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PROCESS OPTIONS FOR A SEWAGE LAGOON IN SUB ARCTIC CANADA

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Abstract: The existing sewage lagoon for the community of Fort Resolution, Northwest Territories is located in a waste management area approximately 1.5 kilometres north of the community centre. The sewage lagoon is a facultative/infiltration process consisting of seven cells of various sizes linked by channels. The treatment system begins at a truck discharge point into a cell, and wastewater ultimately percolates through the sandy soil in a northerly direction to a wetland area in the Slave Lake delta approximately 400 metres from site. Detention in the lagoon, and the infiltration process through the sandy soil provides treatment to an secondary level of effluent quality.

In 2008, it was anticipated that the sewage lagoon was approaching the end of its service life with its current configuration, as indicated by decreasing available freeboard in the cells. A Waste Management Planning Study was completed, which recommended the construction of a new lagoon to meet the twenty-year wastewater generation demand. The report presented 2 options: a facultative infiltration process, and a retention process. It was recommended that a facultative / infiltration lagoon be advanced, but it was recognized that this option may not receive regulatory approval.

Based upon the ongoing concerns with the performance and operation of a facultative infiltration lagoon system, and regulatory feedback, a decision was made to advance the design of a lined retention lagoon. Preliminary engineering was advanced on the new lagoon system in 2017, and a comparison of various configurations of a retention lagoon were considered. These configurations included a single lined cell, two lined cells with primary and secondary cells, and three lined cells with a polishing filter. The three cell configuration was a recent process innovation proposed as a result of a comprehensive research program on northern lagoon systems.

Based on cost and the anticipated performance information on the lagoon systems, the two-cell lagoon process configuration proposed was confirmed to be the most appropriate option for Fort Resolution. The capacity of the proposed sewage lagoon is 31,000 m^3 based on the sewage generation projection. The design and construction of the two cell process configuration is scheduled to be completed in 2018.

1 Community Location, Topography and Geology

The Hamlet of Fort Resolution is geographically situated on Great Slave Lake and immediately south of the Slave River delta, at 61°10'16" N latitude and 113°40'20" W longitude. It is the oldest mondern community in the Northwest Territories, and a National Historic Site of Canada. The Hamlet of Fort Resolution is accessible by road, and is approximately 160 km by road from Hay River and at 153 km by air south of Yellowknife.

The shore area around the community is characterized by swamps because of a high ground water table. The settlement is located on land that is flat and clear of trees approximately 160 m above mean sea level and 4 m above the Great Slave Lake level. Below the surface layer of organic matter there is 1 to 1.5 m of fine sand and silt. Underneath are alluvium and glacial drift deposit noted to be up to 37 m thick, these deposits are underlain by Devonian limestone, which is exposed in several locations of the Hamlet. Fort Resolution is within the southern margin of the discontinuous permafrost zone, and permafrost may be found at depths of 0.5 m in shaded areas.

2 Existing Sewage Collection and Disposal

Sewage is collected from approximately 225 homes in Fort Resolution and trucked to the current lagoon site. The sewage is then emptied into the lagoon at the truck dump on the north side of the lagoon area. Approximately 12 to 15 trucks with 9,100 litres of sewage are collected in the community each day, five days a week. The estimated annual sewage generation rate in 2016 was 24,760 cubic metres.

The current lagoon system consists of seven cells of various sizes interconnected by a series of channels. The sewage lagoon system begins at a truck discharge point into cell 1. The first cell was excavated in approximately 1979, and additional cells were excavated subsequently whenever the lagoon appeared to be reaching capacity or when borrow material was needed **(See Figure 5).** The most recent cell (number 7) was constructed in 2008. The total capacity of the 7 existing cells is estimated at 21,000 m^3.

The receiving water body of the treated and infiltrate effluent is a wetland 400 metres north of the lagoon and ultimately the wetland discharges into Nagle Bay located on Great Slave Lake **(See Figure 1).**

Figure 1: Lagoon location and local features

3 Location for a New Lagoon

On the basis of a review and the information gathered during community interviews, three (3) potential locations for a new lagoon were considered. The three (3) locations were, the existing site, a site 16 km to the south located in a gravel quarry; and a site 50 km to the southwest in an abandoned mine area.

