



Centre for Alternative Wastewater Treatment



Tundra Wetlands: the treatment of municipal wastewaters

RBC Blue Water Project - companion report

Chouinard, Balch, Jørgensen, Yates & Wootton

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Tundra Wetlands: the treatment of municipal wastewaters

**- a companion report to the RBC Blue Water Project - Tundra Wetlands:
performance and operational tools (manual)**

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Tundra Wetlands: the treatment of municipal wastewaters

Performance Review & Operational Tools

-Companion Report

Intent of this summary report

The following document focuses on the use of natural wetlands in the treatment of domestic sewage and / or effluent in Canada's far north. The intent of this paper is to provide a summary of current knowledge regarding the efficacy of these lands in the treatment of municipal wastewater and an overview of existing data gaps and science needs that still persist. Funding provided by the federal government of Canada through the International Polar Year programme and Environment Canada was awarded to the Centre for Alternative Wastewater Treatment (CAWT) to conduct site investigation at 13 tundra treatment wetland sites located in Nunavut and the Northwest Territories. This companion document along with the full report (e.g., Tundra Wetlands: the treatment of municipal wastewater – performance and operational tools, 374 pages) summarizes the findings of the site investigations and from that data has generated a guidance document concerning operational tools and management considerations for tundra treatment wetlands. The generation of this companion document along with the full report was funded by the Royal Bank of Canada (RBC) Blue Water Project in partnership with the Institute for Watershed Science (IWS), Trent University. The RBC Blue Water Project funding was awarded to the IWS who in turn subcontracted the CAWT to produce the performance and operational tools document to serve as a wastewater guidance document for indigenous communities of Canada's far north.

In many northern communities, the retention of the wastewaters in lagoons alone is not sufficient to produce municipal effluents that meet the Canadian Council of Ministers of the Environment (CCME) proposed National Performance Standards (NPS) for carbonaceous biochemical oxygen demand (cBOD), total suspended solids (TSS) or un-ionized ammonia ($\text{NH}_3\cdot\text{HOH-N}$). Natural wetlands that have either naturally existed or serendipitously developed downstream of sewage lagoons are viewed by some as key contributors to the overall treatment of municipal wastewaters. However, until recently, the data to support this claim has been generally lacking or at best very sparse. The lack of solid scientific evidence has hampered the ability of regulatory agencies and governments in their ability to come to firm conclusions regarding the efficacy of natural wetlands and the role they may play in the treatment of municipal wastewaters in Canada's far north.

Because of this need, the Centre for Alternative Wastewater Treatment (CAWT) developed and established a research program in Canada's far north to examine the contribution that natural wetlands afforded in the treatment of municipal wastewaters and the level of treatment plausible when using a lagoon / wetland hybrid treatment process. A high level summary of the key findings from this study are presented below. Funding for the wetland studies was awarded to the CAWT by the federal government of Canada in their support of the International Polar Year program and more recently by Environment Canada in their support of the Canadian Council of Ministers of the Environment (CCME) implementation of a Canada-wide strategy for the management of municipal wastewater effluents.

The intent of this companion report is to provide a brief overview of the finding and to direct those wishing to learn more about this work to the larger concluding reports that are available on the websites for the CAWT and the Institute for Watershed Science (IWS) for viewing and/or download. Funding for the compilation of the wetland research findings into summary documents was provided from the RBC Blue Water Project awarded to the IWS, Trent University and its project partner: the Centre for Alternative Wastewater Treatment (CAWT), an applied research facility located at Fleming College. The focus of the RBC award was to develop teaching materials and tools dedicated to the protection of drinking water within indigenous communities of Canada's north. The CAWT's contribution to this work was focussed on the treatment of domestic sewage in the belief that the proper treatment is an important component in the overall protection of source waters used for drinking purposes.

This companion document provides an overview of the key findings generated from the CAWT studies and a commentary on data gaps, science needs and regulatory consideration surrounding the use and management of natural wetlands dedicated to the treatment of municipal wastewaters.

CCME National Performance Standards: framing the need

Performance standards for wastewater effluents are currently in transition within Canada as the federal government is developing national performance standards (NPS) for municipal wastewater effluent. In 2009, the Canadian Council of Ministers of the Environment (CCME) released the final draft of the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* which details regulatory changes to be implemented through the Canadian *Fisheries Act*. The intent of the strategy is to ensure there are no deleterious effects to the water bodies receiving the treated effluent, particularly with regard to fish health and or fish habitat. This strategy has identified specific national performance standards for effluent of Canadian wastewater treatment facilities at 25 mg L⁻¹ for the parameters of carbonaceous biochemical oxygen demand (cBOD) and total suspended solids (TSS), 1.25 mg L⁻¹ for un-ionized ammonia expressed as NH₃·HOH-N @ 15°C±1°C and a standard of 0.02 mg L⁻¹ of total residual chlorine (TRC) (Canadian Council of Ministers of the Environment, 2009).

The Federal Government recognizes that conditions in portions of Canada's Far North (Nunavut, Northwest Territories, and regions located north of the 54th parallel in Quebec and Newfoundland and Labrador) are unique and as such national performance standards have not yet been determined for these areas. This recognition is based on the fact that most of the small isolated communities within Nunavut and the Northwest Territories (particularly those areas with permafrost) have domestic sewage hauled by truck and deposited to either lagoons for treatment, or in some cases, directly discharged to a natural depression (wetland) of the surrounding landscape. The logistical challenges of bedrock and / or permafrost together with the lack of financial and human resources and within the cold arctic climate represent significant impediments to the development of mechanized wastewater treatment infrastructures commonly used in more southern locations within Canada. As such wastewater disposal to lagoons, engineered lagoons, facultative lakes and/or direct discharge to land have been seen as the most feasible historical options

available. The release of primary treated municipal effluent to the land occurs through the intentional decanting of effluent from a lagoon or via exfiltration (intentional or unavoidable leakage) of the effluent through the wall of the lagoon berm on to the land. In a few locations municipal wastewater is directly discharged to natural depressions or surface water bodies termed facultative lakes without prior treatment. Anecdotal information suggests that the release of municipal wastewaters or primary treated wastewater effluents into natural depressions appears to have either enhanced vegetative growth or, in some cases may have even facilitated vegetative growth in areas that were naturally devoid of vegetation. For the purpose of this study, natural wetlands refer to vegetative lowland areas that regularly receive discharges of untreated or primarily treated municipal wastewater.

The wastewater treatment services afforded by these natural wetlands has until recently been sparsely assessed. The lack of rigorous scientific data coupled by logistical challenges in assessments and the management of flows has hindered the debate on whether wetlands provide any significant treatment benefit and the overall discussion and development of performance standards suitable for the north.

Wetland treatment: how does it work?

The processes (biochemical, chemical, physical) operative in the treatment of municipal sewage / effluents are common to all wetlands. Research illuminating the underlying mechanisms of action has expanded greatly in recent years with the vast majority of peer reviewed work being published in the past one to two decades. The published literature contains many references to the efficient and effective use of constructed wetlands for the treatment of municipal effluents. Most of what is currently known however refers to constructed wetlands or engineered wetlands. Although terminology has not yet become standardized, the term constructed wetland is often associated with manmade structures which have been designed to control many of the treatment processes within well-defined spatial dimensions, process parameters and operational conditions. Engineered wetlands are much the same, but generally refer to wetlands specifically designed to optimize specific treatment processes necessary for the effective treatment of a specific waste stream such as the removal of particular trace elements or organic constituents. Natural treatment wetlands have by contrast developed more through natural or spontaneous processes and as such many of the characteristics regarding the biochemical, chemical, physical processes and spatial conditions are often unrecorded and or unregulated. Because of this, each natural

wetland is unique and many of the characteristics of the treatment process remain undocumented.

In brief, the treatment of municipal sewage or effluents has, in general terms, the purpose of: i) oxidizing organic and chemical constituents to harmless products, ii) the removal of viable pathogens, and iii) removal of suspended solids. More advanced treatment options often involve the selected removal or degradation of specific constituents deemed deleterious to human health or the general environment. The biochemical oxygen demand (BOD) is a primary water quality parameter and it, along with the concentration of total suspended solids (TSS), and un-ionized ammonia ($\text{NH}_3 \cdot \text{HOH-N}$) have been identified in the Canada-Wide Strategy as three key parameters for which NPS are being set. In addition, the Canada-Wide Strategy is also setting a NPS for free chlorine, however, chlorine is rarely used as a primary wastewater treatment in the north and therefore will not be discussed.

