February 25, 2012

EXP Services Inc.
100 – 2650 Queensview Drive
Ottawa, ON
K2B 8H6

Attention: Mr. S. Burden, P.Eng.

**Re: Geothermal Modeling of Lagoon Containment Structure
Whale Cove, NU**

Dear Sir:

This letter provides details, results and recommendations with respect to preliminary geothermal modeling and a technical assessment of a sewage lagoon structure near the Community of Whale Cove, NU. The purpose of the modeling and assessment was to determine if thermosyphons could be used as a means of inducing permafrost within an existing talik (unfrozen zone) under the existing lagoon berm thus providing long-term containment of lagoon effluent. This report describes the numerical modeling conducted and other technical assessments related to this issue.

Geotechnical Investigations and Related Information

EXP undertook a geotechnical investigation at and around the site of the existing lagoon from September 16 to 19, 2011. Five boreholes were drilling as part of the project geotechnical investigation, but only one borehole was advanced in each of the two existing lagoon structures. This section provides a summary of the geotechnical character of the subsurface conditions. For a full description of the site conditions, and other important details of the investigation and testing, the reader is referred to the geotechnical investigation report (EXP, 2011[1]).

EXP Borehole #2 was drilled from the crest of containment berm #2, located along the eastern part of existing sewage lagoon facility. The borehole was drilled to a depth of 9.5 m. The general stratigraphy at Borehole #2 consisted of a layer of fill soils comprising sands and gravels with some boulders. The fill layer was approximately 1.5 m thick. The water content

[1] EXP Services Inc. 2011. Geotechnical investigation: Proposed and existing sewage lagoon, Hamlet of Whale Cove, NU. Prepared for the Government of Nunavut. Project No. OTT-00201369-AO.

was approximately 5% to 10%. Native soils comprising fine to coarse sand and gravel with some cobbles and boulders. Water contents were typically in the 20% to 30% range.

This stratum was present from about 1.5 m depth to approximately 4.5 m. Under the upper native granular layer, a similar sand and gravel layer was present, but without the identified cobbles and boulders. This layer was approximately 1 m thick, terminating at 5.5 m below existing ground surface (top of containment berm). Silt and sand was present from a depth of 5.5 m to the bottom of the borehole at 9.5 m depth. The water content of this finer stratum was typically about 20%.

A thermistor cable was installed in Borehole 2. The ground temperatures were measured one day after drilling and thermistor casing installation. These data are shown on Figure 1. as evident from the temperature curve, it is apparent that the temperatures recorded are not representative of *in situ* equilibrium conditions. A linear extrapolation of the available data is also shown, which suggests a mean annual ground temperature may be less than -5 °C.

No published ground temperature data for Whale Cove was found; however, data from the 1970s for the Community of Rankin Inlet, located some 72 km north of Whale Cove was published by Brown (1978)[2] for two terrain conditions. These data are also shown on Figure 1. From these data, it is estimated that the mean annual ground temperature in Rankin Inlet may be nominally about -8 °C.

Based on the available data, it was assumed that the mean annual ground temperature for Whale Cove in undisturbed and thermally stable ground is -5 °C, which is considered to be conservative. The active layer at Whale Cove in undisturbed and thermally stable ground would likely be about 1 m.

The EXP geotechnical report identified in Borehole 2 that at the time of the geotechnical investigation in September 2011, the ground was thawed to a depth about 5.7 m. The presence of a deep unfrozen layer is considered to be a thermal aberration for this location. That is, under normal conditions the ground would have an active layer of about 1 m with permafrost conditions below this depth. The fact that a deep talik exists means that there are other actions taking place to impact the thermal regime. Groundwater seepage from the lagoon under the berm is one likely cause for the deep talik.

Lagoon Containment Structure

The proposed modified east lagoon containment berm is understood to have the following dimensions, based on a schematic provided by EXP:

Crest width	10 m
Typical dyke height	2 m

[2] Brown. R. J. 1978. Ground temperatures at Rankin Inlet.

