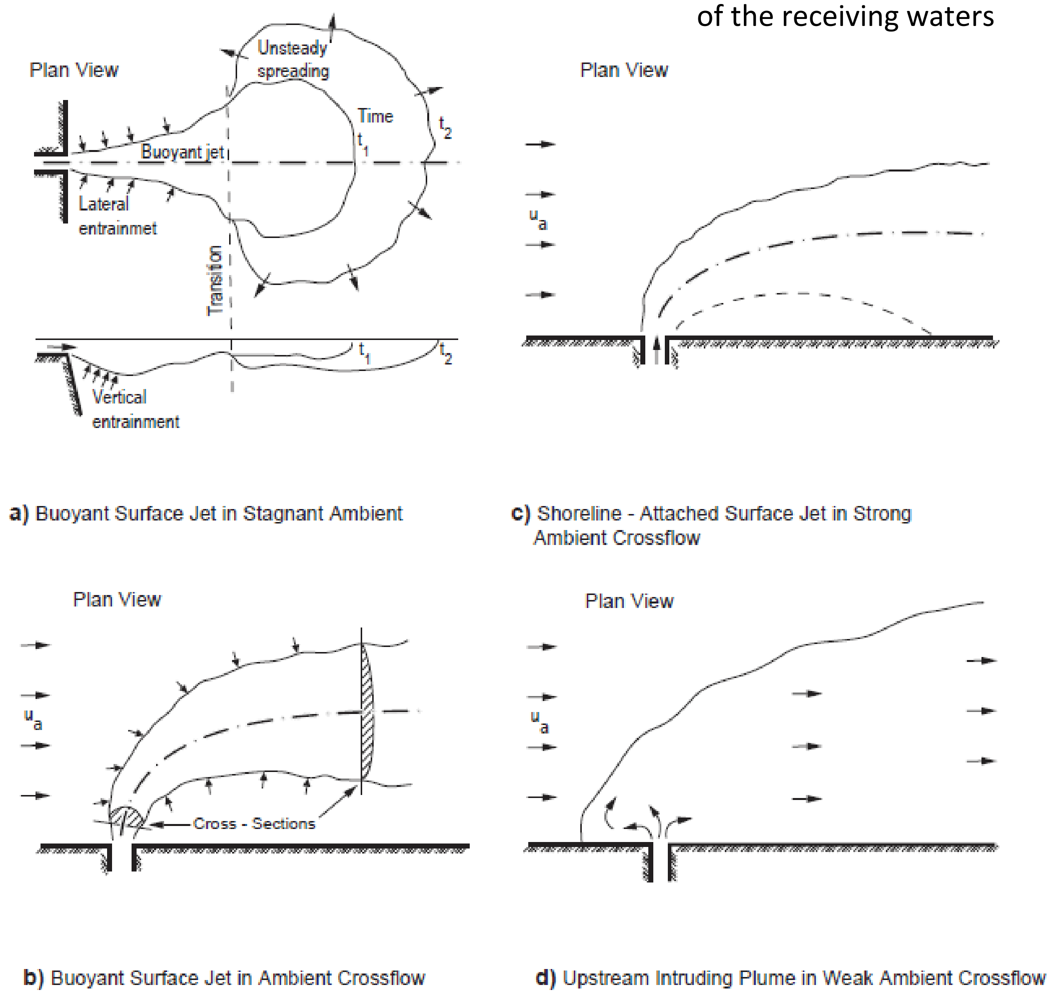


FIGURE 2. TYPICAL BUOYANT SURFACE JET MIXING FLOW PATTERNS UNDER STAGNANT OR FLOWING AMBIENT CONDITIONS (SOURCE: DONEKER AND JIRKA, 2007).

The mixing characteristics of an effluent discharge in a receiving water environment is a function of both the characteristics of the discharge, and the waters into which it is discharged. Important definitions used to describe the mixing processes in the receiving environment include:

- Near-Field Mixing: Defined as the mixing processes that are dominated by the wastewater jet characteristics (i.e. momentum, buoyancy, and mass fluxes). Typically occur over small spatial (< 10^2 m) and time scales (minutes).
- Far-Field Mixing: Defined as the mixing processes that are dominated by the characteristics of the ambient receiving water environments. Typically occur over greater spatial (> 10^2 m) and time scales (hours).

It is usually assumed that near-field mixing typically occurs within the IMZ, but the two terms are not interchangeable.

2.0 Methodology

2.1 Dalhousie University research program

The Centre for Water Resources Studies (CWRS) at Dalhousie University conducted a research program on wastewater treatment infrastructure in Nunavut, Canada from 2011 to 2014. The research program was a collaborative effort with, and funded by, the Community and Government Services (CGS) department of the Government of Nunavut (GN).

A focus area of the broader infrastructure research program was to conduct risk assessments on the receiving water environments typical of communities in Nunavut. The risk assessments on the receiving environments focused on two aspects consisting of: 1) benthic invertebrate community impacts; and 2) the assimilative capacity of the receiving environment in relation to water quality. This report summarizes the results from the second part of the receiving water risk assessment studies.

Comprehensive site-specific receiving water quality studies were conducted in the hamlet communities of Pangnirtung, Kugaaruk, and Pond Inlet, Nunavut (Figure 3). Fieldwork was conducted between July and September 2013. The study sites were selected to include different geographic localities to ensure that the climatic variability across Nunavut was represented. Other justifications for the site selection included primary treatment of the wastewater prior to discharge into the receiving environment. Marine receiving environments were chosen because they are the most common type of receiving water in Nunavut.

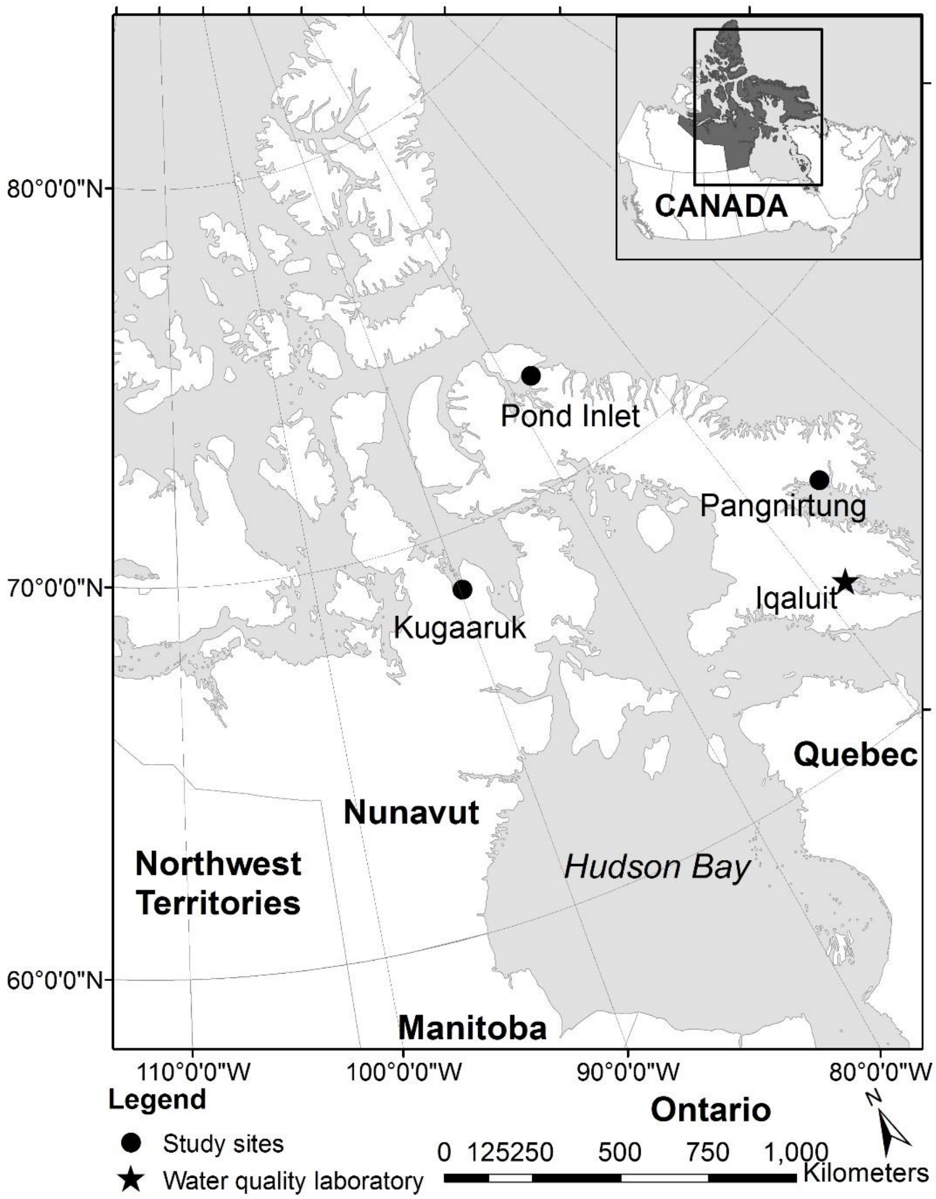


FIGURE 3. SITE LOCATOR MAP FOR THE SITE-SPECIFIC STUDIES ON THE RECEIVING WATER ENVIRONMENTS IN PANGNIRTUNG, KUGAARUK, AND POND INLET, NUNAVUT.

To date, there have not been any studies that assess the assimilative capacity of arctic receiving water environments and the water quality impacts associated with MWWE discharges in these extreme environments. An analysis of the typical MWWE discharge scenarios throughout the territory was undertaken with the following research objectives to:

i) Characterize the MWWE discharge scenarios and receiving water characteristics for typical sites;
ii) Understand the water quality in the vicinity of the MWWE discharge location; and

iii) Identify potential human-health risks associated with current MWWE discharge scenarios in Nunavut.

The following sections summarize the results obtained from the receiving environment assessment component of the research program.

2.2 Site descriptions

Three study sites were selected for the assessment of the water quality impacts to receiving water environments. These sites consisted of: Pangnirtung, Kugaaruk, and Pond Inlet. For comparison, the general characteristics of the receiving environments are summarized in Table 1 below.

TABLE 1. CHARACTERISTICS OF WASTEWATER TREATMENT SYSTEMS AND RECEIVING ENVIRONMENTS AT EACH SITE.

Location	Pop.[c]	Treatment type	Discharge timing	System Effluent Sampling Location	Receiving Environment	Max Tidal Range (m)	Exposed sediment at low tide
Pangnirtung	1425	Mechanical treatment (activated sludge)	Continuous - year round	Discharge pipe	Marine - medium size bay, high tidal range	6.7[a] – 7.6[b]	200-300 m - sandy sediment
Kugaaruk	771	WSP, decant cell and wetland	Annual – end of summer	End of wetland	Marine - small cove	2.9[a] – 3.3[b]	10 m rocky intertidal area
Pond Inlet	1549	WSP	Annual - end of summer	End of discharge channel	Marine - open channel	2.3[a]	<5 m rocky intertidal area

[a] Based on recorded data available from the Canadian tides and water levels data archive (DFO, 2015a).
[b] Based on tidal prediction data available from the Department of Fisheries and Oceans (DFO, 2015b).
[c]"Pop." is population size.

2.2.1 *Pangnirtung*

The hamlet of Pangnirtung is located on Baffin Island (66° 08' 48" N, 65° 42' 04" W) and has an estimated population of 1425 (Statistics Canada, 2012). Data collection for the characterization of the receiving water environment was conducted from July 23, 2013 to July 29, 2013. Average air temperatures range from –23°C to –31°C in January, and from 12°C to 4°C in July. Precipitation averages 197 mm as rainfall, and 2293 mm as snow, for a total of 404 mm of precipitation annually (Government of Canada, 2015a - Iqaluit).

Approximately 136 m^3/d (49,751 m^3/year) of primarily domestic municipal wastewater is generated in Pangnirtung (Nunavut Water Board, 2011a). MWWE is collected via truck and transported to a wastewater treatment facility approximately 300 m from the community boundary. This wastewater treatment facility consists of a mechanical treatment plant (activated sludge); which at the time of this report was being replaced with a new membrane bioreactor system. MWWE is discharged from Pangnirtung throughout the entire year, at a rate of approximately 105 – 260 m^3/day.