BOD refers to the amount of oxygen that is consumed during the microbial degradation of organic matter within the sewage or effluent. The underlying concern is related to the potential for significant oxygen depletion to occur in receiving waters when sewage or effluent is poorly treated before its release into the environment and thus has the potential to significantly reduce oxygen levels in the receiving environment as microbial degradation continues. If the oxygen depletion in the receiving environment is significant and occurs for an extended period of time, then there is the potential to negatively affect the biota of that region. The ability of the wetland to mediate this process before effluents are released to the environment can be influenced by several factors. Microbial action is known to be influenced by temperature, and the lack of scientific investigation into the performance of wetlands under cold arctic conditions has raised questions regarding the efficacy of natural wetlands. In addition, BOD is also influenced by the contact time between the microorganisms and the effluent's organic constituents. If the contact time is too short or too long, this treatment process can be impeded. To date, little is known about the rate that effluent flows through the tundra wetlands; often referred to as the hydraulic retention time (HRT). HRT can change drastically amongst wetlands and within wetlands through natural influences and operational practices, thus making it necessary to assess wetland treatment performance on a site by site basis.

It is generally known that municipal sewage and effluent have the potential to contain pathogens in significant quantity and virulence to cause harm to humans if released to the

environment through the contamination of drinking water or country foods or to biota directly or through a reduction of habitat quality. Several indicator organisms exist that provide an indication that human pathogens potentially exist within municipal effluents with *E. coli* generally being the organism most often used for surveillance purposes along with the surveillance of fecal coliforms as an indicator of fecal contamination. In conventional municipal wastewater treatment plants, strong oxidants such as chlorine (or its various forms) are used as a disinfection technique designed to significantly reduce the number of harmful organisms. The Canadian Council of Ministers of the Environment in their *Canada-Wide Strategy* has stipulated a NPS for total residual chlorine within treated effluents. However, chlorine is not routinely used as a disinfection agent in municipal effluents exiting sewage lagoons or natural wetlands and thus this water quality parameter will likely not be routinely measured in municipal effluents reliant on lagoons and or wetlands as their primary treatment option. Wetlands can often achieve disinfection levels similar to what is achieved through chlorination or other chemical means. The mechanisms of action are, however, more through the entrapment of harmful organisms on biofilms within the wetland or through the filtration of suspended particles which the pathogens have attached to. Once trapped, these organisms are often eliminated through a variety of mechanisms such as bacteriophages or consumption by nematodes. Once again, many of the pathogen elimination processes operative in the treatment wetlands can be influenced by temperature, HRT and other biological/chemical/physical processes which can be both unique to the site and easily influenced by natural and human events.

Wetlands can be effective in the removal of suspended solids contained within municipal effluents. The removal process is usually one of entrapment within the matrices of the wetlands substrate or attachment to biofilms and the force of gravitational pull causing solids to fall out of solution. Some of the prime factors affecting a wetlands effectiveness in reducing the concentration of total suspended solids (TSS) are water velocity, HRT, and the size and volume of the interstitial spaces through which the effluent flows. The release of high concentrations of suspended solids to the receiving environment can have deleterious effects on natural habitats or biota if not removed during treatment through the burial of vital habitat components or through the co-transport of other harmful contaminants or pathogens. The potential for wetlands to reduce TSS provides a surrogate measure for the removal of other potentially more harmful contaminants attached to suspended solids such as trace elements, pathogens, nutrients like phosphorus and other chemicals. Thus removal of the suspended solids often correlates to a reduction in the concentration of these contaminants within the treated effluent.

Nitrogen constituents are often monitored during the treatment process since some nitrogenous forms like un-ionized ammonia ($\text{NH}_3 \cdot \text{HOH-N}$) can be quite toxic to certain aquatic biota, while other nitrogen forms can also consume oxygen during the formation of oxidized nitrogenous species. As with the other water quality parameters, treatment efficiencies are often influenced by many factors intrinsic to the individual wetland.

Questions concerning the efficacy of natural wetlands as a treatment option

Despite the wealth of knowledge demonstrating that constructed wetlands can effectively treat municipal wastewaters there still is relatively little data specific to the use of natural wetlands within a cold climate regime. The primary distinction being made here is between the use of “constructed” wetlands in a temperate or warm climate and “natural” wetlands within a cold climate area.

Constructed wetlands are manmade structures designed with specific shapes, media and hydrology. Natural wetlands used for the treatment of domestic effluents are much different. The boundaries of the natural wetlands are defined by the landscape and not an engineer and as such less is typically known about the physical and hydrological aspects of the wetland.

Much of what we know about constructed wetlands has been generated from controlled studies performed under climatic conditions warmer than those typically found within Nunavut and the Northwest Territories of Canada. Because of these dissimilarities many questions have arisen regarding the efficacy of using natural wetlands within Canada’s cold north. Some of the major questions include:

- What impact does the cold climate have on the microbial community and how does this impact treatment performance?
- Can the wetlands provide adequate treatment during the spring freshet at a time when the loading rates may be high due to a backlog of winter effluent that requires treatment?

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- Do the wetlands provide any additional treatment which is above and beyond that achieved by the lagoon systems?
 - What percentage of treatment is resulting from phy/chem/biol processes inherent within the wetlands and what percentage results from dilution alone?
 - Are the existing wetland systems oversized or undersized and can they accommodate future growth?
 - Are there predictive tools (e.g., mathematical models) that can be used to assess the present or future treatment capacity of the wetland or treatment response under different operational scenarios?

Overview of the CAWT research efforts

Funding for this work was provided during three different funding envelopes. In 2007 and the CAWT was awarded funds through the **International Polar Year** program to investigate a total of six treatment wetlands located in the Kivalliq region of Nunavut along with the construction of a small scale horizontal subsurface flow constructed wetland (total surface area = 15 m²) developed near the sewage lagoon at Baker Lake. This constructed wetland was the first of its kind in Nunavut. IPY field studies were conducted during the frost free seasons of 2008, 2009 and 2010. During this period a total of six treatment wetlands were studied near the communities of Arviat, Baker Lake, Chesterfield Inlet, Coral Harbour, Repulse Bay and Whale Cove. Wastewater parameters were measured entering and exiting the wetland on a weekly basis in order to provide an indication of effluent treatment over a temporal scale during the frost free season. Each wetland was also intensely studied at several locations along the flow path over a two day period to provide a onetime “snap-shot” illustrating the spatial aspect of treatment as the effluent flowed through the wetland. The study investigated a wide range of physical (TSS, VSS, temp, etc.), chemical (cBOD₅, COD, total ammonia nitrogen expressed as NH₃-N, TNK, nitrite/nitrite, phosphorus, etc.) and biological parameters (e.g., *E. coli*, total coliform), in addition to the recording of effluent flow / volume, slope, soil types, wetland size, vegetation and other relevant aspects of the wetland. During this time, a subsurface horizontal wetland model, named SubWet was modified for use with natural northern tundra wetlands.

In 2009 to 2011 this work was expanded with funds provided by **Environment Canada** which supported investigations of treatment wetlands in Nunavut and Northwest Territories near the communities of Paulatuk and Pond Inlet (2009), Gjoa Haven, Fort Providence and Ulukhaktok (2010) along with Edzo and Taloyoak (2011). Each of the

wetlands was assessed using the same wastewater parameters as those used in the IPY study. Wetlands were sampled in an intensive manner that provided a onetime snap shot of treatment throughout the wetland. This information was then used in an interpolated manner to generate detailed maps that provided a visual overview of the treatment efficiencies throughout the wetland.

A high level summary of these results has been presented below. The intent is to illustrate the type of data that has been generated through these studies.

In 2010, funding provided by the **RBC Blue Water Project** was used to conduct a needs assessment and to consult with northern stakeholders to determine what tools would provide the greatest benefit to maximizing the potential use of natural tundra wetlands for the treatment of domestic wastewaters. This funding was also used to collect background information on tundra treatment wetlands and to summarize it into a format for delivery to northern stakeholders. In 2011, much of the effort was spent on developing a user's manual for the SubWet 2.0 modelling program that was recently modified by the CAWT in partnership with Dr. Sven Jørgensen (originator of SubWet) for use with natural tundra wetlands. Meetings were also held with northern stakeholders to provide then an update on progress. The final guidance document was completed with funding provided in 2014. This guidance document "Tundra wetlands: the treatment of municipal wastewaters – performance and operational tools (manual 160 pages + appendices 220 pages) provides an overview of wetland performance in the treatment of domestic effluents / sewage and details operational tools (e.g., SubWet 2.0) along with guidance regarding the management of these treatment wetlands.

