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PROJECT MEMORANDUM

To:	**Nunavut Water Board**	**Fax No.:**	**780.443.4080**
Attention:	**David Hohnstein**	**CC:**	
From:	**Kevin Biggar**	**Date:**	**February 15, 2008**
Subject:	**Third Party Review of Meadowbank Project, NU**		
No. of Pages (including this page): 13		**Project No:**	**0308004-01**

1.0 TERMS OF REFERENCE

This report is provided by BGC Engineering Inc. (BGC) in response to your letter dated 16 January, 2008 requesting BGC to carry out a Third-Party review of the Meadowbank Project geotechnical and permafrost aspects related to the tailings dam designs, dikes and dams within lakes, and the open pit design. A listing of the documents provided to us for the review is contained at the end of the report.

2.0 REVIEW COMMENTS

Our review first discusses general issues such as design effort compared to standard of practice, and key uncertainties. The second part provides more focused comments on technical deficiencies or details that should be addressed and/or clarified. We have broken the technical issues into five broad categories:

- Open Pit;
- Portage Tailings Storage Facility (TSF);
- Dewatering Dikes;
- Permafrost Thermal Analyses; and
- Miscellaneous.

For each category we have provided background material, specific references and detailed comments in separate tables at the end of the report. A synopsis of the detailed comments is provided in the report body. Under each category of comments, we have arranged the items to reflect our perceived order of priority.

The tables will also be forwarded in electronic form so you may include them with other review material for reference for future technical meetings and hearings. The number in parenthesis at the end of paragraphs in the detailed comments pertains to the number in the Tables.

2.1 General

2.1.1 Pit Slope Design

The pit slope design work carried out by Golder Associates Ltd. follows the basic steps of assessing kinematically controlled failures to develop bench scale and interramp slope angles, and analyzing the overall slope using limit equilibrium stability analysis methods (Golder, 2007d) incorporating predicted strength anisotropies in the rock mass. The approach is consistent with current standards of practice.

Data for the stability assessments appear to be adequate, although some inconsistencies were noted between the levels of effort for the various proposed open pits. There remains some uncertainty in the continuity of the structural discontinuities on the larger scale, as most of the discontinuity information has been obtained from drilling, logging and sampling of core, without the benefit of mapping large exposures. Also, there is currently no local experience with mining operations at nearby pits in similar rock types to lend additional confidence to the design.

The distinct element analyses conducted would not likely have been justified strictly for pit wall designs at the feasibility level. However, the planned presence of numerous dikes behind the crests of the proposed pit slopes requires estimates of pit wall movements be made to assist in assessing potential deformations at the toe of the dikes. Slope monitoring proposed for the Portage and Goose Island Pits will provide important information on the deformation behaviour of the rock mass, and will be helpful in calibrating the numerical analyses, which in themselves should still currently be considered to be highly uncertain. There has been no criteria defined for allowable displacement or strain in the dike; however, the predicted displacements are minimal and, if these are accurate predictions, would not likely pose any threat to the integrity of the various dikes proposed.

2.1.2 Design of Dikes and Tailings Dams

There are no significant technical deficiencies in the level of investigation and design of the major dewatering dikes and tailings dams and dikes. However, there are uncertainties related to the execution of construction of these dikes and dams. The following summarizes BGC's assessment of the reviewed reports.

Stability and seepage analyses for the design of the dewatering dikes and the dikes and dams for the tailings storage facilities are consistent with current standards of practice. Permafrost conditions at the site were characterized in a broad, general sense in the reviewed reports. Inconsistencies were found in the results of the thermal analyses. Furthermore, the approach to calibrating the thermal model did not conclusively validate the thermal analyses conducted to predict permafrost development in the tailings and dikes.

It is understood that the majority of the earthworks activities will be carried out only during a four-month period in the summer when ambient air temperatures are above $0^{o}C$. It is planned to use till from pre-stripping of the overland portion of the Portage Pit to construct the initial dikes. The amount and quality of harvestable till is uncertain given that the till will be in a mostly frozen state, the short summer season, the potential for excess ground ice, groundwater seepage through the active layer, and the presence of boulders and cobbles. It is understood that Golder carried out a site investigation in August 2007 to better characterize the quantity and quality of the till, but BGC has not reviewed the results.

