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Project No: 0308-006-01

Mr. David Hohnstein
Acting Director, Technical Services
Nunavut Water Board
P.O. Box 119
Gjoa Haven, NU X0B 1J0

Dear Sir:

**RE: NWB 3BM-ARC0810 ARCTIC BAY SEWAGE LAGOON WATER LICENSE AMENDMENT – GEOTECHNICAL AND GEOTHERMAL REVIEW**

## 1.0 INTRODUCTION

Further to your request, BGC Engineering Inc. (BGC) has completed a review of geotechnical and geothermal issues from documents filed for an amendment application for the Hamlet of Arctic Bay's water license (NWB 3BM-ARC0810). A list of the documents reviewed is attached. No construction specifications related to the construction of the sewage lagoon facility have been received to date.

As part of our review, we addressed the following general questions:

1. Does the design effort reflect a standard of practice and level of effort appropriate?
2. Are there obvious technical deficiencies related to water issues?
3. What are the key uncertainties?
4. What, if anything, requires ongoing attention/monitoring?

The geotechnical design of the sewage lagoon was carried out by Trow Associates Inc. (Trow). Naviq Consulting Inc. (NCI) was subcontracted by Trow to conduct geothermal analyses to support the geotechnical design.

## 2.0 BACKGROUND

Trow was retained by the Department of Community and Government Services, Government of Nunavut, to review the existing sewage lagoon and complete detailed planning and design for the construction of a new sewage treatment facility for the Hamlet of Arctic Bay, Nunavut. The existing sewage lagoon is located 2 km east of the community and is to be decommissioned.

According to Trow (2008b), the existing facility currently does not meet the storage requirements of the Hamlet nor does it meet the treatment requirements of the Hamlet's water license. The new sewage facility is intended to meet both the 20-year needs of the Hamlet and provide sewage treatment to meet the requirements of the Hamlet's water license as issued by the Nunavut Water Board.

Trow is recommending that a new sewage lagoon, with additional treatment through natural wetlands, be constructed in a small valley to the northwest of the existing facility. Trow also recommends that the sewage lagoon be designed to drain to the northwest towards Victor Bay and that the lands between the sewage lagoon and Victor Bay remain as undisturbed tundra and act as filterstrip wetlands.

## 3.0 SITE DESCRIPTION

The existing lagoon was constructed in 1976 but is not currently being operated by the Hamlet (Trow, 2008b). Sewage is currently discharged directly into the ice pack area. Site A was recommended by Trow as the preferred of three alternative sites proposed by the Government of Nunavut, Department of Community and Government Services (CGS) for the construction of the new lagoon. It is sited in a relatively flat valley between two hills. It is proposed to construct two earthfill berms, one at each end of the valley. To the northwest of the valley is a significant natural wetlands area. The valley drains to the northwest towards Victor Bay and to the southeast towards Admiralty Inlet (Trow, 2008a). The area of the proposed lagoon is approximately 100 m wide, 350 m long and 5 m deep. A small pond is located within the proposed lagoon site. The lagoon is designed with 1.0 m freeboard.

Three boreholes were drilled on the immediate downgradient (south) side of the ice field berm (Trow, 2008d). From 1.2 m to at least 1.7 m of fill was encountered in the three boreholes. Two other boreholes were drilled further downgradient of the lagoon/ice field.

Nine boreholes were drilled in the vicinity of the proposed lagoon (Trow, 2008a). The area is reportedly covered with 50 to 400 mm of topsoil and peat. Underlying soils are generally comprised of ice-rich, layered sand and gravel, silty sand, and silty sand till which extends to the bedrock surface. Bedrock (gabbro or quartzite) was encountered in five of the nine boreholes and was characterized as very poor to good quality. Where encountered, depths to bedrock varied from 1.5 to 3.8 m. Rock sampled at the sides of the valley was characterized as poor quality (Trow, 2008b). No pore water salinity measurements were taken from any of the recovered soil samples.

