# Wetland Treatment Area Study in Naujaat, Nunavut

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## List of Abbreviations

| | |
|---|---|
| % | Percent |
| $\theta$ | Nominal Retention Time |
| $BOD_5$ | Five-Day Biochemical Oxygen Demand |
| °C | Degrees Celsius |
| $C_{out}$ | Outgoing Effluent Concentration |
| $CBOD_5$ | Five-Day Carbonaceous Biochemical Oxygen Demand |
| CFU/100mL | Colony Forming Unit per 100 mL |
| CGS | Community of Government Services |
| cm | Centimetre |
| CWRS | Centre for Water Resources Studies |
| d | Day |
| DEM | Digital Elevation Model |
| DO | Dissolved Oxygen |
| ET | Evapotranspiration |
| *Et al* | *Et Alii* |
| *E. coli* | *Escherichia coli* |
| Eq. | Equation |
| 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 |

| | |
|---|---|
| kg | Kilogram |
| km | Kilometre |
| $km^2$ | Kilometre Squared |
| L | Litre |
| m | Metre |
| mm | Millimetre |
| $m^2$ | Metre Squared |
| $m^3$ | Cubic Metre |
| MB | Manitoba |
| mL | Millilitre |
| MLA | Member of the Legislative Assembly |
| mg | Milligram |
| MPN/100mL | Most Probable Number of Colony Forming Units per 100mL |
| N | North |
| $NH_3$-N | Un-ionized Ammonia Nitrogen |
| NWB | Nunavut Water Board |
| OH | Ohio |
| P | Precipitation |
| PAEK | Polynomial Approximation with Exponential Kernel |
| PET | Potential Evapotranspiration |
| Q | Discharge |
| QC | Quebec |
| RBG | Red Blue Green |
| 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 |
| µg | Micrograms |
| µS | Microsiemens |
| V | Volume |
| VSS | Volatile Suspended Solids |
| SAO | Senior Administrative Official |
| W | West |
| WSER | Wastewater Systems Effluent Regulations |
| WSP | Waste Stabilization Pond |
| WTA | Wetland Treatment Area |
| yr | Year |

# Executive Summary

This report provides an assessment of a Wetland Treatment Area (WTA) currently used for municipal wastewater treatment in the community of Naujaat, Nunavut. The current WTA receives wastewater in an un-controlled manner from a natural depression where wastewater is deposited. 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 in June and the late summer in August. The assessment included characterization of the physical, biological, and hydrological attributes of the WTA, and water quality sampling to quantify the current level of treatment provided by the system.

The WTA and contributing watershed were delineated using a publicly available digital elevation model, satellite imagery, and with field observations. The WTA was determined to be approximately 3.6 ha in size, while the contributing watershed was 96 ha. The large watershed area resulted in significant dilution of both the wastewater stored in the natural depression, 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 104 – 247% in the spring freshet, and 275% 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 licence requirements, with five-day carbonaceous biological oxygen demand ($CBOD_5$) concentrations < 80 mg/L, total suspended solids concentrations (TSS) < 70 mg/L, and *Escherichia coli* (*E. coli*) concentrations < $1x10^6$ CFU / 100 mL during both spring freshet and late summer sampling periods. These regulatory criteria are set for an upgraded system, which was not in current use at the time of the study. The low concentrations of these parameters observed at the WTA outlet was primarily attributed to dilution from external hydrologic contributions.

A mathematical model was constructed and parameterized using site-specific data collected from the WTA. A suite of scenarios was 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 was 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 86 mg/L, *E. coli* concentrations would range from $3.7x10^4$ – $4.6x10^4$ CFU/100mL TN concentrations would be approximately 44 mg/L, and TP concentrations would be approximately 5 mg/L. These effluent concentrations were predicted based on the assumption that the WSP was decanted over a 2-month period. The 2-month discharge period produced better effluent quality than the 3-week discharge 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 August 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 helped 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 licence. Community members generally expressed knowledge of the presence of sewage within the wetland and most tried to avoid the area. A seasonal snowmobile route crosses the WTA and marine mammals are known to cross by the outlet of the WTA. Generally, there was genuine interest in the findings and yet no major concerns associated with the WTA noted by the community members queried.

# 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 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 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 and used 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 and 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 Naujaat during the treatment season (June to September). The four main objectives of the study were to:

i) Assess the treatment performance of the WTA in Naujaat;
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 Naujaat WTA. 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 may 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 2.7.4.

## 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 provided 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; and
- Public consultation.

### 2.2 Site Description

#### *2.2.1 Naujaat*

The hamlet of Naujaat (66° 31’ 19” N, 086° 14’ 16” W) is located along the Northern shore of Hudson Bay with an estimated population of 945 people (Statistics Canada, 2012). The site-specific study on the WTA in Naujaat was conducted from June 10 to 21, 2016 and August 24 to 31, 2016**.** Average air temperatures range from –34°C and –28°C in January, and from 4°C and 13°C in July. Total precipitation averages 339 mm, with 124 mm as rainfall, and 2154 mm as snow (215 mm Snow Water Equivalent), (Government of Canada, 2016a).

### *2.2.2 Wetland Treatment Area*

Currently, wastewater is transported by trucks to a natural depression where it is deposited located approximately 1.4 km to the east of the hamlet (Nunavut Water Board, 2015). Approximately 97 $m^3$/d (35,430 $m^3$/year) of primarily domestic municipal wastewater is generated and transported to the natural depression in the landscape where it is deposited (Hamlet of Repulse Bay, 2013, 2014, 2015). The tundra WTA consists of the natural depression and a tundra WTA, approximately 1.2 km in length. The sewage is collected and retained over the winter months in the natural depression; wastewater then begins to flow into the WTA in an uncontrolled manner during the spring melt period. The WTA eventually discharges to the Hudson Bay. The WTA is shown below in Figure 1. As per the water licence, the effluent quality limits at the outlet must be less than 80 mg/L for five-day biochemical oxygen demand ($BOD_5$), <70 mg/L for TSS, < $1x10^6$ CFU/100mL for faecal coliforms, and have a pH between 6 and 9 (Nunavut Water Board, 2015).

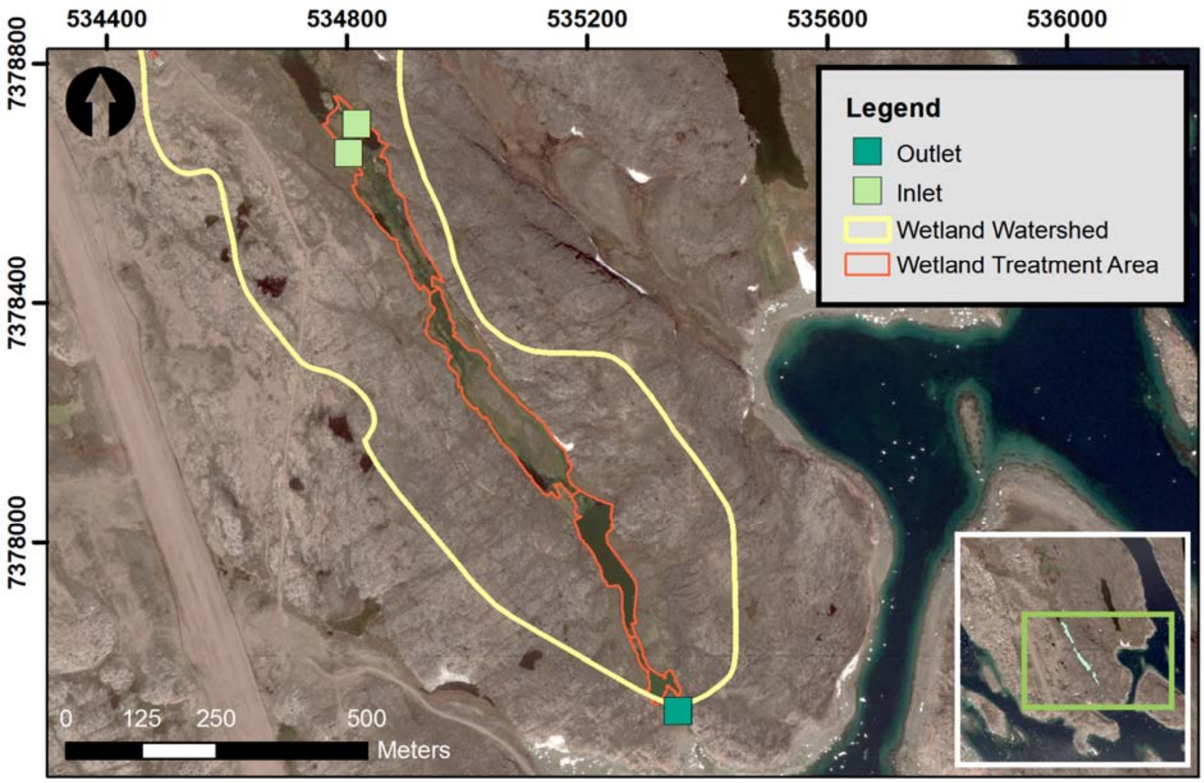


**Figure 1. Site map of the WTA in Naujaat that was the focus of this study.**

The WTA covers an area that is approximately 36,500 $m^2$. The topography is characterized by a 1.3% north to south downward sloping terrain. The WTA consists of wetland areas characterized by various willows, fireweed, carex, grasses and mosses and upland areas characterized by mosses, white heather, mountain avens, and lichens.

