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June 5, 2008

Project No: 0308-005-01

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

Dear Sir:

Re: NWB 3BM-CLY0308 Clyde River Sewage Lagoon Water License Amendment – Geotechnical and Geothermal Review

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 Clyde River's water license (NWB 3BM-CLY0308). A list of the documents reviewed is attached. No construction specifications related to the construction of the sewage lagoon facility have been reviewed 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 facility 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.

1.0 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 Clyde River, Nunavut. The existing sewage lagoon is located 1.2 km west of the community and approximately 800 m north of Patricia Bay. The following deficiencies were observed in the existing facility during an August 2007 site inspection (Trow, 2008b):

- Existing discharge locations are in a poor state of repair and do not have a sewage discharge chute;
- Erosion was noted at the outlet of the overflow pipe;
- Localized areas of partial failure of the existing dyke system were noted, as were indications of slope instability;
- Minor seepage from the lagoon along the southern berm was noted.

According to Trow (2008b), the existing facility currently does not meet the storage requirements of the new 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 the existing facility be rehabilitated and utilized as a storage cell and that a new sewage lagoon cell be constructed to the south and west of the existing lagoon to supplement lagoon storage capacity (Trow, 2008b).

2.0 SITE DESCRIPTION

A topographic survey of the area for the proposed expansion of the sewage treatment facility indicates that the average slope across the site is approximately 4 percent to the south, toward Patricia Bay (Trow, 2008b).

A total of nine boreholes, six from the crest of the perimeter berm of the existing facility and three across the proposed expansion site, were drilled in August 2007 to depths of up to 7.5 m (Trow, 2008a). Subsurface conditions across the site reportedly consist of silty sand (1.6 m to 1.7 m thick) over ice-rich sandy silt up to 5.2 m depth overlying silty sand. Bedrock was observed in only one borehole, BH-8, at 3.2 m depth. No pore water salinity measurements were taken from any of the recovered soil samples.

Ground ice was observed in two boreholes: BH-6 and BH-8. In Borehole BH-6, layers of ice up to 1.1 m thick were reported. Thermistors were installed in two boreholes: one from the crest of the west end of the perimeter berm of the existing facility (BH-2), and one in undisturbed terrain within the proposed expansion site (BH-6). The ground temperature cables extended to 4.0 m depth beneath the ground surface. In late-November 2007, ground temperatures at 3 m depth below ground surface and deeper ranged from -3.5^{o}C to -4.5^{o}C at both borehole locations. Ground temperatures were also measured in late-August 2007, shortly after thermistor installation, but BGC considers these measurements unrepresentative due to possible thermal disturbance from drilling.

Boreholes drilled through the berm of the existing facility typically encountered sand and gravel overlying silty sand till over sand and gravel.

NCI (2008) pointed out that Clyde River is located in the zone of continuous permafrost. The mean annual air temperature over the period of 1970-2006 is estimated to be -12.5^{o}C. NCI also pointed out that local soils are expected to be saline, referencing data from Clyde River published by Nixon (1988) and Hivon and Sego (1993). Given the lack of site-specific pore water salinity measurements, NCI looked at the pore water salinity profile data published in Nixon (1988) and assumed a salinity of 20 parts per thousand (ppt) for geothermal analysis, corresponding to a freezing point depression of approximately -1^{o}C. For geothermal analyses, NCI (2008) presented late-October temperature measurements from Nixon (1988), which showed ground temperatures ranging from -6.5 ^{o}C at 3.0 m depth to -10.0^{o}C at 8.5 m depth.