The sewage trucking costs associated with the potential locations were estimated. Based upon these costs and the overall impact of the existing site, it was determined that the new lagoon should be developed adjacent to the existing site.

4 Geotechnical Investigation and Wetland Opportunity

4.1 Geotechnical Investigation

A geotechnical investigation was conducted at the proposed location of the new sewage lagoon and produced the following information.

- The project site has been identified to contain permafrost terrain, and siting of the lagoon should avoid permafrost.
- The predominant soil texture at the test pit locations is fined grained sand, and these soils are technically unsuitable for use as a natural soil liner or impermeable barrier for the sewage lagoon.
- The native soils are considered to be generally suitable for use for perimeter berm construction, and it is possible that the native soils may be sensitive in terms of compaction and optimum water content.
- The lagoon should be constructed predominately "above-grade" because excavation into the existing subgrade may encounter groundwater, which will be problematic for lagoon base preparation and long-term performance of the lagoon and installed impermeable liners.
- The presence of organic layers at depths of about 3 m may result in migration of gases towards the ground surface, and the lagoon liner should be appropriately vented and ballasted to avoid the potential of “floating”.
- Engineered berms for the lagoon should be designed based on preliminary side slopes of 3H:1V to ensure long-term stability.

4.2 Supplementary Wetland Treatment Opportunity

The subsurface discharge from the existing lagoon ultimately discharges into a substantial wetland area approximately 400 metres north of the existing sewage lagoon site. This wetland system discharges into Nagle Bay and ultimately into Great Slave Lake.

Supplementary wastewater treatment from this wetland will occur, and therefore it should be considered as part of the overall wastewater treatment system. Wetlands are well recognized in the far north for their treatment capabilities, and wetlands allow for the decrease of suspended solids, organic matter, nitrogen, phosphorus, trace elements including metals, and microorganisms.

5 Sewage Characteristics and Volume, and Effluent Criteria

5.1 Sewage Characteristics and Volume

Wastewater generated in Fort Resolution is primarily domestic in source and characteristics. The wastewater quality from the community may be a "high strength" waste because of the use of a trucked sewage collection and water supply. The "high strength" condition is typical for trucked sewage and water systems due to the low water usage which translates into low dilution of the raw sewage. Limited measurements were made on the raw sewage characteristics, and are tabulated in **Table 1.**

Table 1: Raw Sewage Characteristics in Fort Resolution

Parameter	Unit	Sample Location (Truck Dump - Cell 1)	Typical High Strength Domestic Wastewater
BOD_5	mg/L	421	400
TSS	mg/L	224	389
E. Coli	MPN/100 mL	1,600,000	10^5 - 10^8
Total Coliforms	MPN/100 mL	>1,600,000	10^7 – 10^{10}
Ammonia-N	mg/L	66	41
pH	pH Units	7.2	--

Based upon population projection, the generation of sewage waste is estimated for the next 20 years (starting from 2017). The 2037 population is estimated to be 553 and the annual sewage generation is estimated to be 32,000 cubic metres.

5.2 Effluent Guidelines

The Hamlet of Fort Resolution's current water license stipulates the effluent quality requirements. The water license came into effect in 2015 and expires in 2025. The Effluent from the Wastewater Disposal Facilities discharging into Great Slave Lake (Nagle Bay adjacent to the wetland) shall meet the effluent quality standards of 25 mg/L for total Suspended Solids, 25 mg/L for $CBOD_5$.