The second major uncertainty is the how well the till core, placed in the wet, can be compacted/consolidated with the proposed method of placing a surcharge rockfill cover and, if deemed necessary using deep dynamic compaction methods. The proposed compaction methodology will likely be effective for shallow depths, but sections of Goose Dike are planned to be constructed in 20 m of water and deep dynamic compaction is typically effective only to approximately 10 m depth, and less so in saturated silty sands. Other means of ground improvement or even construction materials need to be identified for the deeper sections of the dike.

Further attention is recommended for dike and dam design near the abutments and islands, where the foundation is in a permafrost condition, which would limit the effectiveness of a grout curtain into the bedrock and which would require that the permafrost foundation be maintained throughout operations and after closure to act as the barrier to seepage through the foundation. The effects of permafrost development in the lakebed foundation beneath the Central Dike during Stages 2 and 3 construction also need to be considered, as this may also affect key trench excavation and the effectiveness of a grouting program.

Concept-level designs were provided for certain structures, such as the Vault Dike, South Camp Dike, Saddle Dam and Stormwater Dike. Apart from the Stormwater Dike, no geotechnical investigation has been carried out along the alignments of these structures and are recommended to characterize the foundation conditions. The design basis of the Vault Dike and South Camp Dike should be elaborated prior to construction.

2.2 Open Pit

Feasibility level open pit designs that were developed for the Portage and Goose Island Deposits (Golder, 2007d) appear to be to a higher level of effort than the design for the Vault pit

(Meadowbank, 2007a) although many of the same technical issues still apply. Based on the references reviewed, it is unclear if any of the key recommendations in the Vault Pit Design Memorandum have been carried out. (OP-1)

The limited borehole information between the open pits and the proposed dikes is a concern as it relates to the ability of the proponents to adequately address the overall stability of the dike and the overburden slope between the toe of the dike and the open pit. (OP-2)

Pit wall stability analysis for the southeast walls of the Portage and Goose Pits, and the northeast wall of the Goose Pit assumes pit wall depressurization is achieved, and the depressurization will be implemented solely using horizontal drain holes designed based on packer test results. The horizontal drain holes are a passive system and can only be installed once the pit slope has been excavated. It is recommended that the proponents revisit this issue possibly considering pumping tests for better hydraulic conductivity characterization, and that they do not assume that rock bridging will be effective unless it can effectively demonstrated for specific discontinuity sets. (OP-3).

Two relatively strong discontinuity sets dipping flatly to moderately to the southeast were not included in the kinematic analyses conducted, and could have a significant impact on the stability of the southeast pit wall beneath the Bay Zone Dike. Also, the discontinuity sets described in Section 11.6.5 (Golder, 2007d) which are described as "controlling the stability of the slope" do not appear to correspond with those shown in the stereonets in Figures 5.9 and 5.10 of the same report. (OP-4)

The modelled predictions of pit wall and associated dike toe displacements are viewed as tentative until the model is calibrated against observed behaviour, and should be used with caution. Therefore, contingencies should be developed for the dewatering methods and dike construction to account for potentially higher deformations. (OP-5)

It is unclear why deformation modeling of the southeast wall of the Portage Pit has not been carried out, as this pit wall is just as critical as the southeast wall of the Goose Pit. Displacements may be of concern, particularly if the flatter dipping discontinuity sets identified in point OP-4 are incorporated into the stability analysis model for that area of the pit. (OP-6)

2.3 Portage Tailings Storage Facility

It is proposed that the grout curtain planned for the Central Dike will extend to the abutments. However, the foundation at the abutments is expected to be permafrost and the grout take in the existing permafrost is anticipated to be low. Thus seepage will have to be mitigated by the low conductivity frozen rock. The proponents need to demonstrate (via adequate thermal analysis) that the permafrost foundation in the abutments will remain frozen during operations and closure. (TSF-1)

The thermal analysis of the dewatering dyke till core indicates that frost will penetrate approximately 6 m into the unfrozen till core after one year. Stage 2 of the Central Dike construction is scheduled for year 2, approximately 2 to 3 years following completion of Stage 1 construction. As the lakebed till is typically less than 6 m thick along the Central Dike alignment, this implies that the top of the bedrock in the Stage 2 construction zone will be frozen before construction begins. This could limit grout take in the stages 2 and 3 zones. Thus similar to the point above, thermal analysis needs to be done to confirm that partially-frozen foundation beneath the Central Dike will remain frozen to be an effective seepage barrier during operations and after closure. (TSF-2)