Effluent is released through a small grassy channel over a distance of approximately 120 m prior to eventual discharge to the intertidal receiving water environment (Pangnirtung Fiord) as shown in Figure 4a. This area has a maximum tidal range of 6.94 m, which at low tide exposes a gently sloping tidal flat that is mainly composed of sand, with some patches of gravel and small boulders (Figure 4b). Variable ambient receiving water currents were observed on-site, depending on the active tidal regime. In general, currents observed on-site were cross-shore in an N-NE direction.

Traditional activities occur in the intertidal zone of the shoreline in the vicinity of Pangnirtung. Of note is the practice of shellfish harvesting in the intertidal zone near the community. Due to the location of the wastewater treatment plant and lack of signage there is the possibility of shellfish harvesting near to the MWWE discharge area. Migratory fish passage, hunting, and fishing are also possibilities beyond the intertidal zone.

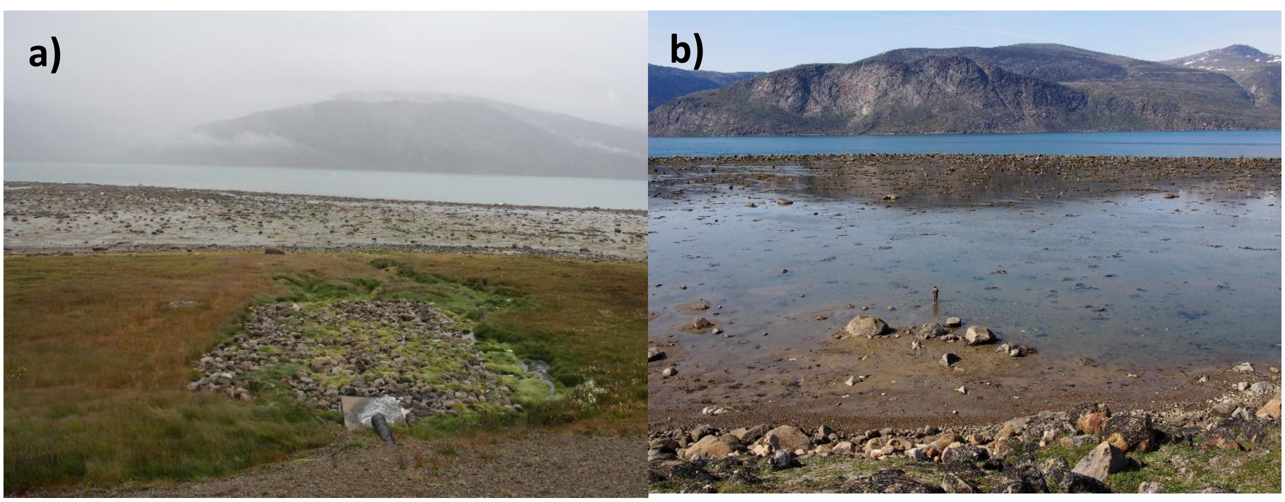


FIGURE 4. A) DISCHARGE CHANNEL AND THE EXPOSED TIDAL FLATS AT LOW TIDE ON AUGUST 22, 2012; AND B) SHALLOW RECEIVING WATER ENVIRONMENT NEAR LOW TIDE IN PANGNIRTUNG ON JULY 28, 2013

2.2.2 *Kugaaruk*

The hamlet of Kugaaruk (68° 32’ 05” N, 089° 49’ 29” W) has an estimated population of 771 (Statistics Canada, 2012). The site-specific study on the receiving water quality was conducted in Kugaaruk from August 21, 2013 to August 28, 2013. Average air temperatures range from –30 °C and –37 °C in January, and from 14°C and 5°C in July. Precipitation averages 117 mm as rainfall, and 1460 mm as snow, for a total of 261 mm of precipitation (Government of Canada, 2014).

Approximately 76 m^3/d (27,588 m^3/year) of primarily domestic municipal wastewater is generated daily (NWB, 2011b). Pump trucks are used to transport the wastewater from individual houses and establishments to the wastewater treatment facility, consisting of a single-cell WSP with a decant cell and wetland treatment area. The wastewater treatment facilities are located approximately 1 km south of the hamlet.

The WSP is typically decanted with a pump and generator into the decant cell twice for a period of several days between July and October. During the study period of 2013, effluent discharge rates into the receiving environment ranged from approximately 10 to 48 m^3/d. The variability in discharge rates can be attributed in part to a breakdown of the WSP pump during the site visit, which caused lower flow rates through the treatment systems. The effluent discharges from the WTA into a coastal marine receiving environment. The MWWE discharges into Pelly Bay, which has a maximum tidal range of approximately 3 m. Ambient receiving water currents were both cross-shore and inshore in direction, with the prevalent current direction being in the N-NE direction. The receiving environment is characterized by a moderately sloping boulder field that transitions to soft sediments ~50 m from shore (Figure 5a). Only a small rocky area is exposed at the lowest tides as shown in Figure 5b.

Traditional uses of the receiving waters near the discharge location of the MWWE may include fishing, hunting, and boating. Tourism activities are also popular in the area such as kayaking and boating.

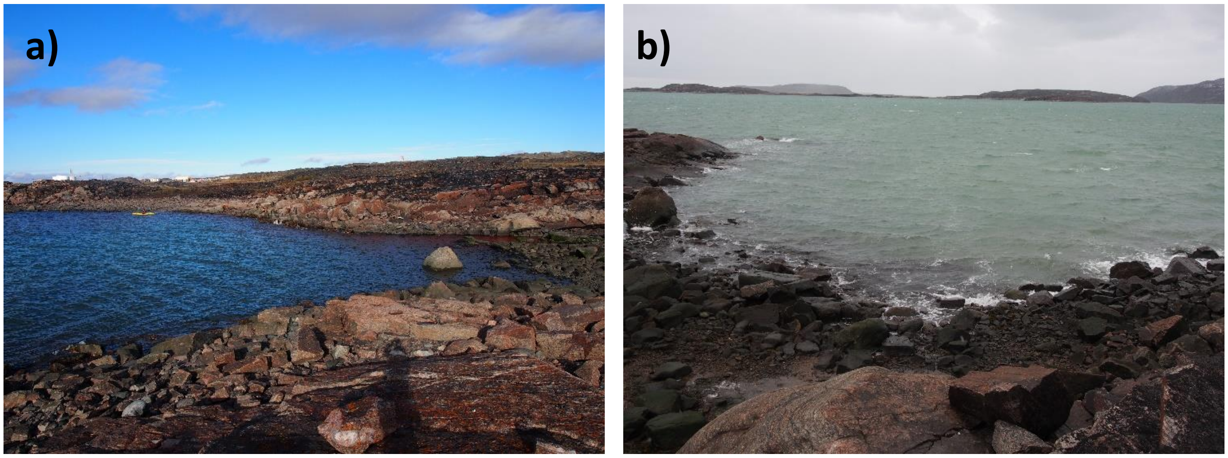


FIGURE 5. A) THE RECEIVING ENVIRONMENT IN KUGAARUK, NU ON AUGUST 23, 2013; AND B) ROCKY INTERTIDAL ZONE WHERE DISCHARGE POINT IS LOCATED IN KUGAARUK, NU ON AUGUST 26, 2013.

2.2.3 *Pond Inlet*

The hamlet of Pond Inlet is located on Baffin Island (72° 42’ 00” N, 77° 57’ 31” W) and has an estimated population of 1549 (Statistics Canada, 2012). The site-specific study on the receiving water environment in Pond Inlet was conducted from September 11, 2013 to September 18, 2013. Average air temperatures range from –30°C to –37°C in January, and from 11°C to 3°C in July. Precipitation averages 91 mm as rainfall, and 1319 mm as snow, for a total of 189 mm of precipitation annually (Government of Canada, 2015b).

Approximately 114 m^3/d (41 046 m^3/year) of primarily domestic municipal wastewater is generated in Pond Inlet (Nunavut Water Board, 2014). Pump trucks are used to transport the wastewater from individual houses and establishments to a single-cell WSP. The WSP is located approximately 1.4 km to the east of the hamlet. A manual decant of the WSP is performed annually for a period of three weeks in September or early October. A pump powered by a generator is used to lift the wastewater from the WSP to the discharge channel, at a rate measured within a range of approximately 1300 – 2400 m^3/d, over 12 hours each day during the discharge period. The range of flows observed can be attributed to pump issues and periodic pump outages due to refueling requirements. The discharge channel is rocky and approximately 275 m in length and descends steeply from the berm of the WSP in a perpendicular direction towards the marine receiving environment (Figure 6a).

Primary treated effluent discharges into Baffin Bay. The nearshore environment is characterized by a shelf (1 – 8 m depth) composed mainly of rocks and gravel interspersed with patches of sand that extends ~200 m from shore before dropping off to deeper depths (Figure 6b). This area has a maximum tidal range of 2.5 m, and very little of the shelf is exposed at low tide. The ambient receiving water currents were generally in a cross-shore direction, though the direction of these currents (predominantly in either the E or W directions) was observed to change between studies, dependent on the tidal regime.

Traditional uses of the receiving waters includes boating, fishing, and hunting. There is a known migratory route of Arctic Char during the summer period past the effluent discharge point. Timing of the discharge of MWWE into the receiving environment attempts to avoid release of effluent during the migratory fish passage.

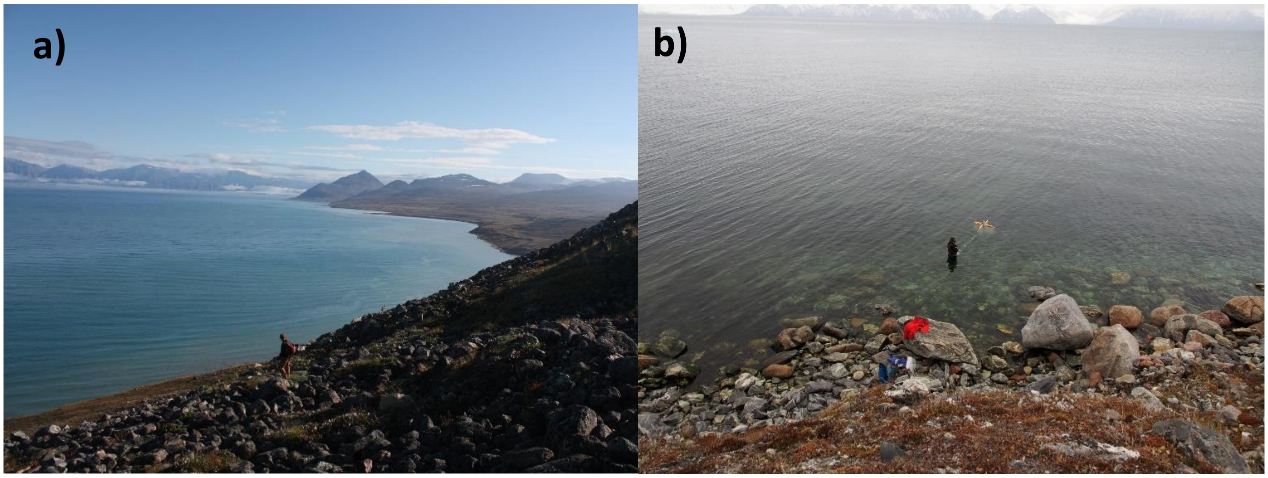


FIGURE 6. PHOTOGRAPHS OF POND INLET, NU SHOWING THE: A) STEEP SLOPE OF DISCHARGE CHANNEL ON AUGUST 19, 2010; AND B) RECEIVING ENVIRONMENT ON SEPTEMBER 12, 2013.