International Polar Year sites: 2008 – 2010

Results generated from the six wetland treatment sites in Nunavut have been detailed by Yates *et al.* 2012 and the reader is urged to review this work for greater insight into the study findings. Highlights of those results are briefly summarized in Table 1. Results from this investigation indicated that on average, the reductions (improvements) ranged from 47 to 94% for carbonaceous biochemical oxygen demand (cBOD₅), 57 to 96% for chemical oxygen demand (COD), 39 to 98% for TSS, >99% (2 log reduction) for *E. coli*, 84 to 99% for ammonia (TAN), and 80 to 99% for total phosphorus. Natural background concentrations for total ammonia nitrogen (NH₃-N) and total phosphorous were determined by measuring these parameters in nearby wetlands that were not being impacted by municipal effluents. The range of background levels for ammonia and total phosphorus

were found to be 0.0 to 0.18 mgL⁻¹ and 0.02 to 0.2 mgL⁻¹, respectively. The Baker Lake, Whale Cove and Chesterfield wetlands have final effluents within the range of natural background for ammonia and total phosphorus concentrations. The raw wastewater being discharged from the sewage pump trucks ranged in cBOD₅ concentrations from approximately 550 to 1000 mg L⁻¹. Pre-treatment either from retention within a lagoon or facultative lake effectively reduced the strength of the wastewater entering the natural wetland. This is evident when comparing the mean cBOD₅ concentrations observed at Baker Lake (466 ± 288 mg L⁻¹) which discharged wastewater into a small detention pond that afforded minimal pre-treatment to the cBOD₅ concentration observed at Whale Cove (40 ± 73 mg L⁻¹) where pre-treatment was accomplished by first discharging to a facultative lake. The study also found that those communities which had minimal winter time wastewater storage capacity exhibited higher cBOD₅ concentrations during the spring freshet than normally observed during the summer months, suggesting that frozen wastewater had accumulated in the wetlands during the winter months and was released during the spring melt.

Table 1. Summer time means of wastewater quality parameters (mean \pm s.d.) measured weekly during June to September, 2009 at six natural treatment wetlands with the Kivalliq region of Nunavut, which received municipal wastewaters.

Community	Discharge volume (m ³ /d)	No. Sample Events	cBOD5 (mg L ⁻¹)		TSS (mg L ⁻¹)		NH ₃ -N (mg L ⁻¹)	
			influent	effluent	influent	effluent	influent	effluent
Arviat	235	11	103 \pm 50	16 \pm 6	56 \pm 39	19 \pm 23	73 \pm 43	11 \pm 10
Baker Lake	167	13	466 \pm 228	6 \pm 4	314 \pm 521	3 \pm 4	83 \pm 16	0.1 \pm 0.1
Chesterfield Inlet	36	12	221 \pm 117	14 \pm 11	75 \pm 45	10 \pm 16	40 \pm 18	0.1 \pm 0.1
Coral Harbour	96	14	181 \pm 180	14 \pm 14	93 \pm 146	11 \pm 10	22 \pm 11	2.8 \pm 5.5
Repulse Bay	66	11	385 \pm 237	25 \pm 18	197 \pm 321	35 \pm 28	70 \pm 34	2.8 \pm 2.6
Whale Cove	82	13	40 \pm 73	21 \pm 48	29 \pm 34	18 \pm 35	9.3 \pm 3.3	<0.1 \pm <0.1

Community	Discharge volume (m ³ /d)	No. Sample Events	TP mg (L ⁻¹)		E. coli (cfu /100 mL)	
			influent	effluent	influent	effluent
Arviat	235	11	11.3 \pm 7.8	2.3 \pm 2.2	3.70E+04 \pm 5.56E+04	1.68E+02 \pm 3.39E+02
Baker Lake	167	13	13.9 \pm 3.7	0.2 \pm 0.2	1.41E+08 \pm 1.51E+08	1.65E+02 \pm 3.10E+02
Chesterfield Inlet	36	12	5.6 \pm 1.6	0.4 \pm 0.3	7.59E+03 \pm 9.50E+03	3.60E+01 \pm 3.90E+01
Coral Harbour	96	14	5.5 \pm 2.5	0.8 \pm 0.8	2.95E+04 \pm 1.86E+04	8.98E+02 \pm 1.35E+03
Repulse Bay	66	11	9.2 \pm 2.4	11.4 \pm 3.8	1.64E+07 \pm 1.67E+06	1.40E+01 \pm 1.40E+01
Whale Cove	82	13	4.1 \pm 1.4	0.1 \pm 0.1	1.39E+06 \pm 2.67E+06	8.70E+01 \pm 1.82E+02

Studies funded by Environment Canada: 2009 – 2011

The research conducted for Environment Canada focussed on gaining a better insight into the progress of treatment as the effluent stream passed through the wetland. Thus more effort was placed into the collection of data along several transects which were perpendicular to the general flow pattern. Several samples locations were situated along each transect which then allowed the investigators the opportunity to generate detailed maps of the wetland with interpolated zones of concentrations for each of the wastewater parameters. The intent was to provide a visual overview illustrating locations within the wetland where the greatest treatment was occurring, or zones of no-flow (e.g., stagnant waters) or areas of preferential flow. It should be noted that this data represents only a one day snap-shot into the treatment processes and cannot be extrapolated to express weekly or seasonal variability. However, despite this fact, it can suggest if the wetland is functioning to

full capacity, or if short circuiting of the flow is occurring. These maps can also provide some evidence as to whether the majority of the treatment is occurring within the upstream portions of the wetland or if the full length of the wetland is required to achieve a reasonable level of treatment.

The results of this work have been summarized in Table 2 for cBOD₅, TSS, NH₃-N and E. coli. Similar to the IPY result, cBOD₅ and ammonia levels were significantly reduced in the treated effluent exiting the wetland. Exceptions were however, seen in Pond Inlet and Fort Providence where treatment efficiencies were less than 50%. Pond Inlet was particularly poor for cBOD₅, however, the wetland in this community is atypical in that this site is basically a steep rocky hillside where the effluent passes over the area quickly with little hydraulic retention time provided for treatment to occur. The poor performance noticed at the Fort Providence site is likely due in part to the fact that the wetland was sampled during the yearly decant period at a time when flow rates were high and retention time within the wetland was low.

Table 2. Wastewater parameters measured at seven natural treatment wetlands within Nunavut and the Northwest Territories. All values represent a one day "snap-shot" of treatment performance. Surveys were conducted in August of the year visited.

		Wetland Site (year)						
Performance Measure		Paulatuk (2009)	Pond Inlet (2009)	Edzo (2011)	Fort Providence (2010)	Gjoa Haven (2010)	Ulukhaktok (2010)	Taloyoak (2011)
cBOD ₅ mg L ⁻¹	influent	40	70	26	60	113	94	80
	effluent	2	50	2	32	2	5	25
	% Reduction	95	29	92	47	98	95	69
TSS (mg L ⁻¹)	influent	800	110	500	200	400	800	20
	effluent	30	45	1800	100	20	7500	1500
	% Reduction	96	59	-260	50	95	-838	-7400
Total Ammonia N (mg L ⁻¹)	influent	3.2	75.4	16.1	26	76.4	9.6	4.6
	effluent	0.01	31.6	0.31	18	1	0.1	0.13
	% Reduction	100	58	98	31	99	99	97
E. coli (cfu/100 mL)	influent	2850		9090	2480	408000	9210	1300
	effluent	1		1	990	300	1	24
	Log Reduction	3		4	<1	3	4	1.5
Est. Wastewater volume (m ³ /d)		34	104	109	76	119	41	86
Size of Wetland (m ²)		14600	5800	21300	8700	169000	72900	61200
Approximate length of wetland (m)		275	250	300	160	750	530	480

The TSS results summarized on Table 2 indicate that removal was poor in Edzo, Ulukhaktok and Tayloyak, despite good treatment for cBOD₅ and ammonia within these wetlands. This may not be too surprising since a group of expert panellists attending a workshop hosted by Environment Canada on arctic wastewaters in Yellowknife 2009 concluded that TSS was not an appropriate performance standard to be used in wetlands (Terriplan Consultants, 2009). The concern is that wetlands can inherently generate suspended solids and thus provide values which are not indicative of the suspended material originating from wastewater sources. A review of the TSS data for Tayloak reveals that over 70% of the TSS entering the wetlands is in the form of volatile suspended solids (VSS). The high VSS portion of the TSS represents a high concentration of organic material commonly associated with municipal wastewaters. However, as the effluent travels towards the outlet of the wetland, the concentration of TSS not only increases, but the percentage of VSS decreases rapidly (see Figure 1) suggesting that the wetland may be generating or releasing inorganic suspended solids, which may or may not be related to the wastewater.



