CUMBERLAND
RESOURCES LTD.

# MEADOWBANK GOLD PROJECT

## PROJECT ALTERNATIVES REPORT

OCTOBER 2005

# TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF APPENDICES

## DESCRIPTION OF SUPPORTING DOCUMENTATION

Cumberland Resources Ltd. (Cumberland) is proposing to develop a mine on the Meadowbank property. The property is located in the Kivalliq region approximately 70 km north of the Hamlet of Baker Lake on Inuit-owned surface lands. Cumberland has been actively exploring the Meadowbank area since 1995. Engineering, environmental baseline studies, and community consultations have paralleled these exploration programs and have been integrated to form the basis of current project design.

The Meadowbank project is subject to the environmental review and related licensing and permitting processes established by Part 5 of the Nunavut Land Claims Agreement. To complete an environmental impact assessment (EIA) for the Meadowbank Gold project, Cumberland:

1. Determined the VECs (air quality, noise, water quality, surface water quantity and distribution, permafrost, fish populations, fish habitat, ungulates, predatory mammals, small mammals, raptors, waterbirds, and other breeding birds) and VSECs (employment, training and business opportunities; traditional ways of life; individual and community wellness; infrastructure and social services; and sites of heritage significance ) based on discussions with stakeholders, public meetings, traditional knowledge, and the experience of other mines in the north.

2. Conducted baseline studies for each VEC and compared / contrasted the results with the information gained through traditional knowledge studies (see Columns 1 and 2 on the following page for a list of baseline reports).

3. Used the baseline and traditional knowledge studies to determine the key potential project interactions and impacts for each VEC (see Column 3 for a list of EIA reports).

4. Developed preliminary mitigation strategies for key potential interactions and proposed contingency plans to mitigate unforeseen impacts by applying the precautionary principle (see Columns 4 and 5 for a list of management plans).

5. Developed long-term monitoring programs to identify residual effects and areas in which mitigation measures are non-compliant and require further refinement. These mitigation and monitoring procedures will be integrated into all stages of project development and will assist in identifying how natural changes in the environment can be distinguished from project-related impacts (monitoring plans are also included in Columns 4 and 5).

6. Produced and submitted an EIS report to the Nunavut Impact Review Board (NIRB).

As shown on the following page, this report is part of a documentation series that has been produced during this six-stage EIA process.

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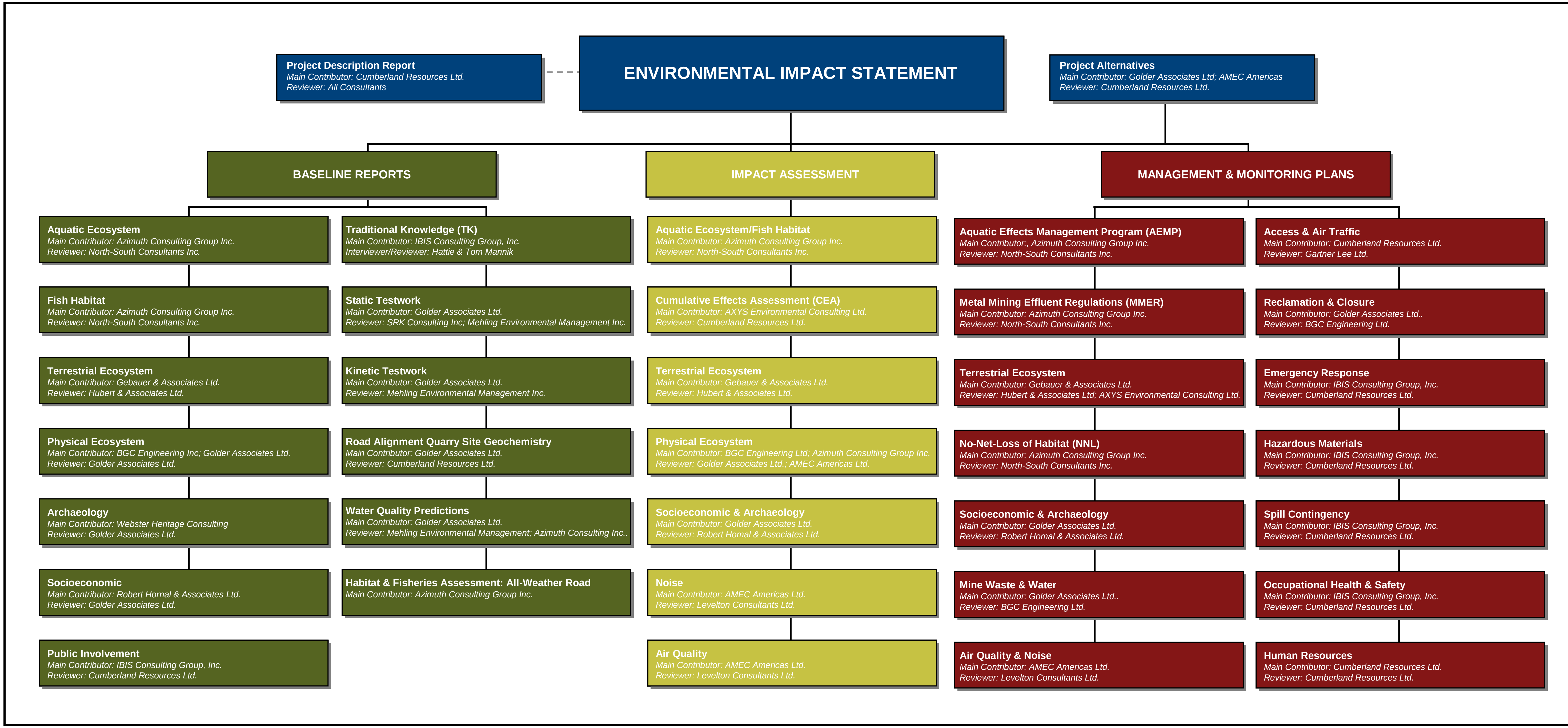
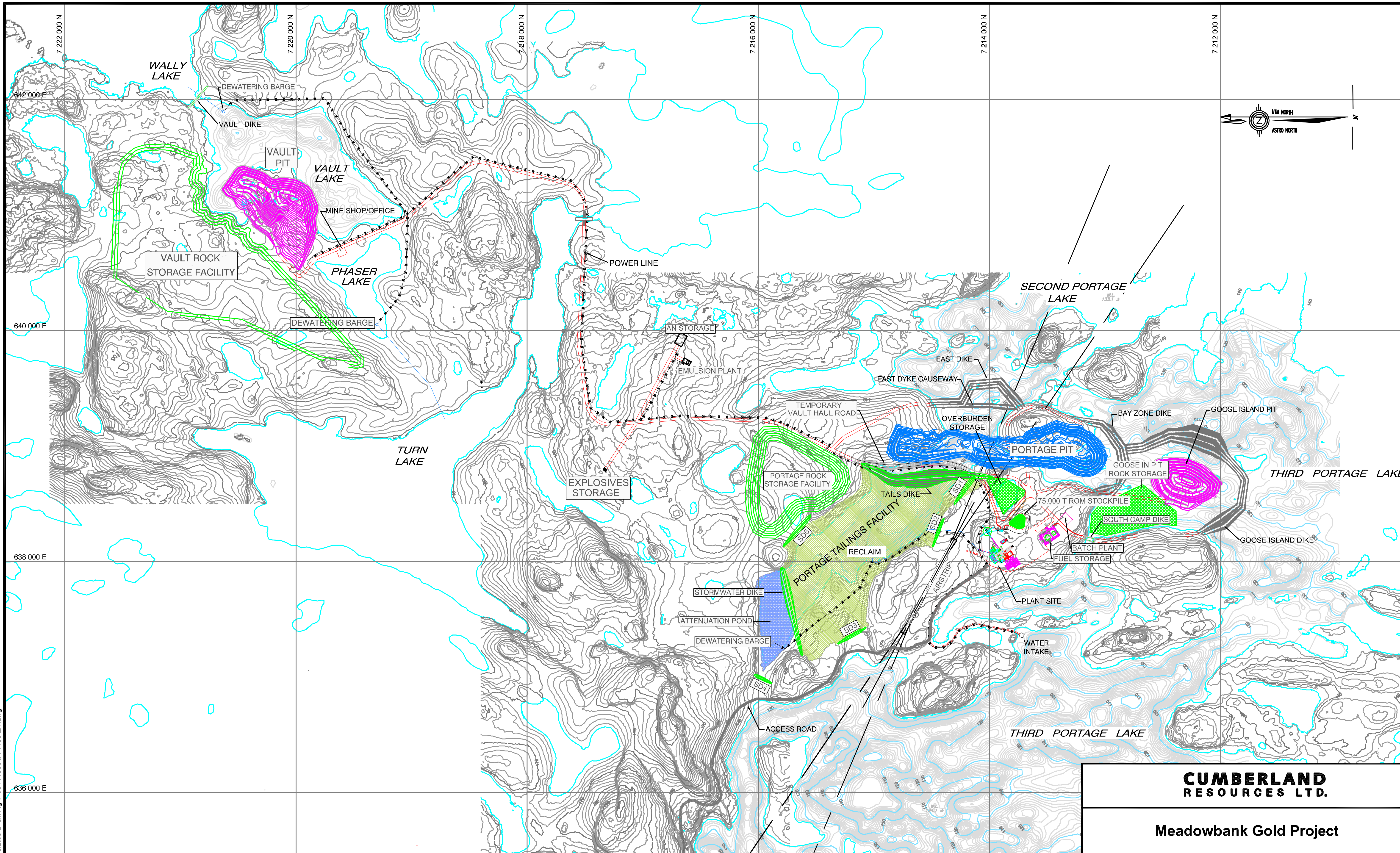
## EIA DOCUMENTATION ORGANIZATION CHART




**Date: October 2005**

## PROJECT LOCATION MAP




Source:Golder Associates Drawing # 05141303GA-1400-2.1.dwg

0 300 600 900 1200 1500

Scale in Meters

**NOTES**

1) Topographic contour interval 2m.
2) Bathymetric contour interval 1m.
3) Scale As shown.

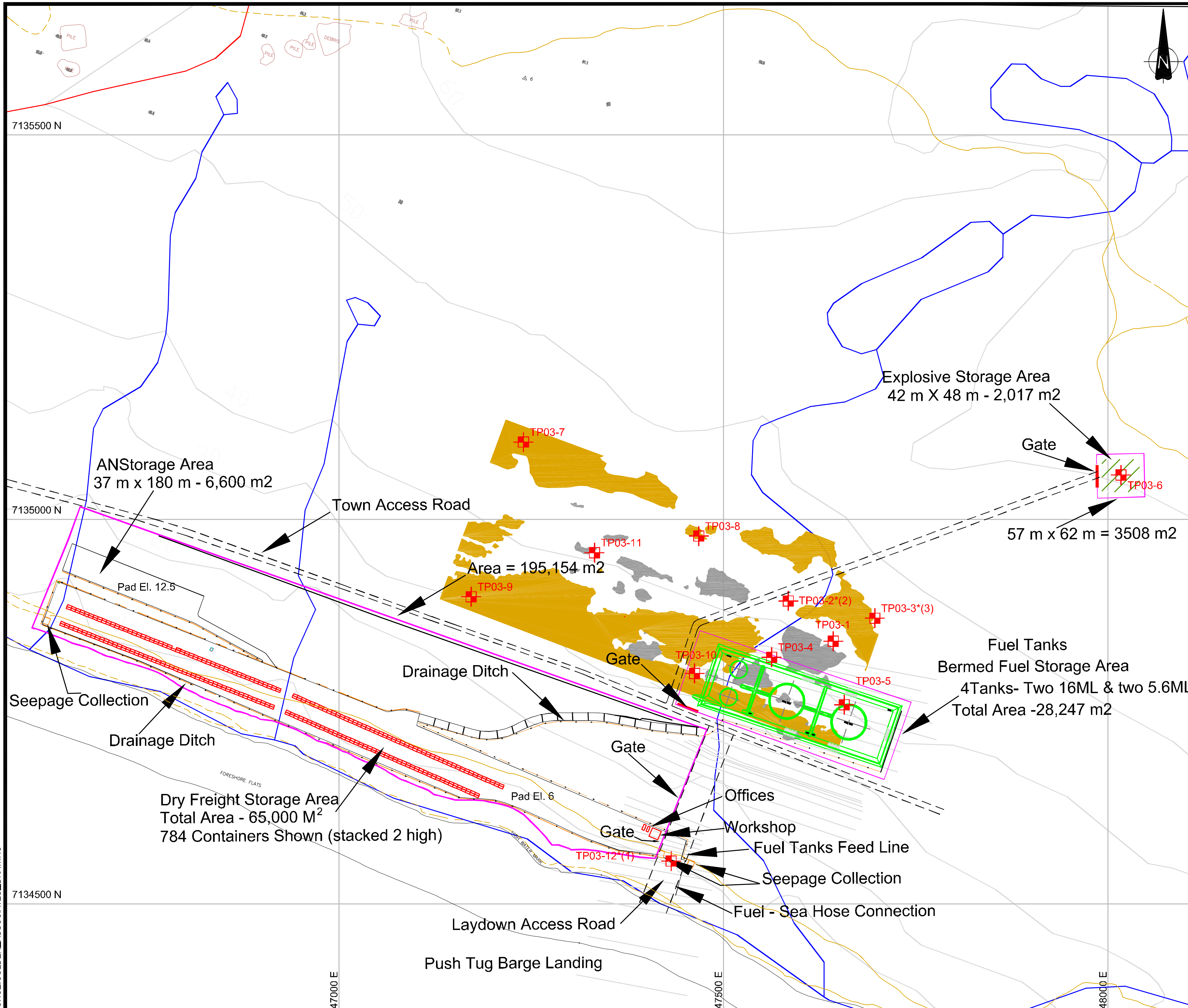
**LEGEND**

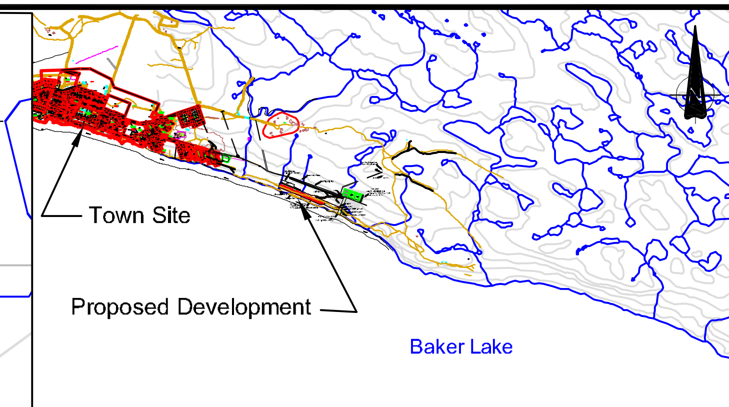
SD: SADDLE DAM

**CUMBERLAND RESOURCES LTD.**

**Meadowbank Gold Project**

**General Site Plan**




## LOCATION MAP

### LEGEND

- Test Pit Location (Approximate)
- Property Limit
- Contour Interval
- Bedrock Outcrop (Approximate)
- Interpreted Frost-susceptible Ground

### NOTES

1) Northing and eastings are in metres referenced to UTM Zone 14, NAD83.

2) Elevations are in metres referenced to geodetic datum.

3) Testpit, bedrock outcrop, seismic line and EM31 survey boundary locations were determined using GPS equipment and are considered approximate.

0 50 100 150 200 250
Scale in Meters

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**Meadowbank Gold Project**

**Baker Lake Storage & Marshalling Area**

# SECTION 1 • INTRODUCTION

Cumberland is committed to developing a mine that maximizes benefits and minimizes or reduces potential negative impacts. The approach taken by Cumberland is to weigh and consider possible project alternatives before final design decisions are made. Examples of alternatives that have been evaluated for the project include:

- tailings disposal methods
- waste rock storage facilities
- blasting practices
- milling process
- permanent versus winter access road
- power supply at Baker Lake or at site, barge-mounted or on land.

It should be recognized that project development is ongoing, and issues may arise that require the consideration of new alternatives or the re-evaluation of concepts that were previously considered but not selected. Most major project decisions will be made upon completion of the feasibility study, before the commencement of detailed design. Other items, such as blast designs, can be modified during operations as experience is gained during mining and processing activities.

The ensuing sections discuss the main alternatives being considered for the project at this time. Other than the “No-Go” alternative, each issue is described according to service requirements, other selection criteria such as environmental impact, and the ability of the selected option to best meet Cumberland’s objectives.

## SECTION 2 • THE "NO-GO" ALTERNATIVE

In the "No-Go" alternative, the Meadowbank mine project would not be developed. None of the potential impacts from project development would occur, and the natural conditions would remain essentially the same. No other currently foreseeable factors would affect the resources.

Possible reasons for implementing the "No-Go" alternative include regulatory denial of one or more of the permits necessary for project development; and/or Cumberland deciding to abandon the project either due to unsatisfactory project economics (higher development and production costs, lower gold prices) or in order to direct its mine development resources elsewhere.

Under this scenario, all existing site facilities would be decommissioned. All buildings, structures, and non-native materials would be removed, and disturbed land would be reclaimed. The test trenches in the Third Portage and Vault areas and adjacent trails would be backfilled to encourage native plant growth and minimize erosion and sediment transport. Contaminated soils would be collected and, if practical, remediated on site.

# SECTION 3 • SITE & FOOTPRINT

This section describes the sites and footprints considered during the prefeasibility and feasibility phases for major elements of the project: the process plant, open pits and dewatering dikes, waste rock piles, tailings storage impoundment, airstrip, and Vault haul road. The selected locations for these facilities are shown in Figure 3.1.

## 3.1 PLANT SITE OPTIONS

The plant site area will include the process facilities, service complex, camp complex, power plant, and fuel storage and distribution facility. Six potential plant site locations were assessed (see Figure 3.2):

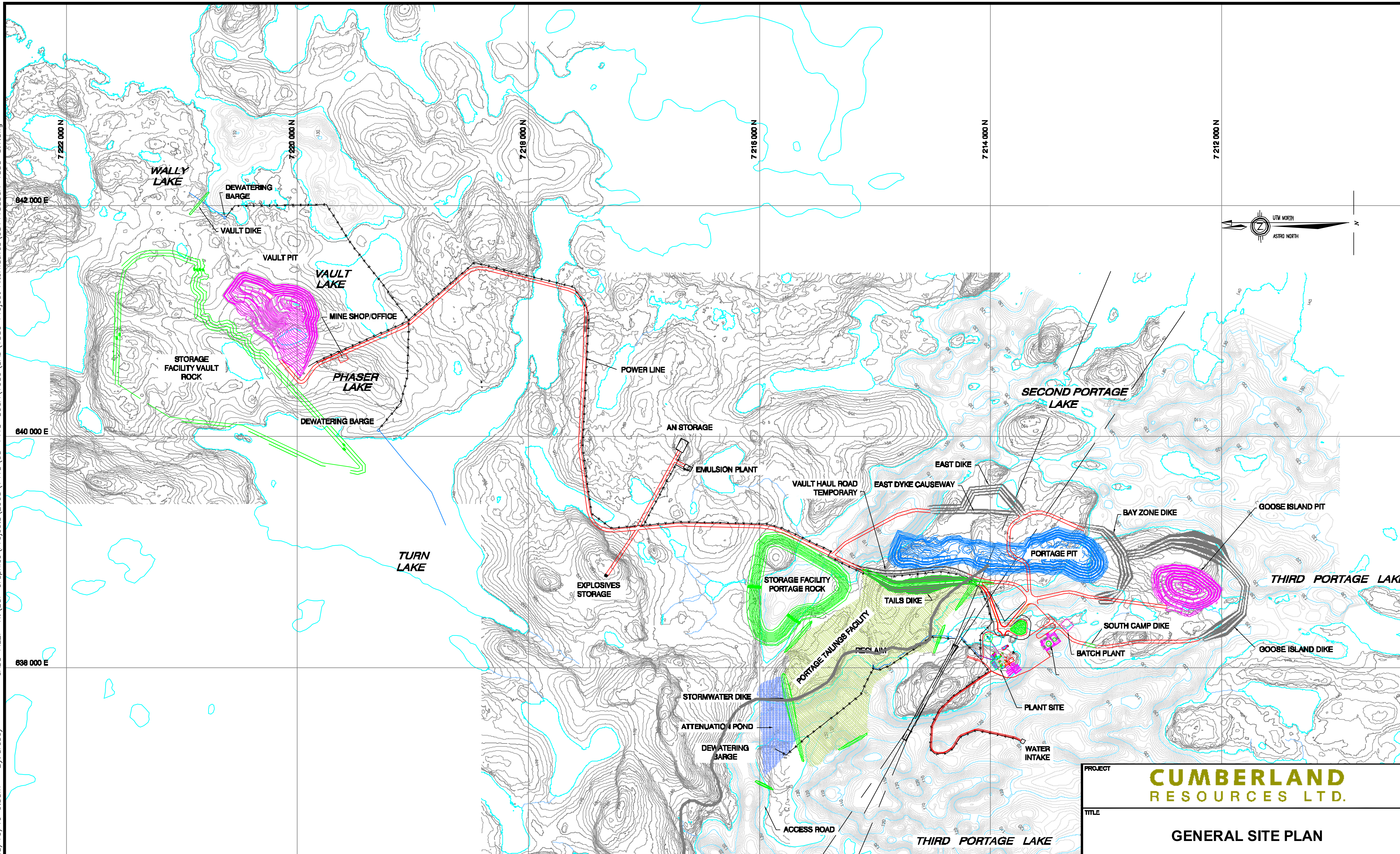
- **Site 1**, on the eastern end of South Camp Island, previously used for the exploration camp
- **Site 2**, on a small isthmus east of Goose Island
- **Site 3**, immediately west of the Third Portage deposit, on the isthmus between Second Portage and Third Portage lakes; **Site 4**, to the northwest of Site 3
- **Site 5**, on a prominent ridge to the north of the northwest end of Second Portage Lake
- **Site 6,** on the north side of Second Portage Lake, near to the location of the proposed Portage rock storage facility.

The following criteria were used to evaluate these potential plant sites:

- proximity to ore resources
- flat/gentle grades with good foundation and drainage conditions
- compatibility with future access requirements.

Site 3 was selected for the following reasons:

- central location between the Portage and Goose Island deposits
- proximity to the tailings disposal site
- relatively large area of flat, though elevated, terrain, providing enough room for the proposed facilities and permitting the airstrip to be conveniently located immediately to the northwest
- competent bedrock at or close to surface for good foundation conditions
- remote from culturally sensitive areas
- best opportunity for water management and spill containment
- least overall land disturbance.

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By: sreddy

REVISION DATE: 05/10/19 9:5am

## LEGEND

SD: Saddle Dam

## NOTES

1) Topographic contour interval 2m.
2) Bathymetric contour interval 1m.

## REFERENCES

1) Amec Americas Ltd., Drawing Number A1-131395-100-C-0001 (100-C-0001.DWG), Meadowbank Feasibility Study, April 2005.

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

# GENERAL SITE PLAN

Golder Associates

| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-3.1 |
|---|---|---|---|---|
| DESIGN | CJC | 17OCT05 | SCALE | AS SHOWN — REV. 0 |
| CADD | WLI | 17OCT05 | | |
| CHECK | CJC | 17OCT05 | FIGURE 3.1 | |
| REVIEW | CJC | 17OCT05 | | |

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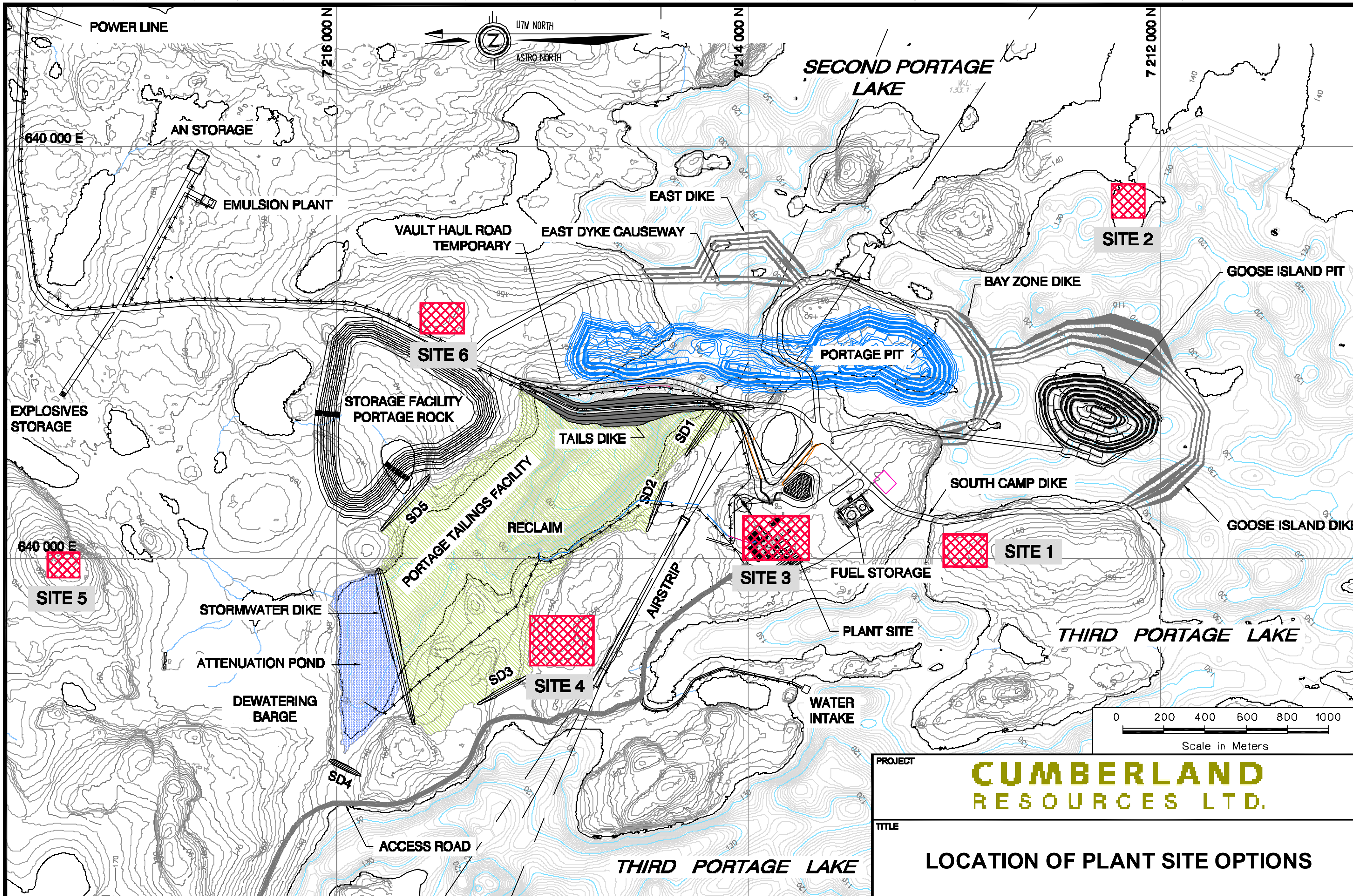


PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

## LOCATION OF PLANT SITE OPTIONS

## REFERENCES

1) Amec Americas Ltd., Drawing Number A1-131395-100-C-0001 (100-C-0001.DWG), Meadowbank Feasibility Study, April 2005.

## NOTES

1) Topographic contour interval 2m.
2) Bathymetric contour interval 1m.

Golder Associates

| PROJECT No. | | 05-1413-036A | FILE No. | 051413036A-1050-3.2 |
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| CHECK | CJC | 30SEP05 | | |
| REVIEW | CJC | 19OCT05 | | |

**FIGURE 3.2**

Site 1 was rejected because of its greater distance from the Portage deposit and consequent higher ore haulage costs. Site 2 encroaches into an area of possible cultural sensitivity. Site 4 is less central than Site 3 and offers no specific advantages. Site 5 was rejected because of its distance from the tailings storage facility, and its distance from the Portage and Goose Island deposits.

## 3.2 OPEN PIT LIMITS & DEWATERING DIKE LOCATION

The location of the open pit is determined by the position of the ore body and alternatives are focused on pit optimization. Three geological models were built outlining the gold bearing zone. After resource modelling was completed, these models were examined individually to determine the potential for open pit mining of each area. Pit designs were created for each model and measured and indicated mineralization above the economic cut-off. Pit optimization block models was exported from GEMCOM® to Whittle 4X®

A series of pit shells were created at various gold prices utilizing a varying revenue factor between 0.3 and 2.0, these pit shells were then reviewed with Cumberland and a selection was made that best fit the profile selected for the project based on the maximum gold available at a selected base case revenue factor.

The locations of the open pits are as shown on Figure 3.1

### 3.2.1 Portage Area Open Pits

The footprint area of the Portage and Goose Island open pits have increased since the Meadowbank Prefeasibility Study was completed, as additional reserves have been identified. At the time the Prefeasibility Study was completed, it was envisaged that the Third Portage and North Portage deposits would be mined as two separate open pits. Additional exploration activities have resulted in the delineation of additional reserves beneath Second Portage Lake that allow the Third and North Portage deposits to be mined by a single open pit, known as the Portage pit.

The currently defined Portage pit will be approximately 1,800 m in a north-south direction and approximately 300 m in an east-west direction, and will be mined to a maximum depth of about 120 m. The pit will extend from just south of the Third Portage peninsula, northward across Second Portage Lake to include the North Portage deposit.

The Goose Island pit is located approximately 1,000 m south of the Portage pit, as shown on Figure 3.1. The Goose Island pit will be approximately 650 m in a north-south direction and 380 m in an east-west direction and will be mined to a maximum depth of about 170 m.

