Trow

Vegetated Filter Strip Wetland Assessment
Hamlet of Clyde River, Nunavut

Prepared for:
Department of Community Government and Services
Government of Nunavut

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Executive Summary

Trow Associates Inc. (Trow) was retained by the Department of Government and Community Services (CGS), Government of Nunavut (GN) to evaluate an existing sewage lagoon and plan and design a new sewage lagoon for the Hamlet of Clyde River.

Treatment of raw sewage in the new sewage lagoon in Clyde River will be combined with the utilization of a vegetated filter strip treatment wetland as final polishing step. Trow assessed the suitability of the filter strip treatment wetland area for further reduction of contaminants and pathogens.

The proposed sewage lagoon will be constructed next to the existing lagoon and the area between the lagoon and the Patricia Bay will be incorporated into the sewage treatment process. The filter strip wetland area is 23.5 hectare, 58 acres in size (approximately 720 m long and 325 m wide) with a slope of 6 to 7 %. Treatment of the pre-treated sewage in the filter strip wetland area will include removal of TSS, BOD, nutrients and pathogens.

Geotechnical investigations carried out in August 2007 found that the soil in the filter strip wetland area is comprised of silty sand with permafrost at 1 m in the summer months. This type of soil is suitable for infiltration processes and will facilitate the two main processes of contaminant removal from pre-treated sewage: uptake of contaminants and nutrients by plant roots and degradation by microorganisms in the rhizosphere.

The well established, native vegetation community will be used and alterations or modifications to the plant community composition are not necessary to increase removal of contaminants. The plant species present which include willows, grasses, sedges and mosses are suitable for the phytofiltration processes that will reduce BOD and TSS. Willows are commonly used in phytoremediation processes to remove organic and inorganic contaminants from groundwater, soil and wastewater from sewage lagoons, landfills and acid mine drainage. Sedges and mosses are used in constructed treatment wetlands and are known to contribute to the removal of excess nutrients and contaminants. Mosses in particular are effective in phytofiltration processes for the removal of suspended solids and BOD. The availability of additional nutrients from the pre-treated sewage will result in increased biomass production and growth of the existing vegetation.

The microorganisms found in extreme cold environments such as the arctic are extremophiles such as obligate cryophilic/psychrophilic bacteria and archaea which grow and reproduce in temperatures between -20^{o}C and 20^{o}C. These bacteria and archaea are known to grow and reproduce in arctic ice and permafrost. The microbial processes that are involved in the degradation of organic materials are generally carried out by heterotrophic bacteria which use organic compounds as carbon source for energy. Heterotrophic species are ubiquitous in soils, particularly in the rhizosphere of plants where organic materials are present. The presence of additional organic material from

the pre-treated sewage will result in increased microbial biomass which in turn increases the degradation of organic material.

BOD/COD removal is estimated to be 72-92%, with an average reduction of 82% and TSS removal between 64-98 %, with an average reduction of 80.5%.

Pathogen removal in the filter strip wetland is expected to be almost 100 % as pathogen survival is very limited outside of host organisms. Nitrogen and phosphate reduction are estimated to be around 80 %.

It is expected that the requirements of the water license of the Nunavut Water Board will be met at the monitoring endpoint of the filter strip wetland.

Table of Contents

1.0 Introduction

Trow Associates Inc. (Trow) was retained by the Department of Government and Community Services (CGS), Government of Nunavut (GN) to evaluate an existing sewage lagoon and plan and design a new sewage lagoon for the Hamlet of Clyde River (Trow, 2008). In addition, the project included assessment of the suitability of a filter strip treatment wetland area for further reduction of contaminants and pathogens.

Clyde River is a small, arctic community located on the west shore of Patricia Bay within Clyde Inlet. The average annual rainfall in Clyde River is 4.6 cm and the average annual snowfall is 203 cm (RWDI, 2008). Temperatures in the summer range between 0 and 8°C and in winter between -22.5°C and -30°C. It is generally quite windy with an average wind speed of 14.4 km/h (Dillon, 2003). Permafrost is present in the soil, it recedes to approximately 1 m below the surface in the summer time.

