Guidelines for the Process Design of Wastewater Stabilization Ponds in Nunavut

Prepared for:
Community and Government Services (CGS)
Government of Nunavut
P.O. Box 1000 STN 700
4th Floor, W.G. Brown Building
Iqaluit, NU X0A 0H0

January 27, 2017

Prepared by:
Centre for Water Resources Studies
Dalhousie University
1360 Barrington St. D514
Halifax, NS
B3H 4R2

The *Guidelines for the process design of wastewater stabilization ponds in Nunavut* was prepared by Dr. Rob Jamieson Canada Research Chair in Cold Regions Ecological Engineering, Dr. Colin Ragush, and Jenny Hayward at the Centre for Water Resources Studies (CWRS) at Dalhousie University.

Further information in regards to this document may be obtained by contacting:

Centre for Water Resources Studies
Dalhousie University
1360 Barrington St., D514
Halifax, NS
B3H 4R2
902.494.6070
water@dal.ca

Acknowledgements

The authors would like to thank the many people who contributed to the CWRS research program that produced the data necessary to inform the development of this document. Especially the members of the Wastewater Treatment Advisory Committee (WTAC) who offered technical review. The WTAC committee was comprised of Dr. Barry Warner of the University of Waterloo, Dr. Donald Mavinic of the University of British Columbia, Dr. Graham Gagnon of Dalhousie University, Jamal Shirley of the Nunavut Research Institute, Dr. Bu Lam, and Bill Westwell of the CGS department of the GN.

The authors express gratitude to the many people who provided support in the hamlet communities in Nunavut of Kugaaruk, Grise Fiord, Clyde River, and Pond Inlet. Thank you to the Nunavut Research Institute for providing laboratory space at the Northern Water Quality Laboratory in Iqaluit, NU. The research program was made possible with the hard work of many of the graduate students from Dr. Jamieson's lab. Thank you to the students.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

%	Percent
°C	Degrees Celsius
BOD5	Biological Oxygen Demand
$CBOD_5$	Five-Day Carbonaceous Biochemical Oxygen Demand
CGS	Community and Government Services
cm	Centimetre
CWRS	Centre for Water Resources Studies
d	Day
DO	Dissolved Oxygen
et al.	*Et alii*
etc	*Et cetera*
GN	Government of Nunavut
ha	hectare
HRT	Hydraulic Retention Time
i.e.	*Id est*
kg	kilogram
L	Litre
LED	Light Emitting Diode
m	Metre
mm	Millimetre
m^2	Metres Squared
m^3	Cubic Metre
mg	milligram
NPS	National Performance Standards
NH_3-N	Un-ionized Ammonia Nitrogen

NU	Nunavut
OLR	Organic Loading Rate
PAR	Photosynthetic Active Radiation
s	Second
TAN	Total Ammonia Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
uE	Microeinsteins
WSER	Wastewater Systems Effluent Regulations
WSP	Wastewater Stabilization Pond
WTAC	Wastewater Treatment Advisory Committee

Executive Summary

This document provides *Guidelines for the process design of wastewater stabilization ponds in Nunavut*. The guidelines were prepared by the Centre for Water Resources Studies (CWRS) at Dalhousie University for the community and Government Services (CGS) Department of the Government of Nunavut (GN). The guidelines are a deliverable of the research contract on municipal wastewater infrastructure in Nunavut funded by the GN and granted to CWRS. This document provides engineers with proposed guidelines for the process design of wastewater stabilization ponds (WSPs), and are a product of the research results of the CWRS, and a review of the arctic WSP literature.

The document first reviews research conducted by CWRS on WSP performance in arctic climates. Field scale studies conducted by CWRS provided information on the performance of current single cell WSP systems in Nunavut, and highlighted limitations associated with current system designs. A series of bench scale experiments were then conducted in a climate controlled facility at Dalhousie University to better understand how environmental and operational factors affect WSP performance. This work also led to the development of a mathematical model of WSP biological processes. This research illustrated that current WSP systems are overloaded with respect to organic carbon. From the experimental work, and application of the process-based model, specifications for initial organic carbon concentrations, and areal organic loading rates were developed to facilitate increased levels of aerobic biological treatment at cool temperatures.

The field and experimental research was used to develop recommendations for the configuration and sizing of WSPs systems for truck-haul wastewater systems in Nunavut. A two stage WSP treatment system has been recommended, which includes a primary cell for winter storage and solids removal, and 2 parallel secondary cells that operate during the summer to treat effluent from the primary cell with biological processes. Due to anticipated algae growth in the secondary cells, a final filtration system would be required to remove algal biomass. Experiments conducted by CWRS have indicated that geotextiles could be used for this polishing step.