The Vault pit is located approximately 6 km north of the Portage area. It is envisaged that the deposit will be mined by a single open pit to a maximum depth of about 160 m. The pit will be approximately 930 m in a northeast-southwest direction, and 550 m in a northwest-southeast direction.

### 3.2.2 Portage Perimeter Dikes

To mine the Portage and Goose Island deposits, a series of perimeter de-watering dikes will need to be constructed east of the Portage deposit, and extending southward to encircle the Goose Island deposit.

The location of the Portage area dikes are shown on Figure 3.1. The locations and alignments of the dikes were selected to provide a nominal set-back distance of approximately 80 m from the toe of the dikes to the pit crests, and to minimize the depth of water through which the dikes will need to be constructed in order to simplify construction and minimize risk. In general the dikes will be constructed through shallow water, up to about 6 m depth. In certain areas, such as the southeast portion of the Goose Island dike, water depths will be greater, up to 20 m.

### 3.2.3 Vault Area Open Pit

The Vault deposit is located some 6 km northeast of the Portage area deposits. In order to mine the deposit, Vault Lake will need to be de-watered. To accomplish this, a small dike will be constructed at the narrows joining Vault Lake to Wally Lake to the north. The depth of water through this narrows is estimated to be on the order of 2 to 4 m in depth. The location of the Vault pit and the proposed dike are shown on Figure 3.1.

## 3.3 ALTERNATIVE CONTROL STRATEGIES FOR MINE WASTE DISPOSAL IN COLD REGIONS

The generation of acidic drainage is a concern for mining projects. In evaluating the potential control strategies for the disposal of the mine waste at the Meadowbank project, consideration was given to control strategies that are effective in cold regions. Many reports have been prepared that relate to the disposal of mine waste in cold regions. The Mine Environment Neutral Drainage (MEND) program was initiated in 1989 by the Canadian mining industry, non-government organizations, and provincial and federal governments to develop and apply scientifically based new technologies for predicting, monitoring, treating, preventing, and controlling acidic drainage from mining activities. The MEND initiative developed a set of technologies available to all stakeholders. Under this program Some reports under this program that are relevant to the Meadowbank project are listed in Table 3.1.

Common control strategies for the prevention or reduction of acid mine drainage are:

1. Control of acid generating reactions
2. Control of migration of contaminants
3. Collection and treatment.

In assessing the overall control strategies for the Meadowbank project, an emphasis has been placed on methods that satisfy items (1) and (2) in the above list, which then have an impact on item (3), collection and treatment by potentially reducing the requirements for these activities.

Various acid mine drainage control alternatives (Dawson and Morin; MEND 1.61.2, 1996) for Arctic areas are listed in Table 3.2.

***Table 3.1**: MEND Project – Report Listing*

| MEND Project | Title | Year |
|---|---|---|
| 6.1 | Preventing AMD by Disposing of Reactive Tailings in Permafrost | 1993 |
| 1.61.1 | Roles of Ice, in the Water Cover Option, and Permafrost in Controlling Acid Generation from Sulphide Tailings | 1996 |
| 1.61.2 | Acid mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements | 1996 |
| 1.61.3 | Column Leaching Characteristics of Cullaton Lake B and Shear (S) – Zones Tailings Phase 2: Cold Temperature Leaching | 1997 |
| 1.62.2 | Acid mine Drainage Behaviour in Low Temperature Regimes – Thermal Properties of Tailings | 1998 |
| W.014 | Managing mine Wastes in Permafrost Zones, Summary Notes MEND Workshop | 1997 |
| 5.4.2d | MEND Manual, Volume 4 – Prevention and Control, Chapter 4.8 Permafrost and Freezing | 2001 |
| 1.61.4 | Covers for Reactive Tailings Located in Permafrost | 2004 |

***Table 3.2**: Acid Mine Drainage Control Strategies for the Arctic*

| Strategy | Tailings | Waste Rock |
|---|---|---|
| Freeze Controlled | Total or perimeter freezing options can be considered<br>Can freeze up to greater than 15 m annually if freezing in thin layers<br>Process chemicals could cause high unfrozen water contents | Requires considerable volumes of non-acid waste rock for insulation protection<br>Better understanding of air and water transport through waste rock required for reliable design |
| Climate Controlled | May not be a reliable strategy for saturated tailings | Requires control of convective air flow through waste rock, infiltration control with modest measures and temperature controls<br>Better understanding of waste rock air, water, and heat transport for reliable design |
| Engineered Cover | Special consideration for freeze-thaw effects<br>Availability and cost of cover materials are major impediments | |
| Subaqueous Disposal | Special considerations for winter ice conditions and pipeline freeze-up | Very difficult to dispose of waste rock beneath winter ice |
| Collection and Treatment | Costly to maintain at remote locations<br>Long term maintenance cost | |
| Segregation and Blending | Tailings are normally geochemically homogeneous | May be very effective<br>Research and development on-going |

**Reference:** (MEND 1.61.2, 1996).

### 3.3.1 Summary

A review of control strategies for mine waste disposal, both waste rock and tailings, in cold regions has been presented. The following lists aspects of the project that must be considered in selecting an overall waste management philosophy:

- The Meadowbank project site is located in the zone of continuous 'dry' permafrost.
- The permafrost is classified as 'dry', having ice content of less than 10% based on regional permafrost classification maps.
- The permafrost is continuous, and up to 450 to 550 m in depth based on thermal data collected from site since 1996.
- The mean annual air temperature at the site is about -11.3°C.
- The project site is considered to be arid and dry, with mean annual precipitation on the order of about 290 mm (rainfall and estimated snowfall).
- There is a shortage of naturally occurring thaw-stable materials at the site.
- Most of the waste rock that will be produced during mining is potentially acid-generating.
- There is an abundance of acid-neutralizing ultramafic waste rock material at the site. This material has a buffering capacity about five times that of the other waste rock types, and will be available in large quantities during the middle to late stages of mining.
- All of the tailings are acid-generating and metal leaching.

Based on the summary of conditions at the site, the strategies outlined below for waste management are appropriate from a technical perspective.

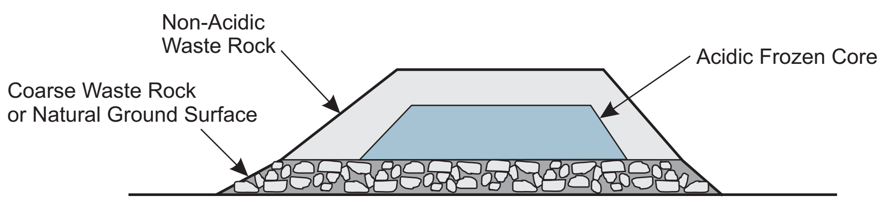
### 3.3.2 Waste Rock Disposal Alternatives

Waste rock should be disposed of on land using a total freezing control strategy, followed by a convective insulating cover of acid-neutralizing waste rock. The waste rock will freeze with time, encapsulating the potentially acid-generating waste material within permafrost. The waste rock could be placed in a heaped dump construction in lifts of about 2 to 3 m to allow freezing during placement if required for control of acid mine drainage. The cover material would be coarse to allow the development of convective cooling during winter, and insulation through trapped air within voids during the summer. Given the high evaporation rate and low annual average precipitation at site, the average annual infiltration into the pile is expected to be low. Freeze and climate control strategies for potentially acid-generating rock are shown on Figure 3.3.

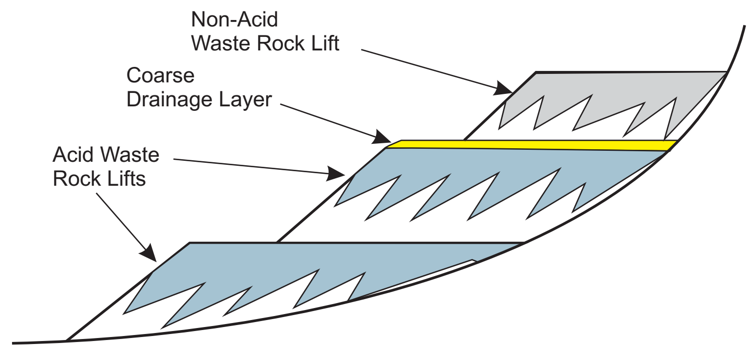
### 3.3.3 Tailings Disposal Alternatives

Due to the arid climate and permafrost environment, tailings should be disposed of in a manner that encourages total freezing as a control strategy. Subaerial disposal is preferred, given the length of time that water at the site is ice covered, allowing the tailings to be frozen in thin layers rather than one thick layer in order to maximize the total frozen thickness. This can be accomplished through the use of slurry pipelines. The tailings will eventually become encapsulated by permafrost, thus limiting oxygen diffusion and water infiltration into the pile, thereby limiting the generation of acid mine drainage. This is shown conceptually on Figure 3.4.

**HEAPED CONSTRUCTION**




**CONSTRUCTION CONFIGURATION**

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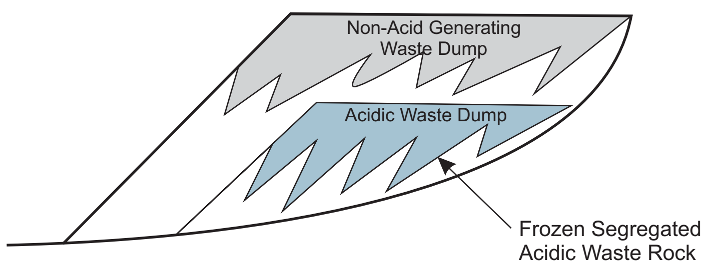


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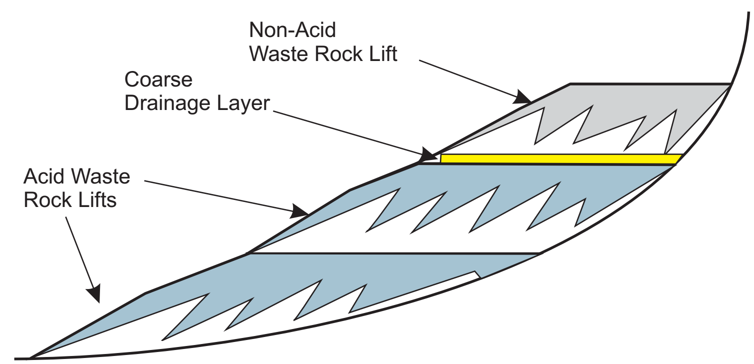


**Freeze Controlled ARD Strategies**

**Climate Controlled ARD Strategies**

Not to Scale

Reference: MEND 1.61.2, 1996

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

**WASTE ROCK STORAGE FACILITY CONSTRUCTION METHODS**

| | | | |
|---|---|---|---|
| PROJECT No. | 05-1413-036A | FILE No. | FIGURE 3.3 |
| DESIGN | CJC | 05OCT05 | SCALE NTS / REV. |
| CADD | SS | 05OCT05 | **FIGURE 3.3** |
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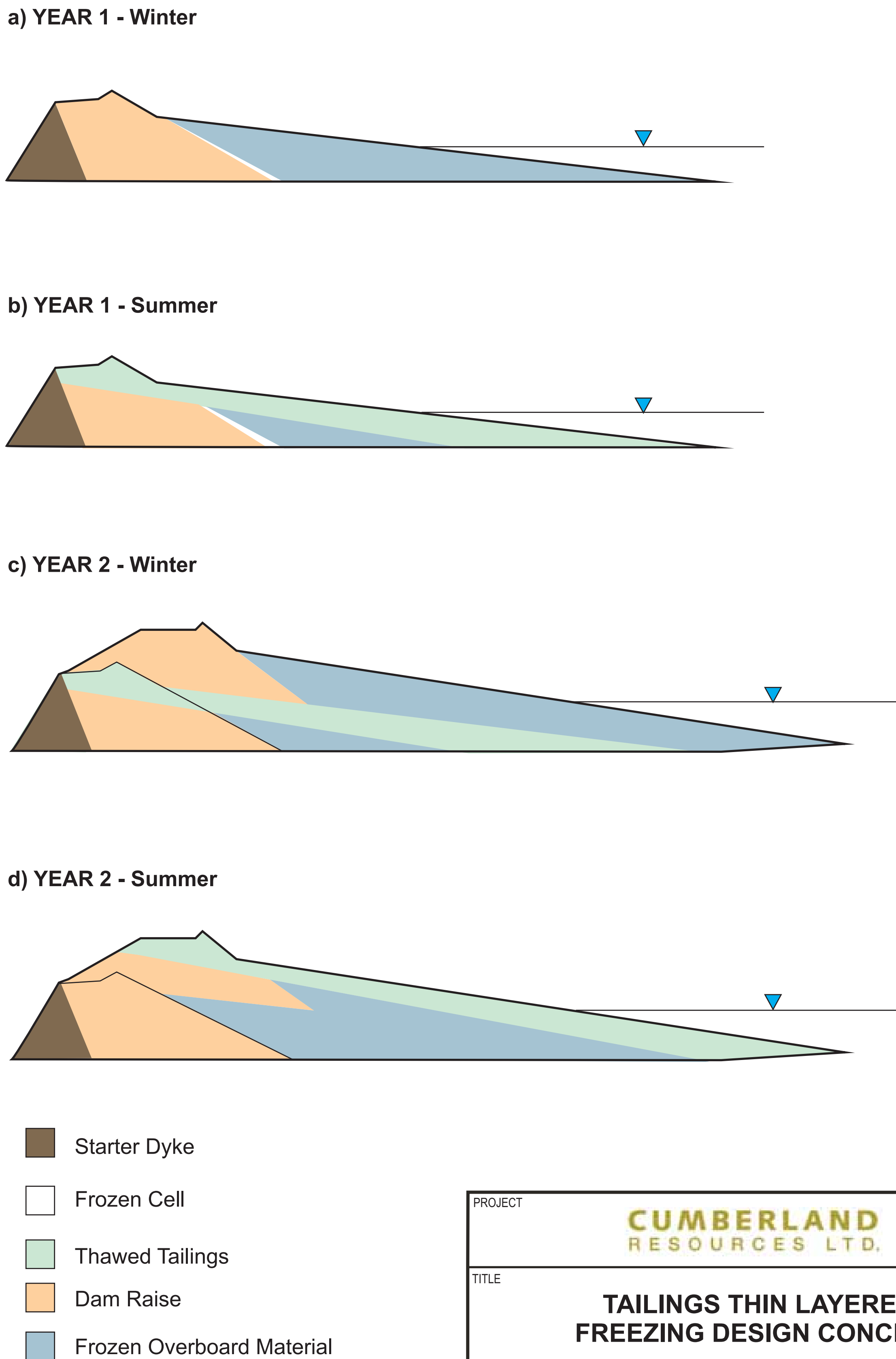
Golder Associates




Reference: MEND 1.61.2, 1996

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

**TAILINGS THIN LAYERED FREEZING DESIGN CONCEPT**

Golder Associates

| | | | |
|---|---|---|---|
| PROJECT No. 05-1413-036A | | | FILE No. FIGURE 3.4 |
| DESIGN | CC | 06OCT05 | SCALE NTS / REV. |
| CADD | SS | 06OCT05 | **FIGURE 3.4** |
| CHECK | CC | 06OCT05 | |
| REVIEW | | | |

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Capping of the tailings storage facility would consist of the placement of a coarse convective insulating layer of ultramafic rock over the facility to a minimum depth of about 2 m. This thickness is consistent with other cover designs over reactive tailings in the north (see Figure 3.5). During winter, convective heat transfer developed within the coarse cover material will transfer heat out of the tailings pile; during the summer trapped air within the voids will act as insulation. This will limit the depth of annual thaw penetration to within the acid-neutralizing ultramafic waste rock. During detailed design, a cover design will be developed that will consider the addition of a fine-grained layer of soil material as a base layer to the coarse rock cover. This layer would retain moisture within it, resulting in a reduction in the thickness of the active layer. It is possible that this layer could consist of till material dozed in a thin layer over the tailings facility. There are sufficient quantities of till material that will be produced during pre-mining and pre-stripping that could be stockpiled and used for this purpose.

The above discussion has presented a basis for the initial consideration of waste disposal strategies in continuous permafrost environments. Additional discussion and analysis to determine the best management strategy for the Meadowbank project are presented in the following sections, and in supporting documents. The following presents a case history of disposal of reactive mine tailings subaerially within a natural rock basin.

## 3.4 MINE WASTE STORAGE ALTERNATIVES

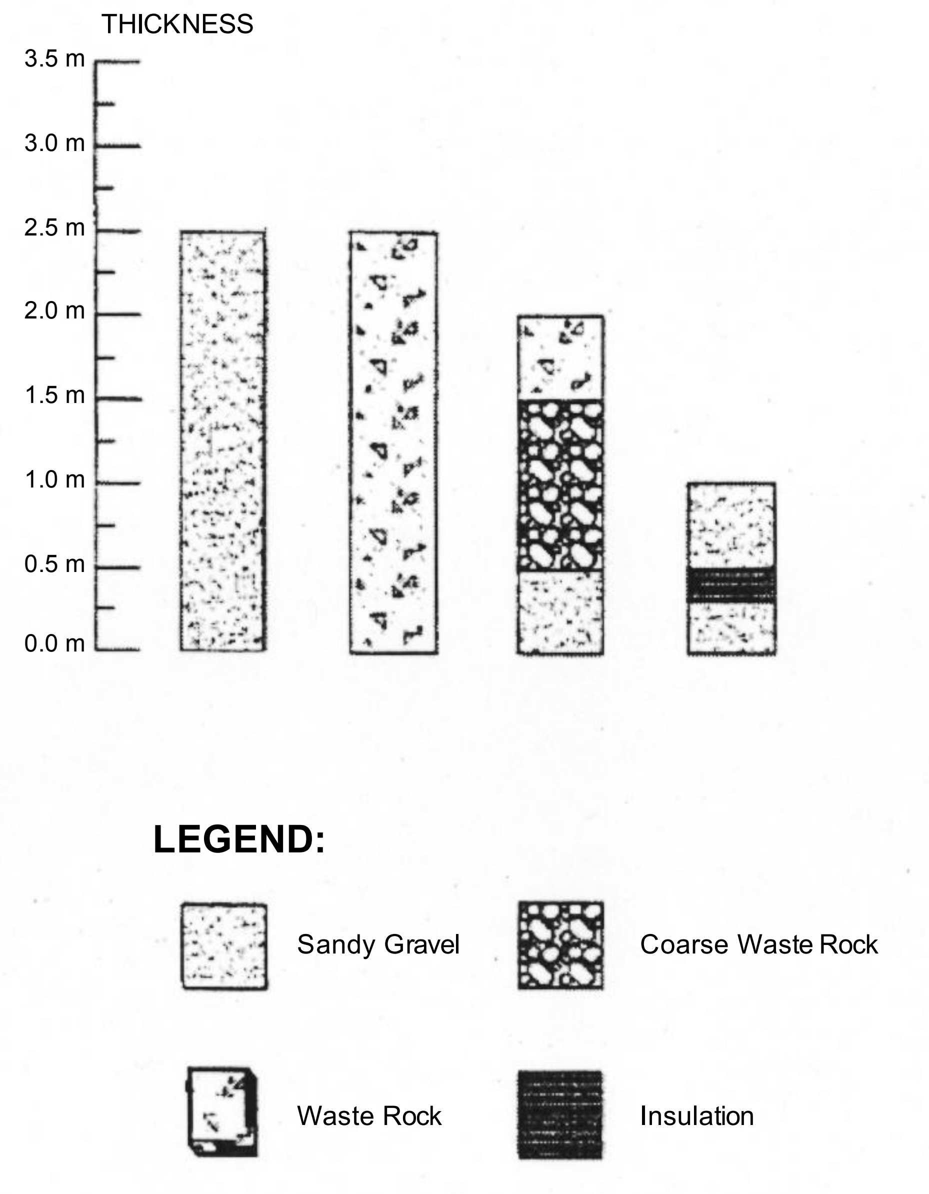
Mine waste storage alternatives, both rock and tailings, were evaluated using a decision matrix approach whereby a series of selection criteria were developed to describe environmental, operational, and economic factors and to allow a comparison of the relative importance of these factors for the different sites and for the different waste streams.

The process used to evaluate the alternatives associated with the following:

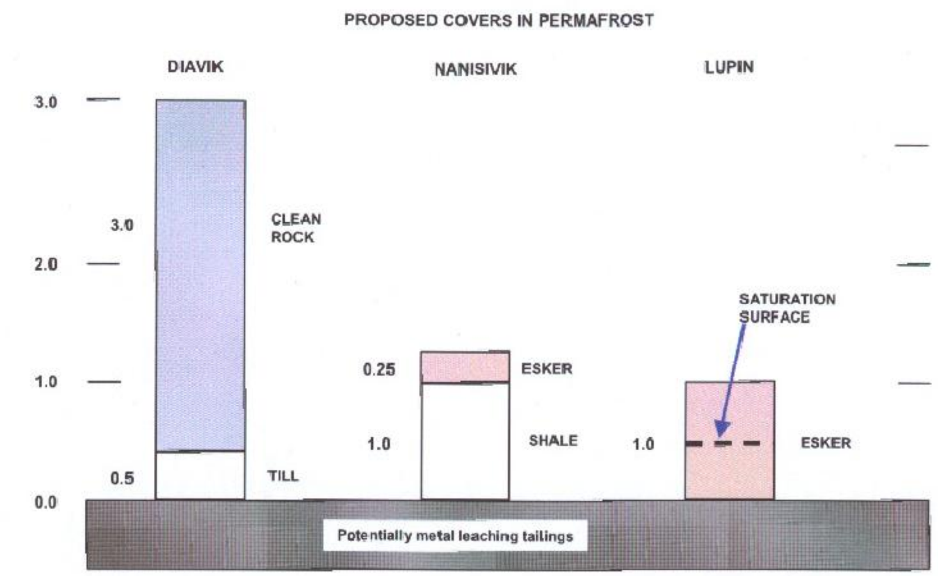
- identifying potential locations
- developing a site-specific decision matrix model to evaluate, rank, and select the best overall facility or facilities.

Decision matrix types of analyses are also sometimes referred to as Multiple Accounts Analyses (MAA) or alternatives analyses. These types of analyses have been used as site selection tools for tailings facilities and other mining-related decision processes at the following:  Zortman and Landusky mine sites, Montana (Shaw et al, 2001); Red Dog mine, Alaska (Northern Liner, 2005); and Questa Molybdenum mine, New Mexico (Molycorp Watch project). Numerous papers have been published on the subject of MAA, including: Robertson and Shaw (1998 and 1999); Caldwell and Robertson (1983); Vick (1990); Brown (2002); and the Decision Makers Field Guide (2005).

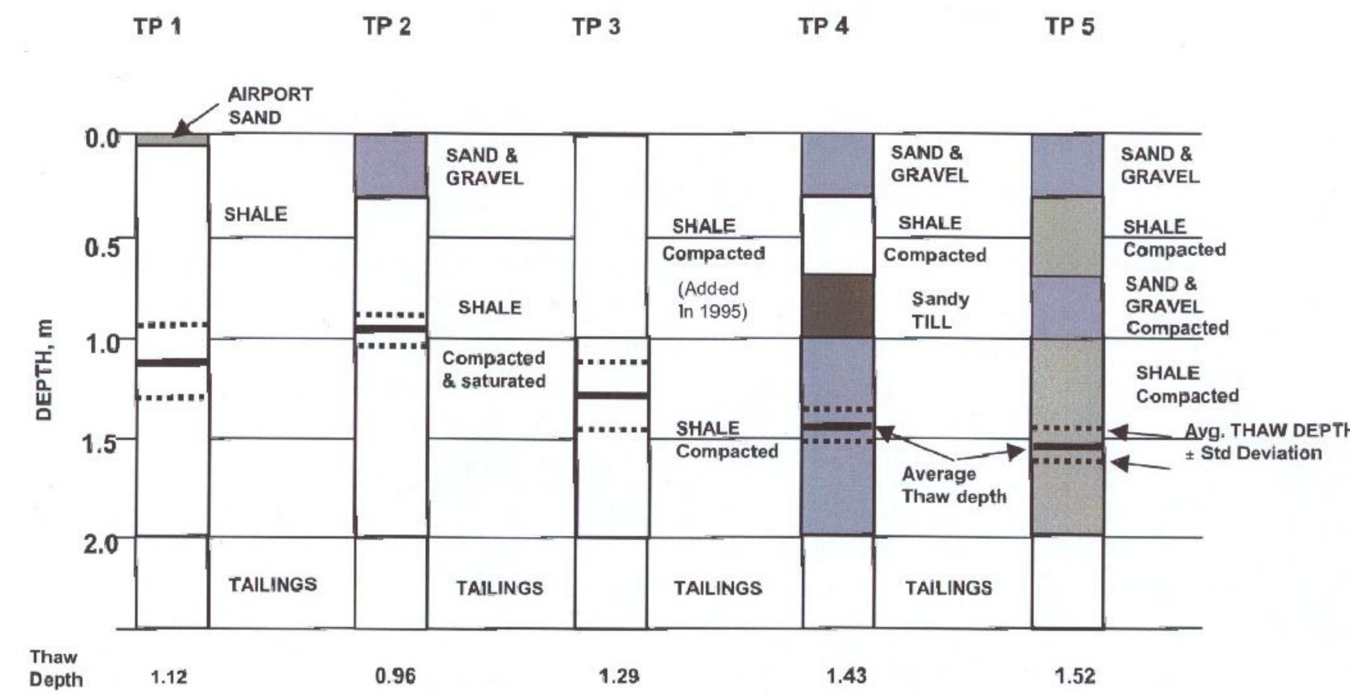
Similar types of analyses are also used in the fields of risk assessment, risk management, selection of the best available technologies or options for environmental remediation projects, resource planning, and sustainable development (Canter, 1985; International Atomic Energy Agency, 2000; CH2MHill, 2004, Robson Valley Land and Resource Management Plan, 1999).




Typical Insulating Cover Options for Total Freezing in Continuous Permafrost Regions (after MEND 6.1, 1993)




Cover Design Concepts for Reactive Tailings at Existing Mine in Permafrost
(reference: MEND 1.61.4, 2004)




Test Pad Statigraphies at Nanisivik Mine
(reference: MEND 1.61.4, 2004)

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**INSULATING COVER DESIGN FOR TOTAL FREEZING IN CONTINUOUS PERMAFROST**

Golder Associates

| | | | | |
|---|---|---|---|---|
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| REVIEW | CJC | 17OCT05 | | |

**FIGURE 3.5**

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REVISION DATE:05/10/21 10:52am By: sreddy

Four reports have been issued describing the strategy for selecting the waste rock storage facility and detailing the mine waste and water management plan:

- Golder Associates Ltd., Report on Evaluation of Tailings Alternatives, Meadowbank Project, Nunavut. October 2005 – See Appendix A.
- Golder Associates Ltd., Report on Evaluation of Waste Rock Management Alternatives, Meadowbank Project, Nunavut. October 2005 – See Appendix B.
- Golder Associates Ltd., Report on Alternative Waste and Water Management Plan, Meadowbank Gold Project, Nunavut. 7 March 2005.
- Golder Associates Ltd., Report on Mine Waste and Water Management, Meadowbank Gold Project, Nunavut. 5 March 2004.

The reports "Evaluation of Tailings Alternatives" and "Evaluation of Waste Rock Management Alternatives" are contained as appendices to this report.

The objectives of the above reports was to identify the most appropriate method for disposal of waste rock and tailings for the Meadowbank project based on an evaluation of technical, environmental, and economic considerations. The requirements for each facility are as follows:

- minimal net adverse effects on the environment, now and in the future
- technically sound with the minimal potential for failure
- economic.

The contributions of the three primary categories to the overall decision-making process are shown for the baseline conditions for the rock and tailings storage facilities in Table 3.3.

***Table 3.3**: Relative Contribution of Primary Categories to Decision Analysis*

| Primary Category | Contribution to Overall Weighting Rock Storage | Contribution to Overall Weighting Tailings Storage |
|---|---|---|
| Environmental | 50% | 55% |
| Operational | 30% | 33% |
| Cost | 20% | 12% |

Each of the primary categories was subdivided to consider other sub-indicators.

#### *3.4.1.1 Scale Factor*

In order to separate the best alternatives from the worst, a scaling (or scoring) factor was applied. Each sub-indicator was assigned a score between 1 and 9 points, similar to the system described by Robertson and Shaw (1999). The scores provide a relative ranking between the options with the best option receiving a score of 9, and the worst a score of 1. All subsequent options were then compared to the best option and assigned a lower relative score. An example of the scoring method is shown in Table 3.4.

***Table 3.4**: Example of Scoring System used in Decision Matrix*

| | Footprint Area | Points | Notes |
|---|---|---|---|
| Option A | 30 ha | 9 | 9 points awarded for least footprint area (BEST) |
| | | 8 | - |
| | | 7 | - |
| | | 6 | - |
| Option C | 60 ha | 5 | 9 points x 30 ha (least area) / 60 ha = 5 points |
| | | 4 | - |
| Option B | 90 ha | 3 | 9 points x 30 ha (least area) / 90 ha = 3 points |
| | | 2 | - |
| | | 1 | - |

#### *3.4.1.2 Relative Weighting Factor*

Each sub-indicator of the primary categories was assigned a relative weighting factor to introduce a value bias between the individual sub-indicators, based on the relative subjective importance of one indicator versus another. A higher weighting factor indicates a perceived greater relative value or importance between sub-indicators. For example, the relative importance of the impact of acid mine drainage is considered greater than the visual impact of the facility. Consequently, the sub-indicator of acid mine drainage is given a relative weighting factor that is greater than the weighting factor for visual impact.

The weighting factors used for the evaluation of the waste rock storage alternatives are shown in Table 3.5, along with the maximum possible weighted score and category score if a sub-indicator was given the maximum possible individual score of 9.

The weighting factors used for the evaluation of the tailings storage alternatives are shown in Table 3.6, along with the maximum possible weighted score and category score if a sub-indicator was given the maximum possible individual score of 9.