### *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 not within close proximity of the community and is un-impacted by sewage. It located approximately 500 m east of the study WTA. It is downstream of an archaeological site, which was an early settlement of the Thule people. The reference wetland is one of the only wetlands located within proximity of the study site that shares similar geomorphic characteristics. Water quality samples were collected at two locations within the reference wetland and the vegetation was characterized.

## 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. 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 Global Positioning System (GPS) survey which was supplemented by analysis of high spatial resolution satellite imagery (0.4 m).

### *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 ponds 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 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 derive 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 injection of a conservative solute, in this case fluorescent dye, Rhodamine WT (RWT), into the flow stream. The RWT is injected upstream and the concentration of the RWT and is measured over time at a defined point downstream.

Over the course of the June and August study periods, six tracer tests were completed in the WTA. The amount of RWT tracer injected was computed based on a desired target concentration 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).

### 2.4 Physical and Biological Characterization

#### *2.4.1 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 August 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 85 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. The main resource used to aid with the identification of vegetation species was *Common Plants of Nunavut* by Mallory and Aiken (2004). Figure 2 is an example of a quadrat plot.

**Figure 2. Example photograph of a vegetation quadrat showing a wetland vegetative cover (August 27, 2016).**

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 based on species that co-occurred within 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 11, 2016 by GeoEye-1 from Digital Globe. A three-band (RBG) QuickBird satellite image of Naujaat 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.

#### *2.4.2 Wildlife*

A wildlife survey was completed during this site visits. This involved documentation of the presence of any wildlife with notes and photos. The results of this wildlife survey were discussed during the community consultation to gain additional insight of the types of wildlife that frequent the area.

### 2.5 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 ($CB0D_5$), total suspended solids (TSS), faecal indicator organisms, nitrogen, and phosphorous. The biogeochemistry of the WTA was also characterized with the measurement of water quality parameters such as temperature, dissolved oxygen (DO), pH, and conductivity.

#### *2.5.1 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 were based on suspected flow increases or additions, where two stream channels converged, or before and after a pond within the WTA. In the Naujaat WTA, most sampling sites were equally spaced between the inlet and outlet of the treatment area. Figure 3 shows the sample and gauging sites within the Naujaat WTA.

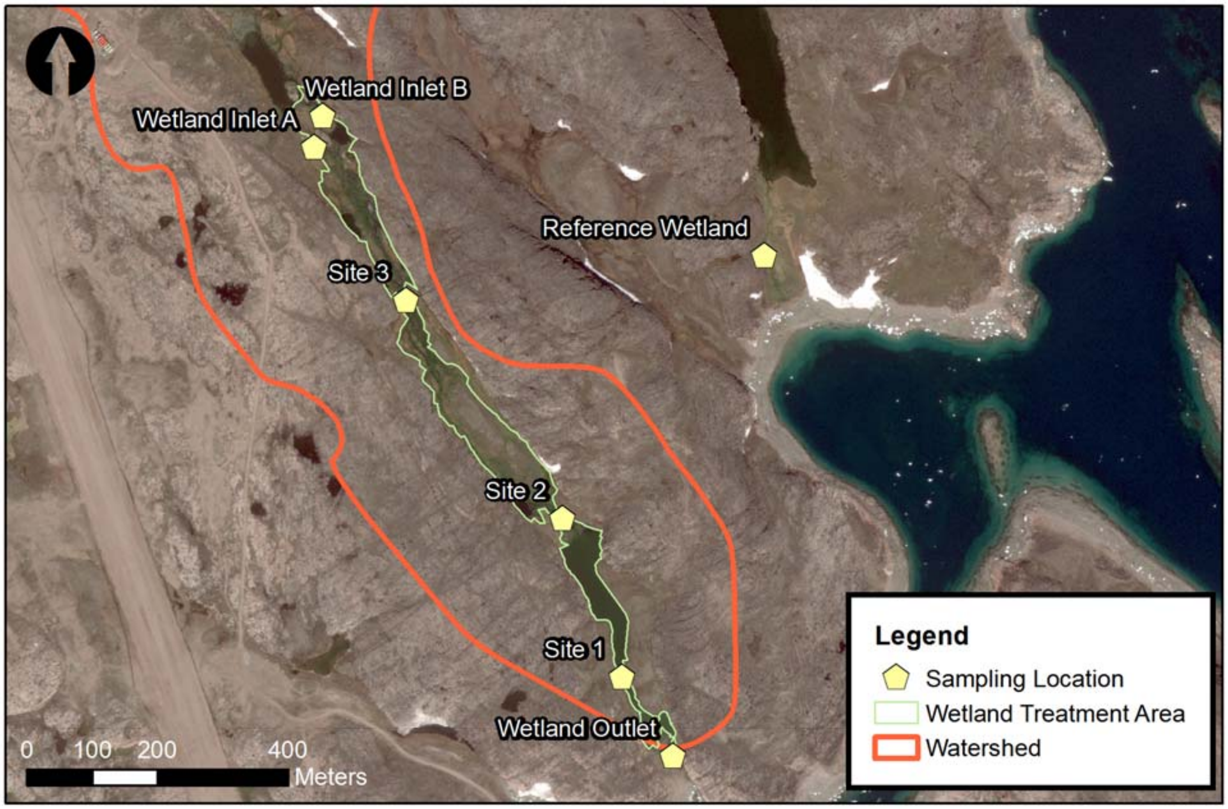


**Figure 3. Map of sampling locations within WTA in Naujaat, NU.**

### *2.5.2 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 Naujaat. Discrete measurements were also performed on samples from the reference wetland and the raw wastewater samples directly from the pump trucks upon discharge into the natural depression.

### *2.5.3 Treatment Performance Samples*

The treatment performance assessment of the wetland entailed the collection of samples at key points in the WTA and analysis 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 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 discharged into the natural depression. 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 Naujaat (four rounds in total). An average of eight samples were collected for each round of sampling. This includes samples within the WTA, the reference wetland, and raw sewage.

#### *2.5.4 Solid Waste Considerations*

In Naujaat, the WTA is downgradient of a solid waste facility that is no longer in use. Old debris and barrels were still visible at the site, which is just north of the inlet of the WTA. According to CWRS (2016), it is necessary to ascertain whether contaminants which originated 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 or subsurface flow. Landfill leachate can contain heavy metals, acidic pHs, 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; and
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 collected over the course of the study may also give an indication if there was 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 the potential for solid waste leachate influences within the WTA.

### 2.6 Rate Constant Derivation

First order rate constants were determined by parameterizing TIS chemical reactor 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 models to represent each wetland segment and the entire wetland 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 data 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 were 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 optimization of 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 (Kadlec and Wallace, 2009). The temperature coefficients that were used to adjust the rate constants were taken from Hayward & Jamieson (2015).

## 2.7 Model Construction

### *2.7.1 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.

### *2.7.2 Model Approach*

Tracer tests were conducted during site visits in June and August 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 with a moment analysis to determine mean HRT, and with a gamma distribution model fit 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 the tracer tests results in Naujaat.**

| Tracer | Start Date | End Date | Study Period | HRT (d) | Average Depth (m) | Area ($m^2$) | $E_v$ (%) |
|---|---|---|---|---|---|---|---|
| 3 - 1 | 6/12/16 | 6/14/16 | Spring | 0.59 | 0.14 | 21,142 | 91 |
| 3 - 2 | 6/12/16 | 6/12/16 | Spring | 0.07 | 0.16 | 12,078 | 24 |
| 3 - 2 | 6/18/16 | 6/18/16 | Spring | 0.08 | 0.07 | 12,078 | 26 |
| 4 - 3 | 6/19/16 | 6/20/16 | Spring | 0.12 | 0.06 | 12,690 | 43 |
| 4 - 2 | 6/14/16 | 6/15/16 | Spring | 0.14 | 0.08 | 24,768 | 17 |
| 4 - 3 | 8/27/16 | 8/28/16 | Summer | 0.36 | 0.08 | 12,690 | 42 |
| 3 - 2 | 8/26/16 | 8/27/16 | Summer | 0.37 | 0.09 | 12,078 | 4 |

The 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 difference between the

HRT and number of tanks for spring and summer conditions was negligible, thus only one model was developed. The TIS wetland spreadsheet calculator tool provided in CWRS (2016) was modified to represent the conditions at the Naujaat site. A detailed methodology for the TIS modeling technique is provided within CWRS (2016).

The model was 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.