Figure 1. Percent composition of the organic portion (e.g., volatile suspended solids – VSS) of total suspended solids (TSS) at various locations along wastewater flow path through wetland.

Examples of the interpolated data are shown for selected wastewater parameters measured within the wetland at Ulukhaktok are illustrated in Figures 2 to 8. The intent of providing these examples is to illustrate the type of information that was generated and how this information can be used to develop a visual representation of the treatment occurring with

the wetland. Figures 9 a,b,c &d illustrate how the cBOD₅ was being treated in four of the wetlands examined.

This type of information can be useful when making management decision regarding flow patterns and perhaps the inclusion of berms or other structures intended to increase the wastewaters residency time within the wetland. Readers wishing to view a more complete listing of interpolated maps and the raw data for all wetland sites are directed to the appendices of the summary report located on the websites for the CAWT and the IWS.

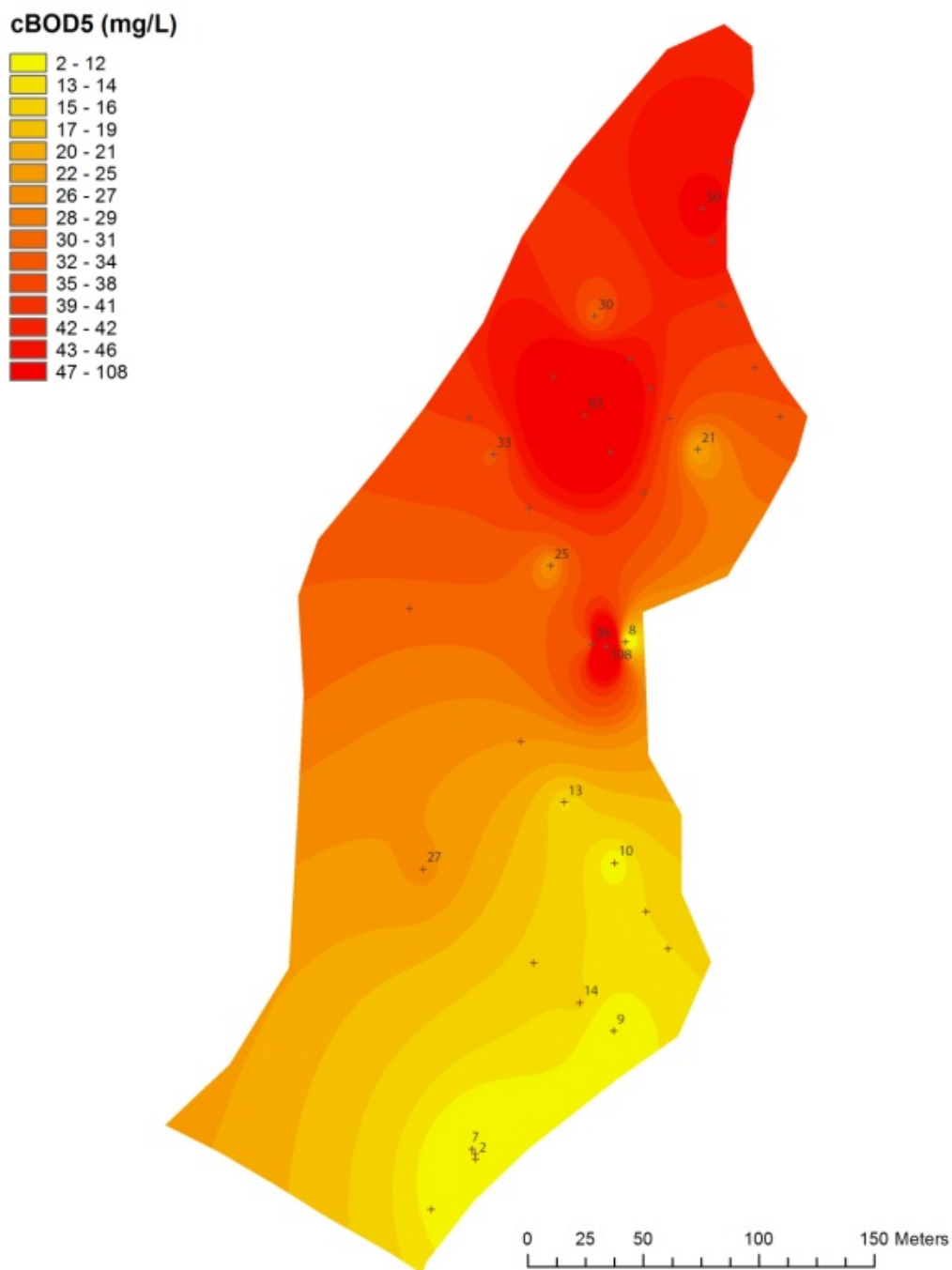


Figure 2. Carbonaceous biochemical oxygen demand of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

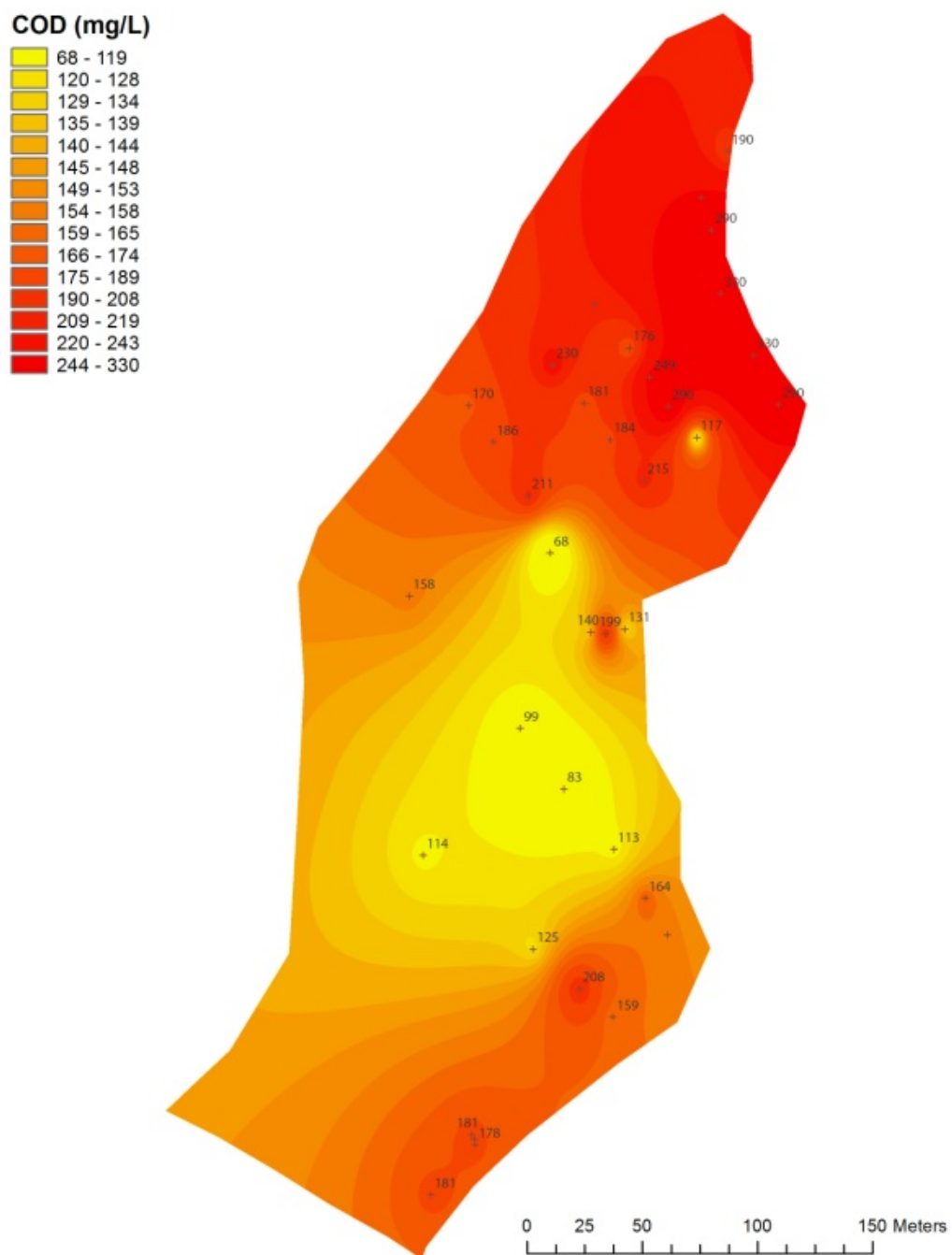


Figure 3. Chemical oxygen demand of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