Downstream face slope	33.3% (18°)
Upstream face slope	15% (8.5°)

Modifications consist of changes to the berm geometry, primarily upstream slope flattening through the placement of additional fill. The modified berm is understood to consist of materials similar to the existing structure.

Geothermal Modeling: Set-up and Results

Modeling of the lagoon structure was undertaken to assess the technical feasibility of using thermosyphons to help induce permafrost in the existing talik beneath the containment berm. As noted above, the talik is believed to have formed as a result of water seepage through the subsoils or as surface water flow along a drainage channel prior to construction of the containment berm.

The modeling was conducted using commercial geotechnical software from Geo-Slope International Inc. of Calgary AB. The thermal program TEMP/W is a finite element thermal analysis program. To address the impact of effluent seepage, the numerical problem could also be analyzed using SEEP/W, another Geo-Slope finite element analysis program for groundwater flow. These two programs may be coupled to provide full thermal and seepage modeling, thus providing the effects of conductive and convective heat transfer. As an initial analyses only TEMP/W was used to model the thermal influence of vertical thermosyphons under conditions of zero groundwater flow.

The modelling domain of the problem is shown schematically in Figure 2. The model considers a 1 m thick horizontal slice of soil through the berm with a thermosyphon located at one edge of the finite element mesh. This model geometry represents a series of vertical thermosyphons along the length of the berm and symmetry is used to minimize the extent of the modelling domain. For the thermosyphon in the model, a thermosyphon heat flux boundary condition was used whereby heat was extracted at a rate proportional to the temperature difference between the winter air temperature and the soil temperature adjacent to the thermosyphon. The thermosyphons were modeled under conditions of zero groundwater flow. In a second phase of the modeling, water seepage from left to right was to be introduced act to convectively warm the soil.

Figure 3 presents the results of the modeling (thermosyphons with zero groundwater seepage). The plot shows the temperature history (starting Sept. 1) at the thermosyphon node (red line on Figure 3) and at a distance 1 m from the thermosyphon (blue line on Figure 3), which represents a thermosyphon spacing of 2 m. By early February (about 150 days), the soil immediately adjacent to the thermosyphon cools down to nominally -26 °C while the minimum temperature between the thermosyphons reaches nominally -10 °C in March (about 180 days). However, by the end of the summer (August) soil temperatures at both the thermosyphon and at 1 m distance, warm to near -1°C.

The results of this modeling shows that it would be conceptually possible to freeze back the sub-grade to permafrost conditions over time under static groundwater conditions, however, this requires a relatively close vertical thermosyphon spacing of 2 m, which may be impractical and likely uneconomic. Furthermore, even at a spacing of 2 m between vertical thermosyphons, it is expected that permafrost development between thermosyphons would be compromised by groundwater flow through the berm

The results shown in Figure 3 may be conservative in several aspects including ignoring the surface climatic conditions (with a mean annual air temperature of -5 °C or colder) and the likelihood of permafrost aggrading from below the talik. However, this initial analysis does not address the impact of convective heat transfer from the flowing groundwater. It is considered that the impact of flowing groundwater would be to reduce the effectiveness of the thermosyphons and that they would not be able to induce permafrost in the ground all-year round, at any reasonable thermosyphon spacing (such as 3 to 4 m).

The conclusion from the modeling is that vertical thermosyphons alone do not represent a technically and economically viable method to provide long-term subgrade seepage control and containment below berm #2.

Proposed Hybrid Containment Scheme

In light of the analysis presented above, other containment options should be considered. One such option is referred to herein as a hybrid option. In this option, a combination of synthetic (or other) liner in combination with a horizontal thermosyphon may provide the desired seepage containment. The concept would consist of a liner system installed in trench excavated on the downstream side of the containment berm. The trench would be excavated to an elevation of about 17 m (based EXP preliminary drawings), which is expected to be close to the depth of permafrost. Near the ground surface the liner would be buried within the containment berm along the downstream face and extended to the crest of the berm.