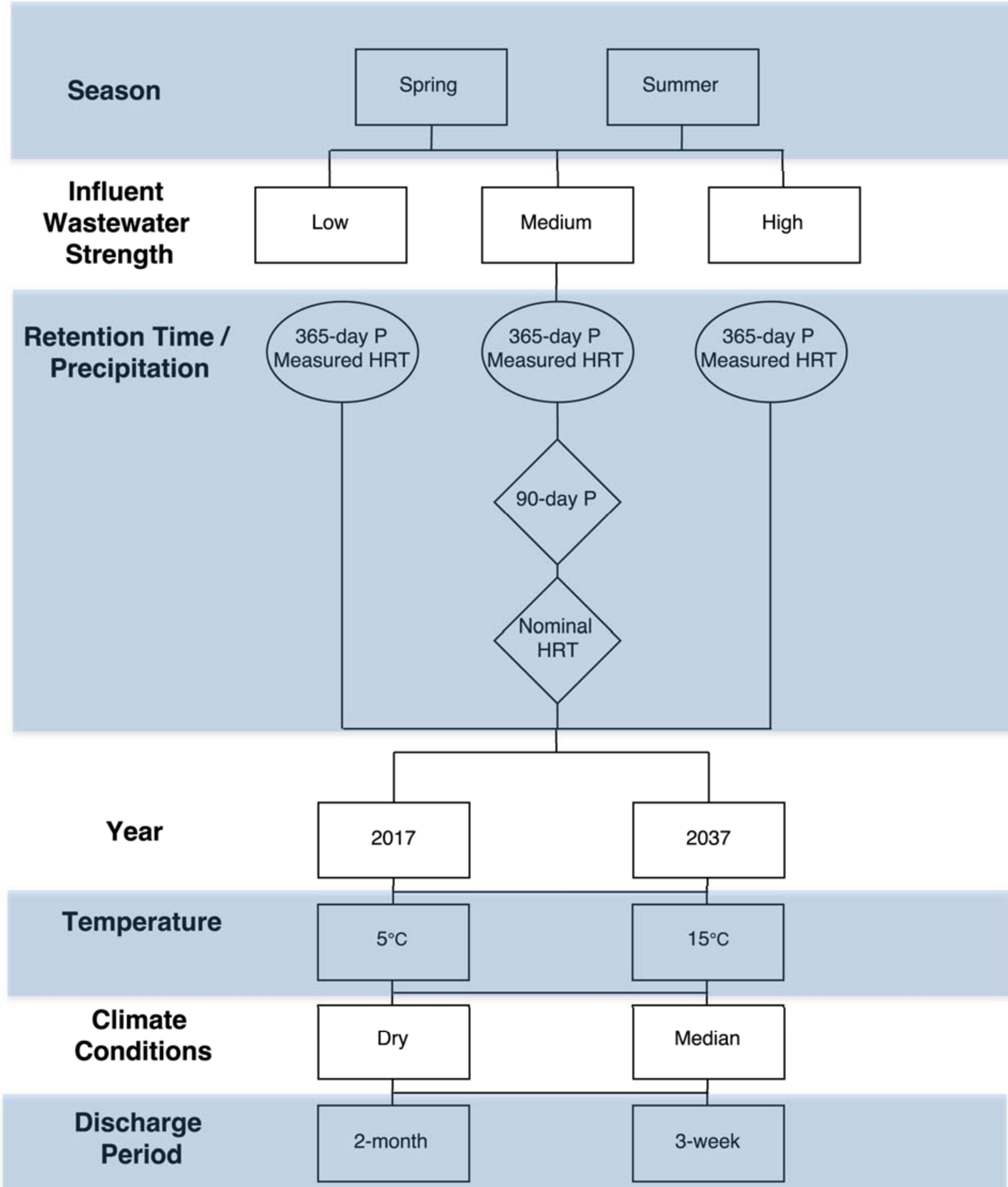


**Figure 4. Flow chart of the factors and scenarios assessed within treatment performance modeling.**

### 2.7.3 Model Assumptions

The following assumptions were made to conduct the modeling analysis:

- The contaminant ranges for 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 natural depression;
- 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 fieldwork findings from Naujaat in summer 2016.

### 2.7.4 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 introduced slight uncertainty in the treatment performance estimations;
- Long-term climatic changes were not considered for the model scenarios; however, they were 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.

### 2.7.5 Model Input Parameters

#### 2.7.5.1 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 and moment analysis of the tracer test data in Microsoft Excel as per the procedure detailed in Hayward & Jamieson (2015). The nominal HRT ($\theta$) was calculated for each model run and is given by Equation 2 as follows:

$$\theta = \frac{V}{Q} \qquad \text{[Eq. 2]}$$

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.

*2.7.5.2 Surface Areas, Depths, and Volumes*

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. For the modeling, the wetland volume varied with the discharge ($m^3/d$) for a given scenario. The discharge was divided by the wetland area ($m^2$) and multiplied by the HRT (d) to give the wetland depth. The active wetland volume is given by the product of the area and the depth. Wetland segment areas and retention times are available in Table 2.

*2.7.5.3 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 3.

**Table 3. 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 |

*2.7.5.4 Selection of Rate Constants*

The rate constants that were selected for use in the treatment performance modeling are presented in Table 4. The rate constants were selected from a combination of literature values and site-specific rate constants in an effort to be conservative in the treatment performance modeling. Site-specific rate constants were used when the values were within or below the 60% percentile in comparison to literature values in Kadlec and Wallace (2009).

**Table 4. Rate constants selected for the treatment performance modeling.**

| Rate Constant | $CBOD_5$[a] | *E. Coli*[b] | TN[b] | TAN[a] | TP[c] |
|---|---|---|---|---|---|
| $K_5$ (m/d) | 0.01 | 0.14 | 0.04 | 0.01 | 0.06 |
| $K_{15}$ (m/d) | 0.01 | 0.29 | 0.05 | 0.03 | 0.05 |

[a]Hayward & Jamieson (2015), [b]Naujaat data, [c]Sanikiluaq data.

#### 2.7.5.5 *Climate Data*

Historical climate data was downloaded for Coral Harbour A, which is the closest climate station with historical datasets from the Environment Canada historical climate data website (Government of Canada, 2016b). Bulk downloads of multi-year datasets were performed according to the directions provided by Government of Canada (2016c). 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 65 mm/yr based on the historical temperature dataset from Environment Canada (Government of Canada, 2016b).

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 284 mm/yr (Government of Canada, 2016b). This was converted to a volume of water per day by multiplying by the watershed area and dividing by 365 d/yr.

#### 2.7.5.6 *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 shorter decant.

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 3 as follows:

$$RWU \times [1.0 + (0.00023 \times P)] \qquad \text{[Eq.3]}$$

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.

## 2.8 Community Consultation

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

A community forum was also held at the Co-op store. 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 had conducted in the community.

# 3.0 Results

## 3.1 Hydraulics and Hydrology

### *3.1.1 Watershed Delineation*

The watershed of the Naujaat WTA is shown in Figure 5. The total area of the watershed was approximately 0.96 $km^2$ (96 ha).


**Figure 5. Map of the watershed of the WTA in Naujaat, NU.**

### *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 Naujaat.

**Table 5. Summary of instantaneous discharge measurements.**

| Sampling Location: Naujaat | | | | |
|---|---|---|---|---|
| **Date Range** | **Gauging Site** | **Flow ($m^3$/d)** | | |
| | | **Minimum** | **Maximum** | **Average** |
| **2016/06/10 - 2016/06/21** | **Inlet** | 1488 | 7057 | 2977 |
| | **Site 3** | 2240 | 7180 | 4450 |
| | **Site 2** | 1913 | 6871 | 3919 |
| | **Site 1** | 2115 | 4753 | 3456 |
| | **Outlet** | 2192 | 6378 | 3775 |
| **2016/08/24 - 2016/08/31** | **Site 3** | 62 | 153 | 110 |
| | **Site 2** | 198 | 545 | 348 |
| | **Site 1** | 121 | 317 | 189 |
| | **Outlet** | 120 | 317 | 244 |

Figure 6 illustrates the effluent flow continuously over the treatment season and study periods. This series was developed from the stage-discharge relationships for outlet gauging sites. The corresponding precipitation totals recorded by Environment Canada in the region are shown on the secondary axis. Flows within the WTA were higher in the spring due to the freshet, and then rapidly decreased as the season progressed. The precipitation events caused a corresponding increase in WTA outflows.

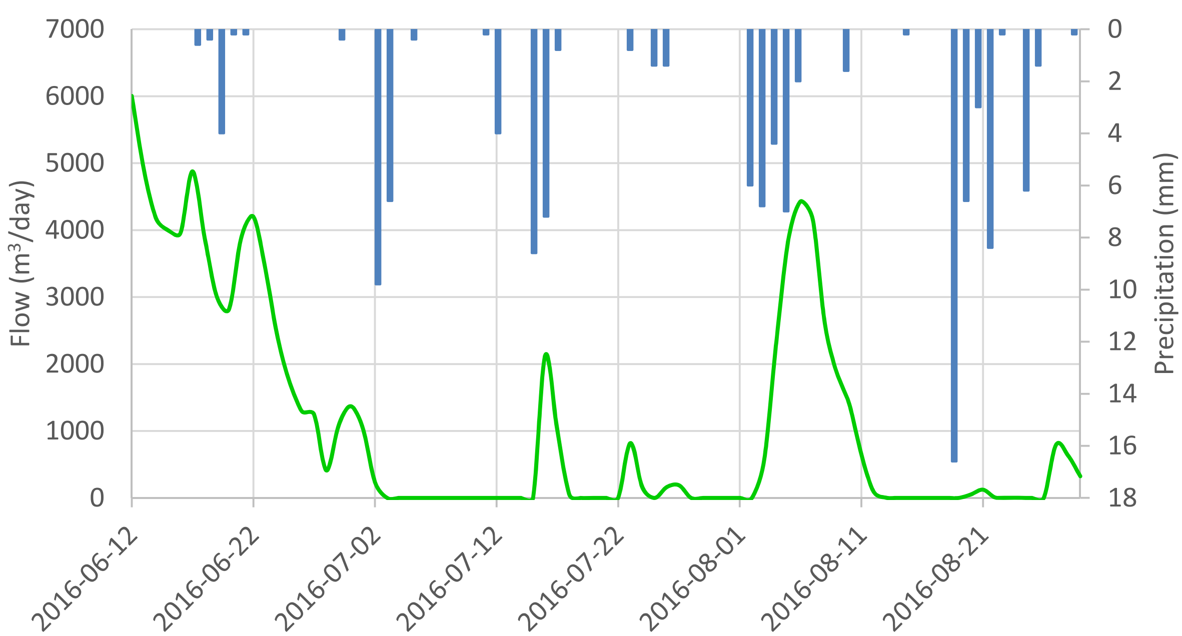


**Figure 6. Outlet flow and precipitation series for the 2016 treatment season.**

## 3.2 Physical and Biological Characterization

### *3.2.1 Vegetation*

The dominant vegetation species within the main classes in the Naujaat WTA are provided in Table 6. The results from the vegetation classification, resulted in two primary classes: wetland and upland/transition.