Ice layers, varying in thickness from 0.5 m to 3.7 m, were encountered in the majority of the boreholes. Thermistors were installed in two boreholes: BH-7, located within the proposed lagoon, and BH-10, located near the south abutment of the northwest berm. The ground temperature cables extended to 4.8 m and 3.0 m depth below the ground surface, respectively. One set of ground temperature measurements was taken on September 18, 2007, almost three weeks after the thermistors were installed. Ground temperatures at 3 m depth below ground surface and deeper ranged from -6.5$^{o}$C to approximately 0$^{o}$C at the two borehole locations. NCI (2008) commented that the measured temperatures between the two boreholes are divergent and appear warmer than would be typically expected.

The mean annual air temperature over the period of 1977-2007 is estimated to be -15$^{o}$C, based on the historical climatic record from the nearest long-term meteorological station at Nanisivik Airport, located approximately 20 km to the southeast (NCI, 2008). NCI also noted that local soils are expected to be saline, referencing data from Hivon and Sego (1993). Given the lack of site-specific pore water salinity measurements, NCI assumed a salinity of 20 parts per thousand (ppt) for geothermal analysis, corresponding to a freezing point depression of approximately -1$^{o}$C.

RWDI (2008) reported that the prevailing winds in the Arctic Bay region is from the southeast, east, northwest, and north. RWDI also reported that the existing snowdrift conditions in the proposed sewage lagoon area are poorly understood because it is located beyond the developed area of the Hamlet.

### 3.1 Comments

Boreholes 4 and 5 in the Sewage Lagoon Decommissioning report (Trow, 2008d) are located in areas different from the New Sewage Lagoon report (Trow, 2008a). Yet, the borehole logs and field descriptions of these boreholes are identical in each report. Clarification is recommended.

In the absence of site-specific measurements, the assumption of a uniform pore water salinity of 20 ppt for the foundation soils is considered reasonably conservative.

There was no description of the surficial geology or geomorphology of the proposed sewage lagoon site. The areal extent of the ice-rich permafrost foundation along each berm alignment has not been delineated. From the aerial photograph base map presented in Figure 1 of the Design Brief (Trow, 2008b), there appears to be ephemeral streams northwest of the pond. It is unclear whether or not streams cross the proposed berm alignments, and if so, whether or not deepened taliks exist in the vicinity of these streams. Furthermore, there was no description of the pond itself, and of the potential impacts of a talik developing around this pond and affecting the water-retention capability of the lagoon. The possible existence of taliks, and how they may affect the lagoon design, should be addressed.

As NCI (2008) commented, the measured ground temperatures between the two boreholes are divergent. With such short ground temperature cables, additional measurements at different times of the year would have been useful in better understanding the geothermal regime and calibrating the geothermal model.

Environment Canada's meteorological station at Nanisivik is located at Elevation 642 m, while the Arctic Bay sewage lagoon is at approximately Elevation 96 m, and closer to the sea. As such, air temperatures at Arctic Bay can be expected to be warmer than at Nanisivik due to the moderating effect of the coastal waters. Furthermore, snow pack conditions may differ (RWDI, 2008). The effects of these differences should be addressed.

## 4.0 GEOTHERMAL ANALYSES

Geothermal analyses were conducted by NCI. The geothermal model was calibrated to a mean ground temperature of -6.5$^{o}$C using representative climate data from Nanisivik.

An average air temperature warming rate of 0.08$^{o}$C/year was adopted in the geothermal analyses to consider the effects of long-term climate change.

Thermal modeling considered the lagoon contents at a constant +1$^{o}$C temperature year-round.

Two-dimensional geothermal analyses were carried out assuming the following berm geometry:

- Crest width = 4 m
- Berm height = 5 m
- Downstream slope of berm = 3.0H:1.0V
- Upstream slope of berm = 3.0H:1.0V

The results of the geothermal analyses led to the following conclusions and recommendations by NCI:

- The dyke is predicted to freeze to ambient conditions by mid-winter following dyke construction (assumed in July).
- Seasonal thawing of the containment berm precludes a "frozen-core" or "ice-dam" as the means of containment.
- The primary barrier to seepage should be a liner or other impermeable system, located along the upstream face of the dyke and keyed beneath the upstream toe of

the dyke to a depth of approximately 2.0 m below the native ground surface. The key trench should be located approximately 5 m horizontally from the upstream berm toe.