Predicted settlement of the Central Dike crest is nearly 1 m. The proponents must confirm that these displacements will have no adverse effects on the liner and the thermistor strings. (TSF-3)

Inconsistent tailings properties have been presented and it is unclear for what properties the tailings storage facility was sized for and what allowance was made in sizing the facility for possible ice entrainment. The proponent should clarify this. (TSF-4)

The steep side slopes of the dike (1.5 H:1.0 V) will make it difficult to effectively install the specified filter material. The proponents need to address how the specified filter will be installed. (TSF-5)

For the Saddle Dam, it is unclear how the impervious element will be adequately sealed into the bedrock. If the permafrost is to be counted upon as an effective component of the cutoff, it should be justified by thermal analyses. (TSF-6)

The soil on either side of the bituminous geomembrane liner may contain stone that may damage the liner during installation and backfilling. The proponents must address how such damage will be mitigated. (TSF-7, TSF-8)

For the storm water dike, it is unclear what the impermeable liner will be keyed into, if a grout curtain into the bedrock foundation is required, or if seepage through the foundation is permissible. The proponent should clarify the design intent on this detail. (TSF-9)

The detail showing the optional bituminous geomembrane liner for the storm water dike and saddle dam indicates that the liner is set in the till at the bottom but that the upper portion is exposed to the atmosphere. An exposed liner risks damage due to extreme environmental conditions. The proponents need to clarify this design detail. (TSF-10)

There is no geotechnical information presented along the South Saddle Dam alignment. This is necessary to verify that the embankment design is appropriate. It is also anticipated that thermal analyses will be required to show the effectiveness of the design. (TSF-11)

On the Central Dike, the width of the liner at the top of Stages 1 and 2 crests is quite narrow (0.5 m), and is anticipated to be difficult to seam when raising the dike. The proponents need to address how the liner will be effectively seamed at this location. (TSF-12)

Where the impermeable components of the Saddle Dam and Central Dike meet, there is insufficient detail in the reports available to evaluate the effectiveness of the proposed design. The proponent needs to provide this design detail prior to construction. (TSF-13)

For the Central Dike, there appears to be an error in the Stage 2 filter/liner quantity requirements that should be checked and verified. (TSF-14)

2.4 Dewatering Dikes

Dynamic compaction of the till core, though with precedent, also has some limitations, particularly in deep water, and where the water table is near the surface. Other means of compaction of the till should be investigated, and contingency plans in place if dynamic compaction proves ineffective. (DD-1)

It is anticipated that trenching through the till core and into the bedrock will pose challenges, and that there will be difficulties in ensuring a competent seal between the cutoff wall and the bedrock, and possibly between the jet grouted curtain and the cutoff wall. The presence of nests of boulders should be anticipated. Seepage through this region has the potential to erode cutoff material where only soil and bentonite are used. It is recommended that a more erosion resistant cutoff be considered such as soil-cement-bentonite. (DD-2)

No specifications have been provided for foundation preparation of the footprint areas beneath the Dewatering Dikes. It is understood that the lakebed sediments will not be removed beneath the rockfill berms, apart from the deep section of Goose Dike. However, it is understood that the lakebed sediments and boulders will be removed beneath the footprint areas of the filter zones. Construction details need to be provided, in addition to a description of where the dredged materials will be disposed. (DD-3)

The hydraulic conductivity of the till-bentonite backfill with 1.6% bentonite was the same as the hydraulic conductivity reported from the till laboratory consolidation test. The specifications for the till grain size distribution are quite broad, and not well documented in the laboratory tests reported. More test results are required to determine the minimum bentonite content required to satisfy the design permeabilities independent of the till grain size distribution. (DD-4)

It is not planned to use artificial freezing in the dike abutments which contain permafrost, but rather to grout these regions, and to provide a 3 m thick rock cover to minimize thaw of the abutment soils. The permafrost will limit the grouting effectiveness to seal the abutment, so the ground must remain frozen to be effective. Thermal analyses are necessary to demonstrate that the permafrost will remain an effective seepage barrier in the abutments, accounting for global warming. (DD-5)