**Table 6. Vegetation classification results of the Naujaat WTA study site.**

| Class | Dominant | 1st Dominant |
|---|---|---|
| **Wetland** | Alfalfa, Arctic Willow, Broad Leaved Fireweed, Club Moss, Grass, Northern Willow, Sedge, Carex Aquatilics, Sphagnum Moss | Mountain Avens, Net-veined Willow, Richardson's Willow, White Heather |
| **Upland/ Transition** | Club Moss, Lichen, Mountain Avens, Sphagnum Moss, White Heather, unidentified yellow flower | Alfalfa, Blueberry, Broad Leaved Fireweed, Grass, Net-veined Willow |

From the vegetation survey, an image classification map was created. Figure 7 shows the final classification map of the WTA which illustrates 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 surface flow; therefore, it would be expected that there would be 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.

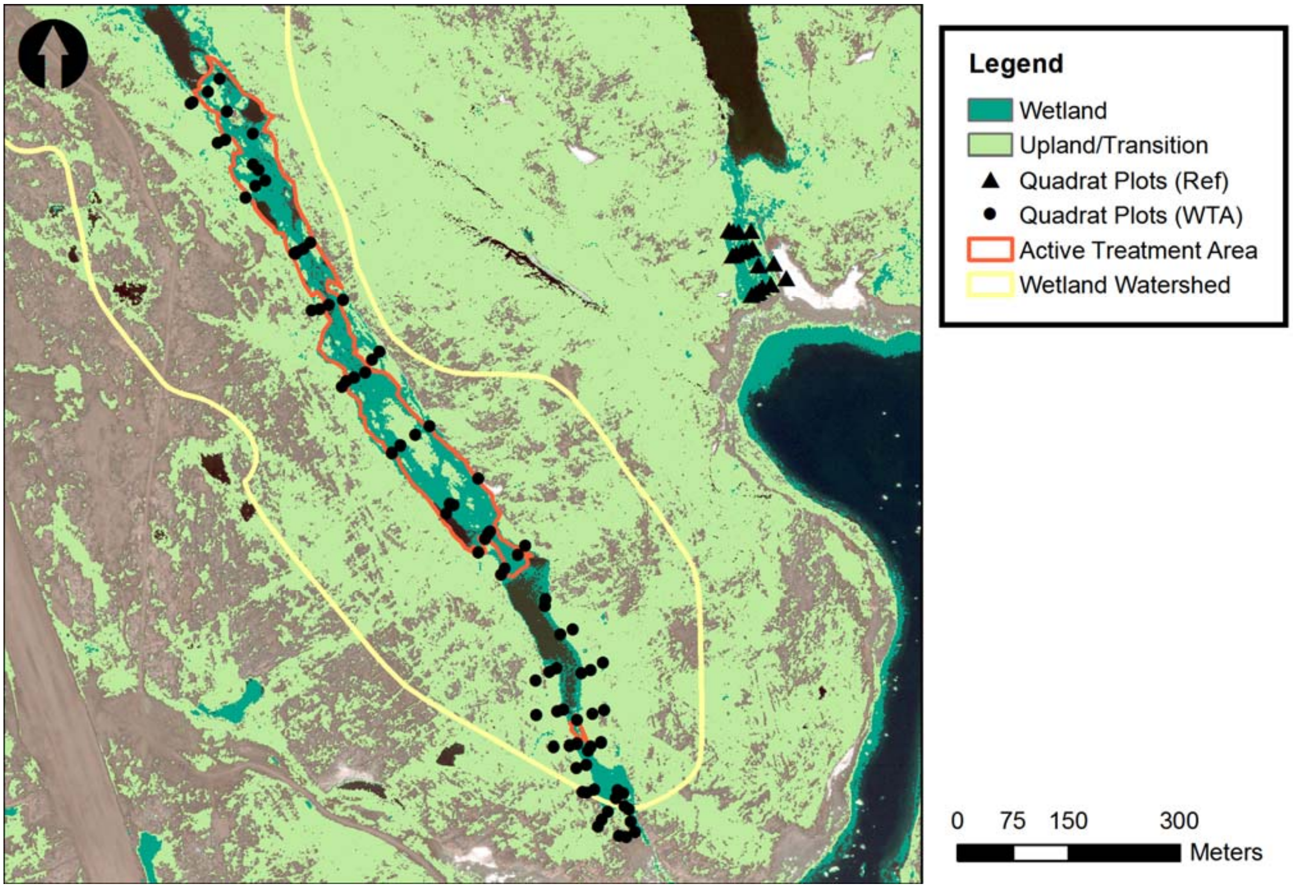


**Figure 7. Vegetation classification map of the Naujaat WTA in 2016.**

### *3.2.2 Wildlife*

There was wildlife present in the WTA throughout the duration of the study. Geese and arctic ground squirrels, commonly known as 'sik sik', frequented the areas of the WTA. 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. It was reported by community members that polar bears, caribou, arctic hares, and ptarmigan (snow quail) pass through the site. Narwhals have also been known to pass by the outlet of the WTA.

## 3.3 Treatment Performance Assessment

### *3.3.1 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, DO, conductivity, and pH. Table 7 shows the minimum, maximum and average values for each sampling site for the first trip in June, while Table 8 shows the values from the August trip. The majority of the DO concentrations were greater than 2 mg/L, which suggested that aerobic biological treatment processes occurred throughout the WTA. This was especially true later in the treatment season when flows were reduced. There was one instance in the outlet where the DO was below 2 mg/L, which could mean that anoxic conditions in the end of the pond at the outlet had occurred during the spring freshet. Based on site observations, there was algae present at the outlet in August, which was supported by elevated DO concentrations (~20-30 mg/L).

**Table 7. Summary of the general water quality results for the June 2016 study period.**

| **Naujaat**<br>2016/06/11 - 2016/06/20 | | | | | |
|---|---|---|---|---|---|
| **Sampling Location** | | **Water Quality Parameters** | | | |
| | | **Temperature (°C)** | **Conductivity (µS/cm)** | **DO (mg/L)** | **pH** |
| **Raw** | **Min** | 18.8 | 1279 | 4.50 | 7.78 |
| | **Max** | 25.1 | 1364 | 4.96 | 7.93 |
| | **Average** | 21.9 | 1321 | 4.77 | 7.87 |
| **Inlet** | **Min** | 1.5 | 186 | 5.81 | 7.54 |
| | **Max** | 5.4 | 500 | 10.22 | 7.80 |
| | **Average** | 3.3 | 363 | 7.96 | 7.66 |
| **Midpoint** | **Min** | 1.1 | 203 | 8.01 | 7.39 |
| | **Max** | 6.7 | 290 | 9.71 | 7.49 |
| | **Average** | 4.2 | 249 | 8.86 | 7.45 |
| **Outlet** | **Min** | 3.1 | 224 | 1.57 | 7.37 |
| | **Max** | 6.1 | 315 | 9.73 | 7.66 |
| | **Average** | 4.5 | 278 | 7.41 | 7.51 |
| **Reference** | **Min** | 1.5 | 170 | 13.69 | 7.19 |
| | **Max** | 2.7 | 197 | 14.00 | 7.33 |
| | **Average** | 2.2 | 184 | 13.85 | 7.26 |

### *3.3.2 Treatment Performance Samples*

Two rounds of treatment performance samples were collected during each study period. 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 Table 9 and 10. Concentration reductions were observed for all parameters as the effluent travelled through the WTA. Significant concentration reductions were also observed when comparing raw wastewater to the WTA influent (effluent from the natural depression), indicating treatment within the natural depression. For all of the sampling events, the wetland effluent met the guidelines outlined in the water licence (Nunavut Water Board, 2015). These guidelines state that a grab sample of the effluent, at the regulatory compliance point, should not exceed 80 mg/L for $BOD_5$, 70mg/L TSS, and $1x10^6$ CFU/100 mL faecal coliforms. Concentrations of CBOD5 were < 25 mg/L for all samples, while effluent TSS concentrations varied from < 15 mg/L in the spring to 40 - 43 mg/L in the late summer.

