Wetland Treatment Area Study in Sanikiluaq, Nunavut

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List of Abbreviations

%	Percent
C_{out}	Outflowing Effluent Concentration
°C	Degrees Celsius
µg	Micrograms
µS	Microsiemens
$CBOD_5$	Five-Day Carbonaceous Biochemical Oxygen Demand
CFU/100mL	Colony Forming Units per 100 mL
CGS	Community of Government Services
cm	Centimeter
CWRS	Centre for Water Resources Studies
d	Day
DEM	Digital Elevation Model
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
Eq.	Equation
Et al	*Et alii*
ET	Evapotranspiration
GN	Government of Nunavut
GPS	Global Positioning System
ha	Hectare
HLR	Hydraulic Loading Rate
hr	Hour
HRT	Hydraulic Retention Time
i.e.	*Id Est*
k	Areal First Order Rate Constant

K	Hydraulic Conductivity
kg	Kilogram
km	Kilometre
km^2	Square Kilometre
L	Litre
m	Metre
m^2	Square Metre
m^3	Cubic Metre
mg	Milligram
mL	Millilitre
mm	Millimetre
MPN/100mL	Most Probable Number of Colony Forming Units per 100mL
N	North
NAD83	North American Datum 1983
NH_3-N	Un-ionized Ammonia Nitrogen
NU	Nunavut
NWB	Nunavut Water Board
OH	Ohio
P	Precipitation
PAEK	Polynomial Approximation with Exponential Kernel
PET	Potential Evapotranspiration
Q	Discharge
QC	Quebec
RTK	Real-Time Kinematic
RWT	Rhodamine WT
RWU	Residential Water Use
TAN	Total Ammonia Nitrogen

TIS	Tanks-In-Series
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
V	Volume
VSS	Volatile Suspended Solids
W	West
WS	Wetland Segment
WSER	Wastewater Systems Effluent Regulations
WSP	Wastewater Stabilization Pond
WTA	Wetland Treatment Area
yr	Year
θ	Hydraulic Retention Time

Executive Summary

This report provides an assessment of a Wetland Treatment Area (WTA) currently used for municipal wastewater treatment in the community of Sanikiluaq, NU. The current WTA receives wastewater in an un-controlled manner from a detention lagoon. The Centre for Water Resources Studies (CWRS) at Dalhousie University undertook a detailed assessment of the WTA during the 2016 summer treatment season. Fieldwork was conducted in the community during two site visits in the spring freshet period and the late summer. The assessment included characterization of the physical, biological, hydrogeological and hydrological attributes of the WTA, and water quality sampling to quantify the current level of treatment occurring within the system.

The WTA and contributing watershed were delineated using survey data collected on-site in combination with a publically available digital elevation model and satellite imagery. The WTA was determined to be approximately 3.3 ha in size while the contributing watershed was 170 ha. The large watershed area results in significant dilution of both the wastewater stored in the lagoon, and as it flows through the WTA. Flow rates of water were measured at the inlet and outlet of the WTA and showed that influent wastewater was diluted by 392% to 1111% in the spring freshet and 310% in the late summer by external hydrological contributions.

The concentrations of key water quality parameters in the WTA effluent were well below the Nunavut Water Board water license requirements, with five-day carbonaceous biological oxygen demand ($CBOD_5$) concentrations < 6 mg/L, total suspended solids concentrations (TSS) < 15 mg/L, and *Escherichia coli* (*E. coli*)concentrations < 30 CFU / 100 mL during both spring freshet and late summer sampling periods. The low concentrations of these parameters observed at the WTA outlet was primarily attributed to the dilute nature of the influent that seeped through the lagoon berm, and the additional dilution which occurred in the WTA.

A mathematical model was constructed and parameterized using site-specific data collected from the WTA. A suite of scenarios were run to assess how the WTA would perform as a function of influent quality, loading rates, and climate. For a typical scenario in which an engineered WSP is used for storage and primary treatment, it is expected that WTA influent concentrations would be 150 mg/L for $CBOD_5$, $1x10^5$ CFU/100mL for *E. coli*, 80 mg/L for total nitrogen (TN), and 10 mg/L for total phosphorus (TP). For this level of influent quality, and median climate conditions, it was predicted that the WTA would achieve effluent $CBOD_5$ concentrations of 43 – 45 mg/L, *E. coli* concentrations would range from $1.5x10^4$ – $2.9x10^4$ CFU/100 ml, TN concentrations would be approximately 23 mg/L, and TP concentrations would be approximately 3 mg/L. This effluent concentrations were predicted assuming the WSP was decanted over a 2-month period. Again, the modeling results demonstrated that the primary mechanism for contaminant concentration reductions in the WTA was dilution.

A community consultation was conducted during the site visit in September 2016. This consisted of a presentation to the council members during the monthly hamlet council meeting, and a community forum at the Co-op store, which consisted of a booth and posters. CWRS communicated that the WTA helps to improve the wastewater effluent quality prior to discharge into the marine receiving environment. One of the main findings was that the water quality of the discharge into the marine environment was of favorable quality and was well below the NWB license. Community members expressed concern over the status of the lagoon infrastructure, the environmental health of the marine receiving environment, and they requested additional water quality sampling during the early period of the spring freshet next year.

1.0 Introduction

1.1 Project Context

In 2010, the Community and Government Services (CGS) department of the Government of Nunavut (GN) awarded a five-year research contract to the Centre for Water Resources Studies (CWRS) at Dalhousie University to conduct research on the municipal wastewater treatment systems in Nunavut. This research contract was commissioned in response to the Wastewater Systems Effluent Regulations (WSER) that were introduced by Environment Canada in 2012 (Government of Canada, 2012). Nunavut is not currently required to adhere to the WSER; however, the GN initiated the research contract to inform science based decision making for wastewater treatment infrastructure projects within the unique constraints and conditions in Nunavut. Under the research contract, CWRS investigated many elements of the wastewater treatment systems which included: (i) an assessment of the treatment performance of wastewater stabilization ponds (WSPs) and tundra wetland treatment areas (WTAs), (ii) development of design criteria and resources, and (iii) human and environmental risk assessments of the receiving environments.

Sixteen of the twenty-five wastewater treatment systems in Nunavut feature a WSP or natural (un-engineered) lake lagoon in combination with a tundra wetland treatment area. Results of the CWRS study demonstrated that additional treatment of wastewater can occur within these tundra WTAs (Hayward et al, 2014). Important factors, including the hydrological and hydraulic settings of the wetlands, were observed to influence the amount of treatment that can be obtained from these systems. A performance model was used to estimate treatment potential within the WTAs was developed as part of the CWRS research contract. For this work, a first order tanks-in-series (TIS) chemical reactor model from Kadlec and Wallace (2009) was modified to account for external hydrologic contributions to use for performance modeling of tundra WTAs. This model was used to derive first order rate constants for various contaminants within the Coral Harbour tundra WTA (Hayward & Jamieson, 2015). First order rate constants are important for wetland design because they are used to describe how fast various wastewater constituents are treated within the wetland. Within the Hayward and Jamieson (2015) study, it was identified that additional data collection and modeling work for other sites would be useful to refine and test the wetland modeling approach.

1.2 Objectives

This study was conducted to assess the treatment provided by the tundra wetland treatment area in Sanikiluaq during the treatment season (June to September). The four main objectives of the study were to:

i) Assess the treatment performance of the wetland treatment area in Sanikiluaq;
ii) Validate and refine the performance model technique developed in Hayward and Jamieson (2015);
iii) Model design scenario(s) to assess if additional treatment could be achieved in the wetland treatment area; and
iv) Consult with community members about the wetland treatment area risks, extents and function.

1.3 Project Scope and Limitations

This project provided an assessment of the current and anticipated treatment performance of the Sanikiluaq wetland treatment area. If the treatment performance of the WTA is observed to be inadequate for the treatment requirements, then additional work beyond the scope of this project will be required to reconfigure the wetland.

The results of the modeling component are based on hypothetical ranges of input parameters. There are many assumptions made in the parameterization process and therefore the results have an inherent uncertainty. Additional limitations specific to the modeling component are outlined in Section 2.8.4.

2.0 Methodology

2.1 Guideline Resources

A document prepared by CWRS titled *Guidelines for the Design and Assessment of Tundra Wetland Treatment Areas in Nunavut*, was the main resource used in the formulation of this study (CWRS, 2016). The document provides a proposed framework for the design and use of tundra WTAs for applications in municipal wastewater treatment within Nunavut. The design guidelines are presented as a recommended series of steps for the assessment of existing and proposed WTAs in Nunavut. The following steps outlined in the design guidelines framework were completed for this study:

- Desktop mapping analysis
- Characterization of the physical and biological environment
- Hydraulic and hydrological characterization
- Hydrogeological characterization
- Treatment performance assessment
- Construction and application of a performance model
- Public consultation

2.2 Site Description

2.2.1 Sanikiluaq

The hamlet of Sanikiluaq (56°32’34” N, 079°13’30” W) is the southernmost community of Nunavut. It located on Flaherty Island, which is a large central island of the Belcher Islands. These islands are located off the west coast of Nunavik, Quebec in Hudson Bay. The community has an estimated population of 812 people (Statistics Canada, 2012). The Sanikiluaq WTA site-specific study was conducted from May 20 to 31 and September 1 to 9, 2016**.** Average air temperatures range from –28°C and –19°C in January, and from 6°C and 16°C in July. Total precipitation averages 671 mm, with 422 mm as rainfall, and 2488 mm as snow (249 mm Snow Water Equivalent), (Government of Canada, 2016a).

2.2.2 Wetland Treatment Area

Currently, wastewater is transported by trucks to the sewage lagoon located approximately 2.9 km to the west of the hamlet (Nunavut Water Board, 2015). The sewage lagoon is a natural ditch and was not engineered specifically for wastewater treatment purposes. The lagoon has a semi-permeable berm constructed on one side to increase its storage capacity. Approximately 88 m^3/d (322 155 m^3/yr) of primarily domestic municipal wastewater is generated and transported to the lagoon (Hamlet of Sanikiluaq, 2012, 2013, 2014, 2015). The tundra WTA consists of the sewage lagoon and a tundra WTA, approximately 1 km in length. The sewage seeps through the berm of the lagoon, at an uncontrolled rate, or depending on the season, has the potential to breach the berm. The effluent travels through the tundra WTA and eventually discharges in a small

Harbour, which feeds into the Hudson Bay (Nunavut Water Board, 2015). The WTA is shown below in Figure 1. According to the Nunavut Water Board (NWB) water licence, the compliance point is located at the outlet of the WTA (SAN-4). Effluent quality limits at the outlet must be less than 120 mg/L for five-day biochemical oxygen demand (BOD_5), 180 mg/L for TSS, 1 x10^6 CFU/100mL for faecal coliforms, and have a pH between 6 and 9 (Nunavut Water Board, 2015).

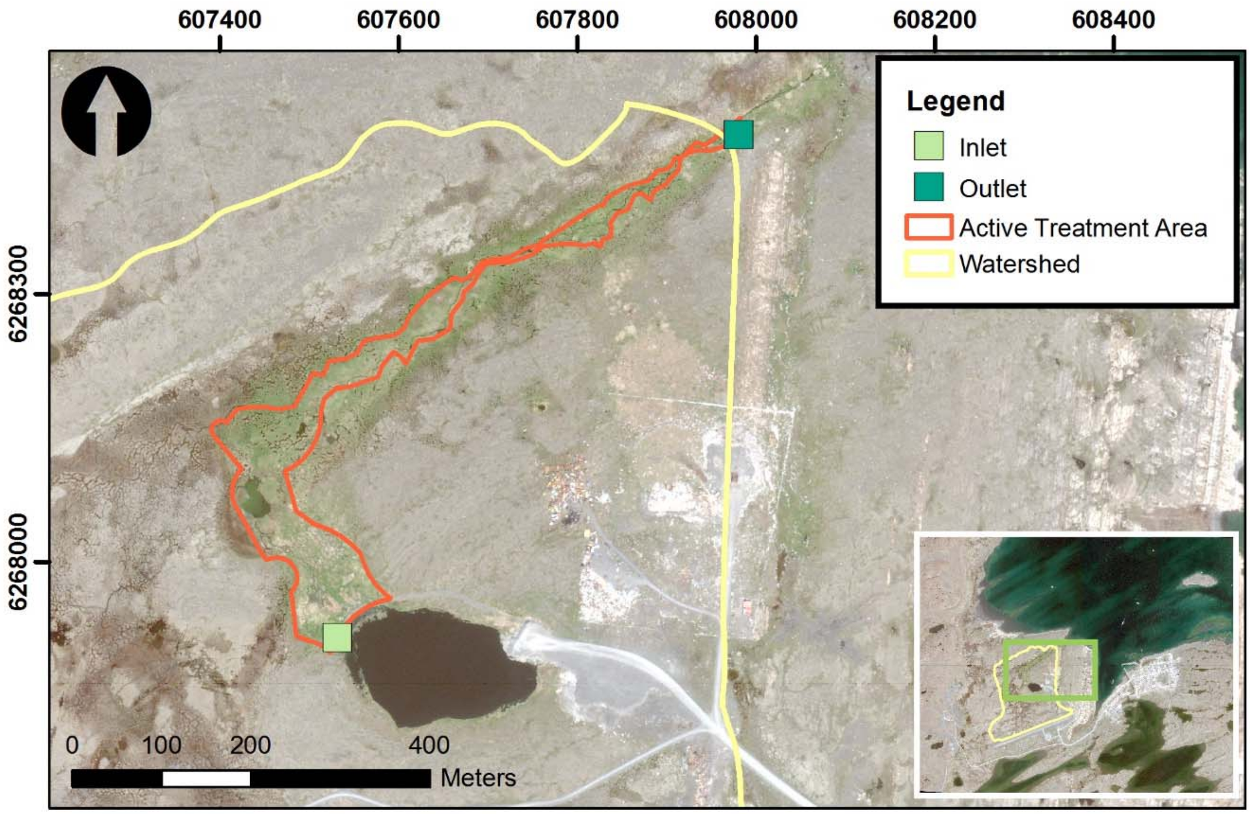

Figure 1. Site map of the WTA in Sanikiluaq, NU that was the focus of this study.