Although the design report states that a one metre thick layer of rock atop the dike cutoff will prevent active layer penetration into the cutoff wall, the design drawings do not show a rock cover on top of the cutoff. The proponent needs to clarify the design intent and associated drawings. (DD-6)

It is unclear from the design drawings how the cutoff from the Bay Zone Dike will be tied into the cutoff of the Goose Island Dike. The proponent needs to clarify this detail of the design and construction. (DD-7)

2.5 Permafrost Characterization and Thermal Analysis

The Mine Waste and Water Management Report suggests that deep active layers are due to close proximity to lakes at the site, yet deep thaw was observed at BH 02-GT09 which was not close to the lake, but rather a result of a rock outcrop. The warm ground temperatures and deep thaw at BH 02-GT03 are the result of deep snow cover rather than proximity to the lake. No thermal analyses were presented that demonstrate that the input parameters used in the thermal model are reasonable by performing model predictions of measured ground temperatures for the variety of ground conditions observed. Model calibrations should be performed to local measured ground temperatures using appropriate thermal properties and boundary conditions to verify that the models are sufficiently accurate for thermal forecasting. (PF-1, PF-2, PF-3, PF-5)

Freezeback of the tailings is considered a key component of the tailings management strategy. The design indicates that if the freezeback is slower than predicted that mitigative measures to enhance freezing will be implemented. However, tailings freezeback will be influenced by the deposition plan, tailings thermal properties and climatic conditions. Considering the points in PF-1, 2, 3, and 5, it is uncertain if there is sufficient accuracy in the thermal modelling to adequately determine if the actual tailings freezeback is responding “as expected” due to the uncertainty in the as expected (i.e. modelled) behaviour. It is necessary to better demonstrate that thermal modelling is sufficiently calibrated and accurate to instil confidence that the tailings freezeback behaviour can be adequately modelled. (PF-2)

The modelling of the impact on active layer thickness by extreme warm and cold years appeared to have inconsistent results with what would have been expected. The results of the models should be examined in detail, and if deemed valid after scrutiny an appropriate justification given for the predicted results. (PF-4)

The sensitivity analysis performed to evaluate the freezeback of the tailings varied the thermal conductivity and heat capacity of the tailings, but did not vary the moisture content of the tailings. It is possible that tailings placed in the winter will entrap ice, increasing the water content and thus the volumetric heat capacity as well as the latent heat in the tailings. Sensitivity analysis of the thermal modelling should be re-run to determine the impact of moisture content variation in the tailings. (PF-6)

When mining is complete and the mines are filled with water, the specific heat of the water will warm the downstream rockfill slopes of the dykes. It was unclear from the material available for review if the warming effect of the water had been considered in the modelling of the freezeback of the dike. The proponent needs to clarify if this changing thermal boundary condition on the downstream slope of the dikes was considered. If not, the modelling should be re-run to determine the impact of the flooding on freezeback of the dike. (PF-7)

The presence of high ice contents in the till will hamper its use as a construction material. The borehole data available for review was insufficient to accurately assess this. Improved ground ice assessment and logging during future activities at the site will better prepare the designers for potential design and construction challenges should the ground ice be higher than currently anticipated. (PF-8)

A 2 m thick rock cover is proposed to cover the tailings to limit thaw into the tailings. The modelling predicts active layer thickness in the till from 1.3 to 1.9 m. If the thaw predictions in the till are correct, greater thaw depths would be anticipated in the dry, granular rock cover, which may then not protect the tailings from thaw after closure. A properly calibrated model will provide insight into an appropriate thickness of rock cover to prevent thaw of the tailings. (PF-9)

The tailings freezeback model only used a 40 m thick bedrock base. This small modelled thickness of bedrock may impact the predicted long-term outcome due to boundary effects. It is recommended that the solution be verified with increased bedrock thickness. (PF-10)