The location of the existing sewage lagoon is approximately 1.2 km west of the Hamlet, 800 m north of Patricia Bay (Figure 1). It is adjacent to a scrap metal dump which is located to the north and the community landfill to the east. There is a small watercourse to the west of the lagoon which runs south to Patricia Bay.

The existing sewage lagoon does not have sufficient holding capacity for the present population size of Clyde River of 800 people. The berms of the lagoon are failing and raw sewage is leaking out of the toes of the berms in several places. Presently, the sewage treatment does not meet the requirements of the Nunavut Water Board's water license.

The new sewage lagoon will have a larger holding capacity and takes the Hamlets population growth over the next 20 years into consideration. The proposed location of the newly designed lagoon is south and west of the existing lagoon. Treatment of raw sewage in new sewage lagoon in Clyde River will be combined with the utilization of a vegetated filter strip wetland as a final polishing step. The area of vegetation that will be utilized is adjacent to the proposed location of the new lagoon (Figure 1). The total annual design flow from the new lagoon is expected to be 64,000 m^3. The effluent water quality after treatment in the lagoon and the filter strip wetland is estimated to be for Biological Oxygen Demand (BOD) 18 mg/L and Total Suspended Solids (TSS) 22 mg/L, total fecal coliforms are expected to be less than 100,000 colony forming units (cfu) per 100 ml. These numbers are lower than the requirements of the Nunavut Water Board water license.

A planning study for the Clyde River sewage management was completed by Dillon Consulting Limited in 2003. The study forms the basis of Trow's detailed detail and design work.

Trow staff carried out a site visit in August of 2007 to determine the most suitable location for the new lagoon and filter strip treatment wetland. During the site visit, geotechnical investigations and surveying also took place. A vegetation survey was carried out to take inventory of the tundra plant community in the proposed filter strip wetland area. The proposed area was staked and surveyed by Trow staff (Figure 2).

1.1 Vegetated Filter Strips

Vegetated filter strips are described as areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, absorption, decomposition and volatilization. A vegetated filter strip is an area that maintains soil aeration as opposed to a wetland that, at times, exhibits anaerobic soil conditions (ADCRA, 2008).

The use of vegetated filter strips is well established in a number of areas and includes agriculture, stormwater management, municipal sewage lagoon effluent and water quality improvement (Franti, 1997, Nunez et al., 1995, Cameron et al., 2003, U.S. EPA, 2006, Woerner and Lorimor, 2008).

1.2 Clyde River Vegetated Filter Strip Wetland

The proposed sewage lagoon for the Hamlet of Clyde River will be constructed next to the existing lagoon and the area between the lagoon and Patricia Bay will be incorporated into the sewage treatment process (Figure 1). The vegetated filter strip at Clyde River sewage lagoon will be a combination of treatment wetland and vegetated filter strip based on the existing conditions and vegetation community composition.

The filter strip wetland area is 23.5 hectares, 58 acres in size (approximately 720 m long and 325 m wide) with a slope of 6 to 7 %. Treatment of the pre-treated sewage in the filter strip wetland area will include removal of TSS, BOD, nutrients and pathogens.

Geotechnical investigations carried out in August 2007 found that the soil in the filter strip wetland area is comprised of silty sand with permafrost at 1 m in the summer months. This type of soil is suitable for infiltration processes and will facilitate the two main processes of contaminant removal from pre-treated sewage: uptake of contaminants and nutrients by plant roots and degradation by microorganisms in the rhizosphere.

1.3 Vegetation Community

A vegetation survey was carried out during the site visit in August 2008 to assess the suitability of the species present for the treatment of pre-treated sewage from the lagoon.

The plant species list is shown in Table 1. It should be noted that this list is not complete as it reflects only a summer season survey.

