Wetland Treatment Area Study in Cape Dorset, Nunavut

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

%	Percent
°C	Degrees Celsius
$CBOD_5$	Five-Day Carbonaceous Biochemical Oxygen Demand
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*
GN	Government of Nunavut
GPS	Global Positioning System
ha	Hectare
HLR	Hydraulic Loading Rate
hr	Hour
HRT	Hydraulic Retention Time
ISE	Ion Selective Electrode
kg	Kilogram
km	Kilometer
L	Litre
m	Metre
m^2	Square Metre
m^3	Cubic Metre
mL	Millilitre
MPN/100mL	Most Probable Number of Colony Forming Units per 100mL

NH_3-N	Un-ionized Ammonia Nitrogen
ORP	Oxidation Reduction Potential
PAEK	Polynomial Approximation with Exponential Kernel
PET	Potential Evapotranspiration
Q	Discharge
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
µg	Micrograms
µS	Microsiemens
V	Volume
WSER	Wastewater Systems Effluent Regulations
WSP	Waste Stabilization Pond
WTA	Wetland Treatment Area

Executive Summary

This study on the wetland treatment area (WTA) in Cape Dorset was conducted by the Centre for Water Resources Studies (CWRS) at Dalhousie University. Findings from this study were part of the final deliverables of a 6-year research contract for the Community and Government Services (CGS) department of the Government of Nunavut (GN), which aimed to assess municipal wastewater treatment across the Territory of Nunavut. In particular, this study provided additional information on the design of proposed WTAs and validation of performance modeling techniques.

The municipal wastewater treatment in Cape Dorset currently consists of an under-sized multiple cell pond system that accepts raw wastewater from pump trucks on a year-round basis. In 2008, a new wastewater stabilization pond (WSP) was constructed at a different location to the south-west of the community up gradient of a natural freshwater lake termed P-Lake. The proposed WTA in this study refers to the area bounded by P-Lake, and a wetland and smaller lake which follow P-Lake. These three systems are characteristic of a shallow water wetland. The new WSP was intended to be used for wastewater storage and treatment prior to discharge into P-Lake. However, since the construction of the WSP, transportation of the wastewater generated in the Hamlet to the new WSP is challenged by a steep and winding access road—which is difficult to navigate in the winter-months—and a leak that had developed in the WSP after construction. As a result of these challenges, the WSP has not been used regularly for treatment of wastewater from the Hamlet.

In order to inform the decision-making process for the wastewater infrastructure in the Hamlet, this study on the WTA was initiated. Specifically, the amount of treatment that could be expected from the existing WTA was of interest. This wetland was not in use at the time of the study and therefore it served as a proof of concept for the methodology for designing proposed WTAs that were presented in the design guidelines as per CWRS (2016). Furthermore, alternate design scenarios were considered to assess the merit of upgrading the infrastructure in the WTA.

A site visit was conducted from July 17 to 22nd, 2016 to collect data necessary to inform a model used to assess estimated treatment performance of the WTA. The fieldwork activities consisted of a detailed topographic survey with Real-Time Kinematic (RTK) Global Positioning System (GPS) equipment. This topographic data was used to calculate the surface areas and volumes of water stored in the existing and upgrade configurations of the WTA. A detailed vegetation assessment was conducted to document baseline vegetation conditions. General baseline water quality was assessed with a handheld water quality sonde. A hydraulic tracer test was conducted to simulate the hydraulic conditions of a seasonal decant and to determine the hydraulic retention time (HRT) of the WTA system as-is. The tracer test was conducted with rhodamine WT (RWT) fluorescent dye. A pump powered by a diesel generator was used to lift water collected in the WSP over the berm and to discharge water into the inlet of P-Lake. The RTW dye was injected into the discharge stream entering P-Lake during the manual decant. Concentrations

of the RWT were measured *in situ* at the outlet of P-Lake and the smaller lake. Discharge rates from the seepage into P-Lake from the WSP and during the hydraulic tracer test were measured with a pygmy current meter. The discharge rate during the tracer was 2024 m^3/d.

The findings from the fieldwork were used to parameterize a tanks-in-series (TIS) first order chemical reactor model to assess predicted treatment for the WTA. The model was used to estimate treatment from the existing WTA, and an upgrade scenario which consisted of 2.7 m vertical berms constructed at the outlet of P-Lake and the smaller lake (Upgrade 1). An additional upgrade scenario was considered, which consisted of 5 m vertical elevation berms at the outlet of P-Lake and the smaller lake (Upgrade 2). Several different model scenarios were simulated based on variable input parameters consisting of: a 2-month and 3-week discharge period, 5 and 15°C temperatures, dry and median historical climate conditions, and low, medium, and high strengths of influent wastewater.

Based on results from Ragush et al (2015), the anticipated quality of the influent entering the WTA from the existing WSP would fall approximately in the range of 80 - 160 mg/L for $CBOD_5$, 25 - 100 mg/L for TSS, and <1.25 mg/L for NH_3-N. The results of the modeling suggested that the existing WTA would provide modest treatment of effluent after discharge from the WSP. For instance, the existing system, assuming median climate conditions with medium strength influent and a 2-month discharge rate, was estimated to have effluent concentrations (percent/log reductions) of 119 mg/L (21%) for $CBOD_5$, 7.9 x 10^2 MPN/100mL (0.1 log) for *E. coli*, 64 mg/L (20%) for TN and TAN, and 0.27 mg/L (10%) for NH_3-N. While for the same conditions with 3-week discharge rate, this would be estimated to result in effluent concentrations of 137 mg/L (9%) for $CBOD_5$, 9.1 x 10^2 MPN/100mL (0.04 log) for *E. coli*, 73 mg/L (9%) for TN and TAN, and 0.29 (3%) for NH_3-N.

Moderate additional treatment of $CBOD_5$ was estimated for upgrade 1 when considering the medium strength influent and median climate conditions. For example, the effluent concentrations ranged from 53 – 108 mg/L (28 – 65%) for $CBOD_5$ for the 2-month discharge rate, and 100 – 133 mg/L (11 – 33%) for the 3-week discharge rate assuming median climate conditions. The Upgrade 2 scenario was estimated to provide a further modest increase in treatment performance in terms of $CBOD_5$ removal.

The findings from this study can be used to make an informed decision as to whether the existing WSP located at P-Lake would be worthwhile to use for treatment of wastewater for the Hamlet. Factors such as desired concentrations of effluent parameters should be identified to assess whether the existing system would provide adequate treatment of effluent prior to discharge into the receiving environment. The advantage of using a passive system such as this existing WSP is that there is limited reliance on operational input and relatively low continued maintenance requirements in comparison to mechanical treatment options.

1.0 Introduction

1.1 Project Context

In 2010, the Community and Government Services (CGS) department of the Government of Nunavut (GN) awarded a six-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 including: (i) an assessment of the treatment performance of the wastewater stabilization ponds (WSPs) and tundra wetland treatment areas (WTAs), (ii) development of design criteria and resources, and (iii) conducting 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 WTA. 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 developed to estimate treatment potential within the WTAs 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 the hydrologic contributions to use for performance modeling of tundra WTAs. This model was used to derive the first order rate constants for various contaminants within the Coral Harbour 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 the rate constants expected from tundra WTAs.

This prompted the need for additional site-specific studies of WTAs to be able to reduce the uncertainty of the WTA design process. Cape Dorset was chosen as one of the communities to complete a site-specific study. Cape Dorset currently has one sewage treatment facility in use, located approximately 1.5 km to the west of the Hamlet. It is designed as a three-cell primary treatment lagoon system. Historically, the facility has had berm stability issues due to the natural topography where it was built. There have been discharges of untreated sewage as a result of berm failures. Various replacement treatment options have been considered by the GN. In 2007, Dillon Consulting Limited was retained to construct a new sewage lagoon (WSP) near P-Lake—which is a natural lake located approximately 1.5 km to the south-west of the Hamlet (Dillion Consulting, 2006). Since then, the P-Lake WSP has had a few issues, one problem being the access road, which is too steep to safely navigate in the winter. Furthermore, a leak has been observed in the berm of the P-Lake WSP; as a result of these issues the new WSP near P-Lake is not currently in use by the Hamlet. An assessment report of the P-Lake WSP was prepared by Stantec in March 2015. They recommended improvements for the WSP and steps that could be taken moving forward to make the site suitable for wastewater treatment (Stantec, 2015). The first of which is to attempt to plug the leak in the berm, which Stantec gives recommendations on different ways this could be resolved (Stantec, 2015). An alternative treatment strategy identified by the GN would involve utilizing the area downgradient of the new WSP as a WTA, which prompted the need for this current study.

1.2 Objectives

This study was conducted to assess the potential additional treatment provided by the proposed wetland treatment area in Cape Dorset if it were to accept effluent from the P-Lake WSP in the future. The three main objectives the study were to:

i) Assess the expected treatment performance of the proposed WTA in Cape Dorset;
ii) Apply the performance model technique for proposed WTAs, developed in Hayward and Jamieson (2015); and
iii) Model alternate design scenario(s) that could be developed to increase treatment in the WTA.

1.3 Project Scope and Limitations

This project will provide an assessment of the treatment performance of the proposed Cape Dorset WTA. Alternate scenarios for increased treatment will be explored in the modeling portion of the study. The scope of this project does not extend to include any design configurations beyond the use of two berm structures to provide effluent detention. If the predicted 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 develop new system designs. Community consultation was beyond the scope of this study because the WTA was not in active use by the community. The results of this study were based on the best information available at the time of the study. The authors should be notified should new pertinent information arise, as the outcomes of the study may be rendered less accurate.

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 2.5.4.