The WTA covers an area that is approximately 33,850 m^2. The topography is characterized by a 1.6% west to east downward sloping terrain. The WTA consists of wetland areas characterized by various willows, sedges, fireweed, mosses, and grasses; transition areas are predominantly made up of mosses, willow, grasses and sedge; and upland areas are characterized by berries, white heather, lichens and grasses.

2.2.3 Reference Wetland

A reference wetland was selected as a baseline to compare with the study WTA. The reference wetland (56°33'10" N, 079°15'50" W) is un-impacted by sewage and located approximately 1 km north-west of the study WTA. The reference wetland is one of the only wetlands located within proximity of the study site that shares similar characteristics; the hydrology, geology, and physical characteristics are similar. The water quality and diversity of vegetation communities in the reference wetland was compared to the WTA. Two water quality sampling locations, approximately within 50 m of each other, were chosen within the reference wetland area.

2.3 Hydraulics and Hydrology

2.3.1 Watershed and Wetland Delineation

The watershed delineation was performed with ESRI ArcGIS 10.2.2 software. A digital elevation model (DEM) was downloaded from Natural Resources Canada and supplemented with a real-time kinematic (RTK) topographic survey. The watershed was initially delineating using Arc Hydro and further adjusted by hand and smoothed using the Smooth Polygon tool with the PAEK method. The wetland was delineated using a ground-based handheld GPS survey.

2.3.2 Discharge measurement

Characterization of the hydraulics and hydrology of the WTA involved the measurement of the influent and effluent discharges from the WTA. Additionally, intermediate flow measurement points in the WTA were established when external hydrologic contributions were suspected. Surface water flow rates were measured on a near daily frequency at key locations within the WTA for the study period. Stream gauging points were chosen based on suspected flow increases, where two stream channels converged, or before and after a lake within the WTA. These sites were spaced fairly equally along the effluent flow path. Gauging sites were added as needed based on the temporal changes of the WTA.

The velocity area method was used to determine the discharge at a stream gauging sites according to Dingman (2002). A 625DF2N digital pygmy meter (Gurley Precision Instruments, Troy, New York, United States) was used to measure the current velocity and depth at each gauging site. The pygmy meter was equipped with a 2 m gauging rod, cable and 1100 model indicator digital readout. A measuring tape was used to measure the width of the stream channel. More detailed information of the gauging process is described in Hayward (2013).

Water levels at the inlet and outlet of the WTA were monitored continuously using HOBO® U20 Water Level Loggers (Onset® Computer Corporation, Bourne, Massachusetts, United States). The loggers were fastened at each site for long term deployment between May and September. An atmospheric logger was also deployed to account for changes in the barometric pressure. The water levels from loggers were plotted with corresponding discharge measurements to provide a stage-discharge relationship for the inlet and the outlet. The equation of the trendline with the best R^2 fit was used to create the continuous flow series, which was then used to predict the discharge for the whole study season of May - September.

2.3.3 Tracer Studies

Tracer tests were conducted to characterize the hydraulic conditions of the WTA. The tests allowed for determination of the hydraulic retention time (HRT) within the wetland. The HRT is representative of the average amount of time required for water and conservative solutes to move through the wetland. The tracer tests involve injecting a conservative solute, in this case a fluorescent dye Rhodamine WT (RWT) was selected. The RWT is injected upstream and the concentration of the RWT is measured over time at a defined point downstream.

Over the course of the May and September study periods, six tracer tests were completed in the WTA. The amount of RWT tracer injected was computed based on a desired target concentration of 200 µg/L at the termination point of the tracer, where dye measurements were observed. The concentration of RWT was measured *in-situ* with an optical fluorometer YSI 6130 RWT sensor installed on a YSI multi-parameter water quality sonde (YSI Inc., Yellow Springs, Ohio, United States). Methods for analysis of the tracer test data and calculation of the hydraulic parameters is described in detail in Hayward (2013) and Hayward et al. (2014).

2.3.4 Topography

The topography of the study site, and the position and elevation of sample points and effluent flow paths, were determined with a RTK topographic survey. A HiPer Ga (Topcon Positioning System, Inc., Livermore, California, United States) Global Positioning System (GPS) unit was used to conduct the survey. The base station was set up near the inlet of the wetland, which was deemed a suitable spot to cover all area needed for the survey. Therefore, the maximum baseline length was approximately 1 km and on average ranged from 10 to 400 m. The Topcon was coordinated in the NAD83 CSRS datum, using a 4-hour static survey, processed with the Precise Point Positioning (PPP) service offered by Natural Resources Canada.

2.4 Hydrogeology

The hydrogeological setting of the WTA in Sanikiluaq was examined in the field and through laboratory testing. Soil samples were taken between the inlet of the WTA, Site 1, and the pond (POB) to determine if subsurface flow is of relevance (see Figure 3 for sample site locations). Nine soil samples were taken within the area. The hydraulic conductivity of the soil (K) was determined through falling head permeability tests conducted at Dalhousie. The hydraulic conductivity represents the ease at which water can flow through the void spaces of a soil. The amount of wastewater that could be transmitted through the soil was then computed using Darcy's Law, assuming the hydraulic gradient was equal to the slope of the land surface in the region of suspected subsurface flow.

2.5 Physical and Biological Characterization

2.5.1 Vegetation

The physical attributes of the study sites were characterized with vegetation assessments as described in Hayward (2013). The spatial distribution of vegetation and landcover was determined using a three-step methodology, consisting of a field vegetation survey, data analysis, and image classification. The vegetation survey was performed during the September site visit by positioning transects across the effluent flow path. The survey extended from the inlet to the outlet. Each transect was approximately 100 m in length. A total of 90 sample points were taken throughout the entire WTA with approximately 20 m spacing between points along the length of the transect.

At each sample point, a 1 m x 1 m quadrat was placed on the ground and a handheld GPS waypoint was taken for reference. A photograph was taken to show vegetation and land cover over the whole quadrat. Supplemental photographs were taken of each section of the quadrat to provide a higher spatial resolution of the vegetative species present within the quadrat. All identifiable vegetation species within the quadrat were noted in the field notes, along with the approximate percent cover of each species. This was based on the approximate spatial distribution of that species within the quadrat. The main resource used to aid in identifying species was *Common Plants of Nunavut* by Mallory & Aiken (2012). Figure 2 is an example of a quadrat plot.

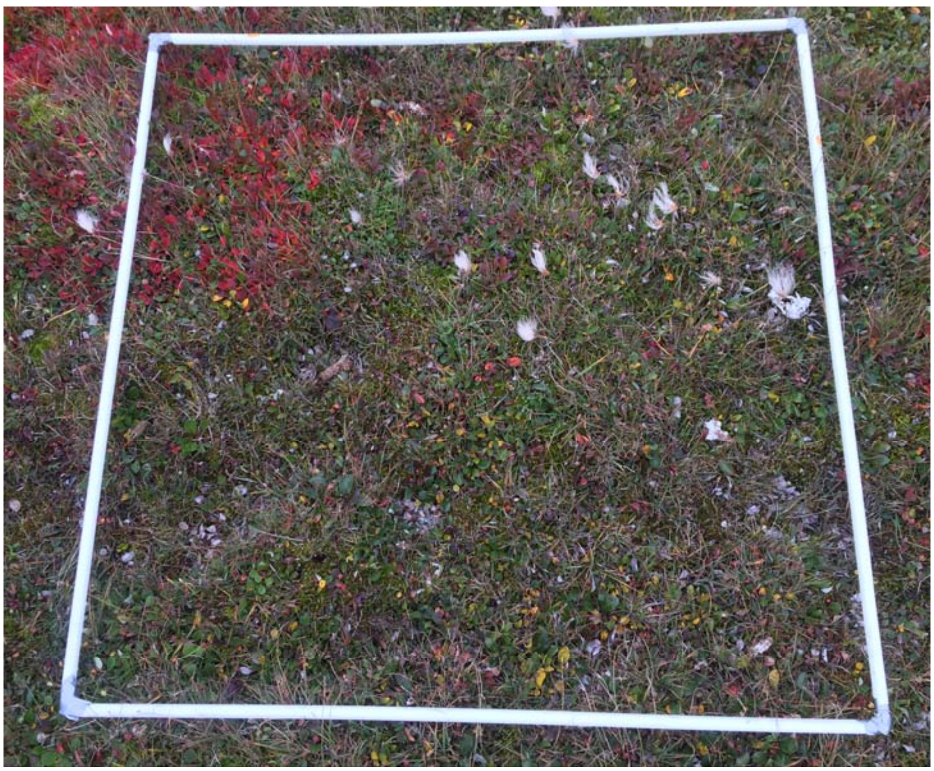

Figure 2. Example photograph of a vegetation quadrat showing an upland vegetative cover.

For the data analysis component, records for each sample point were transcribed into Excel and a dominant rank table was developed, based on species percent cover (see Table 1). Species covering less than 10% of a quadrat were considered negligible and therefore was not included.

Table 1. Example of the dominant ranking for vegetation quadrat

Plot	Dominant	Dom 1	Dom 2	Dom 3	Dom 4	Dom 5
4	Mountain Avens	Sedge	Net-vein Willow	Arctic Willow	White Heather	Peat Moss

Three classes (wetland, transition, and upland) were formed on the basis of frequently co-occurring species, seen in the dominant rank table. For example, Mountain Avens and White Heather commonly occurred as the dominant cover, with Blueberry, Sedge (*Carex*), Lichen, and Peat Moss as the 1st Dominant, forming the upland class. Non-vegetative landcover classes included bedrock/road and water.

A table was created with coordinates and the assigned class for each sample point. Every third sample was designated a "test" point to complete an accuracy check. The remaining points were used to create training samples to classify the image. The table was imported into ArcMap and displayed as XY points.

A supervised image classification was performed with the Spatial Analysis extension on a 0.4 m spatial resolution satellite image acquired on July 7, 2016 by WorldView-3 from Digital Globe. A three-band (RBG) QuickBird satellite image of Sanikiluaq was used as the Image Classification Layer. *Select by Attributes* was used to select sample points belonging to the wetland class and designated for training. In the Image Classification toolbar, the *Draw Polygon* tool was used to create training samples. Polygons were drawn around the selected points and adjacent cells. These training samples were merged to form one class in the Training Sample Manager. The process was repeated for the remaining classes, and a Signature File was created. The Signature File was then used to perform a Maximum Likelihood Classification, and the output was run through the Majority Filter tool twice, to reduce noise. An accuracy check was performed by checking the number of "test" sample points that match the final output raster.

2.5.2 Wildlife

A wildlife survey was completed during the site visits. This involved documenting the presence of any wildlife through notes and photos.

2.6 Treatment Performance

To assess the treatment performance of the WTA, samples were analyzed for a suite of common wastewater parameters including five-day carbonaceous oxygen demand ($CB0D_5$), suspended solids, fecal indicator organisms, nitrogen, and phosphorous. The biogeochemistry of the WTA was also characterized through the measurement of water quality parameters such as temperature, dissolved oxygen (DO), pH, and conductivity.

2.6.1 Sample Collection Strategy

The strategy for sample collection was developed after a visual inspection of the WTA had been completed. The strategy involved sampling the influent and effluent from the WTA. As well, intermediate sampling points in the WTA were established when external hydrologic contributions were suspected. These sampling points were chosen to give information about the spatial performance of the WTA. As previously mentioned, sampling points are based on suspected flow increases or additions, where two stream channels converged, or before and after a pond within the WTA. In the Sanikiluaq WTA, most sampling sites were equally spaced between the inlet and outlet of the WTA. Site 5 was suspected to add meltwater contribution to the effluent flow and therefore was chosen as a sampling point of interest. Figure 3 shows the stream gauging and sampling sites within the Sanikiluaq WTA.