Preface

The Wastewater System Effluent Regulations (WSER) were introduced by Environment Canada, in 2012, to harmonize municipal wastewater treatment requirements across Canada. The WSER stipulates that all wastewater treatment facilities with an effluent production volume of 100 m^3/d or greater must produce an effluent that has the quality of having below 25 mg/L for carbonaceous five day biological oxygen demand ($CBOD_5$), 25 mg/L for total suspended solids (TSS), and 1.25 mg/L for un-ionized ammonia nitrogen (NH_3-N). In recognition of the unique challenges and differences of wastewater treatment in Canada's Northern provinces and territories, a grace period was extended to the Northwest Territories, Nunavut, and above the 54^{th} parallel in Quebec and Newfoundland and Labrador, to allow an opportunity for research on northern wastewater treatment. The resultant research is meant to inform the development and implementation of wastewater regulations in the Northern provinces and territories. The WSP design guidelines presented herein are a result of the insights gathered during the research grace period.

1.0 Introduction

1.1 Purpose

This document provides guidelines for process level design of wastewater stabilizations ponds (WSPs) in small arctic communities primarily serviced by trucked water and wastewater systems. These guidelines specifically focus on situations where effluent cannot be discharged for extended time periods (8-10 months) of the year due to ice cover, and therefore wastewater must be stored, and released, during the summer months.

1.1 Scope and Limitations

The Centre for Water Resources Studies (CWRS) has conducted both field and bench scale studies on WSP performance in arctic conditions in the past 6 years. This report will first provide an overview of these research findings, as they were basis of the design recommendations that are being put forth. Readers are directed to additional reports and technical journal articles for more information related to these research activities. Existing WSP guidelines for arctic environments are then reviewed and gaps identified. Finally, process-level guidelines for improving WSP treatment performance are proposed. The guidelines specifically focus on the configuration, volumes, retention times, organic loading rates (OLRs), and operating depths of WSP systems. Other design components, including siting, geotechnical design, inlet/outlet structures, were beyond the scope of this work, and have been covered in other existing design guidance documents (e.g. Heinke et al., 1991).

1.2 Wastewater Treatment in Nunavut

The majority of hamlets in Nunavut use WSPs as a component of their wastewater treatment system. WSPs consist of constructed depressions or barriers to create an area to detain (short term) or retain (long term) wastewater for treatment prior to discharge to the environment. In the Arctic, these systems may be lined with engineered materials, or the impervious nature of permafrost may be relied upon to maintain barrier integrity. WSPs depend on natural biological, physical, and chemical processes to reduce contaminants to an acceptable level before discharge to the environment. Although simple in physical design, the dynamics of the processes occurring in these systems are complex and treatment performance can be difficult to predict. The natural processes occurring in the WSP are influenced by prevailing climate and weather such as temperature, irradiance, and wind. Due to the impact of external, and uncontrollable, conditions the treatment performance of WSPs can be variable and inconsistent if the process design is not robust.

The process control of WSPs, once commissioned, is limited, but operators have potential control of factors such as water depth, hydraulic retention time, and organic loading rate.

In the Arctic, due to limited biological treatment in the winter, WSPs are operated as retention systems. WSPs are sized to retain 9-10 months of wastewater by volume. WSPs are decanted annually in the summer either to a marine receiving environment or a wetland treatment area. The majority of the systems operating in Nunavut are single cell systems.

2.0 Summary of Findings from Dalhousie University Studies

2.1 Field Study

The CWRS monitored the performance of existing WSP systems in Nunavut in the summers of 2011-2014 in 4 communities: Clyde River, Grise Fiord, Kugaaruk, and Pond Inlet (Figure 1). More detailed discussion of the study and its results can be found in a companion report (CWRS, 2015).