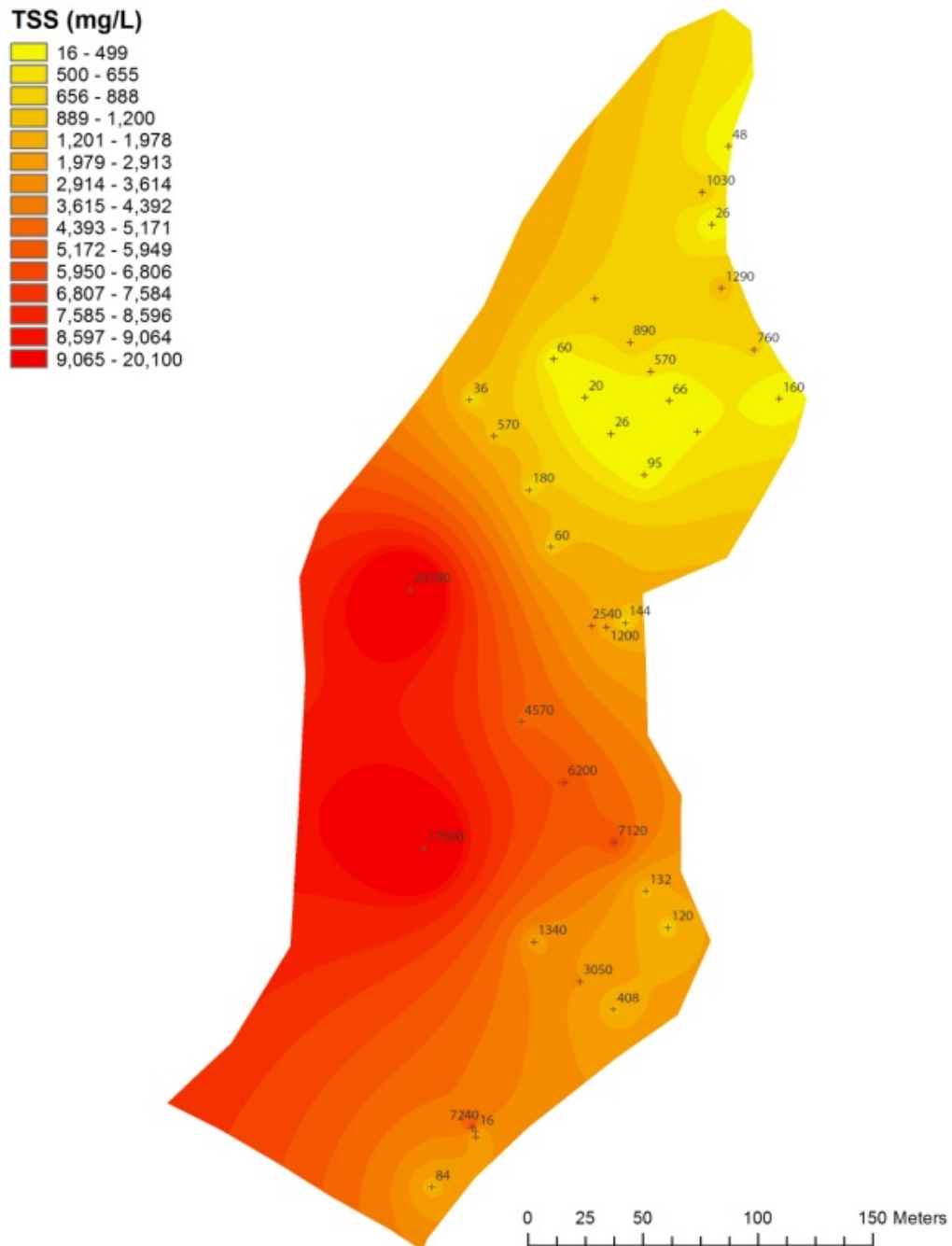


Figure 4. Total suspended solids of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

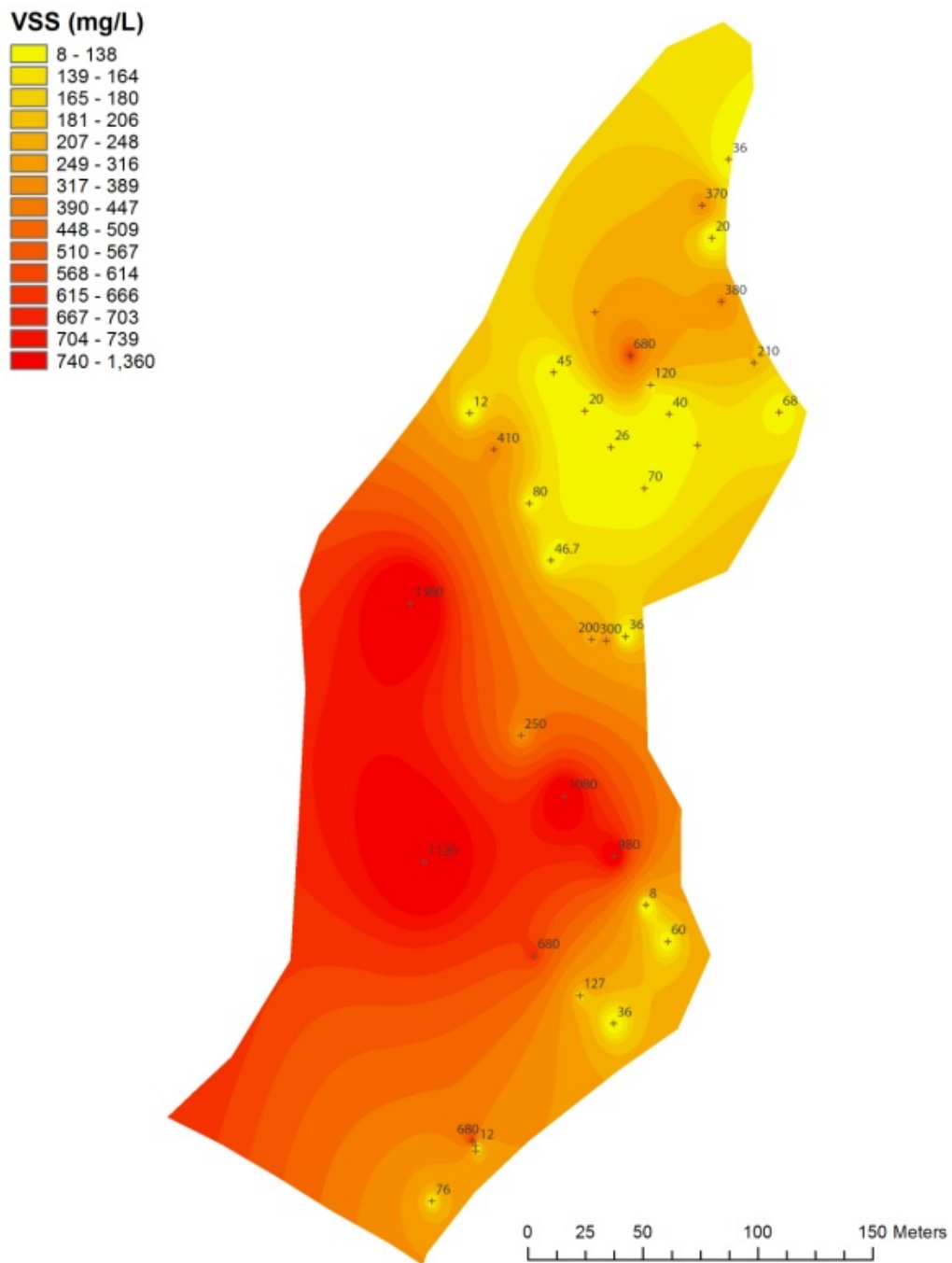


Figure 5. Volatile suspended solids of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