Table 1: Plant Species- Proposed Filter Strip Wetland Location

	Lichen
Caloplaca sp.	lichen
Cladonia sp.	lichen
Masonhalea richardsonii	antler lichen
Rhizocarpon geographicum	map lichen
Thamnolia subuliformis	worm lichen
Umbilicaria sp.	rock tripe
Xanthoria sp.	jewel lichen
	Mosses
Lycopodium annotium	club moss
Sphagnum sp.	moss
Graminae	**Grasses**
Poa sp.	blue grass
Poa spp.	grasses
Cyperaceae	**Sedge Family**
Eriophorum spp.	Arctic cotton
Carex spp.	sedges
Salicaceae	**Willow Family**
Salix reticulata	net-veined willow
Salix sp.	willow
Betulaceae	**Birch Family**
Betula glandulosa	dwarf birch
Polygonaceae	**Buckwheat Family**
Oxyria digyna	mountain sorrel

Caryophyllaceae	**Pink Family**
Cerastium sp.	mouse-ear chickweed
Melandrium apetalum	purple bladder-campion
Silene acaulis	moss-campion
Ranunculaceae	**Buttercup Family**
Anemone richardsonii	Richardson's anemone
Ranunculus sp.	buttercup
Anemone sp.	anemone
Papaveraceae	**Poppy Family**
Papaver radicatum	Arctic poppy
Rosaceae	**Rose Family**
Dryas integrifolia	mountain avens
Saxifragaceae	**Saxifrage Family**
Saxifraga nivalis	Alpine saxifrage
Saxifraga oppositifolia	purple mountain saxifrage
Saxifraga sp.	saxifrage
Empetraceae	**Crowberry Family**
Empetrum nigrum	crowberry
Ericaceae	**Heath Family**
Cassiope tetragona	white arctic heather

The native vegetation is highly adapted to the extreme conditions of the high arctic region. The composition of the vegetation community was found to be suitable for the proposed filter strip wetland treatment process.

1.4 Phytoremediation and Vegetated Filter Strip Efficiency

Phytoremediation is the use of plants to decontaminate soil and water. Plants such as hybrid poplars and willows have been planted to reduce contaminants of concern such as volatile organic compounds (VOCs), petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals at Brownfield sites, landfills and abandoned mine sites for many years. Constructed treatment wetlands with cattails and reeds are used to treat landfill leachate, acid mine drainage, sewage, industrial effluents and agricultural run-off (Kadlec and Knight, 1996).

Vegetated filter strips with lower growing vegetation such as grasses and sedges are equally successful biofilters for a number of contaminants and excess nutrients, including nitrogen compounds, phosphates, salts, metals, organic contaminants and pathogenic bacteria and viruses.

Studies completed for nonpoint source pollution using vegetated filter strips have shown improvements in water quality from silvicultural, urban, construction and agricultural sources. Research studies in Nebraska have indicated that a 7.6 metre (25 foot) wide strip can reduce off-site movement of nitrogen by 70% due to increased infiltration and phosphorus by 85% due to sediment removal on a 6 to 7% slope of silty clay loam soil and 56 to 97% on 3 to 12% slope of silt loam soils (Franti, 1997).

Table 2 shows data from open animal feedlots published by the United States Environmental Protection Agency for an overland flow of 91 m length (EPA, 2006).

Table 2: Pollutant Removal Rates Animal Feedlot (EPA, 2006)

Pollutant	Range of Removal	Average Removal
TSS	24 – 87 %	64.5 %
COD/BOD	15 – 92 %	75 %
Nitrogen	18 – 95 %	71.5 %
Ammonia	18.6 – 99 %	70 %
Phosphorus	12 – 97 %	69 %
TKN	71 – 89 %	80 %
Fecal Coliforms	31 – 100 %	77 %

2.0 Implementation and Estimated Performance

The wetland area present at the site (Figure 2) is typical of the High Arctic Wetland Region of northern and northeastern parts of Baffin Island. It is characterized as a lowland polygon fen with very small shallow water tundra ponds, located mostly around rocks covered with lichen and mosses.