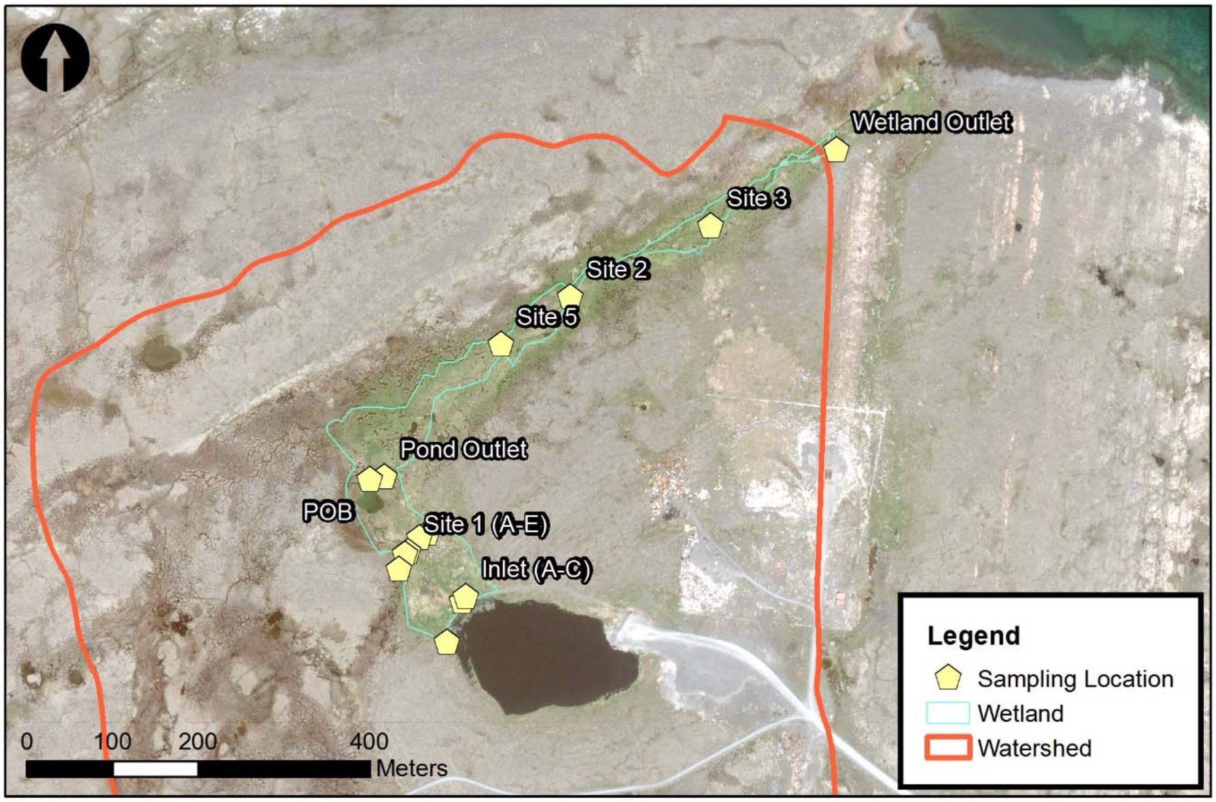

Figure 3. Map of sampling locations within the WTA in Sanikiluaq.

2.6.2 General Water Quality

Discrete measurement of the biogeochemistry of the WTA was performed with handheld YSI 600 multi-parameter sondes (YSI Inc., Yellow Springs, OH). Each of the handheld sondes was calibrated for dissolved oxygen at the beginning of each day of the fieldwork. Each of the handheld sondes was calibrated for pH and conductivity at the commencement of site work as per the manufacturer's specifications. The water quality indicators of pH, DO, specific conductivity, and temperature were taken on a daily basis for the duration of both trips to Sanikiluaq. Discrete measurement of samples were also collected from the reference wetland and the raw wastewater samples directly from the pump trucks discharging into the lagoon.

2.6.3 Treatment Performance Samples

The treatment performance assessment of the wetland was performed by collecting water samples at key points in the WTA and analyzing for a suite of parameters. These parameters included $CBOD_5$, TSS, volatile suspended solids (VSS), *E. coli*, total nitrogen (TN), total ammonia nitrogen (TAN), un-ionized ammonia nitrogen (NH_3-N), and total phosphorus (TP).

Samples were taken in bottles provided by Maxxam Analytics in Montreal, QC and in Winnipeg, MB. Treatment performance samples were also collected raw from the trucks with sample bottles attached to a sample pole. The raw wastewater samples were collected as the pump trucks were discharging into the sewage lagoon. Consistent sampling locations were used for each site visit as seasonal changes within the WTA allowed.

Two rounds of treatment performance samples were taken during each trip to Sanikiluaq (four rounds in total). In each round of sampling, an average of nine samples were taken. This includes sampling points within the WTA, samples from the reference wetland, and raw sewage samples.

2.6.4 Solid Waste Considerations

In Sanikiluaq, the WTA is located in close proximity to the solid waste facility. According to CWRS (2016), it is necessary to ascertain whether contaminants originating in the solid waste facility have the potential to migrate into the WTA. It may be possible for additional contaminants from the solid waste facility leachate to reach the wetland either by surface flow or subsurface flow. Landfill leachate can contain heavy metals, acidic pHs, organics, and other organic contaminants. Steps were taken to determine whether there is interaction between the WTA and the landfill leachate. These steps included:

i) A watershed delineation of the WTA.
ii) Visual inspection of the down gradient area of the landfill to verify for potential seepage into the WTA.

The treatment performance samples that were taken over the course of the study can also give an indication if there is an influence on the WTA from the solid waste facility. The concentrations of heavy metals within the raw water and outlet treatment samples were examined to also assess potential for solid waste leachate to be influencing the WTA.

2.7 Rate Constant Derivation

The first order rate constants were determined by parameterizing plug flow and TIS (tanks-in-series) models with the hydraulic information obtained from the tracer test, the discharge and treatment performance data. This was done for each wetland segment and for each round of treatment performance samples. The input parameters that were used to parameterize the TIS and plug flow models to represent each wetland segment are presented in the results section of this report. The areal decay rate constant (*k*-value) was determined for a suite of treatment performance parameters for each WS where a tracer test was conducted. When multiple sets of flow, depth, and treatment performance data were collected during periods of similar hydraulic conditions, average k-values were calculated for each set of observed field conditions. Areal first order rate coefficients were used consistently throughout the modeling.

Outgoing treatment performance parameter concentrations for each of the respective tanks of the model was calculated using Eq. 1 and Microsoft® Excel™ from CWRS (2016).

$$C_{out} = \frac{\left(\frac{Q_{in}}{Q_{out}}\right) C_{in} + \left(\frac{\frac{Q_{ws}}{N}}{Q_{out}}\right) C^* + \frac{k\tau C^*}{Nd}}{1 + \frac{k\tau}{Nd}}. \qquad \text{[Eq.1]}$$

The model was calibrated by setting the outgoing effluent concentration (C_{out}) to equal the field data concentration by optimizing a universal k-value for each treatment performance parameter. The optimization of the set of mass balance equations was performed using the SOLVER function in Microsoft® Excel™. Additional details on the method used to determine the rate constants can be found in Hayward & Jamieson (2015). The rate constants were adjusted to 5 and 15°C according to Arrhenius equation as per Equation 5 (Kadlec and Wallace, 2009). The temperature coefficients that were used to adjust the rate constants were taken from Hayward & Jamieson (2015).

2.8 Model Construction

2.8.1 Modeling Objective

The objectives of the modeling were twofold, which were to: (i) derive the first order rate constants, and (ii) assess the variation in treatment that may be expected given changes in influent strength, hydraulic loading rate, and climate conditions.

2.8.2 Model Approach

Tracer tests were conducted during site visits in May and September to characterize the internal hydraulics of the wetland during the treatment season. The tests were performed in small segments to be able to adequately characterize the hydraulic regime within key wetland components. A pulse of rhodamine dye was injected into the wetland and its concentration measured at the segment outlet. This data was processed by performing a moment analysis to determine mean HRT, and fitting the data to a gamma distribution model to determine the number of model tanks needed to characterize the mixing within the system (Hayward, 2013). Table 2 below shows the tracer tests performed for individual wetland segments.

Table 2. Summary of Tracer Tests Performed

Tracer	Start Date	End Date	Study Period	HRT (days)	Average Depth (m)	Area (m^2)	E_v (%)
Inlet - 1b	5/28/16	5/29/16	Spring	0.28	0.17	8673	19.3
Inlet - PO	5/28/16	5/29/16	Spring	0.64	0.14	14728	30.6
PO - 2	5/26/16	5/28/16	Spring	0.59	0.21	14048	25.7
2 - 3	5/24/16	5/25/16	Spring	0.12	0.25	2680	31.5
3 - Outlet	5/23/16	5/23/16	Spring	0.09	0.22	2393	53.6
3 -Outlet	9/05/16	9/05/16	Summer	0.09	0.06	2393	3.7
5 - 3	9/06/16	9/07/16	Summer	0.24	0.04	5959	0.8

The May tracer results produced positively skewed bell-shaped curves, thus a TIS model was observed to be appropriate to represent the hydraulics of the system. The TIS wetland spreadsheet calculator tool provided in CWRS (2016) was modified to represent the spring conditions at the Sanikiluaq site. A detailed methodology for the TIS modeling technique is provided within CWRS (2016).

During the September visit, tracers were performed from site 5 to site 3 and site 3 to outlet. The results of the gamma distribution fit indicated an excessive number of tanks (> 15), thus it was determined these segments were behaving like plug flow reactors. The TIS wetland spreadsheet calculator tool was modified, adding a plug flow component (Equation 2) to represent the summer conditions at the Sanikiluaq site.

$$k = q \cdot ln\left(\frac{C_i - C^*}{C_o - C^*}\right) \qquad \text{[Eq. 2]}$$

Both the spring and summer models were run, varying a number of climate and design factors. The series of factors that were assessed are illustrated in Figure 4. Two additional scenarios were run for the medium strength influent which consisted of the following:

- **90-day precipitation** – this scenario averaged the annual precipitation over 90 days instead of 365, to represent high flow spring melt conditions; and
- **Nominal hydraulic retention time** – this scenario used the nominal HRT instead of the measured HRT to model the impact of increasing the hydraulic efficiency of the WTA.

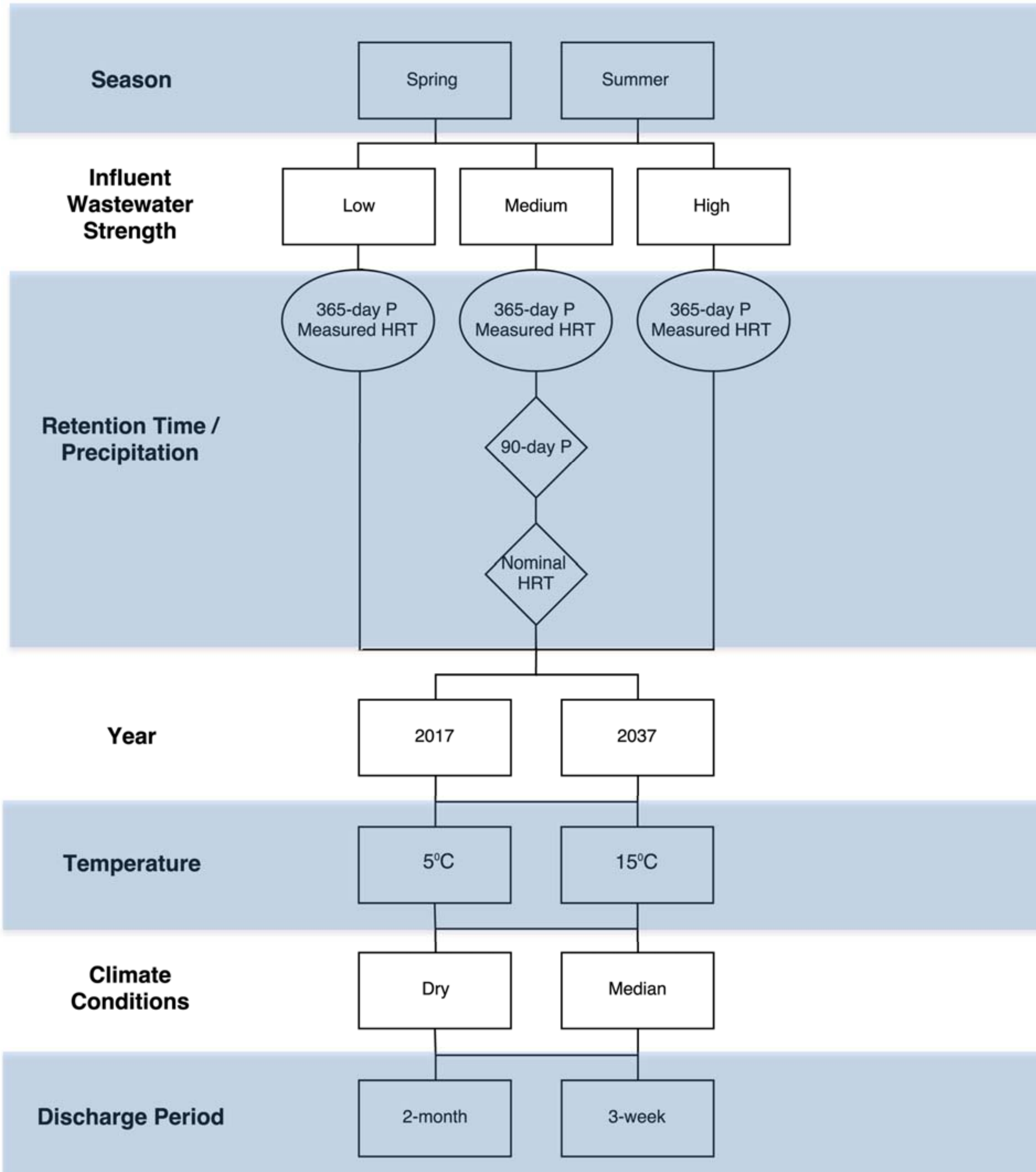

Figure 4. Flow chart of the factors and scenarios assessed with in performance modeling.