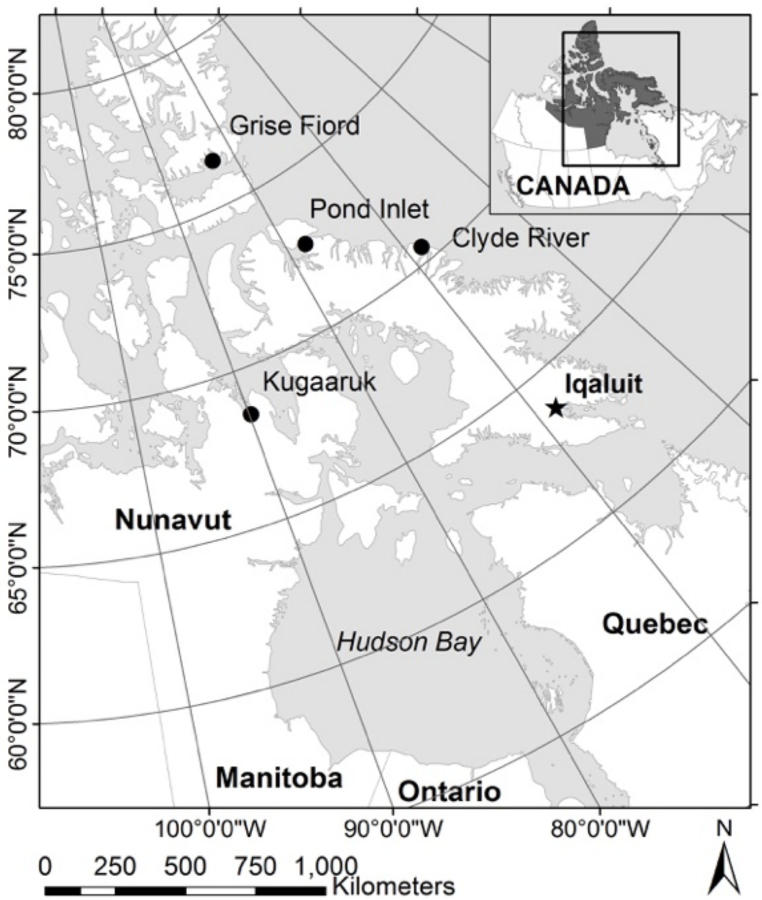

Figure 1. Map of the study sites.

Pond Inlet, Kugaaruk, and Grise Fiord have single-cell WSPs while Clyde River has a two-cell WSP. Key characteristics of each system, including areal organic loading rates in mass of biological oxygen demand (BOD) per day are shown in Table 1. The Clyde River WSP is operated in semi-parallel, with both cells receiving raw wastewater. Periodically, wastewater is transferred from the smaller cell 1 to the larger cell 2. All of the WSPs are operated as intermittent discharge WSPs with a controlled decant generally occurring at the end of the ice-free summer treatment season.

Due to continuous permafrost all of the communities utilize vacuum truck sewage collection. Northern communities operating on trucked sewage collection systems generally have water consumption rates that are much lower than piped systems, which results in a high strength raw wastewater.

Table 1. Summary of the study site systems.

Community	Population	Surface Area (ha)	Depth (m)	Organic Loading Rate (kg BOD/ha/d)
Pond Inlet	1612	4	1.9	15
Kugaaruk	878	1	5.4	28
Grise Fiord	157	0.4	1.5	25
Clyde River	1004	Cell 1: 0.6 Cell 2: 1.5	Cell 1: 1.1 Cell 2: 2.3	Cell 1: 57

Dissolved oxygen (DO) and pH was measured continuous throughout the ice free treatment season in Pond Inlet, Kugaaruk, and Clyde River. In Grise Fiord spot samples were taken as multiple site visits were not possible. In general, the Pond Inlet, Kugaaruk, and Clyde River WSPs operated anoxically with DO concentrations less than 0.5 mg/L and near-neutral pH. Little microalgae growth was observed in the systems. In contrast, the Grise Fiord WSP had significant microalgae growth. During a July 2011 site visit, DO concentrations exceeded saturation levels and pH was 10.8.

Depth, organic loading rate, and climate were all likely factors resulting in low dissolved oxygen. Studies conducted in temperate climates suggests maximum depths and organic loading rates of 2 m and 22 kg BOD/ha/d, respectively, to promote aerobic conditions in facultative WSPs. Therefore, the Kugaaruk WSP was likely too deep (5.4 m), and had too high of a loading rate (26 kg BOD/ha/d) to allow for aerobic conditions. The Pond Inlet WSP was within the recommended limits, however climate may have hindered biological productivity. Due to the semi-parallel operation of the Clyde River WSP, the cause of these anoxic conditions is unknown. These conditions may be due to a combination of climate and a high organic loading rate.

Treatment performance was assessed by sampling each WSP throughout the ice-free treatment season. Sampling was done from an inflatable boat or using a telescopic sampling pole. Each sample was analyzed for a full suite of chemical and biological parameters including five-day carbonaceous biological oxygen demand ($CBOD_5$), total suspended solids (TSS), total ammonia nitrogen (TAN), un-ionized ammonia nitrogen (NH_3-N), and total phosphorus (TP). From these results, an understanding of expected effluent quality generated by WSP systems operating in Nunavut was developed (Table 2).

Table 2. Expected effluent quality from WSP systems operating in Nunavut.

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
NH_3-N (mg/L)	< 1.25	< 1.25

The Kugaaruk WSP (deep, ~5.4 m) generated effluent with low levels of TSS (< 30 mg/L), but $CBOD_5$ concentrations were higher, as compared to effluent produced by the shallower systems in Pond Inlet, Grise Fiord, and Clyde River. Concentrations of $CBOD_5$ in the Kugaaruk WSP did not change during the summer treatment season, which indicated that minimal biological treatment was occurring. In contrast, $CBOD_5$ decreased in the Pond Inlet WSP and cell 2 of the Clyde River system, which provided evidence of biological treatment during the ice-free season in shallower systems. However, $CBOD_5$ levels in the shallow systems were still well above 25 mg/L. TSS levels were also generally higher in the shallower WSPs due to the algae growth. During the microalgae bloom in the Grise Fiord WSP, TSS concentrations exceeded 400 mg/L.