2.3 Mixing and dispersion characterization

2.3.1 *Tracer tests*

Dye tracer tests were conducted at each site to characterize the transport of the wastewater discharge in the nearshore receiving water environments. A fluorescent dye tracer, Rhodamine WT (RWT), was used for the tracer because it provided a visual indication of the extent of the plume. RWT dye tracer is a suitable tracer for receiving waters because it is conservative in surface waters over short time frames.

The methodology for conducting the tracer tests was primarily designed based on the *Revised technical guidance on how to conduct effluent plume delineation studies* document (Jacques Whitford and Natech, 2003), supplemented with additional information from various tracer studies found in the peer-reviewed literature (e.g. Pecly and Roldao, 2011; Carvalho et. al, 2002). Methods had to be adapted to the relatively low flow conditions that are characteristic of outfall sites in Nunavut. It is important to note that since the conditions occurring during the tracer tests are based on a fairly site-specific set of environmental conditions, the methodology used to complete the tracer tests differed slightly from what was found in literature, as well as, on a site by site basis.

The tracer tests consisted of a series of tasks conducted at each site. First, a quantity of 20% RWT dye was diluted with wastewater, in order to ensure matching densities with the wastewater stream. The dye mixture was then injected into the wastewater stream at an appropriate location so as to ensure adequate mixing prior to discharge to the receiving water environment. Two water quality sondes with RWT sensors were then used to measure the dispersion and transport of the dye within the receiving environment; one stationary, and one tracking the movement of the dye through the receiving waters. Transects were made across the dye plume in a perpendicular direction to the plume trajectory, as illustrated in Figure 7. Depending on the site conditions, a combination of wading, kayaks, and motorized boats were used to perform transects. The locations of the sondes were tracked using GPS logging equipment during transects that were conducted through the observed dye plume in the receiving environment.

These tracer tests were completed for various tidal regimes for each of the Pangnirtung, Kugaaruk, and Pond Inlet sites. The information collected within these tracer tests was then used to create 'dilution zones' to illustrate the observed wastewater mixing zones at these study sites. These dilution zones also provided insight into the transport characteristics at each location.

As these sites all feature marine discharges, considerations for the various tidal scenarios were required. As a result, the study approach focused on obtaining information from various tidal regimes including:

- Incoming Tide (IT),
- High Tide (HT),
- Outgoing Tide (OT), and
- Low Tide (LT).

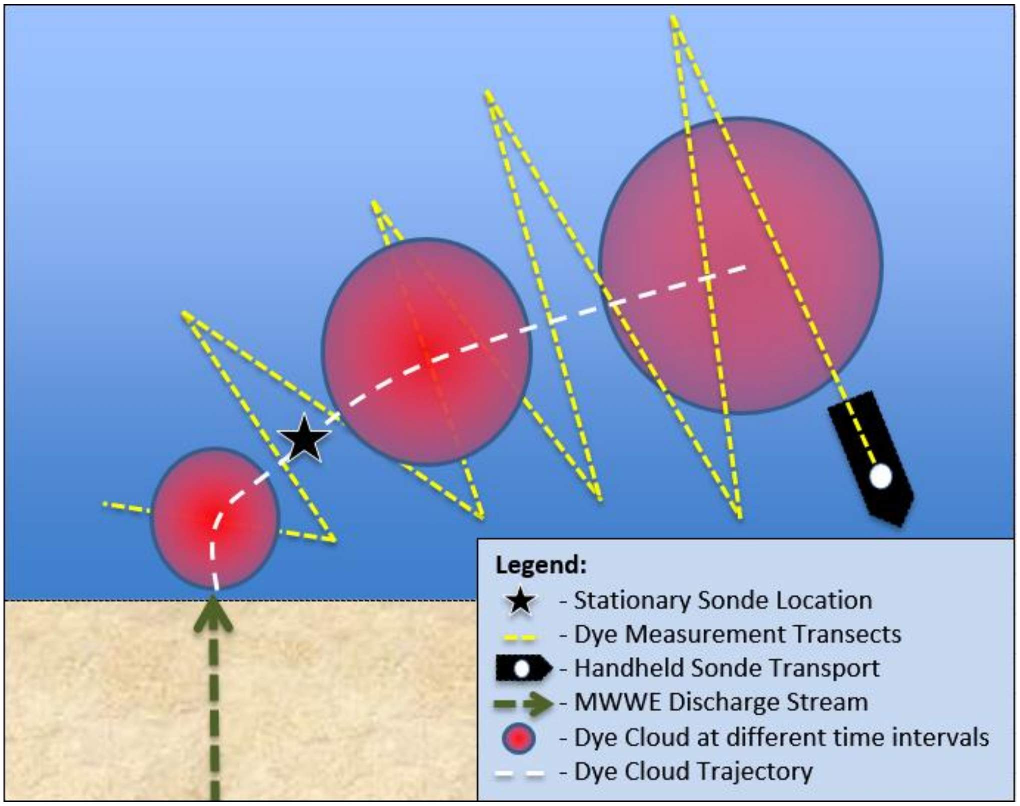


FIGURE 7. CONCEPTUAL DIAGRAM OF THE TRACER STUDY MONITORING TECHNIQUE.

2.4 GPS positioning

The positions of RWT dye concentration and water quality samples measurements were determined with Real Time Kinematic (RTK) GPS equipment. When RTK GPS was not feasible, handheld Garmin eTrex20 and Garmin Montana 650 units were used.

2.5 Plume delineation

The plumes of the MWWE in the receiving water were delineated to determine zones of dilution using the RWT concentrations measured within the nearshore environment. These zones of dilution represent the boundaries of: 1) minimal dilution, where less than 3x dilution of the concentration of RWT occurred; and 2) increased dilution, which has between 3 and 15x dilution of the concentration of RWT. These two dilution zones were arbitrarily selected as 3 and 15x dilutions through an analysis of the measured field data and are presented to provide a visual illustration of the plume behavior in the plume delineation maps that were generated for each site. Both the GPS data and the RWT concentration readings from the handheld sonde were linked together by assigning a RWT concentration reading to the GPS reading at each sample location. Once the datasets were combined, dilution zones were developed based on the maximum RWT concentrations observed at each sampling location within the study area. Several tracer tests were conducted per site and dilution zones were created by superimposing and connecting the dilution zones for each tracer study.

2.6 Water quality characterization

The locations where water quality samples were collected were determined based on the tracer study results. For instance, samples were collected where the dye tracer study concentrations were the highest, as well as along the dye tracer plume boundaries. Based on the site conditions, a combination of wading, kayaks, and motorized boats were chosen to collect the water quality samples. Water quality samples were analyzed for a suite of parameters including $CBOD_5$, TSS, *E. coli*, enterococci, TN, TAN, un-ionized ammonia (NH_3), and TP according to APHA (2012), and/or manufacturer's specifications. Discrete measurements of water quality indicators consisting of pH, dissolved oxygen (DO), specific conductivity, and temperature were made with handheld YSI multi-parameter sondes.

E. coli and enterococci were used as indicator organisms to assess microbial fate and transport in receiving waters. When possible, both were measured. However, there were several occasions where the laboratory conducting the analysis was only able to analyze for one of the indicator organisms. Water quality criteria of 35 MPN/100 mL for enterococci and 200 MPN/100 mL for *E. coli* were used to characterize human health exposure risk (Health Canada, 2015). These numeric criteria are based on the geometric mean sample criteria proposed by Health Canada, as this represents a more stringent requirement than the single sample maximum concentration criteria. Samples were analyzed for fecal streptococcus and not solely the subgroup enterococcus at the Kugaaruk location by the laboratory used; these results have been assumed to be analogous to the other enterococcus results to be conservative.

Reference sites were also selected at each of the three study communities. These reference sites were representative of areas of the marine environment where there are no human impacts from MWWE affecting the ambient water quality. These reference sites were selected to have similar site conditions as the receiving water site, and were located 2.5 – 5.0 km from the effluent discharge point. The locations of the reference sites in relation to the MWWE are shown in Figures 11 to 13.

3.0 Results

3.1 Dilution zones

3.1.1 *Pangnirtung*

Tracer study monitoring was conducted by wading in Pangnirtung due to the shallow receiving waters. Figure 8 shows the dye study during incoming (a) and high tide (b) in Pangnirtung. Overall, the MWWE plume boundaries observed in Pangnirtung extended a maximum of approximately 150 m from the discharge channel. The large tidal range observed in Pangnirtung caused substantial differences in plume characteristics between tidal regimes. As shown in Figure 11, the results of the tracer tests show major differences in tracer dye plume boundaries between the HT, IT, OT, and LT scenarios.

Pangnirtung had a unique low-tide discharge scenario, and was observed to have different effluent transport characteristics than the other study sites. During the low tide, there was a significant exposed intertidal beach zone, extending approximately 300 m from the high tide water level. As a result, wastewater discharged during this tidal regime traveled across the intertidal zone, braided into several small channels, with the majority of effluent ponding before reaching the receiving water environment (ponding at approximately 170 m from the observed high water level). Figure 11 shows the LT boundary which represents the extents of wastewater transport in these channels, before all channels were observed to be ponded and stagnant.

In addition, the OT study showed a significant amount of transport of RWT across the exposed intertidal zone as the water level receded. The timing of the recession of the tides was fairly quick, which transported both the effluent and associated RWT along the beach as the tide receded. With the minimal discharge quantity, velocity, and thus total discharge energy, near field processes were limited at this particular study site.

A separate site visit was completed on May 6, 2014 by GN representatives in order to collect information related to the winter discharge conditions observed in Pangnirtung. The purpose of the site visit was to assess the winter discharge conditions since Pangnirtung discharges effluent on a near-continuous annual basis. From this visit, it was difficult to determine transport characteristics, as ice cover extended to the approximate high water level previously observed on site, leaving the wastewater discharge hidden as it entered the intertidal zone.