2.8.3 Assumptions

The following assumptions were made to conduct the modeling analysis:

- The contaminant ranges in the influent wastewater were adopted from literature values based on Ragush et al (2015), and these were assumed to be representative of the range that could be discharged from the lagoon;
- Infiltration into the subsurface was assumed to be negligible based on site conditions;
- The evapotranspiration fraction was assumed to be 0.5;
- Water distribution in the community was assumed to remain on trucked until 2037;
- Water use in the community was assumed to be 90 L/person/d, which was adjusted according to Smith (1996); and
- Background concentrations were estimated based on Hayward & Jamieson (2015) in Coral Harbour and fieldwork findings from Sanikiluaq and Naujaat in summer 2016 (yet to be published).

2.8.4 Limitations

There are limitations to the findings of the modeling component of this study which include the following:

- The rate constants and temperature correction coefficients were adopted from Hayward & Jamieson (2015) which introduces slight uncertainty in the treatment performance estimations;
- Long-term climatic changes were not considered for the model scenarios; however, they are considered to have small impact on the model outcomes for the next 25 years; and
- Changes to the discharge rates used within the model input would result in different treatment outcomes.

2.8.5 Model Input Parameters

2.8.5.1 Hydraulic Retention Times

The hydraulic retention times were set as the actual measured HRTs obtained from the tracer tests. The actual measured HRT was determined by a gamma model fit of the tracer test data in Microsoft Excel as per the procedure detailed in Hayward & Jamieson (2015). The nominal HRT (θ) was calculated for each model run and is given by Equation 3 as follows:

$$\theta = \frac{V}{Q} \qquad \text{[Eq. 3]}$$

Where V is the volume of wetland (m^3), and Q is influent flow (m^3/d). The nominal HRT is the theoretical maximum HRT; however wetlands are not 100% hydraulically efficient and therefore in reality, actual HRTs are always less than nominal HRTs.

2.8.5.2 Volume and Surface Areas

The wetland area was determined in ArcGIS from survey points taken during a site visit. The wetland was captured by walking its perimeter with a handheld GPS. This area was multiplied by the average water depth over the wetland to determine the wetland volume. Table 3 summarizes the volume and area of each wetland segment used in the modeling. The depth was held constant at 0.2 m and 0.09 m, for the spring and summer conditions, respectively. These are the average depths that were measured for the entire wetland during the spring and summer periods.

Table 3. Wetland areas and volumes for the wetland segments used in the performance modeling

Segment	Area (m^2)	Volume (m^3)	
	Spring/Summer	Spring	Summer
Inlet - 1	8673	1735	768
1 - PO	6056	1211	537
PO - 5	10768	2154	954
5 - 2	3280	656	291
2 - 3	2680	536	237
3 - Outlet	2393	479	212
Wetland Total	33849	6770	2999

2.8.5.3 Influent Wastewater Strength

The influent wastewater strength ranges were selected to span the minimum, mean, and maximum values from the findings of Ragush et al (2015). The values were summarized based on the wastewater parameter concentrations observed in the WSPs located in Pond Inlet, Clyde River, and Kugaaruk during the treatment seasons from 2012 to 2014. The influent wastewater strength values that were used as model input parameters are summarized in Table 4.

Table 4. Input parameters for wastewater strength based on Ragush et al (2015).

Parameter	Strength		
	Low	Medium	High
$CBOD_5$ (mg/L)	60	150	300
E. coli (MPN/100mL)	$1x10^3$	$1x10^5$	$1x10^8$
TN (mg/L)	40	80	140
TAN (mg/L)	40	80	140
TP (mg/L)	5	10	15

2.8.5.4 *Selection of Rate Constants*

The rate constants that were used for the modeling and their sources are outlined in Table 5. The rate constants that were used for the performance modeling were selected from literature from data from Coral Harbour, NU presented in Hayward & Jamieson (2015). These alternative rate constants were used because the rate constants determined from the site-specific data in Sanikiluaq were relatively high compared to literature and therefore would potentially produce non-conservative results.

Table 5. Rate constants selected for the performance modeling from Hayward & Jamieson (2015).

Rate constant	$CBOD_5$	*E. coli*	TN	TAN	TP
K_5 (m/d)	0.01	0.06	0.004	0.01	0.31
K_{15} (m/d)	0.01	0.15	0.006	0.03	0.27

2.8.5.5 *Climate Data*

Historical climate data was downloaded for Kuujuarapik, which is the closest climate station with historical datasets from the Environment Canada historical climate data website (Government of Canada, 2016a). Bulk downloads of multi-year datasets were performed according to the directions provided by Government of Canada (2016b). The statistical software package R was used to generate annual amounts of precipitation based on the daily historical climate records at each site. No data was reported when more than 30 consecutive days of data were missing from any given year. Potential evapotranspiration (PET) was estimated using the Priestley and Taylor (1972) method according to Xu and Singh (2002). The median evapotranspiration rate was determined to be 91 mm/yr based on the historical temperature dataset from Environment Canada (Government of Canada, 2016a).

Two climate scenarios were considered: (i) median historical precipitation and evapotranspiration, and (ii) dry conditions. The dry conditions scenario was assessed to simulate a worst-case scenario with no dilution. In these cases, the precipitation was set to zero for the model runs. The median historical precipitation was determined to be 642 mm/yr (Government of Canada, 2016a). This was converted to a volume of water per day by multiplying by the watershed area and dividing by 365 d/yr.

2.8.5.6 *Influent Discharge Rates*

Two influent discharge rates were selected for model runs which included discharge rates generated from a 2-month discharge period and a 3-week discharge period. The 2-month discharge period was selected to simulate the effects of a continuous summer discharge. Whereas, the 3-week discharge period was selected to simulate the effects of a short decant—such as provided actively by a pump and generator configuration.

The predicted annual wastewater production was based on residential water use and the projected population from 2017 to 2037 available from the Government of Nunavut (Government of Nunavut, 2014). The residential water use (RWU) was assumed to be 90 L/person/d for trucked water as assumed from Smith (1996). The total water use per capita was estimated using Equation 4 as follows:

$$RWU \times [1.0 + (0.00023 \times P)] \qquad \text{[Eq. 4]}$$

The 2-month and 3-week discharge rates were calculated by taking the annual wastewater production value and dividing by 60 days and 21 days, respectively.

2.9 Community Consultation

A public consultation session was conducted during the second site visit to Sanikiluaq in September. The purpose of this session was to give an introduction to treatment wetland science, outline CWRS's role in studying the Sanikiluaq WTA, and to communicate the results of the wetland mapping and water quality. A presentation was given by CWRS in a council meeting organized by the hamlet.

A community forum was also held in the community Co-op. This allowed the public to ask questions and participate in a conversation about the WTA and the work of CWRS. Posters and maps were used to help explain the research that CWRS was had conducted in the community.

3.0 Results and Discussion

3.1 Hydraulics and Hydrology

3.1.1 Watershed Delineation

The watershed of the Sanikiluaq WTA is shown in Figure 5. The total area of the watershed is approximately 1.7 km^2 (170 ha). There are well defined topographic divides that represent the boundaries of the watershed. The southern boundary runs along the airport runway. There was some concern that there was an influence of sewage runoff in the swimming lake below the airport. However, due to the topographic divide of the watershed, it would not be possible for the sewage from the lagoon to flow in the direction of this lake. The boundary on the east side of the watershed runs through the community's solid waste disposal site, which prompted the need to identify if the solid waste has any influence on the quality of the water in the WTA. This was addressed in Section 3.4.3.

Figure 5. Map of the watershed of the WTA in Sanikiluaq.

The watershed and the area of land that contributes flow to the WTA was larger than initially anticipated. A considerable amount of dilution was apparent within the WTA and even before the sewage entered the WTA. The treatment performance sample results, outlined in Section 3.4.2, show that the concentrations of parameters entering the WTA were very dilute in comparison to the raw water samples. The berm of the sewage lagoon could provide significant filtration/treatment, or drainage from upgradient portions of the watershed could dilute the sewage. This could be particularly significant during the spring snowmelt period

3.1.2 Discharge Measurements

Instantaneous discharge measurements were taken on a regular basis at key points in the wetland. Table 5 shows a summary of the instantaneous discharge measurements taken in Sanikiluaq.

Table 6. Summary of instantaneous discharge measurements.

Sampling Location: Sanikiluaq				
Date Range	**Gauging Site**	**Flow (m^3/d)**		
		Minimum	**Maximum**	**Average**
2016/05/21 - 2016/05/30	**Inlet**	97	1295	430
	Site 1	238	742	485
	Pond Outlet	62	2436	1236
	Site 2	124	2431	972
	Site 3	1076	3098	1867
	Site 5	1692	5943	2696
	Outlet	735	6714	2857
2016/09/05 - 2016/09/07	**Inlet**[a]	-	-	-
	Site 2	15	17	16
	Site 3	20	72	49
	Site 5	25	164	95
	Outlet	36	220	111

[a]Flow was not observed at the inlet during the September site visit.

Figure 6 and 7 illustrate the influent and effluent flow continuously over the treatment season and study period. These series were developed from the stage-discharge relationships for the inlet and outlet gauging sites. The corresponding precipitation totals recorded by Environment Canada in the region are shown on a secondary axis. In general, the outflow from the WTA is an order of magnitude greater than the WTA inflow, which demonstrated a significant dilution effect.

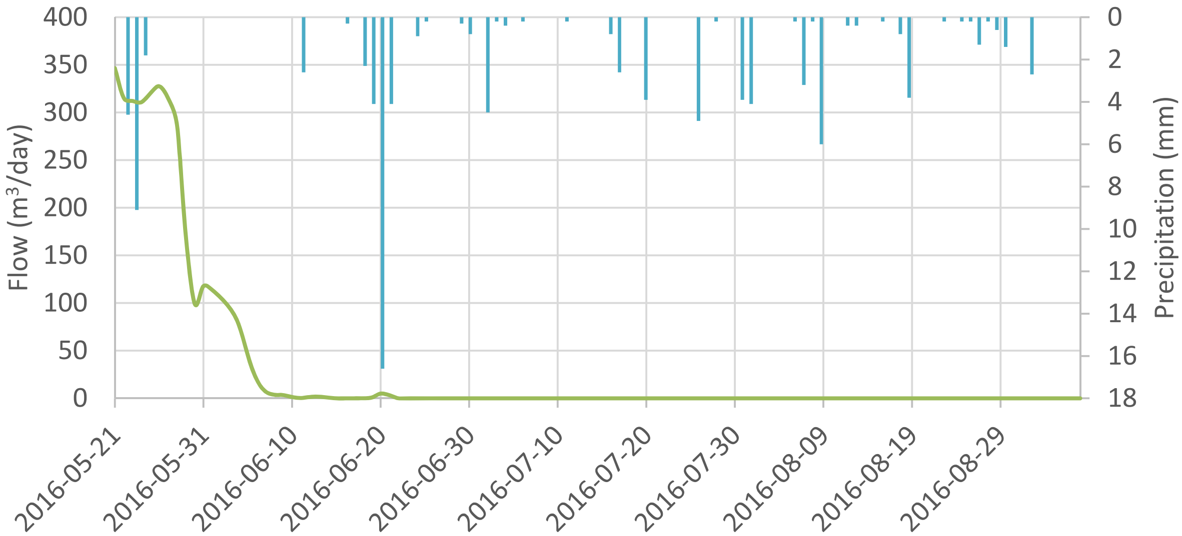

Figure 6. Inlet flow and precipitation series for the 2016 treatment season.

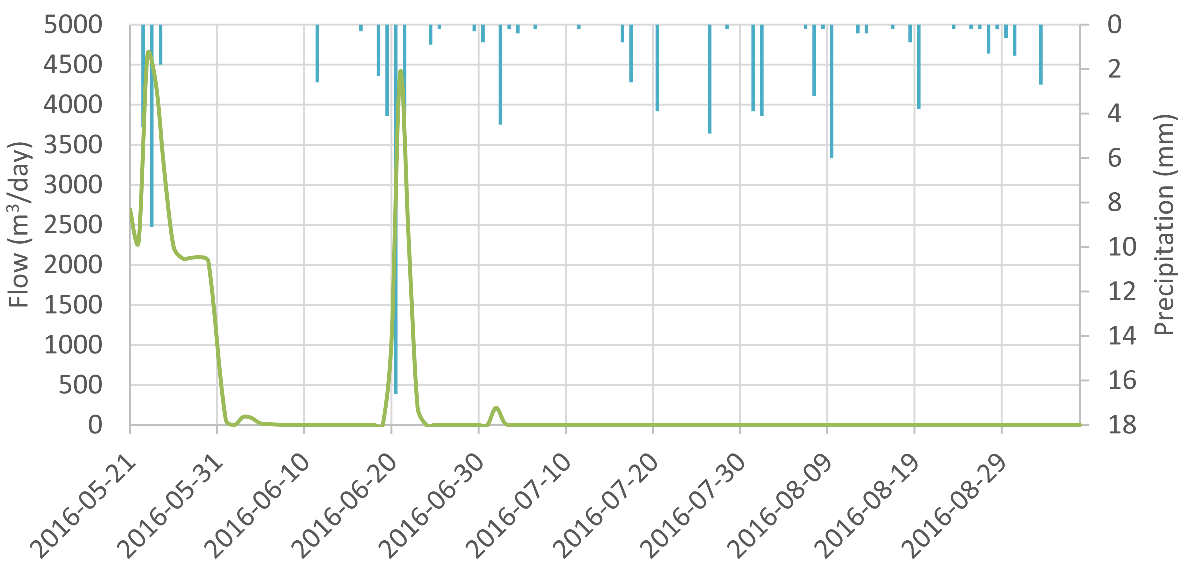

Figure 7. Outlet flow and precipitation series for the 2016 treatment season.