The Pond Inlet, Kugaaruk, and Clyde River WSPs had minimal nitrogen removal. However, due to a neutral pH, unionized ammonia concentrations remained below the WSER national performance standards (NPS) (1.25 mg N/L). In contrast, the Grise Fiord WSP had a much higher pH (10.8) due to carbon dioxide utilization by microalgae. This caused significant nitrogen removal due to ammonia volatilization. However, due to the high pH, most of the remaining nitrogen was present as un-ionized ammonia.

Some key observations included:

1. The deeper WSP in Kugaaruk provided consistent primary treatment, with effective solids removal, but very little biological treatment occurs during the ice-free season due to the depth and elevated organic loading rates.
2. Shallow WSP systems (<2.5 m) were able to provide some level of biological treatment during the ice free season, removing up to 80% of $CBOD_5$. However, concentrations of $CBOD_5$ were still generally greater than 100 mg/L at the end of the treatment system. These systems generally had very low concentrations of dissolved oxygen, which limited their treatment potential. This indicates that facultative WSP

design criteria currently applied in the North may need to be refined (i.e., WSP depths and organic loading rates may need to be decreased).

2.2 Bench Scale Studies

In this component of the research program experimental mesocosm WSPs were operated at different temperatures, irradiance, initial organic concentrations, and loading conditions to ascertain the impact of environmental and operational conditions. This study was designed to provide a controlled environment where the process dynamics and treatment performance of WSP systems could be examined in a systematic manner. Mesocosms with the environmental and operational characteristics of arctic WSPs were constructed and operated for 30-40 days. The creation of the mesocosms provided an environment where the relative impact of environmental conditions (irradiance and temperature) and operational parameters (initial organic concentration and organic loading) of WSPs in the Arctic could be quantified. A description of these experiments, and findings, can be found in Ragush et al. (2017a) and Ragush (2016), however a synopsis is provided here.

PVC columns, 15 cm in diameter and 1.25 m in length with 4 sampling valves, were capped at one end and erected and irradiated by an LED light bank (Figure 2). The sampling valves were located at the bottom, and every ¼ of the length upwards. The columns were wrapped in black plastic starting at 10 cm from the top of the column until the bottom to eliminate diffuse irradiance from entering the column. Synthetic wastewater with water quality characteristics comparable to Pond Inlet's WSP was used to fill the column, and to simulate the addition of wastewater on a daily basis. The columns were seeded with cultures of phytoplankton and bacteria species isolated from the Pond Inlet WSP. The experiment was performed as a 4^2 factorial design (4 factors each with 2 levels), and all conditions were tested in duplicate. The factors were temperature, irradiance, organic loading rate, and initial $CBOD_5$ concentration, and the tested levels can be found in Table 3.

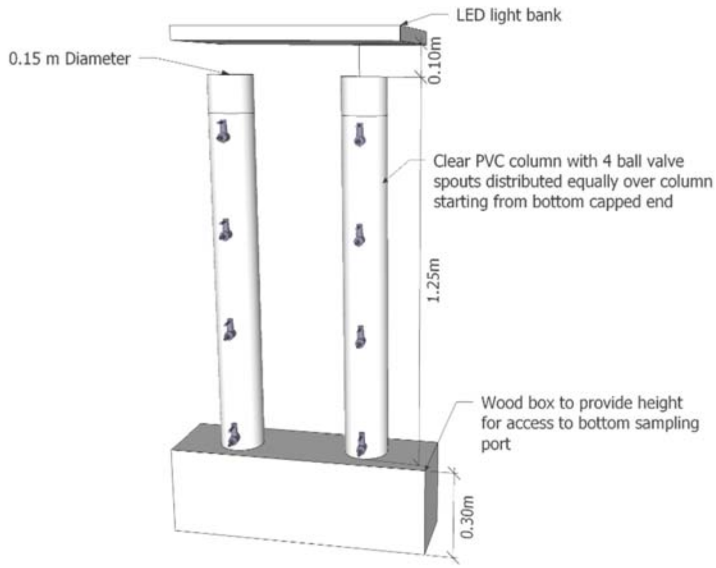

Figure 2. The mesocosm experimental apparatus.

Table 3. Factorial design – experimental factors and levels.

Factors	Levels	
Temperature	5 ˚C	15 ˚C
Irradiance	225 PAR (ue/m^2/s)	1050 PAR (ue/m^2/s)
Organic Loading Rate	3.8 kg $CBOD_5$/ha/d	15 kg $CBOD_5$/ha/d
Initial $CBOD_5$	80 mg/L	240 mg/L

Key findings from experiments included the following list.