To help insure containment of effluent at and below the base of the liner, which is expected to be near the base of the identified talik, it is proposed that a horizontal thermosyphon be installed along the base of the excavated liner trench. This thermosyphon would faciliate extraction of heat along the bottom of the trench and result in permafrost aggregation in the currently unfrozen soils that may be present at or below the base of the liner. It is estimated that a thermosyphon placed horizontally along the base of the liner trench would have a thermal radius of influence of at least 1 m. Information provided by a thermosyphon contractor indicate that horizontal thermosyphons are much more economically efficient in heat extraction from the ground per unit soil volume than vertical thermosyphons (Jardine, 2012[3]).

[3] John Jardine, Arctic Foundations Inc., Winnipeg Manitoba. Personal communications. February, 2012.

One collateral advantage of the liner system is that when seepage below the berm is eliminated the permafrost under the berm will start to aggrade into the talik and will eventually freeze off the talik up to a typical active layer depth for this climate below the crest of the berm.

Limitations of this proposed system include the possibility that the liner and horizontal thermosyphons do not reach the base of the talik and that seepage may still occur beneath the installed system. In addition, the bedrock or the base of permafrost may be of variable depth across the length of the berm. This may impede the successful installation the liner and/or the horizontal thermosyphon.

Recommendations for Additional Studies

It is considered that some additional studies may be recommended to provide further design information.

First, it is possible, if not likely, that the bedrock surface at depth may be variable and could be shallower near the two ends of the existing containment berm. To investigate the bedrock depth profile along the length of the berm, consideration could be given to conducting a geophysical survey, using for example, ground penetrating radar.

Second, the specific design and installation of thermosyphons is a proprietary process. Thus it is recommended that the need for, and specific design details of a horizontal thermosyphon placed within the liner trench be assessed by the specialist thermosyphon contractor.

Closure

This letter has provided a professional engineering opinion regarding the geothermal effects of using thermosyphons to induce permafrost within an existing talik under a sewage lagoon containment berm at Whale Cove NU. The opinions and assessment are based on the review and interpretation of information provided by EXP Services Inc. If the actual site conditions or other factors are found to be different than what was assumed then Naviq should be advised so that the results of this assessment may be reconsidered.

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We trust that this is sufficient for you present needs. If you have any questions or require any additional information, please do not hesitate to contact the undersigned

Yours truly,
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NAPEG Permit to Practice: P611