The well established, native vegetation community will be used and alterations or modifications to the plant community composition are not necessary to increase removal of contaminants. The plant species present which include willows, grasses, sedges and mosses are suitable for the phytofiltration processes that will reduce BOD and TSS. Willows are commonly used in phytoremediation processes to remove organic and inorganic contaminants from groundwater, soil and wastewater from sewage lagoons, landfills and acid mine drainage. Sedges and mosses are used in constructed treatment wetlands and are known to contribute to the removal of excess nutrients and contaminants. Mosses in particular are effective in phytofiltration processes for the removal of suspended solids and BOD. The availability of additional nutrients from the pre-treated sewage will result in increased biomass production and growth of the existing vegetation.

The microorganisms found in extreme cold environments such as the arctic are extremophiles such as obligate cryophilic/psychrophilic bacteria and archaea which grow and reproduce in temperatures between -20^{o}C and 20^{o}C. These bacteria and archaea are known to grow and reproduce in arctic ice and permafrost (Friedmann, 1994, Rivkina et al., 2000, Junge et al., 2004). The microbial processes that are involved in the degradation of organic materials are generally carried out by heterotrophic bacteria which use organic compounds as carbon source for energy. Heterotrophic bacteria are ubiquitous in soils, particularly in the rhizosphere of plants where organic materials are present. The presence of additional organic material from the pre-treated sewage will result in increased microbial biomass which in turn increases the degradation of organic material.

Maximum effectiveness of the biological processes are achieved when the depth of the input (flowing) is less than the height of the vegetation, when sediment and nutrient levels are low in the vegetation and when the filter strip vegetation is maintained and not damaged (Franti, 1997).

The estimated performance of the filter strip wetland in Clyde River is shown in Table 3. Removal rates are based on comparable site conditions from literature reviews (Doku and Heinke, 1993, Nunez et al., 1995, Kadlec and Knight, 1996, Franti, 1997, Cameron et al., 2003, US EPA, 2006, Woerner and Lorimor, 2008).

Table 3: Estimated Reduction in BOD and TSS

Outgoing Concentration From Filter strip Wetland (mg/L)	BOD (mg/L)			TSS (mg/L)		
	75	100	125	80	105	135
Highest	21	28	35	29	38	49
Lowest	6	8	10	1.6	2	3
Average	13.5	18	22.5	16	20.5	26

3.0 Contaminants Removal

Wetlands can be utilized to remove TSS and BOD from waste water in northern regions of Canada such as the Northwest Territories and Nunavut (Doku and Heinke, 1993, Bays et al., 2007).

The existing and the new treatment lagoon in Clyde River will be used for storage for 335 days. Once warmer temperatures start melting the frozen sewage, pollutants and pathogens are removed though chemical and biological processes as well as settling. Between mid August and the end of August, depending on the weather, the decanting of the lagoons is scheduled to begin. It will be carried out over a period of approximately 30 days. The pre-treated sewage is anticipated to meet the water license requirements for BOD, TSS and fecal coliforms at this point.

The additional polishing step, the vegetated filter strip wetland, is incorporated into the process to remove contaminants which may remain in the effluent leaving the lagoon. After the initial pre-treatment of the sewage in the lagoons, the main purpose of the vegetative filter strip wetland is to provide additional treatment through continued reduction of total suspended solids and biological oxygen demand as well as pathogens. The decanting process will aerate the pre-treated sewage which will add oxygen needed for aerobic bacterial degradation processes in the filter strip wetland area. It is recommended to ensure even distribution of the pre-treated sewage to maximize treatment within the wetland area.