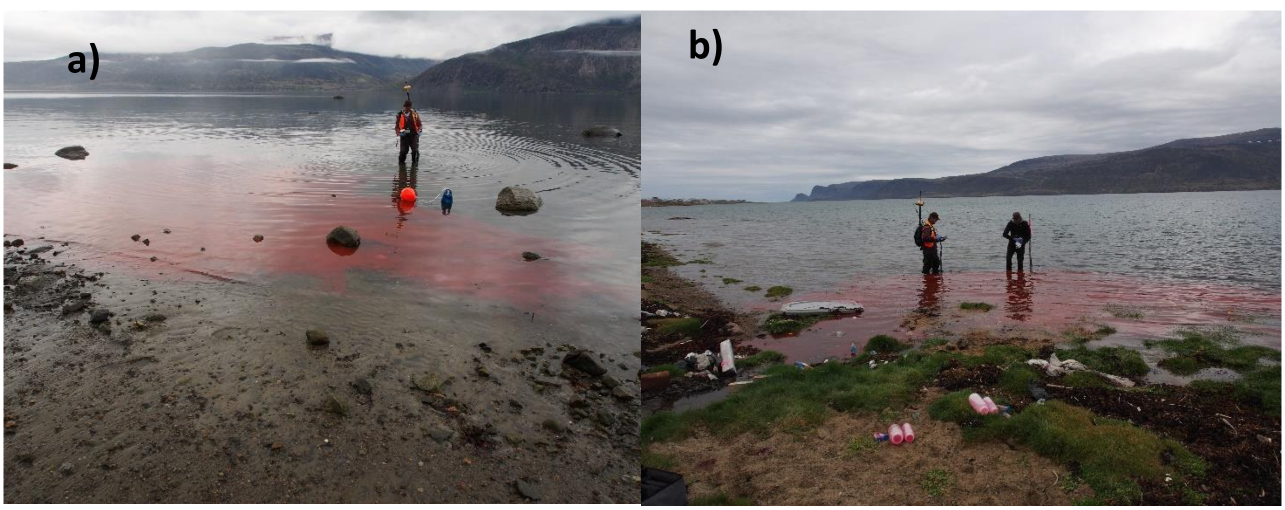


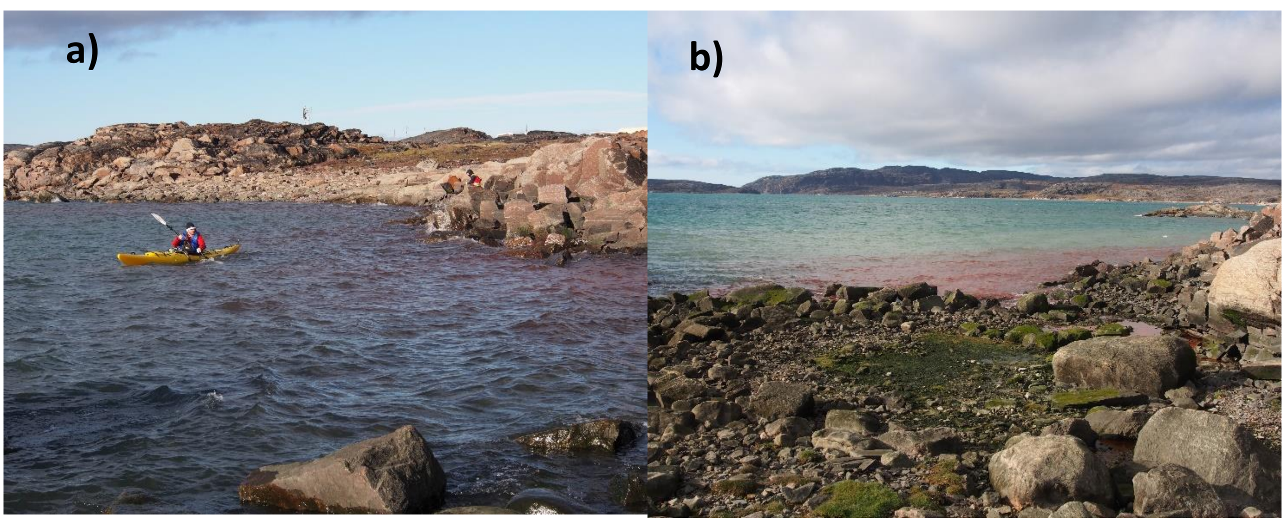
FIGURE 8. A) MONITORING THE TRACER STUDY AT IT ON JULY 27, 2013 IN PANGNIRTUNG, NU; AND B) DISCHARGE POINT AND DYE INJECTION POINT AT HT ON JULY 26, 2013.

3.1.2 *Kugaaruk*

Tracer monitoring was performed from a kayak in Kugaaruk due to predominately nearshore observed plume transport characteristics, as shown in Figure 9a. In Kugaaruk, the effluent entered the receiving water environment with minimal energy. This was due to both the dampening of discharge velocities through the treatment system, and the subsurface infiltration of the flow into a rocky tidal area prior to discharge into the marine environment. Discharges were observed to be transported with the ambient current along the shoreline in a north-eastern direction (Figure 9b). The highest concentrations of RWT were localized within a narrow banded area which extended approximately 60 m from the location where the wastewater entered the receiving waters (Figures 9c and 12). The measured maximum extent of the observable and measurable plume boundaries from the discharge location was approximately 100 m.

The dye plume attached to the downstream shoreline in all of the tracer study cases undertaken (Figure 9d). This is likely due to the absence of energy in the discharge, leading to minimal jet-like properties in the nearshore environment. As such, the flow at this location could be deemed either shoreline attached or upstream intruding.

Moderate and persistent winds (e.g., average of 27 km/hr measured during August 26th sampling event) generated wave action in the nearshore environment, which mixed the water column in the nearshore region. There was also slight density stratification along the nearshore travel path of the RWT, with values of specific conductivity at surface of approximately 11500 µS/cm, where bottom specific conductivity values were approximately 20200 µS/cm. As the values measured at surface have similar temperatures than those measured at bottom, it is likely that this measured difference in salinity is due to the discharged effluent. The differences in salinity at surface were also shown to have a declining trend as measurements were taken further from the discharge location. This further suggests that the effluent is mixing throughout the water column within a fairly small distance from the discharge location.



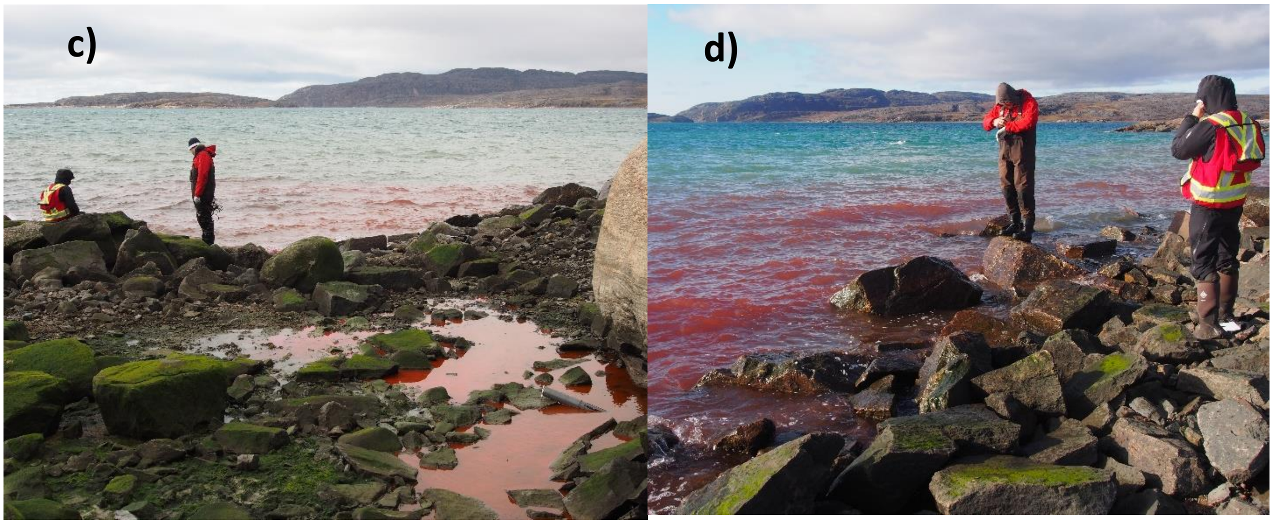


FIGURE 9. PHOTOGRAPHS OF THE TRACER STUDY IN KUGAARUK, NU ON AUGUST 23, 2013 SHOWING THE: A) MONITORING OF THE DYE PLUME IN A KAYAK; B) PLUME BOUNDARY TAKEN FROM THE NORTH-EASTERN PERSPECTIVE; C) DISCHARGE POINT JUST DOWNSTREAM OF WHERE DYE TRACER WAS INJECTED AND ENTERING THE ROCKY ZONE OF SUBSURFACE FLOW; AND D) SHORELINE ATTACHED BEHAVIOR PLUME BOUNDARY.

3.1.3 *Pond Inlet*

Tracer study monitoring in Pond Inlet was conducted by wading at the shore, as well as, from a boat when weather conditions permitted (Figure 10a). Pond Inlet's MWWE discharge rate and velocity were much higher than the other study sites. This was partly due to the discharge schedule (once a year, occurring over approximately three weeks), and a steep discharge channel that is not buffered by a wetland.

Figure 13 shows the extent of the dilution zones in Pond Inlet. At this site, initial dye dilution through spreading on the surface of the receiving waters occurred once effluent reached the nearshore marine environment (Figures 10b and c). Minimal dilution was observed once the ambient current became the dominant transport process. Several of the tracer tests completed at this location had conditions where wave action was minimal but currents remained strong. Under these scenarios, the dye was observed to remain in a small layer (approximately 5 – 15 cm) on the surface of the receiving waters, as it was transported through the receiving water environment. This resulted in long-range transport of elevated tracer dye concentrations, measured as far as ≥ 450 m during one of the tracer tests (Figure 10d). Minimal turbulent mixing occurred when receiving water conditions were calm and diffusion likely governed the mixing process.

In addition to the conditions outlined above, discharge scenarios accompanied by significant wind and wave action were observed during sampling events. Unfortunately, it was not safe to be in the boat, so minimal data could be obtained related to these events. Visual RWT observations were still made, however, and in one case samples were taken by wading during a period of strong wave action in the discharge location. These results indicated that the increased wave action in the nearshore environment significantly increased the mixing occurring in these scenarios, with dilution occurring at a rate much faster than the calm scenarios.

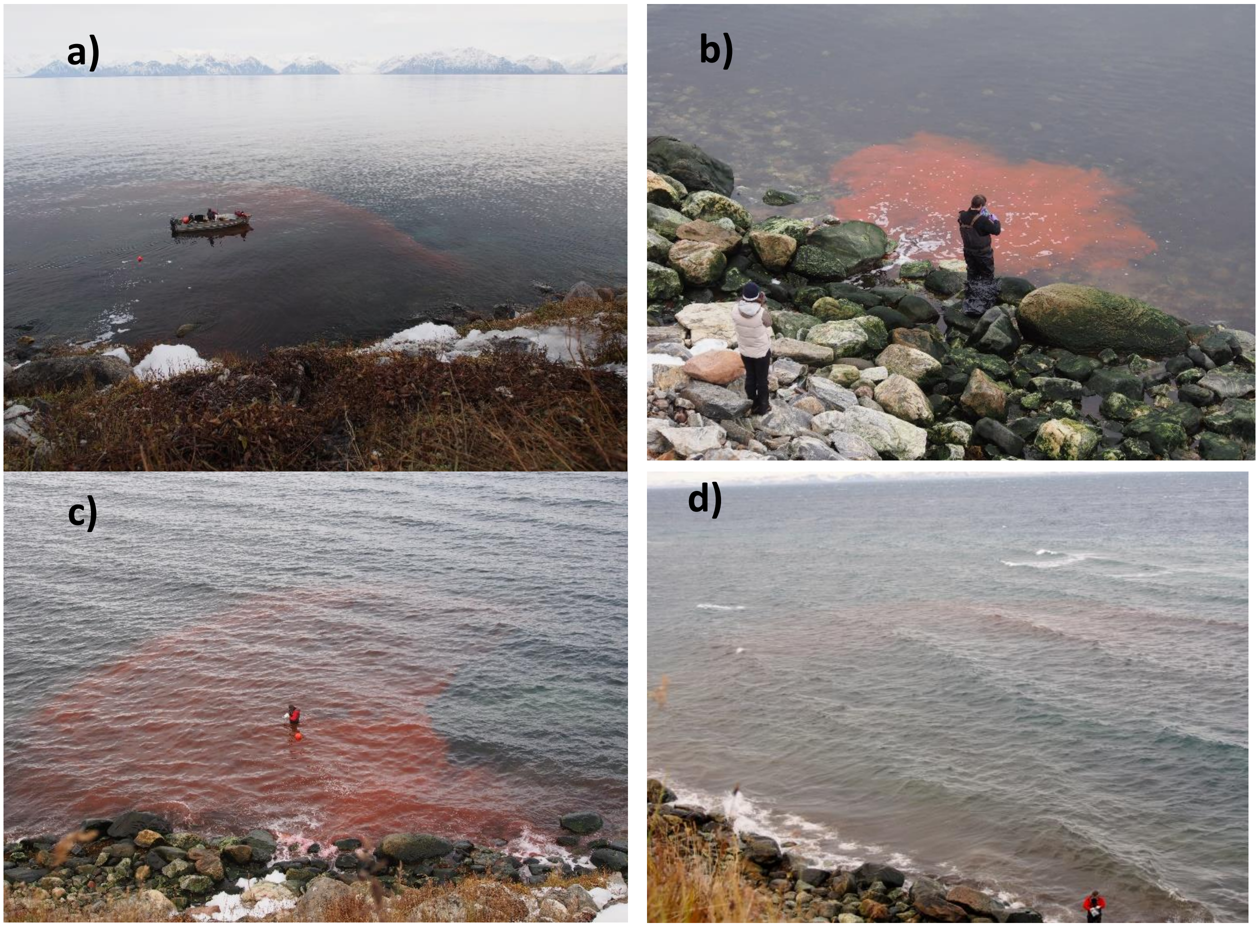


FIGURE 10. PHOTOGRAPHS OF THE RECEIVING ENVIRONMENT IN POND INLET, NU SHOWING THE: A) TRACER STUDY MONITORING FROM A BOAT ON SEPTEMBER 17, 2013; B) INITIAL MIXING OF THE DYE AT THE DISCHARGE LOCATION ON SEPTEMBER 12, 2013; C) NEAR-SHORE MONITORING OF THE DYE PLUME ON SEPTEMBER 15, 2013; AND D) LONG-RANGE TRANSPORT OF THE DYE ON SEPTEMBER 15, 2013.