1. Temperature, irradiance, initial carbon concentration, and organic loading rate were all significant factors impacting oxygen state and removal of $CBOD_5$.
2. $CBOD_5$ removal was positively correlated with temperature and irradiance and negatively correlated with organic loading rates and initial carbon concentration.
3. WSPs are highly sensitive to operational and environmental changes at the low temperatures characteristic of arctic WSPs.
4. Oxygen state was strongly influenced by the development of a large phytoplankton population, and as a result the presence of a large phytoplankton population greatly improved $CBOD_5$ removal.

Results of the bench scale study confirmed that elevated temperatures and incident irradiation were beneficial for increasing the $CBOD_5$ removal, and highlighted that cells that are shallow and have larger surface area are expected to perform better for $CBOD_5$ removal. The improved $CBOD_5$ removal is most attributable to the increased oxygen production by phytoplankton under higher temperature and irradiance conditions. Further information on these experiments can be found in Ragush et al. (2016a).

2.3 Process Model Development

A process-based computer model of arctic WSPs was developed to simulated dissolved oxygen and $CBOD_5$ concentrations observed in the mesocosm studies. The model is a detailed mathematical representation of critical processes controlling algae growth and biological degradation of organic material in Arctic WSPs. The calibrated model was then used as a tool for assessing appropriate organic loading criteria for arctic WSPs. In the process model, a system of equations were developed based on literature, experience, and system analysis. This model progresses in time by small incremental time steps and at every time step state variables such as phytoplankton concentrations, and contaminants are recalculated. The results of this work was used to assess our understanding of processes influencing dynamics of dissolved oxygen and $CBOD_5$ concentration in arctic WSPs and was also used to assess appropriate organic loading in the arctic environment.

In the model, the dynamics of: phytoplankton and bacteria communities; oxygen and carbon dioxide and the carbon pool (as measured by $CBOD_5$), are simulated in the photic zone. The photic zone defines the depth to where less than 1% of irradiance can be measured, and is the depth to which phytoplankton can be expected to actively partake in photosynthesis. Below the photic zone, in environments with large organic loads, anoxic conditions can be expected to exist. As demonstrated in Figure 3, the aforementioned dynamics are coupled. In this system inputs include influent wastewater and irradiance. In addition, temperature is a key controlling factor as it influenced the rates of biological growth and atmospheric gas exchange. A more detailed explanation of the model development and results can be found in Ragush et al. (2017b) and Ragush (2016).

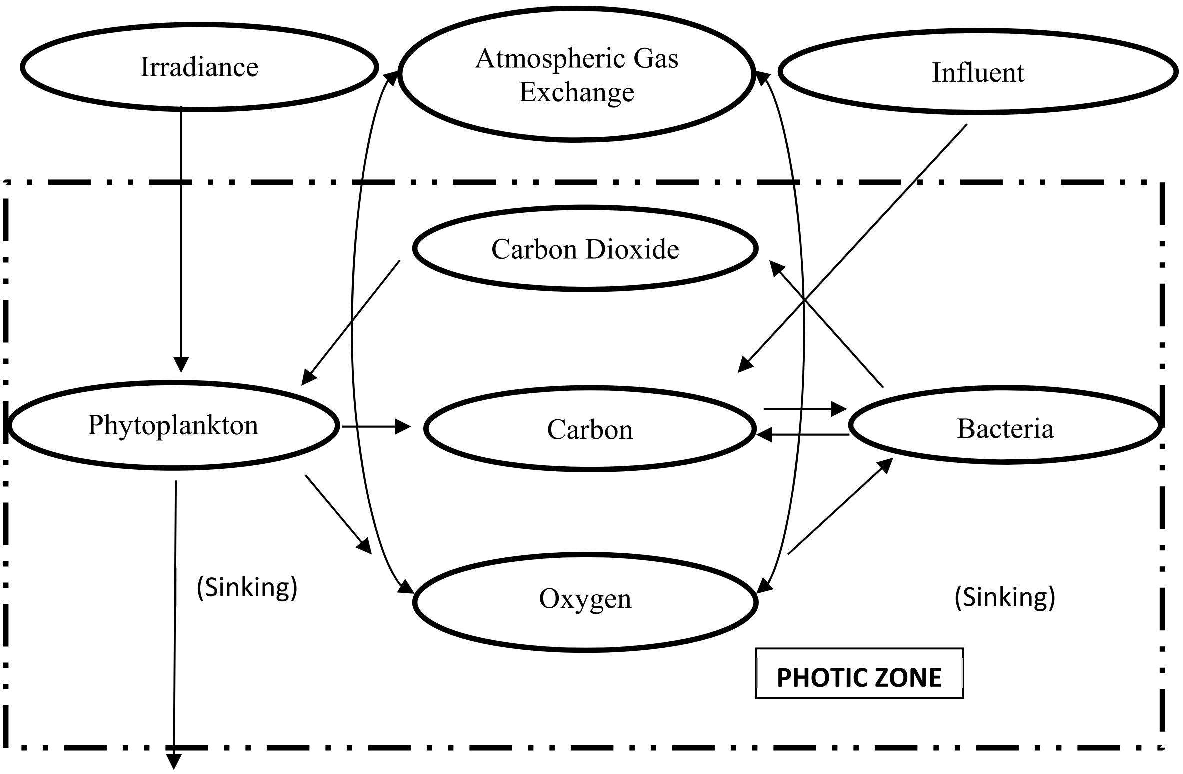

Figure 3. Flow diagram of the modeled processes.