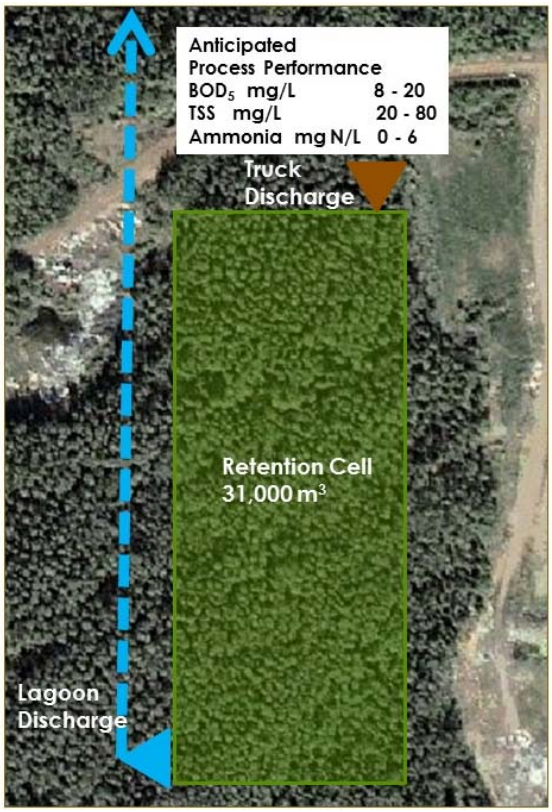

Figure 2: Single cell configuration for Fort Resolution sewage lagoon.

6 Sewage Lagoon Processes

The consideration of sewage treatment processes did not include mechanical systems because northern experience has demonstrated that passive systems, which generally operate slower, tend to perform well in the far north. Passive systems are technologically simple and make use of the natural attributes of the northern environment, such as extended daylight in the summer.

6.1 Single Cell Lagoon

Single cell retention lagoons are a common process for sewage treatment facilities across northern Canada because the configuration provides simple and cost effective means of treating wastewater **(See Figure 2)**. Although a recommendation was made for a two-cell configuration with a primary cell and a storage cell (long term retention cell), the single cell option was reviewed for the purpose of benchmarking its potential performance against multiple cell lagoons.

6.2 Multiple Cell Lagoon

A multiple cell lagoon may produce a considerably better effluent quality to a single cell lagoon as presented in **Figure 3.** Considerable improvement in effluent quality will occur with the addition of a primary cell in the overall process for a 12 month storage lagoon. The addition of more cells beyond 2 for a treatment lagoon may provide only limited additional effluent quality improvements.

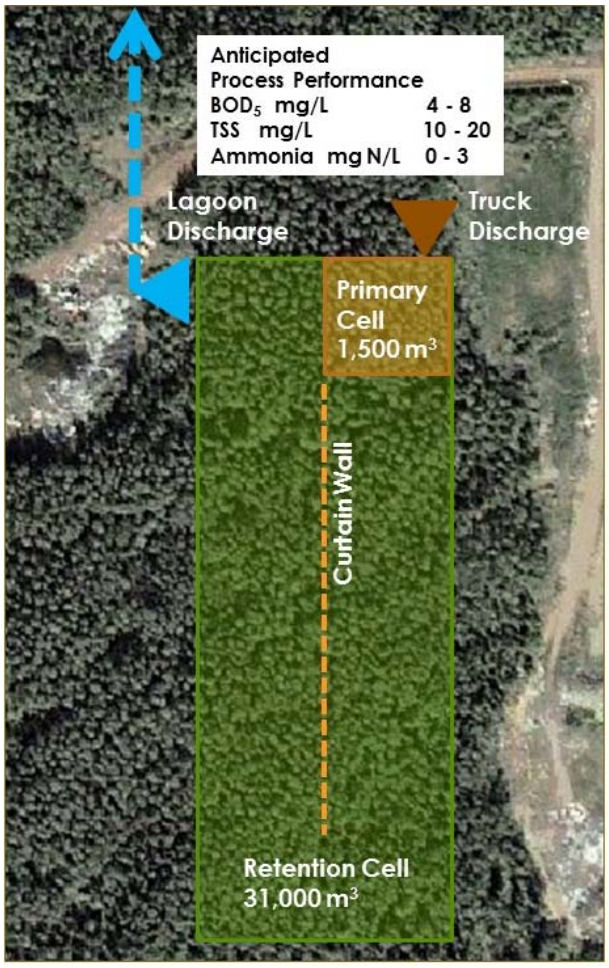

Figure 3: Multiple cell configuration for Fort Resolution sewage lagoon.

6.3 Nunavut Multi Cell Lagoon

The Nunavut multi cell wastewater process is a Waste Stabilization Pond (WSP) design concept **(See Figure 4)** is based upon research completed by Dalhousie University over the past several years. The process has been presented through the publication of guidelines for wastewater systems operating in Nunavut, however the process application remains only theoretical. The proposed configuration has three cells, which includes a primary treatment cell designed to store 10 months of wastewater generation during the winter months, and two secondary treatment cells designed to provide biological treatment of primary treated wastewater during the summer months.