The individual sub-indicator weighting values were then multiplied by the score to arrive at a weighted score. The weighted scores for each category were then summed to arrive at a total weighted score for each option. The best alternative for waste rock and tailings disposal was then determined as the alternative having the highest overall score, relative to the other alternatives.

***Table 3.5**: **Weighting Factors for Sub-Indicators for Rock Storage Facility Selection***

| Factor | Sub-Indicator | Relative Weighting | Max, Possible Score | Max. Weighted Score[1] | Max. Category Score[1] |
|---|---|---|---|---|---|
| Environmental | Sub-catchment area | 5 | 9 | 45 | 396 |
| | Footprint area | 4 | 9 | 36 | |
| | Potential for generating dust | 4 | 9 | 36 | |
| | Potential for acid rock drainage (ARD) generation during operation | 3 | 9 | 27 | |
| | Potential for metal leaching (ML) during operation | 3 | 9 | 27 | |
| | Potential for seepage to impact groundwater | 6 | 9 | 54 | |
| | Potential for geotechnical hazards[2] | 6 | 9 | 54 | |
| | Lake area impacted | 7 | 9 | 63 | |
| | Visual impact | 6 | 9 | 54 | |
| Operational | Difference between crest and adjacent land | 5 | 9 | 45 | 234 |
| | Ease of water management | 7 | 9 | 63 | |
| | Catchment Impacted | 6 | 9 | 54 | |
| | Ease of decommissioning/closure | 8 | 9 | 72 | |
| Economic | Distance from north edge of North Portage pit | 18 | 9 | 162 | 162 |
| **Total** | | | | | **792** |

**Notes:** **1.** Values represent the maximum score, if 9 points was assigned for each sub-indicator. **2.** Includes consideration of foundation conditions, impact of seismicity, and height of structure.

***Table 3.6**: Weighting Factors for Sub-Indicators for Tailings Facility Evaluation*

| Factor | Sub-Indicator | Relative Weighting | Max, Possible Score | Max. Weighted Score[1] | Max. Category Score[1] |
|---|---|---|---|---|---|
| Environmental | Sub-catchment area | 1 | 9 | 9 | 603 |
| | Footprint area | 1 | 9 | 9 | |
| | Potential for generating dust during operation | 6 | 9 | 54 | |
| | Potential for generating dust after closure | 4 | 9 | 36 | |
| | Potential for acid rock drainage (ARD) generation during operation | 5 | 9 | 45 | |
| | Potential for ARD generation after closure | 7 | 9 | 63 | |
| | Potential for metal leaching (ML) during operation | 2 | 9 | 18 | |
| | Potential for ML after closure | 5 | 9 | 45 | |
| | Potential for seepage to impact groundwater during operation | 5 | 9 | 45 | |
| | Potential for seepage to impact groundwater after closure | 6 | 9 | 54 | |
| | Potential for geotechnical hazards[2] | 5 | 9 | 45 | |
| | Lake area impacted | 5 | 9 | 45 | |
| | Number of lakes impacted | 4 | 9 | 36 | |
| | Visual impact | 2 | 9 | 18 | |
| | Relative loss of high value fish habitat | 9 | 9 | 81 | |
| Operational | Ease of operation | 9 | 9 | 81 | 351 |
| | Distance from mill | 8 | 9 | 72 | |
| | Potential for delays due to freezing | 10 | 9 | 90 | |
| | Construction risk | 4 | 9 | 36 | |
| | Disposal system has precedent in arctic environment | 8 | 9 | 72 | |
| Economic | Total present value of costs (initial cost + delayed costs) | 15 | 9 | 135 | 135 |
| **Total** | | | | | 1089 |

**Notes: 1.** Values represent the maximum score, if each sub-indicator assigned a maximum scoring factor of 9 points.
**2.** Includes consideration of foundation conditions, impact of seismicity, and height of structure.

## 3.5 EVALUATION OF WASTE ROCK DISPOSAL ALTERNATIVES

Mine rock storage facilities will be developed in both the Portage and the Vault mining areas. The complexity of disposing of potentially acid-generating mine tailings and mine waste rock in a permafrost environment presents specific challenges primarily due to climatic conditions. Consequently, any type of waste disposal facility in the Arctic must take into consideration these challenges. Control strategies such as freeze control and climate control are commonly used in permafrost environments as effective methods for controlling ARD.

Because of the distance between the Portage and Vault deposits it was decided that two waste rock storage facilities were required. One storage facility near the Vault pit was selected on the basis of available on-land storage space near this pit, topographic relief, and the desire to have the facility located within the same watershed as the open pit. The rock storage facility near the Portage deposit (called Portage waste rock storage) was selected to dispose of waste rock generated from the Portage and Goose Island open pits.

Primary objectives established for the selection of an appropriate waste rock storage facility (or facilities) were to:

- minimize potential long-term environmental impacts (including ARD generation, metal leaching, seepage to the underlying groundwater regime)
- maximize ease of water management during operation
- maximize ease of decommissioning/closure
- minimize catchment area impacted
- minimize dust generation
- minimize visual impact
- minimize areas of lakes impacted
- minimize footprint area (to reduce the volume of affected runoff)
- minimize the potential for geotechnical hazards (including slope instability, seismic risk)
- minimize haul costs.

### 3.5.1 Portage Rock Storage Alternatives

Four areas on the north side of Second Portage Lake were considered as potential waste rock storage areas. The weighted scores for the various options are summarized in Table 3.7; the storage options are illustrated on Figure 3.6. The full decision matrix is contained in the supporting documentation in the appendices.

***Table 3.7*: Summary of Weighted Scores for Rock Storage Facility Options**

| Option | Description | Weighted Score |
|---|---|---|
| A | North from Second Portage Lake – small footprint | 560 |
| B | Northwest from Portage Lake – large footprint | 459 |
| C | East from Vault Haul Road – small footprint | 436 |
| D | East from Vault Haul Road – large footprint | 355 |

**Note:** The highest score indicates the most desirable option.

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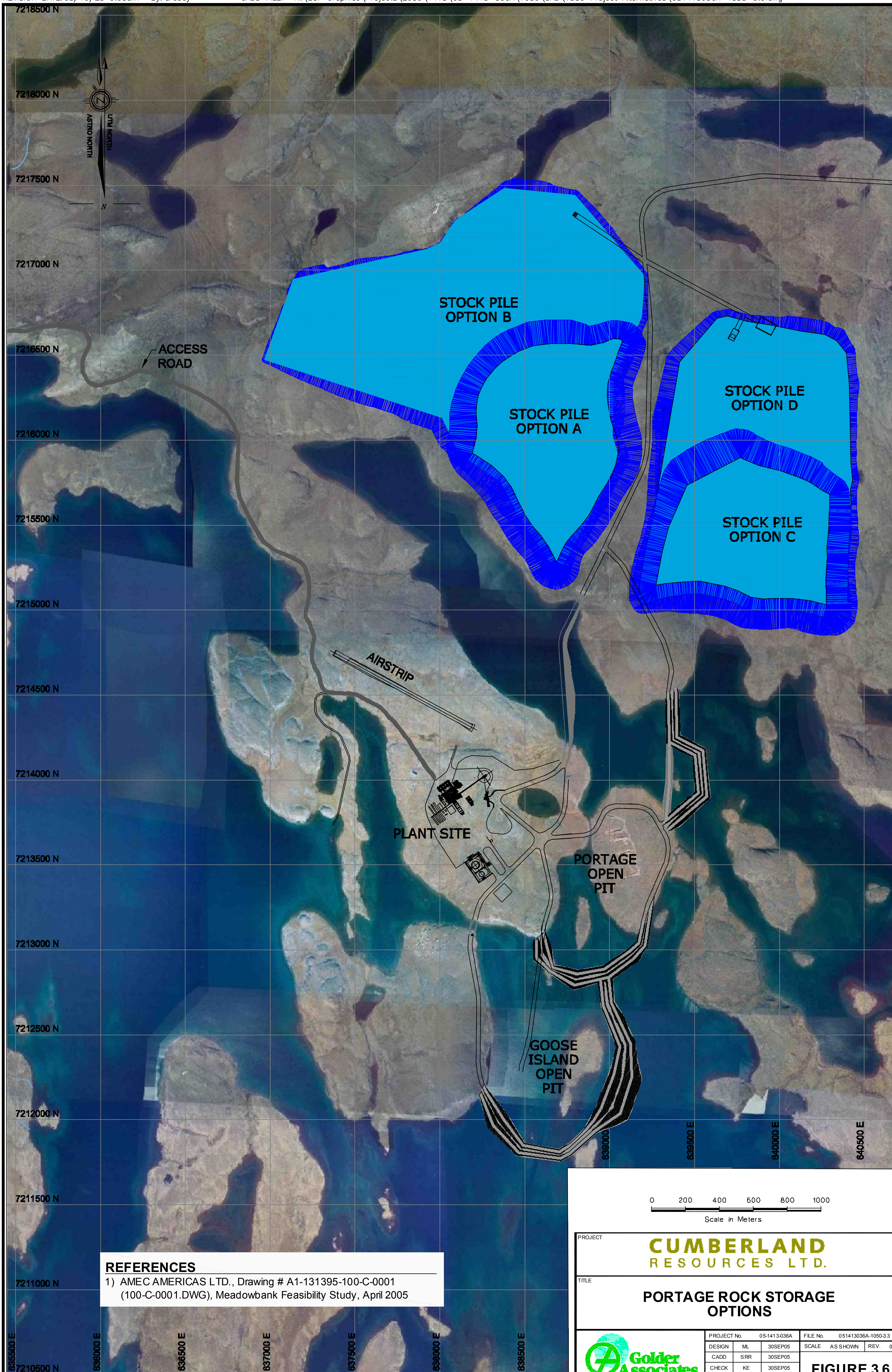


**REFERENCES**

1) AMEC AMERICAS LTD., Drawing # A1-131395-100-C-0001 (100-C-0001.DWG), Meadowbank Feasibility Study, April 2005

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**PORTAGE ROCK STORAGE OPTIONS**

Golder Associates

| | | |
|---|---|---|
| PROJECT No. | | 05-1413-036A |
| DESIGN | ML | 30SEP05 |
| CADD | SRR | 30SEP05 |
| CHECK | KE | 30SEP05 |
| REVIEW | CJC | 18OCT05 |

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**FIGURE 3.6**

The options were evaluated using a decision matrix as described above where individual sub-indicators within three key categories—environmental, operational, and cost considerations—were assigned “weight” values based on subjective estimates of their relative importance. In this exercise, overall weighting factors of 50% were assigned to environmental considerations, 30% to operational considerations, and 20% to cost factors for each option.

The options were allocated a score for each of the evaluation criteria listed above to show the relative difference between options. Weighted scores were derived by multiplying the allocated scores by the individual sub-indicator weighting values and summing the totals. The highest score indicates the most desirable option. On this basis, option A, on-land disposal of rock on the north side of Second Portage Lake, was selected as the preferred rock storage facility. The facility is predicted to eventually freeze, resulting in a reduction in the rates of acid mine drainage over the long-term. This methodology is a common strategy used in cold climates and takes advantage of permafrost and climate conditions. The site will be progressively reclaimed and capped with acid-neutralizing ultramafic rock.

### 3.5.2 Vault Waste Rock Storage Alternatives

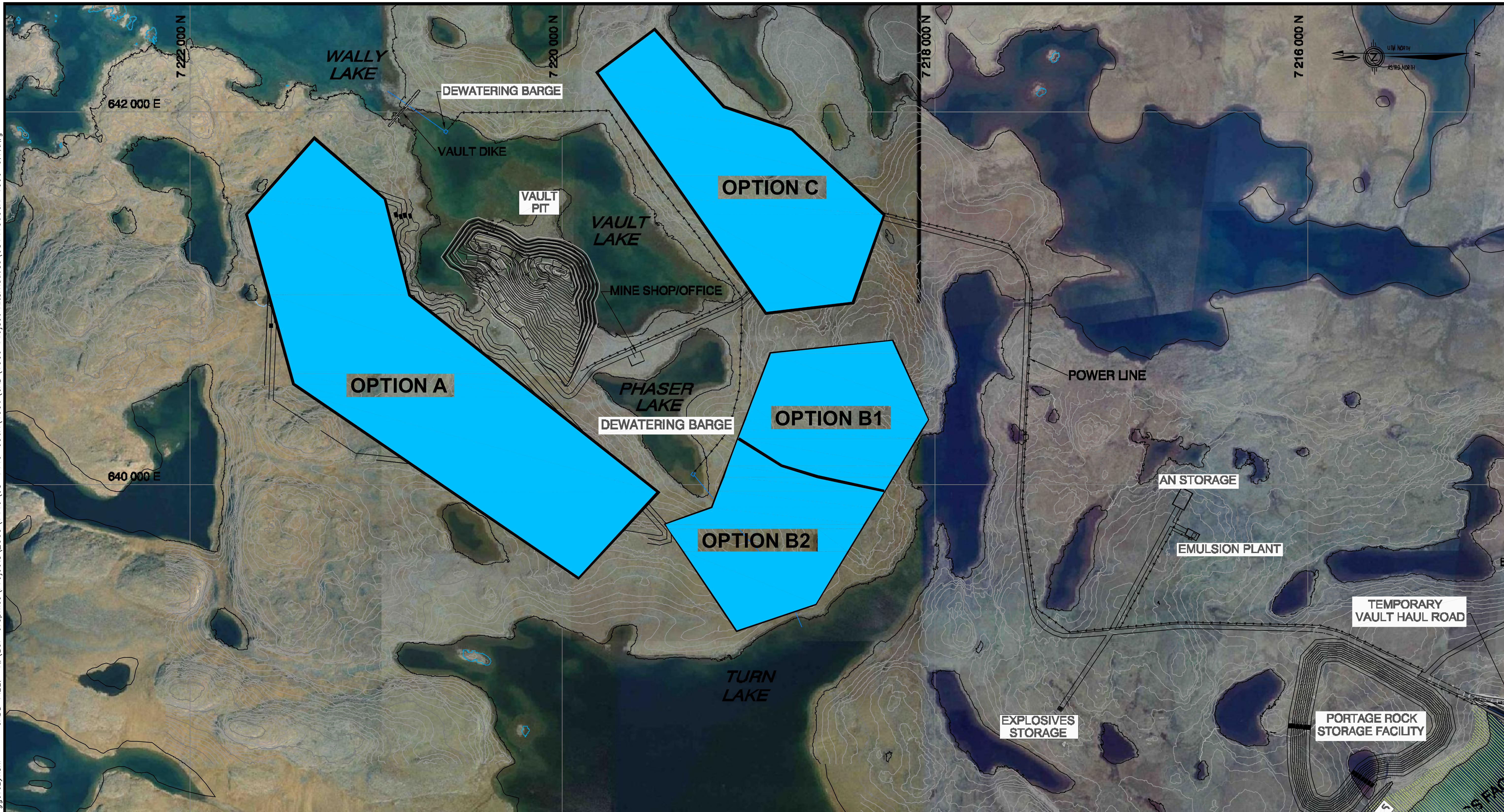
There are few suitable locations for a waste rock storage facility near the Vault pit owing to the presence of numerous lakes adjacent to Vault Lake and the lack of topographical relief in the immediate area. The lack of topographical relief limits the height to which a rock storage facility can be constructed without becoming visible at great distance from the site. In addition, placing waste rock in areas south of Vault Lake would affect a sub-watershed that does not drain toward the Vault open pit.

As with the Portage rock storage facility, the Vault facility was selected based on consideration of the following criteria:

- the potential for long-term environmental impacts, including ARD generation and metal leaching
- ease of water management during operation and closure
- ease of decommissioning and closure
- impact on lakes and catchment areas
- visual impact
- footprint size to reduce the volume of affected runoff
- the potential for geotechnical hazards, such as slope instability and response to seismic activity haulage costs.

Alternatives that were considered are shown on Figure 3.7 and listed below:

- *Immediately west of the Vault pit (option A*) – This alternative consists of a broad, relatively flat area within the catchment area of the Vault pit. This alternative offers the advantage of allowing the storage facility to be developed with a low profile, reducing the potential visual impact as well as reducing the potential impact to wildlife movement. The location of option A results in the least travel distance for waste rock haulage and disposal.

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## REFERENCES

1) AMEC Americas Ltd., Drawing Number A1-131395-100-c-0001 (100-c-0001.dwg), Meadowbank Feasibility Study, April 2005.

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TITLE
VAULT ROCK STORAGE OPTIONS

Golder Associates

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| DESIGN | CJC | 17OCT05 |
| CADD | GG | 17OCT05 |
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| REVIEW | CJC | 17OCT05 |

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FIGURE 3.7

- *South of the Vault deposit (options B1 and B2)* – This alternative was rejected as it places the waste rock material within a catchment area and sub-watershed that previously remained unaffected.
- *On-land storage to the east of Vault Lake (option C)* – This alternative was rejected due to the small area in which to store the waste rock, and due to the distance from the deposit area, which would result in an increase in the overall footprint area for the mine development, as well as an increase in haulage costs. The smaller area in which to store the material would result in a waste dump with a higher final elevation, resulting in visual impact as well as exposure to wind dispersion. The additional distance for haulage would require the construction of additional roads. Increased traffic would result in increased levels of particulate matter (including dust and exhaust) to the atmosphere to be transported and deposited elsewhere.
- *Disposal into Wally Lake (option D)*. This alternative was rejected because there is no convincing evidence to suggest that placing the Vault waste rock material in a submerged environment will have less impact than placing on land. Placing the waste rock into Wally Lake would un-necessarily impact on fish habitat within that lake.

The best alternative for the storage of the waste rock from the Vault pit is on a broad area of land immediately to the west of the open pit area. A cover layer of non-PAG rock is not presently required at the Vault waste rock storage facility because this rock is considered to be non-PAG. Further testing and monitoring during operations will be completed to confirm this.

## 3.6 EVALUATION OF TAILINGS STORAGE ALTERNATIVES

### 3.6.1 Tailings Initial Site Selection Criterion

A list of initial site selection criterion that any tailings storage facility for the Meadowbank mine site must meet was developed. This list was used as an initial screening tool, and any locations that did not meet these criteria were eliminated from further analysis. The following key site selection criteria were utilized:

- the site should have sufficient volume to store planned volume of tailings
- the site should have the potential to provide additional capacity for tailings storage
- the location should be able to accommodate mine expansion
- the location should be within catchments of the open pits
- the site should allow the control and collection of the tailings supernatant.

Sites that failed to meet the initial site selection criteria were removed from further consideration.

### 3.6.2 Tailings Disposal Alternatives

Initially seven potential tailings storage sites were identified (see Figure 3.8). These are listed in Table 3.8 along with the disposal methodology for each site.

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## REFERENCES

1) Amec Americas Ltd., Drawing # A1-131395-100-C-0001 (100-C-0001.DWG), Meadowbank Feasibility Study, April 2005

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TAILINGS STORAGE OPTIONS

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| REVIEW | CJC | 17OCT05 |

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FIGURE 3.8

***Table 3.8: Summary of Initial Tailing Storage Alternatives***

| Option | Location | Disposal Type |
|---|---|---|
| A | Second Portage Arm and North Portage Pit | Subaqueous Slurry |
| B | Second Portage Arm | Subaerial Paste or Drystack |
| C | Second Portage Arm | Subaerial Slurry |
| D | Third Portage Lake | Subaqueous Slurry |
| E | East from Vault Haul Road | Subaerial Slurry |
| F | North of Second Portage Arm | Subaerial Slurry |
| G | North of Second Portage Arm | Subaerial Paste or Drystack |

These alternatives were then compared to the initial site selection criteria, as a pre-screening process, prior to conducting the overall decision matrix analysis. Based on the pre-screening assessment, only four of the initial seven options met the site selection criteria. These four are listed in Table 3.9.

***Table 3.9: Alternatives Evaluated Using the Decision Matrix***

| Option | Location | Disposal Type |
|---|---|---|
| B | Second Portage Arm | Subaerial Paste or Drystack |
| C | Second Portage Arm | Subaerial Slurry |
| F | North of Second Portage Arm | Subaerial Slurry |
| G | North of Second Portage Arm | Subaerial Paste or Drystack |

All locations and methods that met the initial criterion proceeded to the next phase of analyses which involved the use of the decision matrix as described above.

### 3.6.3 Base Line Analysis

Tailings facility options B, C, F, and G for the proposed Meadowbank project were evaluated using the decision matrix method of analysis described above. Table 3.10 summarizes the results. The highest score represents the best alternative for site conditions.

***Table 3.10: Summary of Baseline Analysis Decision Matrix Results***

| | Options | | | |
|---|---|---|---|---|
| **Factor** | **B Second Portage Arm Subaerial Paste** | **C Second Portage Arm Subaqueous/ Subaerial Slurry** | **F West of Waste Rock Storage Subaerial Slurry** | **G West of Waste Rock Storage Subaerial Paste** |
| Environmental | 438 | 475 | 372 | 432 |
| Operational | 263 | 216 | 160 | 256 |
| Economic | 60 | 135 | 75 | 60 |
| **Total** | **761** | **826** | **607** | **748** |

The full decision matrix is contained in the supporting documentation in the appendices.

### 3.6.4 Sensitivity Analyses

In order to evaluate the decision analysis process to changes in the weightings and the perceived relative importance of certain factors, three sensitivity analyses were completed.

### 3.6.5 Sensitivity Analysis – Part 1

To consider the impact of the weighting factors used in the decision matrix, a sensitivity analysis was conducted with all sub-indicator weightings set equal to one. This results in each of the sub-indicators having equal importance in the decision process and removes the value bias between the sub-indicators that might be imposed by personal preferences. The greatest numbers of sub-indicators were associated with the environmental category, while the lowest numbers of sub-indicators were associated with the economic category. Consequently, the relative importance of each category is determined by the number of sub-indicators representing that category. Based on the revisions to the weightings, the relative distribution of influence on the weighted total is:

Environment........................................................................................................71%
Operational ........................................................................................................24 %
Economic ...........................................................................................................5%

The results of this analysis are summarized Table 3.11.

***Table 3.11**: Summary of Decision Matrix Results – Sensitivity Analysis (Part 1)*

| Factor | Options | | | |
|---|---|---|---|---|
| | **B**<br>**Second Portage Arm**<br>**Subaerial Paste** | **C**<br>**Second Portage Arm**<br>**Subaqueous/**<br>**Subaerial Slurry** | **F**<br>**West of Waste Rock**<br>**Storage**<br>**Subaerial Slurry** | **G**<br>**West of Waste Rock**<br>**Storage**<br>**Subaerial Paste** |
| Environmental | 106 | 113 | 91 | 104 |
| Operational | 31 | 26 | 23 | 34 |
| Economic | 4 | 9 | 5 | 4 |
| **Total** | **141** | **148** | **119** | **142** |

As with the baseline case, option C received the highest overall score although only marginally better than options B and G.

### 3.6.6 Sensitivity Analysis – Part 2

An additional sensitivity analysis was carried out by excluding economic factors, and by reducing the effect of operational factors. The resulting decision matrix was weighted strongly towards the influence of environmental factors. Based on the revisions to the weightings, the relative distribution of influence on the weighted total is:

Environment........................................................................................................89%
Operational ........................................................................................................11%
Economic ............................................................................................................0%

Table 3.12 summarizes the results of the analysis.

***Table 3.12**: Summary of Decision Matrix Results – Sensitivity Analysis (Part 2)*

| **Factor** | **Options** | | | |
|---|---|---|---|---|
| | **B<br>Second Portage Arm<br>Subaerial Paste** | **C<br>Second Portage Arm<br>Subaqueous/<br>Subaerial Slurry** | **F<br>West of Waste Rock<br>Storage<br>Subaerial Slurry** | **G<br>West of Waste Rock<br>Storage<br>Subaerial Paste** |
| Environmental | 438 | 475 | 372 | 432 |
| Operational | 8 | 40 | 72 | 64 |
| Economic | 0 | 0 | 0 | 0 |
| **Total** | **446** | **515** | **444** | **496** |

The analysis indicates that when the decision matrix is heavily weighted towards the consideration of environmental factors, option C (tailings slurry disposal in Second Portage Lake) is the preferred option.

### 3.6.7 Sensitivity Analysis – Part 3

A final sensitivity analysis was carried out on the baseline case to evaluate the effect the proposed methods of disposal may have on fish and fish habitat. For this case, issues relating specifically to impact on fish and fish habitat were adjusted to weight these indicators high in the overall analysis. Based on the revisions to the weightings, the relative distribution of influence on the weighted total is:

Environment........................................................................................................57%
Operational ........................................................................................................31%
Economic ...........................................................................................................12%

The relative weighting factor for "number of lakes impacted" and "impact on fish and fish habitat" were adjusted so that these two indicators carried the highest relative weights of all the environmental sub-indicators. The scale factors for the sub-indicator "number of lakes impacted" remained the same as the previous analyses, as the number of lakes impacted by either on-land or in lake disposal is the same regardless of the disposal method selected. The scale factors for the sub-indicator "impacts on fish and fish habitat" however were increased to the maximum possible value of 9 for on-land disposal, representing the best possible case, and were maintained at the least possible value of 1 for disposal in Second Portage Arm, representing the worst possible case. The result of this re-scaling is that "impacts on fish and fish habitat" and "number of lakes impacted" contribute between 31% and 35% to the overall environmental weighting for on-land storage, compared with 13% to 17% contribution for disposal within Second Portage Arm

Table 3.13 summarizes the results of the analysis.

***Table 3.13**: Summary of Decision Matrix Results – Sensitivity Analysis (Part 3)*

| | Options | | | |
|---|---|---|---|---|
| **Factor** | **B<br>Second Portage Arm<br>Subaerial Paste** | **C<br>Second Portage Arm<br>Subaqueous/<br>Subaerial Slurry** | **F<br>West of Waste Rock<br>Storage<br>Subaerial Slurry** | **G<br>West of Waste Rock<br>Storage<br>Subaerial Paste** |
| Environmental | 468 | 520 | 462 | 522 |
| Operational | 263 | 216 | 160 | 256 |
| Economic | 60 | 135 | 75 | 60 |
| **Total** | **791** | **871** | **697** | **838** |

The analysis indicates that when environmental factors are weighted heavily towards impact on lakes and on fish habitat, disposal on-land or in Second Portage Lake carry equivalent total environmental weighting, resulting in a ‘null’ decision based on that category alone. When economic and operational issues are considered in the decision analysis, then option C, disposal of slurry tailings in the basin of Second Portage Arm, is the preferred option.

Based on the decision matrix method, option C (tailings slurry disposal in the northwest arm of Second Portage Arm) is the best tailings management strategy for the Meadowbank project site. The primary advantages provided by option C are as follows:

- lowest potential for the generation of acidic drainage and the release of metal constituents to the environment
- lowest potential for the generation of dust from the facility during operations and closure, and consequently the lowest potential for transportation and deposition into lakes or on land downwind of the facility and off-site
- simplest construction methodology requiring construction materials from the mining activities
- simplest closure methodology, requiring least amount of borrow materials, and utilizing the natural environment to encapsulate the tailings
- low risk of instability of tailings facility, and hence lower risk of potential release of tailings to the environment
- ease of operation in harsh Arctic climates
- lowest relative capital cost
- precedence in Arctic climate.

The primary disadvantage of the proposed disposal method is that the northwest arm of Second Portage Lake will be permanently filled. However, regardless of the tailings disposal strategy adopted for the project, the northwest arm of Second Portage Lake will be impacted in one form or another by mining activities. The arm of the lake will need to be completely de-watered in order for mining to be undertaken. If the tailings are disposed of on land, there will still be a requirement for attenuation storage and reclaim water management. It is likely that the northwest arm of the lake would be used for these purposes.

## 3.7 ASSESSMENT OF THE STRATEGY TO FREEZE THE PORTAGE TAILINGS FACILITY

A strategy of total freezing of the tailings will be used to control ARD and ML. Permafrost encapsulation of the tailings is the preferred management alternative for the project.

### 3.7.1 Thermal Modelling

Simplified thermal modelling of the proposed tailings deposit in the northwest arm of Second Portage Lake was carried out to predict the range of time required to freeze the tailings and into the underlying talik. The detailed analyses were presented previously in:

- Golder Associates Ltd., Technical Memorandum - Item #56 - Tailings thermal Modelling and Climate Change Effects. 22 July 2005.
- Golder Associates Ltd., Report on Thermal Modelling of the Tailings Deposit in the Second Portage Lake, Meadowbank Gold Project. 16 February 2004.

The assumptions and results of the modelling are summarized in the following sections.

### 3.7.2 Assumptions

Site climate data were considered with various snow packs to represent ground covers of snow, soil, and vegetation to estimate the range of surface temperature functions on the bedrock profile. Ground temperatures were estimated using each of the surface temperature functions and compared to site thermistor data for calibration.

Thermal properties for the bedrock and tailings materials were estimated from published correlations for the range of expected geotechnical conditions. In addition, the following assumptions were used in the modelling:

- Only bedrock was considered in the subsurface profile.
- A constant temperature boundary of 4°C was used at the bottom of the lake.
- All the tailings were assumed to be placed instantaneously.
- Tailings were deposited at either 6°C (unfrozen) or -0.2°C (frozen) to bind the expected deposition sequence.

### 3.7.3 Impact of Climate Change

To investigate the potential effect of climate change, the precautionary principal was applied to consider the effect of a temperature increase of 5.5°C over the next century. For this simplified model, the effect of climate change is considered by uniformly incrementing the annual average temperature function by 5.5°C over the first 100 years in the model and then maintaining a constant mean monthly temperature for the next 200 years. The prediction of climate change beyond 100 years is considered to be unreliable due to unpredictable variables.