3.1 Total Suspended Solids (TSS)

The majority of suspended solids are removed through sedimentation over time in the sewage lagoon. The TSS remaining in the wastewater will enter the filter strip wetland where the solids will be trapped and settle along the route to Patricia Bay. Sewage biosolids are a source of organic matter which will be utilized by bacteria and plants to grow and reproduce (OMOE, 1996).

The typical removal efficiencies (based on a lower limit of 2 to 10 mg/L) of a treatment wetland for TSS is 50 to 90% (Bays et al., 2007). For vegetated filter strips the additional removal of suspended solids is expected to occur at a rate of 64 to 98%, with an average reduction of 80.5% (Yu et al., 1993).

3.2 Biological Oxygen Demand (BOD)

The most efficient BOD removal is dependant on aerobic conditions which the vegetated filter strip wetland will provide in addition to the increased aeration from the pumping process. In contrast, a treatment wetland may experience periods of anaerobic conditions, especially if ice persists which depletes oxygen.

Removal efficiencies for BOD in vegetated filter strips range from 64 to 98%. This could potentially give an overall removal efficiency in the vegetated filter strip wetland of approximately 81%.

3.3 Pathogens

Pathogens present in sewage include fecal coliforms and *E. coli* which have a limited life span outside of their host organism (warm blooded animals). It is expected that 90% of pathogens will be removed during treatment in the lagoon. The numbers of remaining pathogens will be further reduced in the filter strip wetland because of the unfavourable conditions which will not allow the pathogens to grow and reproduce. Numbers of pathogens from sewage are expected to be very low at the monitoring point at the end of the filter strip wetland area. However, it should be noted that animals frequent the area and animal feces may contribute to total fecal coliforms and *E. coli* numbers.

3.4 Nutrients

Sewage effluent is high in nutrients such as nitrogen compounds and phosphorus. Land application of sewage effluent and biosolids can potentially result in nutrient rich run-off. This may lead to eutrophication of surface water bodies such as ponds and lakes which can be detrimental to aquatic animals and plants. The high arctic wetland region to which Clyde River belongs is relatively nutrient poor and nutrients are generally in short supply. Availability of additional nutrients is unlikely to result in eutrophication and the nutrients are readily taken up by plants and metabolized. This will result in increased plant biomass and growth rates. As a consequence, more organic compounds will be available for bacteria in the rhizosphere which will increase bacterial growth and reproduction and subsequently degradation of contaminants. It is therefore unlikely that the nutrients will be a concern beyond the boundaries of the treatment wetland.

4.0 Vegetated Filter Strip Wetland Area

In order to remove contaminants effectively, treatment wetlands have to be a certain size, thus ensuring sufficient retention time. Design of constructed treatment wetlands takes contaminant loading, desired effluent concentrations and background concentrations into consideration.

The Guidelines for the Approval and Design of Natural and Constructed Treatment Wetlands for Water Quality Improvements by Alberta Environment use the following equation to calculate the required area for treatment (AE, 2000):

$$A = \left(\frac{0.0365 \times Q}{k}\right) \times \ln\left(\frac{C_i - C^*}{C_e - C^*}\right)$$

Q	=	Design Flow, m^3/d
C_i	=	Influent Concentration
Ce	=	Target Effluent Concentration
C*	=	Wetland background limit (mg/L) for TSS, C* = 8 for BOD, C* = 5
k	=	Areal rate constant @ 20 ^oC (m/yr) for TSS, k = 35 for BOD, k = 34
A	=	Required wetland area (ha)

The flow rate from the lagoon is expected to be 2,133 m^3/day for 30 days.

The BOD concentration in the influent into the wetland area from the lagoon is 100 mg/L. As a conservative approach, the target concentration to leave the filter strip wetland was set at 20 mg/L with a wetland background concentration of 5 mg/L. The required size of a treatment wetland for BOD removal is 4.2 ha.

The TSS concentration in the influent from the lagoon is 120 mg/L and the target concentration for TSS was set at 20 mg/L. The background concentration in the wetland is estimated at 8 mg/L. The required size for a treatment wetland for TSS removal is 4.9 ha.