During the summer months, once the cells have thawed, effluent from the primary cell would be discharged into 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 the anticipated high solids (algal biomass) before final discharge. The theoretical performance of the Dalhousie process suggests effluent quality of less than 30 mg/L for both $CBOD_5$ and TSS.

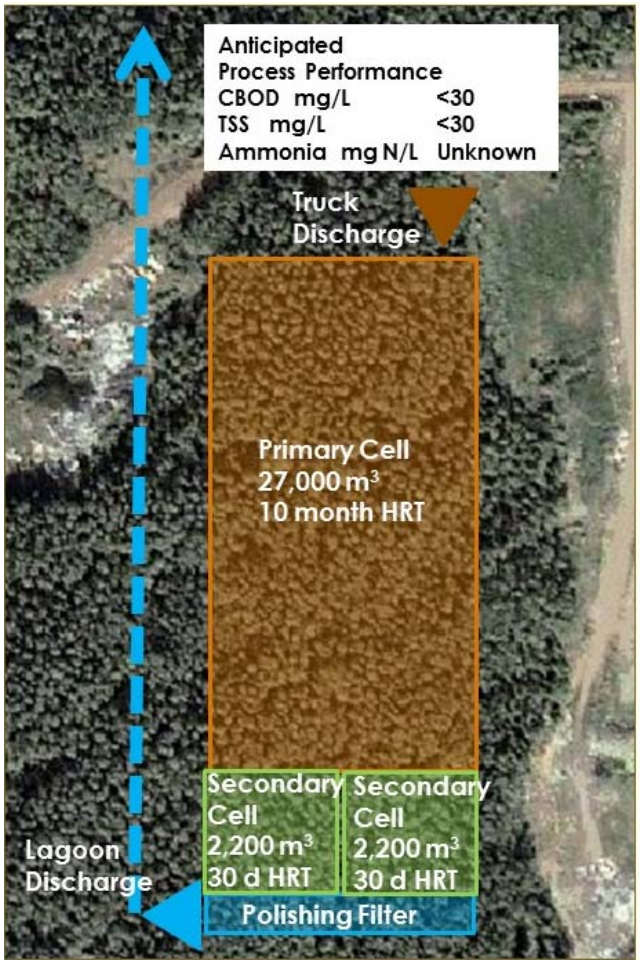

Figure 4: Nunavut cell configuration for Fort Resolution sewage lagoon.

6.4 Comparison of Lagoon Options

The following table is a simple descriptive overview of various criteria for the lagoon related options for wastewater treatment in Fort Resolution.

Table 2: Comparison of Lagoon Cost and Performance Information

	Option 1 - Single Lined Cell	Option 2 - Two Lined Cells with External Primary Cell	Option 3 - Two Lined Cells with Internal Primary Cell and Curtain Wall	Option 4 – Two Lined Cells with Aligned Primary Cell	Option 5 - Dalhousie Process (Three Lined Cells and Polishing Filter)
Anticipated Process Performance mg/L	BOD 8 - 20 TSS 20 - 80	BOD 4 - 8 TSS 10 - 20	BOD 4 - 8 TSS 10 - 20	BOD 4 - 8 TSS 10 - 20	BOD <30 TSS <30 theoretical performance
Capital Cost	Lowest	Mid-Range	Mid-Range additional construction cost with curtain wall	Mid-Range potential construction cost saving with aligned cells	Highest additional costs for multiple cell construction
Operation and Maintenance Cost	Regular inspections and annual discharge by pump or gravity	Regular inspections and annual discharge by pump or gravity	Regular inspections and annual discharge by pump or gravity	Regular inspections and annual discharge by pump or gravity	Regular inspections and annual discharge by pump or gravity with additional maintenance for polishing filter
Simplicity of Operation and Maintenance	Simplest with control of single discharge	Simple with control of multiple discharge systems	Simple with control of multiple discharge systems	Simple with control of multiple discharge systems	Less Simple with operation of secondary cells and polishing filter
Aesthetic Impact	Visible from access road	Visible from access road	Visible from access road	Visible from access road	Visible from access road
Constructability	Simplest with single cell construction	Simple, but independent primary cell	Simple, but independent primary cell	Simple and aligned primary cell	Least Simple with construction of 3 cells
Service Life	Sludge removal every 10 - 15 years from entire cell	Sludge removal every 5 - 10 years from smaller primary cell	Sludge removal every 5 - 10 years from smaller primary cell	Sludge removal every 5 - 10 years from smaller primary cell	Sludge removal every 10 - 15 years and annual maintenance of polishing filter