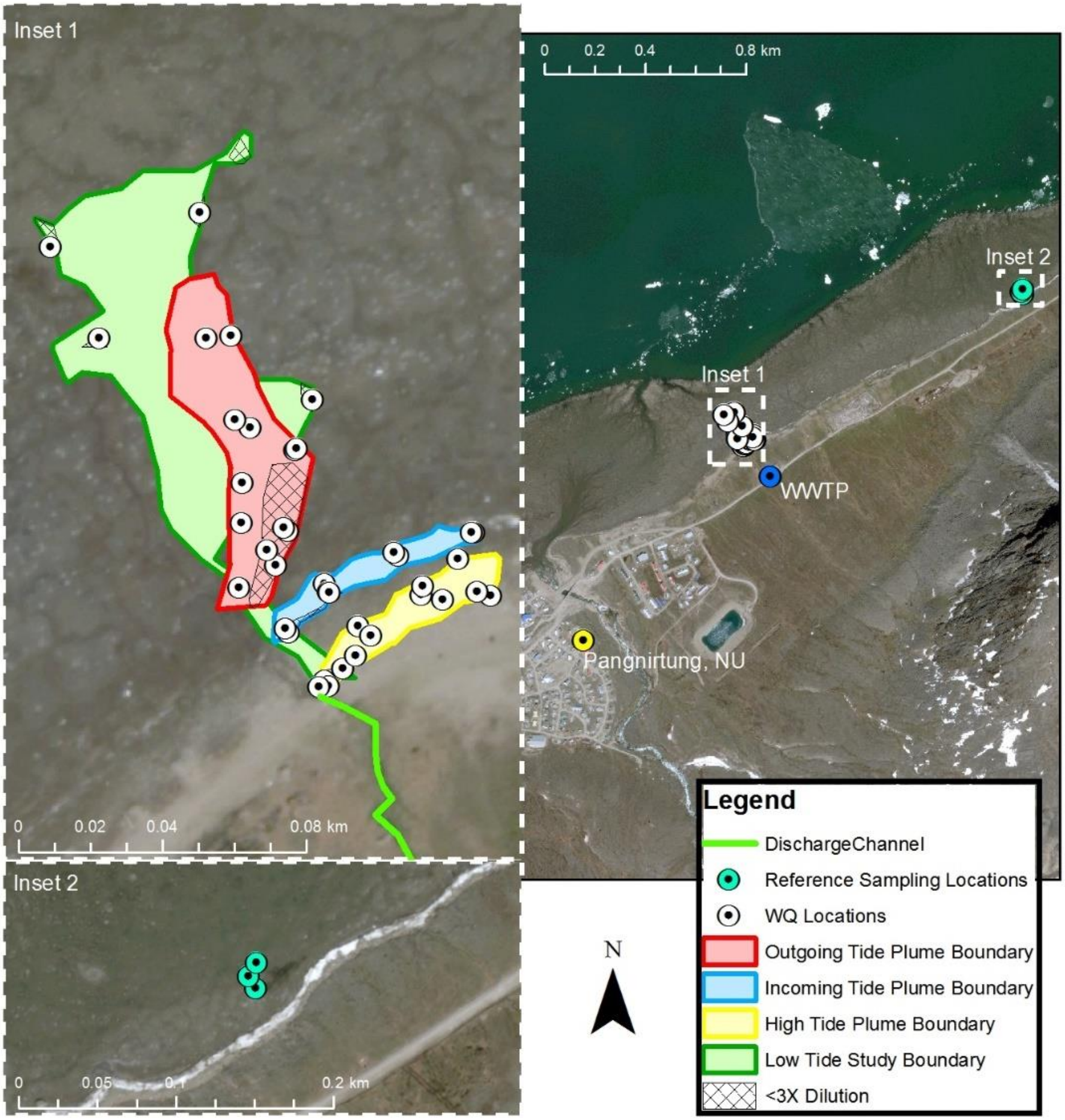


FIGURE 11. DELINEATION OF THE DILUTION ZONES AND WATER QUALITY SAMPLES IN PANGNIRTUNG, NU.

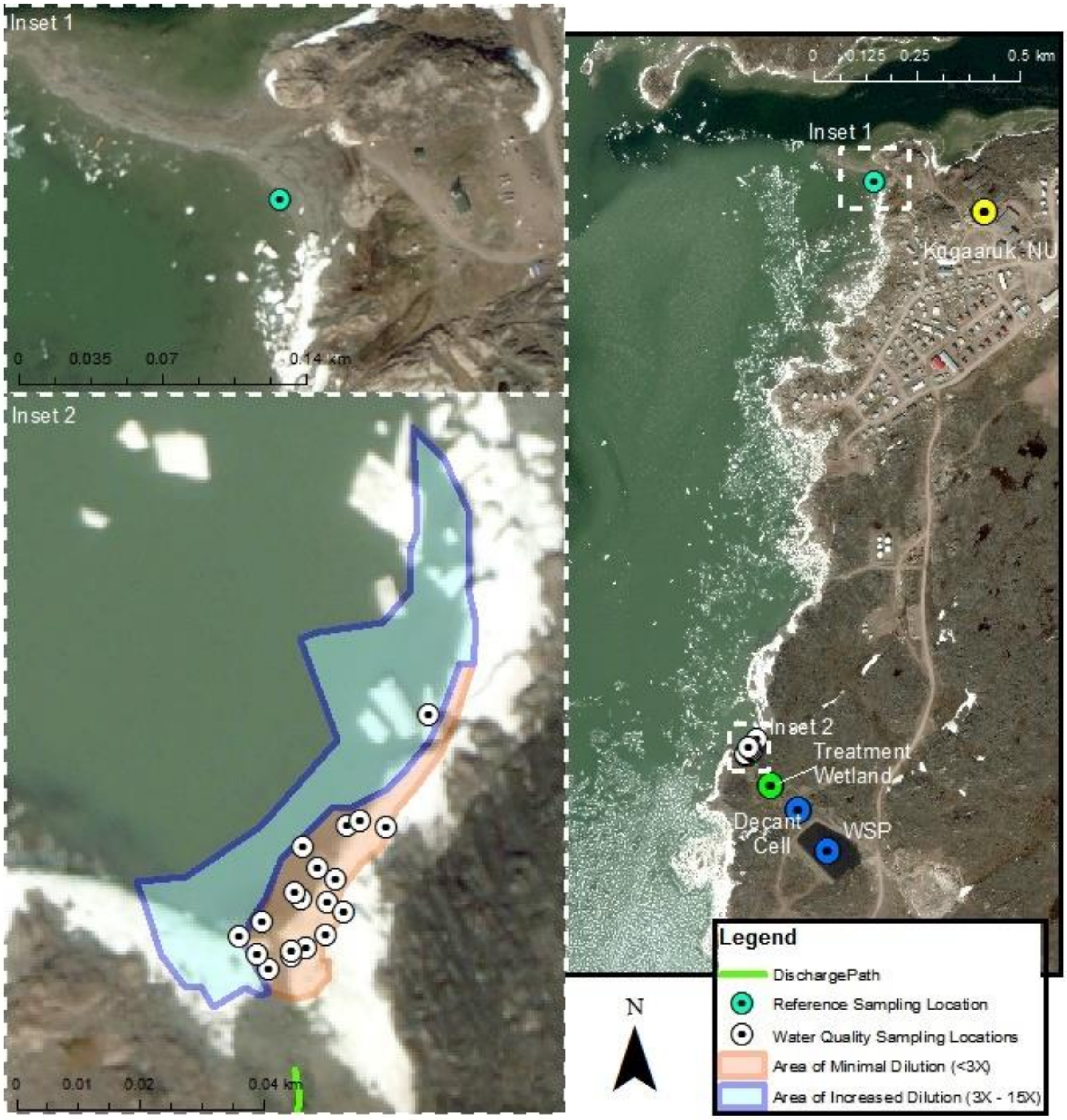


FIGURE 12. DELINEATION OF THE DILUTION ZONES AND WATER QUALITY SAMPLES IN KUGAARUK, NU.

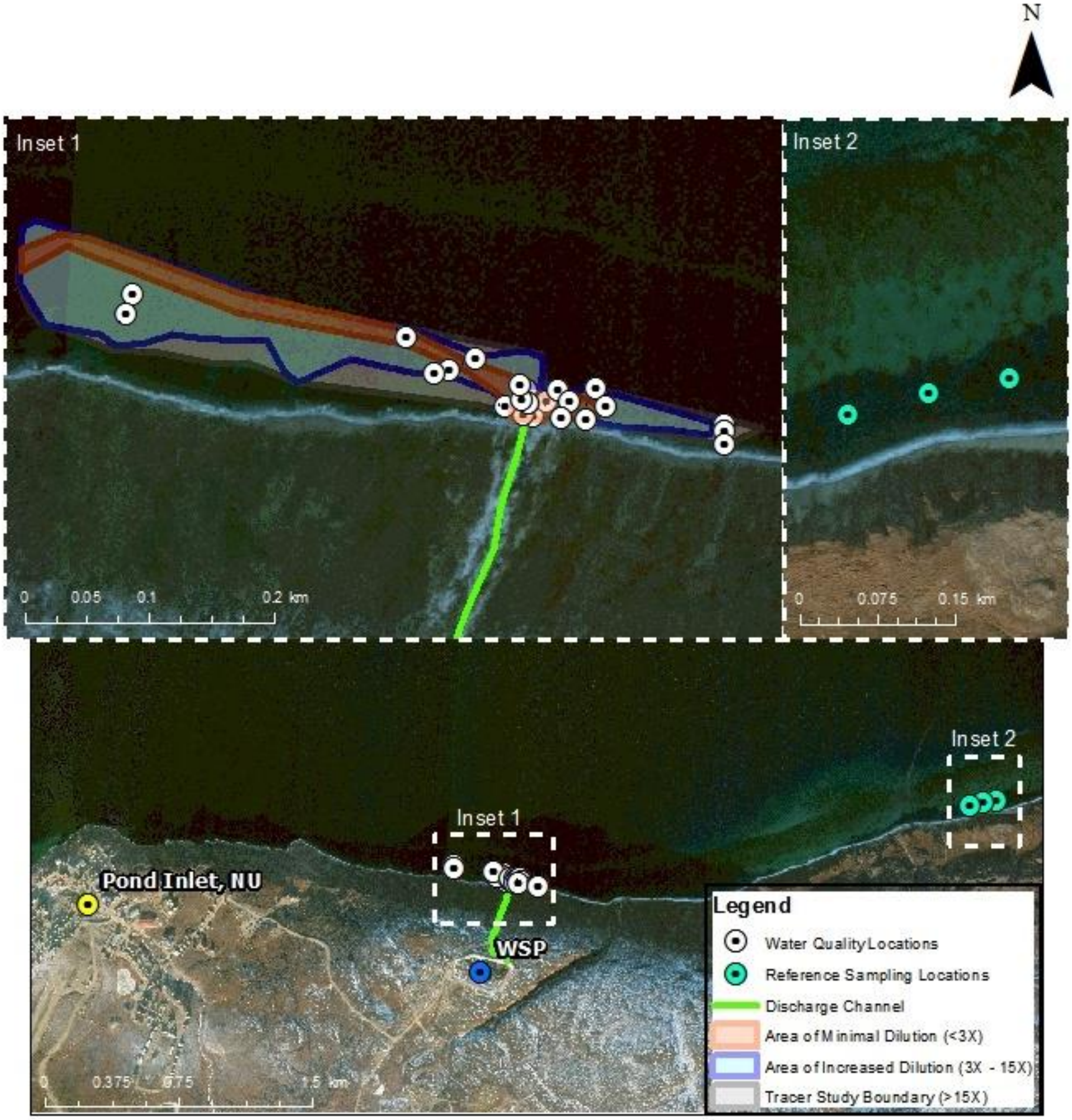


FIGURE 13. DELINEATION OF THE DILUTION ZONES AND WATER QUALITY SAMPLES IN POND INLET, NU.