#### *3.7.3.1 Accepted Climate Change Predictions*

The climate change considered in the Meadowbank Gold project feasibility design followed the worst case "high sensitivity" models described in the precautionary principal (INAC, 2003 "Implications of Global Warming and The Precautionary Principle in Northern mine Design and Closure"). These models suggest that an increase of 5.5°C to the mean annual air temperature (MAAT) by the year 2100 for a site located at 65°N latitude is reasonable for climate change predictions. Table 3.14 presents a summary of reported climate change predictions used on a number of northern projects that have been reported in the engineering and scientific literature.

***Table 3.14: Summary of Reported Climate Change Rates Used in Northern Projects Engineering Studies***

| Reference | Increase in MAAT by Year 2100 (°C) | Notes |
|---|---|---|
| INAC (2003) | 5.5 | Used in Meadowbank DEIS for site at 65° North Latitude |
| Hayley (2004) | 4.7 | Used in design studies for the Inuvik Regional Health Center. Reported as increase of 0.47°C per decade. |
| Hayley and Cathro (1996) | 5.0 | Used for Raglan Dam analyses. |
| Mackenzie Valley Land and Water Board (2002) | 3.0 | Used for the Ekati mine expansion |
| Diavik | 3.2 | Used for the Processed Kimberlite Containment Facility Design |
| Burn (2003) | 6.0 | For use in the Western Arctic for pipeline design projects. Reported as increase of 1.75°C over a 29 year period |
| IPCC (2003) | 0.8-5.2 | Predicted range for change in the global average surface air temperature |

For comparison purposes, climate records for Baker Lake were reviewed. Figure 3.9 presents the complete record of MAAT data from Baker Lake weather station for the period between 1951 and 2004, during which time the long-term MAAT is reported as being -11.9°C. A linear regression of the data for this period indicates an increase in MAAT of about 2°C when projected over a 100-year period Trend lines for a climate change rates of 2°C and 5.5°C for 100 years are also shown on Figure 3.9.

Consequently, a climate warming trend of 5.5°C for 100 years is considered to be a reasonable upper estimate of the climate change rate for the project area and is consistent with predicted and recommended climate change trends for projects in the north.

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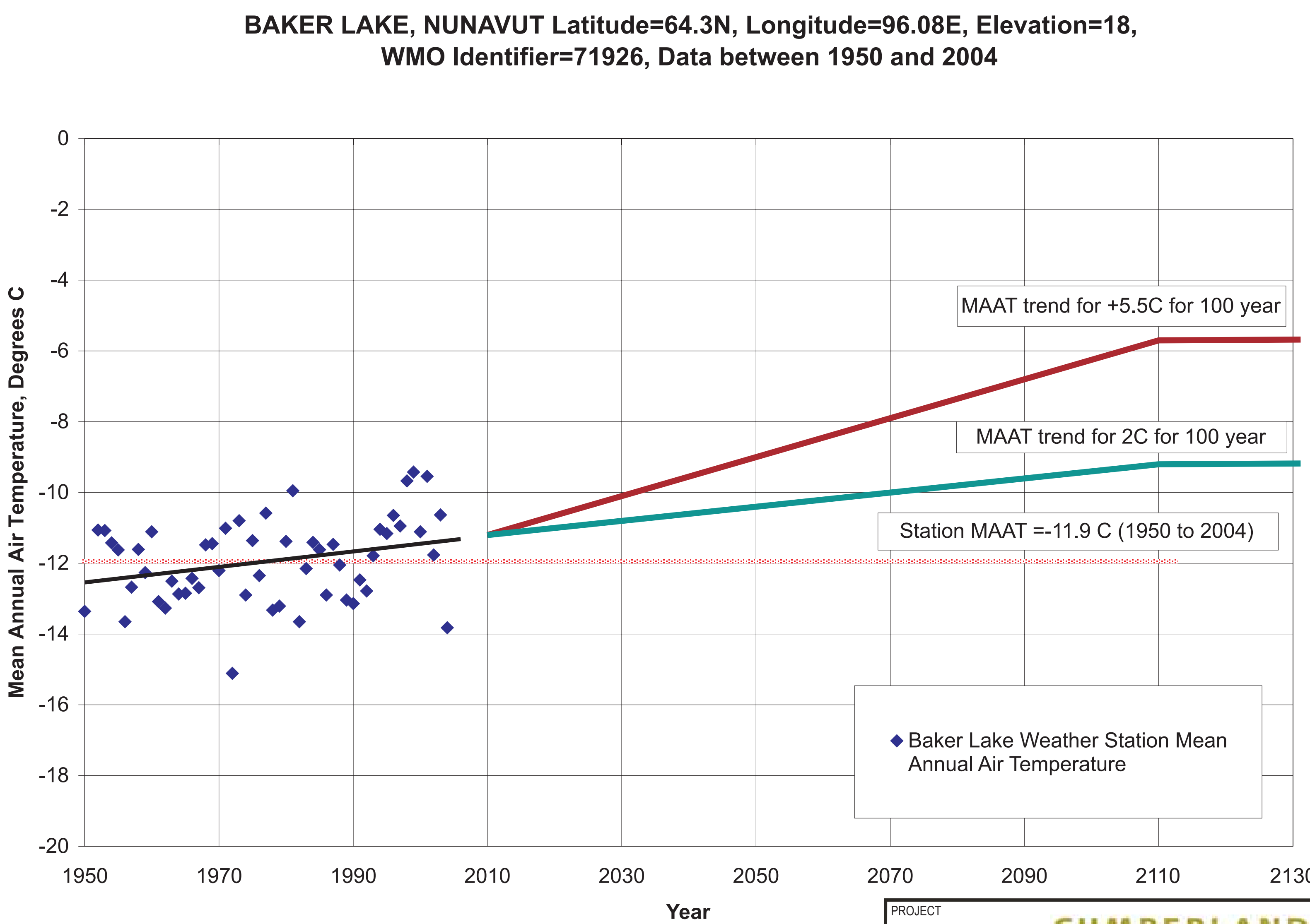


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| PROJECT | CUMBERLAND RESOURCES LTD. | | | | |
| TITLE | BAKER LAKE WEATHER STATION DATA AND CLIMATE CHANGE TRENDS | | | | |
| Golder Associates | PROJECT No. | 05-1413-036A | | FILE No. | FIGURE |
| | DESIGN | CJC | 10OCT05 | SCALE NTS | REV. |
| | CADD | SS | 10OCT05 | FIGURE 3.9 | |
| | CHECK | CJC | 10OCT05 | | |
| | REVIEW | CJC | 17OCT05 | | |

### 3.7.4 Results of Modelling

After establishing the existing ground temperature conditions in the model, the tailings deposit was modelled by instantaneous replacement of the lake with either unfrozen or frozen tailings. The thermal models were run between 100 and 300 years to predict ground temperature profiles beneath the tailings impoundment.

The results indicate that complete freezing of the tailings and bedrock beneath the lake will occur with time. For tailings not frozen during deposition, the time to begin freezing the talik beneath the lake could be as long as 200 years if climate change is not considered and 270 years if climate change is considered.

If the tailings are frozen soon after deposition, the time to freeze 5 m into the talik is between 1 and 45 years, depending on the location within the lake. When climate change is considered, this time is increased to 50 years. Freezing of the tailings will limit the ability of contaminants to migrate beyond the tailings storage facility.

### 3.7.5 Sensitivity Analysis

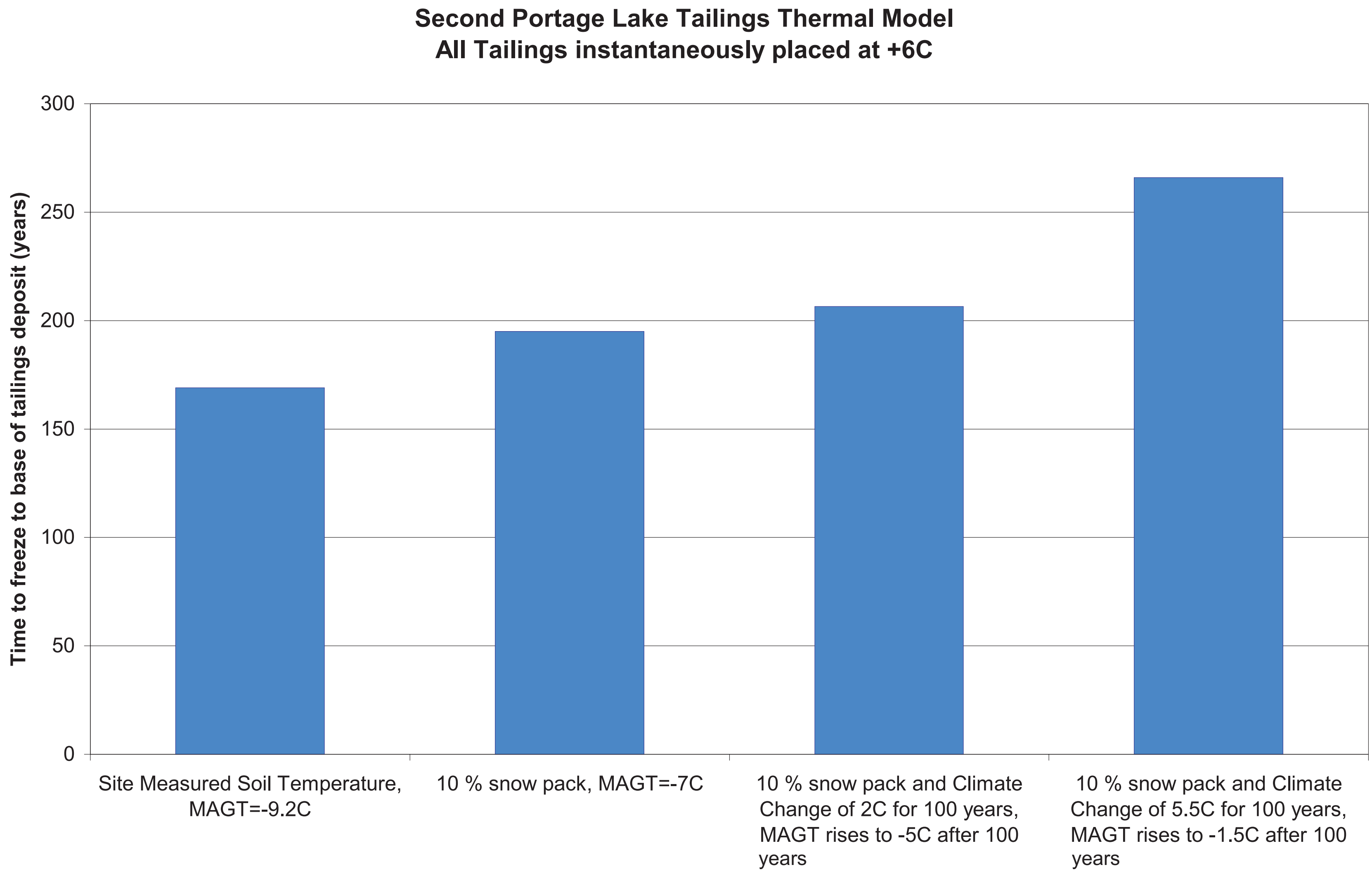
To investigate the sensitivity of the model to climate change rate and the predicted time to freeze the tailings deposit, an additional thermal model was developed which considered a 2°C for 100-year climate change rate for the case of the initially thawed (+6C) tailings instantaneously replacing the lake. Table 3.15 presents these results as well as a summary of the predicted times to freeze the initially thawed tailings deposit.

***Table 3.15**: Time to Freeze at Base of Tailings (38 m) for Initially Thawed Tailings*

| Ts function (MAGT[1]) Based on | MAGT (°C) | MAGT after 100 Years (°C) | Time to Freeze Initially Thawed Tailings Deposit (Years) |
|---|---|---|---|
| Site Measured Soil Temperature | -9.2 | -9.2 | 170 |
| 10 % snow pack | -7 | -7 | 200 |
| 10 % snow pack and Climate Change of 2C for 100 years | -7 | -5 | 210 |
| 10 % snow pack and Climate Change of 5.5C for 100 years | -7 | -2.5 | 270 |

**Note:** MAGT is mean annual ground temperature.

As expected, an increase in MAGT results in a longer time for the tailings deposit to freeze. From the modelling results, a 2°C climate change rate adds 10 years to the time to freeze, while a 5.5°C climate change rate adds 70 years to the case with no climate change. The variation in time to freeze tailings without consideration for climate change is 30 years when comparing the MAGT based on the climate station data and a 10% snow pack. Figure 3.10 provides a summary of the results of freezing time for the tailings deposit vs. the Ts function.




**LEGEND:**

MAGT - Mean Annual Ground Temperature

PROJECT: CUMBERLAND RESOURCES LTD.

TITLE: **TIME TO FREEZE TAILINGS FACILITY**

Golder Associates

| | | | |
|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. FIGURE 3.10 |
| DESIGN | CJC | 14OCT05 | SCALE NTS / REV. |
| CADD | SS | 14OCT05 | **FIGURE 3.10** |
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| REVIEW | CJC | 17OCT05 | |

## 3.8 AIRSTRIP

In coordination with the selection of the plant site, two options were considered for the site of the airstrip: one along the isthmus between the northwest arm of Second and Third Portage lakes, and the other along the southwest side of Third Portage Lake (see Figure 3.11). Although the more southern route requires less cut and fill, it would involve the construction of a roadway crossing over a narrow section in Third Portage Lake. The selected northern alternative, northwest of the plant site, is better aligned with the prevailing wind direction from the northwest and will permit the development of a more compact site with less overall disturbance.

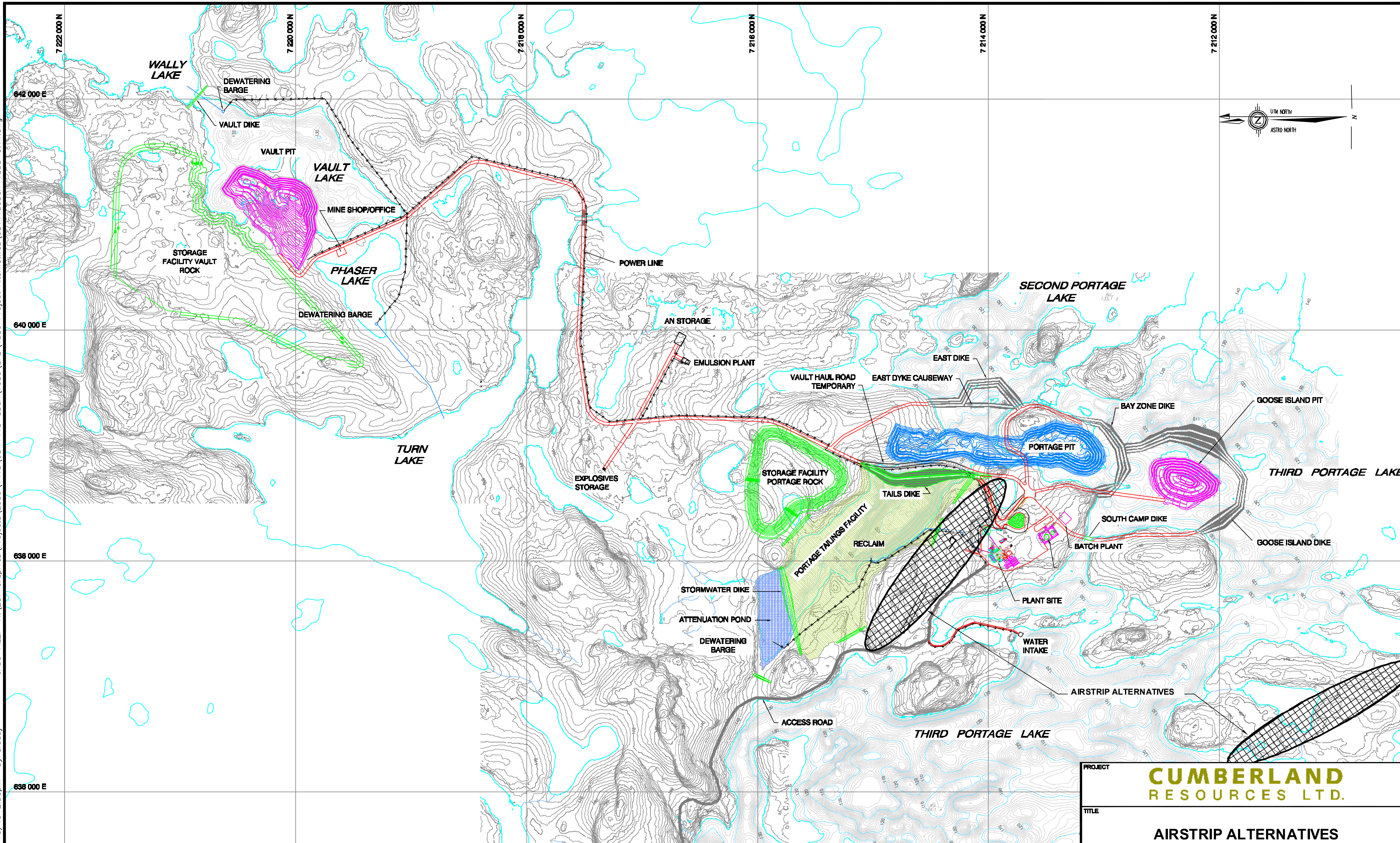
The alignment of the airstrip has been selected based on minimizing cut and fill requirements for construction and has been based on a near balance of the excavation and backfill quantities. However, it is anticipated that additional fill materials will be required from locally available borrow sources to complete the airstrip embankment. The airstrip will be constructed in two development sequences. The first sequence will involve the construction of a gravel-surfaced pioneer airstrip nominally 915 m long x 30.5 m wide for use by aircraft such as the Beechcraft King Air B200 Jet Prop during the first years of development. This will minimize impact to Third Portage Lake as the entire strip will be constructed on land. Drainage ditches, settling ponds, and silt fences will be used to manage runoff during construction and operation of the pioneer strip. Later in mine life, the airstrip will be extended to about 1,525 m long x 50 m wide for use by larger aircraft such as Hercules and 737 aircraft. This will require the extension of the airstrip by about 380 m off-shore of Third Portage Lake. It is expected that the frequency of usage of the airstrip will be less than 100 takeoffs/landings per month.

The design of the airstrip allows for the use of intermediate volcanic (IV) rock produced from mining activities. The majority of the IV rock is non-acid-generating; however, some is expected to generate acid. The rock will be submerged off-shore, which will reduce the potential for acid generation. A capping of non-acid-generating rock will be placed over the main airstrip rock fill. To achieve the full length of 1,525 m, however, approximately 198,000 $m^3$ of fill will need to be placed at the west end of the strip, extending into the lake.

The alignment of the airstrip has been selected based on minimizing cut and fill requirements for construction and has been based on a near balance of the excavation and backfill quantities. However, it is anticipated that additional fill materials will be required from locally available borrow sources to complete the airstrip embankment. With the current alignment, the initial 915 m long strip can be built while minimizing impact to Third Portage Lake through the use of settlement ponds and silt fencing to control runoff during construction. To achieve the full length of 1,525 m, approximately 198,000 $m^3$ of fill will need to be placed at the west end of the strip, extending into the lake. The design allows the use of PAG mine rock from the Portage pit in airstrip construction. A permanent capping of non-PAG rock from the Portage pit will be placed over the mine rock fill.

## 3.9 VAULT ACCESS ROAD

The Vault pit is approximately 6 km north of the main project facilities in the Portage area and will be connected by a haul road. A road will need to be constructed to access the Vault pit and to haul ore back to the processing facilities at the Portage area. The road will be constructed with rockfill produced from the Portage pit mining activities. The road embankment will be designed to preserve

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By: sreddy

REVISION DATE: 05/10/19 2:36pm

## LEGEND

SD: SADDLE DAM

POSSIBLE AIRSTRIP LOCATION

## NOTES

1) Topographic contour interval 2m.
2) Bathymetric contour interval 1m.

## REFERENCES

1) Amec Americas Ltd., Drawing Number A1-131395-100-C-0001 (100-C-0001.DWG), Meadowbank Feasibility Study, April 2005.

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

# AIRSTRIP ALTERNATIVES

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-3.11 |
| DESIGN | CJC | 17OCT05 | SCALE | AS SHOWN REV. 0 |
| CADD | WLI | 17OCT05 | | |
| CHECK | CJC | 17OCT05 | | FIGURE 3.11 |
| REVIEW | CJC | 17OCT05 | | |

the permafrost, and will be constructed to thicknesses of at least 2 m over thaw unstable soils. In areas underlain by bedrock, or thaw stable soils, a lesser thickness of rockfill will be required.

The selection of the route considered the following:

- minimizing footprint area of disturbance
- preserving permafrost
- avoidance of any culturally sensitive areas
- minimizing impacts on lakes and streams

Two general routes were considered:

- A route to minimize the haul distance between Portage and Vault, crossing Turn Lake at its narrowest point.
- A route crossing the outflow area of Turn Lake to Drilltrail Lake and requiring the construction of a culvert crossing.

The selected route, shown in Figure 3.1, crosses Turn Lake approximately 4.5 km north of the plant site at its narrowest point where the water is less than about 6 m deep. Other than this crossing, the route avoids major drainages and requires only minor culvert crossings at other watercourses.

# SECTION 4 • MINING METHODS

The prefeasibility study considered a total mining rate of 2,000 t/d from both open pit and underground mining at the Portage and Goose Island deposits. This concept was found to be marginally economic. After further exploration and inclusion of the Vault deposit in the mine plan, throughput was increased to 7,500 t/d over approximately 8.3 years or the current feasibility study. Of this amount, the Vault pit will contribute between 1,200 and 1,500 t/d.

Only open-pit mining is contemplated at this time because the reserve grades do not support economical underground development. To ensure the safety of underground mine operations, crown pillars of ore would have to be left in place, resulting in poor resource utilization. Depending on the results of additional exploration, underground mining may be an option for future extraction from deeper sections of the Goose Island and Vault deposits.

The selected size and type of mining equipment take into account the variability of the deposits and the need for flexibility to achieve a steady supply of ore from the various sources. Because of the need for trailing cable and greater difficulty in manoeuvring, electric-powered equipment was rejected in favour of diesel-powered. Diesel-driven equipment is more flexible and is especially suited to the double-bench mining that may be required for operating efficiency in some areas.

## 4.1 BLAST DESIGN ALTERNATIVES

Because of the remote location, Cumberland expects to use a 70/30 ANFO/emulsion mix for blasting, although this ratio could range from 70/30 to 30/70 depending on the water resistance required and energy yield required. Early conceptual design considered proportions of emulsion as low as 10%, but final design will need to ensure adequate blasting performance while considering the advantages of waste reduction and preservation of water quality (reduced contribution of nitrates to the runoff water).

An assessment of blast-induced vibration (peak particle velocity) and instantaneous pressure change was carried out during the feasibility study to estimate the effects of blasting with various charge weights and how they relate to recommended guidelines by Fisheries and Oceans Canada (DFO). Three blast design reports have been produced for the project:

- Technical Memorandum: Item #85/85a - Meadowbank Gold Project- Blasting Addendum, Golder Associates. October 2005.
- Report: Blast Design, Meadowbank Gold project, Golder Associates. 10 February 2004.
- Addendum: Blasting Report Addendum, Golder Associates. 25 May 2004
- Supporting documentation for blast design is included in Appendix C.

The assessments assumed an ANFO/emulsion ratio of 30/70 to provide an upper bound for the assessment of the impact of explosives use with respect to fisheries guidelines. The greater proportion of emulsion results in a higher energy yield. The assessments were based on design guidelines governing the use of explosives adjacent to Canadian fisheries waters (Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters; Wright and Hopky, 1998).

The initial analyses were carried out for 3 charge weights for 12 and 6 m high operating benches: 420, 250, and 86 kg. A charge weight of 12 kg was also considered for a 3 m high operating bench in ore. The recently completed feasibility study (AMEC, 2005) specified a bench height of 6 m and charge weight of 77 kg. In the following sections, charge weights of 12, 77, and 250 kg are presented. (see Table 4.1) Charge weights of 420 kg are no longer considered.

For the assessment of blast induced vibration and instantaneous pressure change, the following alternative bench configurations, blasthole sizes, and charge weights have been considered to provide a range in possible blast designs for planning purposes. The proposed 77 kg charge weight used by AMEC in the feasibility study has been incorporated:

***Table 4.1**: Range in Charge Weights Considered for the Meadowbank Project*

| Charge Weight (kg) | Blasthole Diameter (mm) | Bench Height (m) |
|---|---|---|
| 250 | 165 | 12 |
| 77 | 165 | 6 |
| 12 | 165 | 3 |

### 4.1.1 Blast Induced Vibration

Blast induced vibrations have the potential to reduce the stability and performance of nearby earthen structures such as dikes. Where saturated conditions exist within the foundation materials and within the earthen structural fills of the de-watering dikes and the tailings dike, blast induced vibrations could result in the development of increased pore water pressures within the foundation and structural fill materials. This could lead to potential settlement of the structures and consequently impact to the water retaining capacity of the dikes.

The effects of blasting are typically assessed in terms of peak particle velocity (PPV).

### 4.1.2 Estimates of Peak Particle Velocity

The preliminary estimates of peak particle velocity (PPV) are based on the current understanding of the site layout, mine plan, and blast design. Changes to the current site layout, mine plan, and blast design will result in changes to the estimates of PPV. Certain site-specific factors that are required to calculate PPV have been estimated based on published values. However, site specific parameters can only be determined by site vibration monitoring of actual blasts. Consequently, the actual PPV values may differ from those presented here.

The US Bureau of mines has established that the peak particle velocity, PPV, is related to the scaled distance by the following relationship:

$$PPV = k * (R/W^{0.5})^{-b}$$

Where:

| | | |
|---|---|---|
| PPV | = | Peak Particle Velocity, mm/s |
| R | = | Distance from blast to point of concern, m |
| W | = | Charge weight per delay, kg |
| k | = | Confinement factor – specific to site |
| b | = | Site factor |

The constants k and b are specific to the site, and can be determined by blast vibration monitoring.

For this evaluation, a value of b = 1.6 was assumed. The PPV was evaluated for a range of values of confinement, ‘k’, of 400, 800, and 1,500, for downhole blasting. This range in values is considered to be reasonable for the site and to provide an estimate of the sensitivity of PPV to different values of confinement.

Based on the current understanding of site conditions and experience at two other northern sites, the confinement value of 800 is expected to be the most likely representative value for average conditions at the site. The actual value for confinement can only be determined through a detailed field monitoring program.

### 4.1.3 Minimum Setback Distance for Canadian Fisheries Guidelines

Design guidelines governing the use of explosives adjacent to Canadian fisheries waters (Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters; Wright and Hopky, 1998) indicate that no explosive is to be detonated that produces a peak particle velocity greater than 13 mm/s in a spawning bed during the period of egg incubation.

The PPVs were evaluated for the Second Portage Lake East dike, the Third Portage Peninsula east shoreline, the Bay dike, and the Goose Island east shoreline.

### 4.1.4 Setback Distance for Peak Particle Velocity

The minimum setback distances to achieve a PPV of 13 mm/s have been estimated for various values of confinement, ‘k’, and for four potential charge weights per delay. Table 4.2 summarizes the estimates of minimum setback required to achieve a PPV value of 13 mm/s.

***Table 4.2**: Minimum Setback Distance for 13 mm/s Peak Particle Velocity Guideline*

| | **Minimum Setback Distance to Achieve PPV = 13 mm/s** | | |
|---|---|---|---|
| **k** | **12 kg Charge Weight per Delay (3 m Bench, 76 mm Hole)** | **77 kg Charge Weight per Delay (6 m Bench, 165 mm Hole)** | **250 kg Charge Weight per delay,(12 m Bench, Decked Charge, 229 mm Hole)** |
| 400 | 30 m | 75 m | 135 m |
| 800 | 46 m | 115 m | 208 m |
| 1,500 | 67 m | 171 m | 308 m |

The relationships presented in the above table are shown on Figure 4.1 for a confinement value, k, of 800.

With the exception of a short segment of shoreline adjacent to the Portage pit wall at the south end of the pit, the proposed charge weight of 77 kg per hole on 6 m benches will result in a PPV less than the required 13 mm/s.

For the portions of the dike or shoreline where the 13 mm/s guideline is exceeded, modified blast designs consisting of lower charge weights on lower bench heights have been shown to result in PPV that meet the guideline requirement. Alternatively, additional fill materials could be placed along the shoreline or dike upstream (lake side) face to increase the distance from the blasting area.

### 4.1.5 Minimum Setback Distance for Threshold Damage Levels

General guidelines for blasting nears dams indicate vibration damage thresholds on the order of 50 mm/s to be reasonable for dams having medium to dense sand or silts within the dam or foundation materials. Table 4.3 summarizes the estimates of minimum setback required to achieve a PPV value of 50 mm/s for the charge weights considered.