Notes:

1. Environmental risk the same for all options in consideration that all configurations include lined cells
2. Space for expansion the same for all options
3. Accessibility generally the same for all options

Based on the simple cost and performance information presented in **Table 3,** on the lagoon systems, the two-cell lagoon process configuration (Option 4), with an aligned primary cell was selected for the Hamlet of Fort Resolution as the most appropriate option. The aligned primary cell has a simpler construction, and therefore may have a lower capital cost. The capacity of the proposed sewage lagoon is 32,000 m^3 based on the sewage generation projection.

7 Sewage Lagoon and Sewage Lagoon Discharge Layout

7.1 Horizontal and Vertical Configurations

The overall footprint of the lagoon is 315 meters by 85 meters, with a 2.5 meter depth. Various elevations of the lagoon base were reviewed in consideration of the cut and fill balance for the construction of the lagoon berms, and the in-situ ground conditions. The test pits observed groundwater seepage within 2 metres of the surface, and it was also observed that the ground above this seepage was “damp to moist”. These observations suggest a fluctuating groundwater table that could seasonally, particularly in the spring, be very close to the ground surface. To avoid potential issues with groundwater, the need for a subdrain system, and to protect the liner system from “floating”, the base of the lagoon has been set very close to the ground surface for the majority of the lagoon footprint.

7.2 Liner Considerations

A synthetic liner system will be required for the lagoon to provide retention for the sewage. Several liner configurations were reviewed in consideration of the retention requirements and the base material. A redundant liner to the primary liner was considered as a leak detection provision, however this configuration is considered to have an unnecessary level of redundancy because of the sandy in-situ base and the expected high performance of a single liner system.

The in-situ sandy base material provides an ideal liner base for long term protection, and support of the liner system. The current installation practices of liner systems provide a very high degree of quality assurance, and quality control, therefore a redundant liner system is not needed. As well, number of liner segments for on-site assembly may be minimized with current factory fabrication techniques.

The recommended liner is a 60 mil LLDPE (Linear Low Density PolyEthylene) material with cold temperature rating to minus 40°C. An LLDPE liner may be installed with as little as 12 panels because of the opportunity for factory fabrication of larger and lighter panels.

7.3 Lagoon Discharge

The lagoon will seasonally discharge into a wetland area to the north of the lagoon site, that ultimately discharges into Nagle Bay, which in turn flows into Great Slave Lake. The wetland will provide supplemental treatment to the effluent. The discharge may be by gravity or pumped from the secondary cell of the sewage lagoon system.

A pumped discharge may be configured with a portable pumping system that is mobilized in the late summer to the lagoon site every year. A reasonable discharge period would be approximately 12 weeks during the late summer / early fall period. The pumping may consume 1000 to 1500 litres of fuel during this period, and the pump would require periodic daily inspections depending upon the hours of pumping operation.

A gravity discharge may be configured with a 0.4 percent slope with a 150 mm or 200 mm, 550 metre discharge pipeline **(See Figure 5)** to a wetland area.