3.2 MWWE water quality

The water quality of the treated MWWE entering the receiving waters in each of the study sites was characterized. This water quality data is summarized in Table 2. Overall, the MWWE entering the receiving environment varies in quality from levels typical of primary to secondary treated wastewater. According to the Droste (1997) classification, the Pangnirtung system obtains primary treatment levels with <50% removal of CBOD and TSS; the Kugaaruk system achieves secondary treatment levels with >90% removal of CBOD and TSS; and the Pond Inlet system can be classified as an advanced primary level of treatment with between 50 – 90% removal of CBOD and TSS. Therefore, Kugaaruk and Pangnirtung had the best and worst MWWE quality, respectively.

3.3 Background water quality

The background water quality at the reference sites is summarized in Table 3. Many of the parameters were below the detection limit, with the exception of TSS. TSS was elevated at the reference sites likely as a result of wave action, which suspends sediment in the water column. This was especially prevalent at Kugaaruk where background concentration of TSS averaged 27 mg/L.

3.4 Receiving water quality

3.4.1 *Maximum concentrations*

The maximum concentration values, and the distance from the discharge point to where they were observed, at each study site are summarized in Table 4. Out of all the sites, Kugaaruk had the lowest maximum concentrations of all the parameters. The overall concentrations were low in Kugaaruk due to the relatively lower MWWE concentrations, which can be attributed to the polishing treatment capacity of the wetland area. Also, greater mixing and associated dilution was observed in Kugaaruk compared to the other sites. Pangnirtung had the highest maximum observed concentrations in terms of TSS, TN, NH_3-N, and TP. Furthermore, the location of maximum concentrations in Pangnirtung were further away from the from the discharge location than the other two sites (e.g., ~140 m vs. 10 m).

Effects of the tidal cycle on the maximum observed concentrations of parameters varied between the sites and parameters of interest. In Pangnirtung, many of the maximum observed concentrations were observed during LT. In contrast, maximum concentrations were observed to generally occur in conjunction with the LT and IT in Kugaaruk. Maximum concentrations were observed during the HT, OT, and IT in Pond Inlet. If feasible, a potential management technique for lowering overall maximum concentrations would be to time the discharges around the tidal schedules. For example, in Pangnirtung discharge could be limited to HT periods where there would be maximum dilution, and decreased likelihood of human contact with the effluent on the exposed tidal flat.

Table 2. Summary of average wastewater system effluent quality from the study sites from samples taken during the treatment seasons from 2010 - 2013.

Site name	Parameter	$CBOD_5$ (mg/L)	TSS (mg/L)	NH_3 (mg/L)	*E. coli* (MPN/ 100 mL)	Enterococci (MPN/100 mL)	TN (mg N/L)	TP (mg P/L)	pH	DO (mg/L)
Pangnirtung	Average	104	253	0.80	6.0E5	1.8E5	66	8.9	7.8	7.5
	# of samples	6	6	6	6	3[a]	3	3	6	6
Kugaaruk	Average	12	3	0.42	4.5E3	1.0E2	53	4.4	7.5	4.6
	# of samples	2	3	3	3	1[a]	3	3	3	3
Pond Inlet	Average	47	77	1.85	9.1E5	1.5E4	80	5.4	8.2	15.1
	# of samples	4	8	7	7	4[a]	7	8	3	3

[a] – Taken from discharge stream just prior to entry into receiving water in 2013 samples, as identified as a parameter of interest primarily for this study alone. Represents a high level estimate.

Table 3. Receiving water quality results for the reference sites.

Site Name	Parameter	TSS (mg/L)	TAN (mg/L)	*E. coli* (MPN/100 mL)	Enterococci (MPN/100 mL)	TN (mg/L)	TP (mg/L)	pH	DO (mg/L)
	Average Value	11	0.020	1.5	<1	0.4	<0.01		
Pangnirtung	# of Samples	3	3	3	3	3	3	7.8	10.9
	Average Value	27.3	<0.005[b]	1	3.4	<2[b]	0.12	7.8	
Kugaaruk	# of Samples	3	3	3	3	3	3		13.9
		5.5	0.032	<1	36.3	<2[b]	0.06		
	Average Value								
Pond Inlet	# of Samples	2[a]	3	3	3	3	3	7.9	13.9

[a] – With one outlier (32 mg/L).

[b] – Detection limit.

TABLE 4. RECEIVING WATER TRACER STUDY WATER QUALITY SAMPLING RESULTS – MAXIMUM CONCENTRATIONS AND LOCATIONS.

Site Name	Parameter	TSS (mg/L)	TAN (mg/L)	*E. coli* (MPN/100 mL)	Enterococci (MPN/100 mL)	TN (mg/L)	TP (mg/L)
Pangnirtung	Maximum Value	383	85.8	2.20E3	<1.55E3	96.8	12.8
	Distance from Discharge (m)	140	130	50	50	140	140
	# of Samples	72	73	7	6	72	73
	Tidal Regime	LT	LT	OT[b]	HT[c]	LT	LT
Kugaaruk	Maximum Value	120[d]	9.7	6[a]	36.4	17.1	1.39
	Distance from Discharge (m)	10	5	5	8	5	5
	# of Samples	19	19	19	19	18	17
	Tidal Regime	OT/LT	LT/IT	LT/IT	LT/IT	LT/IT	LT/IT
Pond Inlet	Maximum Value	208[d]	20.8	5.90E4	1.9E4	21.9	2.01
	Distance from Discharge (m)	10	5	10	15	40	60
	# of Samples	41	41	29	33	41	41
	Tidal Regime	HT	HT	OT	LT	IT	IT

[a] - Fecal Coliform in CFU/100 mL.

[b] - Based on only OT data.

[c] - Based on only HT data.

[d] – Values influenced by background concentrations at time of sampling, represent concentrations larger than corresponding MWWE samples.

Pangnirtung and Pond Inlet distances to discharge based on HT Water Level Discharge locations.

Tidal Regimes: IT - Incoming Tide, LT - Low Tide, OT - Outgoing Tide, HT - High Tide.

TABLE 5. RECEIVING WATER TRACER STUDY WATER QUALITY SAMPLING RESULTS – LOCATIONS WHERE WATER QUALITY CRITERIA WERE MET.

Citations for water quality guideline		**CCME (2015).**	**B.C.MoE (2001).**	**HC (2015).**	**HC (2015).**	**Background[c]**	**Background[c]**
Site Name	**Parameter**	**TSS (mg/L)**	**TAN (mg/L)**	***E. coli* (MPN/100 mL)**	**Enterococci (MPN/100 mL)**	**TN (mg/L)**	**TP (mg/L)**
Pangnirtung	Water Quality Guideline	16[b]	7.5	200	35	<2	0.01
	Distance from Discharge (m)	>150[d]	>150[d]	>150[d]	>150[d]	>150[d]	>150[d]
	Tidal Regime	LT	LT	LT	LT	LT	LT
Kugaaruk	Water Quality Guideline	-[a]	7.5	200	35	<2	0.12
	Distance from Discharge (m)	-	<5	<5	<5	50	30
	Tidal Regime	-	LT/IT	LT/IT	LT/IT	LT/IT	LT/IT
Pond Inlet	Water Quality Guideline	10.5[b]	7.5	200	35	<2	0.05
	Distance from Discharge (m)	>330[d]	115	>330[d]	>330[d]	165	>330[d]
	Tidal Regime	HT	HT	HT	HT	LT	HT

[a] – Background concentrations much larger than MWWE results at this location.

[b] – Based on CCME WQAL marine requirements of 5 mg/L above background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d).

[c] – Guideline value based on maximum concentrations observed in the reference samples, as no CCME water quality guideline for protection of aquatic life exists for these parameters.

[d] – Values given as 'greater than' as sample results exceeded criteria at sampling boundary.

3.4.2 *Initial mixing zones*

The initial mixing zones, according to available guideline levels, were determined for the study sites. These were determined as the distance from the discharge point to the boundary where water quality parameters were below applicable guidelines, as shown in Table 5. Table 5 has been developed by taking the worst case scenarios of the distance from discharge point to where applicable water quality criteria were met based on the sampling information available. This provides a conservative assessment of what IMZ sizing definitions would be required in order to meet existing criteria based on current discharge scenarios.

Based on this analysis, Kugaaruk had the smallest IMZs for all parameters of equal to or less than 50 m. Pangnirtung had an IMZ of approximately 150 m in all cases, which was due to exposed intertidal zone of the nearshore environment. This intertidal zone was periodically exposed resulting in minimal dilution during low tides. Pond Inlet had the worst cases for IMZs due to the characteristics of the receiving environment, with minimal mixing and strong currents. For instance, some of the parameters of interest did not meet the guideline values within the water quality sampling boundary (i.e., 330 m from the discharge location) during worst-case scenarios in Pond Inlet.

3.4.3 *Total suspended solids*

In terms of TSS, Pangnirtung showed variable water quality depending on the tidal cycle, as shown in Figure 14. The worst case scenario in Pangnirtung for TSS coincided with the low tide where concentrations close to 50 mg/L were observed approximately 150 m from the discharge point. The MWWE entering the receiving environment in Pangnirtung had much higher TSS concentrations than Pond Inlet (e.g., up to 650 mg/L in Pangnirtung compared to 50 mg/L in Pond Inlet). Comparatively, Pond Inlet had the worst case scenario for TSS with concentrations of roughly 50 mg/L up to 330 m from discharge point during the HT sampling event (Figure 15). It should be noted that values from this tidal regime were observed to have very high TSS values when compared to the TSS observed in the MWWE discharge and the results from the other tidal regimes (Figure 15). Therefore, it is possible that the ambient TSS levels were high due to sediment entrainment from wave and current actions instead of from the MWWE.

3.4.4 Enterococci *and E. coli*

Pond Inlet had the worst case for long-range transport of enterococci with concentrations of $1x10^2$ to $1x10^3$ MPN/100mL up to 330 m from the discharge location during high tides (Figure 16). This was due to strong currents and limited mixing and dispersion of the effluent plume. Kugaaruk had the best case for enterococci concentrations with concentrations of less than 100 MPN/100 mL entering the receiving waters and a maximum distance of influence of 50 m (Figure 17). Generally, all of the parameters monitored in Kugaaruk followed this trend of having measurable concentrations localized to a small area. Figure 18 shows concentrations of $1x10^2$ to $1x10^3$ MPN/100mL *for E. coli* observed at 60 to 80 m from the discharge point in Pangnirtung.

3.4.5 *Ammonia*

In terms of TAN, the best case discharge scenario was observed in Kugaaruk with a localized area of less than 50 m from the discharge point where measureable concentratons were observed (Figure 19). In Pond Inlet, concentrations above the water quality criteria of 7.5 mg/L for TAN were observed in the effluent plume for distances of up to 115 m from the discharge location (Figure 20). As a result, long-range transport of TAN (i.e., greater than 150 m) was noted in Pond Inlet and in the LT tidal regime in Pangnirtung. Whereas, Kugaaruk was below the *Ambient water quality criteria for ammonia to protect marine aquatic life* (B.C. MoE., 2001) defined in Table 5 within 5 m of the discharge location.