It should be noted that the above calculations are generally used for constructed treatment wetlands such as open water surface wetlands. The filter strip wetland area is a hybrid between a filter strip in the classical sense and a treatment wetland which doesn't allow for direct comparison. However, the area of the proposed filter strip wetland is 23.5 ha in size, which provides ample area for treatment.

5.0 Filter Strip Wetland Area and Watercourse Protection

Arctic tundra and wetland vegetation communities are very sensitive to physical damage and take a long time to recover from disturbances. Arctic plant species have very slow growth rates and areas damaged by construction activities will not re-vegetate for many years. It is therefore important that construction equipment and trucks do not enter the wetland area. Damage to the wetland area would result in a decrease in treatment efficiency.

A small watercourse runs west of the filter strip wetland area and proposed location of the new lagoon from the north south to Patricia Bay. For the protection of the water course from lagoon wastewater a small berm should be constructed to separate the stream from the main filter strip wetland area. Construction of such a berm has to take place from outside the wetland area to protect the vegetation community and integrity of the wetland.

6.0 Conclusions and Recommendations

The following summarizes the conclusions and recommendations for the filter strip treatment wetland:

1. The area between the new sewage lagoon and Patricia Bay is a suitable location for a filter strip treatment wetland.

2. Geotechnical investigations found the soils at the site to be suitable for infiltration and biodegradation processes.

3. The filter strip wetland which will be receiving pre-treated sewage from the newly constructed sewage lagoon is expected to successfully remove BOD, TSS, pathogens, nitrogen compounds and phosphate before the wastewater enters the Patricia Bay.

4. Existing, native vegetation and microorganisms will be the main contributors to the reduction of contaminants and nutrients.

5. Even distribution of the pre-treated sewage is recommended to maximize treatment within the wetland area.

6. BOD removal is estimated to be 72-92%, with an average reduction of 82% and TSS removal between 64-98%, with an average reduction of 80.5%.

7. Pathogen removal in the filter strip wetland is expected to be as high 100% as pathogen survival is very limited outside of host organisms.

8. High rates of nutrient reduction, particularly of nitrogen compounds are expected as they are utilized by plants

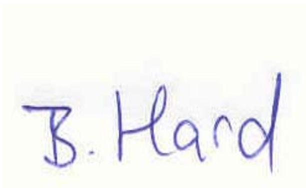
9. The area available for the filter strip treatment wetland is more than sufficient to successfully remove BOD, TSS and pathogens.

10. It is recommended that the filter strip wetland area be protected from disturbance and that equipment and vehicles do not enter the area to avoid long term damage.

11. It is recommended to build a berm between the wetland area and the water course that runs from north to south. The berm should be built from outside the wetland area to avoid long term damage to the vegetation community.

12. It is anticipated that the requirements of the water license from the Nunavut Water Board will be met at the monitoring endpoint of the filter strip treatment wetland.

Trow Associates Inc.



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Appendix A:
Photographs

Figure A-1: Existing sewage lagoon, looking northeast. Metal dump is visible in the background (to the left of the picture)

Figure A-2: Area between existing lagoon (east berm) to the right) and landfill to the left, overlooking filter strip wetland area and Patricia Bay to the south

Figure A-3: South berm of existing lagoon, looking east to landfill site

Figure A-4: Looking south from existing lagoon to filter strip wetland area and Patricia Bay

Figure A-5: Looking west from existing lagoon

Figure A-6: Overflow pipe in west berm of existing lagoon

Figure A-7: Looking north west from existing lagoon

Figure A-8: West berm of existing lagoon with overflow pipe, showing berm erosion

Figure A-9: Looking north to existing lagoon, overlooking filter strip wetland and watercourse

Figure A-10: Watercourse and wetland north east of the existing lagoon, looking east to metal dump and lagoon (to the right)