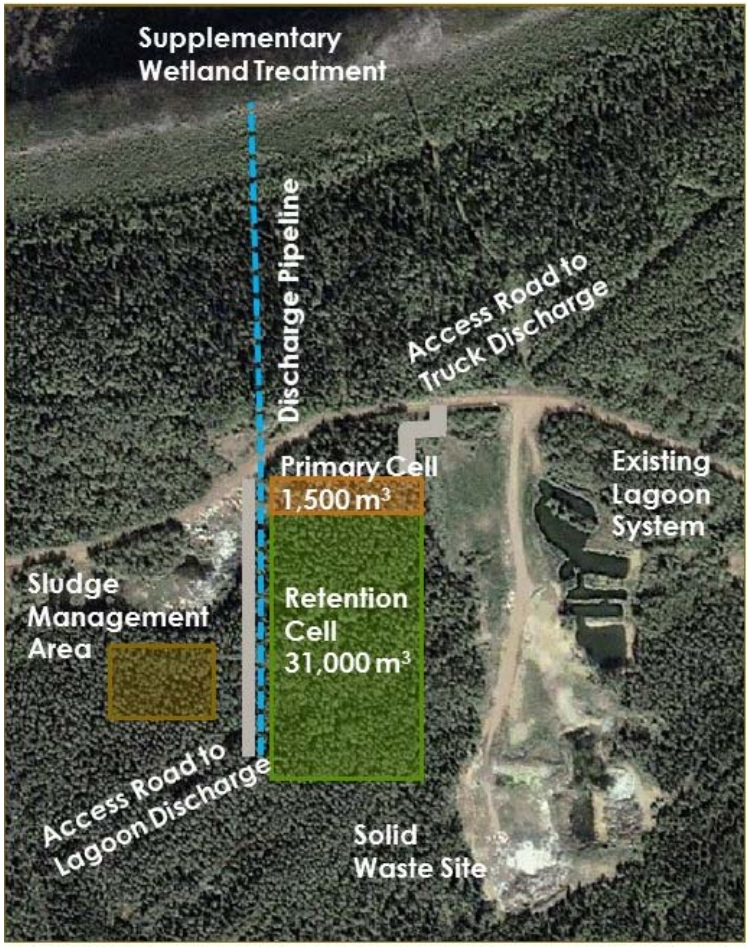

Figure 5: Lagoon and discharge configuration for Fort Resolution sewage lagoon.

8 Wetland Supplementary Treatment

The lagoon discharge will be directed to natural wetlands north of the lagoon, which will provide supplementary treatment the effluent before it flows naturally to Nagle Bay, which ultimately discharges into Great Slave Lake. Approximately 10 ha of wetland is in the flow path from the new lagoon to Nagle Bay. The discharge from the lagoons through the wetland is proposed to be continuous during the summer season, of approximately three months' duration. At a 30 cm, operating depth, the wetland will provide about 50 days' detention.

To ensure that the wetland surface area is accessed by the discharge flows, the discharge may be directed to the centre of the wetland, which will accommodate a distribution of lagoon flows along the southern border of the wetland. Water will proceed through the wetland to an existing outlet stream, which will transport treated water plus other runoff about 300 m to the Lake.

Flow from the lagoon to the wetland may be by gravity or by pumping, as circumstances dictate. Pumping provides a greater measure of flow control, but gravity discharge requires less energy and equipment.

The pollutant reductions in those six systems were of 47 to 94% $cBOD_5$; 57 to 96% COD; 39 to 98% TSS; >99% TC; >99% E. coli; 84–99% NH3-N (Ammonia Nitrogen); and 80 to 99% TP (Total Phosphorous).

Table 3: Anticipated Performance of Wetland with Lagoon Discharge Upper Limit

BOD, mg/L Discharge from Lagoon	BOD, mg/L Anticipated Effluent Range	TSS, mg/L Discharge from Lagoon	TSS, mg/L Anticipated Effluent Range	Ammonia mg N/L Discharge from	Ammonia mg N/L Anticipated Effluent Range
8	0.3 – 4.2	20	0.4 - 12	3	0.03 - 0.5

9 Capital Cost

The opinion of probable cost for the Fort Resolution sewage lagoon facility, based upon the completed preliminary engineering is $2.15 million. The cost breakdown for the lagoon includes the site preparation cost of $240,000, the berm construction (fill) cost of $750,000, the access road costs of $100,000, the liner system (LLDPE liner) cost of $300,000, and the discharge pipeline cost of $65,000.

10 Conclusions

- A two-cell lagoon system may provide an effluent quality that meets the current effluent quality standard in the Fort Resolution water licence for a 20 year design horizon.
- A sewage lagoon with a geomembrane liner is necessary.
- The wetland discharge area adjacent to the lagoon will provide significant supplementary treatment to the lagoon discharge.
- The in situ materials are suitable for the construction of the facility, but the geotechnical conditions on the site will require special attention because of the position of the groundwater table and its seasonal influence of the in situ soils, particularly as it applies to the construction of the berms.
- The “opinion of probably cost” for the facility is $2.15 million.