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 characterization
- Completion of a performance model analysis

2.2 Site Description

2.2.1 Cape Dorset

The Hamlet of Cape Dorset (64° 13’ 54” N, 076° 32’ 25” W) is located on the southwestern tip of Baffin Island. The community has an estimated population of 1363 people (Statistics Canada, 2012). Average air temperatures range from –28°C and –22°C in January, and from 4°C and 12°C in July. Total Precipitation averages 449 mm, with 158 mm as rainfall, and 2907 mm as snow (291 mm Snow Water Equivalent), (Government of Canada, 2014a). The Cape Dorset WTA site-specific study was conducted from July 17 to 22, 2016**.**

2.2.2 Wastewater Treatment System

Currently, the wastewater in the Hamlet is transported to a 3-cell system located approximately 1km to the west of the Hamlet. The current system is undersized for the production of wastewater generated by the Hamlet. A new WSP was constructed in 2008 to accommodate and treat the wastewater produced by the Hamlet. This WSP is located approximately 1.5 to the south-west of the Hamlet. The WSP is located upstream of a natural lake named P-Lake (11,100 m^2), a small wetland (1,120 m^2), and a smaller un-named lake (1,730 m^2). These three waterbodies downstream of the WSP compose the existing WTA that was studied and are characteristic of a shallow water wetland system. The Cape Dorset WTA is currently in the planning phase and not actively receiving effluent. Wastewater would be transported by pump trucks to the WSP if it was currently in use. Operationally, the effluent would travel through the WTA and discharge into a larger bay area, which would feed into the Hudson Bay. The WTA is shown in Figure 1. Approximately 143 m^3/d (52,038 m^3/yr) of primarily domestic municipal wastewater is generated daily in Cape Dorset (Hamlet of Cape Dorset, 2012, 2014, and 2015).

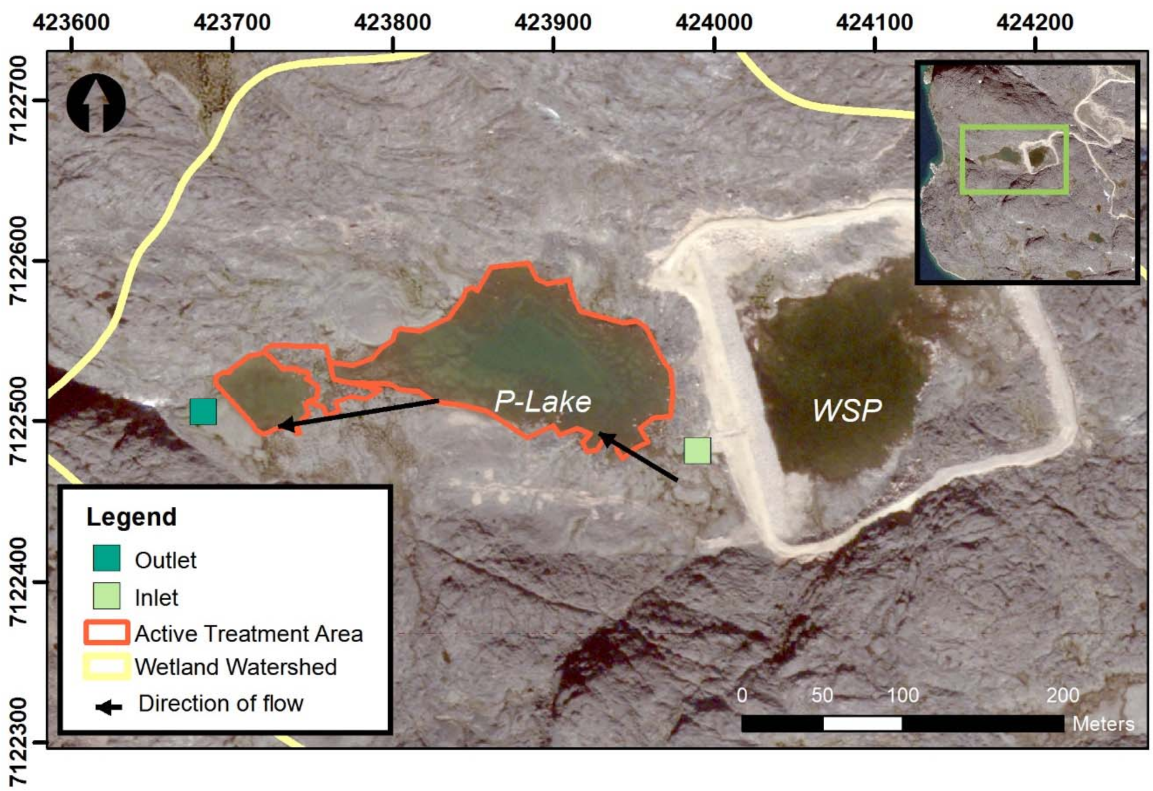

Figure 1. Site map of the WTA in Cape Dorset, NU.

The WTA is approximately 260 m in length from the inlet to the outlet. It has less than a 1% east to west downward sloping terrain. There are steep inclines on either side of the WTA, with a 1:1 slope north of the site and 1:3 slope to the south of the site. P-Lake is the larger of the two lakes with an approximate volume of 11220 m^3, while the smaller lake has a volume of 980 m^3. The WTA consists of wetland areas characterized by willows, lichen, and mosses, with upland areas characterized by varieties of heath plants (Mallory and Aiken, 2012).

2.3 Hydrology and Hydraulics

2.3.1 Watershed and Wetland Delineation

The watershed delineation was performed with ESRI ArcGIS 10.2.2 software and the Arc Hydro toolbar. A digital elevation model (DEM) was downloaded from Natural Resources Canada. The DEM was preprocessed with the Arc Hydro toolbar and the contributing area was then delineated from the wetland outlet using the Interactive Point Delineation tool. The watershed polygon was adjusted by hand and smoothed using the Smooth Polygon tool with the PAEK method.

The wetland was delineated based on observations made during the site visit, supplemented with satellite imagery. Observations used to delineate the wetland included examination of soil characteristics, moisture content, and vegetation.

2.3.2 Discharge Measurement

Characterization of the hydraulics and hydrology of the site involved the measurement of the influent and effluent discharges from the WTA. As well, 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. Figure 2 shows the gauging sites at the Cape Dorset P-Lake WTA.

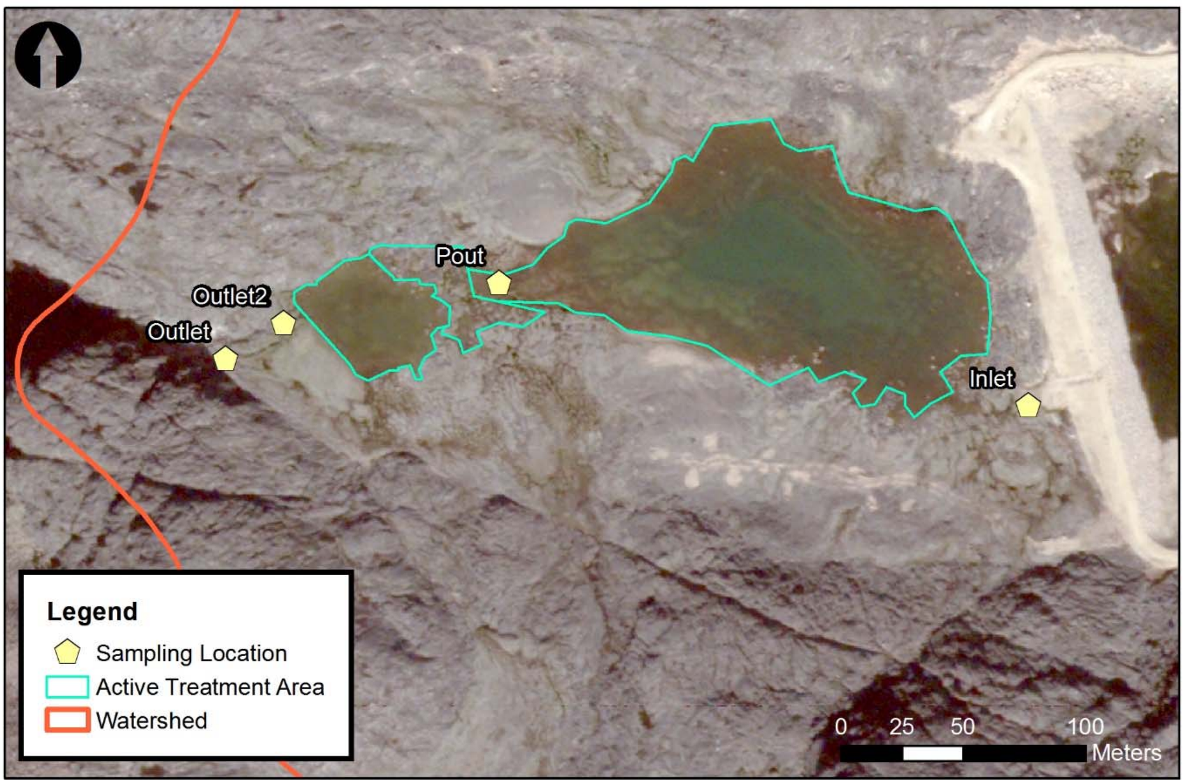

Figure 2. Sampling Locations within the WTA in Cape Dorset.

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 2m 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).

2.3.3 Tracer Test

A tracer test was conducted to characterize the hydraulic conditions of the WTA, specifically to determine the hydraulic residence time (HRT). The HRT is representative of the average amount of time required for water and conservative solutes to move through the wetland. The tracer test involved injecting a conservative solute, in this case a fluorescent dye Rhodamine WT (RWT), into the inlet flow stream. The RWT is injected upstream of a defined downstream measurement location and the concentration of the RWT within the stream is measured over time.

One tracer test was completed at the Cape Dorset site during the site visit on July 20, 2016. This was conducted with the assistance of the Hamlet water foreman and operators. A generator and locking hoses were sourced from the Hamlet and set-up on the berm of the WSP. The generator was kept pumping for approximately 6 continuous hours to simulate a decant flow into P-Lake WTA. The RWT dye tracer was injected into the decant flow stream in the channel at the toe of the WSP berm, and near the beginning of P-Lake, near where the existing berm seepage has observed to occur. The amount of RWT tracer injected for was computed based on the concentration at the termination point of the tracer, where measurements are being taken, being approximately 200 µg/L. Approximately 1 L of RWT (20% w/w) was diluted in six 18L carboys. The concentration of RWT was measured at the outlet of P-Lake and at the small lake outlet *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). The sondes were kept in for over 24 hours to monitor the flow of dye through the WTA.

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 Real-Time Kinematic (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 on the berm between the WSP and the inlet to P-Lake, which was deemed a suitable spot to be able to cover all area needed for the survey. Therefore, the maximum baseline length was approximately 1 km and on average ranging 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. The topographic data are in Universal Transverse Mercator Zone 18N projection.