2.1 Comments

The occurrence of ice-rich soils is consistent with subsurface observations from the Quluak School geotechnical investigation reported by Nixon (1988). Inconsistencies in the reported soil description and laboratory test data were noted. For instance, in borehole BH-6, three layers described as “ice” were reported, although two moisture content measurements sampled from these layers indicated gravimetric moisture content of approximately 15 percent which, if correct, indicate that the sample is predominantly mineral soil with some excess ground ice. Another example is also drawn from Borehole BH-6, between 4.3 m and 4.6 m depth. This soil interval is described as “Sandy Silt, organic, black, wet”, yet the measured moisture content of approximately 8 percent is considered relatively dry for a typical sandy silt, let alone one with organics present. The absence of ground ice descriptions and measured pore water salinities in the borehole log, combined with the inconsistencies between the soil descriptions and measured moisture contents, make it difficult to estimate how much creep or thaw settlement would result if the “ice” layers warmed and melted.

The assumption of a uniform pore water salinity of 20 ppt for the foundation soils is considered conservative. The pore water salinity is expected to be much lower (4 ppt or less) within the active layer (top 1 to 2 m depth), as was reported by Nixon (1988).

No distinction was made between the natural soils and fill materials for the boreholes drilled through the perimeter berm of the existing facility. Judging from the surrounding topography and berm configuration, it is believed that the existing berm was constructed of silty sand and gravel and covered with a layer of sand and gravel, possibly for erosion protection. The presence of cobbles and boulders reported in the "till" layer suggests that oversize materials were not removed during embankment construction, which could have resulted in poor compaction.

There was no description of the surficial geology or geomorphology of the proposed sewage lagoon site. An anomalous terrain feature can be seen immediately west of the proposed lagoon facility (see Figure 1). The Designers should comment on this feature and discuss whether or not it affects the site suitability.

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Figure 1 Aerial view of project area.

The three boreholes drilled within the proposed new lagoon facility are located south of the existing lagoon. It is noted that no boreholes were drilled west of the existing lagoon, although the preferred lagoon layout extends there.

The borehole logs provide little information, considering the limited penetration depths into the natural permafrost foundation (only two boreholes penetrated more than 5 m depth into the natural soils), for what is essentially a 5 m high dam constructed on likely saline, ice-rich permafrost.

The shallow ground temperature cables (to 4.0 m depth below ground surface) offer limited information on the geothermal regime of the project site, particularly since only the late-November 2007 temperature measurements are considered representative of site conditions. Ideally, the ground temperature cables should extend to a depth where there is little to no seasonal variations in temperature; otherwise, more frequent measurements are recommended to refine the calibration of the geothermal model and input parameters.

Reference has been made in Trow (2008a; 2008b) to the geotechnical design of the original lagoon facility, as carried out by Thurber. It is unclear if Trow had reviewed Thurber's report, but if so, it would have been useful to include all geotechnical data reported by Thurber, including borehole logs and ground temperature measurements, if any.

3.0 GEOTHERMAL ANALYSES

Geothermal analyses were conducted by NCI. The geothermal model was calibrated to a mean ground temperature of -9^{o}C using representative climate data from Environmental Canada's meteorological station at Clyde River. The predicted temperature profile was noted to be warmer than what Nixon (1988) measured in the community, and NCI concluded therefore that the assumed conditions are conservative.

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 of the lagoon contents considered two scenarios:

i) constant +1^{o}C temperature year-round, and

ii) seasonal variations in lagoon temperatures (averaging +0.58^{o}C over the year).

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

- Crest width = 4 m
- Berm height = 5 m
- Downstream slope of berm = 2.75H:1.0V
- Upstream slope of berm = 3.5H: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.
- 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.

3.1 Comments

The measured late-November ground temperatures at the proposed lagoon site (BH-6) are 3°C to 4°C warmer than measured late-October ground temperatures reported by Nixon (1988) at depths of 3 to 4 m. Near-surface late-November ground temperatures are expected to be colder than in late-October. The trumpet curve presented in Figure 3-3 of NCI (2008) indicates that the maximum active layer (depth of the -1°C isotherm) is less than 0.5 m thick, and is less than what was reported during the 2007 geotechnical investigation (up to approximately 1.5 m depth, as inferred by the depth to which the split spoon sampler from the standard penetration test could penetrate in the undisturbed boreholes, BH-6 to BH-8) and by Nixon. This suggests that the initial mean ground temperatures may be warmer than was assumed in the geothermal analyses.