2.6 Miscellaneous

The planned use of glacial till as core material for dewatering dikes and as a possible impermeable element for Stormwater Dike and South Saddle Dam is predicated on the availability of adequate quantities of till that will be stripped from pre-mining development. The proponents have assumed that approximately 50% of the available till volume will be harvestable for use. Although this may be a reasonable assumption, till availability is sufficiently critical to dike construction that an effort to better quantify this assumption is warranted. Factors that will lead to reduced volumes of till availability include the presence of ground ice, boulders and cobbles, and the ability to excavate till in a permafrost environment. It is unclear if the proponents plan to excavate frozen till or only remove it once it has thawed. If the latter, till availability will be time dependent and should be evaluated in construction sequence planning. Additionally, in the Central Dike Design report (section 4.4.3), the proponents note that excavated till became fluid like when thawed, though they also purport that the till is ice-poor (i.e. Mine water & waste management report, Section 2.4.2, p. 2-6). This dichotomy suggests a degree of uncertainty. If the till becomes fluid-like when thawed, handling and placement will be problematic. Additionally, if till is stockpiled, handling and placement will become challenging when freezing temperatures begin in the late summer or fall. If till availability limited by thawing impacts the construction schedule, what contingencies are planned? The proponents are urged to provide a more detailed description of till management for dike construction. (MISC-1)

No detailed design has been presented for the Vault Dike and the South Camp Dike. No geotechnical investigation information was provided to the reviewers along the proposed alignment. Additionally no details regarding the design criteria (e.g., freeboard requirements, cutoff requirements, etc.) for these structures were provided. Additional details for these structures are required. (MISC-2, MISC-3)

The proposed plan to deal with excess till removed from mining preparation is to place some till in rock storage facility, either as separate stockpile for future use (e.g., reclamation) or to be mixed with waste rock. To enhance convective cooling and permafrost development within waste rock pile, the waste rock should be as porous as possible, and overburden should not be mixed with the waste rock. (MISC-4)

The Type A Water License Application (Section 3.2.1) states that geotechnical laboratory testing will be conducted on the till samples collected from the August 2007 sampling and final review will be provided to the NWB prior to construction of the dike till cores. This item appears to be still outstanding. (MISC-5)

3.0 CLOSURE

We trust these comments are adequate for you at this time. Please contact us if you have any questions or require additional information.

BGC Engineering Inc. (BGC) prepared this report for the account of the Nunavut Water Board. The material in it reflects the judgement 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 report, 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 report.

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Yours truly,

Per BGC Engineering Inc.

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Attachments: Tables containing detailed comments

LISTING OF DOCUMENTS REVIEWED

Golder, 2007a. Detailed Design of Central Dike-vol.1 (Doc.420) Final Application (Sept'07), 273 pages.

Golder, 2007a. Detailed Design of Central Dike-vol.2 (Doc.420) Final Application (Sept'07), 151 pages.

Golder, 2007a. Detailed Design of Central Dike-vol.3 (Doc.420) Final Application (Sept'07), 101 pages.

Golder, 2007b. Detailed Design of Dewatering Dikes Report - Addendum Final Application(Sept'07), 69 pages.

Golder, 2007c. Detailed Design of Dewatering Dikes – Volume 1 (Doc.342) Final Application (Sept'07), 247 pages.

Golder, 2007c. Detailed Design of Dewatering Dikes – Volume 2 (Doc.342) Final Application (Sept'07), 159 pages.

Golder, 2007c. Detailed Design of Dewatering Dikes – Volume 3 (Doc.342) Final Application (Sept'07), 210 pages.

Golder, 2007d. Pit Slope Design Criteria for the Portage and Goose Island Deposits – Vol.1 (Doc.449) Final Application (Sept'07), 276 pages.

Golder, 2007d. Pit Slope Design Criteria for the Portage and Goose Island Deposits – Vol.2 (Doc.449) Final Application (Sept'07), 323 pages.

Golder, 2007e. Mitigative Measures for Potential Seepage from Tailings Facility (Doc.375) Final Application (Sept'07), 11 pages.

Meadowbank Mining Corp., 2007a. Mine Waste and Water Management (Doc.500) (Aug'07).

Meadowbank Mining Corp., 2007b. Type A Water Licence Application – Main Document (Doc.485) Final Application (Sept'07), 137 pages.

Meadowbank Mining Corp., 2007c. Fault Testing and Monitoring Plan (Doc.432) Supplemental Information (Nov.'07), 10 pages.

Morgenstern, 2007. Expert review of Meadowbank Tailings and Dewatering Dike Designs Final Application (Mar 30'07), 9 pages.

Stacey Mining Geotechnical Ltd., 2007. Independent review of Pit Slope Design Criteria for Portage and Goose Island Deposits, Final Application (Sept'07), 11 pages.