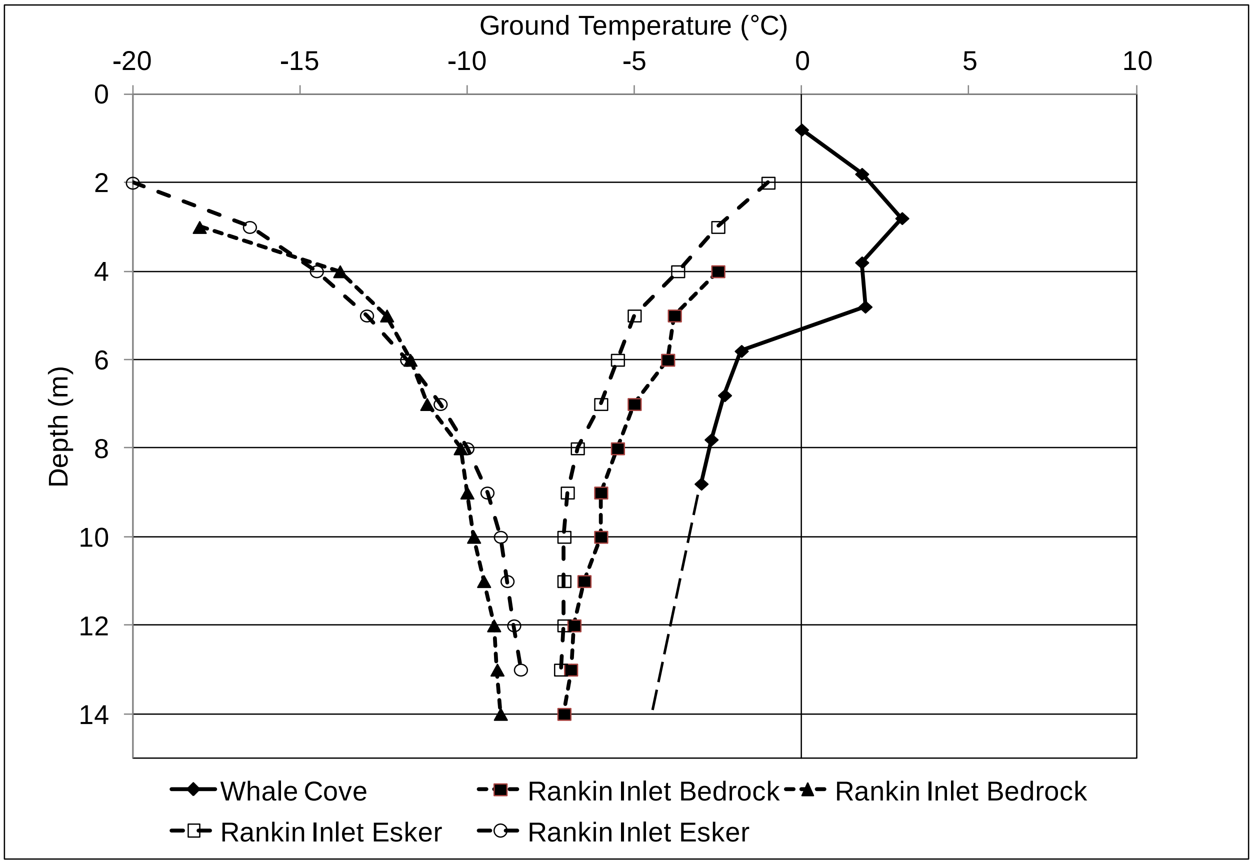

Figure 1. Ground temperature data from EXP (2011), denoted as “Whale Cove”, and ground temperature data from Rankin Inlet (Brown, 1978).