A secondary cooling system, such as thermosyphons, is not supported by the current analyses but could be installed at a later date should monitoring of dyke and subgrade temperatures indicate greater warming than predicted.

## 4.1 Comments

Figures 4-1 and 4-2 of the NCI report presented the predicted ground temperatures after 20 years of lagoon operation with and without climate warming, respectively. It is assumed in the discussion below that these figures show temperature distributions at the same time of year. Temperatures downstream of the berm, in undisturbed terrain and at 10 m depth, appear colder than -11$^{o}$C in Figure 4-1 and colder than -7$^{o}$C in Figure 4-2. The ground temperature at 10 m depth in the first case is well colder than the minimum temperature (approximately -7.7$^{o}$C) presented in the calibrated geothermal profile in Figure 3-3. The temperature difference between the two analyses (~ 4$^{o}$C) at this depth is much greater than would be expected under the climate warming scenario used (+1.6$^{o}$C/20 years). Furthermore, the locations of the 0$^{o}$C to -4$^{o}$C isotherms beneath the centre of the berm (Distance = 32 m) are practically identical between the two figures, which is unexpected because it suggests that the geothermal regime in the berm shows little response to climate warming. Finally, the location of the -1$^{o}$C isotherm downstream of the berm (undisturbed terrain) is less than 1 m depth while the calibration temperature profile (Figure 3-3) shows it to be greater than 2 m depth at the warmest time of year. BGC recommends that the results of the geothermal analyses be reviewed by Trow and NCI to address and comment on these apparent discrepancies.

No details were provided in NCI's report regarding input soil conditions (e.g., soil profile, soil/thermal properties, snow cover) and ground surface parameters used in the geothermal analyses. These parameters should be described to demonstrate that they are consistent with the design sections used in the stability analyses.

Given prevailing winds from the northwest and southeast, as reported by RWDI (2008), there is a potential for deep snowpack to develop at the toes of the berms. The insulating effect of thick snow pack could result in ground temperatures in the vicinity of the berm toe being warmer than predicted, thereby possibly adversely affecting slope stability. The results of the geothermal analyses do not appear to have taken snow drifting into consideration and thus may predict colder ground temperatures than might be experienced due to the insulating effect of the snow. This matter should be clarified by Trow and NCI.

NCI recommends that sealed PVC casings be installed through the dyke structure and into the subgrade soils into which thermistor cables be installed to monitor ground temperatures. NCI also recommends that select casings be battered to the upstream side of the berm. Design Drawing DE-2 shows the PVC casing for the thermistors as vertical and penetrating only 2 m into the subgrade soils. It is BGC's opinion that some of the thermistors should extend deeper into the subgrade soils to better understand and monitor the influence of the lagoon facility on the geothermal regime. The discrepancy between the NCI recommendation and the Trow drawings needs to be clarified, and the recommended depth of thermistor cables below original grade needs to be reviewed.

The design of the facility is based on the premise that the liner and permafrost foundation are impermeable barriers to seepage and the liner must be keyed into frozen soils to provide containment. Given the importance of the latter detail, BGC recommends that thermistors also be installed in the liner key trench to verify that the soil remains frozen around the liner.

NCI (2008) recommended that the key trench be located approximately 5 m horizontally upstream of the berm toe, yet the berm liner detail on Drawing DE-2 shows the key trench located approximately 3.5 m horizontally from the toe, which is inconsistent with the geothermal recommendations. This detail should be reviewed.