2.4 Physical and Biological Characterization

2.4.1 General Water Quality

Discrete measurement of the biogeochemistry of the WTA were performed with handheld YSI 600 multi-parameter sondes (YSI Inc., Yellow Springs, Ohio, United States). Each of the handheld sondes was calibrated for dissolved oxygen at the beginning of each day of the fieldwork. The sondes were also calibrated for pH and conductivity at the commencement of site work as per the manufacturer’s specifications. This calibration provided an accuracy verification on the sonde measurements to ensure that they were operated within specifications. The water quality indicators of pH, dissolved oxygen (DO), specific conductivity, oxidation reduction potential (ORP), and temperature were taken on a daily basis for the duration the study period in Cape Dorset.

2.4.2 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 July 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 98 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 resolution image 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 Carolyn Mallory and Susan Aiken (2004). Figure 3 is an example of a quadrat plot.

Figure 3. Example photograph of a vegetation quadrat.

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 as such not considered.

Table 1. Example of the dominant ranking for a vegetation quadrat.

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

Two classes (wetland 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. A three-band (RBG) QuickBird satellite image of Cape Dorset 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 Model Construction and Scenario Analysis

2.5.1 Modeling Objective:

The objectives of the modeling were to assess the treatment that could be provided from the existing configuration of the system. Furthermore, the treatment potential resulting from two potential upgrades to the system were analyzed to assess the estimated provision of additional treatment. In total, three modeling scenarios were assessed which consisted of the:

(i) Existing system configuration with discharge from the WSP into P-Lake, the wetland, and the small lake downstream of P-Lake;
(ii) construction of two berms with 2.7 m vertical elevation, equivalent to 1.8 m of additional water depth (termed Upgrade 1); and
(iii) construction of two berms with 5 m vertical elevation, equivalent to 3.8 m of additional water depth (termed Upgrade 2).

The upgrade scenarios were conceptualized as having berms with overflow structures located at the end of P-Lake, and the small lake, respectively. Therefore, the upgraded system is conceptualized as a three-cell WSP system with the latter two cells operating as passive overflow retention structures.

2.5.2 Model Approach

A modified TIS model was used to estimate the treatment performance of each scenario. The actual HRT and number of tanks were calculated based on the results of the tracer test. From the tracer response curve, a TIS model was observed to be appropriate to represent the hydraulics of this system. The TIS wetland spreadsheet calculator tool provided in CWRS (2016) was modified to represent the conditions at the Cape Dorset site. A detailed methodology on the TIS modeling technique is provided within CWRS (2016). The upgraded system configurations were also modeled with the TIS technique because the hydraulics of the upgraded cells were assumed to be similar to the existing conditions. The series of factors that were assessed for each of the scenarios are illustrated in Figure 4.

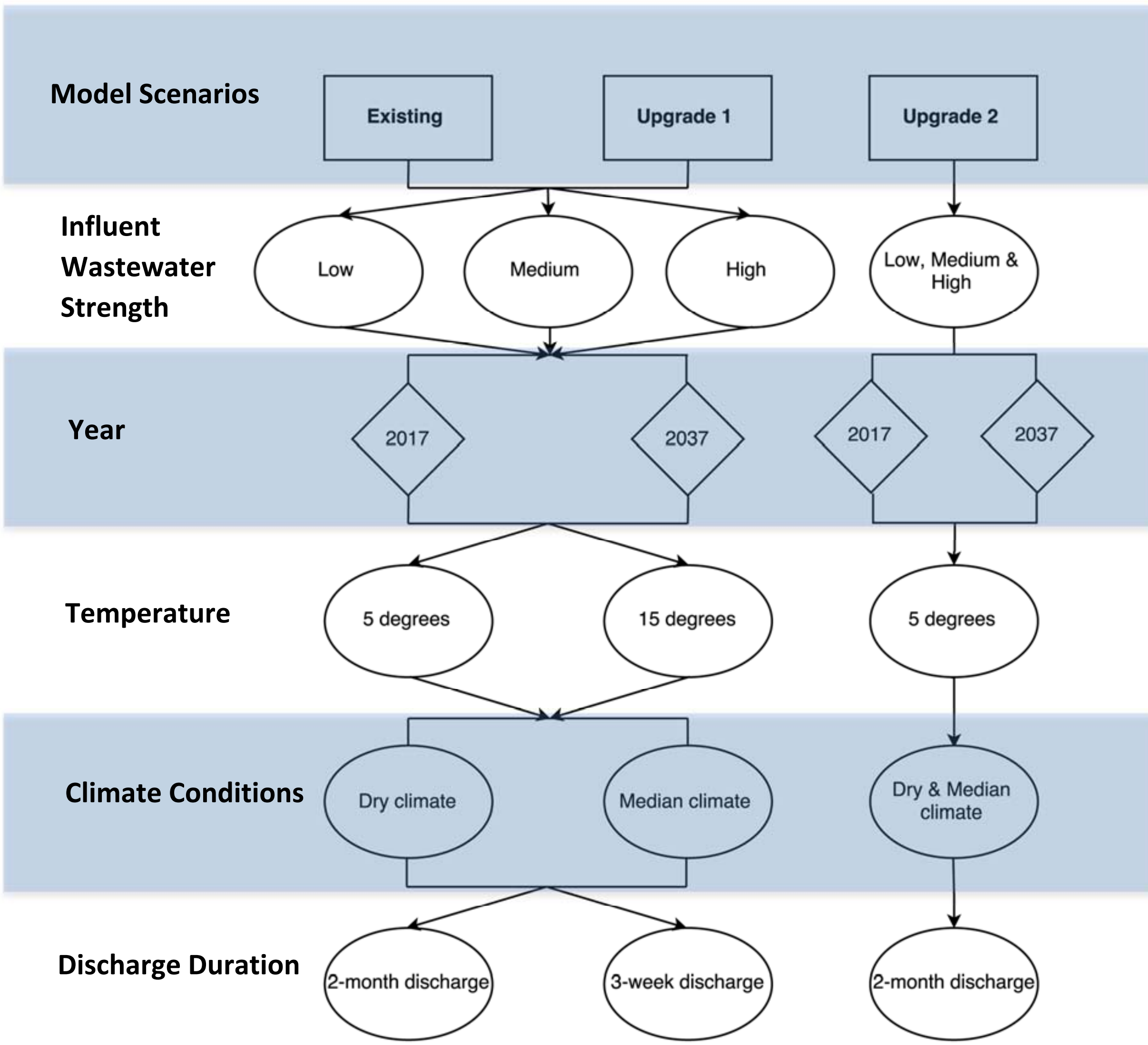

Figure 4. Flow chart of the factors and scenarios included in the performance modeling.

2.5.3 Assumptions

The following assumptions were made to conduct the modeling analysis:

- The hydraulic behavior of the upgraded configurations was assumed to be consistent with the existing P-Lake and the small lake, which was considered a best estimate.
- The ranges of concentrations of parameters 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 would be discharged from the existing WSP;

- The upgraded system configurations were assumed to have passive continuous flow structures;
- The hydraulic efficiency of P-Lake after upgrade 1 (scenario ii) was assumed to be 50% and the HRT was adjusted accordingly;
- The hydraulic efficiency of P-Lake after upgrade 2 (scenario iii) was assumed to be 100% in order to simulate a 90-day HRT scenario.
- Infiltration into the subsurface was assumed to 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);
- 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); and
- The bathymetry of P-Lake was assumed to be representative of the bathymetric map produced in Dillon Consulting (2006).

2.5.4 Limitations

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

- The actual hydraulic retention times and hydraulic efficiencies of the upgraded scenarios may vary from the assumptions made within this study, which would result in changes to expected treatment performance of the system configurations;
- The rate constants and temperature correction coefficients were adopted from literature; however, and some are limited in applicability to arctic WSPs, this introduces uncertainty in the treatment performance estimations;
- Seepage from the WSP upstream of P-Lake was not considered in the modeling calculations;
- When external hydrologic sources were considered, the median annual precipitation was distributed equally over the entire year. Therefore flow spring melt conditions were considered to be negligible for the existing and upgraded scenarios because decant would occur later in the summer;

- 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.

2.5.5 Model Input Parameters

2.5.5.1 Hydraulic Retention Times

The HRT for the existing condition was set as the actual measured HRT obtained from the tracer test, which was 18.3 hr for the combined system consisting of P-Lake, the wetland, and the smaller lake. The nominal hydraulic retention time (θ) was calculated for each model run for the upgrade conditions, and is given by Equation 1 as follows:

$$\theta = \frac{V}{Q} \qquad [1]$$

Where V is the volume of the lakes (m^3) and wetland, and Q is influent flow (m^3/d).

2.5.5.2 Volumes and Surface Areas

The volumes and surface areas of the existing and upgraded scenario for P-Lake, wetland, and smaller lake were calculated with ArcGIS. The study area was modeled as a triangular irregular network (TIN) using elevation data from several sources:

- RTK topographic survey
- Digitized bathymetry map (Dillon Consulting, 2006)
- 10 m contours (Government of Canada, 2016a)

The polygon volume tool was then used to calculate the volume and surface area between a specified elevation and the TIN surface. The existing scenario is modeled below in Figure 5 and the upgrade 1 scenario in Figure 6.