**Table 8. Summary of the general water quality results for the August 2016 study period.**

| **Naujaat**<br>2016/08/24 - 2016/08/31 | | | | | |
|---|---|---|---|---|---|
| **Sampling Location** | | **Water Quality Parameters** | | | |
| | | **Temperature ($^oC$)** | **Conductivity (µS/cm)** | **DO (mg/L)** | **pH** |
| **Raw** | **Min** | 18.0 | 1014 | 5.76 | 7.60 |
| | **Max** | 22.8 | 1408 | 6.72 | 8.09 |
| | **Average** | 20.6 | 1237 | 6.27 | 7.85 |
| **Inlet** | **Min** | 6.73 | 650 | 6.32 | 7.52 |
| | **Max** | 13.2 | 695 | 11.79 | 8.34 |
| | **Average** | 9.7 | 666 | 9.41 | 8.04 |
| **Midpoint** | **Min** | 5.6 | 540 | 9.01 | 7.80 |
| | **Max** | 11.3 | 641 | 11.54 | 7.94 |
| | **Average** | 8.1 | 581 | 10.30 | 7.87 |
| **Outlet** | **Min** | 6.7 | 429 | 19.52 | 9.39 |
| | **Max** | 10.8 | 448 | 31.44 | 9.84 |
| | **Average** | 8.0 | 440 | 25.37 | 9.63 |
| **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 |

It is likely that the higher TSS concentrations observed in the late summer are partially attributed to internal generation of TSS in the WTA from algae growth as opposed to poorer sewage treatment performance. Concentrations of *E .coli* at the WTA outlet were $1x10^5$ CFU/100mL during the spring sampling, and < 10 CFU/100mL in the late summer. Concentration reductions of approximately 50% were observed for both TN and TP moving from the WTA inlet to the WTA outlet. It should be noted that the regulatory compliance point is not located at the wetland outlet identified in this study. Concentrations observed at the regulatory compliance point were generally similar to those observed at the WTA outlet (Table 9 and 10).

**Table 9. Summary of the treatment performance analysis for the June 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) | $NH_3$-N (mg/L) | TP (mg/L) |
| 16-06-2016 | Raw 1 | 510 | 292 | 277 | 4110000 | 141 | 86.9 | 1.45 | 18.6 |
| | Raw 2 | 456 | 263 | 286 | 17300000 | 133 | 99.5 | 2.26 | 17.9 |
| | Raw 3 | 421 | 217 | 200 | 14100000 | 138 | 96 | 1.99 | 18 |
| | Inlet | 125 | 57 | 50 | 261000 | 39.5 | 27.6 | 0.42 | 4.74 |
| | Site 3 | 15.9 | 52 | 46 | 51700 | 24.3 | 53 | 0.10 | 3.25 |
| | Site 2 | 21 | 3 | 3 | 100000 | 14.3 | 10.7 | 0.09 | 1.55 |
| | Site 1 | 27 | 14 | 14 | 200000 | 19.7 | 13.5 | 0.09 | 2.28 |
| | Outlet | 24 | 9 | 9 | 100000 | 17.8 | 12.2 | 0.08 | 2.14 |
| | Reference 1 | 2 | 7 | 7 | <1.0 | 0.3 | <0.005 | 0.00 | 0.046 |
| 21-06-2016 | Inlet | 85 | 44 | 44 | 1730000 | 33 | - | - | 4.13 |
| | Site 3 | 60 | 34 | 34 | 505000 | 27.1 | - | - | 4.09 |
| | Site 2 | 37 | 26 | 26 | 798000 | 25.5 | - | - | 3.2 |
| | Site 1 | 20 | 18 | 18 | 100000 | 17 | - | - | 1.99 |
| | Outlet | 17 | 13 | 13 | 100000 | 15.6 | - | - | 1.84 |
| | CP[a] | 20 | 15 | 15 | 10000 | 15.8 | - | - | 1.86 |
| | Reference 2 | 2 | <2 | <2 | <1.0 | 0.23 | - | - | 0.015 |
| | Reference 3 | <2 | <1 | <1 | 21.3 | 0.29 | - | - | 0.021 |

[a]Regulatory compliance point

**Table 10. 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) | $NH_3$-N (mg/L) | TP (mg/L) |
| 29-08-2016 | Inlet | 41.5 | 64 | 61 | 460000 | 27.5 | 23 | 1.16 | 2.79 |
| | Site 3 | 18.4 | 17 | 13.7 | 9300 | 22.4 | 23 | 0.41 | 2.44 |
| | Site 2 | 9.2 | 10.4 | 8.9 | 93 | 15.7 | 13 | 0.25 | 1.93 |
| | Site 1 | 20.5 | 45.9 | 43.2 | 9 | 6.73 | 6.5 | 2.94 | 1.65 |
| | Outlet | 17.1 | 40 | 39.5 | 9 | 6.43 | 1 | 0.52 | 1.48 |
| | CP[a] | 17.5 | 37.3 | 36.7 | 23 | 7.11 | 6.9 | 3.47 | 1.51 |
| | Ref 1 | <6.0 | 4.4 | 3.8 | <3 | 0.65 | 0.039 | 0.00 | 0.056 |
| | Ref 2 | 6.4 | 5.4 | 3.4 | <3 | 0.714 | 0.041 | 0.00 | 0.082 |
| 31-08-2016 | Raw 1 | 478 | 434 | 402 | >1100000 | 149 | 140 | 3.48 | 16.1 |
| | Raw 2 | 411 | 372 | 356 | >1100000 | 84.4 | 56 | 0.91 | 10.3 |
| | Raw 3 | 493 | 368 | 402 | >1100000 | 139 | 130 | 1.40 | 13.9 |
| | Inlet | 35.6 | 48 | 44 | 1100000 | 16.6 | 15 | 0.37 | 2.86 |
| | Site 3 | 21.8 | 27 | 23 | 240000 | 30.1 | 18 | 0.30 | 2.85 |
| | Site 2 | 11.4 | 15.5 | 14 | 2300 | 8.42 | 9.4 | 0.18 | 2.11 |
| | Site 1 | 16.6 | 42 | 42 | <3 | 7.33 | 3.7 | 1.53 | 1.49 |
| | Outlet | 17.6 | 43 | 41 | <3 | 7.12 | 3.5 | 1.94 | 1.4 |

[a]Regulatory compliance point

### 3.3.3 *Solid Waste Considerations*

It was known, prior to visual inspection of the site, that the WTA is downgradient of a solid waste facility that is no longer in use. This meant that 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 assess the likelihood that 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 showed some reduction. This indicated that external leachate was likely not impacting the WTA or quality of the effluent.

## 3.4 Rate Constant Derivation

Treatment rate constants were determined for the wetland for the spring and summer conditions. Table 11 presents the results of the rate constant analysis. The rate constants that were determined fell in the high ranges (i.e., 60 – 80%) in comparison to many other wetlands that were summarized by Kadlec and Wallace (2009).

**Table 11. Minimum rate constants determined from the modeling with the percentiles where they compare to many other wetlands summarized by Kadlec and Wallace (2009).**

| Rate Constant | *$CBOD_5$* | *E.coli* | TN | TAN |
|---|---|---|---|---|
| $K_5$ (m/d) | 0.22 | 0.14 | 0.04 | 0.08 |
| $K_{15}$ (m/d) | 0.25 | 0.29 | 0.05 | 0.14 |
| $K_{20}$ (m/yr) | 98 | 146 | 22 | 66 |
| Percentile compared to literature | 70% | 60% | 60% | 80% |

Dilution from external hydrologic sources could have accounted for some of the contaminant reductions observed as shown in Table 12. During the spring, the influent stream was diluted by 104 – 247% once reaching the outlet, which could account entirely for the reductions observed for TN, and TAN. During the summer conditions, the influent stream was diluted by variable amounts depending on precipitation. During the tracer studies, it was determined that the influent was diluted by approximately 275%, which could account entirely for the reductions observed for $CBOD_5$, *E. coli*, and TP during that time period.

**Table 12. Summary of effect of dilution in WTA during the tracer studies.**

| Description | Date | HRT (hrs) | $Q_{in}$ ($m^3/d$) | $Q_{out}$ ($m^3/d$) | Percent Dilution | CBOD$_5$ (mg/L) | | | TN (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $C_{in}$ | $C_{out}$ | $C_{out}$ theoretical | $C_{in}$ | $C_{out}$ | $C_{out}$ theoretical |
| Entire wetland | 16-Jun | 19.5 | 2578 | 6378 | 247% | 125 | 24 | 51 | 40 | 18 | 16 |
| Entire wetland | 21-Jun | 19.5 | 2112 | 2192 | 104% | 85 | 17 | 82 | 33 | 33 | 32 |
| ¾ wetland (Site 3 to outlet) | 29-Aug | 190 | 115[a] | 317[a] | 275% | 18 | 17 | 7 | 22 | 6 | 8 |
| ¾ wetland (Site 3 to outlet) | 31-Aug | 190 | 115[a] | 317[a] | 275% | 22 | 18 | 8 | 30 | 7 | 11 |

[a]Flows for August were the same because this was the date flow was measured closest to the tracer test dates.