Results from the modeling work included the key findings listed as follows.

1. The $CBOD_5$ treatment is dependent on the presence of oxygen, and in calm surface conditions is directly dependent on sufficient photosynthesis by phytoplankton.
2. Temperature is the strongest influencer of $CBOD_5$ treatment, followed by dissolved oxygen concentrations.
3. Models of highly eutrophic systems must be modeled differently than traditional ecosystems because of high light attenuation conditions.

A scenario where organic carbon loading and initial carbon concentration were reduced to 160 mg/L and 10 kg/ha/d respectively was simulated to further assess treatment capacity of an arctic WSP under lower loading conditions. In this simulation the low temperature (5 ˚C) and low light condition (225 ue/m^2/s) were assumed, as this was considered the worst case scenario. The simulation results suggest that at these reduced loading conditions, an arctic WSP can be expected to achieve a $CBOD_5$ concentration of 25 mg/L at the end of the treatment season. Figure 4 illustrates that $CBOD_5$ treatment rates increase as the simulation progresses, and this increase is attributed to the increased oxygen availability as a result of increasing phytoplankton population.

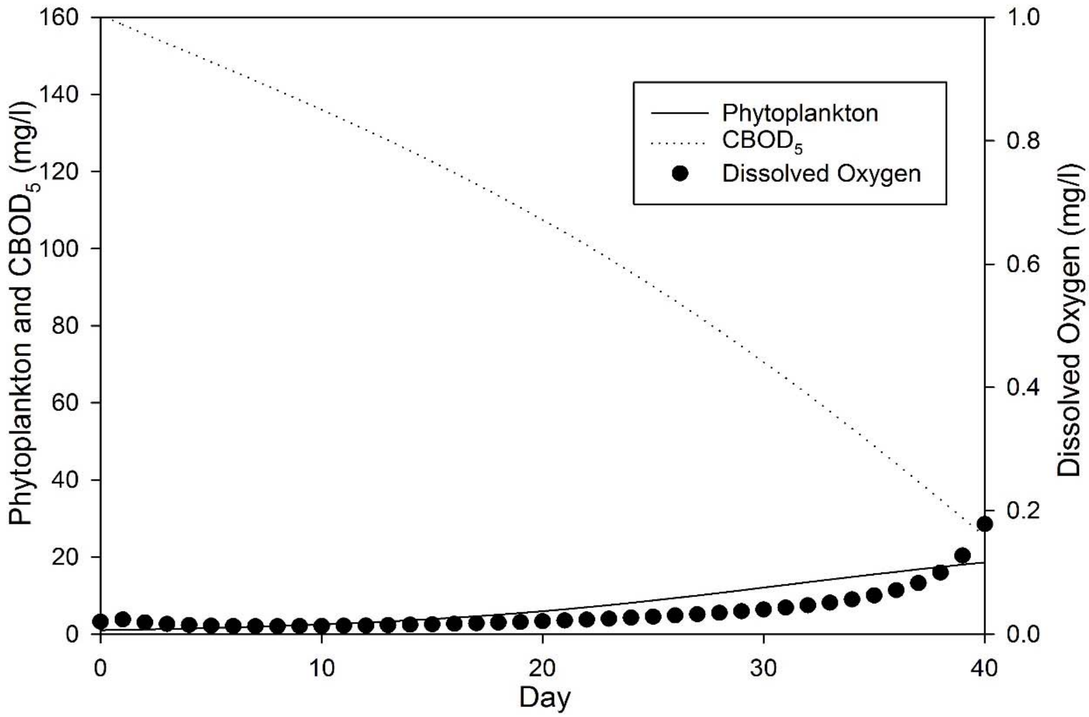

Figure 4. $CBOD_5$ concentrations and dissolved oxygen levels in a simulated WSP loaded with a $CBOD_5$ concentration of 160 mg/L and at an organic loading rate of 10 kg/ha/d.

2.4 Geotextile Filtration of WSP Effluent

It is well known that fixed film biological treatment systems are more efficient for wastewater treatment, due to the enhanced contact between microorganisms and wastewater constituents. One simple approach for incorporating this type of treatment mechanism into a northern WSP design would be place a geotextile filter within, or on the surface of, a permeable berm of the WSP. After the spring thaw, effluent in the WSP would exfiltrate through the geotextile and berm at a controlled rate. The effluent would be treated by physical and biological processes as it flowed through the geotextile, and there would be no need for mechanical pumping systems to decant the WSP. A series of test cells were constructed to mimic a granular berm lined with a geotextile. Two nonwoven, continuous filament geotextile, acquired from Terrafix® Geosynthetics Inc., were used (the 400R and 600R products). The 400R product has an apparent opening size of 0.21 mm and the 600R has an apparent opening size of 0.15 mm. The test cells were housed in a climate controlled cold room to simulate temperature conditions experienced in the arctic. Primary treated municipal wastewater was applied to the columns at controlled rates and effluent water quality and the hydraulic conductivity of the geotextile were measured at regular intervals.