# 5.0 GEOTECHNICAL ASSESSMENT

## 5.1 Assessment of Existing Lagoon

Sludge and groundwater samples were obtained from the existing lagoon and analyzed for metals, VOCs and hydrocarbons. Based on analytical results from these samples, Trow (2008d) concluded the following:

- There are no sites within the vicinity of the existing lagoon identified to have been affected by waste spills;
- The underlying sludge is not adversely impacted by contaminants and the potential for hazardous material to exist within the decommissioned lagoon cell is minimal;
- The potential for future impact beyond the lagoon is minimal;
- The proposed drainage pattern is designed to promote surface drainage across the site;
- The depth of sludge is estimated at approximately 0.1 m;
- The fill should be well-graded material with a maximum size of 200 mm.

Based on the above observations, Trow assessed that there was minimal risk of contamination from the existing sewage lagoon. Therefore, the proposed remediation plan for the lagoon cell is to fill the cell to cover the sludge and encapsulate the sludge in frozen (permafrost) granular material. The report text indicates that the proposed finished grade shall have a minimum of 1.5 m of cover, while the cross-sections in Figure 3 shows the fill as being 1.5 m ±. This design detail needs to be clarified.

## 5.2 Slope Stability

Trow (2008a) conducted slope stability analyses to determine the appropriate slope angles at which the berm would be stable. Analyses were carried out for the berms located at each end of the valley. Stability analyses were carried out based on shear strength parameters for unfrozen soils, and assuming that the underlying foundation soils (including beneath the lagoon, as inferred by the ice layers present) would be maintained in a perennially frozen condition. The crest width of the berm was assumed to be 5 m. It was assumed that the berm would be constructed with silty sand and gravel fill with some cobbles and boulders. Berm fill and foundation soils were assigned a friction angle of 34 degrees. A layer of ice was incorporated in the foundation soils and assigned an effective cohesion of 100 kPa. The design section's ground surface appears to slope at approximately 1 percent grade (upstream for the northwest berm B-B and downstream for the southeast berm A-A). The modeled stratigraphy shows the surficial sand and gravel layer becoming thinner from upstream to downstream in Section A-A, and from downstream to upstream in Section B-B. The soil layers beneath the surficial sand and gravel cover, including the ice layer, are assumed to be of uniform thickness and constant elevation for the entire cross-section.

Limit equilibrium slope stability analyses were carried out for static and seismic loading to satisfy minimum factors of safety of 1.5 and 1.1, respectively. For seismic loading, a pseudostatic analysis was carried out assuming a peak ground acceleration of 0.05g.

The recommended slope angle of 3.0H:1V for the upstream slope was based on satisfying minimum factor of safety requirements under static loading and with the lagoon drained for the southeast berm. The results of stability analyses under the same loading conditions were not presented for the northwest berm. The same slope angle was recommended on the downstream slope for both berms based on static loading and steady state seepage.

Although not specified in the design reports, Drawing DE-1 indicates that the recommended liner is a geosynthetic clay liner (Bentomat ST or equivalent).

## 5.3 Seepage Containment

NCI (2008) noted that there are uncertainties regarding the ability of the soil and rock surrounding the lagoon impoundment to remain impermeable over the design life of the facility. NCI suggested installing impermeable liners over each side of the valley to reduce the potential for lateral migration of lagoon contents. Trow (2008b) expanded on this concept by recommending that the liner be keyed into permafrost or sound rock at the bottom of the side slopes. Design Drawing DE-2 shows the liner keyed 2 m into existing ground.

## 5.4 Comments

The proposed abandonment plan for decommissioning the existing lagoon is to add a cover of fill materials over the sludge to encapsulate the sludge in frozen (permafrost) granular material. The Designers should clarify if maintaining the sludge in a permafrost condition is a design requirement or simply an added benefit. If it is the former, geothermal analyses should be carried out to confirm that the proposed cover thickness (1.5 m) is sufficient to encapsulate the sludge in permafrost, and if so, for how long a design period, considering the effects of climate change.