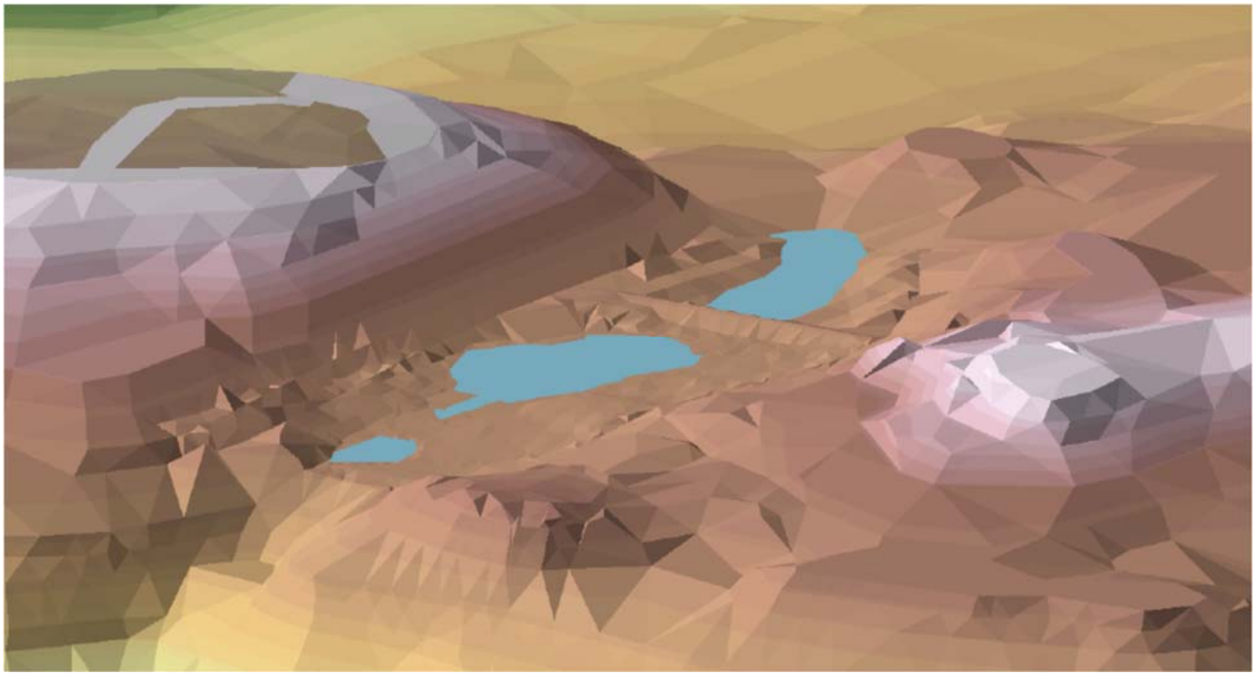

Figure 5. Schematic of the existing model scenario.

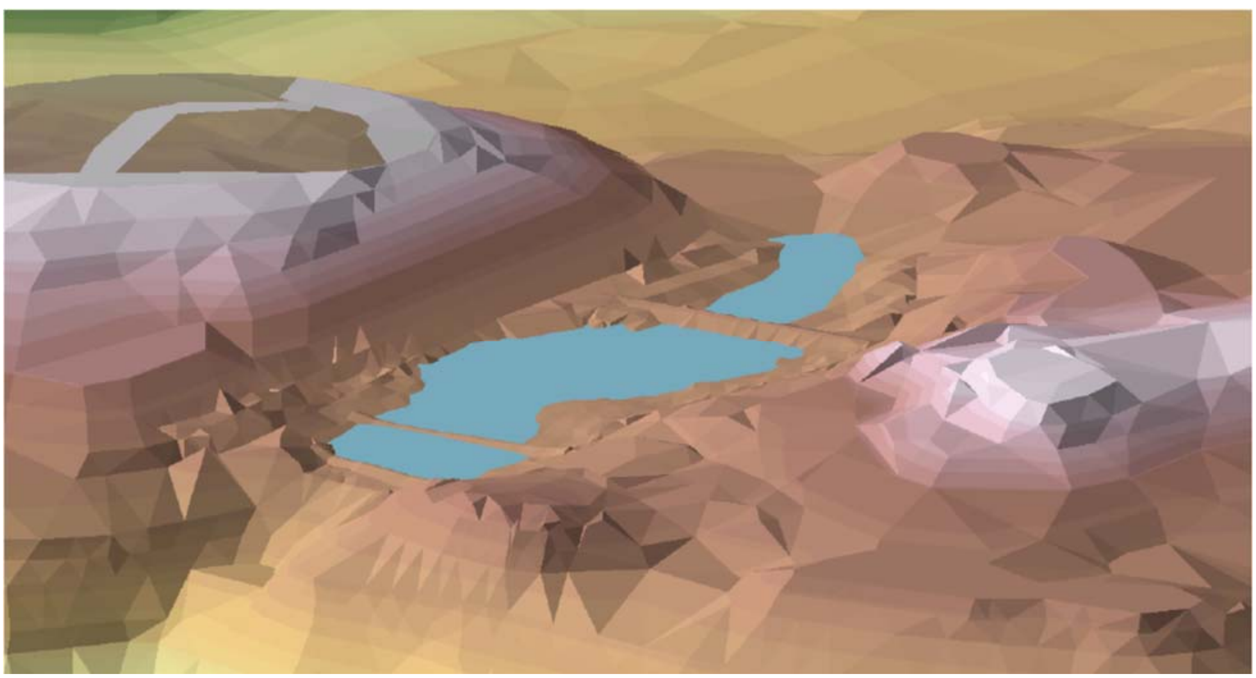

Figure 6. Schematic of the Upgrade 1 model scenario.

Table 2 summarizes the P-lake, wetland, and smaller lake volume and surface areas for the existing conditions and the upgrade scenarios.

Table 2. System surface area and volume input parameters for model.

Waterbody	Existing		Upgrade 1		Upgrade 2	
	Volume (m^3)	Surface Area (m^2)	Volume (m^3)	Surface Area (m^2)	Volume (m^3)	Surface Area (m^2)
P-Lake	11220	11100	45800	24510	100000	32000
Small Lake	980	1730	9060	6090	9060	6090
Wetland	40	1120	0	0	0	0

2.5.5.3 Influent Wastewater Strength

The influent wastewater strength ranges were selected to span the minimum, mean, and maximum values from the findings from 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. These influent values that were used as input parameters are summarized in Table 3 below. Total suspended solids (TSS) was not included in the modeling component of the study. This was because the removal of TSS in wetlands is not well represented by first order reaction kinetics, and as such have more traditionally been presented in terms of influent and effluent concentrations and expected percent removals (Kadlec and Wallace, 2009; Kadlec, 1987). It was recommended in CWRS (2016) that TSS not be used as a compliance parameter due to the potential for internal TSS generation in wetlands.

Table 3. Input parameters for wastewater strength.

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
NH_3-N (mg/L)	0.1	0.3	1.0

2.5.5.4 Selection of Rate Constants

The rate constants that were used for the modeling and their sources are outlined in Table 4. It should be noted that there is uncertainty in the adoption of rate constants for WSP operating in arctic environments. Therefore, the rate constants adopted for this modeling were adjusted from WSPs operating in non-arctic conditions for *E. coli* and nitrogen. The rate constants were adjusted for 5 and 15°C according to the Arrhenius equation given in Kadlec and Wallace (2009) as per Equation 2. The temperature coefficients used in the correction are stated in Table 4.

$$k_T = k_{20}\theta^{(T-20)} \qquad \text{[Eq.2]}$$

where k_T is the rate constant at the field temperature (m/d), k_{20} is the rate constant normalized to 20°C (m/d), T is the field temperature in °C, and θ is the temperature correction coefficient (dimensionless). These two temperature ranges were selected because they represent the typical range of temperatures experienced over an arctic summer (e.g., June – September).

First order rate constants for *E. coli* were developed for a study in Pond Inlet and Clyde River were two magnitudes lower than the one chosen for this model (Huang, in review). In this case, a higher rate constant should produce more treatment. Even with the higher rate constants chosen, shown in Table 4, an increase in treatment was not observed. For $CBOD_5$, the rate constants were determined from bench-scale experiments simulating arctic conditions.

Table 4. Summary of rate constants used in the modeling.

Parameter	k at 5°C (d^{-1})	k at 15°C (d^{-1})	Temperature coefficient	Source	Description of source
$CBOD_5$	0.020	0.090	1.050	Ragush et al (2017)	Results of a bench-scale study.
E. coli	0.018	0.029	1.050	Ellis & Rodrigues (1995)	Adjusted results from a warm climate environment.
TN, TAN, NH_3-N	3.2×10^{-3}	5.3×10^{-3}	1.039	Reed (1985)	Adjusted results from US states (New Hampshire, Kansas, Utah and Mississippi).

2.5.5.5 Climate Data

Historical climate data was downloaded for Cape Dorset Station A/Climate from the Environment Canada historical climate data website (Government of Canada, 2016). Bulk downloads of multi-year datasets were performed according to the directions provided by Government of Canada (2015). 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 63 mm/yr based on the historical temperature dataset from Environment Canada (Government of Canada, 2016).

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 372 mm/yr

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

2.5.5.6 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, which was representative of a system configuration with a passive discharge structure. 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 projected wastewater production from 2017 to 2037 was determined based on population projections available from the Government of Nunavut (Government of Nunavut, 2014). Population was multiplied by estimated per capita wastewater production to obtain a total annual wastewater production.

The annual projected wastewater production based upon the calculated population and residential water use. The residential water use (RWU) was assumed to be 90 L/person/d for trucked water as assumed from Smith (1996). This compared well with the recent water use reports which consisted of 101, 99, and 91 L/person/d for 2012, 2014, and 2015, respectively (Hamlet of Cape Dorset, 2012, 2014, 2015). The total water use per capita was estimated using:

$$RWU \times [1.0 + (0.00023 \times P)] \quad \text{[Eq.2]}$$

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. Table 5 summarizes the discharge rates calculated to inform the model simulations.

Table 5. Estimated discharge rates for 2017 and 2037 for the 2-month and 3-week discharge scenarios.

Year	Population Projection	Discharge Duration	Estimated per capita water use (L/per person/d)	Estimated Discharge Rate (m^3/d)
2017	**1578**	**2-month**	**123**	**1178**
		3-week		**3365**
2037	**1956**	**2-month**	**130**	**1552**
		3-week		**4435**

3.0 Results

3.1 Hydrology and Hydraulics

Instantaneous discharge measurements were taken on a regular basis at key points in the wetland, this included the inlet, outlet, and various relevant midpoints throughout the WTA. Table 6 shows a summary of the instantaneous discharge measurements taken in Cape Dorset.

Table 6. Summary of instantaneous discharge measurements.