No details were provided in NCI's report regarding input soil conditions (e.g., soil profile, soil/thermal properties) and ground surface parameters used in the geothermal analyses.

NCI recommends placing the liner to a depth of 2 m below the native ground surface, or approximately 1.5 m into the permafrost (given that the predicted location of the -1°C isotherm, or active layer depth, is approximately 0.5 m in undisturbed terrain according to Figures 4-1 to 4-3 in NCI's report). No construction methodology was presented in any of the documents describing how the key trench would be excavated into the permafrost to the required design depth.

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. Design Drawing DE-1 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 much deeper into the subgrade soils to better understand and monitor the influence of the lagoon facility on the geothermal regime, particularly along the southern berm.

The cost for installing vertical thermosyphons at some future date could be substantial, particularly if it is required over the entire perimeter berm. It has been suggested that the thermosyphons would enhance the development of a frozen core within the dyke. Given that a liner is recommended as the primary containment barrier, the thermosyphons should serve to ensure that the liner is keyed into impervious materials, i.e., the permafrost soils. The effectiveness of a remedial solution using thermosyphons may be influenced by the extent and magnitude of seepage.

The greatest uncertainty in the geothermal analyses relate to the initial ground temperatures, although conservatism was applied in the selection of pore water salinity profile of the permafrost foundation and in modeling the effects of climate warming and lagoon contents.

4.0 GEOTECHNICAL ASSESSMENT

4.1 Assessment of Existing Lagoon

The problems experienced by the existing lagoon have been attributed to permafrost thaw and degradation and the resulting thaw settlements (Trow, 2008b). The occurrence of seepage through the berm was explained by the use of permeable sand and gravel fill for berm construction. Finally, slope instability was attributed to the fact that the as-built slopes were constructed too steep (downstream slope of approximately 1.5H:1V).

The recommended remedial measures include restoring permafrost under the existing berm to arrest berm settlement, preventing seepage out of the berms, and flattening the slopes to a stable inclination (Trow 2008b). The proposed side slope angles (3.5H:1V upstream and 2.75H:1V downstream) are based on stability analyses carried out for the proposed new sewage lagoon facility. No geothermal analyses or temperature measurements via thermistor cables were carried out specifically for rehabilitation of the existing facility. As indicated by the results of the geothermal analyses, operation of the existing facility has likely resulted in general warming in the vicinity of the existing berm and permafrost foundation. The effect of the warmer berm and foundation temperatures is that it may take longer for the berm to freeze to the design temperatures.

The use of permeable soils for berm construction does not fully explain the observed seepage from the lagoon through the berm, since it has been reported only along the southern berm; if so, seepage should have been reported all around the perimeter of the existing facility. Other factors, such as increased solar radiant heating over the south-facing downstream berm slope or from a flatter-constructed downstream slope on the north berm, may have contributed to the spatial variations in permafrost distribution within the berm and underlying foundation.

4.2 Slope Stability

Trow (2008a) conducted slope stability analyses to determine the appropriate slope angles at which the berm would be stable. Stability analyses were carried out based on shear strength parameters for unfrozen soils, and assuming that the underlying foundation soils (including beneath the lagoon) 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 fairly conservative friction angles (27 to 32 degrees). A layer of ice was incorporated in the foundation soils and assigned an effective cohesion of 100 to 125 kPa. The design section ground surface appears to slope towards the downstream at approximately 4 percent grade. The modeled stratigraphy shows the surficial silty sand layer becoming thinner from upstream to downstream. The soil layers beneath the surficial silty sand cover are of uniform thickness and constant elevation.

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 0.15g.

Stability analyses of the upstream slope were also conducted for the rapid drawdown condition. To maintain a minimum factor of safety of 1.0 under seismic loading, the upstream slope needed to be 5.5H:1.0V or flatter.