Results from this experiment indicated that it is possible to form a biomat on the geotextile during the three month period at temperatures typically seen in arctic communities (2 – 10 ^{o}C). However, as expected, the biomat grew faster in warmer temperatures. The formation of a biomat provides the benefits of fixed-film biological treatment on the surface of the geotextile and filtration of the exfiltrating wastewater. Significant differences in water quality improvements for TSS and BOD_5 were observed with the use of the geotextiles compared to the control columns (no geotextiles). The geotextile, and associated biofilm, resulted in significant reductions in the concentrations of key regulatory wastewater parameters, such as BOD_5 and TSS. Passage of primary treated wastewater through the geotextile produced an effluent that generally met secondary wastewater treatment standards for TSS (< 25 mg/L). This study shows promising results for improving WSP design by incorporating alternative passive treatment technologies such as installation of geotextiles on WSP berms. Further information on these experiments can be found in Bridson-Patemen et al. (2016).

2.5 Conclusions

Results from both the field and bench scale studies indicate that current WSP systems are not likely to operate as facultative systems on a consistent basis. This has a significant impact on treatment performance as phytoplankton growth is required to produce oxygen for aerobic biological processes. At current organic carbon loading conditions WSP systems operating in arctic climates generally produce effluent with $CBOD_5$ concentrations greater than 100 mg/L. Experimental work, in combination with results from model simulations, indicate that reducing organic carbon loading conditions (both areal loading rates and initial concentrations) would have a positive impact on treatment performance, and that WSP systems could achieve $CBOD_5$ effluent concentrations approaching 25 mg/L under reduced loading conditions.

3.0 WSP Process Design Recommendations

3.1 Existing Design Guidelines

Heinke et al. (1991) proposed a suite of design guidelines for wastewater lagoons operating in cold climates, which continue to form the basis for the design of new WSPs in Nunavut. The guidelines cover all aspects of WSP design including siting, estimating flow rates, berm construction, inlet/outlet structures, etc. They also provide process design guidelines for short detention WSPs, long detention WSPs, and storage WSPs. They specifically identify WSPs treating wastewater from a community on a truck-haul system as a "Special" WSP that will require storage of wastewater during the winter months (6-9 months). For storage WSPs, which would be required for Nunavut communities using truck-haul systems, they recommend a 365 storage period, with a summer treatment detention time of 60 days, and a liquid depth of 1.5 – 2.0 m. There is no specification of organic loading rates and expected treatment performance associated with these types of WSPs.

3.2 Process Design Recommendations

In this section, proposed process design guidelines for WSP systems operating in a Nunavut community using a truck haul collection systems are provided. The proposed configuration would involve two WSPs cells: (i) a primary treatment cell designed to store 10 months of wastewater generation during the winter months, and (ii) two secondary treatment cells designed to provide biological treatment of primary treated wastewater during the summer months (Figure 5). Wastewater would be deposited from the trucks into the primary cells on a year round basis. During the summer months, once the cells have thawed, effluent from the primary cell would be transferred to the secondary cells at a controlled rate for the duration of the summer treatment season. Effluent from the secondary cells would discharge passively into a polishing filter to remove algal biomass before eventual discharge to the receiving environment. The process design specifications for the two cells are provided in Table 4.

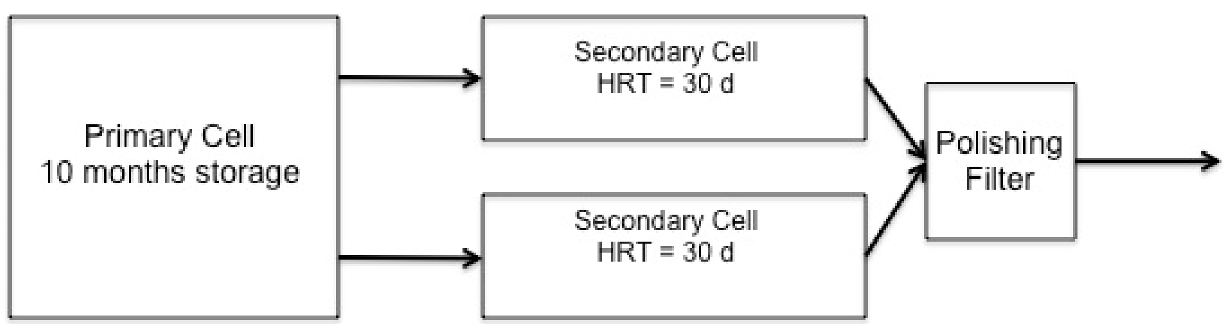

Figure 5. Proposed WSP system configuration.