***Table 4.3**: Minimum Setback Distance for a Peak Particle Velocity of 50 mm/s for Various Blast Configurations*

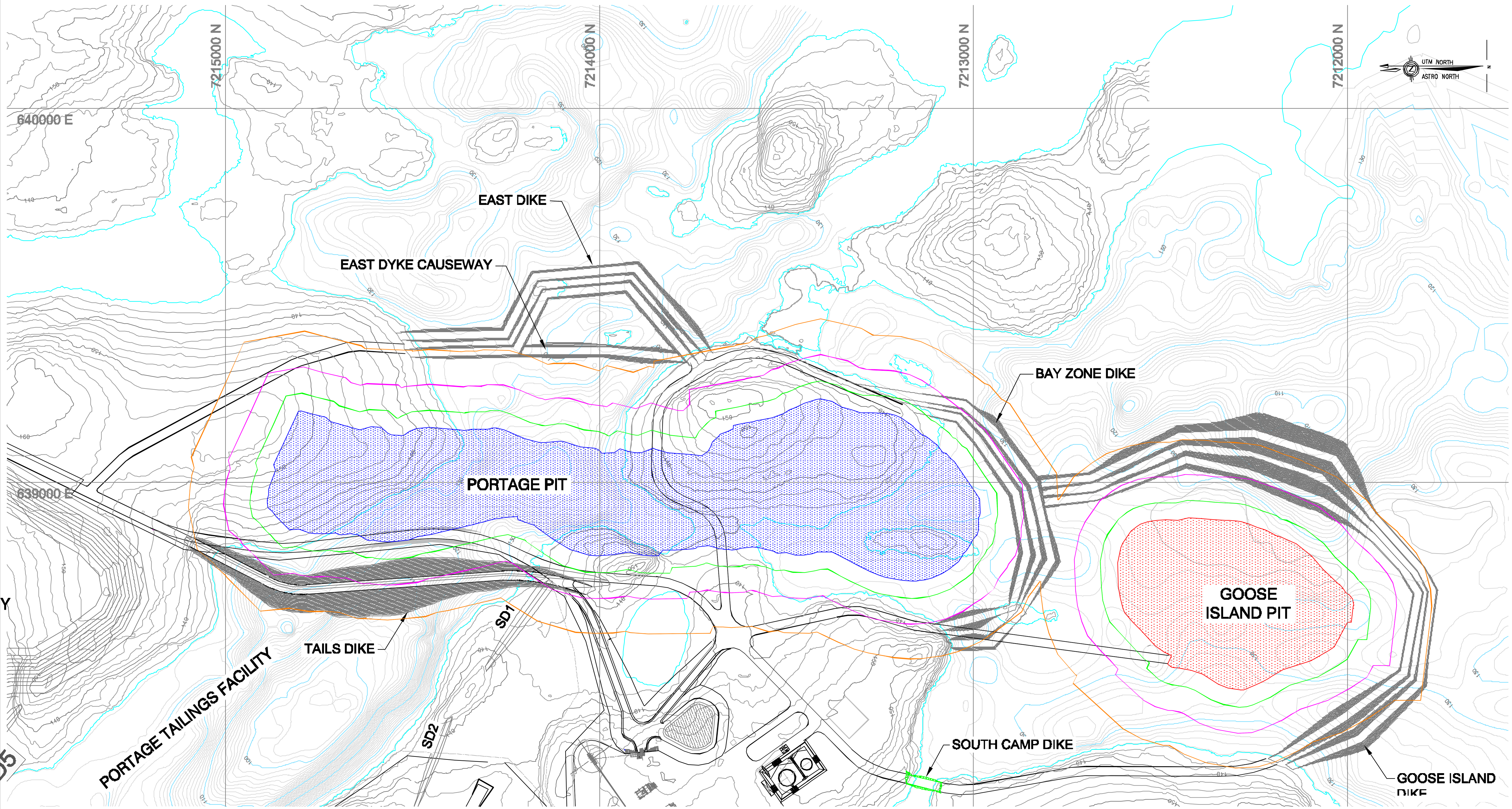
| | Minimum Setback Distance to Achieve PPV = 50 mm/s | | |
|---|---|---|---|
| **k** | **12 kg Charge Weight per Delay (3 m Bench, 76 mm Hole)** | **77 kg Charge Weight per Delay (6 m Bench, 165 mm Hole)** | **250 kg Charge Weight per delay, (12 m Bench, Decked Charge, 229 mm Hole)** |
| 400 | 13 m | 32 m | 58 m |
| 800 | 20 m | 50 m | 89 m |
| 1,500 | 29 m | 74 m | 133 m |

The relationships presented in the above table are shown on Figure 4.2 for a confinement value, k, of 800.

The analysis indicates that for the proposed 80 m toe setback for the dikes at the Meadowbank project, and the proposed 77 kg charge weight, a PPV of 50 mm/s will not be exceeded in the toe areas of the perimeter dikes or tailings dike. Additional blast monitoring during construction will be required to confirm the assumptions on which these results are based.

### 4.1.6 Instantaneous Pressure Change for Canadian Fisheries Guidelines – 100 kPa Criteria

The required setback distance for confined explosives to achieve the 100 kPa instantaneous pressure change guideline can be estimated from relationships presented in “Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters” (Wright and Hopky, 1998).




0 100 200 300 400 500
Scale in Meters

## LEGEND

12 kg Charge Weight, 46m Offset

77 kg Charge Weight, 115m Offset

250 kg Charge Weight, 208m Offset

Confinement, k = 800

Recommended Charge Weight

## NOTES

1. Contour Interval 2 Metre.
2. All Dimensions in Metres.
3. Elevations in Metres above Sea Level.
4. UTM Zone 14, NAD83.
5. Area behind Dikes is De-watered during Operations.
6. Reference: Feasibility Study Report, AMEC, June 2005.

## REFERENCES


1) AMEC Americas LTD, Drawing # A1-131395-100-C-0001 (100-C-0001.dwg), Meadowbank Feasibility Study, April 2005.
2) Golder Associates: Report on Blast Design, Meadowbank Golder Project, February 2004.
3) Golder Associates: Blasting Report Addendum, May 2004.


PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

PEAK PARTICLE VELOCITY
13 mm/s ISOPLETH

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-4.1 |
| DESIGN | CJC | 03OCT05 | SCALE AS SHOWN | REV. 0 |
| CADD | WLI | 03OCT05 | | |
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| REVIEW | CJC | 17OCT05 | | |

FIGURE 4.1

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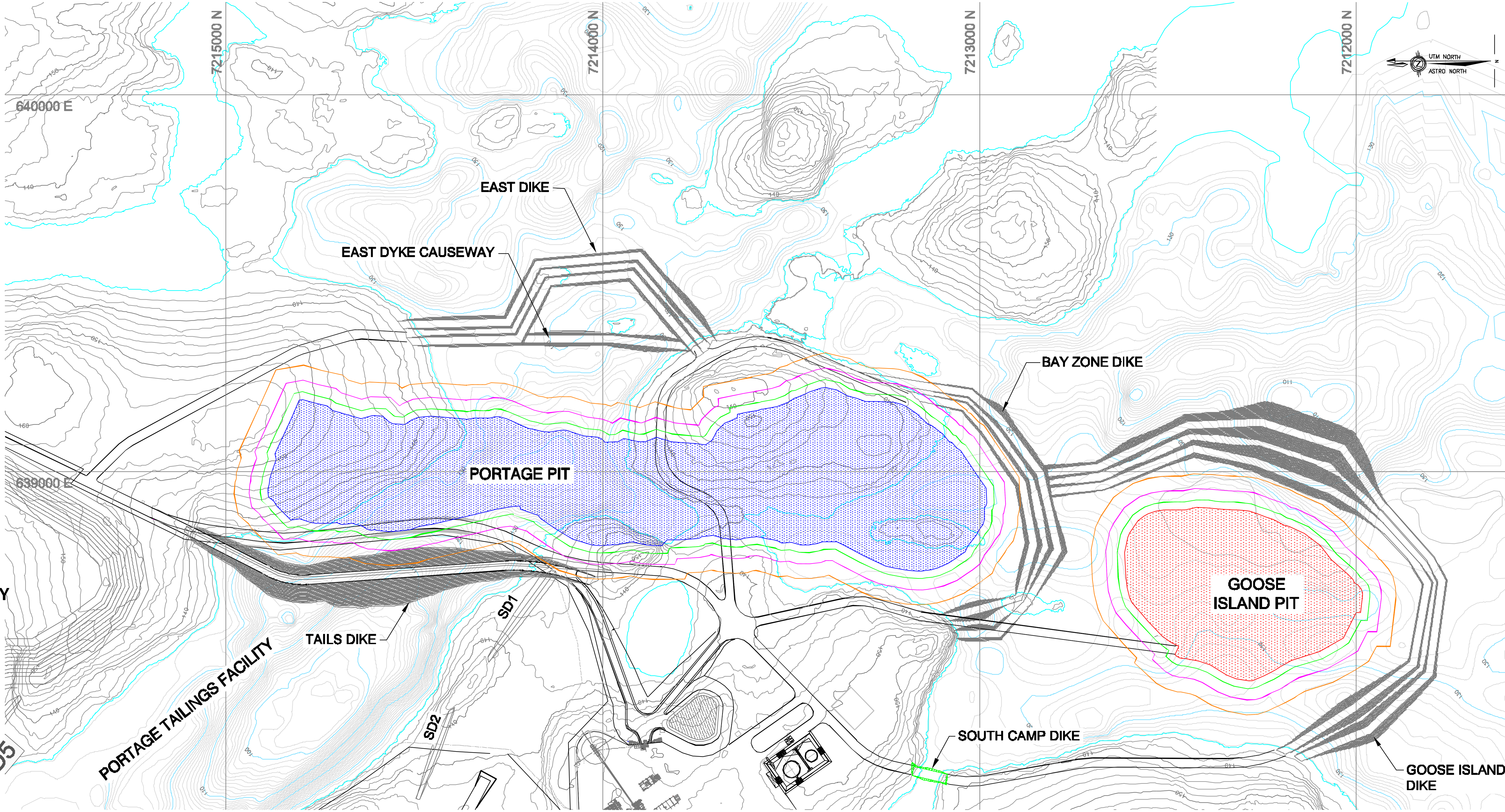


0 100 200 300 400 500
Scale in Meters

## LEGEND

12 kg Charge Weight, 20m Offset

77 kg Charge Weight, 50m Offset

250 kg Charge Weight, 89m Offset

Confinement, k = 800

Recommended Charge Weight

## NOTES

1. Contour Interval 2 Metre.
2. All Dimensions in Metres.
3. Elevations in Metres above Sea Level.
4. UTM Zone 14, NAD83.
5. Area behind Dikes is De-watered during Operations.
6. Reference: Feasibility Study Report, AMEC, June 2005.

## REFERENCES

1) AMEC Americas LTD, Drawing # A1-131395-100-C-0001 (100-C-0001.dwg), Meadowbank Feasibility Study, April 2005.
2) Golder Associates: Report on Blast Design, Meadowbank Golder Project, February 2004.
3) Golder Associates: Blasting Report Addendum, May 2004.

PROJECT
**CUMBERLAND RESOURCES LTD.**

TITLE
**PEAK PARTICLE VELOCITY 50 mm/s ISOPLETH**

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-4.2 |
| DESIGN | CJC | 03OCT05 | SCALE | AS SHOWN REV. 0 |
| CADD | WLI | 03OCT05 | | |
| CHECK | CJC | 03OCT05 | | |
| REVIEW | CJC | 17OCT05 | | |

**FIGURE 4.2**

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The properties used to assess the minimum setback distance are shown in Table 4.4.

***Table 4.4**: Properties Used to Assess Setback Distance for Instantaneous Pressure Change*

| Medium | Density, $g/cm^3$ | Compressional Wave Velocity, cm/s |
|---|---|---|
| Water | 1 | 146,300[1] |
| Rock (Intermediate Volcanic) | 2.8 | 457,200[1] |

**Notes: 1.** Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters; Wright and Hopky, 1998

Based on the above properties, range of potential charge weights, and range in confinement value, the following minimum setback distances—below which the 100 kPa overpressure guideline will not be exceeded—are estimated, as summarized in Table 4.5.

***Table 4.5**: Minimum Setback Distance for Instantaneous Pressure Change Guideline (<100kPa)*

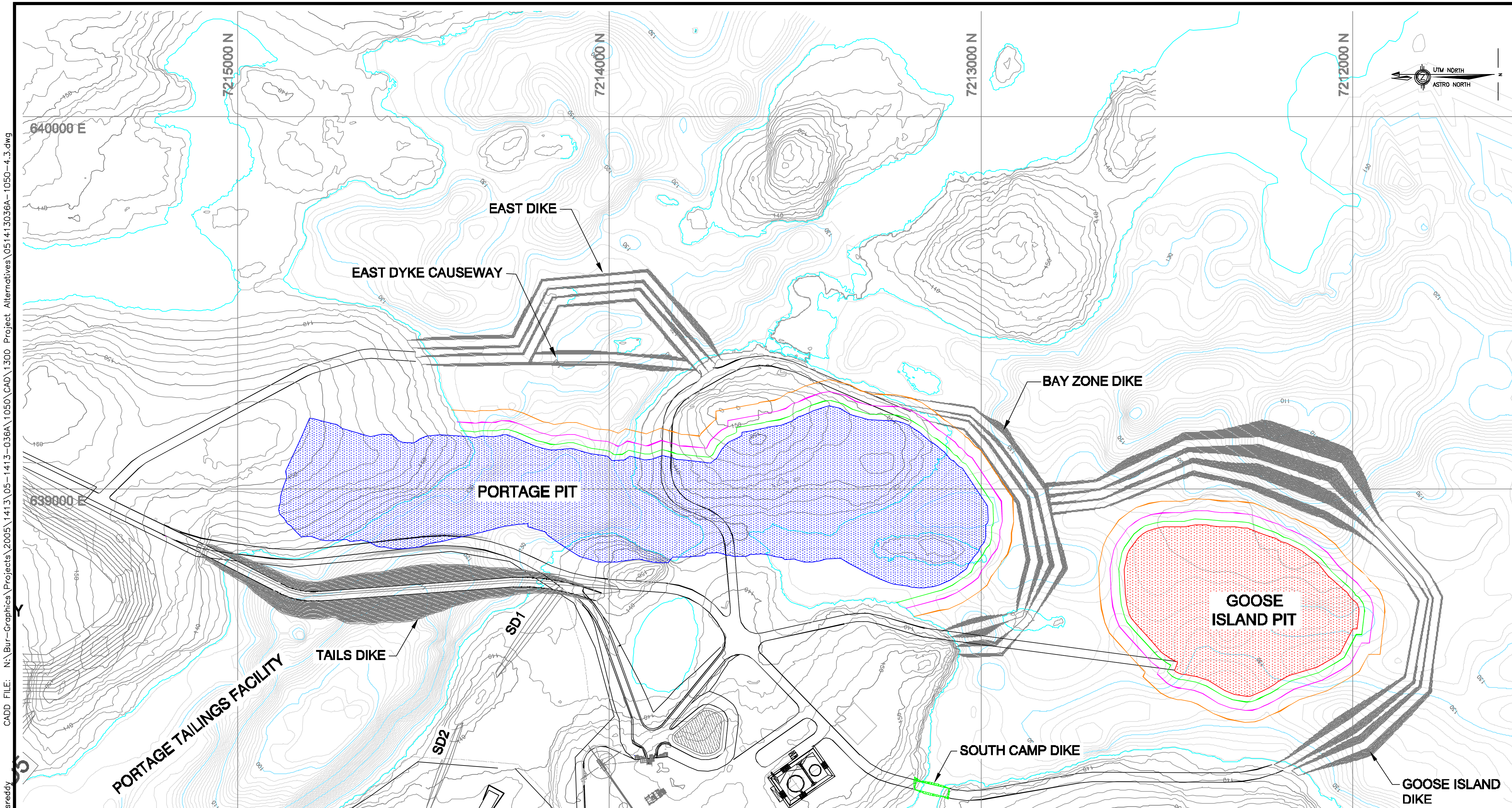
| Charge Weight per Delay | Minimum Setback Distance, m | | |
|---|---|---|---|
| kg | k=400 | k=800 | k=1,500 |
| 12 | 10 m | 15 m | 22 m |
| 77 | 25 m | 38 m | 57 m |
| 250 | 45 m | 69 m | 102 m |

The results in Table 4.5 are presented on Figure 4.3 for a confinement of 800. Based on the currently proposed de-watering dike configuration, the average distance from the pit crest to the outside (lake side) dike face will be on the order of 160 m. In order for the instantaneous pressure change measured on the outside (lake side) face of the dike to exceed 100 kPa, a charge weight in excess of 1,300 kg would be required, based on the assumptions in this report. Consequently, for the range of charge weights considered in the analyses for the Meadowbank project, none will result in an instantaneous pressure change greater than 100 kPa.

### 4.1.7 Instantaneous Pressure Change for Canadian Fisheries Guidelines – 50 kPa Criteria

In addition to the legislated criteria, Cumberland has assessed the effect of blast induced vibration and instantaneous overpressure resulting from blasting adjacent to waters during ice cover periods. For this condition, the Department of Fisheries recommends an evaluation to consider an instantaneous pressure change of 50 kPa.

For the range of potential charge weights, and for a range in confinement value, the minimum setback distances below which the 50 kPa overpressure guideline will not be exceeded are estimated, as summarized in Table 4.6.

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REVISION DATE: 05/10/21 10:32am By: sreddy

## LEGEND

| | |
|---|---|
| (green line) | 12 kg Charge Weight, 15m Offset |
| (magenta line) | 77 kg Charge Weight, 38m Offset |
| (orange line) | 250 kg Charge Weight, 69m Offset |
| Confinement, k = 800 | Recommended Charge Weight |

## NOTES

1. Contour Interval 2 Metre.
2. All Dimensions in Metres.
3. Elevations in Metres above Sea Level.
4. UTM Zone 14, NAD83.
5. Area behind Dikes is De-watered during Operations.
6. Reference: Feasibility Study Report, AMEC, June 2005.

0 100 200 300 400 500

Scale in Meters

## REFERENCES

1) AMEC Americas LTD, Drawing # A1-131395-100-C-0001 (100-C-0001.dwg), Meadowbank Feasibility Study, April 2005.
2) Golder Associates: Report on Blast Design, Meadowbank Golder Project, February 2004.
3) Golder Associates: Blasting Report Addendum, May 2004.

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

# INSTANTANEOUS OVERPRESSURE 100kPa ISOPLETH

Golder Associates

| | | |
|---|---|---|
| PROJECT No. | 05-1413-036A | |
| DESIGN | CJC | 03OCT05 |
| CADD | WLI | 03OCT05 |
| CHECK | CJC | 03OCT05 |
| REVIEW | CJC | 17OCT05 |

FILE No. 051413036A-1050-4.3

SCALE AS SHOWN REV. 0

**FIGURE 4.3**

***Table 4.6: Minimum Setback Distance for Instantaneous Pressure Change Guideline (50 kPa Ice-Covered Water)***

| Charge Weight per Delay | Bench Height | Hole Diameter (mm) | Minimum Setback Distance, m | | |
|---|---|---|---|---|---|
| kg | m | mm | k=400 | k=800 | k=1500 |
| 12 | 3 m (ore) | 76 | 15 | 23 | 34 |
| 77 | 6 m (ore and waste) | 165 | 38 | 59 | 87 |
| 250 | 6 m (waste) | 165 | 69 | 106 | 157 |

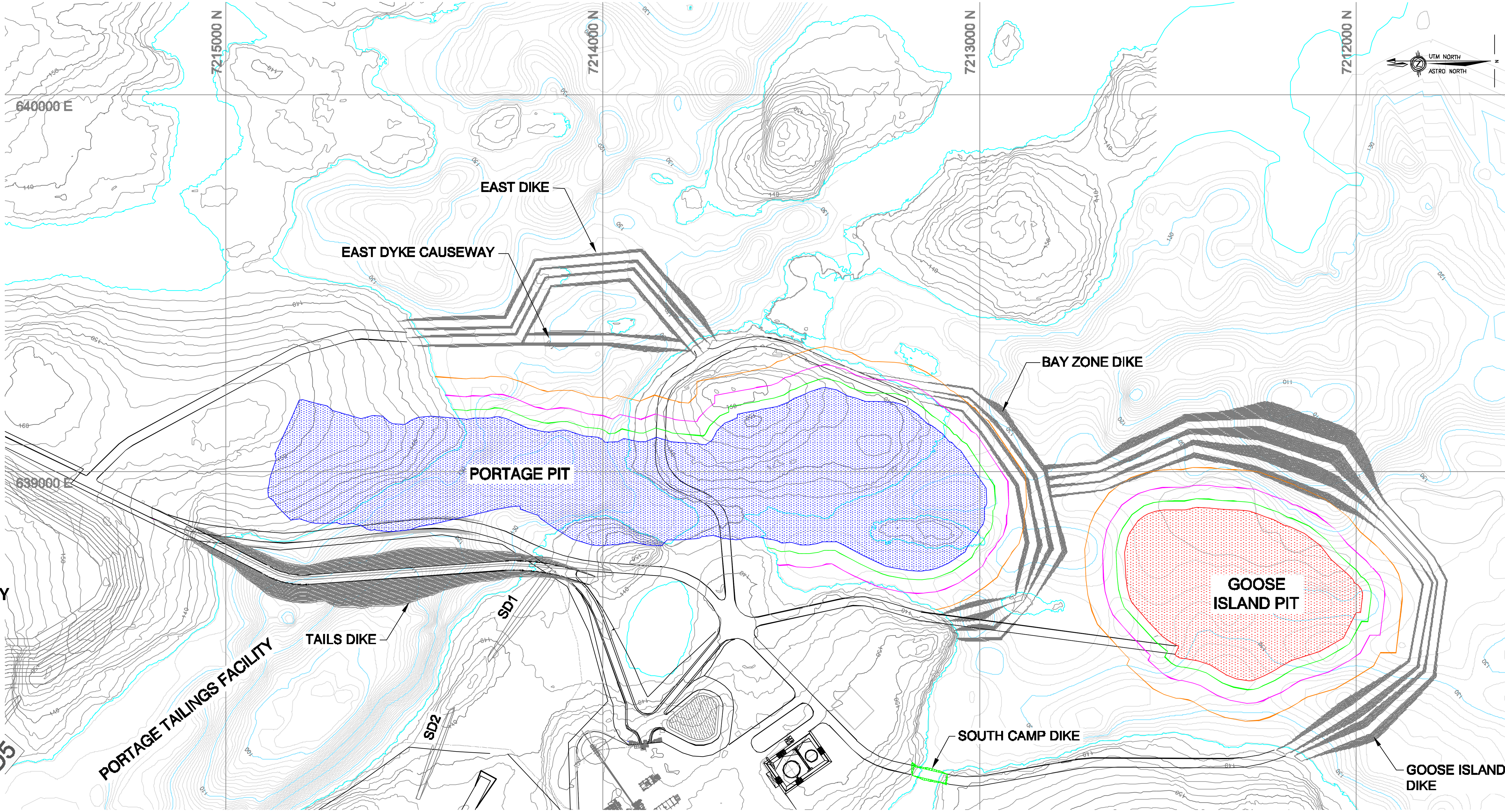
The relationships presented in Table 4.6 are shown on Figure 4.4 for a confinement value of 800. Based on the analysis, an instantaneous pressure change of 50 kPa will not be exceeded for the proposed 77 kg charge weight per hole, and for a confinement value of 800.

### 4.1.8 Conclusions

The following summarizes the conclusions of the previous and current assessment:

- With the exception of a short segment of shoreline adjacent to the southeast wall of the Portage pit, the PPV of 13 mm/s will not be exceeded for the proposed 77 kg charge weight per hole. This relates to fisheries guidelines.
- The PPV of 50 mm/s will not be exceeded in the toe region of the perimeter dikes or tailings dike for the proposed 77 kg charge weight per hole. This relates to the structural stability of the dikes.
- The instantaneous pressure change along the upstream (lake side) face of the East dike, Bay Zone dike, and Goose Island dike is predicted to be less than the 100 kPa guideline for the proposed 77 kg charge weight per hole. This relates to fisheries guidelines.
- The instantaneous pressure change along the upstream (lake side) face of the dikes during periods of ice cover is predicted to be less than 50 kPa for the proposed 77 kg charge weight per hole.
- For the Vault deposit, PPV and instantaneous pressure change guidelines along the Vault dike face will not be exceeded for any of the proposed blast designs or charge weights. The Vault dike lies about 750 m from the nearest crest of the Vault pit.

The analyses have shown that peak particle velocities and instantaneous overpressure can be effectively managed through the use of lighter charge weights, decreased blasthole diameters, and decreased operating bench heights, or a combination of these mitigative measures.




0 100 200 300 400 500
Scale in Meters

## LEGEND

12 kg Charge Weight, 23m Offset

77 kg Charge Weight, 59m Offset

250 kg Charge Weight, 106m Offset

Confinement, k = 800

Recommended Charge Weight

## NOTES

1. Contour Interval 2 Metre.
2. All Dimensions in Metres.
3. Elevations in Metres above Sea Level.
4. UTM Zone 14, NAD83.
5. Area behind Dikes is De-watered during Operations.
6. Reference: Feasibility Study Report, AMEC, June 2005.

## REFERENCES

1) AMEC Americas LTD, Drawing # A1-131395-100-C-0001 (100-C-0001.dwg), Meadowbank Feasibility Study, April 2005.
2) Golder Associates: Report on Blast Design, Meadowbank Golder Project, February 2004.
3) Golder Associates: Blasting Report Addendum, May 2004.

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

# INSTANTANEOUS OVERPRESSURE 50 kPa ISOPLETH UNDER ICE CONDITION

Golder Associates

| PROJECT No. | | 05-1413-036A | FILE No. 051413036A-1050-4.4 |
|---|---|---|---|
| DESIGN | CJC | 03OCT05 | SCALE AS SHOWN REV. 0 |
| CADD | WLI | 03OCT05 | |
| CHECK | CJC | 03OCT05 | FIGURE 4.4 |
| REVIEW | CJC | 17OCT05 | |

REVISION DATE: 05/10/21 10:38am By: sreddy CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-4.4.dwg

### 4.1.9 Monitoring

As part of the mine development, a vibration monitoring program will be required to measure the response of the de-watering dikes and tailings dike to pit blasting. The data from this program would be assessed in conjunction with continuous measurements from piezometers that would be installed in the dikes, and within the dike foundation materials. From this analysis, the blasting could be adjusted to minimize the impact on the dikes. Mitigative measures to the blast design to minimize the development of blast induced vibration could include modifications to the blasthole patterns; reduction in blasthole size, and hence charge weight, in critical areas of the pit walls within a certain distance from the proposed de-watering and tailings dike; single blasthole initiation per delay; reduction in operating bench height in critical areas; or a combination of these measures.

A more comprehensive program of blast vibration modelling and test blasting may be required during operations if blast vibration levels remain high and their frequency (cycles per second) is low.

# SECTION 5 • PERIMETER DIKES

The Portage, Goose Island, and Vault deposits are all partially overlain by lakes. Consequently, a series of perimeter water-retaining dikes must be constructed to permit mining operations. Three major dike structures are required:

- East (Second Portage) dike (including a causeway)
- Bay Zone dike
- Goose Island dike.

Dike configurations have evolved as the pit limits have become better defined. For the most part, dike alignments have been selected to minimize dike height by connecting shallow sections of lake floor. More recent study has shown that additional shallow diking will be required around the south end of the Portage pit as mining extends into that area.

## 5.1 SITE CONDITIONS

Dewatering dike locations are as shown in Figure 3.1. The majority of the perimeter dikes will be constructed in shallow water, less than 4 m to 6 m in depth though in deeper water along the east-southeast segment of the Goose Island dike, reaching up to 20 m at the lakeside toe of the dike and about 16 m at the dike centreline. Diagrams showing the centreline profiles along the proposed dikes are shown on Figure 5.1 and 5.2.

Construction in areas of deeper water will be deferred until experience with materials and techniques has been acquired in the initial years. Construction of the deeper dike sections is scheduled over several years to ensure that the types of rock material required are available from the open pits.

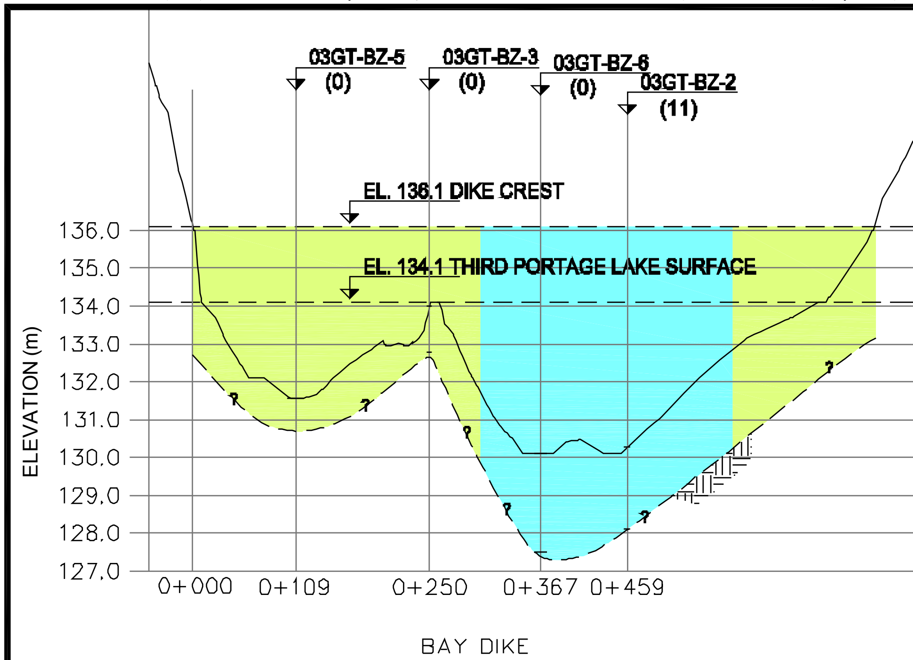
The rockfill and till materials that will be used for the construction of the dikes will initially come from pre-stripping operations and from the development of a starter pit at the Portage deposit. Quantity estimates indicate that approximately 380,000 $m^3$ of rockfill and 90,000 $m^3$ of till will be required for the dikes prior to start-up.