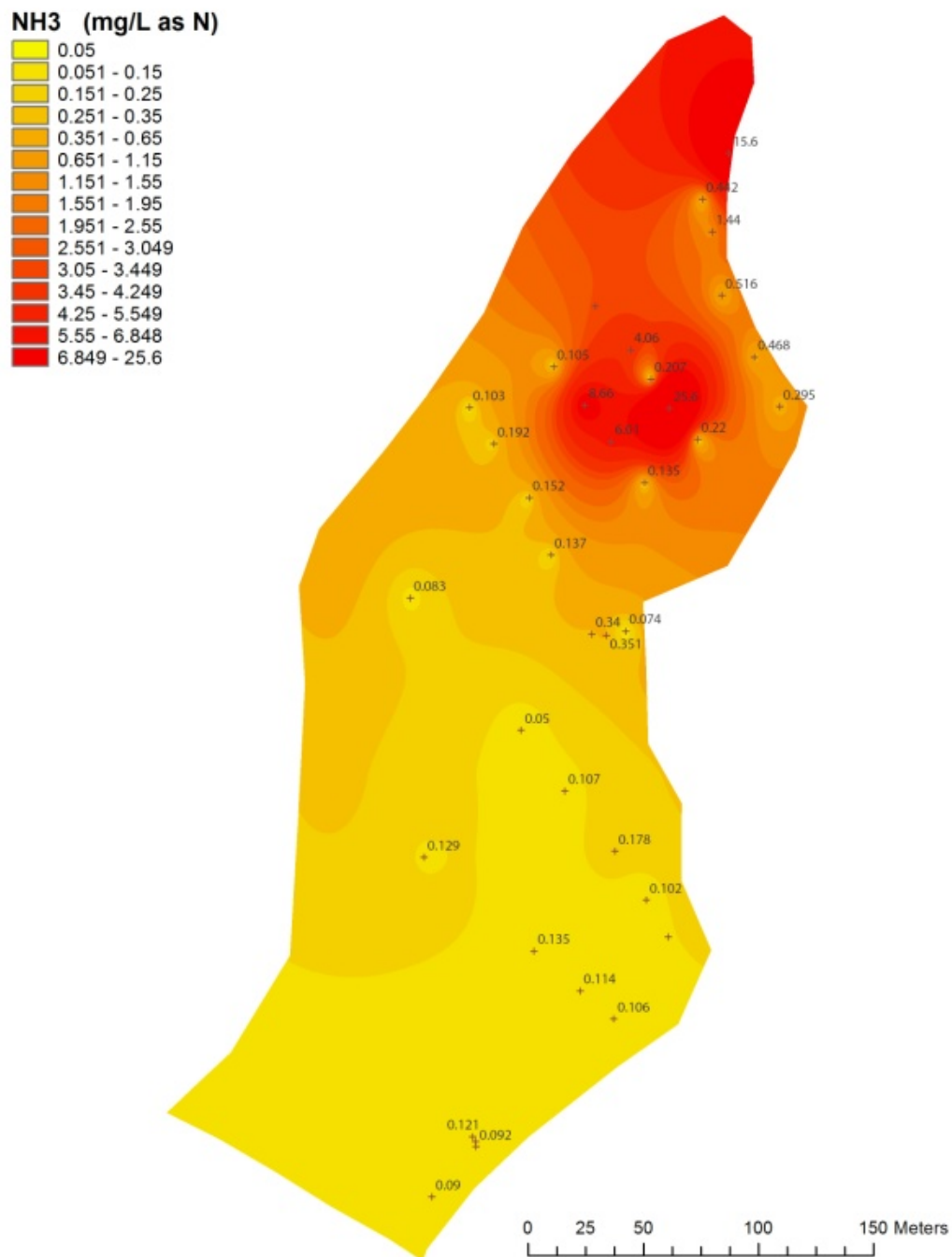


Figure 6. Total ammonia nitrogen (NH_4^+ and NH_3 as N) of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

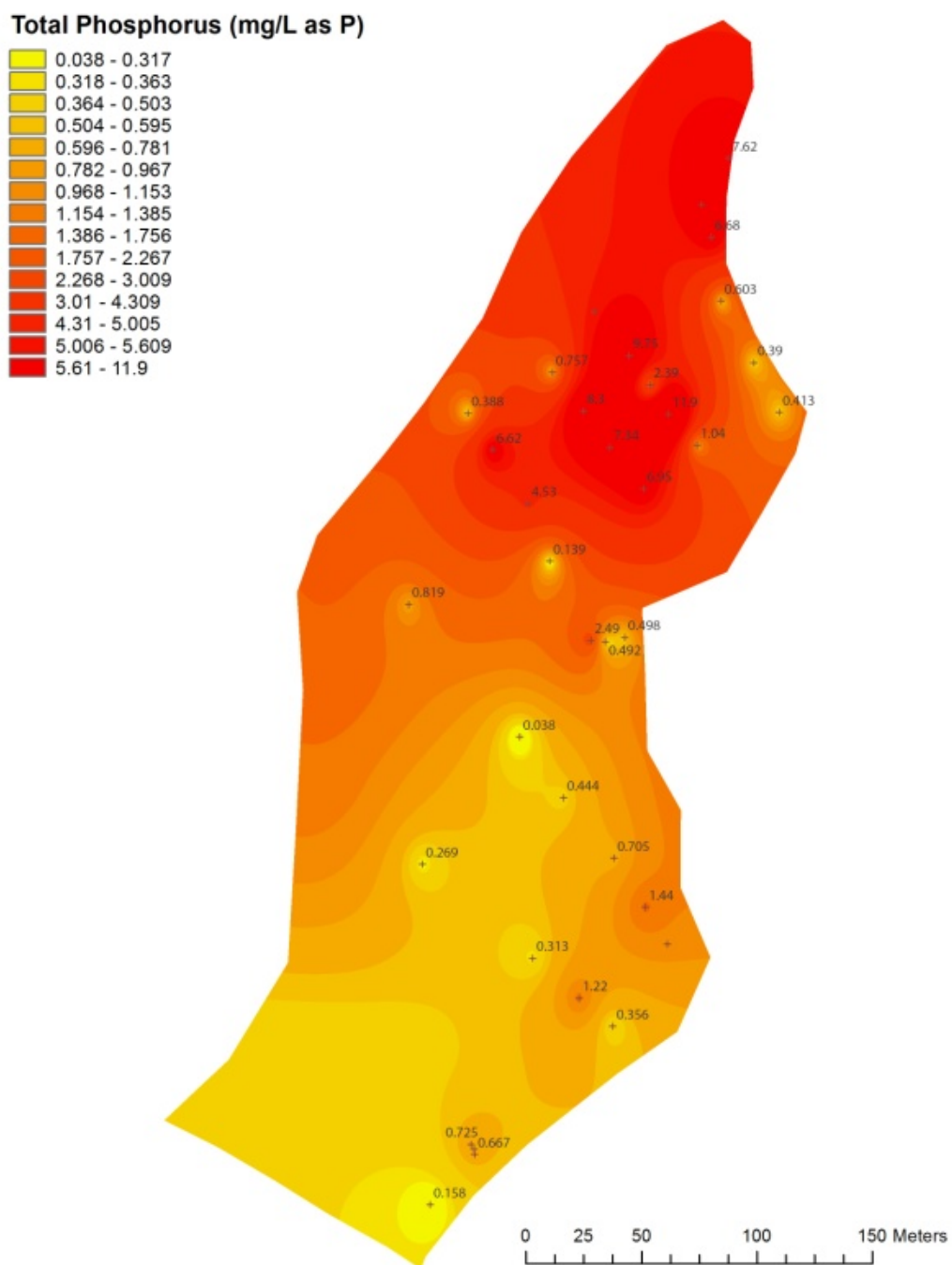


Figure 7. Total phosphorus of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.