The recommended slope angles of 3.5H:1V and 2.75H:1V for the upstream and downstream slopes, respectively, were based on satisfying minimum factor of safety requirements under seismic loading. Typical sections showing the recommended berm design configuration were presented in Figure 4 of Trow (2008b). The section for the interior berm (the berm between the existing and new lagoon) shows both slopes lined and at a slope angle of 3.5H:1V. Although not specified in the design reports, Drawing DE-1 indicates that the recommended liner is a geosynthetic clay liner (Bentomat ST or equivalent).

4.3 Comments

There is a disconnect between the geotechnical and geothermal analyses. Furthermore, there is missing information on how some of the design soil profile and strength parameters were derived.

The geotechnical investigation report (Trow, 2008a) describes the location of the analyzed berm cross section AA shown in Figure 1, but this location is not shown on the figure. No description was provided for how the design cross section was derived. The representativeness of the foundation conditions of the design cross section is highly questionable, given that the alternating layers of soil and ice were reported in only one borehole, BH-6, and some of the critical slip surfaces are along the silty sand-top ice layer interface. In the absence of better subsurface data, the sensitivity of the stability analyses should be tested for different configurations of the ice layer, including as a minimum, one where the top of the ice layer follows the slope of the ground surface. Additionally, the potential impact on slope stability of thaw consolidation at the interface between the upper ice layer and the overlying soil should be examined and reported on. Ground disturbance from construction will likely increase the thaw depth immediately around the berm, particularly in the short-term and on the southern exposure of the berm, which may result in deeper thaw, and thus thaw of ice-rich permafrost. If the sensitivity analysis determines that the depth of the ice-rich permafrost may have an adverse impact on stability, the Designers may wish to consider an additional site investigation program to better define the extent of the ice-rich soil as a means of reducing uncertainty in design.

It was not clear from the report how the shear strength of the ice layer was derived. Johnston (1981) reported the 50-year shear strength of freshwater ice-rich soils, Cu (kPa), relative to temperature below freezing, T (^oC), based on the following equation:

$$Cu = 35 + 28T$$

Therefore, the selected effective cohesion is considered representative of the long-term strength of freshwater ice-rich soils at a temperature of approximately -2^{o}C to -2.5^{o}C. As described in Section 2, soils in Clyde River are expected to be saline and the effective cohesion of the ice layer may be much smaller than 100 to 125 kPa. The Designers are referred to Nixon and Lem (1984) for example strengths of ice-rich saline soils.

It is also unclear from the geotechnical report how the design peak ground acceleration parameter was derived and what condition it represents.

The recommended berm design geometry (3.5H:1.0V upstream slope and 2.75H:1.0V downstream slope) was based on stability analyses carried out prior to conducting the geothermal analyses and assumed that the foundation soils would be maintained in a perennially-frozen condition. However, the results of the geothermal analyses indicate that the permafrost foundation beneath the upstream slope of the berm and underneath the lagoon is predicted to warm and thaw over the long term, a condition that has not been considered in any of the stability analyses conducted.

The recommended minimum berm crest width is 4 m, yet the stability analyses were carried out assuming a 5 m crest width. The stability analyses should reflect the recommended berm geometry.

No estimates of the magnitude of thaw settlement and creep strain beneath the upstream toe have been made, nor has the potential impact of tearing of the upstream liner due to berm settlement been assessed. These should be addressed.

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.

The design section for the interior berm appears to have been extended from the design of the exterior (perimeter) berms. Geothermal analyses should be conducted for the different boundary condition (warm lagoon contents on both sides of the berm) to ensure that the configuration satisfies design criteria.

Trow reported that the inside slope of 3.5H:1.0V would be stable provided that the berm was not subjected to the rapid drawdown condition. It is understood that the lagoon cells will be decanted in mid- to late-August and continue until mid- to late-September, over a period of 30 days, which would in fact correspond to a rapid drawdown condition. Trow should elaborate on how the rapid drawdown analyses were considered in design.