Table 4. Process design specifications for the WSP cells

Parameter	Primary Cell	Secondary Cell
Storage Volume or Hydraulic Retention Time (HRT)	10 month storage period (or ice-covered period)	30 d HRT
Depth	4-6 m	< 1.25 m
Organic Loading Rate	-	< 10 kg/ha/d

The primary cell must accommodate the wastewater generated during the period of ice cover. The primary cell will provide primary treatment while the wastewater is retained, and should be at least 4 m to promote sedimentation and retention of solids. The expected effluent quality from the primary pond is provided in Table 5, based largely on results from the field study conducted in Kugaaruk.

During the summer treatment season effluent from the primary cell would be transferred to the two secondary cells, which would be operated in parallel. It is recommended that the transfer of effluent from the primary to the secondary cell be accomplished using pumps to ensure a controlled flow rate, and the fact that other passive liquid transfer systems have been prone to failure in the Arctic. The secondary cells should not be deeper than 1.25 m, and ideally will be 1 m or less. This will allow for more radiative heating, increasing water column temperatures and promoting more biological growth. The recommended HRT for the secondary cells is 30 d, based on experimental and mathematical modeling work presented in Sections 2.2 and 2.3. The organic loading rates for the secondary cells should be < 10 kg/ha/d to facilitate the development of phytoplankton populations and facultative conditions. The expected effluent quality from the secondary cells are presented in Table 5. Due to algae growth, TSS levels in the effluent may be elevated (>100 mg/L), requiring the use of a polishing filter after the secondary cell. The two secondary cells would operate as continuously flowing systems during the summer season, and should be designed with a length:width ratio of 3:1 or greater to promote hydraulic efficiency (i.e. decrease short-circuiting). Options for polishing the effluent from the secondary cells include rock filters or geotextile filters, as discussed in Section 2.4.

Table 5. Expected treatment performance for Proposed WSP configuration.

Treatment System Component	$CBOD_5$ (mg/L)	TSS (mg/L)
Primary Cell	< 175 mg/L	< 75 mg/L
Secondary Cell	< 40 mg/L	> 100 mg/L
Geotextile Filter	< 30 mg/L	< 30 mg/L

4.0 Conclusions

This report provides proposed process design guidelines for WSP systems treating municipal wastewater from truck-haul systems in the Territory of Nunavut. The proposed design guidelines were developed based on field and laboratory scale research conducted by CWRS over a six year period. Experimental and modeling work indicates that biological treatment processes in WSPs operating in arctic climates can be enhanced if organic loading conditions (initial carbon concentrations and areal organic loading rates) are lowered, and cell depths are less than 1.25 m. A proposed WSP configuration, involving a deep (> 4 m) primary storage cell, and two, parallel secondary treatment cells (< 1.25 m depth, 30 day HRT) was presented. In conjunction with the use of a geotextile filter for removal of algal solids from secondary cell effluent, the proposed system is expected to achieve secondary wastewater treatment standards.

References

Bridson-Pateman, E., Jamieson, R., & Lake, C. (2016). Biofilm-enhanced wastewater treatment in arctic climates with geosynthetic clay liners. *Geotextiles and Geomembranes.* 44:824-831.

CWRS (Centre for Water Resources Studies) (2015). *Treatment Performance of Municipal Waste Stablization Ponds in Nunavut.* Final Report prepared for the Community and Government Services Department, Government of Nunavut. 41pp.

Heinke, G., Smith, D., & Finch, G. (1991). Guidelines for the planning and design of wastewater lagoon systems in cold climates. *Canadian Journal of Civil Engineering.* 18:556-567.

Ragush, C., Schmidt, J., Krkosek, W., Truelstrup-Hansen, L., Gagnon, G. & Jamieson, R. (2015). Performance of municipal waste stabilization ponds in the Canadian Arctic. *Ecological Engineering.* 83:413-421.

Ragush, C., Poltarowicz, J., Lywood, J., Truelstrup-Hansen, L., Gagnon, G., & Jamieson, R. (2017a). Understanding the influence of light, temperature and organic loading rates on oxygen dynamics and carbon removal in waste stabilization ponds operating in arctic environments. *Ecological Engineering.* 98:91-97.

Ragush, C., Gentleman, W., Truelstrup-Hansen, L., & Jamieson, R. (2017b). Representing phytoplankton growth in eutrophic systems – Insights from modelling oxygen dynamics and carbon removal in arctic waste stabilization ponds. *Ecological Modeling.* In Review.

Ragush, C. 2016. Oxygen Dynamics and Carbon Removal in Municipal Waste Stabilization Ponds in Arctic Regions. PhD Thesis. Dalhousie University.