From the developed flow series, it is evident that the flow dramatically decreased, to almost no flow, as the season changed from spring to summer. The melting of ice and snow that occurred during freshet had a substantial effect on the flows in the WTA. However, the average hydraulic loading rates (HLRs) that were measured in the spring and summer site visits were 1.21 cm/d (121 m^3/ha-d) and 0.93 cm/d (93 m^3/ha-d), respectively. These HLRs were within the recommended range for optimal treatment of wastewater effluent which is a maximum of 2.5 cm/d CWRS (2015).

Outlet flows from the WTA showed a response to large rainfall events, such as the rainfall event that took place in June 2016. There was a dramatic increase in the flow at the outlet, with only a minor increase at the inlet.

3.2 Hydrogeology

The hydraulic conductivity, porosity, and moisture content of soil samples collected in the WTA are provided in Table 6.

Table 7. Summary of soil physical and hydraulic characterization.

Sample	Average Hydraulic Conductivity (cm/s)	Porosity	Moisture Content (%)
1	2.4×10^{-5}	0.95	88
2	1.3×10^{-4}	0.95	88
4	1.9×10^{-4}	0.88	68
5	3.5×10^{-4}	0.97	93
6	1.4×10^{-4}	0.80	68
7	2.0×10^{-4}	0.95	88
8	4.0×10^{-4}	0.58	29
9	1.2×10^{-4}	0.94	84

The theoretical Darcy flux was calculated using the maximum average hydraulic conductivity and the average land surface slope between the WTA inlet and the pond, which was the area where subsurface flow was observed. The Darcy flux required to transmit sewage flows assuming both a 2 month and 3 week discharge period were also computed. It was found that the theoretical Darcy flux was at least 2 orders of magnitude lower than that required to transmit the required wastewater flows. This indicates that treatment of wastewater within a subsurface flow regime would not occur within this wetland. If any appreciable flow of wastewater is applied to the WTA, the effluent would quickly break out to the surface and travel through the system as surface flow.

3.3 Physical and Biological Characterization

3.3.1 Vegetation

Table 8 shows the dominant vegetation species within the main classes in the Sanikiluaq WTA.

Table 8. Vegetation classification results of the Sanikiluaq WTA study site.

Class	Dominant	1st Dominant
Upland	Alpine Bear Berry, Blueberry, Lapland Rosebay, Lichen, Mountain Avens, Grass, White Heather	Net-vein Willow, Peat Moss, Crowberry, Northern Willow, Arctic Paintbrush
Wetland	Arctic Willow, Field Horsetail, Broad Leaved Fireweed, Buttercup, Club Moss, Dwarf Fireweed, Net-vein Willow, Northern Starwort, Northern Willow, Peat Moss, Poa Arctica, Polar Grass, Arrow Leaved Coltsfoot, Richardsons Willow, Grass, Sedge, Wheat	*Carex Aquatilis*, Cloudberry, Felted Willow, Mare's Tail, Purple Loosestrife
Transition	Club Moss, Net-vein Willow, Peat Moss, Grass, Sedge	Buttercup, Blueberry, Crowberry, Lichen, Northern Willow, Poa Arctica, Sedge

From the vegetation survey an image classification map was also created. Figure 8 shows the final classification map of the WTA which illustrated the approximate distribution of vegetation in the vicinity of the WTA. It should be noted that the wetland vegetation extends beyond the active treatment area delineated on site. Therefore the actual area of influence of the wastewater may extend beyond the active treatment area boundaries. The active treatment area represents where wastewater was observed as flowing as surface flow; therefore, it would be expected that there is subsurface influence beyond these boundaries. This surrounding wetland vegetation could provide additional provision of wastewater treatment and could also be a resource for additional treatment if flow was diverted to and retained within these wetland areas.

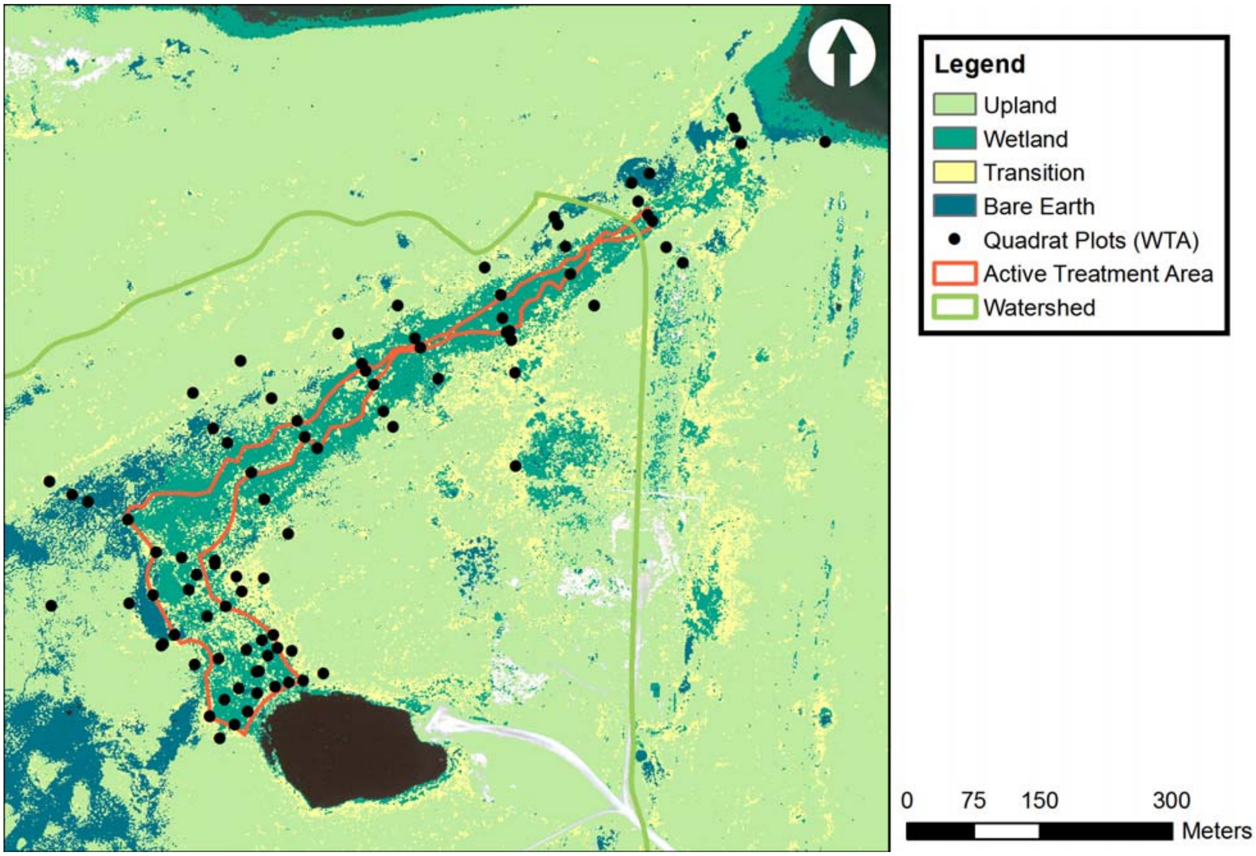

Figure 8. Vegetation classification map of the Sanikiluaq WTA based on satellite imagery acquired on July 7, 2016.

3.3.2 Wildlife

There was wildlife present in the WTA through the duration of the study, shown in Figure 9. Geese frequented the hummocky areas of the WTA and their droppings were found over a large portion of the site. Smaller birds, like sandpipers, were also noted during the site visit. These geese and other waterfowl can add substantial amounts of faecal bacteria to the WTA. This can elevate bacteria levels at the outlet; however it would not originate from the sewage. Since these animals come into contact with the sewage, they could act as potential disease vectors. Care should be taken by the community members who may consume the animals to ensure proper cleaning and preparation. This message was communicated to the council during the council meeting and to community members at the Co-op forum.

Figure 9. Example of wildlife present on the WTA during the site visit in May 2016.

3.4 Treatment Performance Assessment

3.4.1 Biogeochemistry

Handheld multi-parameter water quality sondes were used to provide discrete measurements of basic biogeochemical parameters on a daily basis over the two study periods. These included temperature, dissolved oxygen, conductivity, and pH. Table 9 shows the minimum, maximum and average values for each sampling site for the first trip in May, while Table 10 shows the values from the September trip. Beyond the inlet location of the WTA dissolved oxygen concentrations were always greater than 2 mg/L, which would support aerobic biological treatment processes.

Table 9. Summary of the general water quality results for the May 2016 study period.

Sanikiluaq 2016/05/21 - 2016/05/28					
Sampling Location		**Water Quality Parameters**			
		Temperature (^oC)	**Conductivity (µS/m)**	**DO (mg/L)**	**pH**
Raw	**Min**	18.5	2889	0.69	7.63
	Max	25.3	3225	8.49	8.13
	Average	18.5	3005	3.51	7.91
Inlet	**Min**	0.3	350	0.30	7.15
	Max	5.1	793	2.60	7.46
	Average	1.7	588	0.99	7.34
Midpoint	**Min**	0.5	354	7.46	7.45
	Max	3.8	542	12.54	7.67
	Average	2.1	479	10.04	7.53
Outlet	**Min**	0.3	252	11.19	7.55
	Max	3.5	437	13.12	7.76
	Average	1.8	353	12.24	7.64
Reference	**Min**	3.1	2	10.83	7.68
	Max	9.8	253	13.60	8.19
	Average	7.7	181	12.46	8.03

Table 10. Summary of the general water quality results for the September 2016 study period.

Sanikiluaq 2016/09/05 - 2016/09/07					
Sampling Location		Water Quality Parameters			
		Temperature (ºC)	Conductivity (µS/m)	DO (mg/L)	pH
Raw	**Min**	16.2	2047	1.21	7.27
	Max	20.6	2297	2.99	8.09
	Average	19.0	2191	2.08	7.55
Inlet	**Min**	10.7	1419	15.04	8.51
	Max	11.8	1460	21.84	9.13
	Average	11.3	1439	18.44	8.82
Midpoint	**Min**	5.8	1789	10.44	7.92
	Max	7.1	1871	11.53	7.99
	Average	6.5	1830	10.99	7.96
Outlet	**Min**	7.2	2516	9.83	7.93
	Max	7.5	2774	11.26	8.09
	Average	7.3	2645	10.55	8.01
Reference	**Min**	6.8	341	9.58	7.91
	Max	11.1	459	10.49	8.01
	Average	8.9	393	9.97	7.95

3.4.2 Treatment Performance Samples

Two rounds of treatment performance samples were collected during each study period to assess the conditions within WTA, across the treatment season. Each round of treatment performance samples consisted of raw wastewater samples, an influent sample, an effluent sample, and samples from all relevant midpoints depending on the season.

The treatment performance data is summarized in Tables 11 and 12. During the spring freshet, reduction occurred within the sewage lagoon, before the sewage travels into the WTA. For this reason, the concentrations of most parameters were already very low coming into to the WTA during the spring freshet. This could be attributed to dilution due to external hydrologic contributions from the watershed. For all of the sampling events, the wetland effluent met the guidelines outlined in the water license, which consist of 120 mg/L for BOD_5, 180 mg/L for TSS, and 1 x 10^6 CFU/100mL for faecal coliforms (Nunavut Water Board, 2015). This was the case for $CBOD_5$, TSS, and *E. coli*, even though incoming concentrations, in the raw water, were high. For TN, TAN, NH_3-N, and TP the concentrations, on average, decreased by an order of magnitude, which resulted in very low concentrations in the effluent at the outlet. This was the case for samples taken in both May and September.

Table 11. Summary of the treatment performance analysis for the May study period.