E.coli (cfu/100mls)

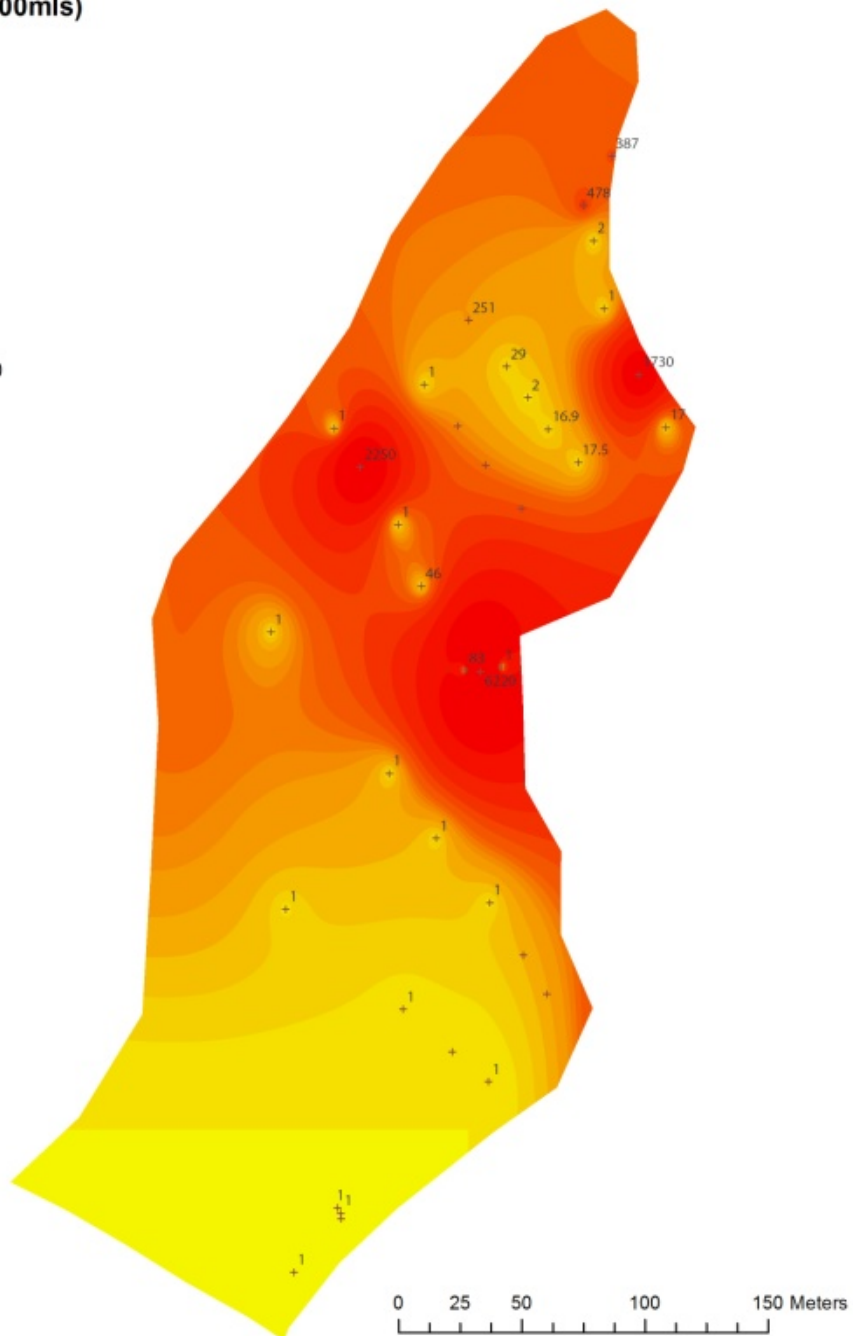
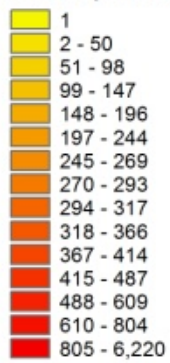
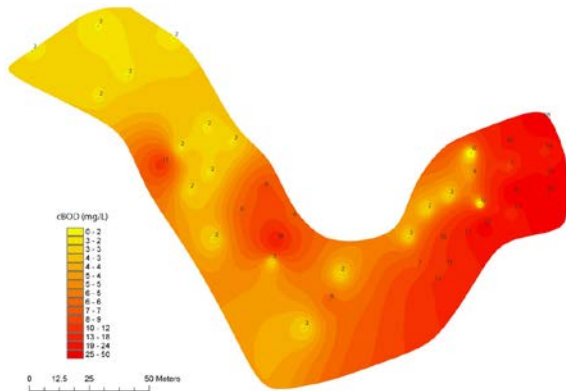
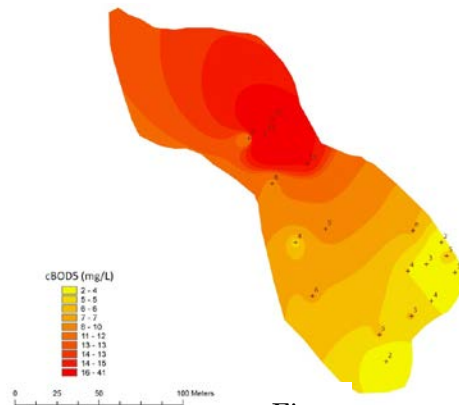


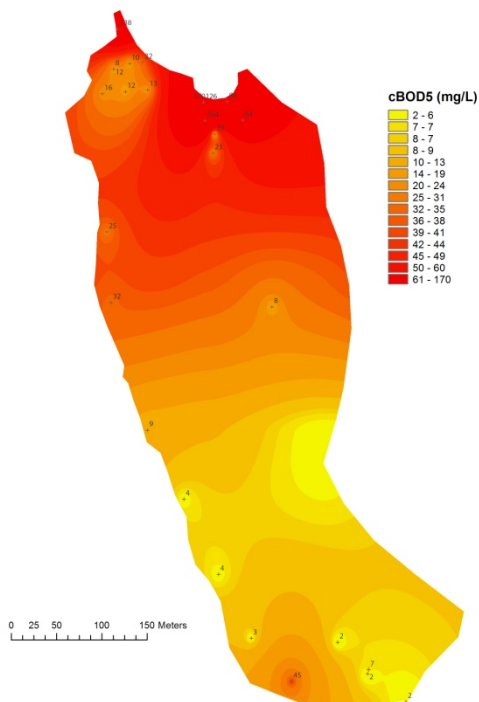
Figure 8. *Escherichia coli* counts of wastewater passing through the natural wetland near Ulukhaktok, NTW, Canada. Note: flow of wastewater is from top to bottom.



Fig



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Figure 9. Carbonaceous biochemical oxygen demand of wastewater passing through the natural wetland near Paulatuk, NWT (Fig 9a), Edzo, NTW (Fig 9b), Gjoa Haven, NU (Fig 9c) and Talyoyak, NU (Fig 9d).

SubWet 2.0

The SubWet model is a software program package used to simulate the treatment of wastewater in subsurface horizontal flow artificial wetlands. This model was originally developed by the United-Nations Environment Programme-Division of Technology, Industry and Economics-International Environmental Technology Centre (UNEP-DTIE-IETC). The model is distributed by the United-Nations as free-ware and can be found on the home web page for UNEP-IETC. The model was initially developed by Dr. Sven Jørgensen for warm climate applications. After being successfully used as a design tool in 15 cases in Tanzania, SubWet was upgraded for use within cold climates for both artificial and natural treatment wetlands. The Centre for Alternative Wastewater Treatment of Fleming College worked in collaboration with UNEP-DTIE-IETC and Sven Jørgensen to develop SubWet 2.0, a new version to accommodate temperate and cold climatic conditions including summer Arctic and temperate winter conditions. SubWet was modified for use in cold climates by calibrating the model with data originating from the natural tundra wetlands investigated during the International Polar Year study detailed earlier in this document. The application of this software to natural tundra wetlands is beyond the original purpose it was designed for. However, the calibration of SubWet with Arctic data has demonstrated its ability to model treatment performance within natural tundra wetlands and thus provide an additional predictive tool to aid northern stakeholders in the treatment of municipal effluents.

The SubWet 2.0 model has been calibrated to all 11 natural tundra wetland sites investigated during the IPY and EC studies. Values for the various rate coefficients used to calibrate the SubWet model to these natural tundra wetlands are contained in the summary report posted on the CAWT and IWS websites. Once calibrated, SubWet 2.0 simulated results were within approximately 10% of the measured values for various wastewater treatment parameters. This report also provides an overview of how SubWet 2.0 can be used to address different operational scenarios that could be expected to arise in the management of natural tundra wetlands providing treatment to domestic wastewaters.