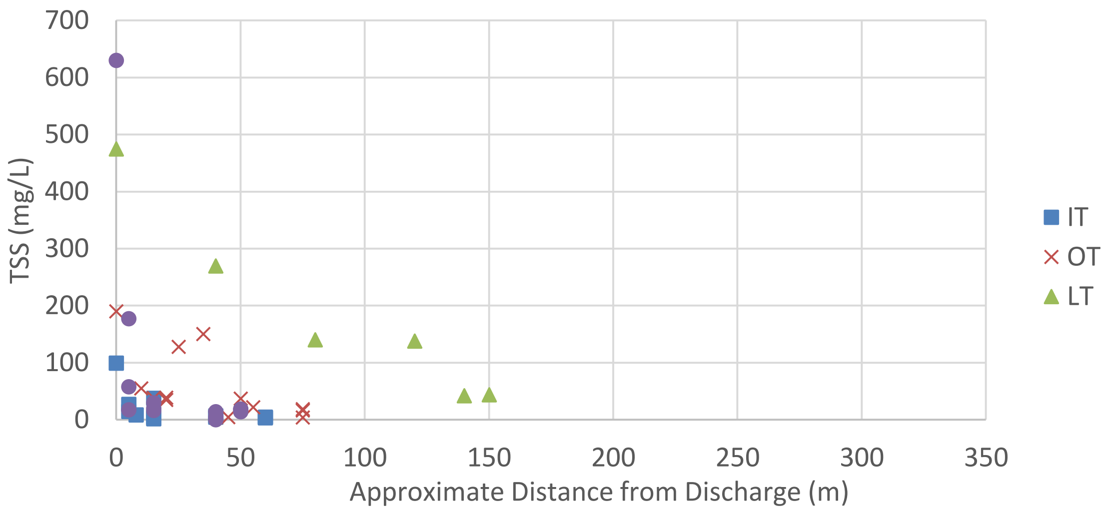


FIGURE 14. TSS IN THE RECEIVING ENVIRONMENT OF PANGNIRTUNG, NU.

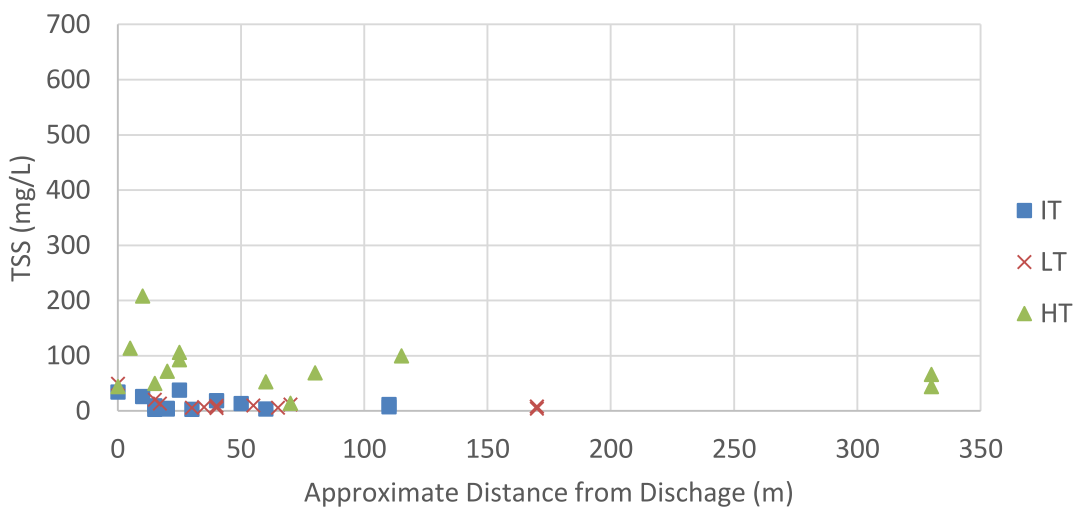


FIGURE 15. TSS IN THE RECEIVING ENVIRONMENT OF POND INLET, NU.

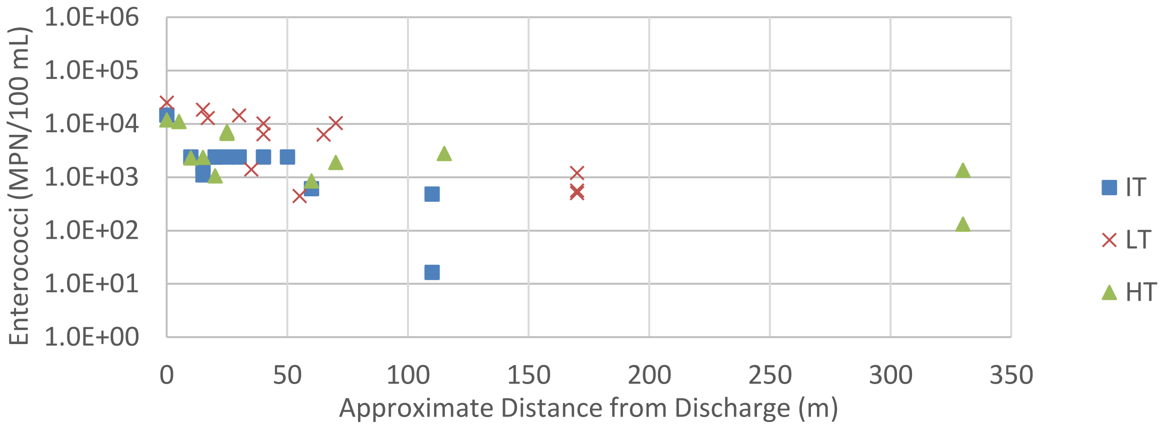


FIGURE 16. ENTEROCOCCI IN THE RECEIVING ENVIRONMENT OF POND INLET, NU.

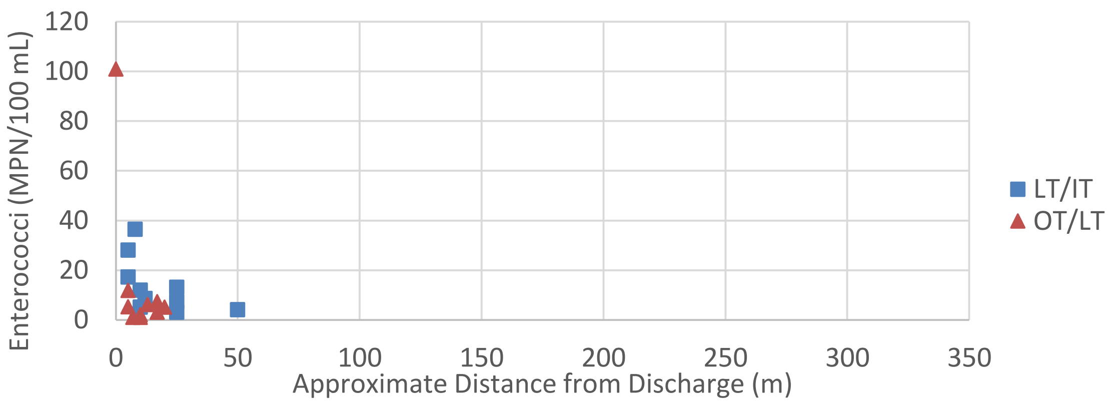


FIGURE 17. ENTEROCOCCI IN THE RECEIVING ENVIRONMENT OF KUGAARUK, NU.

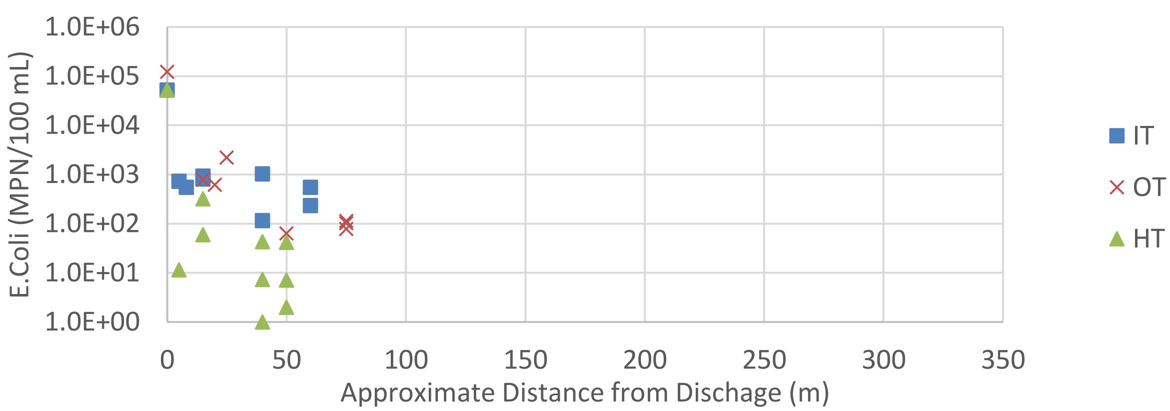


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FIGURE 18. *E. COLI* IN THE RECEIVING ENVIRONMENT OF PANGNIRTUNG, NU.

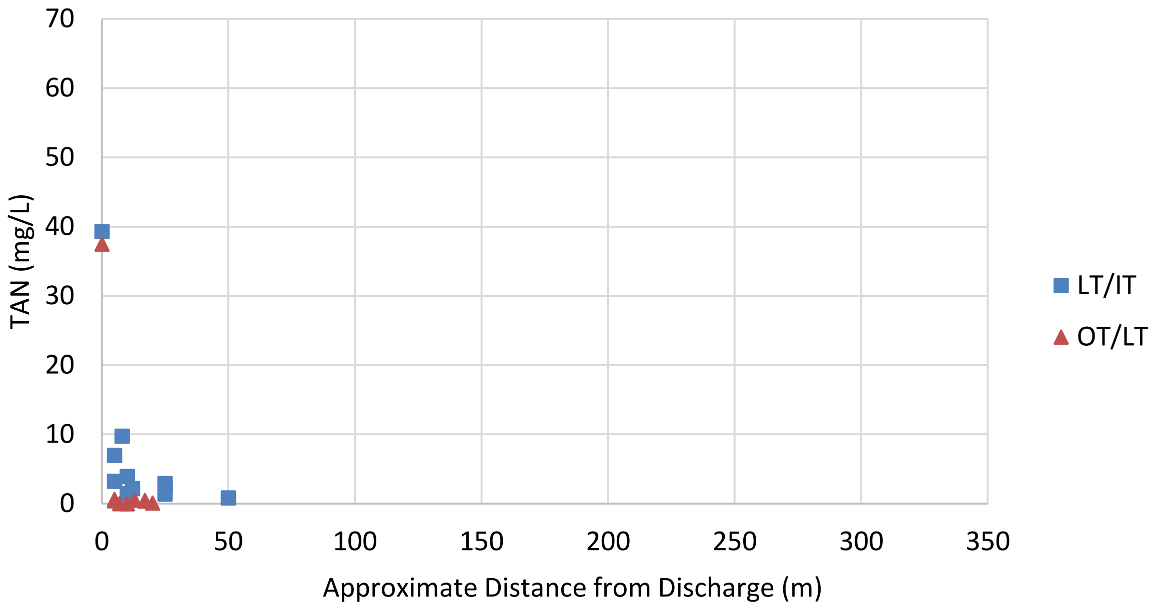

FIGURE 19. TAN IN THE RECEIVING ENVIRONMENT OF KUGAARUK, NU.