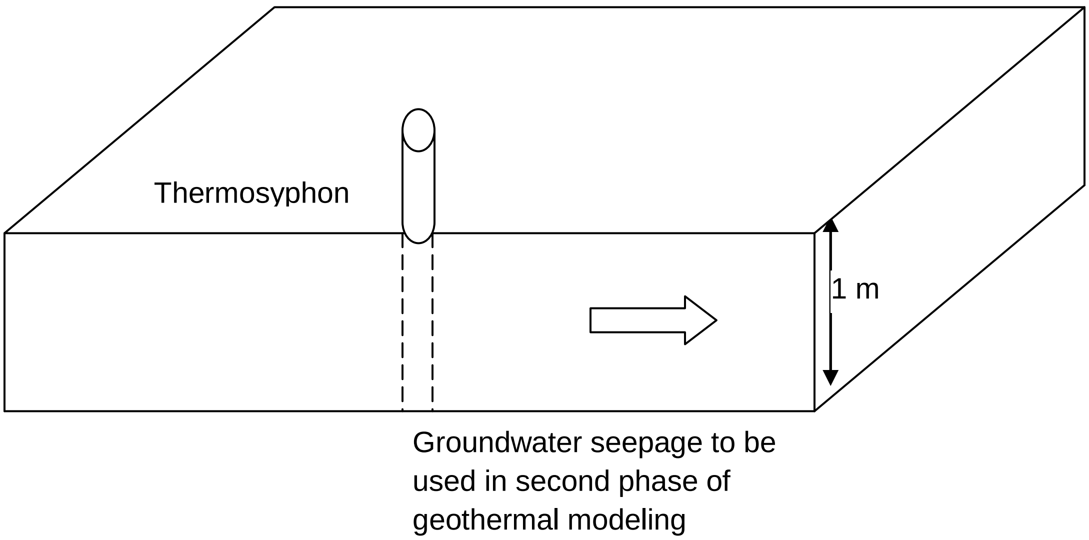

Figure 2. Schematic of initial geothermal model showing placement of a thermosyphon at one edge of the 1 m thick fine element grid.

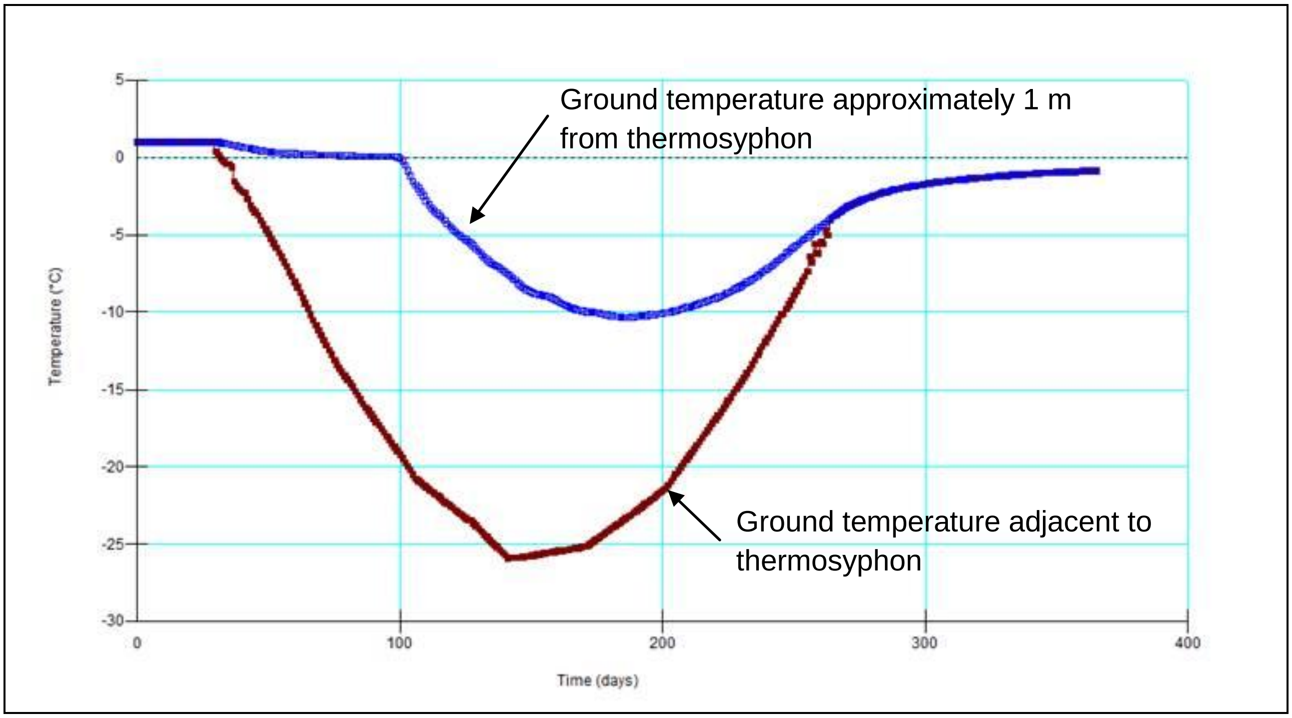

Figure 3. Initial geothermal modeling results showing effect of thermosyphon on the ground temperatures adjacent to and 1 m distance from the thermosyphon with time. Day 0 is September 1.