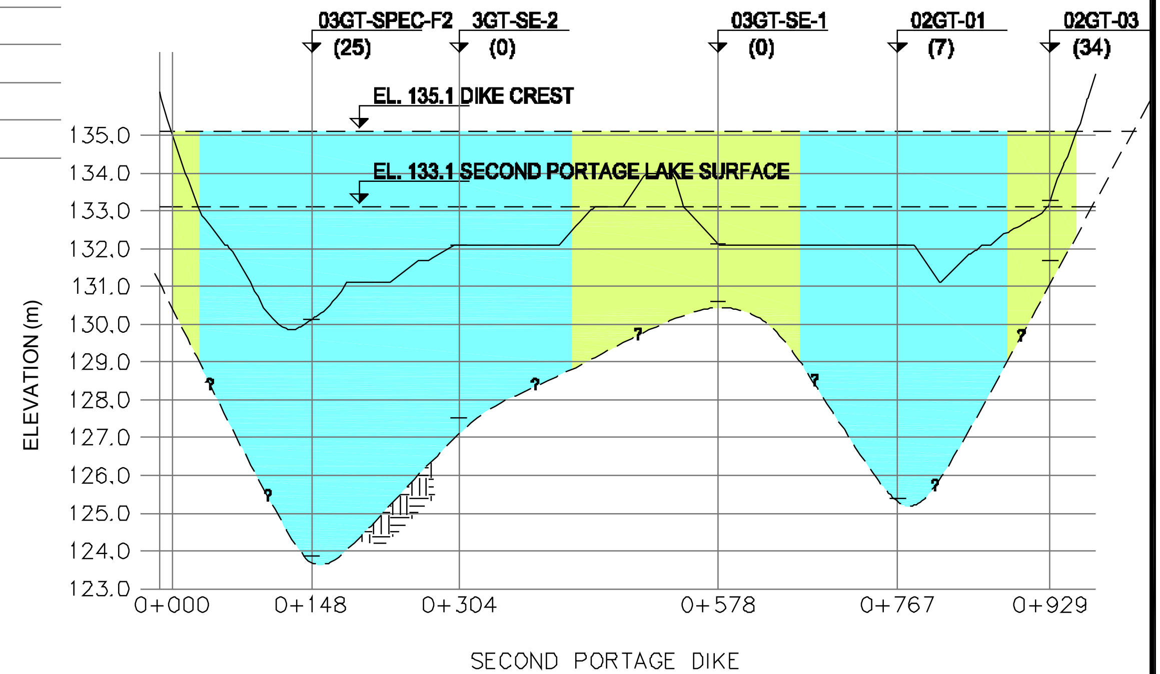
## 5.2 DESIGN ALTERNATIVES

During the pre-feasibility engineering studies evaluations of seepage cutoff alternatives was carried out. The results of the evaluation are presented in:

- Golder Associates Ltd., Letter on Review of Conceptual Dike Cross-Section. 5 December 2001.
- Golder Associates Ltd., Report on Review of Seepage Cut Off Alternatives Open Pit Dewatering Dikes, Meadowbank Gold project, Nunavut Territory. 9 March 2000.

REVISION DATE: 05/10/19 3:05pm By: sreddy CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-5.1-5.2.dwg




## LEGEND

| | |
|---|---|
| (yellow-green fill) | Up to 6 meters - CAT 320 |
| (cyan fill) | 6 to 12 meters - CAT 320BL LONG REACH |
| - -?- - | Possible Bedrock contact |
| —— | Lake bottom |
| 03-GT-BZ-5 | Borehole - Golder 2003 |
| 02GT-01 | Borehole - Golder 2002 |

## NOTES

1) Numbers in brackets are the offset from centreline of dike.
2) Lake bottom determined from Bathymetric surveys by Golder in 2002 and 2003.
3) Depths to bedrock contact based on boreholes logged and tested by Golder in 2002 and 2003.

0 2 4 6 8 10
Vertical Scale in Meters

0 50 100 150 200 250
Horizontal Scale in Meters

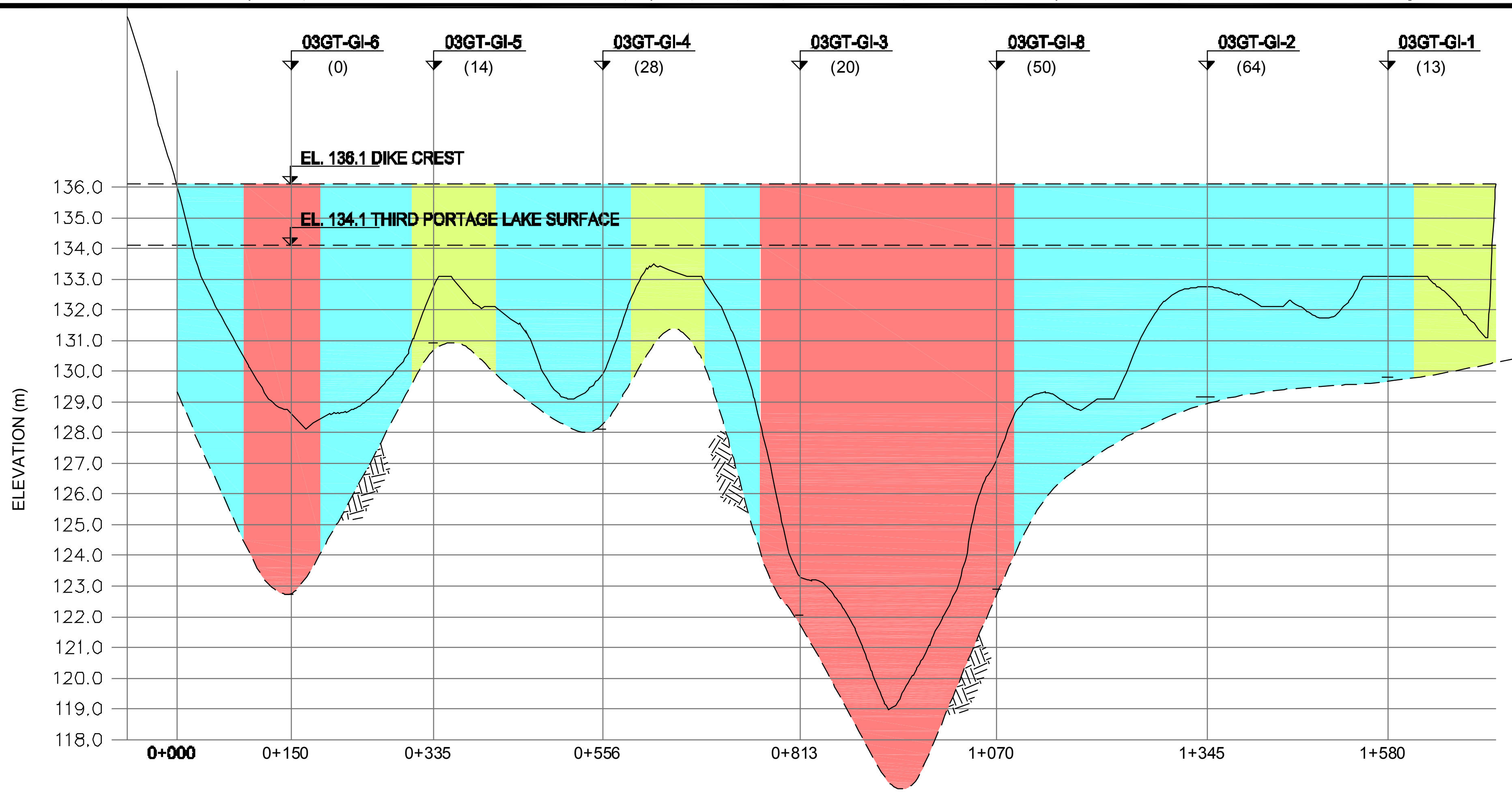
PROJECT
**CUMBERLAND RESOURCES LTD.**

TITLE
**SECOND PORTAGE AND BAY ZONE DIKE - CENTRELINE PROFILE**

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | | 05-1413-036A | FILE No. | 051413036A-1050-5.1-5.2 |
| DESIGN | DSH | 10JUL03 | SCALE AS SHOWN | REV. 0 |
| CADD | WSL | 29JUL03 | | |
| CHECK | DAH | 03OCT03 | **FIGURE 5.1** | |
| REVIEW | CJC | 17OCT05 | | |

REVISION DATE: 05/10/19 3:1pm By: sreddy CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-5.1-5.2.dwg




0 50 100 150 200 250

Horizontal Scale in Meters

0 2 4 6 8 10

Vertical Scale in Meters

## LEGEND

| | |
|---|---|
| (yellow) | Up to 6 meters - CAT 320 |
| (cyan) | 6 to 12 meters - CAT 320BL LONG REACH |
| (red) | CUSTOM-BUILT LONG REACH BOOM >12 meters |
| – – – – | Possible Bedrock contact |
| ——— | Lake bottom |
| 03-GT-BZ-5 | Borehole - Golder 2003 |
| 02GT-01 | Borehole - Golder 2002 |

## NOTES

1) Numbers in brackets are the offset from centreline of dike.
2) Lake bottom determined from Bathymetric surveys by Golder in 2002 and 2003.
3) Depths to bedrock contact based on boreholes logged and tested by Golder in 2002 and 2003.

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**GOOSE ISLAND DIKE - CENTRELINE PROFILE**

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | | 05-1413-036A | FILE No. | 051413036A-1050-5.1-5.2 |
| DESIGN | DSH | 10JUL03 | SCALE AS SHOWN | REV. 0 |
| CADD | WSL | 29JUL03 | | |
| CHECK | DAH | 03OCT03 | | |
| REVIEW | CJC | 17OCT05 | | |

**FIGURE 5.2**

The following alternatives were considered during pre-feasibility studies for the seepage cutoff element within the rockfill dike cross section:

- low permeability upstream blanket
- central low permeability core
- slurry trench cut off wall
- interlocking vinyl sheet piles.

In assessing the relevant seepage reduction measures for the tailings containment dikes, frozen dike alternatives were reviewed. However, there is currently no precedent for the construction of a frozen core dike through a body of water. Due to the continual movement of water through the dike, it would not be possible to maintain a frozen core. Furthermore, past experience at the Raglan mine and Kubaka indicates that a hydraulic head of 15 m or more on the frozen core dike potentially could induce instability and may lead to a failure of the dike. Therefore, this alternative should not be considered as an alternative for the pit dewatering dikes.

Various embankment geometries suited to the depth of water and combination of materials were evaluated, and construction methods and considerations were summarized.

### 5.2.1 Conclusions

It was concluded that a till core combined with a soil-bentonite cutoff wall would be both effective and economical compared to a crushed rock core with slurry cutoff wall. The typical dike section comprises two rockfill embankments with a till core, a filter zone, and a soil-bentonite cutoff wall excavated to the underlying bedrock (see Figure 5.3). The dike crest will be surfaced with material suitable as haul road running course. A capping of ultramafic rock will be placed over materials that are potentially acid-generating.

The preferred option makes use of available stripped material and eliminates the need for crushing and quarrying. The recommended configuration is two parallel rockfill embankments with a core of till. A soil-bentonite cutoff wall will be excavated through the till core and underlying foundation materials to bedrock.

## 5.3 DESIGN BASIS & CRITERIA

The following design criteria were used:

- Dikes are to be constructed to allow open pit mining operations to be carried out year round.
- A portion of the crests of the Second Portage and Goose Island dikes will be used as mine truck haul roads between the open pit and the crusher.
- The dike sections should maximize the use of materials obtained during pre-stripping operations of the open pits, and during mining of a starter pit at the Third Portage deposit. These materials are till and run-of-mine rockfill.

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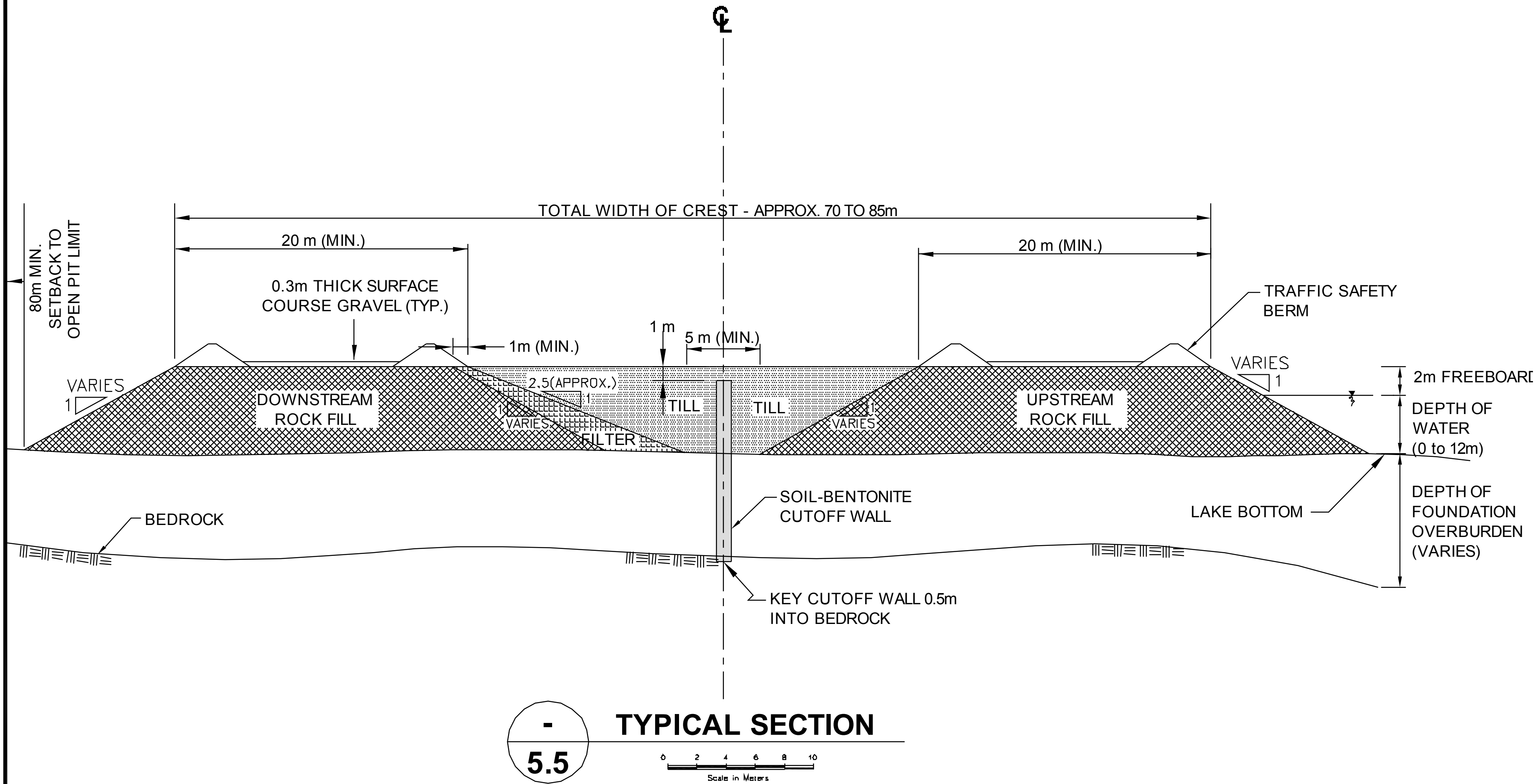



**NOTES**

1) Sideslopes for rockfill as shown are 1.8H:1V.
Actual slopes will vary depending on water depth, rockfill grain size and foundation conditions.
2) NWT Mine Safety and Health Act(1995) states that minimum width of haul road is:
- for one-lane traffic: 2X width of largest vehicle
- for two-lane traffic: 3X width of largest vehicle
- minimum height of safety berm = 0.75X diameter of tire of largest vehicle
3) The 80m minimum setback is based on a similar set back of Diavik and to be confirmed during detailed engineering design.

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**TYPICAL DIKE CROSS - SECTION SECOND PORTAGE, GOOSE ISLAND AND BAY ZONE DIKES**

Golder Associates

| PROJECT No. 05-1413-036A | | | FILE No. 051413036A-1050-5.3 |
|---|---|---|---|
| DESIGN | DAH | 01APR03 | SCALE 1:400 REV. 0 |
| CADD | WSL | 19JUN03 | |
| CHECK | CJC | 13OCT05 | **FIGURE 5.3** |
| REVIEW | CJC | 18OCT05 | |

- A minimum setback of 80 m between the open pit side toe of the dike and the edge of the open pit has been assumed, based on similar setback distances at the Diavik project.
- Part of the southeast dike on Second Portage Lake will be constructed as a rockfill causeway to reduce haul distances between North Portage and Third Portage.
- The dike crest width should comply with NWT mine Health and Safety Act and Regulations, or equivalent regulations for Nunavut, for minimum width of haul roads. For single-lane traffic, the minimum width is twice the width of the widest haulage vehicle used on the road; for double-lane traffic the minimum width is three times the width of the widest haulage vehicle. A shoulder barrier of at least three-quarters the height of the largest tire on any vehicle using the road is required.
- The dike alignment should be selected to minimize the height of the dike.
- The dike section incorporates a soil-bentonite cutoff wall keyed into bedrock where possible.
- The dike will be a high consequence structure, based on Canadian Dam Association criteria.
- The minimum required factor of safety for static load conditions is 1.5 (Canadian Dam Association, 1999).
- The minimum required factor of safety for earthquake load conditions is 1.2 (Canadian Dam Association, 1999).
- The minimum required factor of safety for end-of-construction condition is 1.3. The end-of-construction condition for these dikes ends when personnel and equipment begin to enter the area within the dikes. (Canadian Dam Association, 1999).
- The maximum design earthquake acceleration corresponds to the 1,000-year (nominal) return period event (Canadian Dam Association, 1999).
- The minimum allowable freeboard between the crest of the dikes and lake surface will be 2 m. This is required to provide allowance for settlement, and protection for wave and ice run-up.
- The minimum freeboard between the top of the soil-bentonite cutoff wall and the lake surface must be 1 m.

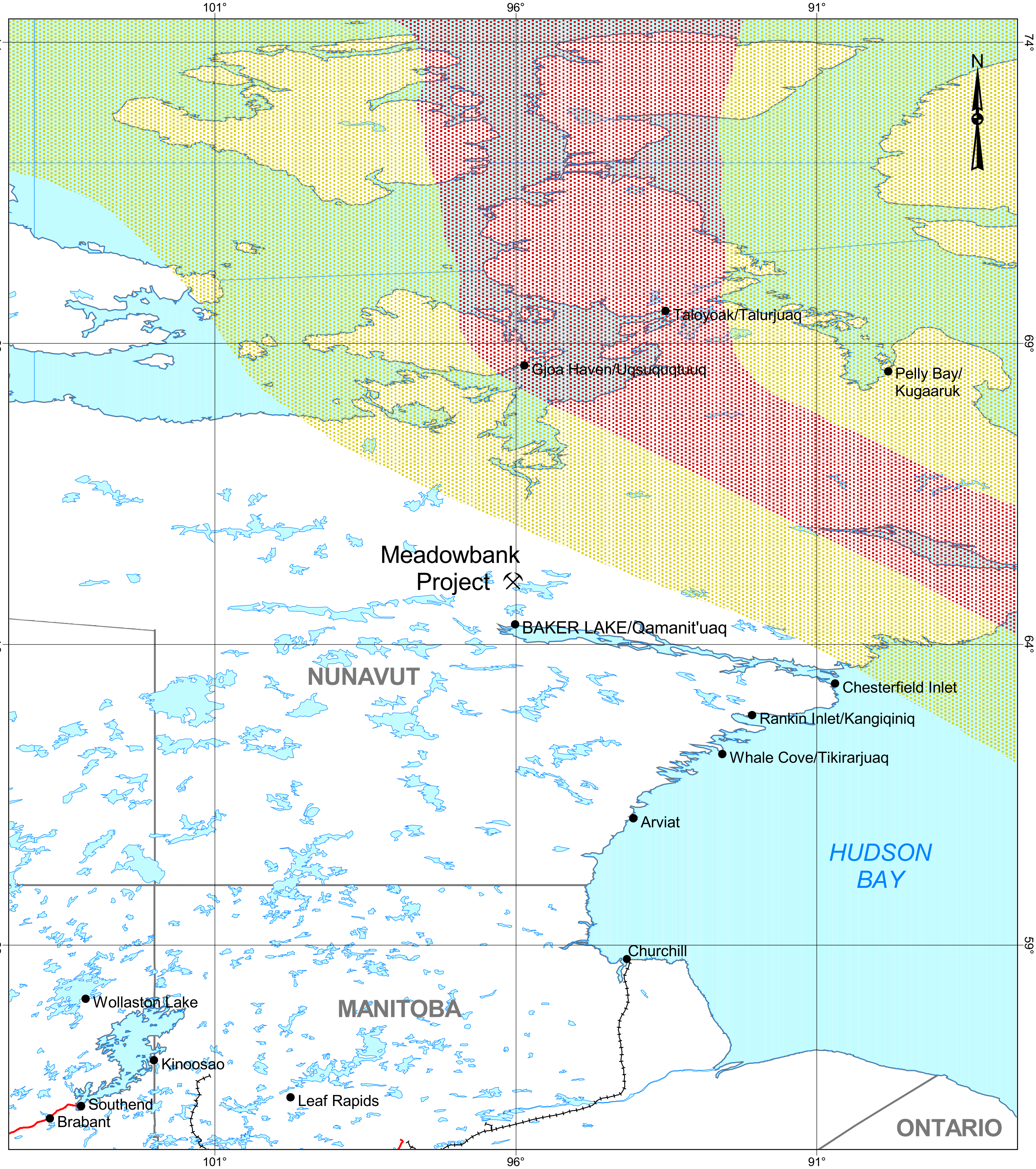
### 5.3.1 Seismicity

Based on the seismic hazard assessment provided by Pacific Geoscience Centre for this site, the proposed development is located within seismic Zone 0 of the National Building Code, which is negligible seismic risk (see Table 5.1 and Figure 5.4).

***Table 5.1: Peak Horizontal Ground Accelerations for Meadowbank Site***

| Return Period of Seismic Event (years) | Peak Horizontal Ground Acceleration (g) |
|---|---|
| 100 | 0.018 |
| 200 | 0.025 |
| 475 | 0.034 |
| 975 | 0.044 |

**Source:** Seismic Risk Calculation for Meadowbank project Site, Geological Survey of Canada, Natural Resources Canada, Sidney, B.C., July, 2003 – See Appendix VI.




## LEGEND

- Meadowbank Project
- Town/Village

Peak Horizontal Ground Acceleration (g), for 10% probability of exceedance in 50 Year Event

- 0 - 0.039
- 0.04 - 0.079
- 0.08 - 0.109
- Provincial Border
- Water
- Primary Highway
- Railroad

200 0 200 Kilometers

Scale - 1:10,000,000

**REFERENCE**

Base digital data obtained from ESRI Inc.,
DATUM: WGS84 PROJECTION: Geographic

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

**SEISMIC ZONING MAP**
**MEADOWBANK PROJECT**

Golder Associates

| PROJECT No. 05-1413-036A | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | DAH | 19 Dec. 2003 | **FIGURE 5.4** | |
| GIS | CDB | 19 Dec. 2003 | | |
| CHECK | DAH | 10 Feb. 2004 | | |
| REVIEW | | | | |

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## 5.4 SLOPE STABILITY

Once the dike cross-section had been selected, a series of slope stability and seepage analyses were carried out for the three main perimeter dewatering dikes. The results of the stability and seepage analyses are reported in detail in:

- Golder Associates Ltd., Report on Design of Dikes with Soil-Bentonite Cutoff Wall, Meadowbank Gold Project. 23 October 2003.

Slope stability analyses show that the dikes will be stable under static and earthquake load conditions. Seepage modelling indicates that the total seepage through all of the dikes will be in the range of approximately 2.4 to 48.3 L/s. This value varies depending on potential cracking in the soil-bentonite cutoff wall and/or a potential gap in the cutoff wall at the bedrock contact.

Slope stability analyses were carried out for three sections along the Goose Island dike. Section locations are shown on Figure 5.5; the sections are shown on Figures 5.6 and 5.7. Section A is located on a relatively flat foundation, section B is the deepest section with the foundation sloping away from the pit, and section C is the deepest section where the foundation is sloping toward the pit. Failure of section A could potentially occur on the inside of the dike towards the open pit. Section B has the deepest water and steepest lake bottom slope along the dike alignment. The lake bottom slopes away from the pit at section B, and failure of the dike at this location could potentially occur on the outside of the dike towards the lake. Section C is similar to section A.

The slope stability scenarios were modelled for each of sections A, B, and C only, as these represent the most critical dike sections. The dikes are high consequence structures, as they will be retaining water while personnel and equipment are working in the pits. The design life of the dikes is less than 20 years.

### 5.4.1 Results of Analyses for End-of-Construction Conditions

Slope stability analyses were carried out to evaluate the short-term, end-of-construction scenario. The soil foundation material was assumed to be undrained. Sections A, B, and C were analyzed to determine the values of the undrained shear strength ($c_u$), which would yield factors of safety of 1.0 and 1.3.

The analyses show that the minimum required undrained strength of the foundation must be in the range of 20 to 30 kPa, to achieve factors of safety of 1.0 and 1.3, respectively. The foundation soils that have been recovered during the geotechnical investigations carried out along the proposed dike alignments range from a silty till material containing significant proportions of gravel and cobbles to silty sand and gravel. Undrained strengths of this material are expected to be at least equal to, if not greater than, 20 to 30 kPa. Undrained shear strength testing will be required during the detailed engineering design stage for the dikes.

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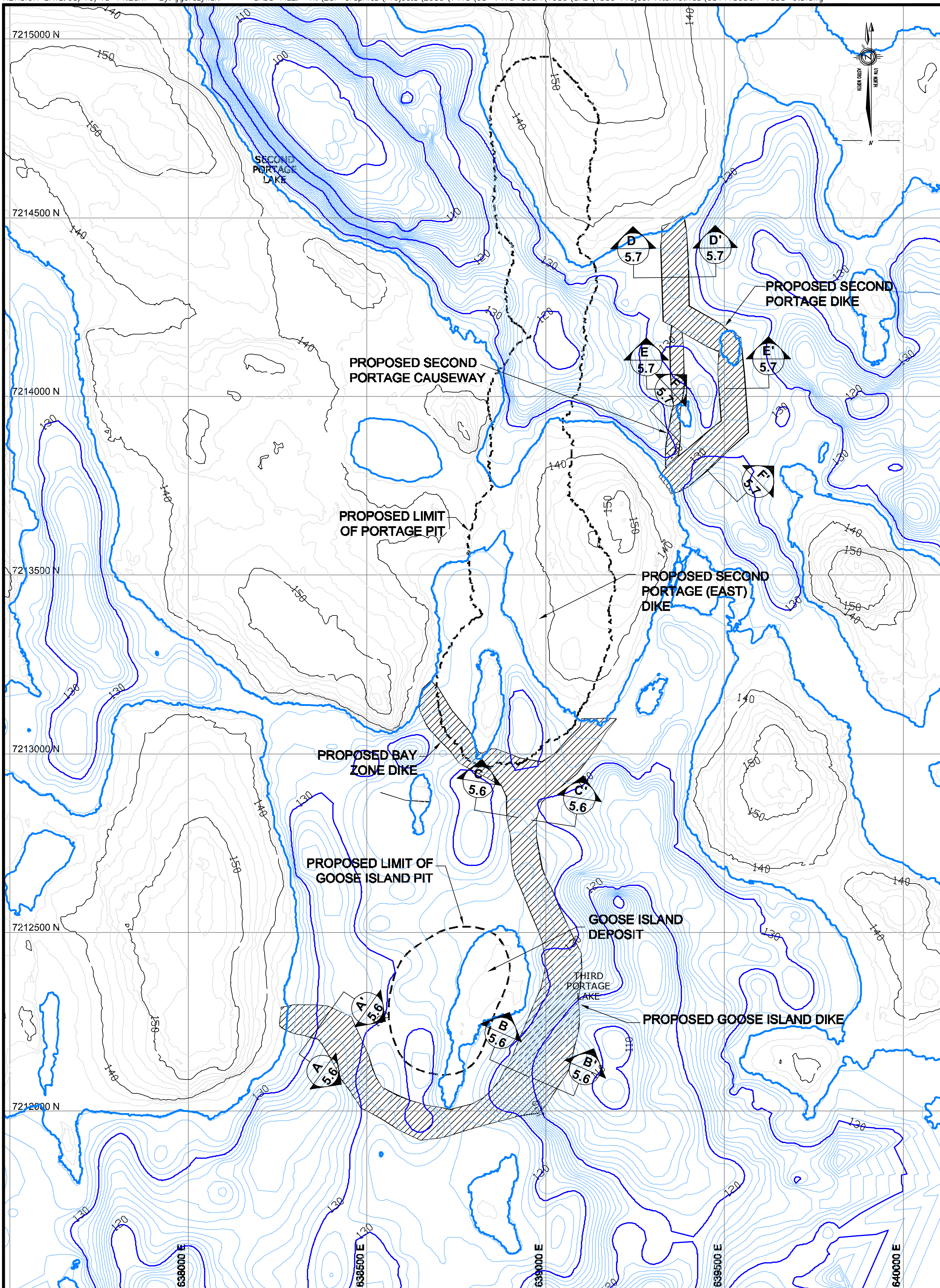



0 100 200 300 400 500

Scale in Meters

**NOTES**

1) Contour information on land supplied by Cumberland Resources Ltd.
2) Contours below lake surface are based on bathymetric surveys by Golder Associates Ltd., 2002 and 2003.
3) Lake contours are based on surveyed lake surface elevations:
   2nd Portage Lake = 133.1 m
   3rd Portage Lake = 134.1 m