Sampling Location: Cape Dorset				
Date Range	**Gauging Site**	**Flow (m^3/d)**		
		Minimum	**Maximum**	**Average**
2016/07/19 - 2016/07/21	**Inlet**	393	428	411
	P-Lake Outlet	569	745	637
	Outlet	394	690	563

The inlet gauging site represents the seepage rates from the WSP berm into P-Lake. These would be considered baseline flows and would be lower than future flows when decanting from the WSP. During the tracer test, the influent flow rate into P-Lake was measured as 2024 m^3/d. There was also a small freshwater stream that flowed into the system near the outlet of P-Lake. Although the flow was not significant, averaging approximately 13 m^3/d, it should be noted.

3.1.1 Tracer Test

The hydraulic tracer test provided a visual indicator of the direction of flow and extent of the wetted area. The design guidelines also recommend a maximum HLR of 2.5 cm/d (250 m^3/ha-d) for WTAs in Nunavut (CWRS, 2016). A mobile pump was set-up to feed additional flow into P-Lake from the WSP during the tracer test to simulate flow during a decant. The flow rate was measured as 2024 m^3/d, which would correspond to a HLR of 14.46 cm/d (1446 m^3/ha-d). In this scenario, the HLR is significantly higher than the recommended maximum of 2.5 cm/d (250 m^3/ha-d), according to CWRS (2016). The discharge rate during the tracer test was representative of what would be a typical flow rate during a mechanical decant of the WSP (see Table 5 for comparison). This demonstrates that in the existing system configuration, the influent would be applied to the WTA at rates that exceed levels for optimized treatment. Figure 7 shows the injection location of the tracer test.

Figure 7. Injection of RWT at seepage location above P-Lake.

The tracer also facilitated the quantitative determination of the actual HRT of the existing WTA. The existing system consisting of P-Lake, the wetland, and the smaller lake combined had a short HRT of 18.3 hours based on the results of the tracer test. The results of the tracer test conducted on the existing system are illustrated in Figure 8. The analysis of the tracer dataset showed that a 4 TIS model would best fit the hydraulic behavior of the existing system. Specifically, P-Lake hydraulics were best represented by 3 TIS, and the wetland and smaller lake by 1 TIS, for a total of 4 TIS. Short-circuiting was also visually observed during the tracer test.

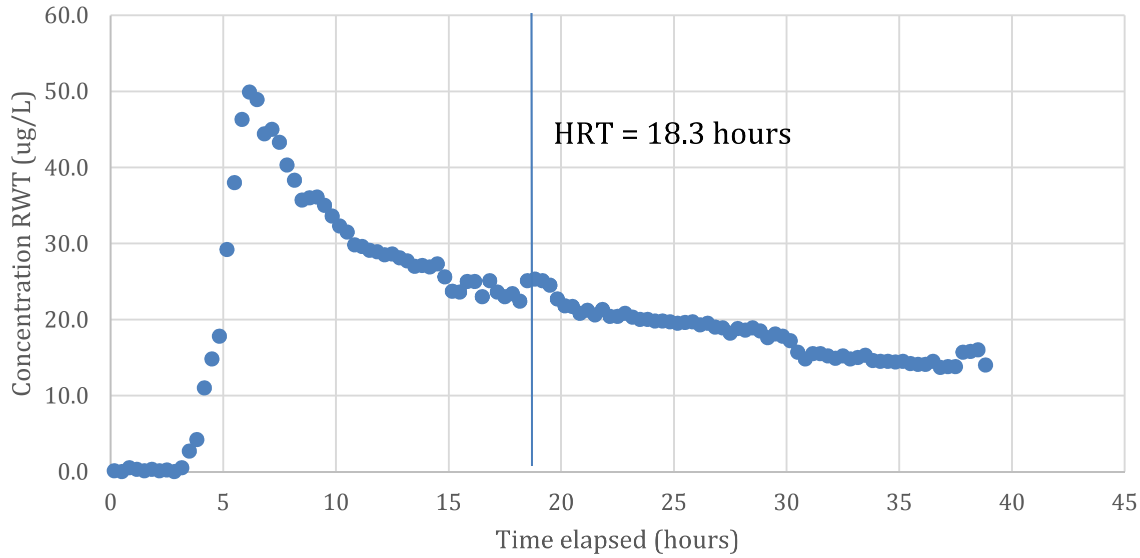

Figure 8. Outlet tracer response curve for the tracer test conducted in Cape Dorset.

3.2 Physical and Biological Characterization

3.2.1 Water quality

Handheld multi-parameter water quality sondes were used to measure the basic biogeochemical parameters *in situ* on a daily basis over the two study periods. These included temperature, dissolved oxygen, conductivity, pH, and ORP. Table 7 shows the minimum, maximum and average values for each sampling site for the trip in July.

Table 7. General water quality summary.

Cape Dorset 2016/07/19 - 2016/07/21					
Sampling Location		Water Quality Parameters			
		Temperature (^oC)	Conductivity (µS/m)	DO (mg/L)	pH
Inlet	Min	8.3	45	9.9	7.42
	Max	8.8	47	12.0	7.48
	Average	8.5	46	10.9	7.45
P-Lake Outlet	Min	11	38	12.1	7.52
	Max	13	50	12.1	7.52
	Average	12	44	12.1	7.52
Outlet	Min	9.5	50	12.1	7.51
	Max	13	52	12.7	7.57
	Average	12	51	12.6	7.54

The results displayed in Table 7 show the baseline water quality conditions of the WTA at various sampling locations. The measured water temperature during the site visit ranged from 8 – 13 ^{o}C.

3.2.2 Vegetation

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

Table 8. Cape Dorset WTA vegetation classification.

Class	Dominant	1st Dominant
Upland	Mountain Avens, White Heather	Blueberry, Sedge, Carex, Lichen, Peat Moss
Wetland	Arctic Willow, Blueberry, Carex, Lichen, Net-vein Willow, Peat Moss, Sedge	Crowberry, Dwarf Fireweed, Mountain Avens, Northern Wood-Rush, White Heather

From the vegetation survey an image classification map was also created. Figure 9 shows the final classification map of the Cape Dorset WTA.

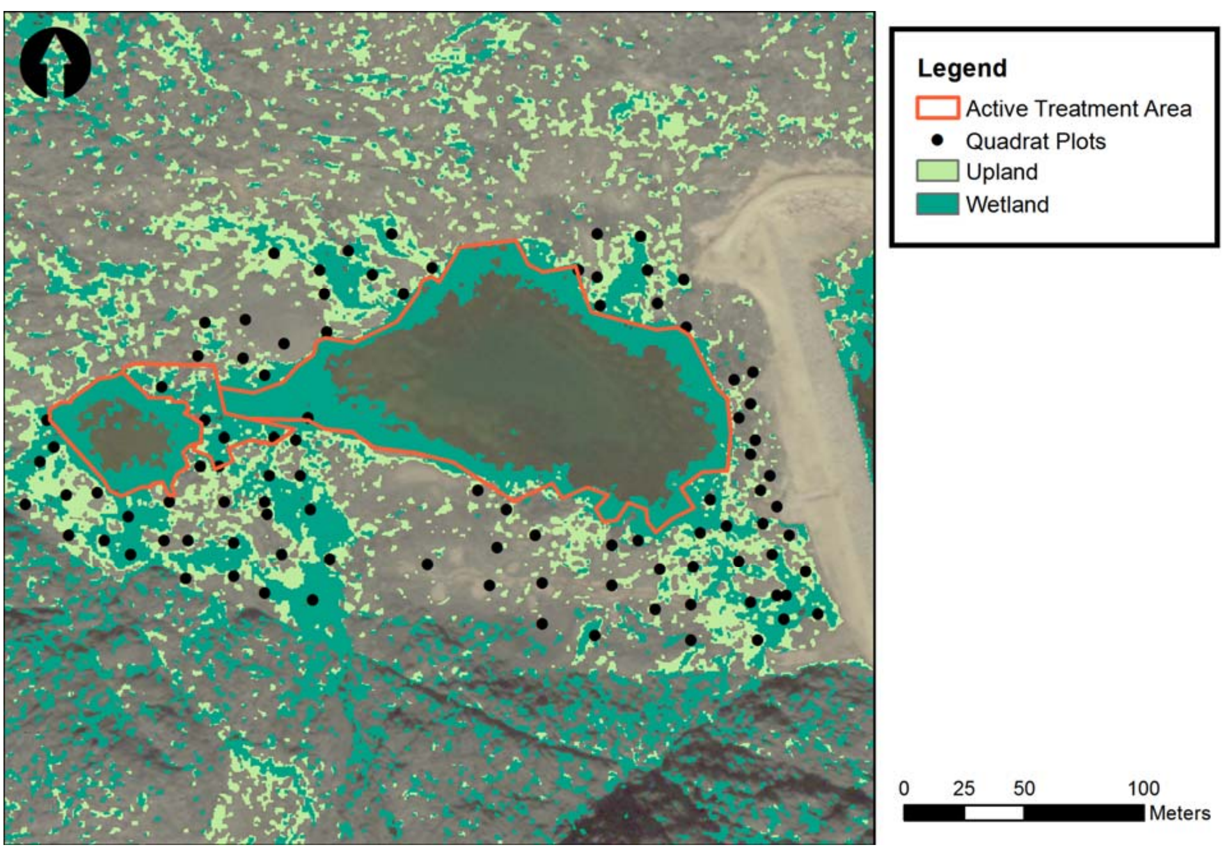

Figure 9. Vegetation classification map for the WTA in Cape Dorset.

This map shows the distribution of the upland and wetland vegetation classes. The area classified as wetland is concentrated around P-Lake and the smaller lake, which is to be expected. There are other areas—further away from the active treatment area—that are considered to have wetland characteristics based on the vegetation. The upland areas were dispersed throughout the site. As there is no sewage currently being treated in the WTA, there is considerable cross-over of plant species between wetland and upland. This map is meant to show the baseline conditions of the WTA. It would be expected that future classification of the vegetation within the WTA, once sewage is being treated, would differ from the current. The division between the vegetation in the upland and wetland classes would most likely become more distinct. Additionally, changes in species occurrence and distribution would be expected.

3.2.3 Wildlife

There was no waterfowl observed during the site visit. There were sporadic sightings of lemmings throughout the visit, specifically in the rocky areas. Droppings from animals were not observed.