## 3.5 Treatment Performance Model Construction and Scenario Analysis

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 13 and 14. Table 13 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 13. Modeled effluent quality results for the median P/ET, 2-month discharge duration, and the 5 - 15 °C temperature range.**

| Parameter | | Wastewater Strength | | |
|---|---|---|---|---|
| | | Low[b] | Medium[b] | High[b] |
| **CBOD$_5$ – mg/L** | **Influent[a]** | **60** | **150** | **300** |
| **(% reduction)** | Effluent | 35 (42%) | 86 (43%) | 172 (43%) |
| ***E. Coli* –MPN/100 mL** | **Influent** | **$1x10^3$** | **$1x10^5$** | **$1x10^8$** |
| **(log reduction)** | Effluent | $3.7x10^2$ – $4.6x10^2$ (0.3 – 0.4 log) | $3.7x10^4$ – $4.6x10^4$ (0.3 – 0.4 log) | $3.7x10^7$ – $4.6x10^7$ (0.3 – 0.4 log) |
| **TN – mg/L** | **Influent** | **40** | **80** | **140** |
| **(% reduction)** | Effluent | 21.9 (43%) | 43.8 (45%) | 76.5 (45%) |
| **TAN – mg/L** | **Influent** | **40** | **80** | **140** |
| **(% reduction)** | Effluent | 22.8 (43%) | 45.5 (43%) | 79.7 (43%) |
| **TP – mg/L** | **Influent** | **5** | **10** | **15** |
| **(% reduction)** | Effluent | 2.7 (46%) | 5.4 (46%) | 8.0 (47%) |

[a] The influent is defined as the discharge from the natural depression into the WTA at site 4.

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

Table 15 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 14 and 15, as temperature variability had a large impact on that parameter. The reductions (in % and log reductions) in Tables 14 and 15 are calculated in relation to the influent concentrations expected to be entering the WTA from the natural depression at site 4.

**Table 14. Model effluent quality results for the median P/ET, 3-week discharge duration, and the 5 - 15 °C temperature range.**

| Parameter | | Wastewater Strength | | |
|---|---|---|---|---|
| | | Low[b] | Medium[b] | High[b] |
| **$CBOD_5$ – mg/L** | **Influent[a]** | **60** | **150** | **300** |
| **(% reduction)** | Effluent | 48 (20%) | 119 (21%) | 238 (21%) |
| ***E. Coli* –MPN/100 mL** | **Influent** | **$1x10^3$** | **$1x10^5$** | **$1x10^8$** |
| **(log reduction)** | Effluent | $6.6x10^2$ – $7.2x10^2$ (0.1 – 0.2 log) | $6.6x10^4$ – $7.2x10^4$ (0.1 – 0.2 log) | $6.6x10^7$ – $7.2x10^7$ (0.1 – 0.2 log) |
| **TN – mg/L** | **Influent** | **40** | **80** | **140** |
| **(% reduction)** | Effluent | 31.2 (22%) | 62.2 (22%) | 109 (22%) |
| **TAN – mg/L** | **Influent** | **40** | **80** | **140** |
| **(% reduction)** | Effluent | 31.7 (21%) | 63.3 (21%) | 111 (21%) |
| **TP – mg/L** | **Influent** | **5** | **10** | **15** |
| **(% reduction)** | Effluent | 3.9 (22%) | 7.7 (23%) | 12 (20%) |

[a] The influent is defined as the discharge from the natural depression into the WTA at site 4.

[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 duration. The model runs which simulated a continuous summer discharge (2-month period) resulted in reductions averaging 44%, while the short decant scenarios (3-week period) produced average reductions of 21% 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 791 $m^3/d$, while the short decant produced 2260 $m^3/d$. The smaller daily discharge was more easily diluted by external hydrologic contributions. Table 15 shows the modeled hydraulic loading rate (HLR) of 2.2 cm/d for the 2-month scenario (2017), which is below the 2.5 cm/d maximum recommended in the CWRS wetland design guidelines, while the 3-week (2017) HLR is 2.5 times the maximum.

**Table 15. Hydraulic loading rates by discharge period for the WTA.**

| Discharge Period | Year | HLR (cm/d) |
|---|---|---|
| 2-month | 2017 | 2.2 |
| 2-month | 2037 | 3.9 |
| 3-week | 2017 | 6.2 |
| 3-week | 2037 | 11.2 |

The potential impact of dilution is illustrated more clearly in Table 16, 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 resulted in minimal treatment (less than 3% reduction), due to the lack of dilution. On the other hand, under median climate conditions the wetland receives external hydrologic contributions and the influent was diluted. For instance, for the 2-month discharge period in 2017, under median conditions, the $CBOD_5$ was predicted as 172 mg/L; whereas, for the same scenario under dry conditions, the $CBOD_5$ was predicted as 293 mg/L. Which indicated that almost all of the reductions observed were attributed to dilution from external hydrologic influences. These simulations were conducted using conservative (low) values for treatment rate constants.

**Table 16. Modeled effluent quality results for the high strength influent with median and dry climate condition at 5 $^{o}$C.**

| 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 (2017) | Dry | 293 (2%) | 7.3E+07 (0.1 log) | 129 (8%) | 136 (3%) | 13 (12%) |
| 2 months (2017) | Median | 172 (43%) | 4.6E+07 (0.3 log) | 76.5 (45%) | 79.7 (43%) | 7.9 (47%) |
| 3 weeks (2017) | Dry | 298 (1%) | 8.9E+07 (0.0 log) | 136 (3%) | 139 (1%) | 14 (4%) |
| 3 weeks | Median | 238 (21%) | 7.2E+07 (0.1 log) | 109 (22%) | 111 (21%) | 12 (23%) |
| 2 months (2037) | Dry | 296 (1%) | 8.4E+07 (0.1 log) | 134 (5%) | 138 (1%) | 14 (7%) |
| 2 months (2037) | Median | 213 (29%) | 6.2E+07 (0.2 log) | 96.3 (31%) | 98.8 (29%) | 10 (33%) |
| 3 weeks (2037) | Dry | 299 (0%) | 9.4E+07 (0.0 log) | 138 (2%) | 139 (0%) | 15 (2%) |
| 3 weeks (2037) | Median | 262 (13%) | 8.3E+07 (0.1 log) | 121 (14%) | 122 (13%) | 13 (14%) |

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 4.6 days versus a measured HRT of 0.8 days for the 2-month discharge period. By using the measured HRTs, the modeled estimates were more conservative because they accounted for hydraulic inefficiencies such as short-circuiting and dead-zones in the wetland.

Given that dilution and HRT have a large impact on treatment performance, two additional scenarios were run to assess their impact. The first scenario increased the HRT by using the longer nominal retention time in place of the shorter measured HRT. 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 against the normal conditions (365-day precipitation and measured HRT) in Table 17 for the medium strength influent, the 2-month (2017) and 3-week (2037) discharge period, and at 5°C for dry and median climate conditions. The 2-month discharge is for 2017 and the 3-week is for 2037 to show a best and worst case for flow conditions.

**Table 17. Modeled effluent quality results (summer model) for the medium strength influent at the 2-month (2017) and 3-week (2037) discharge periods at 5$^{o}$C.**

| Case | Discharge Period | Climate | $CBOD_5$ | *E. coli* | TN | TAN | TP |
|---|---|---|---|---|---|---|---|
| 365-day P/ Measured HRT | 2 months (2017) | Dry | 147 (2%) | 7.3E+04 (0.1 log) | 73.6 (8%) | 78.0 (3%) | 8.8 (12%) |
| 365-day P/ Nominal HRT | 2 months (2017) | Dry | 146 (3%) | 6.8E+04 (0.2 log) | 72.2 (10%) | 77.5 (3%) | 8.6 (14%) |
| 365-day P/ Measured HRT | 2 months (2017) | Median | 86 (42%) | 4.6E+04 (0.3 log) | 43.8 (45%) | 45.5 (43%) | 5.3 (47%) |
| 90-day P/ Measured HRT | 2 months (2017) | Median | 34 (77%) | 1.9E+04 (0.7 log) | 17.1 (79%) | 17.3 (78%) | 2.1 (79%) |
| 365-day P/ Measured HRT | 3 weeks (2037) | Dry | 149 (0%) | 9.4E+04 (0.0 log) | 78.7 (2%) | 79.6 (0%) | 9.8 (2%) |
| 365-day P/ Nominal HRT | 3 weeks (2037) | Dry | 149 (1%) | 9.3E+04 (0.0 log) | 78.4 (2%) | 79.5 (1%) | 10 (3%) |
| 365-day P/ Measured HRT | 3 weeks (2037) | Median | 131 (12%) | 8.3E+04 (0.1 log) | 69.1 (14%) | 69.8 (13%) | 8.6 (14%) |
| 90-day P/ Measured HRT | 3 weeks (2037) | Median | 89 (41%) | 5.6E+04 (0.2 log) | 46.7 (42%) | 47.0 (41%) | 5.8 (42%) |

In the case of the dry climate, with no external hydrologic contributions, an increase in 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 provided a significant reduction (greater than 75%), due to the increased dilution (Table 17).

