**Introduction**

Grise Fiord, NWT, is an Inuit community located on the southern coast of Ellesmere Island at latitude 76°15’N and longitude 83°01’W. Grise Fiord is Canada’s most northerly community, excluding research, weather or military facilities.

The average temperatures in Grise Fiord range from a high and low in July of 10°C and 2.2°C to a high and low in January of -28.2°C and -35°C; the average annual temperature is -16.6°C. The total precipitation consists of 152.4 mm of snow and a trace of rain, and the prevailing winds in the community are southeast at 18 km/h.

The settlement is situated on a narrow strip of beach near the mouth of the Grise Fiord. The surficial soils in the area consist of free-draining gravel deposits and the vegetation consists of mosses, lichens and grasses.

The construction season within the community is limited to a window between early July to early September. This window may be shortened considerably, however, depending upon the prevailing weather and project type.

The original sewage treatment system serving the community was constructed with two detention cells, and filled by sewage pumpout trucks. The lagoon system was designed to drain from a primary cell to a secondary cell, and then exfiltrate from the secondary cell. The lagoon was completely frozen during the winter months, and during the limited summer months, the lagoon was totally free of ice for a period of only 6-8 weeks. The lagoon was undersized, which resulted in several breaches of the berm, and several sewage spills.

**Preliminary engineering**

A preliminary engineering review (UMA Engineering Ltd., 1993) of potential wastewater treatment technologies eliminated mechanical systems in this application based on Territorial Government terms of reference for small municipal wastewater systems.

A single cell retention, earth construction lagoon with permanently frozen core berms, and a seasonal effluent discharge was recommended as the appropriate wastewater technology for Grise Fiord. Considerations for the design of the lagoon were the height of the structure above the existing ground, the necessary depth of any excavations, and the configuration and orientation of the structure. These considerations were influenced by the availability and cost of borrow material, the difficulty of excavating into permafrost and the physical limitations of the site itself.

The lagoon was configured in a rectangular shape to accommodate orientation across the existing slope. This configuration and orientation reduced the potential fill required to extend the lagoon down the 7 percent slope.
of the site, and maintained the existing overland dis-
charge area for the lagoon. This configuration also
required an excavation on the uphill side of the site,
and construction of a berm on the downhill side.

The necessary active storage volume of the lagoon for
a seasonal discharge was estimated to be 6,700 m$^3$ (pre-
dicted population of 219 in the year 2013, with a gener-
ation rate of 85 litres/capita/day). In consideration of
the difficulties encountered with trying to remove
sludge from existing lagoons in the NWT, because the
sewage sludge may remain frozen year round, an addi-
tional 0.5 metres was added to the depth to accommo-
date sludge accumulation over the 20 year design life.
In addition, a further volume allowance of 5% for snow
accumulation was added, producing a total of 7,480 m$^3$
(97 m x 27 m at the base of the lagoon).

Consultation to satisfy all of the applicable regula-
tions, and regulatory agencies was completed at the
time of the preliminary engineering. These agencies
included the GNWT Department of Health, Indian and
Northern Affairs Canada, Environment Canada,
Fisheries and Oceans Canada, the Nunavut Water
Board, and the GNWT Department of Transportation.

**Detailed design**

Based on site excavations, the subsurface soils were
characterized to vary between a coarse gravel with cob-
bles, a coarse sand with organic silt, to sandy silt with
occasional cobbles. The depth of the thawed layer var-
ied between 0.63 m to 1.37 m at the time of the site exca-
vations.

A thermal analysis was completed (Thurber
Engineering Ltd., 1994) and confirmed that the site
materials were feasible for the construction of a sewage
lagoon with a frozen core berm. The geothermal analy-
sis was carried out assuming that the berm would be
built of the available silty sand, with an initial assumed
permafrost temperature of -12°C. The thermal parame-
ters assigned to the berm and foundation are presented
in Table 1.

The one-dimensional thermal analysis suggested that
a 0.7 m seasonal depth of thaw may be expected, based
on a soil moisture content of 10%. Greater depths of
thaw could, however, be expected in areas where the
soils were very coarse and hence well-drained, or in
areas where groundwater flow occurred above the per-
mmafrost.

Based upon the thermal analysis, the preliminary
engineering and the detailed site information, a design
was completed for a berm structure with a minimum
crest width of 5 m, 4:1 horizontal to vertical down-
stream slope and a 3:1 horizontal to vertical upstream
slope. The overall design criteria are presented in
Table 2.