PROJECT

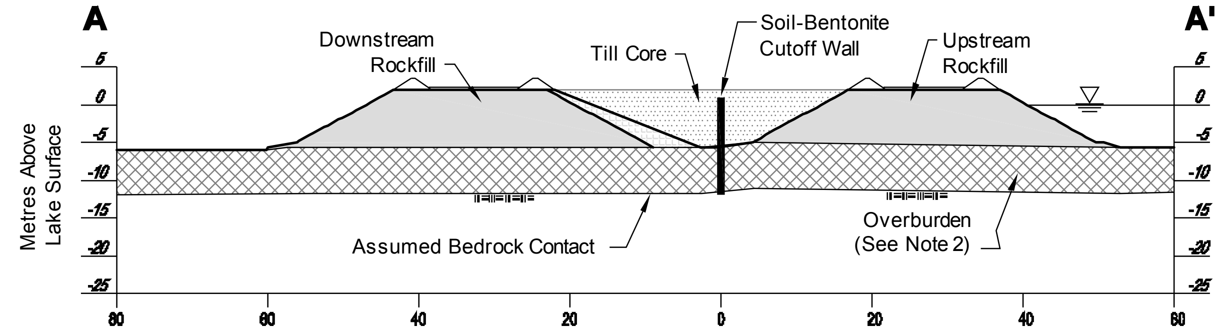
**CUMBERLAND RESOURCES LTD.**

TITLE

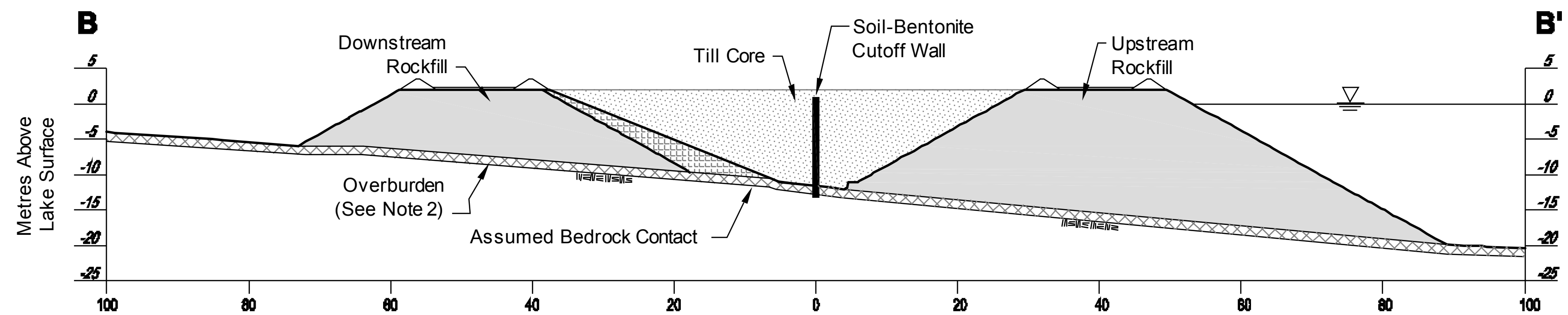
**LOCATION OF STABILITY CROSS SECTIONS**

Golder Associates

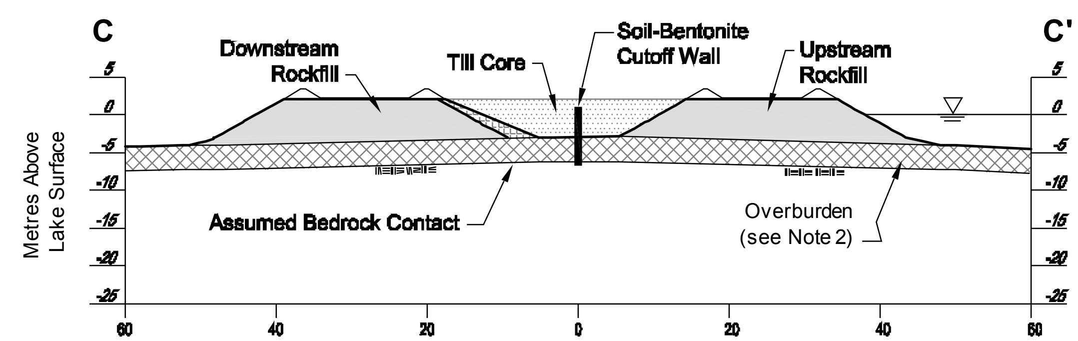
| PROJECT No. | 05-1413-036A | FILE No. 051413036A-1050-5.5 | |
|---|---|---|---|
| DESIGN | DAH | 01APR03 | SCALE: AS SHOWN | REV. 0 |
| CADD | WSL | 10JUL03 | |
| CHECK | CJC | 13OCT05 | **FIGURE 5.5** |
| REVIEW | CJC | 17OCT05 | |




A 5.5 NEAR LEFT ABUTMENT




B 5.5 NEAR GOOSE ISLAND




C 5.5 NEAR RIGHT ABUTMENT

## NOTES

1. Sections are shown for 1.8H:1.0V sideslopes of rockfill. Actual slopes will vary, depending on water depth, rockfill grain size, and foundation conditions.
2. Overburden depth has been estimated based on results from the 2003 Golder geotechnical drilling investigations. Actual overburden depths will vary.
3. All dimensions are in metres unless noted otherwise.

0 10 20 30 40 50
Scale in Meters

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
GOOSE ISLAND DIKE SECTIONS

Golder Associates

| | | |
|---|---|---|
| PROJECT No. | 05-1413-036A | |
| DESIGN | CJC | 13JUN03 |
| CADD | NV/WSL | 19JUN03 |
| CHECK | CJC | 13OCT05 |
| REVIEW | CJC | 17OCT05 |

FILE No. 051413036A-1050-5.6-5.7
SCALE AS SHOWN REV. 0

FIGURE 5.6

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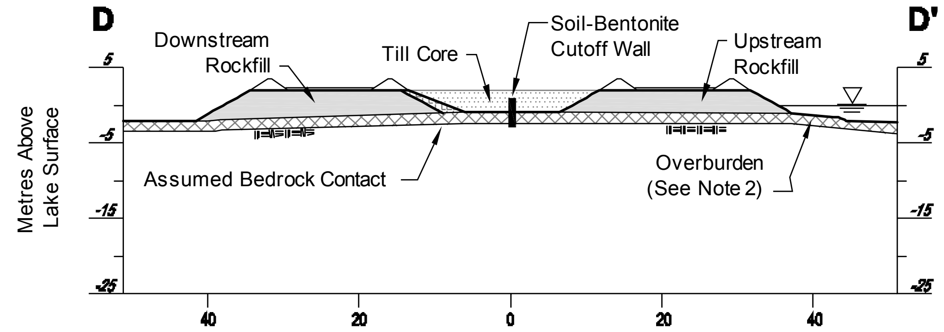
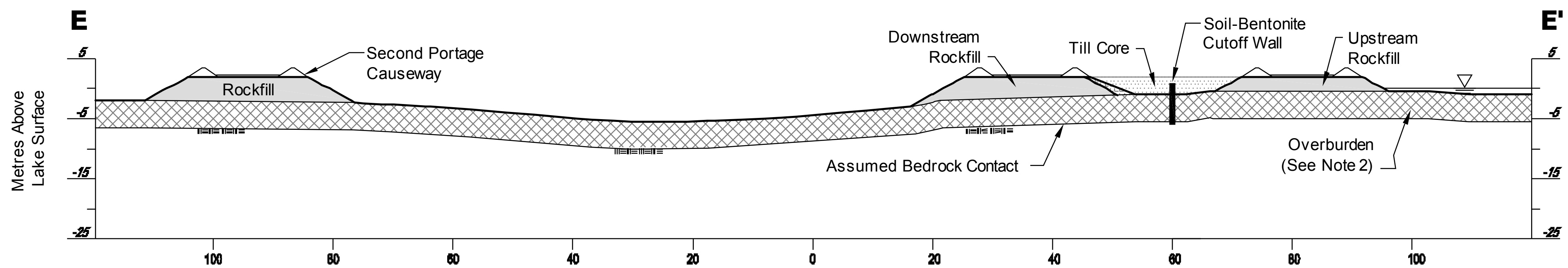
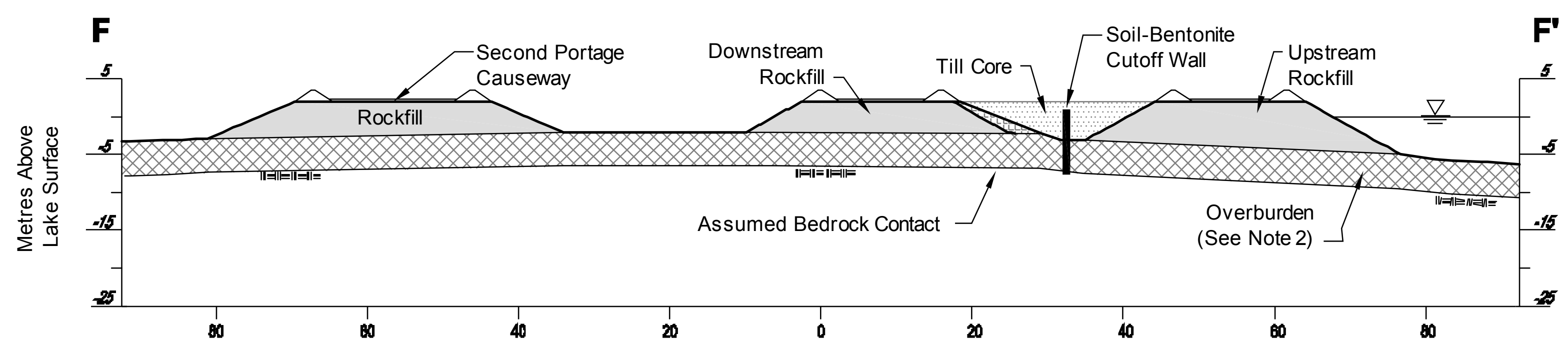
REVISION DATE: 05/10/20 9:47am By: sreddy




D 5.5 NEAR RIGHT ABUTMENT




E 5.5 SECTION THROUGH CAUSEWAY AND DIKE




F 5.5 NEAR LEFT ABUTMENT

## NOTES

1) Sections are shown for 1.8H:1.0V sideslopes of rockfill. Actual slopes will vary, depending on water depth, rockfill grain size, and foundation conditions.

2) Overburden depth has been estimated based on results from the 2003 Golder geotechnical drilling investigations. Actual overburden depths will vary.

3) All dimensions are in metres unless noted otherwise.

0 10 20 30 40 50
Scale in Meters

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**SECOND PORTAGE EAST DIKE AND CAUSEWAY SECTIONS**

Golder Associates

| | | |
|---|---|---|
| PROJECT No. | | 05-1413-036A |
| DESIGN | DAH | 13JUN03 |
| CADD | NV/WSL | 19JUN03 |
| CHECK | CJC | 13OCT05 |
| REVIEW | CJC | 17OCT05 |

| | | | |
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| SCALE | AS SHOWN | REV. | 0 |

**FIGURE 5.7**

### 5.4.2 Results of Analyses for Long-Term Static & Pseudostatic Conditions

Slope stability analyses were done to evaluate the stability of the dikes under long-term, steady-state seepage conditions. The results of the long-term analyses of the critical failure modes are summarized in Table 5.2. The results of all stability analyses are presented in Appendix D.

***Table 5.2: Summary of Long-Term Slope Stability Analyses***

| Failure Mode | Minimum Calculated Factors of Safety | | |
|---|---|---|---|
| | **Section A** | **Section B** | **Section C** |
| Failure through Cutoff Wall Static Conditions (Minimum = 1.5) | 4.1 | 3.5 | 3.9 |
| Failure through Cutoff Wall seudostatic Conditions (Minimum = 1.2) | 3.5 | 3.0 | 3.3 |
| Failure through Rockfill only Static Conditions (Minimum = 1.5) | 2.7 | 1.9 | 3.2 |
| Failure through Rockfill only Pseudostatic Conditions (Minimum = 1.2) | 2.5 | 1.7 | 2.4 |
| Calculated Yield Acceleration (g) | | | |
| Failure through Cutoff Wall | 0.41 | 0.27 | 0.37 |
| Failure through Rockfill only | 0.36 | 0.16 | 0.36 |

**Notes: 1.** FOS = 1.5 is minimum specified for long-term. **2.** FOS = 1.2 is minimum specified for pseudo-static.

As seen in the table, the minimum calculated factor of safety for static conditions is 1.9, and the minimum calculated factor of safety for pseudo-static conditions is 1.5, both of which occur at Section B. These values exceed the minimum values indicated by the Dam Safety Guidelines (Canadian Dam Association, January 1999).

Based on the analyses, the dikes will be stable in the long-term for static and pseudostatic loading conditions.

## 5.5 SEEPAGE

Seepage analyses were carried out for sections A and B. The material parameters used in the analyses are presented in Table 5.3.

The cutoff wall was modelled for the following scenarios:

1. A cutoff wall with no gaps at the bedrock contact, and no cracking within the wall.
2. A gap through the soil-bentonite cutoff wall at the bedrock interface.
3. A crack through the soil-bentonite cutoff wall, in the overburden till material
4. A crack through the soil-bentonite cutoff wall, in the till core material.
5. Combinations of 2, 3, and 4.

Fluxes were computed through the soil-bentonite cutoff wall for each scenario. Table 5.4 shows the predicted fluxes for each of the scenarios modelled.

***Table 5.3: Summary of Material Properties used in Seepage Analyses***

| Material | Hydraulic Conductivity (m/s) | Basis for Properties |
|---|---|---|
| Till Core | 1 x $10^{-5}$ | Falling head tests from Dec 2002 geotechnical testing and; Experience with materials with similar genesis and grain size distribution |
| Rockfill | 1 x $10^{-2}$ | Experience with similar materials |
| Overburden | 1 x $10^{-5}$ | Falling head tests from Dec 2002 geotechnical testing and; Experience with materials with similar genesis and grain size distribution |
| Soil-Bentonite<br>Backfill | 1 x $10^{-9}$<br>1 x $10^{-8}$ | Published values |
| Bedrock | 4.7 x $10^{-7}$ (Section A)<br>2.2 x $10^{-7}$ (Section B) | BH 03GT-GI-6 packer tests<br>BH 03GT-GI-3 packer tests<br>previous geotechnical field investigations |

***Table 5.4: Seepage Fluxes through the Soil-Bentonite Cutoff Wall***

| Scenario Modelled | Predicted Flux (L/s/m of length of dike) | |
|---|---|---|
| | Section A | Section B |
| No gap at bedrock contact; no crack in soil-bentonite wall | 5.8 x $10^{-4}$ | 5.6 X $10^{-4}$ |
| No gap at bedrock contact; crack in soil-bentonite wall within overburden till | 1.5 x $10^{-2}$ | 7.5 x $10^{-3}$ |
| No gap at bedrock contact; crack in soil-bentonite wall within till core | 5.9 x $10^{-4}$ | 5.6 x $10^{-4}$ |
| 0.5 m gap at bedrock contact; no crack in soil-bentonite wall | 1.9 x $10^{-3}$ | 6.7 x $10^{-3}$ |
| 0.5 m gap at bedrock contact; crack in soil-bentonite wall within overburden till | 1.5 x $10^{-2}$ | 1.2 x $10^{-2}$ |
| 0.5 m gap at bedrock contact; crack in soil-bentonite wall within till core | 1.9 x $10^{-3}$ | 5.9 x $10^{-3}$ |

The predicted fluxes result in the following conclusions:

- Cracks through the cutoff wall in the section through the overburden would result in the largest increase in seepage. The increase is in the range of one to two orders of magnitude more than a wall with no cracks or defects in the overburden section. Cracks within the till core section have a negligible effect on seepage.
- A gap in the soil-bentonite cutoff wall at the bedrock contact results in an increase in seepage of approximately one order of magnitude.

Preliminary estimates of the range of seepage flows to be expected through the cutoff wall during operations are summarized on Table 5.5.

*Table 5.5: Seepage Flows through Dikes*

| Dike | Predicted Flux (l/s/m of length of dike) | | Length of Dike (m) | Predicted Flow through Dike and Overburden(see Note 1) (l/s) |
|---|---|---|---|---|
| | Section A | Section B | | |
| *No gap at bedrock contact, no crack within overburden* | | | | |
| Second Portage | $6 \times 10^{-4}$ | n/a | 950 | 0.6 |
| Bay Zone | $6 \times 10^{-4}$ | n/a | 720 | 0.6 |
| Goose Island | $6 \times 10^{-4}$ | $6 \times 10^{-4}$ | 1724 | 1.2 |
| *0.5 m gap at bedrock contact, no crack within overburden (along complete length of dike)* | | | | |
| Second Portage | $2 \times 10^{-3}$ | n/a | 950 | 1.9 |
| Bay Zone | $2 \times 10^{-3}$ | n/a | 720 | 1.4 |
| Goose Island | $2 \times 10^{-3}$ | $2 \times 10^{-3}$ | 1724 | 3.4 |
| *Crack in cutoff wall within overburden (along complete length of dike)* | | | | |
| Second Portage | $1.5 \times 10^{-2}$ | n/a | 950 | 14.2 |
| Bay Zone | $1.5 \times 10^{-2}$ | n/a | 720 | 10.8 |
| Goose Island | $1.5 \times 10^{-2}$ | $1 \times 10^{-2}$ | 1724 | 23.3 |

**Notes: 1.** To calculate total flow at Second Portage and Bay Zone dikes, the seepage flux at Section A flux was applied over the total length of the dikes. To calculate total flow at the Goose Island dike, the Section A and B seepage fluxes were each applied over 70% and 30% of the dike length, respectively.

It is anticipated that the majority of the seepage flows would be captured in toe drains excavated near the downstream toe of the dikes and pumped, most likely to the water treatment plant. The seepage captured at the drains will likely be pumped to the water treatment plant. The remaining flow would report to the open pit dewatering systems.

# SECTION 6 • STABILITY ASSESSMENT OF THE PORTAGE ROCK STORAGE FACILITY

An assessment of the physical and thermal stability of the Portage rock storage facility was carried out by BGC Engineering Inc, as detailed in the following report:

- BGC Engineering Inc., Preliminary Geothermal and Slope Stability Modelling of Rock Storage Facilities. 31 March 2004.

The assessment was based on the initial design of the Portage rock storage facility having a larger footprint area than the current design, and on the previous mine production schedule in which the mine was operated over a period of 10 years. The results of the assessment are summarized in the following sections.

Two sites to store the country rock have been selected based on an evaluation process that considered environmental impacts, costs, and operational constraints. Materials excavated from the Goose Island and Portage pits will be stored at the Portage rock storage facility (RSF), while materials excavated from the Vault pit will be stored at the Vault RSF (see Figure 3.1).

The foundation conditions at the Vault RSF primarily comprise thin deposits of ice-poor glacial till and weathered bedrock, and are expected to pose limited engineering challenges. At some locations, the foundation conditions at the Portage RSF comprise weaker ice-rich sediments and organic soils. Consequently, the Portage RSF was selected for further evaluation of slope stability considerations. This included an evaluation of the predicted ground thermal regime and its potential impacts on slope stability.

The construction, operation, and closure of the rock storage facilities will comply with NWT mine Health and Safety Regulations and Canadian Dam Association Dam Safety Guidelines, and design criteria such as the factors of safety required for construction and long-term conditions are similar to those developed for the tailings facilities.

## 6.1 CONSTRUCTION ALTERNATIVES

If construction of the RSF is initiated during the summer, the first lift of rockfill will be placed on an unfrozen or partially thawed foundation. Based on air photo interpretation, it appears that a portion of the RSF is underlain by ice-rich soil. These materials are expected to display relatively low shear strengths and thermal conductivities. Geothermal modelling, however, suggests that the foundation materials should freeze back within about 270 days of placement of the first lift of rockfill. Furthermore, slope stability analyses show that the bottom lift of rockfill should be stable despite the potential for thawed foundation materials, provided the lift height is limited to about 5 m and overall slope angles of about 3:1 (18.4°) are utilized.

If the first lift of rockfill is placed during the winter, geothermal analyses suggest this will help to “lock in” the cold foundation temperatures, and the foundation should remain frozen in perpetuity.

Geothermal analyses were undertaken to evaluate long-term foundation temperatures beneath as much as 70 m of rockfill placed in the RSF. A climate-warming trend of 5.5°C over the next 100 years was considered. The modelling suggests that foundation temperatures will remain below -4°C for at least the next 200 years in spite of this potential for climate warming.

If the RSF foundations remain frozen, long-term stability will, in part, be governed by creep deformation. Using estimates of creep strength developed for the Diavik project based on laboratory testing and case history review, slope stability modelling indicates creep strain rates less than 0.01 are attainable. If, for example, approximately 2.5 m of creep-susceptible materials are encountered in the foundation of the RSF, this implies deformations in the RSF should be less than 2.5 cm per year.

### 6.1.1 CONSTRUCTION GEOTHERMAL ANALYSIS

The geothermal modelling to evaluate conditions during construction of the RSF had two main objectives:

- to evaluate the potential for thawing the foundation during construction or operation of the facility
- to evaluate the impact of initiating construction in the summer versus the winter on predicted foundation temperatures.

#### *6.1.1.1 Geothermal Model*

The mine waste management plan calls for the filling of Second Portage Arm with tailings during mine operation. This will eliminate the nearby warming effect of the lake, resulting in cooler foundation temperatures near the toe of the facility starting about mid-way through the mine life.

Prior to placement of the first lift of rockfill for the summer placement alternative, the ground surface temperatures are about +6°C, and -8°C at approximately 5 m depth. The ground thermal regime prior to the winter placement scenario indicates a ground surface temperature of about -18°C and a temperature of -8°C at about 2.5 m depth.

As the excavated country rock has a low thermal conductivity and will be placed at temperatures below freezing, placement of the first lift is expected to present the greatest opportunity for thawing of the foundation. Once foundation materials freeze, the active layer is not expected to penetrate the full thickness of any of the additional lifts of rockfill. Therefore, construction of the facility was modelled in two steps: placement of a 5 m lift in Year 1; and placement of all remaining lifts in Year 3. This is expected to be highly conservative, as opportunities for cooling of the rockfill between placement of the intermediate lifts was not accounted for in the modelling.

Predicted temperatures in the foundation materials and the rockfill were monitored for eleven years, and the results are discussed below.

#### *6.1.1.2 Summer Placement Results*

The ground thermal regime was modelled for a period of two years following placement of lift no. 1. The ground temperatures in the summer of Year 2 (approximately 12 months after placement of the first lift) are illustrated in Figure 6.1. By the summer of Year 2, the foundation materials beneath the rockfill are frozen, but at a temperature greater than -2°C. As a result of placing the lift of rockfill at -3°C, the -8°C isotherm below the base of the storage facility shifted downwards from a depth of 5 m to about a depth of 18 m below the original ground surface.

Figure 6.2 shows the ground thermal regime in the summer of Year 11. The foundation materials beneath the rockfill have cooled to between -4°C and -6°C. The majority of the rockfill is between -3°C and -6°C. Except at the toe of the facility, where temperatures remain below -6°C, the bedrock beneath the rockfill has warmed to between -4°C and -6°C.

#### *6.1.1.3 Winter Placement Results*

The ground temperatures in the summer of Year 2 are illustrated in Figure 6.3, and temperatures in Year 11 are illustrated in Figure 6.4. These figures illustrate the potential benefit of "locking in" the cold foundation temperatures by placement of the first lift during the winter. The predicted temperatures in the foundation are between -6°C and -9°C, which will result in a higher creep strength.

Temperatures in the rockfill are similar to those for the summer placement scenario with the majority of the rockfill residing between -3°C and -6°C

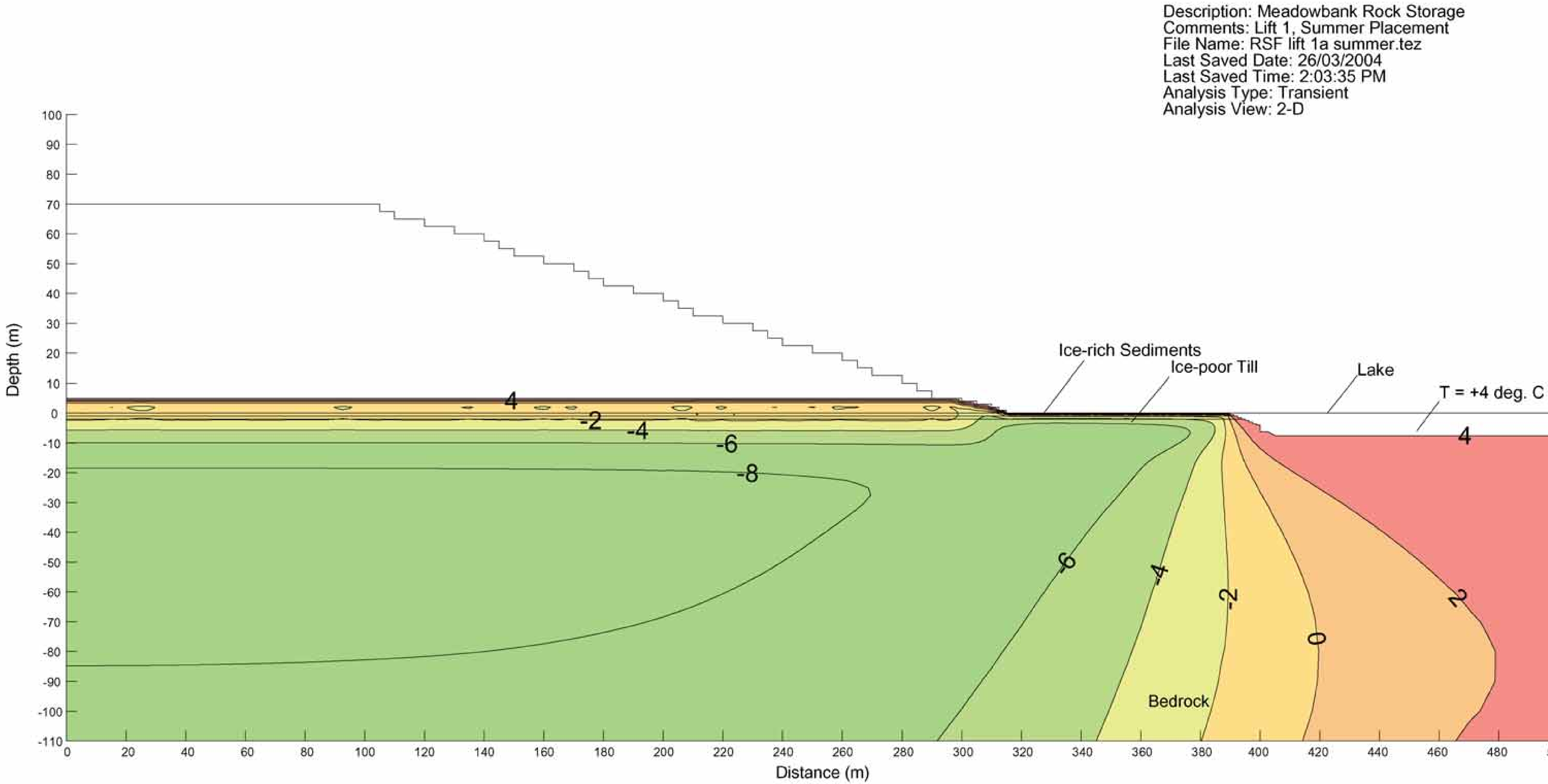
#### *6.1.1.4 Short-term Foundation Temperatures*

A more detailed assessment of predicted foundation temperatures for each placement scenario was completed for the first two years following placement of the first lift of rockfill. The results indicate that, for summer placement of the rockfill, the soil 0.5 m below the original ground surface remains thawed for a period of about 270 days, then drops gradually towards -4°C. For winter placement, the soil 0.5 m below the original ground surface rapidly warms to about -8°C in the first 30 days, then gradually warms towards -7°C.

The modelling results suggest that frozen soil creep strength for temperatures less than -4°C can be relied upon from the time of rockfill placement in the winter placement scenario, but that only partially thawed strengths should be relied upon during the early stages of construction if the first lift of rockfill is placed during the summer.

### 6.1.2 LONG-TERM GEOTHERMAL ANALYSIS

Geothermal analyses were undertaken to evaluate long-term trends in the temperature of the RSF, both under current climatic conditions and under an assumed conservative estimate of climate warming. A time period of 100 years following mine closure was modelled for both the case of no climate warming, while a period of 200 years was modelled for the climate warming scenario. The initial temperature profile was based on the summer placement model data recorded in Year 11 (Figure 6.2).




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 7.

PROJECT CUMBERLAND RESOURCES LTD.