Sampling Date	Sampling Site	Parameter							
		$CBOD_5$ (mg/L)	TSS (mg/L)	VSS (mg/L)	*E. Coli* (CFU/100mL)	TN (mg/L)	TAN (mg/L)	Unionized Ammonia (mg/L)	TP (ug/L)
25-05-2016	Raw 1	320	280	590	>60000	120	99	0.08	13000
	Inlet	13	2	14	>60000	13	12	0.09	1700
	Site 1	12	<2	<10	36000	14	11	0.03	2400
	Site 2	<4	8	<10	590	6	3.5	0.01	930
	Site 3	<4	<2	<10	72	1.6	0.74	0.01	210
	Outlet	<4	4	<10	27	1.2	0.46	0.00	170
	Reference 1	<4	6	<10	<10	0.62	<0.02	0.00	<10
	Reference 2	<4	4	24	<10	0.59	<0.02	0.00	<10
30-05-2016	Raw 2	370	160	530	>60000	100	78	0.02	12000
	Raw 3	300	170	520	>60000	98	83	0.04	11000
	Inlet	5	13	44	31000	6.1	4.9	0.02	1400
	Site 1	5	10	68	220	6.9	4.5	0.00	2100
	Site 2	<4	11	48	10	2.2	1.2	0.00	830
	Site 3	<4	5	58	<10	0.72	0.17	0.00	200
	Site 5	<4	6	56	10	1.1	0.36	0.01	210
	Outlet	<4	8	46	<10	0.61	0.05	0.90	160
	Reference 3	<4	4	150	<10	<0.40	<0.02	0.00	<10

Table 12. Summary of the treatment performance analysis for the September study period.

Sampling Date	Sampling Site	Parameter							
		CBOD$_5$ (mg/L)	TSS (mg/L)	VSS (mg/L)	*E. Coli* (CFU/100mL)	TN (mg/L)	TAN (mg/L)	Unionized Ammonia (mg/L)	TP (mg/L)
06-09-2016	Raw 1	189	256	228	>1100000	121	130	4.22	10.5
	Raw 2	387	238	210	>1100000	123	88	0.44	10.1
	Raw 3	269	208	170	>1100000	78.5	73	0.40	8.21
	Inlet - Lagoon	250	93	83	23000	19.5	8.2	0.67	4.16
	Site 2	<6.0	5	3.4	<3	1.57	0.19	0.00	0.72
	Site 3	<6.0	<1.3	<1.3	<3	0.696	0.73	0.03	0.33
	Site 5	<6.0	2.6	1.9	4	0.759	0.078	0.00	0.23
	Outlet	6	1.4	<1.3	<3	0.561	0.026	0.00	0.26
	Reference 1	<6.0	7.8	6.1	<3	0.353	0.12	0.00	0.018
08-09-2016	Inlet - Lagoon	22.8	72	71	23000	25.6	11	2.96	3.83
	Site 2	<6.0	3.7	2.7	<3	0.672	0.054	0.00	0.682
	Site 3	<6.0	3.2	2.5	4	0.751	0.064	0.00	0.584
	Site 5	<6.0	9	5.2	4	0.584	0.097	0.00	0.389
	Outlet	<6.0	10.6	7.3	<3	0.627	0.029	0.00	0.190
	Reference 2	<6.0	31.7	10.7	<3	0.202	0.10	0.00	0.036
	Reference 3	<6.0	1.3	<1.3	<3	0.11	0.012	0.00	<0.005

3.4.3 Solid Waste Considerations

In the delineation of the watershed of the WTA, it was determined that the boundary of the watershed included some of the solid waste facility. This means that the topographic divide is within the solid waste facility, which means leachate could potentially be directed into the WTA. However, the treatment performance results did not give any indication that the facility influences the WTA or the quality of the effluent. Five parameters were chosen to determine if leachate from the solid waste facility was entering the WTA. The concentration of cobalt, cadmium, iron, lead, and manganese in the raw water and outlet samples, for each round of treatment performance samples, were compared. Summary tables of these results are included in Appendix A. Some metals concentrations were elevated in the raw water samples but all concentrations within the outlet samples were much lower or below the detection limit. This indicated that external leachate was likely not impacting the WTA or quality of the effluent.

3.5 Rate Constant Derivation

In many cases, the rate constants could not be determined because dilution alone from external hydrologic sources accounted for the observed reductions in contaminant concentrations. The effect of dilution in the WTA is presented in Table 13. During the spring freshet, the wetland diluted the influent by approximately 392 – 1111%. Whereas, later in the treatment season, approximately 310% dilution of the influent was observed. During September, the WTA did not exhibit surface flow from the inlet to the pond (directly upstream of site 5); therefore, only the mid-point to outlet area is provided in Table 13.

Table 13. Summary of the effect of dilution in the WTA.

Description	Date	HRT (hrs)	Q_{in} (m^3/d)	Q_{out} (m^3/d)	Dilution	$CBOD_5$ (mg/L)			TN (mg/L)		
						C_{in}	C_{out}	C_{out} theoretical	C_{in}	C_{out}	C_{out} theoretical
Entire wetland	25-May	34	529	2071	392%	13	4	3.3	13	1.2	3.3
Entire wetland	30-May	34	256	2846	1111%	5	4	0.4	6.1	0.6	0.5
Mid-point to outlet	06-Sep	8	25	77	310%	6	6	1.9	0.8	0.6	0.2

It should be noted that the influent concentrations (C_{in}) were relatively low in comparison to concentrations observed in other WTAs (CWRS, 2015). For illustrative purposes, Table 14 shows the relative difference in influent concentrations between other WTAs in Nunavut and the Sanikiluaq WTA.

Table 14. Comparison of influent water quality for WTAs across Nunavut with data from CWRS (2015).

Site	$CBOD_5$ (mg/L)	*E.coli* (MPN/100mL)[b]	TSS (mg/L)	TN (mg/L)
Sanikiluaq spring	9	$3.1x10^4$	7.5	10
Sanikiluaq summer[a]	6	4	5.8	0.7
Coral Harbour	91	$4.3x10^5$	90	35
Kugaaruk	151	$3.2x10^5$	21	81
Grise Fiord	194	$3.0x10^1$	140	23

[a]Concentrations are from the mid-point of the wetland for September because there was no flow at the inlet.
[b]Concentration units are CFU/100mL for Sanikiluaq.

The determination of representative rate constants for $CBOD_5$ was not possible since the water quality was of low strength as it entered the wetland. Therefore, in most cases, $CBOD_5$ concentrations observed within the wetland were below the analytical detection limits. There were a few cases where the rate constants could be determined for *E. coli*, TN, and TAN. However, they were uncharacteristically high and it is believed that the level of dilution in the WTA, and low inlet concentrations, influenced these results. A rate constant for total phosphorus removal was determined based on the site-specific data. The minimum rate constants were determined for total phosphorus as 0.083 m/d (30 m/yr), 0.072 m/d (26 m/yr), and 0.067 m/d (24 m/yr), at 5°C, 15°C, and 20°C, respectively. These rate constants fall below the mean of 32 m/yr and close to the median of 18 m/yr for ten cold climate wetlands presented in Kadlec and Wallace (2009).

3.6 Model Construction and Performance Modeling

The treatment performance model was run for the various scenarios outlined previously in Figure 4. The complete set of results for all model scenarios is provided in Appendix B. Key results are presented below in Tables 15 and 16. Table 15 summarizes the results of the treatment performance model run under median climate conditions (P/ET), over a 2-month discharge period, at temperatures ranging from 5 to 15°C. The influent strength was varied from low to high.

Table 15. Modeled effluent quality results for the median P/ET, 2-month discharge, and the 5 - 15 ^{o}C temperature range.

Parameter		Wastewater Strength		
		Low[b]	Medium[b]	High[b]
CBOD5 – mg/L (% reduction)	**Influent[a]**	**60**	**150**	**300**
	Spring	19 (68%)	45 (70%)	89 (70%)
	Summer	18 (70%)	43 (71%)	85 (72%)
***E. coli* – MPN/100 mL (log reduction)**	**Influent**	**1x10^{3}**	**1x10^{5}**	**1x10^{8}**
	Spring	2.8x10^{2} – 2.9x10^{2} (0.5 – 0.6 log)	2.8x10^{4} – 2.9x10^{4} (0.5 – 0.6 log)	2.8x10^{7} – 2.9x10^{7} (0.5 – 0.6 log)
	Summer	1.5x10^{2} – 2.3x10^{2} (0.6 – 0.8 log)	1.5x10^{4} – 2.3x10^{4} (0.6 – 0.8 log)	1.5x10^{7} – 2.3x10^{7} (0.6 – 0.8 log)
TN – mg/L (% reduction)	**Influent**	**40**	**80**	**140**
	Spring	12 (70%)	24 (70%)	41 (71%)
	Summer	12 (71%)	23 (71%)	40 (71%)
TAN – mg/L (% reduction)	**Influent**	**40**	**80**	**140**
	Spring	12 (71%)	23 (71%)	41 (71%)
	Summer	12 (71%)	23 (71%)	40 (71%)
TP – mg/L (% reduction)	**Influent**	**5**	**10**	**15**
	Spring	1.5 (71%)	2.9 (71%)	4.4 (71%)
	Summer	1.4 (72%)	2.8 (72%)	4.1 (72%)

[a] The influent is defined as the discharge from the lagoon into the WTA.

[b] When a singular value was stated, the temperature had little to no effect on the effluent values.

Table 16 summarizes the results of the treatment performance model run under median climate conditions (P/ET), over 3-week discharge period, at temperatures ranging from 5 to 15°C. The influent strength was varied from low to high. The effluent *E. coli* concentration is presented as a range in both Tables 15 and 16, as temperature variability had a large impact on that parameter. The reductions (in % and log reductions) in Tables 15 and 16 are calculated in relation to the influent concentrations expected to be entering the WTA from the lagoon.

Table 16. Modeled effluent quality results for the median P/ET, 3-week discharge, and the 5 - 15 ^oC temperature range.

Parameter		Wastewater Strength		
		Low[b]	Medium[b]	High[b]
$CBOD_5$ – mg/L (% reduction)	**Influent[a]**	**60**	**150**	**300**
	Spring	33 (45%)	82 (45%)	162 (46%)
	Summer	32 (47%)	79 (47%)	157 (48%)
***E. Coli* – MPN/100 mL (log reduction)**	**Influent**	**$1x10^3$**	**$1x10^5$**	**$1x10^8$**
	Spring	$5.2x10^2$ – $5.3x10^2$ (0.3 log)	$5.1x10^4$ – $5.3x10^4$ (0.3 log)	$5.1x10^7$ – $5.3x10^7$ (0.3 log)
	Summer	$3.3x10^2$ – $4.5x10^2$ (0.3 – 0.5 log)	$3.3x10^4$ – $4.5x10^4$ (0.3 – 0.5 log)	$3.3x10^7$ – $4.5x10^7$ (0.3 – 0.5 log)
TN – mg/L (% reduction)	**Influent**	**40**	**80**	**140**
	Spring	22 (46%)	43 (46%)	76 (46%)
	Summer	21 (48%)	43 (46%)	75 (46%)
TAN – mg/L (% reduction)	**Influent**	**40**	**80**	**140**
	Spring	22 (46%)	43 (46%)	76 (46%)
	Summer	21 (48%)	43 (46%)	75 (46%)
TP – mg/L (% reduction)	**Influent**	**5**	**10**	**15**
	Spring	2.7 (46%)	5.4 (46%)	8.1 (46%)
	Summer	2.6 (48%)	5.2 (48%)	7.8 (48)

[a] The influent is defined as the discharge from the lagoon into the WTA.

[b] When a singular value was stated, the temperature had little to no effect on the effluent values.

Overall, the treatment performance model produced more favorable effluent water quality results with a longer discharge period. The model runs which simulated a continuous summer discharge (2-month period) resulted in reductions averaging 70%, while the short decant scenarios (3-week period) produced average reductions of 47% for $CBOD_5$, TN, TAN, and TP. The difference between these scenarios can be explained by dilution; the continuous summer discharge produced an inflow into the wetland of 658 m^3/d, while the short decant produced 1878 m^3/d. The smaller daily discharge was more easily diluted by external hydrologic contributions. Table 17 shows the modeled hydraulic loading rate of 2.58 cm/d for the 2-month scenario, which was close to the 2.5 cm/d maximum recommended in the CWRS wetland design guidelines, while the 3-week HLR was almost triple the maximum.

Table 17. Hydraulic loading rates for the WTA.

Discharge Period	Year	HLR (cm/d)
2-months	2017	2.58
2-months	2037	3.75
3-weeks	2017	7.37
3-weeks	2037	10.7

The impact of dilution is illustrated more clearly in Table 18, which shows the modeled effluent water quality resulting from high strength influent at 5°C. Notably, under dry conditions (no external hydrologic contribution), all discharge period scenarios show the same minimal treatment, due to the lack of dilution. On the other hand, under median climate conditions the wetland receives external hydrologic contributions and the influent is diluted. For instance for the 2-month discharge period in 2017, under median conditions, the $CBOD_5$ is predicted as 89 mg/L; whereas, for the same scenario under dry conditions, the $CBOD_5$ is predicted as 299 mg/L. Which indicated that almost all of the reductions observed were attributed to dilution from external hydrologic influences.

Table 18. Modeled effluent quality results for the high strength influent with median and dry climate condition at 5°C during the spring period.