3.3 Model Construction and Scenario Analysis

The complete set of results for all the model scenarios and runs are provided in Appendix A. Table 9 summarizes the results of the model runs produced from median precipitation and ET obtained from the historical datasets at a 2-month discharge rate at temperatures ranging from 5 to 15°C. Table 10 summarizes the results of the model runs produced from median precipitation and ET obtained from the historical datasets at a 3-week discharge rate at temperatures ranging from 5 to 15°C. Temperature variability had a varied effect on the effluent concentrations. In some scenarios, $CBOD_5$ and *E. coli*, temperature had a larger effect on the effluent concentrations. Therefore, some of the values in Table 9 and 10 are presented as a range. The rest of the parameters are presented as a singular value. The reductions (in % and log reductions) in Tables 9 and 10 are calculated in relation to the influent concentrations expected to be entering the WTA from the existing engineered WSP.

Table 9. Model effluent results for the median historical P/ET, 2-month discharge rate for the 5 and 15 °C temperature range in 2017.

Parameter		Low Strength[b]	Medium Strength[b]	High Strength[b]
$CBOD_5$ – mg/L	**Influent[a]**	**60**	**150**	**300**
(% and log	Existing	48 (20%)	119 (21%)	237 (21%)
reduction)	Upgrade 1	22 – 40 (33 – 63%)	53 – 98 (35 – 65%)	105 – 195 (35 – 65%)
E. Coli –	**Influent**	**$1x10^3$**	**$1x10^5$**	**$1x10^8$**
MPN/100mL	Existing	7.9×10^2 (0.1 log)	7.9×10^4 (0.1 log)	7.9×10^7(0.1 log)
(% and log	Upgrade 1	6.0×10^2 – 6.6×10^2	5.9×10^4 – 6.6×10^4	5.9×10^7 - 6.6×10^7
reduction)		(0.2 log)	(0.1 – 0.2 log)	(0.2 log)
TN – mg/L	**Influent**	**40**	**80**	**140**
(% and log	Existing	32 (20%)	64 (20%)	112 (20%)
reduction)	Upgrade 1	31 (23%)	61 (24%)	107 (24%)
TAN – mg/L	**Influent**	**40**	**80**	**140**
(% and log	Existing	32 (20%)	64 (20%)	112 (20%)
reduction)	Upgrade 1	31 (23%)	61 (24%)	105 (25%)
NH_3-N – mg/L	**Influent**	**0.1**	**0.3**	**1**
(% and log	Existing	0.1 (0%)	0.27 (10%)	0.86 (14%)
reduction)	Upgrade 1	0.09 (10%)	0.24 (20%)	0.78 (22%)

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

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

Table 10. Model effluent results for the median historical P/ET, 3-week discharge rate for the 5 and 15°C temperature range in 2017.

Parameter		Low Strength[b]	Medium Strength[b]	High Strength[b]
CBOD – mg/L (% and log reduction)	**Influent[a]**	**60**	**150**	**300**
	Existing	55 (8%)	137 (9%)	274 (9%)
	Upgrade 1	40 – 51 (15 – 33%)	100 – 128 (15 – 33%)	199 – 265 (12 – 34%)
E. Coli – MPN/100mL (% and log reduction)	**Influent**	**1×10^3**	**1×10^5**	**1×10^8**
	Existing	9.1×10^2 (0.04 log)	9.1×10^4 (0.04 log)	9.1×10^7 (0.04 log)
	Upgrade 1	8.2×10^2 – 8.6×10^2 (0.05 – 0.07 log)	8.2×10^4 – 8.6×10^4 (0.07 – 0.09 log)	8.2×10^7 – 8.6×10^7 (0.07 – 0.09 log)
TN – mg/L (% and log reduction)	**Influent**	**40**	**80**	**140**
	Existing	37 (8%)	73 (9%)	128 (9%)
	Upgrade 1	36 (10%)	72 (10%)	127 (9%)
TAN – mg/L (% and log reduction)	**Influent**	**40**	**80**	**140**
	Existing	37 (8%)	73 (9%)	128 (9%)
	Upgrade 1	36 (10%)	72 (10%)	127 (9%)
NH_3-N – mg/L (% and log reduction)	**Influent**	**0.1**	**0.3**	**1**
	Existing	0.1 (0%)	0.29 (3%)	0.94 (2%)
	Upgrade 1	0.1 (0%)	0.28 (7%)	0.91 (9%)

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

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

The HRTs expected based on sewage flows for 2017 versus 2037 are presented in Tables 11 and 12 respectively. For the existing system, the HRT used in the modeling was kept consistent at 0.8 day to reflect the results of the on-site tracer test. This ensured that the model results were accurate for the actual conditions on site. It should be noted that the hydraulic efficiency of the existing system was low at 13%; which was attributed to short-circuiting within P-Lake. The Upgrade 1 scenarios HRTs were determined from the nominal retention time assuming a 50% hydraulic efficiency. While the Upgrade 2 scenario HRTs were determined from the nominal retention time.

Table 11. 2017 Hydraulic retention times (d).

Scenario	Discharge Period	P-Lake Model	P-Lake Tracer	Small Lake Model	Small Lake Tracer	Total Model	Total Tracer
Existing	2-month	0.3	0.3	0.5	0.5	0.8	0.8
	3-week	0.3	0.3	0.5	0.5	0.8	0.8
Upgrade 1	2-month	19	-	3	-	22	-
	3-week	7	-	1	-	8	-
Upgrade 2	2-month	85	-	4	-	89	-
	3-week	-	-	-	-	-	-

Table 12. 2037 Hydraulic retention times (d).

Scenario	Discharge Period	P-Lake		Small Lake		Total	
		Model	Tracer	Model	Tracer	Model	Tracer
Existing	2-month	0.3	0.3	0.5	0.5	0.8	0.8
	3-week	0.3	0.3	0.5	0.5	0.8	0.8
Upgrade 1	2-month	15	-	2	-	17	-
	3-week	5	-	1	-	6	-
Upgrade 2	2-month	64	-	4.4	-	69	-

The $CBOD_5$ loading rates were determined for each of the modeled scenarios and are presented in Table 13.

Table 13. CBOD loading rates for the existing WTA and upgrade scenarios (kg/ha/d).

		2017			2037		
Scenario	Discharge Period	Low	Medium	High	Low	Medium	High
Existing	2-month	51	127	253	67	167	334
	3-week	145	362	724	191	477	954
Upgrade 1	2-month	23	58	115	30	76	152
	3-week	66	165	330	87	217	435
Upgrade 2	2-month	19	46	93	24	61	122
	3-week	53	133	265	70	175	349

The hydraulic loading rates were determined for each of the modeled scenarios and are presented in Table 14.

Table 14. Hydraulic loading rates for existing WTA and upgrade scenarios (cm/d)

Discharge Period	Year	Existing	Upgrade 1		Upgrade 2	
		P-Lake & Small Lake	P-Lake	Small Lake	P-Lake	Small Lake
3 weeks	2017	301	14	54	-	-
	2037	397	18	72	-	-
2 months	2017	105	5	18	4	18
	2037	139	6	24	-	-

The scenario analysis also included an assessment of a second upgrade option (Upgrade 2), which considered treatment estimated from a system with a 3-month HRT. Logistically, this would be attained by using the P-Lake pond as a retention pond for an entire year; which would entail significant engineering to render the berm between P-Lake and the smaller lake as impermeable, and to enable a scheduled decant at the end of the treatment season. Figures 10(a) to 10(d) present the model results estimated from the systems for the 2-month discharge rate at 5°C receiving medium strength influent in dry and median precipitation climate conditions.

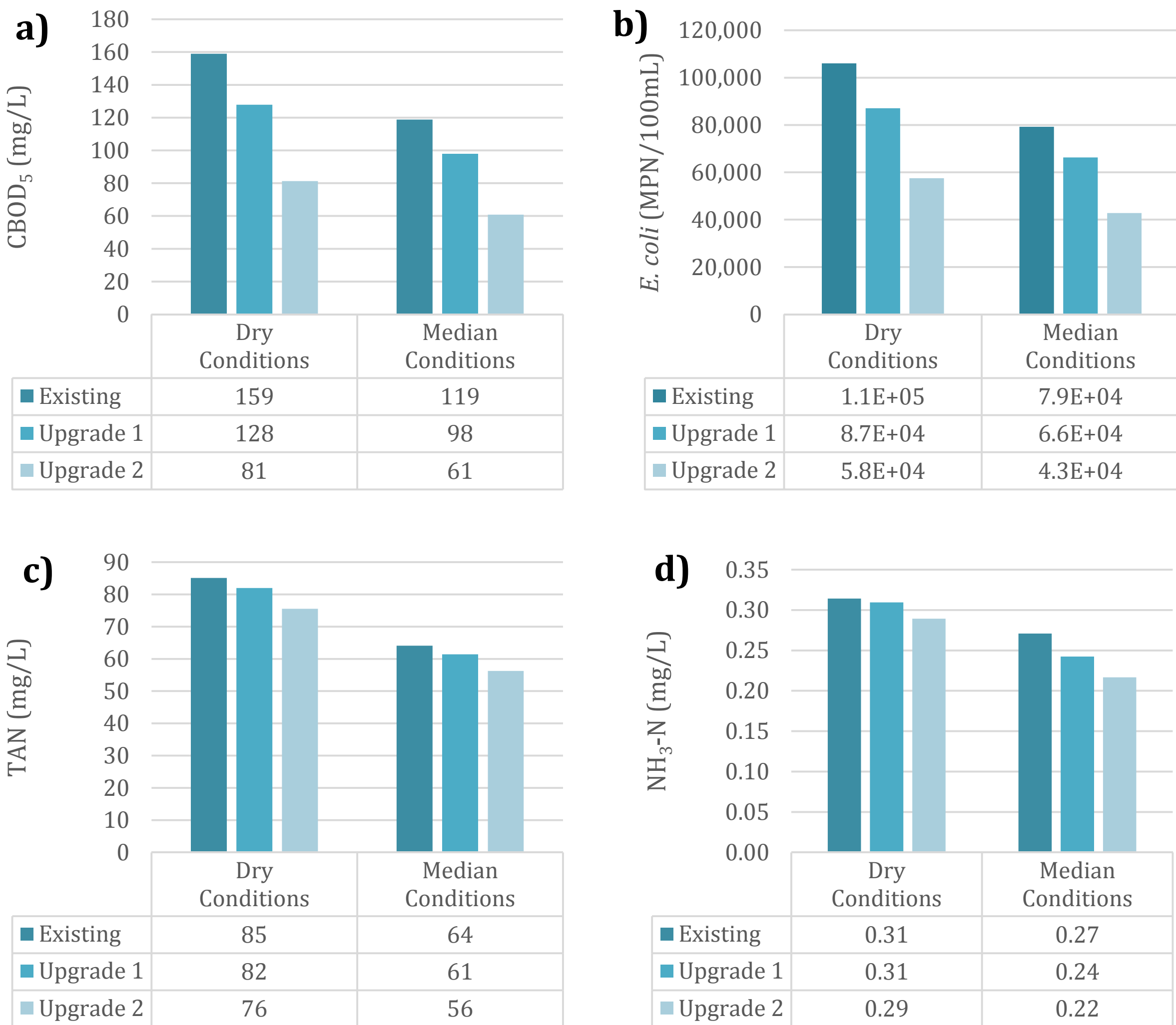

Figure 10. Effluent concentrations estimated for the 2-month discharge rate at 5°C and with medium strength influent in 2017 for (a) $CBOD_5$, (b) *E. coli*, (c) TAN, and (d) NH_3-N