It is unclear from the geotechnical report how the effective cohesion of the ice layer and the design peak ground acceleration parameters were derived. A cohesion value of 100 kPa for the ice layer appears rather high considering that the active layer likely reaches the top of the ice layer each year in the undisturbed terrain downstream of the berm and the ice layer is predicted to warm and thaw beneath and upstream of the upstream berm toe.

Stability analyses were carried out for a berm crest width of 5.0 m, although the Design Brief indicates that the recommended berm crest width is 4.0 m. The Designers should verify slope stability for the recommended berm crest width of 4.0 m.

Given the thick (3.7 m, and possibly more) ice layer encountered in Borehole BH-11 along the northwest berm alignment, there is a high potential for creep deformation due to surcharge loading from the embankment and warming of the permafrost foundation from the lagoon. No estimates of the magnitude of thaw settlement and creep strain beneath the upstream and downstream toes have been made, nor has the potential impact of tearing of the upstream liner due to berm deformation been assessed. These should be addressed.

Given the potential for thaw settlement and creep strain, a settlement and displacement survey monitoring program is recommended.

The source and type of fill used for berm construction has not yet been finalized. Specifications for the fill gradation should be provided to the NWB for review. Apart from serving as erosion-protection, the use of oversize materials for berm construction is not recommended, given that it could result in poor compaction.

BGC agrees with the Designers that the sewage effluent could migrate laterally into the sides of the valley. The Designers proposed keying the liner into the permafrost or sound rock at the bottom of the side slopes. The areal extent of the side-slope liner has not been described. The liner detail in Drawing DE-2 shows the liner buried in a 2 m deep key trench and backfilled with pervious granular fill; this implies that permafrost is required to cut off seepage through the key trench and may be inappropriate for the case where rock is encountered and active layer depths may be deeper than 2 m. The liner detail appears to have been extended from geothermal analyses of the berm. This approach may be erroneous because of differences in vegetation cover, subsurface conditions, and slope aspect, among others. Specific geothermal analyses are recommended to confirm this design. Furthermore, design details for the abutments are recommended.

## 6.0 SUMMARY AND RECOMMENDATIONS

Table 1 summarizes BGC's assessment of the geotechnical and geothermal design of the proposed new lagoon facility.

**Table 1 Summary of Review of Geotechnical and Geothermal Issues**

| Issue | Comment | Recommendation |
|---|---|---|
| Technical Deficiencies | The results of the geothermal analyses appear inconsistent with the methodology described. | The results of the geothermal analyses should be reviewed, and the design needs to better incorporate the results of the geothermal analyses. |
| | Derivation of the value of the effective cohesion for ice layer used in stability analyses has not been adequately described or justified. | Provide basis for strength of ice used in stability analyses, noting that near the top of the ice layer, temperatures may be as warm as 0°C. Test sensitivity of cohesion value on stability analyses. |
| Key Uncertainties | Derivation of design stratigraphic sections used in stability analyses has not been discussed. Design section does not appear to consider the results of the geothermal modeling, parcticularly for the ice layer. | Provide basis for design sections used. Test sensitivity of depth and temperature of ice layer on stability analyses. |
| | Impermeable liner installed along side valleys of lagoon impoundment to minimize lateral migration of effluent. Liner to be keyed into permafrost or sound rock. | Rock is reportedly of poor quality; depth of sound rock or permafrost may be deep (greater than 3 m depth). If keying into permafrost, geothermal analyses should be carried out to confirm that the proposed 2 m key trench depth is appropriate. |
| | Effects of predicted long-term permafrost thaw and warming beneath the upstream toe and lagoon facility on berm stability and settlement have not been discussed. | The effects of long-term thaw settlement and creep strain, parcticularly on liner integrity, should be addressed. |
| | The source and quality of borrow materials for berm construction have not been finalized. | Specifications for fill materials used for berm construction should be forwarded to the NWB for review. |
| Ongoing Attention/ Monitoring | The layout of thermistor strings and sampling wells has been presented in Drawing L-1, with details shown in Drawing DE-2. No settlement and displacement monitoring program has been proposed. | To better understand and monitor the influence of the lagoon facility on the geothermal regime of the berm and permafrost foundation, the 2 m penetration depth into the subgrade soils should be reviewed. Additional thermistors should be installed in the lined key trench. A survey monitoring program is also recommended. The frequency of measurements and trigger values for remedial action will need to be described. |