Discharge Period	Climate	$CBOD_5$ – mg/L (% reduction)	*E. coli* – MPN/100 mL (log reduction)	TN – mg/L (% reduction)	TAN – mg/L (% reduction)	TP – mg/L (% reduction)
2 months	Median	89 (70%)	2.9×10^7 (0.5 log)	41 (71%)	41 (71%)	4.4 (71%)
2 months (2037)	Median	113 (62%)	3.7×10^7 (0.4 log)	53 (62%)	52 (63%)	5.6 (63%)
3 weeks	Median	162 (46%)	5.3×10^7 (0.3 log)	76 (46%)	76 (46%)	8.1 (46%)
3 weeks (2037)	Median	189 (37%)	6.2×10^7 (0.2 log)	88 (37%)	88 (37%)	9.4 (37%)
2 months	Dry	299 (0.3%)	9.8×10^7 (0.009 log)	140 (0%)	140 (0%)	15 (0%)
2 months (2037)	Dry	299 (0.3%)	9.8×10^7 (0.009 log)	140 (0%)	140 (0%)	15 (0%)
3 weeks	Dry	299 (0.3%)	9.8×10^7 (0.009 log)	140 (0%)	140 (0%)	15 (0%)
3 weeks (2037)	Dry	299 (0.3%)	9.8×10^7 (0.009 log)	140 (0%)	140 (0%)	15 (0%)

Another factor which affected the treatment efficiency was retention time. In the model, the measured retention time determined from the tracer tests was used, however the nominal retention time was also calculated, and was generally longer. For instance, the nominal HRT was 10 days versus a measured HRT of 1.4 days during the spring conditions for the 2-month discharge period. Likewise, the nominal HRT was 3.4 days versus a measured HRT of 0.9 days during the summer conditions for the 2-month discharge period. By using the measured HRTs, the modeled estimated were more conservative because they accounted for hydraulic inefficiencies such as short-circuiting and dead-zones in the wetland.

Given that dilution and retention time have a large impact on treatment performance, two additional scenarios were run to assess their impact. The first scenario increased the retention time by using the longer nominal retention time in place of the shorter measured retention time. The second scenario averaged the annual precipitation over 90 days instead of 365 to simulate high flow spring melt conditions. The results of these model runs are presented in Table 19 for the medium strength influent, the 2-month discharge period, and at 5°C for dry and median climate conditions.

Table 19. Modeled effluent quality results for the medium strength influent, and the 2-month discharge period at 5°C with nominal HRT, 365 and 90-day precipitation rates during the summer period.

Climate	Scenario	$CBOD_5$ (mg/L)	*E. coli* (MPN/100mL)	TN (mg/L)	TAN (mg/L)	TP (mg/L)
Dry	Nominal HRT	127 (15%)	$4.2x10^4$ (0.4 log)	75 (7%)	75 (7%)	8.2 (18%)
	Measured HRT/365-day P	131 (13%)	$4.7x10^4$ (0.3 log)	76 (6%)	76 (6%)	8.5 (15%)
Median	Measured HRT/365-day P	43 (71%)	$2.3x10^4$ (0.6 log)	23 (71%)	23 (71%)	2.8 (72%)
	90-day P	14 (97%)	$7.4x10^3$ (1.1 log)	6.7 (92%)	6.6 (92%)	0.8 (92%)

In the case of the dry climate, with no external hydrologic contributions, increasing the retention time provided a very modest increase in treatment. For the 90-day precipitation scenario, the precipitation was averaged over 90 days instead of 365 days to mimic high flow spring melt conditions. In the case of the median climate, the 90-day precipitation provides a significant reduction (greater than 90%), due to the increased dilution (Table 19).

The $CBOD_5$ loading rates were determined for each of the modeled scenarios and are presented in Table 20. In general, the computed $CBOD_5$ loading rates for the medium and high influent strength conditions exceed recommended limits (22 Kg/ha/d) for treatment wetland systems.

Table 20. $CBOD_5$ loading rates (kg/ha/d) for 2017 conditions in relation to influent strength.

Discharge Period	Low	Medium	High
2-month	12	29	58
3-week	33	83	167

3.7 Community Consultations

The council meeting took place in Sanikiluaq on September 8th, 2016. In attendance was the mayor, 6 councillors, the SAO, and Jenny Hayward and Kiley Daley from CWRS. Jenny Hayward gave a presentation during the meeting and then Jenny and Kiley answered questions from the attendees. The transcript of the question period during the council meeting is included in Appendix C.

It should be noted that there were some concerns expressed from the councillors in association with the sewage lagoon and WTA. Specifically, a few councilors expressed concern in regards to having a new lagoon sited and constructed. They wanted to know whether a new lagoon would be constructed and whether an alternate site would be selected. CWRS communicated that this decision-making in regards to wastewater infrastructure upgrades and capital spending is not under the scope of this study on the WTA. However, it was communicated that their concerns would be relayed to the CGS department of the GN. Another councilor expressed concern that the marine life is being negatively impacted by the sewage discharge at the end of the WTA. CWRS communicated that based on the water quality results, there were very low levels of contaminants when the effluent reaches the marine receiving environment. Therefore, there is likely very few negative impacts to the marine life. This was supported by research conducted by CWRS at other sites which showed for that communities approximately the same size as Sanikiluaq, there are only localized impacts to the receiving environment (i.e., <225 m) (Krumhansl et al, 2014). One councillor noted that he saw effluent flow over the snow and ice during the spring freshet. He requested that sample bottles be sent to test for contaminants during that over snow flow period. CWRS did not observe this over snow flow event; however CWRS expressed that high flows over the snow would represent a period of higher risk as treatment would not be possible in the WTA. CWRS expressed that this request from the councillor for early spring sampling in 2017 would be communicated to the CGS department of the GN.

The community forum at the Co-op took place over two days, September 6th from 4:00pm – 5:30pm and on September 7th from 4:30pm – 5:30pm. Jenny Hayward and Kiley Daley set up a research display in the entryway of the Co-op store, which included a CWRS banner, a laptop with a slideshow of field pictures, and large laminated maps (33 x 79”) illustrating the study area within the community. There was also a draw set up where community members could win a $25 gift certificate to the Co-op for participating in the forum.

At the community forum, CWRS delegates explained the research that was being conducted in the community using the visual aids present at the display. The area and flow direction of the sewage area was illustrated visually to the forum participants with the maps. The participants used dry erase markers to illustrate where on the land around and within the WTA they have seen wildlife, or where they have transited by foot or motorized vehicle. Participants asked questions about the wetlands ability to treat the sewage, as well as expressed their observations about travelling through the area in the winter and spring seasons. The participants expressed that wildlife and game hunting and the impacts of the sewage on these activities was a concern. Generally, most participants avoided frequenting and hunting in the WTA because of the risk of contact with sewage. As well, they expressed curiosity about the health of the marine life in the discharge area, which CWRS communicated was of low risk due to the favorable water quality at the wetland outlet. A total of 33 community members visited the display over the course of the two days.

At both the council meeting and the community forum at the Co-op, a key message was communicated that the water quality was low in contaminants and below the NWB water licence requirements at the outlet of the WTA. Also, a message of proper game and waterfowl handling for human consumption was communicated by CWRS. This was communicated because Canada Geese were observed at the WTA in direct contact with the sewage, which can act as potential disease vector to humans if not properly prepared prior to consumption.

4.0 Conclusions

- The current wastewater treatment system in Sanikiluaq consists of a sewage detention lagoon that discharges effluent in an uncontrolled manner through an exfiltration berm to a 3.3 ha WTA. The majority of wastewater flows into the WTA during the spring freshet period.

- The wetland watershed area was determined to be 170 ha, and this contributed to significant amounts of external hydrologic contributions to the WTA. During the spring period the average amount of dilution ranged from 392 – 1111%. During the late summer the average amount of dilution was 310%.

- Concentrations of water quality parameters entering the wetland (leaving the lagoon) were low as compared to other systems studied in Nunavut. For example, the concentration of $CBOD_5$ entering the wetland during the spring period was < 15 mg/L, as compared to a raw wastewater concentrations of 320 – 370 mg/L. This could be attributed to dilution of effluent in the lagoon from upgradient drainage or snow accumulation, or to treatment of wastewater as it seeps through the berm of the lagoon.

- Measured concentrations of key water quality parameters at the outlet of the wetland were always lower than the NWB water license requirements:

    - Measured $CBOD_5$ concentrations were all < 6 mg/L.

    - Measured TSS concentrations were all < 15 mg/L.

    - Measured *E. coli* concentrations were all < 30 CFU/100mL.

- The low concentrations of water quality parameters observed at the wetland outlet were due to the low concentrations of these parameters in the WTA influent, and the large amount of dilution from the wetland watershed. These two factors limited the ability to derive treatment rate constants for the wetland for most parameters, as these factors masked the influence of other treatment mechanisms in the WTA.

- A treatment performance model was constructed for the WTA and used to assess WTA effluent quality for a suite of scenarios that examined the effects of climate variability, length of discharge period, and quality of wastewater entering the wetland. For the median climate conditions and assuming a medium strength wastewater leaving the WSP/lagoon:

    - WTA effluent $CBOD_5$ concentrations would range from 43 – 45 mg/L, *E. coli* concentrations would range from $1.5x10^4$ – $2.9x10^4$ CFU/100mL, and TN concentrations would be approximately 23 mg/L for the 2-month discharge period scenario.

- WTA effluent CBOD5 concentrations would range from 79 – 82 mg/L, *E. coli* concentrations would range from $3.3x10^4$ – $5.3x10^4$ CFU/100mL, and TN concentrations would be approximately 43 mg/L for the 3-week discharge period scenario.
- Additional sensitivity analyses were conducted with the performance model to determine the primary mechanisms contributing to contaminant reductions in the WTA. This analysis confirmed that dilution was the primary mechanism for contaminant reductions in the existing WTA.

- Outcomes of the community consultation included that there was concern expressed by forum participants and councillors for some aspects of the wastewater treatment system and CWRS communicated key findings of the study.
  - CWRS communicated that discussions about infrastructure upgrades were beyond the scope of this project and should be directed at the CGS of the GN.
  - Although the marine environment study was not included in the project scope, based on the water quality results at the outlet, CWRS communicate that there are likely very minimal impacts to the receiving environment.
  - A councilor requested extra sampling during the spring freshet and CWRS responded that the request would be communicated to the CGS of the GN.
  - CWRS communicated the key findings that the water quality at the outlet met the NWB standards and was of good quality.
  - CWRS communicated that proper handling of game and waterfowl should be observed by hunters and trappers as some wildlife were observed within the WTA and these could act as potential disease vectors.

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Appendix A: Summary of Metals Data

Table A 1. Summary of metals data from treatment performance samples.

Sampling Date	Sample	Parameter				
		Cadmium (µg/L)	Cobalt (µg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)
25-05-2016	Raw 1	<0.20	<1.0	<60	<0.50	7.6
	Outlet	<0.20	<1.0	<60	<0.50	3.3
30-05-2016	Raw 2	<0.20	1.1	900	2.1	64
	Raw 3	<0.20	<1.0	770	2.5	62
	Outlet	<0.20	<1.0	<60	<0.50	1.1
06-09-2016	Raw 1	0.35	0.92	766	3.18	53
	Raw 2	0.40	1.15	1040	6.03	67
	Raw 3	0.38	1.33	720	1.88	56
	Outlet	0.16	<0.50	48	<0.2	34
08-09-2016	Outlet	0.33	<0.50	135	<0.2	41

Appendix B: Summary Table of the Modeling Results

Table B - 1 Detailed summary of the effluent concentrations from the modeling analysis of the Sanikiluaq WTA for the spring conditions.