Given the history of berm instability of the existing facility and the potential for thaw settlement and creep strain, a settlement monitoring program is recommended.

5.0 SUMMARY AND RECOMMENDATIONS

Table 1 summarizes BGC's assessment of the geotechnical and geothermal design of the proposed rehabilitation of the existing sewage lagoon facility at the Hamlet of Clyde River, Nunavut, in addition to the proposed design of the new, adjacent facility.

Table 1 Summary of Review of Geotechnical and Geothermal Issues

Issue	Comment	Recommendation
Design Effort	The derivation of design soil profile and strength parameters for stability analyses was not fully explained. Stability analyses do not fully consider results of geothermal analyses.	Additional stability and geothermal analyses are recommended (see below). Stability analyses should be carried out for recommended 4 m wide berm crest.
Technical Deficiencies	Shear strength for ice layer used in stability analyses do not reflect predicted results of geothermal modeling	Conduct slope stability analyses considering pore water salinity and the effects of permafrost thaw and degradation beneath the upstream berm slope and lagoon.
Key Uncertainties	Design soil profile used for stability analyses is questionable, given the limited penetration depths of most of the drilled boreholes.	Additional stability analyses should be carried out to test the sensitivity of the subsurface profile geometry, particularly for the ice layer located immediately beneath the surficial silty sand.
	Rehabilitated berm configuration (3.5H:1V and 2.75H:1V upstream and downstream slopes, respectively) appears extrapolated from design configuration for new berm. The thermal regime in the vicinity of the existing berm has likely changed due to construction of the berm and operation of the sewage facility. No geothermal analyses have been carried out for this condition.	Geothermal analyses should be conducted to demonstrate that permafrost would aggrade into the reconstructed berm and within the time frame required. Temperature measurements within the thawed zone of the existing structure would be beneficial to support the design recommendations.
	Interior berm section (3.5H:1V berm slopes) also appear to be extrapolated from design configuration for new berm.	Geothermal analyses should be conducted to demonstrate that the liner system will remain keyed into the permafrost foundation with warm lagoon contents on each side of the berm.
	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, particularly 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 SP-2, with details shown in Drawing DE-1.	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. A settlement monitoring program is also recommended. The frequency of measurements 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 Clyde River sewage lagoon is inadequate and recommends further geotechnical 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.

6.0 LIMITATIONS AND 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:

Jack T.C. Seto, M.Sc., P.Eng.	Kevin W. Biggar, Ph.D., P.Eng.
Senior Geotechnical Engineer	Senior Geotechnical/Geoenvironmental Engineer

JTCS:KWB/syt

LISTING OF DOCUMENTS REVIEWED

Trow Associates Inc., 2008a. Geotechnical Investigation, Proposed Sewage Lagoon, Hamlet of Clyde River, Nunavut. Report prepared for Mr. Richard Caronnier, CGS Projects – GN, Project OTGE00019055B, January 16, 2008.

Trow Associates Inc., 2008b. Design Brief, New Sewage Lagoon and Rehabilitation of Existing Sewage Lagoon for the Hamlet of Clyde River. Report prepared for Department of Community Government and Services, Government of Nunavut, Project OTCD00019055A, February 2008.

Trow Associates Inc., 2008c. Construction Drawings – GN, Project OTCD00019055A, February 22, 2008.

Naviq Consulting Inc., 2008. Geothermal Analysis of Proposed Sewage Lagoon, Clyde River, NU. Report Prepared for Trow Associates Inc., Project J008, February 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.

Johnston, G.H., 1981. Permafrost Engineering Design and Construction. Associate Committee on Geotechnical Research, National Research Council of Canada. John Wiley & Sons, Toronto. 540 p.

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Nixon J.F., and Lem, G. 1984. Creep and strength testing of frozen saline fine-grained soils. Canadian Geotechnical Journal, 21:518-529.