Published manuscripts arising from this work

For readers wanting additional information regarding study sites and applications of the SubWet 2.0 program you are directed to the following published manuscripts that have arisen from this work:

Chouinard, A., Balch, G.B., Wootton, B.C., Jørgensen, S.E. and Anderson, B.C., in press. Modelling the performance of treatment wetlands in a cold climate. In *Advances in the Ecological Modelling and Ecological Engineering applied on Lakes and Wetlands*. Jørgensen, S.E.; Chang, N.B.; Fuliu, X., Eds. Elsevier: Amsterdam, Netherlands

Chouinard, A., Yates, C.N., Balch, G.C., Jørgensen, S.E., Wootton, B.C., Anderson, B.C., 2014. Management of Tundra Wastewater Treatment Wetlands within a Lagoon/Wetland Hybridized Treatment System Using the SubWet 2.0 Wetland Model. *Water*, 6(3):439-454

Yates, C. N., Wootton, B. C., and Murphy, S. D., 2012. Performance assessment of Arctic tundra municipal wastewater treatment wetlands through an Arctic summer. *Ecological Engineering*, 44(0), 160-173

Yates, C.N., Wootton, B.C., Jørgensen, S.E., Murphy, S.D., 2013. Wastewater Treatment: Wetlands Use in Arctic Regions. In *Encyclopedia of Environmental Management*. Taylor and Francis: New York

Yates, C., Balch, G.B., Wootton, B.C., Jørgensen, S.E., in press. Practical Aspects, Logistical Challenges, and Regulatory Considerations for Modeling and Managing Treatment Wetlands in the Canadian Arctic. In: *Advances in the Ecological Modeling and Ecological Engineering applied on Lakes and Wetlands*. Eds., Jørgensen, S.E., Chang, N. B. and Fuliu, X. Elsevier, Amsterdam, The Netherlands, 560 pages

Yates, C.N., Balch, G.C., Wootton, B.C., Jørgensen, S.E., in press. Exploratory Performance Testing of a Pilot Scale HSSF wetland in the Canadian Arctic. In *Advances in the Ecological Modelling and Ecological Engineering applied on Lakes and Wetlands*. Jørgensen, S.E.; Chang, N.B.; Fuliu, X., Eds. Elsevier: Amsterdam, Netherlands

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Yates, C.N., in press. A Review of Wastewater Treatment in the Canadian Arctic: Comments and Recommendations for New Municipal Effluent Performance Standards. *Arctic*

So what do these results tell us about the efficacy of natural wetlands for wastewater treatment in the North?

Although there still remains much to be learned about natural wetlands and their use to treat municipal wastewaters in Canada's cold northern climate, some things are suggestive in the findings of these studies:

General Observations:

1. **cBOD₅**: All 11 wetlands investigated provided effective treatment for cBOD₅, with the exception of Pond Inlet and Fort Providence, with final concentrations exiting the wetland at or below the proposed NPS of 25 mg L⁻¹. The wetland at Pond Inlet is best characterized as a rocky hillside rather than a wetland and because of this the hydraulic retention time is anticipated to be too short to provide an adequate contact time for treatment. Poor treatment at the Fort Providence site likely was influenced by the volume of effluent entering the wetland from the annual lagoon decant.
2. **Unionized Ammonia (NH₃·HOH as N)**: Total ammonia nitrogen (TAN, e.g., NH₃-N: NOTE: this includes both NH₃ and NH₄⁺) levels were measured in each of the wetlands. TAN levels were greatly reduced in all wetlands except for Pond Inlet and Fort Providence (reasons for poor treatment likely related to those mentioned for cBOD₅ above). The unionized ammonia portion of the TAN values (e.g., NH₃·HOH) exiting the wetland were well below the proposed NPS of 1.25 mg L⁻¹.
3. **TSS**: was variable in some of the studied wetlands. A review of the VSS fraction of the TSS suggests that wetlands could be self generating TSS that may not be associated with the original wastewater. These findings suggest that TSS may not be a good indicator of wetland treatment performance. The monitoring of TSS constituents; namely volatile suspended solids (VSS) and fixed suspended solids (FSS) may provide better interpretive value for understanding the dynamics of TSS within a natural tundra wetland.
4. **Seasonal stability**: the IPY study monitored treatment performance over the course of one season, starting during the spring freshet and continuing to the time when plants started to senesce and temperatures began to approach freezing. For most of that time

the concentrations of wastewater parameters exiting the wetland remained fairly stable with low variability. The greatest variability was noticed during early spring when flows and organic loadings were more variable due to spring freshet and in some cases the organic loadings were higher from the melting of wastewater that had accumulated in a frozen form over the winter time. Colder temperatures also appeared to influence treatment performance at both the beginning of spring and end of summer.

5. **Decanting of lagoons:** Most of the studied wetlands received wastewaters that either intentionally or unintentionally exfiltrated through the berm of the lagoon or was slowly released from a facultative lake. The slow release ensured that the retention time of the wastewater within the wetland was long enough to allow for adequate treatment. Fort Providence was an exception. This wetland undergoes a yearly decant of the wastewater contained in the lagoon. Sampling occurred at this site during the annual decant. Results indicate that wastewater treatment was poor during the decant period at this wetland.
6. **Spatial treatment:** the interpolated data demonstrates that for most wetlands, significant treatment occurred in the early portions of the wetland, suggesting that many wetlands could accommodate greater loadings.
7. **Hybridized treatment strategy:** Many natural tundra treatment wetlands are located downstream of waste stabilization ponds (lagoons) and are therefore the receiving environment for the primary treated wastewaters. It has been shown that the natural tundra wetlands provide additional treatment benefit and a formal recognition of these wetlands as part of the treatment strategy may be worth discussing.
8. **SubWet 2.0:** Once calibrated, the simulated model results for common wastewater parameters were generally within 10% of measured values. Calibration requires that measured values for the wetland exist. SubWet 2.0 has been modified for use with natural tundra wetlands. Simulated values generated by an un-calibrated SubWet operation were generally within 20 to 25% of measured values. SubWet provides wastewater managers a predictive tool to assess anticipated outcomes from different operational scenarios. In particular, management options regarding the release of primarily treated effluents from waste stabilization ponds and the predicted impacts to the treatment efficiency within natural tundra wetlands.

Data gaps / Science needs

The information generated from these studies is suggestive that natural wetlands can contribute greatly to the effective treatment of municipal wastewaters. However, there are still areas that need further investigation in order to more fully assess their potential. The following list some of those areas.

1. **Spring freshet:** a limited amount of information generated from these studies suggest that the level of treatment may vary seasonally and in particular during the spring freshet when subsurface soils are still frozen and wastewater that may have accumulated over the winter on top of the wetland surface begins to melt. There is generally a lack of good understanding regarding early season variability and which wetlands may be overwhelmed by high organic loadings and thus do not have the capacity to assimilate high spring time loadings.
2. **Year to Year variability:** monitoring data conducted in natural tundra wetlands is limited and as such it is rare to have comparable data from one year to the next. As a result, little is known regarding how treatment efficiencies may vary from year to year and the magnitude of natural variability and the primary parameters influenced by this variability.
3. **Hydrology:** site specific information regarding subsurface and surface flow is generally lacking for most wetland sites. The volume of wastewater entering the wetland can be estimated from the volume of waste hauled to the site, however, it becomes difficult to determine flow volumes exfiltrating from the lagoon berm and just as difficult to determine how much of this flow travels overland and what portion travels subsurface. Likewise it is difficult to determine the volume of new water entering the wetland either via surface or subsurface flow and how this might influence wastewater strength through dilution. Knowing this information can help significantly in both interpreting the results and predicting how the wetland would perform under different organic loading regimes.

Regulatory Considerations

The following lists some aspects that could influence either the management or regulation of these wetlands. These aspects are being raise as potential topics for discussion with the hope of generating some common points of agreement and understanding.

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1. Natural wetlands are open and diffuse systems, often with poorly defined boundaries, flow patterns and permeable borders. These conditions present challenges for wastewater regulators who require well defined points of control. Further discussion is needed to address this concern if wetlands are to become formally recognized as part of a wastewater treatment strategy. If wetlands become part of the formalized treatment strategy and are expected to meet prescribed performance standards, then standardized monitoring protocols will be needed.
 2. The natural wetlands were never designed as a wastewater treatment option. Because of this there has not been any formal recognition or designation that would set these lands apart as component of the treatment train. Future discussions should focus on the need and or merit of formally recognizing these natural wetlands in land use planning documents to ensure that they have special designation as part of the treatment strategy. The intent here is to open up the discussion as to how the wetlands are viewed by environmental agencies such as Environment Canada or Fisheries and Oceans Canada and to determine if the wetlands should be considered as part of the receiving environment for the discharged lagoon effluent, or if the wetlands should be designated as an integral component of the treatment strategy.
 3. Standardized assessment methods and predictive tools are needed for wetlands. The work presented in the summary report provides insight into how wetlands can be monitored along with the use of SubWet 2.0 as a predictive tool for wastewater managers. However, the development of a standardized approach should be crafted with a greater representation of key stakeholders. It is hoped that the work outlined in the summary report will provide a starting point for these discussions.

Concluding Remarks

The material above provides an overview of the type of information that is now being gathered for natural wetlands used for the treatment of municipal wastewaters. The intent of this document was to bring this information to the attention of those currently tasked with the oversight of municipal wastewater treatment in Canada's far north and to highlight what is known and what areas require greater attention and or discussion.

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Centre for Alternative Wastewater Treatment

Vision

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