The $CBOD_5$ loading rates were determined for each of the modeled scenarios and are presented in Table 18. 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 18. $CBOD_5$ loading rates (kg/ha/d) for 2017 conditions in relation to influent strength.**

| Discharge Period | Low | Medium | High |
|---|---|---|---|
| 2-month | 13 | 33 | 65 |
| 3-week | 37 | 93 | 186 |

## 3.6 Community Consultations

The council meeting took place in Naujaat on August 25th, 2016. In attendance was the mayor, 8 councilors, the SAO (Rob Hedley), an MLA for the Aivilik region, MLA Aivilik region (Naujaat and Coral Harbour) Steve Mapsalk (in attendance as delegate), and Jenny Hayward and Kiley Daley from CWRS. Jenny gave a presentation during the meeting and then answered questions from the attendees. A delegate from the CGS department of the GN, Megan Lusty, was also in attendance to address any questions that arose concerning the sewage facility. The transcript of the question period is included in Appendix C. Some council members asked what could be done in the future if the infrastructure were to be upgraded to improve treatment. It was communicated that addition of flow diversion and/or retention berms may be useful to further improve treatment in the WTA. Other concerns from the council included effects to marine life, and bacteria levels. CWRS communicated that the risks to marine life was beyond the scope of the study yet likely the risks are low based on other studies on benthic invertebrates conducted by the CWRS. It was also communicated that the bacteria levels were normal for areas associated with sewage disposal and that waterfowl add additional sources of faecal bacteria. Generally, the council was interested in the results yet no major concerns were noted. Meeting the water licence at the outlet was received as a positive finding.

The community forum at the Co-op took place on August 29th from 4:00pm – 6:30pm. 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 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. Generally, most participants avoided frequenting and hunting in the WTA because of the risk of contact with sewage. Some participants indicated that there is a winter transit route for snow mobiles that runs along the length of the WTA. 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. Overall, the participants from the community were curious about the results but generally there were no major concerns expressed by the participants. A total of 42 community members visited the display.

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 Naujaat consists of a natural depression in the landscape where wastewater is deposited which discharges effluent in an uncontrolled manner through an exfiltration berm to a 3.6 ha WTA. The majority of wastewater flows into the WTA during the spring freshet period.
- The wetland watershed area was determined to be 96 ha, and this contributed to varying amounts of external hydrologic contributions to the WTA during the treatment season. During the spring period the average amount of dilution ranged from 104 – 247%.
- Measured concentrations of key water quality parameters at the outlet of the wetland were always lower than the NWB water licence requirements:
    - Measured $CBOD_5$ concentrations were all < 25 mg/L.
    - Measured TSS concentrations were all < 45 mg/L.
    - Measured *E. coli* concentrations were all < $1x10^5$ CFU/100mL.
- Treatment rate constants were derived for several wastewater parameters. The derived rate constants fell within reported ranges for wetlands treatment municipal wastewater in temperate climates, and were higher than rate constants reported in previous studies conducted in Nunavut.
- 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 expected to enter the wetland. For the median climate conditions and a medium strength wastewater leaving the natural depression, the following model results were observed:
    - WTA effluent $CBOD_5$ concentrations would average 86 mg/L, *E. coli* concentrations would range from $3.7x10^4$ – $4.6x10^4$ CFU/100mL, TN concentrations would be

approximately 44 mg/L, and TP concentrations would be 5 mg/L, for the 2-month discharge period scenario.

  - WTA effluent CBOD5 concentrations would average 119 mg/L, *E. coli* concentrations would range from $6.6x10^4$ – $7.2x10^4$ CFU/100mL, TN concentrations would be approximately 62 mg/L, and TP concentrations would be 8 mg/L, for the 3-week discharge period scenario.

  - Additional sensitivity analyses were conducted with the performance model to determine the influence of different mechanisms contributing to contaminant reductions in the WTA. This analysis illustrated that dilution was a primary mechanism for contaminant reductions in the existing WTA.

- Outcomes of the community consultation with forum participants and councilors included that there was interest yet no major concern for some aspects of the wastewater treatment system and CWRS communicated key findings of the study.

  - Community forum participants indicated that a snowmobile route transects the WTA during the winter.

  - Most participants had knowledge that there was sewage present in the WTA and generally tried to avoid the area.

  - CWRS communicated the key findings that the water quality at the outlet met the NWB water licence 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) |
| **16-06-2016** | Raw 1 | 0.2 | 0.8 | 714 | 3.5 | 57.5 |
| | Raw 2 | 0.3 | 0.7 | 788 | 3.5 | 39.6 |
| | Raw 3 | 0.3 | 0.6 | 639 | 3.9 | 42.4 |
| | Outlet | <0.1 | 0.2 | 310 | 0.3 | 26.4 |
| **21-06-2016** | Outlet | <0.1 | 0.1 | 333 | 0.2 | 26.4 |
| **29-08-2016** | Outlet | <0.01 | <0.5 | 278 | <0.2 | 37.6 |
| **31-08-2016** | Raw 1 | 0.4 | 0.6 | 728 | 3.7 | 46.6 |
| | Raw 2 | 0.5 | 0.9 | 630 | 5.5 | 34.5 |
| | Raw 3 | 0.3 | 0.5 | 802 | 3.4 | 61.0 |
| | Outlet | <0.01 | <0.5 | 263 | <0.2 | 37.3 |

# Appendix B: Summary Table of the Modeling Results

**Table B - 1. Detailed summary of the effluent concentrations from the modeling analysis of the Naujaat WTA.**

| Temperature | Strength | Discharge Period | Climate | $CBOD_5$ | *E. coli* | TN | TAN | TP |
|---|---|---|---|---|---|---|---|---|
| 5°C | Low | 2 months | Dry | 58 | 6.8E+02 | 36.1 | 38.7 | 4.3 |
| 5°C | Low | 2 months | Median | 35 | 4.6E+02 | 21.9 | 22.8 | 2.7 |
| 5°C | Low | 3 weeks | Dry | 60 | 9.0E+02 | 38.9 | 39.6 | 4.8 |
| 5°C | Low | 3 weeks | Median | 48 | 7.2E+02 | 31.2 | 31.7 | 3.8 |
| 5°C | Low | 2 months (2037) | Dry | 59 | 8.4E+02 | 38.2 | 39.4 | 4.7 |
| 5°C | Low | 2 months (2037) | Median | 43 | 6.2E+02 | 27.6 | 28.2 | 3.4 |
| 5°C | Low | 3 weeks (2037) | Dry | 60 | 9.4E+02 | 39.4 | 39.8 | 4.9 |
| 5°C | Low | 3 weeks (2037) | Median | 53 | 8.3E+02 | 34.6 | 34.9 | 4.3 |
| 15°C | Low | 2 months | Dry | 59 | 5.4E+02 | 35.8 | 37.8 | 4.5 |
| 15°C | Low | 2 months | Median | 35 | 3.7E+02 | 21.5 | 22.3 | 2.7 |
| 15°C | Low | 3 weeks | Dry | 59 | 8.0E+02 | 38.5 | 39.2 | 4.8 |
| 15°C | Low | 3 weeks | Median | 48 | 6.6E+02 | 30.9 | 31.4 | 3.9 |
| 15°C | Low | 2 months (2037) | Dry | 59 | 7.1E+02 | 37.6 | 38.8 | 4.7 |
| 15°C | Low | 2 months (2037) | Median | 43 | 5.4E+02 | 27.2 | 27.8 | 3.4 |
| 15°C | Low | 3 weeks (2037) | Dry | 60 | 8.9E+02 | 39.1 | 39.6 | 4.9 |
| 15°C | Low | 3 weeks (2037) | Median | 53 | 7.8E+02 | 34.4 | 34.7 | 4.3 |
| 5°C | Medium | 2 months | Dry | 147 | 7.3E+04 | 73.6 | 78.0 | 8.8 |
| 5°C | Medium | 2 months | Median | 86 | 4.6E+04 | 43.8 | 45.5 | 5.3 |
| 5°C | Medium | 3 weeks | Dry | 149 | 8.9E+04 | 77.7 | 79.3 | 9.6 |
| 5°C | Medium | 3 weeks | Median | 119 | 7.2E+04 | 62.2 | 63.3 | 7.7 |
| 5°C | Medium | 2 months (2037) | Dry | 148 | 8.4E+04 | 76.4 | 78.9 | 9.3 |
| 5°C | Medium | 2 months (2037) | Median | 107 | 6.2E+04 | 55.0 | 56.4 | 6.7 |
| 5°C | Medium | 3 weeks (2037) | Dry | 149 | 9.4E+04 | 78.7 | 79.6 | 9.8 |
| 5°C | Medium | 3 weeks (2037) | Median | 131 | 8.3E+04 | 69.1 | 69.8 | 8.6 |
| 15°C | Medium | 2 months | Dry | 146 | 5.4E+04 | 71.5 | 75.6 | 9.0 |
| 15°C | Medium | 2 months | Median | 86 | 3.7E+04 | 42.8 | 44.5 | 5.4 |
| 15°C | Medium | 3 weeks | Dry | 149 | 8.0E+04 | 76.9 | 78.4 | 9.6 |
| 15°C | Medium | 3 weeks | Median | 119 | 6.6E+04 | 61.7 | 62.7 | 7.7 |
| 15°C | Medium | 2 months (2037) | Dry | 148 | 7.1E+04 | 75.2 | 77.6 | 9.4 |
| 15°C | Medium | 2 months (2037) | Median | 106 | 5.4E+04 | 54.3 | 55.7 | 6.8 |
| 15°C | Medium | 3 weeks (2037) | Dry | 149 | 8.9E+04 | 78.3 | 79.1 | 9.8 |
| 15°C | Medium | 3 weeks (2037) | Median | 131 | 7.8E+04 | 68.8 | 69.5 | 8.6 |
| 5°C | High | 2 months | Dry | 293 | 7.3E+07 | 129 | 136 | 13 |
| 5°C | High | 2 months | Median | 172 | 4.6E+07 | 76.5 | 79.7 | 7.9 |
| 5°C | High | 3 weeks | Dry | 298 | 8.9E+07 | 136 | 139 | 14 |
| 5°C | High | 3 weeks | Median | 238 | 7.2E+07 | 109 | 111 | 12 |
| 5°C | High | 2 months (2037) | Dry | 296 | 8.4E+07 | 134 | 138 | 14 |
| 5°C | High | 2 months (2037) | Median | 213 | 6.2E+07 | 96.3 | 98.8 | 10 |
| 5°C | High | 3 weeks (2037) | Dry | 299 | 9.4E+07 | 138 | 139 | 15 |
| 5°C | High | 3 weeks (2037) | Median | 262 | 8.3E+07 | 121 | 122 | 13 |
| 15°C | High | 2 months | Dry | 293 | 5.4E+07 | 125 | 132 | 13 |