**Table 2. Design Criteria for Grise Fiord Sewage Lagoon**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Horizon</td>
<td>20 years</td>
</tr>
<tr>
<td>Active Storage Volume</td>
<td>6,700 m$^3$</td>
</tr>
<tr>
<td>Total Storage Volume</td>
<td>7,500 m$^3$</td>
</tr>
<tr>
<td>Number of Cells</td>
<td>One</td>
</tr>
<tr>
<td>Liquid Depth (Active Zone)</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Freeboard</td>
<td>1 m</td>
</tr>
<tr>
<td>Storage Considerations</td>
<td>Allowance for Sludge (0.5 m) and Snow (5%)</td>
</tr>
<tr>
<td>Geometry</td>
<td>2:1 (length/width)</td>
</tr>
<tr>
<td>Exterior Side Slopes</td>
<td>4:1</td>
</tr>
<tr>
<td>Interior Side Slopes</td>
<td>3:1</td>
</tr>
<tr>
<td>Liner</td>
<td>No</td>
</tr>
<tr>
<td>Erosion Protection</td>
<td>Yes</td>
</tr>
<tr>
<td>Dike Width</td>
<td>5 m (freezeback)</td>
</tr>
<tr>
<td>Soil Density</td>
<td>95% SPD</td>
</tr>
<tr>
<td>Overflow Structure</td>
<td>Yes</td>
</tr>
<tr>
<td>Discharge Structure</td>
<td>Yes (for annual pumpout)</td>
</tr>
</tbody>
</table>

**Construction in 1996**

The expected construction methodology for the
lagoon was to utilize the excavated material from the
lagoon site for berm construction. However, once con-
struction began in July of 1996, it was evident that the
site material could not be used for the frozen berm core
because the extent of the fine material was much less
than anticipated (UMA Engineering Ltd., 1996). In
response to the site condition, a borrow site of fine silty
sand for the berm core was identified behind the com-

Community airstrip.

Construction of the lagoon proceeded very slowly in
1996 due to limited equipment availability and difficul-
ty of excavating into permafrost. The 1996 progress
included removal of the overburden (2,426 m$^3$ of mate-
rial), excavation toward the design grade of 31.0 metres
(5,816 m$^3$ of material), construction of an access road
(80 linear metres), perimeter ditching (120 linear
metres), and limited construction of the berms
(1,271 m$^3$). The excavation toward the design grade
varied from an elevation near 31.0 metres (at grade) in
the northwest corner, to an elevation near 34 metres in
the southeast corner.
During the construction in 1996, it was also noted that seepage through the base of the site could occur on a seasonal basis. This conclusion was reached based upon the observation that surface runoff was entering the site, infiltrating in the construction area, and reappearing in a downslope area outside of the site.

The construction was implemented on a negotiated basis with the Hamlet of Grise Fiord. This type of contract is used in the north as a means of providing local employment and training.

**Discussion and analysis**

A fundamental change in the construction methodology was incorporated into the project based upon the site conditions encountered. This change was the use of borrow material as the material for construction of the berm core. This change in methodology was due to the coarse nature of the majority of in situ material, which would limit the compaction within a berm structure, and in turn increase the permeability of the berm structure. The borrow material available was found to be significantly finer, and thus a better choice for the core structure. The in situ material, however, was still suitable for the armouring the berm.

The design section of the berm was revised to incorporate the use of borrow material for the berm core, and the use of the in situ material for armouring the berm structure (see Figure 1).

The potential problem associated with seepage through the lagoon base could require the placement of a layer of the less permeable borrow material, however, further observations are required before a final conclusion is reached and remedial action implemented if necessary.

Based upon the in situ material constraints and equipment limitations, the following two construction variations were also reviewed in advance of the 1997 construction season. In both cases, the borrow material would be utilized as the berm core, and the in situ material should be used as the berm armour.

1. Excavation of the site into permafrost in accordance with the original design (base of lagoon at 31.0 m).
2. Reduced excavation for the site into permafrost to a base elevation of 32.5 m and an increase in the berm heights.

The sitework of 1996 completed excavations into the permafrost to various elevations. The maximum depth of excavation into the permafrost in 1996 was approximately 2.0 m, therefore, a reasonable expectation for excavation into permafrost in the coming year would be 1.5 m, or to an elevation of 32.5 m given the surrounding 34 m maximum ground elevation. With respect to Option 2, in order to maintain the design depth of 3.5 m (1 m freeboard, 2 m of active, and 0.5 m of sludge storage), the top of the berm would have to be raised accordingly to an elevation of 36 m.

Two analyses were undertaken for Options 1 and 2. The first analysis was an estimated capital cost of lagoon excavation and fill (see Table 3), and the second was the estimated schedule to construct (see Table 4). The capital cost analysis was based upon the approximate volume estimates for core material (borrow), cut material (stockpiled), and armour material (placed from stockpile).

**Conclusion**

Based on the analyses, Option 1 had a reduced capital cost for the overall construction of the lagoon over
Option 2, however, this savings would only be in the range of 15% based upon the capital cost estimates. Option 2 offered a better schedule for construction with potential completion possible in 1997, depending upon the performance of the community equipment and staff.

The increased permafrost excavation for Option 1 posed a risk that the excavation would not be completed because of the equipment limitations, or that the excavation would be delayed even further while waiting for the permafrost to thaw.

Based upon the analyses, the best technical solution to the project was Option 2, which was a combination of continued site excavation, the use of in situ materials for berm armour, and borrow material for berm core construction.

**References**