4.0 Discussion

4.1 Existing Engineered WSP

The existing WSP upstream of the WTA was not in use at the time of this study and therefore the effluent quality that it would discharge is unknown. It is designed as a one-year detention pond and estimates of water quality can be deduced based on previous research that was conducted by Ragush et al (2015). Ragush et al (2015) observed that the approximate water quality expected from one-year detention can be summarized as per Table 15. The quality of the effluent discharge from the existing engineered WSP would be expected to fall within these approximate ranges. Slight differences in quality would be anticipated based on whether the engineered WSP would be operated as a shallow (i.e., < 2.5 m), or deep (i.e., > 2.5 m) system.

Table 15. Approximate ranges of effluent quality from WSPs in Nunavut (Ragush et al, 2015).

Parameter	Shallow (< 2.5 m)	Deep (> 2.5 m)
$CBOD_5$ (mg/L)	80 - 120	120 - 160
TSS (mg/L)	50 - 100	25 - 50
TAN (% removal)	10 – 25%	0
Un-ionized ammonia (mg/L N)	< 1.25	< 1.25

4.2 Existing WTA Performance

The existing WTA performance is summarized in Tables 9 and 10. Overall, the existing system downstream of the WSP was estimated to be capable of providing modest additional treatment of the effluent with reductions of approximately 21% for $CBOD_5$, 0.1 log for *E. coli*, 20% for TN and TAN, and 10% for NH_3-N for the 2-month discharge rate under medium strength influent and median climate conditions (Table 9). Treatment performance of the existing system diminished to 9% for $CBOD_5$, 0.04 log for *E. coli*, 9% for TN and TAN, and 3% for NH_3-N, when the 3-week discharge rate and median climate conditions were considered (Table 10). The reason for the small amount of additional treatment that could be provided by the existing P-Lake, wetland, and smaller lake is that the HRT is short (18.3 hours). In addition, the anticipated $CBOD_5$ loading rate would range from 51 to 724 kg/ha/d (Table 13); which is much greater than the recommended design maximum of 22 kg/ha/d (CWRS, 2016b). Therefore, this suggests that during all modeled scenarios, the existing system would be overloaded with BOD, which can result in anoxic pond conditions and sludge accumulation. The impacts of anoxic pond conditions is that CBOD removal is reduced and aerobic degradation processes are inhibited. Sludge accumulation can be problematic because of the potential for TSS generation and the reduced storage capacity of the pond.

4.3 Upgrade 1 System Performance

The estimated performance from the Upgrade 1 scenario is summarized in Tables 9 and 10. Generally, the Upgrade 1 scenario would be anticipated to provide moderate amounts of additional treatment compared to the existing system in terms of $CBOD_5$; however, almost no additional treatment would occur for *E. coli*, TN, TAN and NH_3-N. For example, at the medium influent strength and 2-month discharge rate with median climate conditions (Table 8), the estimated treatment ranges from 28 – 65% for $CBOD_5$, 0.1 – 0.2 log for E. coli, 21% for TN and TAN, and 17% for NH_3-N. When the 3-week discharge rate and median climate conditions were considered, the estimated treatment performance was reduced to 11 to 33% for $CBOD_5$, 0.05 to 0.09 log for E. coli, 9 – 10% for TN and TAN, and 7% for NH_3-N.

The Upgrade 1 system only provided a moderate level of improvement in treatment beyond the existing system. It was predicted that HRTs would be 8 and 22 days for the 3-week and 2-month discharge rates in 2017, respectively (Table 11). These HRTs would be representative of a two-cell continuous flow berm which provides an additional 1.8 m of storage functioning at 50% hydraulic efficiency. These HRTs of the upgrade 1 system are much longer than the HRT observed for the existing system of only 0.8 day. The BOD loading rates were slightly decreased in comparison to the existing system conditions ranging from 23 to 330 kg/ha/d (Table 13); which are still above the recommended design maximum of 22 kg/ha/d.

4.4 Upgrade 2 System Performance

The estimated performance of one additional potential upgrade (Upgrade 2) was also determined. Figure 10a shows that the Upgrade 2 provides 46 and 60% reduction for $CBOD_5$ at dry and median conditions, respectively (5°C, 2-month discharge rate, and medium strength influent). For comparison, the existing system at those same conditions only provides -6 to 21% reduction for $CBOD_5$ at dry and median conditions, respectively. The Upgrade 2 scenario was estimated to have reductions of 0.2 log for *E.coli*, 5% for TN and TAN, and 4% for NH_3-N for the dry conditions (5°C, 2-month discharge rate, and medium influent strength) (Figure 10). While, the same scenario was estimated to have reductions of 0.4 log for *E. coli*, 30% for TN and TAN, and 27% for NH_3-N when considering the median climate conditions. It should be noted that the HRT of the Upgrade 2 system configuration was modeled with a 90 day retention time (3 month) (Table 11). Therefore, significant engineering measures would be required to achieve this modest increase in treatment performance.

4.5 Dry Conditions Effect

In general, the water quality of the effluent resulting from median precipitation conditions was better than the dry conditions because there was increased dilution.

In all cases, the model runs using dry conditions produced lower water quality due to lack of dilution. The results from the median model conditions are likely more representative of the system. Therefore, the dry conditions are presented as the absolute worst cases in Appendix A.

The effects of dry conditions in comparison to the median precipitation scenarios are demonstrated in Figures 10a to 10d.

4.6 Total Suspended Solids

TSS removal was not modeled for this study because the removal of TSS is not well represented by first order reaction kinetics. The reason for this is because the settling of solids is related to the settling mechanics of the solid particles and not decay reactions such as microbial assimilation or other biological processes. However, based on research by Ragush et al (2015), it would be expected that the influent TSS concentrations entering the existing P-Lake WTA would be on the order of 25 to 100 mg/L, as long as phytoplankton presence is relatively low. Additional removal of TSS would be expected in P-Lake and the small lake due to settling of solids. The concentration of sewage derived TSS would be expected to be less than 25 mg/L at the end of the WTA.

4.7 Performance in 2037

The results of the existing system and upgrade 1 for the 2037 scenarios are presented in Appendix A. Generally, the effluent concentrations in 2037 are fairly similar to the effluent concentrations that were estimated for 2017. This suggests that the increase in flow rates on a 20-year horizon are expected to have limited additional impact on the capacity of the existing system and an upgrade 1 scenario. A contributing factor to the similarities in concentrations is that the HRTs were held the same for the 2037 existing conditions and only differ slightly for the Upgrade 1 scenario (Table 12).

4.8 Advantages of Existing System

It should be determined whether the anticipated ranges of concentrations from the existing system are acceptable for discharge into the receiving environment. One significant advantage of using the existing WSP and WTA (P-Lake, wetland and smaller lake) is that they provide passive treatment of the Hamlet’s wastewater. The operational requirements typically consist of operation of a pump and generator to perform a scheduled decant, which is relatively low in comparison to mechanical treatment options. Passive systems such as WSPs and WTAs are much less prone to failure due to limited reliance on operator input and difficult to access mechanical parts.

5.0 Conclusions

1. **The effluent quality that would be discharged from the WSP would fall approximately in the range of 80 - 160 mg/L for $CBOD_5$, 25 - 100 mg/L for TSS, and <1.25 mg/L for NH_3-N.**

    - This was based on results from extensive studies on other WSPs operating in Nunavut by Ragush et al (2015).

2. **The existing WTA is characterized by a shallow wetland system with wetland vegetation centralized around the lake perimeter.**

    - Changes to the lake water level with berm structures would inundate the existing wetland vegetation and the system would act as two additional WSPs (as a three-cell system en lieu of a shallow water wetland).

3. **The hydraulic loading rates and CBOD loading rates would be higher than the recommended levels for the existing WTA and Upgrade 1 configurations.**

    - The hydraulic loading rates ranged from 105 – 397 cm/d for the existing system, and from 5 – 72 cm/d for the Upgrade 1 conditions, which was greater than the recommended 2.5 cm/d for WTAs.
    - The CBOD loading rates ranged from 51 – 724 kg/ha/d, for the existing system, and from 23 – 330 kg/ha/d for the Upgrade 1 condition, which was above the recommended 22 kg/ha/d.

4. **Modest amounts of additional treatment would be anticipated from the existing WTA because of a short HRT (<1 day).**

    - The results from the tracer test conducted on site indicated that the HRT was very short on the order of less than a day, and there was short-circuiting observed; this suggested that there would be very little additional treatment provided from the existing WTA as-is.
    - The existing WTA system downstream of the engineered WSP in Cape Dorset was estimated to provide the following concentrations and levels of contaminant reductions for medium strength wastewater:
        - 119 mg/L (21%) for $CBOD_5$, 7.9×10^2 MPN/100mL (0.1 log) for *E. coli*, 64 mg/L (20%) for TN and TAN, and 0.27 mg/L (10%) for NH_3-N for the 2-month discharge rate at median climate conditions in 2017; and

- 137 mg/L (9%) for $CBOD_5$, 9.1 x 10^2 MPN/100mL (0.04 log) for *E. coli*, 73 mg/L (9%) for TN and TAN, and 0.29 (3%) for NH_3-N for the 3-week discharge rate at median climate conditions in 2017.