On the basis of the deficiencies and uncertainties noted in Table 1, BGC considers that the Trow submission for the water license amendment of the Arctic Bay sewage lagoon is inadequate and recommends further geotechnical and geothermal assessments to confirm the suitability of the proposed design. BGC would recommend that the NWB reject the submission until the noted deficiencies and uncertainties have been addressed and reviewed. We have included comments related to the documents filed so that these may be responded to by Trow in the course of re-submitting the design documents for NWB approval. The above-noted issues relate to the overall water containment capability of the proposed sewage lagoon and the potential impacts on surface and ground water resources, which are within the mandate of the NWB. When they become available, construction specifications should be submitted to and reviewed by the NWB to ensure that the recommendations proposed by the Designers are implemented in the construction of the facility.

## 7.0 CLOSURE

BGC Engineering Inc. (BGC) prepared this letter for the account of the Nunavut Water Board. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of report preparation. Any use which a third party makes of this letter, or any reliance on decisions to be based on it are the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this letter.

Trow are the Engineers of Record for this project and are wholly responsible for the design and performance of the noted project and its components. None of the review comments and recommendations provided herein by BGC absolves Trow of that responsibility and again, BGC accepts no responsibility for any damages suffered by third parties based on the comments provided herein.

As a mutual protection to our client, the public, and ourselves, all reports and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this report or any data, statements, conclusions or abstracts from or regarding our reports and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. If this report is issued in an electronic format, an original paper copy is on file at BGC Engineering Inc. and that copy is the primary reference with precedence over any electronic copy of the document, or any extracts from our documents published by others.

We trust that the information contained in this letter meets your current requirements. Should you have any questions, please contact BGC at your convenience.

Respectfully submitted,
**BGC ENGINEERING INC.**
**Per:**

| | Reviewed by: |
|---|---|
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| Jack T.C. Seto, M.Sc., P.Eng.<br>Senior Geotechnical Engineer | Kevin W. Biggar, Ph.D., P.Eng.<br>Senior Geotechnical/Geoenvironmental Engineer |

JTCS:KWB/syt

## LISTING OF DOCUMENTS REVIEWED

Naviq Consulting Inc., 2008. Geothermal Analysis of Proposed Sewage Lagoon, Arctic Bay, NU. Report Prepared for Trow Associates Inc., Project J008, Revision 1, April 2008.

Rowan Williams Davies & Irwin Inc., 2008. Snowdrift Assessment, Proposed Wastewater Lagoon, Arctic Bay, Nunavut, Final Report. Report submitted to Trow Associates Inc., Project 08-1032A, April 14, 2008.

Trow Associates Inc., 2008a. Geotechnical Investigation, Sewage Lagoon, Hamlet of Arctic Bay, Nunavut. Report prepared for Government of Nunavut, Department of Community and Government Services, Project Management Division – Baffin Region, Project OTGE00019054B, April 24, 2008.

Trow Associates Inc., 2008b. Design Brief, New Sewage Lagoon for the Hamlet of Arctic Bay. Report prepared for Department of Community Government and Services, Government of Nunavut, Project OTCD00019054A, April 2008.

Trow Associates Inc., 2008c. Design Drawings – Arctic Bay Wastewater Lagoon, Project OTCD00019054A, April 25, 2008.

Trow Associates Inc., 2008d. Arctic Bay Sewage Lagoon Decommissioning. Report prepared for Government of Nunavut, Department of Community and Government Services, Project Management Division – Baffin Region, Project OTGE00019054C, April 2008.

## ADDITIONAL REFERENCES

Hivon, E.G. and Sego, D.C., 1993. Distribution of saline permafrost in the Northwest Territories. Canadian Geotechnical Journal, 30(3), pp. 506-514.