**Table B -1 (cont'd). Detailed summary of the effluent concentrations from the modeling analysis of the Naujaat WTA.**

| Temperature | Strength | Discharge Period | Climate | $CBOD_5$ | *E. coli* | TN | TAN | TP |
|---|---|---|---|---|---|---|---|---|
| 15°C | High | 2 months | Median | 172 | 3.7E+07 | 74.9 | 77.9 | 8.0 |
| 15°C | High | 3 weeks | Dry | 297 | 8.0E+07 | 135 | 137 | 14 |
| 15°C | High | 3 weeks | Median | 238 | 6.6E+07 | 108 | 110 | 12 |
| 15°C | High | 2 months (2037) | Dry | 296 | 7.1E+07 | 132 | 136 | 14 |
| 15°C | High | 2 months (2037) | Median | 212 | 5.4E+07 | 95.0 | 97.4 | 10 |
| 15°C | High | 3 weeks (2037) | Dry | 299 | 8.9E+07 | 137 | 138 | 15 |
| 15°C | High | 3 weeks (2037) | Median | 262 | 7.8E+07 | 120 | 122 | 13 |

**Table B - 2. Performance modeling results for the special cases (90-day P and nominal HRT).**

| Temperature | Case | Strength | Discharge Period | Climate | $CBOD_5$ | *E. coli* | TN | TAN | TP |
|---|---|---|---|---|---|---|---|---|---|
| 15°C | 90-day P | Medium | 2 months | Median | 34 | 1.7E+04 | 16.9 | 17.1 | 2.1 |
| 5°C | 90-day P | Medium | 2 months | Median | 34 | 1.9E+04 | 17.1 | 17.3 | 2.1 |
| 15°C | 90-day P | Medium | 2 months (2037) | Median | 51 | 2.8E+04 | 26.1 | 26.4 | 3.3 |
| 5°C | 90-day P | Medium | 2 months (2037) | Median | 51 | 3.1E+04 | 26.3 | 26.6 | 3.2 |
| 15°C | 90-day P | Medium | 3 weeks | Median | 67 | 3.9E+04 | 34.7 | 35.0 | 4.3 |
| 5°C | 90-day P | Medium | 3 weeks | Median | 67 | 4.1E+04 | 35.0 | 35.2 | 4.3 |
| 15°C | Nominal HRT | Medium | 2 months | Median | 85 | 2.7E+04 | 40.5 | 43.3 | 5.1 |
| 5°C | Nominal HRT | Medium | 2 months | Median | 86 | 3.9E+04 | 42.0 | 44.9 | 5.0 |
| 15°C | 90-day P | Medium | 3 weeks (2037) | Median | 89 | 5.4E+04 | 46.5 | 46.8 | 5.8 |
| 5°C | 90-day P | Medium | 3 weeks (2037) | Median | 89 | 5.6E+04 | 46.7 | 47.0 | 5.8 |
| 15°C | Nominal HRT | Medium | 2 months (2037) | Median | 106 | 4.7E+04 | 53.0 | 55.0 | 6.6 |
| 5°C | Nominal HRT | Medium | 2 months (2037) | Median | 106 | 5.8E+04 | 54.0 | 56.1 | 6.6 |
| 15°C | Nominal HRT | Medium | 3 weeks | Median | 119 | 6.1E+04 | 60.9 | 62.3 | 7.6 |
| 5°C | Nominal HRT | Medium | 3 weeks | Median | 119 | 7.0E+04 | 61.6 | 63.1 | 7.6 |
| 15°C | Nominal HRT | Medium | 3 weeks (2037) | Median | 131 | 7.6E+04 | 68.3 | 69.2 | 8.5 |
| 5°C | Nominal HRT | Medium | 3 weeks (2037) | Median | 131 | 8.1E+04 | 68.8 | 69.7 | 8.5 |
| 15°C | Nominal HRT | Medium | 2 months | Dry | 146 | 4.7E+04 | 69.7 | 74.7 | 8.7 |
| 5°C | Nominal HRT | Medium | 2 months | Dry | 146 | 6.8E+04 | 72.2 | 77.5 | 8.6 |
| 15°C | Nominal HRT | Medium | 2 months (2037) | Dry | 148 | 6.6E+04 | 74.1 | 77.0 | 9.3 |
| 5°C | Nominal HRT | Medium | 2 months (2037) | Dry | 148 | 8.1E+04 | 75.6 | 78.6 | 9.2 |
| 15°C | Nominal HRT | Medium | 3 weeks | Dry | 148 | 7.6E+04 | 76.2 | 78.1 | 9.5 |
| 5°C | Nominal HRT | Medium | 3 weeks | Dry | 149 | 8.7E+04 | 77.2 | 79.1 | 9.5 |
| 15°C | Nominal HRT | Medium | 3 weeks (2037) | Dry | 149 | 8.6E+04 | 77.9 | 78.9 | 9.7 |
| 5°C | Nominal HRT | Medium | 3 weeks (2037) | Dry | 149 | 9.3E+04 | 78.4 | 79.5 | 9.7 |

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

**Transcript of council meeting presentation Q&A in Naujaat delivered on August 25th, 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. Would a berm be helpful to improve treatment?***

JH – Yes, a berm would be helpful to encourage improved treatment of the sewage as it moves through the wetland treatment area. Sewage treatment improves the longer the sewage is retained in the wetland. Slowing the flow of the sewage encourages the natural treatment processes to occur such as settling of solids, UV disinfection of bacteria, microbial consumption of organics. The results from this study suggest that during the sample events, the water quality of the effluent discharging from the outlet meet the NWB water licence standards. Therefore, even during the higher flow period of the spring freshet in June, the overall water quality in the wetland is good. In the future, if upgrades are deemed required, select placement of detention berms would help slow the flow of effluent and therefore improve the treatment capacity of the wetland.

If the flow was controlled with berm structures, the best time to discharge effluent into the wetland treatment area is after the spring. This controlled discharge could be done with a pump and generator over a berm, an overflow structure, or an exfiltration berm. The wetland works best for treatment of sewage when it has time to warm up and for the vegetation to grow. It is ideal to have low and slow flow of the sewage into the wetland after the spring melt has occurred.

***2. What is the purpose of the vegetation survey? What type of information is gained from this type of survey, is it to determine which plants work best? Are the vegetation types you have found in the wetland treatment areas the same across the other study sites in Nunavut that you have observed to date?***

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, lots of Canada Geese. Adding bacteria (confounding factor) but also potential disease vector.

***3. Can you comment on the bacteria results in the wetland, are they normal?***

The bacteria concentrations we observed in the wetland treatment area are normal for areas with sewage. They were found to be below the NWB standard at the outlet during our sampling. Bacteria is a difficult parameter to use as a treatment performance indicator because the wetland attracts many waterfowl, such as Canadian Geese. These geese add another source of bacteria including *E. coli* to the wetland treatment area. Therefore, it can be difficult to discern whether bacteria is associated with the sewage system or added by waterfowl. The Canadian geese can be a potential vector for disease as they are frequently found in the wetland treatment areas.

***4. What are the effects of the snowmelt during the spring on the treatment capacity of the wetland?***

The snowmelt acts to increase the flow in the wetland treatment area. From a treatment perspective, this is not favorable because the sewage moves through the wetland faster during this period. This is offset at times by the increased amount of dilution provided by the snowmelt which acts to dilute the strength of the wastewater and associated contaminants. We observed that sewage moves through the wetland very quickly during the spring freshet. Despite this, the water quality at the outlet was still below the NWB standards, likely from dilution.

***5. Are there effects of the sewage in the marine environment such as with fish and marine mammals?***

The scope of our study on the wetland treatment area did not include a survey of the marine receiving environment. However, we have studied the marine receiving environments in other similar sized communities with comparable water quality discharging into the ocean. We studied the impacts of sewage on benthic invertebrate populations (i.e., small organisms that live in the sediment) and also the extent and water quality of the sewage plume. The communities that were studied were Pond Inlet, Grise Fiord, Pangnirtung, and Kugaaruk. We found from these communities that the zones of impacts to the marine receiving environment are localized within approximately 150 – 300 m from the outlet. The impacts to the benthic invertebrate species was found to be fairly minimal. Based on the water quality of the effluent discharging from the wetland outlet into the ocean, we would expect the impacts on the fish and mammals to be very localized and minimal.