Temperature	Strength	Discharge Period	Climate	$CBOD_5$	*E. coli*	TN	TAN	TP
5°C	Low	2 months	Dry	60	9.8E+02	39.9	39.9	5.0
15°C	Low	2 months	Dry	60	9.5E+02	39.9	39.9	5.0
15°C	Low	2 months	Median	19	2.8E+02	12.0	12	1.5
5°C	Low	2 months	Median	19	2.9E+02	12.1	12	1.5
5°C	Low	2 months (2037)	Dry	60	9.8E+02	39.9	39.9	5.0
15°C	Low	2 months (2037)	Dry	60	9.5E+02	39.9	39.9	5.0
5°C	Low	2 months (2037)	Median	24	3.7E+02	15.3	15.0	1.9
15°C	Low	2 months (2037)	Median	24	3.6E+02	15.3	14.9	1.9
5°C	Low	3 weeks	Dry	60	9.8E+02	39.9	39.9	5.0
15°C	Low	3 weeks	Dry	60	9.5E+02	39.9	39.9	5.0
5°C	Low	3 weeks	Median	33	5.3E+02	21.8	21.6	2.7
15°C	Low	3 weeks	Median	33	5.2E+02	21.8	21.6	2.7
5°C	Low	3 weeks (2037)	Dry	60	9.8E+02	39.9	39.9	5.0
15°C	Low	3 weeks (2037)	Dry	60	9.5E+02	39.9	39.9	5.0
5°C	Low	3 weeks (2037)	Median	38	6.2E+02	25.4	25.2	3.2
15°C	Low	3 weeks (2037)	Median	38	6.0E+02	25.4	25.2	3.1
5°C	Medium	2 months	Dry	149	9.8E+04	79.9	79.9	10.0
15°C	Medium	2 months	Dry	149	9.5E+04	79.8	79.8	9.9
15°C	Medium	2 months	Median	45	2.8E+04	23.7	23	2.9
5°C	Medium	2 months	Median	45	2.9E+04	23.7	23	2.9
5°C	Medium	2 months (2037)	Dry	149	9.8E+04	79.9	79.9	10.0
15°C	Medium	2 months (2037)	Dry	149	9.5E+04	79.8	79.8	9.9
5°C	Medium	2 months (2037)	Median	57	3.7E+04	30.2	29.9	3.7
15°C	Medium	2 months (2037)	Median	57	3.6E+04	30.2	29.9	3.7
5°C	Medium	3 weeks	Dry	149	9.8E+04	79.9	79.9	10.0
15°C	Medium	3 weeks	Dry	149	9.5E+04	79.8	79.8	9.9
5°C	Medium	3 weeks	Median	82	5.3E+04	43.4	43.1	5.4
15°C	Medium	3 weeks	Median	82	5.1E+04	43.4	43.1	5.4
5°C	Medium	3 weeks (2037)	Dry	149	9.8E+04	79.9	79.9	10.0
15°C	Medium	3 weeks (2037)	Dry	149	9.5E+04	79.8	79.8	9.9
5°C	Medium	3 weeks (2037)	Median	95	6.2E+04	50.6	50.4	6.3
15°C	Medium	3 weeks (2037)	Median	95	6.0E+04	50.5	50.3	6.3
5°C	High	2 months	Dry	299	9.8E+07	139.8	139.8	14.9
15°C	High	2 months	Dry	299	9.5E+07	139.7	139.7	14.9
15°C	High	2 months	Median	89	2.8E+07	41.1	41	4.4
5°C	High	2 months	Median	89	2.9E+07	41.1	41	4.4
5°C	High	2 months (2037)	Dry	299	9.8E+07	139.8	139.8	14.9
15°C	High	2 months (2037)	Dry	299	9.5E+07	139.7	139.7	14.9
5°C	High	2 months (2037)	Median	113	3.7E+07	52.6	52.3	5.6

Table B - 2 (Cont'd) Detailed summary of the effluent concentrations from the modeling analysis of the Sanikiluaq WTA for the spring conditions.

Temperature	Strength	Discharge Period	Climate	$CBOD_5$	*E. coli*	TN	TAN	TP
15°C	High	2 months (2037)	Median	113	3.6E+07	52.6	52.2	5.6
5°C	High	3 weeks	Dry	299	9.8E+07	139.8	139.8	14.9
15°C	High	3 weeks	Dry	299	9.5E+07	139.7	139.7	14.9
5°C	High	3 weeks	Median	162	5.3E+07	75.7	75.5	8.1
15°C	High	3 weeks	Median	162	5.1E+07	75.7	75.4	8.0
5°C	High	3 weeks (2037)	Dry	299	9.8E+07	139.8	139.8	14.9
15°C	High	3 weeks (2037)	Dry	299	9.5E+07	139.7	139.7	14.9
5°C	High	3 weeks (2037)	Median	189	6.2E+07	88.3	88.1	9.4
15°C	High	3 weeks (2037)	Median	189	6.0E+07	88.2	88.0	9.4

Table B - 3. Detailed summary of the effluent concentrations from the modeling analysis of the Sanikiluaq WTA for the summer conditions.

Temperature	Strength	Discharge Period	Climate	$CBOD_5$	*E. coli*	TN	TAN	TP
5°C	low	2 months	Dry	53	4.8E+02	38	38	4.3
15°C	low	2 months	Dry	52	1.3E+02	37	37	3.5
5°C	low	2 months	Median	18	2.3E+02	12	11	1.4
15°C	low	2 months	Median	18	1.5E+02	11	11	1.3
5°C	low	2 months (2037)	Dry	55	5.9E+02	38	38	4.5
15°C	low	2 months (2037)	Dry	54	2.4E+02	38	38	3.9
5°C	low	2 months (2037)	Median	23	3.0E+02	15	15	1.8
15°C	low	2 months (2037)	Median	23	2.0E+02	15	15	1.7
5°C	low	3 weeks	Dry	57	7.5E+02	39	39	4.7
15°C	low	3 weeks	Dry	57	4.5E+02	39	39	4.4
5°C	low	3 weeks	Median	32	4.5E+02	21	21	2.6
15°C	low	3 weeks	Median	32	3.3E+02	21	21	2.5
5°C	low	3 weeks (2037)	Dry	58	8.1E+02	39	39	4.8
15°C	low	3 weeks (2037)	Dry	57	5.5E+02	39	39	4.5
5°C	low	3 weeks (2037)	Median	38	5.4E+02	25	25	3.1
15°C	low	3 weeks (2037)	Median	37	4.2E+02	25	25	2.9
5°C	med	2 months	Dry	131	4.7E+04	76	76	8.5
15°C	med	2 months	Dry	129	1.3E+04	73	73	7.1
5°C	med	2 months	Median	43	2.3E+04	23	23	2.8
15°C	med	2 months	Median	43	1.5E+04	23	23	2.6
5°C	med	2 months (2037)	Dry	136	5.9E+04	77	77	8.9
15°C	med	2 months (2037)	Dry	134	2.3E+04	75	75	7.8
5°C	med	2 months (2037)	Median	55	3.0E+04	30	29	3.6
15°C	med	2 months (2037)	Median	55	2.0E+04	29	29	3.4
5°C	med	3 weeks	Dry	142	7.5E+04	78	78	9.4

Table B - 4. (Cont'd) Detailed summary of the effluent concentrations from the modeling analysis of the Sanikiluaq WTA for the summer conditions.

Temperature	Strength	Discharge Period	Climate	$CBOD_5$	*E. coli*	TN	TAN	TP
15°C	med	3 weeks	Dry	141	4.5E+04	77	77	8.7
5°C	med	3 weeks	Median	79	4.5E+04	43	43	5.2
15°C	med	3 weeks	Median	79	3.3E+04	42	42	5.0
5°C	med	3 weeks (2037)	Dry	144	8.1E+04	79	79	9.5
15°C	med	3 weeks (2037)	Dry	143	5.5E+04	78	78	9.0
5°C	med	3 weeks (2037)	Median	93	5.4E+04	50	50	6.1
15°C	med	3 weeks (2037)	Median	92	4.1E+04	50	49	5.9
5°C	high	2 months	Dry	261	4.7E+07	132	132	12.8
15°C	high	2 months	Dry	257	1.3E+07	128	128	10.6
5°C	high	2 months	Median	85	2.3E+07	40	40	4.1
15°C	high	2 months	Median	84	1.5E+07	40	40	3.9
5°C	high	2 months (2037)	Dry	272	5.9E+07	135	135	13.4
15°C	high	2 months (2037)	Dry	269	2.3E+07	132	132	11.7
5°C	high	2 months (2037)	Median	109	3.0E+07	52	51	5.3
15°C	high	2 months (2037)	Median	108	2.0E+07	51	51	5.0
5°C	high	3 weeks	Dry	284	7.5E+07	137	137	14.1
15°C	high	3 weeks	Dry	282	4.5E+07	135	135	13.0
5°C	high	3 weeks	Median	157	4.5E+07	75	75	7.8
15°C	high	3 weeks	Median	157	3.3E+07	74	74	7.4
5°C	high	3 weeks (2037)	Dry	288	8.1E+07	138	138	14.3
15°C	high	3 weeks (2037)	Dry	286	5.5E+07	136	136	13.5
5°C	high	3 weeks (2037)	Median	184	5.4E+07	87	87	9.1
15°C	high	3 weeks (2037)	Median	184	4.1E+07	87	87	8.8

Appendix C: Transcript of the Council Meeting Presentation Q & A

Transcript of council meeting presentation Q&A in Sanikiluaq delivered on September 8, 2016 by Jenny Hayward and Kiley Daley.

The questions were posed by the councillors (in bold and italicized text) and the response from CWRS are directly below the questions.

1. ***Can you elaborate on the E. coli numbers, why is it at the outlet, isn't it dangerous?***
(Note: "*E. coli*" is a big topic in the community as they were recently under a drinking water boil advisory in summer 2016)

JH – *E. coli* is a type of bacteria that is used to indicate whether or not there may be faecal contamination in a water sample. It is sourced from the digestive tracts of warm blooded mammals and birds. It is normal to see higher numbers of *E. coli* associated with sewage treatment systems. The *E. coli* concentrations we observed at the outlet are very low and well below the NWB regulation level. It is expected that we did find low numbers of *E. coli* at the wetland outlet. These bacteria concentrations are not likely a risk to human or environmental health. We found that the concentrations of *E. coli* in the wetland decrease to a very low concentration by the wetland outlet, which suggests the wetland is removing the *E. coli*. Another potential contributor to *E. coli* in the wetland is the waterfowl present, such as the Canadian Geese. It normal to see *E. coli* in association with sewage treatment systems and the low levels at the outlet are low and do not pose a significant risk.

2. ***Is there a health risk associated with picking berries in the area near the wetland?***

JH – A map was used to explain the watershed area (in white) and the area of the wetland treatment area where sewage was observed. It was explained that sewage flows in the north-eastern direction from the lake lagoon inlet towards the outlet. The sewage cannot flow across the watershed high-points denoted by the watershed area that was delineated based on site topography. The councillor indicated the preferred berry-picking area, which although this area was within the watershed, it was not in an area that comes into contact with effluent (although there *are* berries in the treatment area). It is not recommended to pick berries in the area of the map that is in the vicinity of the blue wetland treatment area. Upstream areas of the watershed towards the west of the sewage lagoon are safe for berry picking.

3. ***What is the government going to do with the lagoon? One councillor (younger female) states that she believes the contamination is having an impact on mammals in the ocean/receiving waters. Another councillor (elder female) says that in spring contaminants go to the harbour, impacting char, sculpin, mussels sea urchins and seaweed. She believes that the lagoon and treatment area should be moved as soon as possible.***

JH – The decision of lagoon upgrades and re-location possibilities are made according to the CGS department of the GN. We observed that the wetland treatment area works well to buffer the impacts of the sewage prior to discharge into the marine receiving environment (water quality met the NWB standard at the outlet). We explained that our preliminary results show that the impact at the outfall point appears minimal, however, studying the actual impact on mammals was outside the possibilities/scope of this research study design. Based on our previous studies in similar sized communities with comparable water quality of the effluent discharging into the marine receiving environment, the impacts on the receiving environment are likely localized and minimal (i.e., <225 m). Noted that this concern would be addressed in our reporting to the CGS department of the GN.

4. A councillor noted that in the spring, effluent from the lagoon flows on top of the ice/snow towards the sea. This effluent is possibly highly contaminated (as it hasn't actually "entered" the lagoon or wetland). There was a request for containers to be provided to collect this water/effluent and send it away to a commercial laboratory for analysis.

JH – This description of what was observed by the councillor would be a scenario where there would be greater risk to human and environmental health. This situation was not observed during our site visits, however it is possible that it occurred earlier in the season. This observation was noted as important to communicate to the CGS to attempt to capture in future sampling events of the system. In order to properly characterize this type of scenario, water samples would need to be collected earlier in the season when the wetland is still frozen. Dal indicated that they will communicate this request from the community for future sampling at this time of the year to the CGS.

5. A councillor expressed that Dal should study the lake below the airport (i.e. swimming lake). The councillor noted that the odour of sewage is present there too.

JH – This area was beyond our initial mapping of areas that could be impacted by sewage. We used topographic information to determine the limits to where the sewage can flow based on high elevations in the landscape. Based on our initial mapping, it would not be possible for the sewage to flow in the direction of that lake. It was explained that at the time of this consultation, additional work was being conducted to collect more accurate and detailed information about the site topography. This information was later used to assess whether the lake is connected to the sewage treatment area. Based on the initial desktop assessment, it is was communicated that it was highly unlikely that this would be possible; however that this possibility would be clarified in the final reporting. Since the council meeting, upon further study, it was determined that there is no hydraulic connection between the sewage and the swimming lake.

6. Can you elaborate on the vegetation survey, what are the impacts to the plants from the sewage and how does this affect the animals that eat the plants, such as the geese?

JH – The vegetation surveys are done to collect information on the types of vegetation present within the wetland treatment area. A reference wetland with no impacts of sewage is also surveyed. The study site and reference wetlands are then compared to assess shifts in vegetation resulting from sewage effects. In many cases, the same types of vegetation are found but sometimes less diversity of species in the wetland treatment area and more plant biomass. We also look for areas of the wetland treatment area that may have vegetation die-off. This die-off is observed in areas of the wetland where the amount of sewage has been too much for the wetland to support.

Preliminary results show that willows, grasses prefer wastewater. Sewage has many nutrients including nitrogen and phosphorus which encourage plant growth (similar to a fertilizer). Natural tundra wetlands tend to be nutrient poor, therefore the sewage adds many nutrients that lead to an increase in overall plant biomass (many plants in the sewage area appear more green and larger than natural tundra vegetation). Also, Canada Geese prefer the vegetation in the WTA which adds bacteria (confounding factor) but also potential disease vector.

The geese are likely not affected by eating the vegetation in the wetland treatment area. However, since the geese are located in the wetland treatment area due to increased food supply associated with this area, the geese can act as vectors for disease transmission. Caution and proper food handling practices should be exercised when preparing waterfowl and geese for consumption because they come in direct contact with sewage and as a result can transmit diseases.