- The reduction in parameters modeled for the existing system can mostly be attributed to dilution effects from external hydrologic contributions.
    - This is apparent based on the dry climate model results which showed little to no treatment once dilution effects were removed.

5. **The continuous discharge berm upgrade is predicted to provide moderate amounts of additional treatment of $CBOD_5$:**

    - The Upgrade 1 scenario (1.8 m of additional storage of water) was estimated to provide the following levels of reductions of $CBOD_5$ in the effluent. The reductions that were observed in the medium strength wastewater ranged from:
        - 53 – 98 mg/L (35 – 65%) for $CBOD_5$ for the 2-month discharge rate, and 100 – 128 mg/L (15 – 33%) for the 3-week discharge rate at median climate conditions in 2017.

6. **A long-term retention berm would be anticipated to provide only a modest increase in treatment of $CBOD_5$ beyond the treatment estimated from a continuous discharge berm, and would likely involve more complicated engineering design and operation.**

    - The Upgrade 2 scenario (3.8m additional storage of water) for the 5°C and 2-month discharge scenario in 2017 consisted of estimated reductions of:
        - 61 mg/L (60%) for $CBOD_5$, 4.3x10^4 MPN/100mL (0.4 log) for *E. coli*, 56 mg/L (30%) for TN and TAN, and 0.2 mg/L (27%) for NH_3-N for the discharge rate at median climate conditions; and
        - 81 mg/L (46%) for $CBOD_5$, 5.8x10^4 MPN/100mL (0.2 log) for *E. coli*, 76 mg/L (5%) for TN and TAN, and 0.3 mg/L (3%) for NH_3-N for the dry conditions.

7. **In the future scenarios in 2037—even with the additional wastewater production—there was very little difference observed in treatment from 2017 conditions.**

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Appendix A: Summary Tables of the Modeling Results

Table A 1. Detailed summary of the effluent concentrations from the modeling analysis on the Cape Dorset WTA.

Temp & Strength[a]		Duration	Climate	Existing					Upgrade 1				
				$CBOD_5$	*E. coli*	TN	TAN	NH_3-N	$CBOD_5$	*E. coli*	TN	TAN	NH_3-N
5 °C	LOW	2-months[b]	Dry	64	1.1E+03	43	43	0.10	51	8.7E+02	41	41	0.10
		2 months[b]	Median	48	7.9E+02	32	32	0.10	40	6.6E+02	31	31	0.09
		3-weeks[b]	Dry	61	1.0E+03	41	41	0.10	53	9.0E+02	40	40	0.10
		3 weeks[b]	Median	55	9.1E+02	37	37	0.10	51	8.6E+02	36	36	0.10
		2-months[c]	Dry	63	1.0E+03	42	42	0.10	53	9.0E+02	41	41	0.10
		2 months[c]	Median	50	8.3E+02	34	34	0.10	43	7.3E+02	33	33	0.09
		3 weeks[c]	Dry	61	1.0E+03	41	41	0.10	58	9.6E+02	40	40	0.10
		3 weeks[c]	Median	56	9.3E+02	37	37	0.10	53	8.9E+02	37	37	0.10
15 °C		2 months[b]	Dry	63	1.1E+03	43	43	0.10	27	7.7E+02	40	40	0.10
		2 months[b]	Median	47	7.9E+02	32	32	0.10	22	6.0E+02	30	30	0.09
		3 weeks[b]	Dry	60	1.0E+03	41	41	0.10	44	9.1E+02	40	40	0.10
		3 weeks[b]	Median	54	9.1E+02	37	37	0.10	40	8.2E+02	36	36	0.10
		2 months[c]	Dry	62	1.0E+03	42	42	0.10	32	8.2E+02	40	40	0.10
		2 months[c]	Median	50	8.3E+02	34	34	0.10	27	6.7E+02	32	32	0.09
		3 weeks[c]	Dry	60	1.0E+03	41	41	0.10	47	9.3E+02	40	40	0.10
		3 weeks[c]	Median	55	9.3E+02	37	37	0.10	44	8.6E+02	37	37	0.10
5 °C	MEDIUM	2 months[b]	Dry	159	1.1E+05	85	85	0.31	128	8.7E+04	82	82	0.31
		2 months[b]	Median	119	7.9E+04	64	64	0.27	98	6.6E+04	61	61	0.24
		3 weeks[b]	Dry	153	1.0E+05	82	82	0.30	142	9.5E+04	81	81	0.30
		3 weeks[b]	Median	137	9.1E+04	73	73	0.29	128	8.6E+04	72	72	0.28
		2 months[c]	Dry	156	1.0E+05	84	84	0.31	133	9.0E+04	81	81	0.31
		2 months[c]	Median	125	8.3E+04	67	67	0.28	108	7.3E+04	65	65	0.25
		3 weeks[c]	Dry	152	1.0E+05	81	81	0.30	144	9.6E+04	81	81	0.30
		3 weeks[c]	Median	140	9.3E+04	75	75	0.29	133	8.9E+04	74	74	0.28

Table A 1. Cont'd - Detailed summary of the effluent concentrations from the modeling analysis on the Cape Dorset WTA.

Temp & Strength[a]		Duration	Climate	Existing					Upgrade 1				
				$CBOD_5$	*E. coli*	TN	TAN	NH_3-N	$CBOD_5$	*E. coli*	TN	TAN	NH_3-N
15 °C	MEDIUM	2 months[b]	Dry	157	1.1E+05	85	85	0.31	65	7.7E+04	80	80	0.30
		2 months[b]	Median	117	7.9E+04	64	64	0.27	53	5.9E+04	60	60	0.24
		3 weeks[b]	Dry	151	1.0E+05	82	82	0.30	109	9.1E+04	80	80	0.30
		3 weeks[b]	Median	135	9.1E+04	73	73	0.29	100	8.2E+04	72	72	0.27
		2 months[c]	Dry	155	1.0E+05	84	84	0.31	78	8.2E+04	80	80	0.30
		2 months[c]	Median	123	8.3E+04	67	67	0.28	66	6.7E+04	64	64	0.25
		3 weeks[c]	Dry	150	1.0E+05	81	81	0.30	118	9.3E+04	80	80	0.30
		3 weeks[c]	Median	138	9.3E+04	75	75	0.29	109	8.6E+04	74	74	0.28
5 °C	HIGH	2 months[b]	Dry	318	1.1E+08	149	149	1.05	255	8.7E+07	143	143	1.03
		2 months[b]	Median	237	7.9E+07	112	112	0.86	195	6.6E+07	107	107	0.78
		3 weeks[b]	Dry	305	1.0E+08	143	143	1.02	283	9.5E+07	141	141	1.01
		3 weeks[b]	Median	274	9.1E+07	128	128	0.94	255	8.6E+07	127	127	0.91
		2 months[c]	Dry	313	1.0E+08	147	147	1.03	265	9.0E+07	143	143	1.02
		2 months[c]	Median	250	8.3E+07	117	117	0.89	215	7.3E+07	114	114	0.82
		3 weeks[c]	Dry	304	1.0E+08	142	142	1.01	287	9.6E+07	141	141	1.01
		3 weeks[c]	Median	280	9.3E+07	131	131	0.96	265	8.9E+07	130	130	0.93
15 °C		2 months[b]	Dry	314	1.1E+08	149	149	1.05	129	7.7E+07	140	140	1.00
		2 months[b]	Median	234	7.9E+07	112	112	0.86	105	5.9E+07	105	105	0.76
		3 weeks[b]	Dry	301	1.0E+08	143	143	1.01	218	9.1E+07	140	140	1.00
		3 weeks[b]	Median	270	9.1E+07	128	128	0.94	199	8.2E+07	126	126	0.90
		2 months[c]	Dry	309	1.0E+08	147	147	1.03	156	8.2E+07	140	140	1.00
		2 months[c]	Median	246	8.3E+07	117	117	0.89	131	6.7E+07	112	112	0.81
		3 weeks[c]	Dry	300	1.0E+08	142	142	1.01	235	9.3E+07	140	140	1.00
		3 weeks[c]	Median	276	9.3E+07	131	131	0.96	218	8.6E+07	129	129	0.92

[a] Strength consists of low, medium and high strength influent wastewater as described in section 2.5.5.3, [b] 2017 discharge, [c] 2037 discharge.

Table A 2. Upgrade 2 model effluent concentrations and percent/log reductions from influent.

					Effluent Concentrations (% and log reductions)				
Year	**Temperature**	**Strength**	**Discharge Period**	**Climate**	$CBOD_5$	*E. coli*	TN	TAN	NH_3-N
2017	5 °C	Low	2 months	Dry	33 (45%)	578 (0.2 log)	38 (5%)	38 (5%)	0.10 (0%)
				Median	25 (58%)	431 (0.4 log)	28 (30%)	28 (30%)	0.08 (20%)
		Medium		Dry	81 (46%)	5.8E+04 (0.2log)	76 (5%)	76 (5%)	0.29 (3%)
				Median	61 (60%)	4.3E+04 (0.4 log)	56 (30%)	56 (30%)	0.22 (27%)
		High		Dry	162 (46%)	5.8E+07 (0.2 log)	132 (6%)	132 (6%)	0.95 (5%)
				Median	121 (60%)	4.3E+07 (0.4 log)	98 (30%)	98 (30%)	0.71 (30%)
2037	5 °C	Low	2 months	Dry	37 (38%)	6.3E+02 (0.2 log)	38 (5%)	38 (5%)	0.1 (0%)
				Median	29 (52%)	5.0E+02 (0.3 log)	30 (25%)	30 (25%)	0.1 (0%)
		Medium		Dry	90 (40%)	6.3E+04 (0.2 log)	76 (5%)	76 (5%)	0.3 (0%)
				Median	72 (52%)	5.0E+04 (0.3 log)	61 (24%)	61 (24%)	0.2 (33%)
		High		Dry	179 (40%)	6.3E+07 (0.2 log)	133 (5%)	133 (5%)	1.0 (0%)
				Median	142 (53%)	5.0E+07 (0.3 log)	106 (24%)	106 (24%)	0.8 (20%)