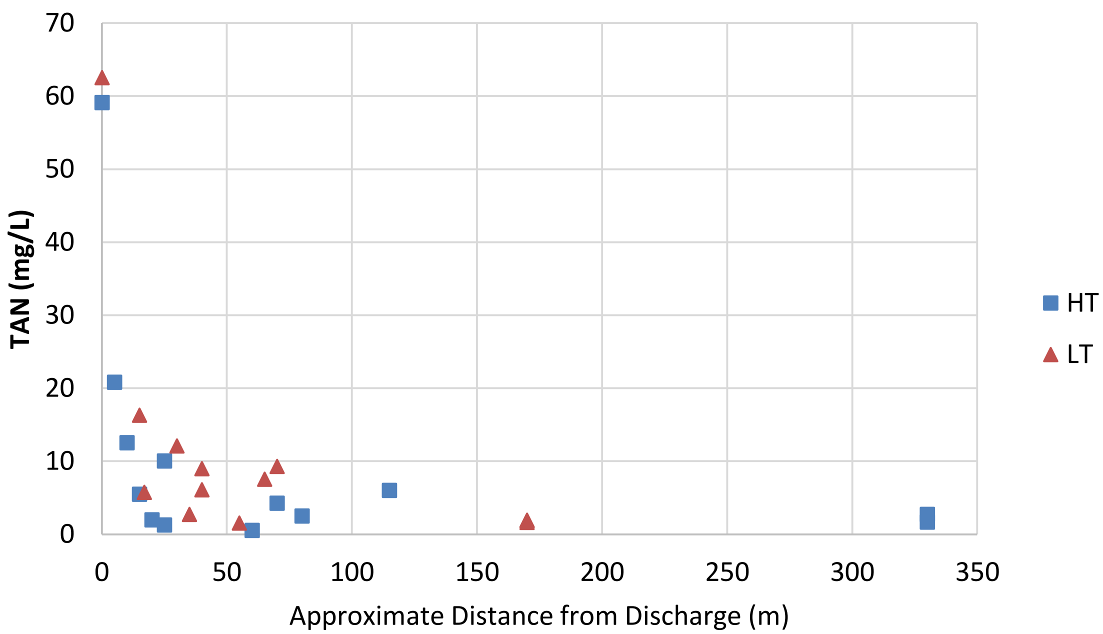

FIGURE 20. TAN IN THE RECEIVING ENVIRONMENT OF POND INLET, NU.

4.0 Discussion

4.1 Factors influencing impacts

There are a variety of factors that affect the water quality impacts in the receiving environment. These factors include the:

- ambient characteristics of the receiving environment,
- discharge rates,
- timing of the discharges,
- water quality of the effluent, and
- receiving water uses.

Although efforts were made to ensure the three study sites provided data that could be related to the most typical MWWE discharges in Nunavut, it was not feasible to cover all the potential scenarios. A few of these factors were difficult to assess with these three study sites. For instance, the type of receiving environment was marine in all three cases; therefore freshwater receiving environments were not assessed. However, it was still possible to compare how different near shore bathymetry, wind exposure, and tidal range scenarios affected mixing. These site-specific studies demonstrated that the characteristics of the receiving environment— specifically the bathymetry, tidal cycle and currents—are important in relation to the water quality impacts associated with each system.

4.1.1 *Ambient characteristics of the receiving environment*

The relationship between the receiving environment bathymetry and tidal ranges was observed to be an important characteristic influencing the water quality impacts associated with the MWWE discharge. This was best demonstrated in Pangnirtung as a result of the intermittingly exposed intertidal area where the effluent was discharged. The least favorable water quality scenarios for this system coincided with low and outgoing tides because the intertidal zone was exposed with little to no dilution of the effluent for up to 150 m from the discharge. The other sites did not include exposed intertidal zones and had steeper nearshore bathymetry, which helped to dilute the effluent within a much shorter distance from the discharge location.

The near-field mixing and dispersion processes were generally not significant as the discharge rates were very low for most of the sites (e.g., <150 m^3/d). Therefore the characteristics of the ambient environment were more important for transport and mixing of the effluent plume. Additionally, the buoyancy differences between the MWWE discharge and ambient receiving water affected the mixing of the effluent plume. This is particularly important because the ambient current conditions were observed to be both highly variable based on site specific conditions (e.g., wind, tides), as well as varying on a site to site basis. For example, the ambient currents were not observed to be as strong in Kugaaruk (e.g., predominantly 0.02 – 0.05 m/s). These ambient currents combined with the receiving water features, resulted in shoreline attached flows at all times in

Kugaaruk. This contributed to a relatively small area of influence of the effluent plume compared to the other sites. There would be concern, however, if there were human activities occurring along the shoreline close to the effluent discharge location. This contrasted with Pond Inlet where strong ambient currents (e.g., consistently measured at 0.17 – 0.25 m/s) transported the effluent plume long distances with limited dilution (i.e., > 450 m in one scenario). Therefore, the ambient currents are very important to assess the water quality impacts of MWWE discharge in these small communities.

4.1.2 *Discharge rates*

Many communities in Nunavut are classified as very small to small according to the WSER (Government of Canada, 2012). These systems have daily discharge rates ranging from approximately 10 to 2400 m^3/d (with exception of Iqaluit). Therefore the volume of wastewater entering the receiving environment is small relative to many other systems across Canada. In this study, Kugaaruk had the lowest daily discharges ranging from 10 to 48 m^3/d, in comparison to Pangnirtung which had discharges of 136 m^3/d. Whereas, Pond Inlet had daily discharges of up to 2400 m^3/d over a short time frame (few weeks). These discharges are all relatively small in magnitude which results in low energy discharges when compared to larger treatment systems common in more southern jurisdictions. Therefore the ambient conditions in the receiving environment quickly become the controlling factor for mixing and dispersion. As a result of the similarity in discharge magnitudes, the differences in mixing and dispersion of the effluent plume were attributed mainly to ambient conditions.

4.1.3 *Timing of discharges*

For these studies, the timing of discharge has been identified as an important management parameter. This significance is best illustrated in Pangnirtung, where when discharge coincided with LT, the effluent discharged onto the exposed tidal flats which do not dilute the effluent. This scenario had impacts on the water quality further from the discharge location. Also, long-range transport of weakly diluted effluent occurred when discharge timing coincided with strong ambient currents with minimal wave action in Pond Inlet. Both of these scenarios demonstrated the importance of timing the discharges to occur during periods when the effects on water quality are minimized, if possible. Despite this, the conditions observed in Pond Inlet may be too variable to implement feasible management changes (i.e., unpredictable currents and wave influenced mixing).

4.1.4 *Water quality of the effluent*

The water quality of the MWWE entering the receiving environment varied depending on the upstream treatment system. Kugaaruk had the best MWWE water quality, and Pond Inlet and Pangnirtung had similar MWWE water quality entering the receiving waters. The Kugaaruk treatment system consists of the wetland and WSP in combination; whereas the Pond Inlet system uses only a WSP; and Pangnirtung relies on a mechanical treatment plant which was undersized at the time of the study. The differences in MWWE quality likely contributed at least in part to better overall results for Kugaaruk in terms of IMZs and distances to maximum observed concentrations.

4.1.5 *Receiving water uses*

The receiving water uses were different between the study sites. For example, the sites with the highest human risk in terms of receiving water uses were Pangnirtung and Pond Inlet. This is because shellfish harvesting occurs in the intertidal zone near the community in Pangnirtung. There is also the chance of boating, hunting, and migratory fish passage in the IMZ of Pond Inlet.

4.2 Assessment of impacts to water quality

The scenarios that most strongly impacted the water quality, in terms of high concentrations and long-range transport, were observed to coincide with periods of strong ambient currents, and inopportune timing of the discharge in conjunction with tidal cycles. Both Pond Inlet and Pangnirtung had poorer receiving water quality than Kugaaruk. This was because specific ambient current conditions in Pond Inlet can lead to long-range transport of minimally diluted effluent (> 330 m). Long-range transport of minimally diluted effluent increases the likelihood of human contact. Pangnirtung also carried human health and environmental risks especially at low and outgoing tidal periods because effluent flowed undiluted through the exposed intertidal zone during these conditions. This is problematic because shellfish harvesting is a common practice in the intertidal zone in Pangnirtung; however, the proximity of this activity to the WWTP was not examined as part of this study.

Kugaaruk was observed to have good water quality compared to the others because the upstream treatment processes improve the quality of the effluent prior to discharge into the receiving environment. Also, the wind action and ambient currents were observed to encourage localized mixing and transport, with no evidence of long-range of the effluent observed at this location.

4.3 Risk mitigation techniques

There are simple and more complex techniques that may be used to mitigate human health and environmental risks associated with the receiving environments. Choice of the appropriate technique depends on the severity of the risks and consequences to human health and the environment. Some of the simpler options to mitigate risk to the receiving environment include strategic timing of discharges and community education. Advanced technical solutions may also be considered depending on the severity of the risks associated with the wastewater treatment systems.

The goal for strategic timing of discharges would be to avoid low tide discharges at sites that have exposed tidal flats or similar shallow bathymetries. Evidence also suggests that the existence of a wetland treatment system area upstream of the discharge location (e.g., Kugaaruk) allows for both improvements to MWWE quality and dissipation of the discharge energy prior to entering the receiving water environment (Hayward et al., 2014).

Community education would aim to engage the local residents and users of the receiving waters to communicate the location of the wastewater discharge and extent of the IMZs. Recreational activities can be avoided in the areas where the plume is suspected to be during discharge periods. Indigenous knowledge on the timing of fish and mammal passage can be gained through community consultation and the timing of discharges can be planned to avoid interference with the aquatic life. Installation of signage near the discharge point would be useful to warn of the presence of municipal wastewater. As shoreline attached plumes were observed to occur at all study sites, signage both at the discharge location and at set distances along the shore surrounding this discharge location would provide an indication to residents of potential areas of concern related to MWWE discharges.

More complex risk mitigation solutions involve improving upstream wastewater treatment systems to improve MWWE water quality; which would have significant capital costs. In some scenarios, it may be more cost-effective to consider using submerged discharge pipe and diffuser system to increase mixing and dispersion in the water column. The design and installation of a single or multi-port diffuser system to promote mixing and dispersion of the MWWE in the receiving waters as it is discharged would provide benefits compared to buoyant surface discharges. For example, this may be an option in Pond Inlet to help mitigate long-range transport of the minimally diluted effluent plume.

5.0 Conclusions

This study focused on characterizing water quality impacts associated with municipal wastewater treatment discharges in Nunavut. This was facilitated with dye tracer tests and water quality monitoring in three marine receiving environments downstream of MWWE treatment facilities. Findings from the studies indicated that there are a variety of factors to be considered to adequately assess the water quality impacts to the receiving environments. These factors include the ambient characteristics of the receiving environment, MWWE discharge rates, timing of the discharge, water quality of the MWWE, and uses of the receiving water.

The most significant factors leading to worst-case scenarios in terms of receiving water quality were demonstrated in Pangnirtung and Pond Inlet. In these cases, the characteristics of the receiving environment, timing of the discharges, and MWWE quality contributed most strongly to the observed impacts to water quality. Pangnirtung's receiving environment was characterized by a shallow intertidal area where discharge during low tides led to exposed and undiluted effluent on the tidal flats observed up to 150 m from the discharge location. In Pond Inlet, higher discharge rates and strong ambient currents facilitated long-range transport of minimally diluted effluent observed over 330 m from the discharge point. The plume was transported in a thin layer on the surface of the water as a result of limited mixing and dispersion due to strong buoyancy differences and lack of wave action. Both of these worst case scenarios increased the likelihood of human contact with effluent that still posed significant health risks (e.g., fecal indicators levels above the recreational water quality guideline of 35 MPN/100mL for enterococci).

In terms of extent of water quality impacts in the receiving environment, the best case scenario was observed in Kugaaruk. This was due to several factors, including the semi-enclosed shoreline morphology, significant wave action observed in the receiving environment, the relatively better water quality of the MWWE, and the dampened discharge rates. As a result, the discharging effluent required less dilution to reach desired water quality criteria and was mixed well within relatively short distances from the discharge point (IMZs generally less than 30 m).

Each study site was different and had a unique set of factors that influenced the overall water quality impacts associated with MWWE discharge into the receiving environment. The findings from this study can be used to perform high-level risk assessments of other systems in the Territory and assign priorities for risk mitigation. A few of the factors that influence the associated human health and environmental risk in the Far North are unique from the rest of Canada. For instance, the discharge rates are generally very small to small (10 – 2400 m^3/d), many discharges are intermittent (period of few weeks at the end of summer), the water treatment systems are varied, and in many cases passive. These treatment systems have variable effluent water quality that typically does not consistently meet southern WSER quality standards due to practical limitations.

These differences should be considered during the formation of a risk assessment framework for the Far North. Of particular importance is the consideration of relatively simple and practical solutions for mitigating the severity of the water quality impacts associated with MWWE discharges, such as strategic timing of discharges around tidal cycles, community engagement and education, and implementing changes to discharge outfalls to promote additional mixing.

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