TITLE **PORTAGE ROCK STORAGE FACILITY GROUND THERMAL REGIME YEAR 2 (SUMMER), SUMMER PLACEMENT**

| | | | |
|---|---|---|---|
| PROJECT No. 05-1413-036A | | | FILE No. THERMAL |
| DESIGN | CJC | 11OCT05 | SCALE NTS REV. |
| CADD | SS | 11OCT05 | |
| CHECK | CJC | 11OCT05 | FIGURE 6.1 |
| REVIEW | CJC | 17OCT05 | |

Golder Associates

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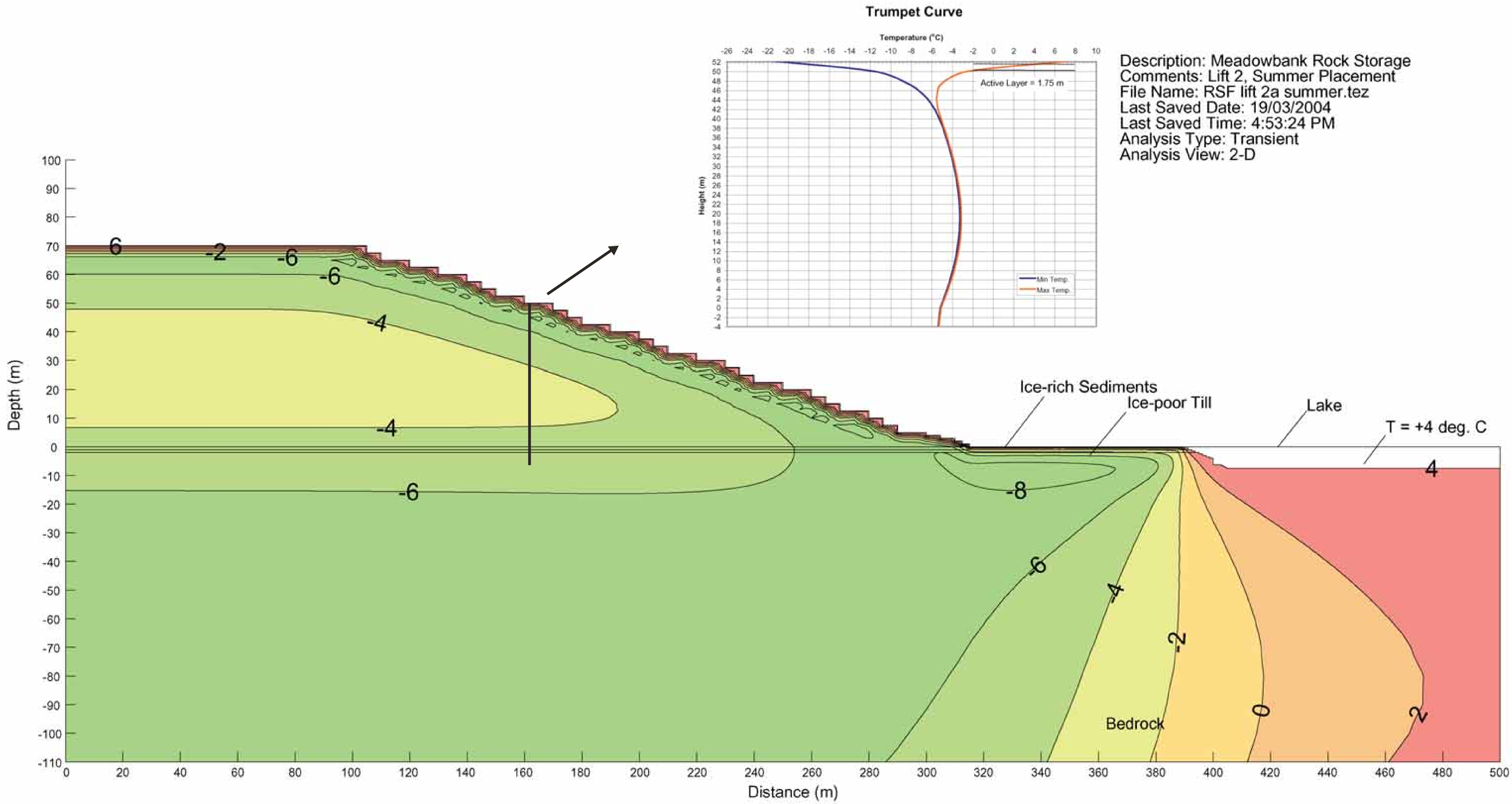


Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 8.

DRAWING DATE: 11-Oct-05 COREL FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\Corel\1300 Project Alternatives\Thermal.cdr

PROJECT

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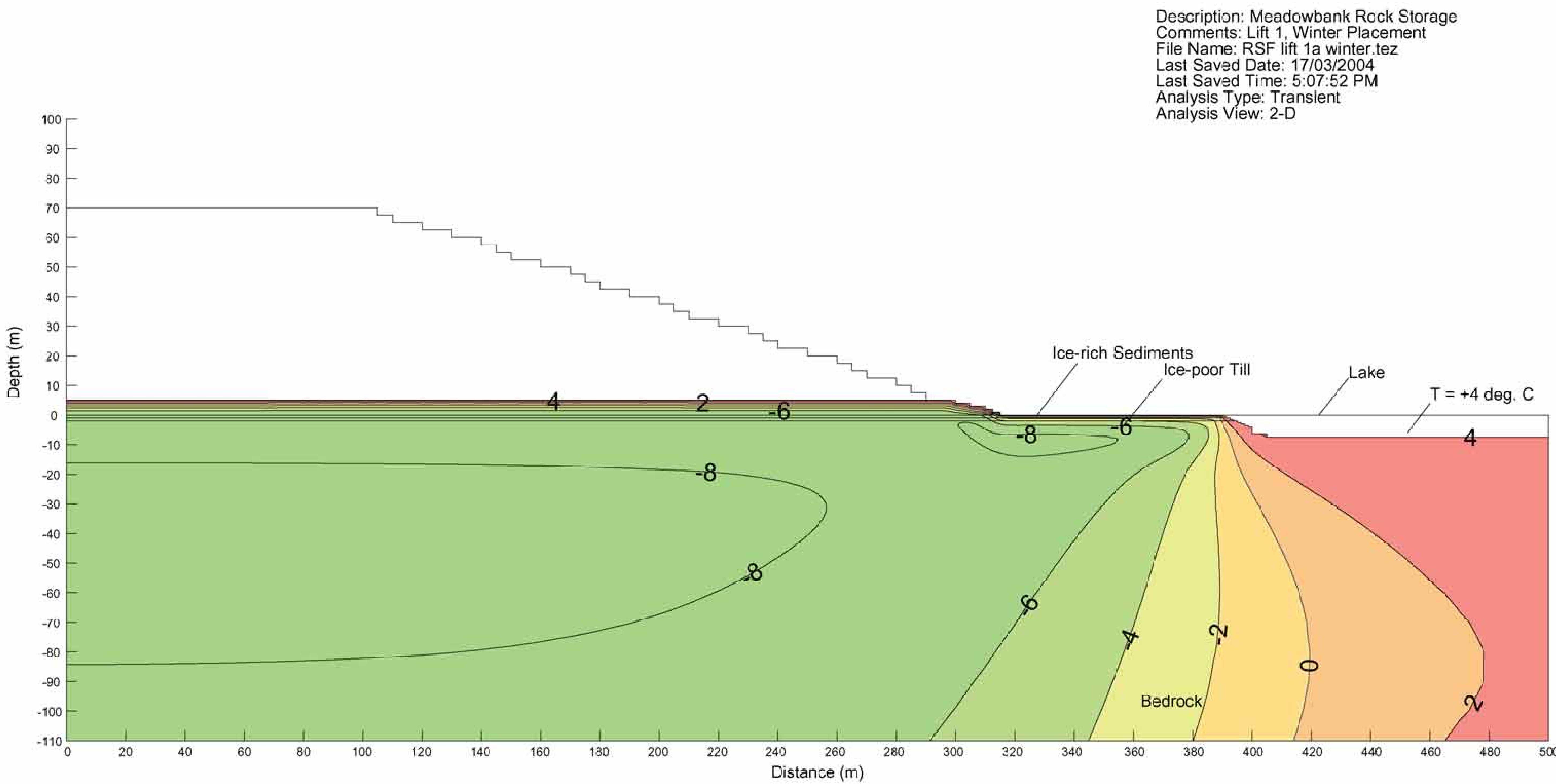
TITLE

**PORTAGE ROCK STORAGE FACILITY**
**GROUND THERMAL REGIME**
**YEAR 11 (SUMMER), SUMMER PLACEMENT**

| | | | | |
|---|---|---|---|---|
| PROJECT No. 05-1413-036A | | | FILE No. THERMAL | |
| DESIGN | CJC | 11OCT05 | SCALE NTS | REV. |
| CADD | SS | 11OCT05 | | |
| CHECK | CJC | 11OCT05 | FIGURE 6.2 | |
| REVIEW | CJC | 17OCT05 | | |

Golder Associates




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 9.

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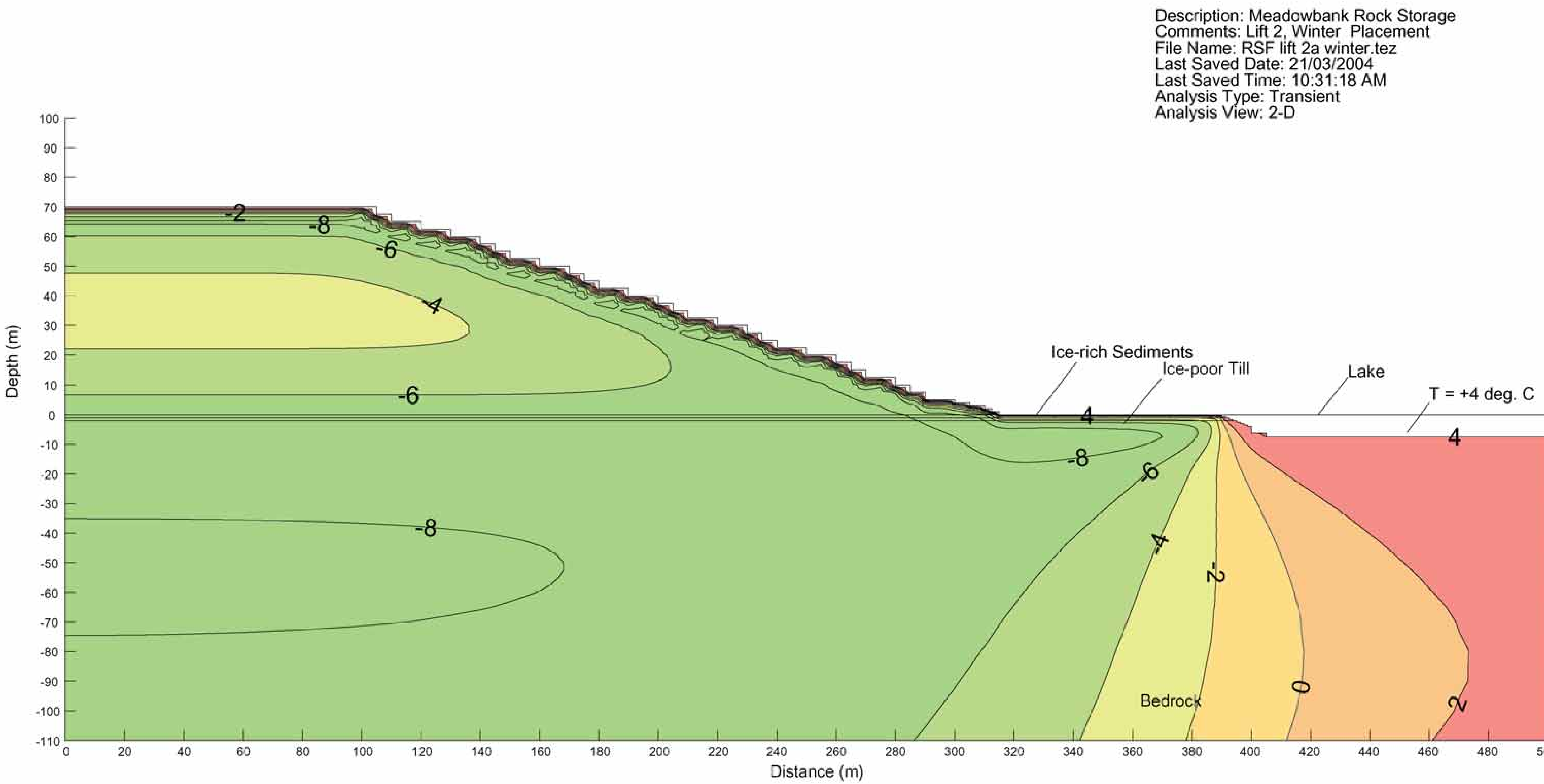
PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
**PORTAGE ROCK STORAGE FACILITY**
**GROUND THERMAL REGIME**
**YEAR 2 (SUMMER), WINTER PLACEMENT**

Golder Associates

| PROJECT No. 05-1413-036A | | | FILE No. THERMAL | |
|---|---|---|---|---|
| DESIGN | CJC | 11OCT05 | SCALE NTS | REV. |
| CADD | SS | 11OCT05 | **FIGURE 6.3** | |
| CHECK | CJC | 11OCT05 | | |
| REVIEW | CJC | 17OCT05 | | |




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling,
Project No. 0374-001-08, Figure 10.

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PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
**PORTAGE ROCK STORAGE FACILITY GROUND THERMAL REGIME YEAR 11 (SUMMER), WINTER PLACEMENT**

| | | | |
|---|---|---|---|
| PROJECT No. | 05-1413-036A | FILE No. THERMAL | |
| DESIGN | CJC | 11OCT05 | SCALE NTS | REV. |
| CADD | SS | 11OCT05 | |
| CHECK | CJC | 11OCT05 | |
| REVIEW | CJC | 17OCT05 | |

Golder Associates

**FIGURE 6.4**

#### *6.1.2.1 Climate Warming Assumptions*

Climate warming assumptions conform with those presented by Golder (2003c) and included a 5.5°C increase in temperature over a period of 100 years. Each year, 0.055°C was added the mean monthly ground surface temperatures assumed for GST No. 3. The resulting mean annual ground surface temperature at the end of 100 years (Year 111) was approximately -3°C. The model was then run for an additional 100 years holding the Year 111 ground surface temperature function constant.

#### *6.1.2.2 Results*

In the case of no climate warming, the foundation temperatures remain between -6°C and -8°C, with slightly cooler temperatures predicted beneath the toe of the facility (Figure 6.5). The majority of the rockfill appears to have cooled towards a temperature of -7°C. Air convection cooling may, however, cause the rockfill to attain lower temperatures.

In the case of climate warming, the foundation temperatures are slightly warming at Year 111, but remain between -4°C and -7°C (Figure 6.6). The majority of the rockfill appears to be at temperatures of between -4°C and -6°C

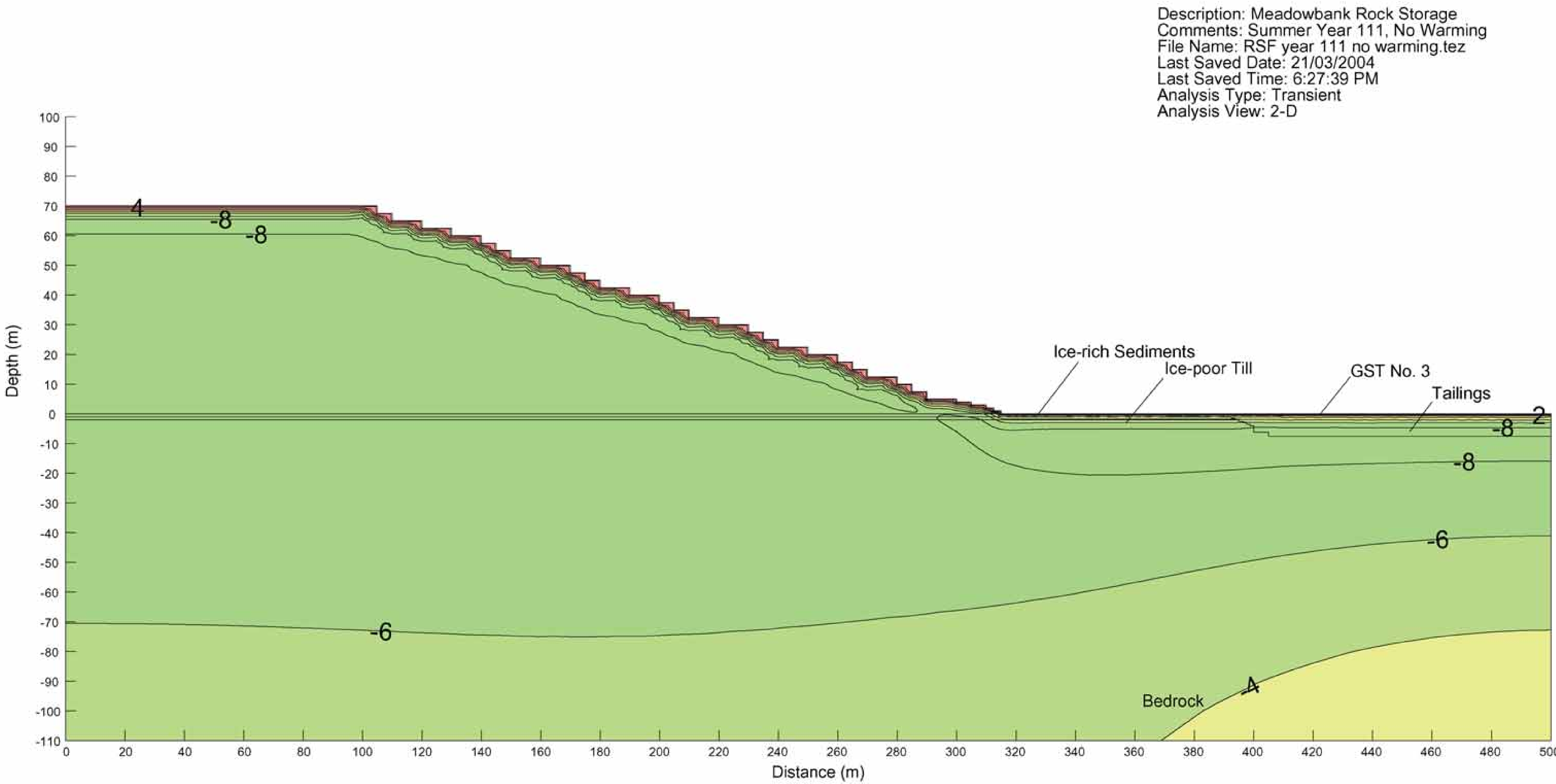
Maintaining the warmest set of ground temperature values for an additional 100 years, the foundation temperatures at Year 211 are between -3°C and -5°C, with cooler temperatures preserved beneath the highest portion of the RSF (Figure 6.7). While a warming trend for foundation temperatures is observed, the rate of warming is extremely slow because of the low thermal conductivity of the rockfill.

## 6.2 STABILITY ANALYSIS

Slope stability analyses were also undertaken to account for seismic loading conditions and the unlikely possibility of a thawing foundation beneath the completed RSF. The results indicate the long-term factors of safety against slope failure under static and seismic loading conditions are well in excess of those typically adopted for earth dams and other civil engineering structures.

The design assumptions used in the preliminary geothermal and slope stability modelling are considered to be conservative, but require verification through additional geotechnical investigation and laboratory testing. The results of this work should be used to optimize the design of the Portage RSF, likely resulting in a net cost savings to Cumberland during mine operation and closure. At the same time, verification of foundation conditions and design of the Vault RSF slopes should be undertaken, as should the design of temporary and/or permanent facilities to store overburden materials.

A process referred to as air convection cooling has been observed in highway embankments and waste rock piles constructed of coarse, poorly graded rockfill. The result is embankment and foundation temperatures that are considerably cooler than predicted by conventional geothermal modelling.




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 12.

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| PROJECT | CUMBERLAND RESOURCES LTD. |
| TITLE | PORTAGE ROCK STORAGE FACILITY GROUND THERMAL REGIME YEAR 111 (SUMMER), SUMMER PLACEMENT |

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|---|---|---|---|---|
| Golder Associates | PROJECT No. | 05-1413-036A | FILE No. | THERMAL |
| | DESIGN | CJC | 11OCT05 | SCALE NTS REV. |
| | CADD | SS | 11OCT05 | FIGURE 6.5 |
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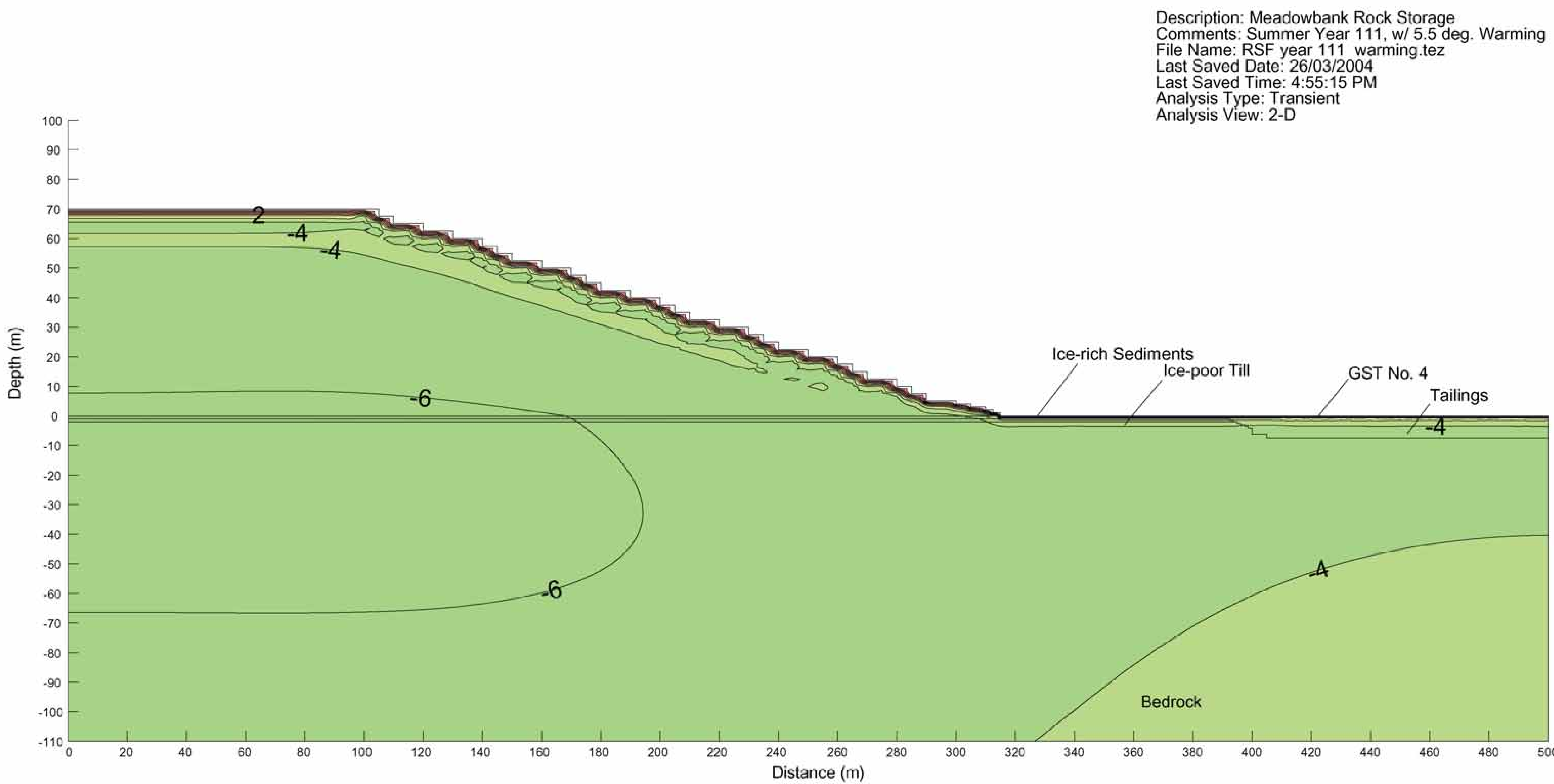
| | REVIEW | CJC | 17OCT05 | |




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 13.

PROJECT

CUMBERLAND RESOURCES LTD.

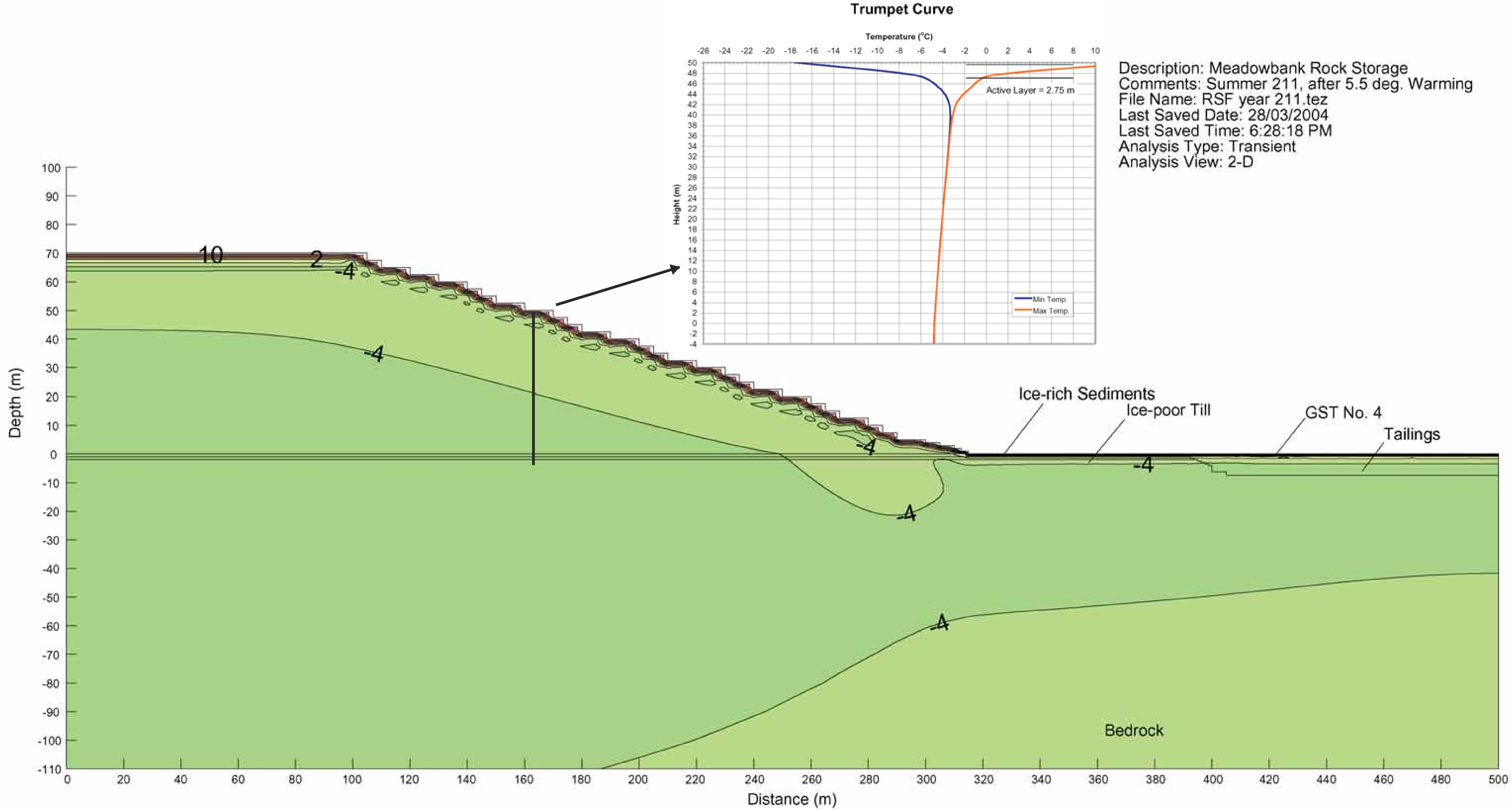
TITLE

**PORTAGE ROCK STORAGE FACILITY GROUND THERMAL REGIME YEAR 111 (SUMMER), WITH CLIMATE WARMING**

Golder Associates

| PROJECT No. 05-1413-036A | | | FILE No. THERMAL | |
|---|---|---|---|---|
| DESIGN | CJC | 11OCT05 | SCALE NTS | REV. |
| CADD | SS | 11OCT05 | | |
| CHECK | CJC | 11OCT05 | **FIGURE 6.6** | |
| REVIEW | CJC | 17OCT05 | | |

DRAWING DATE: 11-Oct-05 COREL FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\Corel\1300 Project Alternatives\Thermal.cdr




Reference: BGC Engineering Inc., Meadowbank Project, Geothermal and Stability Modelling, Project No. 0374-001-08, Figure 14.

DRAWING DATE: 11-Oct-05 COREL FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\Corel\1300 Project Alternatives\Thermal.cdr

PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

**PORTAGE ROCK STORAGE FACILITY**
**GROUND THERMAL REGIME**
**YEAR 211 (SUMMER), AFTER CLIMATE WARMING**

Golder Associates

| PROJECT No. | 05-1413-036A | FILE No. THERMAL | |
|---|---|---|---|
| DESIGN | CJC | 11OCT05 | SCALE NTS | REV. |
| CADD | SS | 11OCT05 | |
| CHECK | CJC | 11OCT05 | **FIGURE 6.7** |
| REVIEW | CJC | 17OCT05 | |

### 6.2.1 CONSTRUCTION SLOPE STABILITY

#### *6.2.1.1 Objectives*

Slope stability analyses were undertaken to assess stability of the Portage RSF during its construction. The objective was to ensure that the factor of safety against failure of the overall slopes of the facility will not fall below a value of 1.3 during construction. A factor of safety of 1.3 for construction conditions is generally accepted for dams and mine tailings facilities.

#### *6.2.1.2 Section for Analysis*

The section for analysis was essentially that used for the geothermal modelling, although the thickness of the ice-rich sediments unit was increased from 1 m to 2.5 m, the stronger glacial till unit was removed, and instead of being level, a -1.1% gradient (4 m elevation in 350 m) was modelled along the base of the RSF. These modifications helped to ensure that the slip surfaces were properly constrained to the weaker ice-rich foundation materials, and that the effects of an outward dipping foundation were accurately accounted for. The water table was assumed to be located at the natural ground surface. Rockfill slope angles were modelled at 3:1 (18.4°) slopes.

Stability of the facility was modelled for two different stages of construction: following placement of the first lift, and following placement of all remaining lifts.

The limit-equilibrium software SLOPE/W, produced by Geo-Slope International Ltd., was used for the analyses. A search for slip surfaces passing through the crest of the RSF that gave the lowest factor of safety was conducted. Strength parameters were varied to account for partially thawed and fully thawed foundation conditions. Results of the analyses are reported below.

#### *6.2.1.3 Partially Thawed Foundation*

In the case that the first lift of rockfill will be placed during the summer, the ice-rich sediments may be thawed or partially frozen. If this occurs, the material is expected to consolidate rapidly under the load of the coarse rockfill, resulting in a gain in strength.

Using a friction angle of 20° for partially thawed ice-rich sediments, a factor of safety against slope failure of 1.3 is predicted for a five metre high lift of rockfill. A check on the required undrained shear strength of the ice-rich sediments was also carried out. Provided a shear strength in excess of 13 kPa can be relied upon, the factor of safety against undrained loading should also exceed 1.3. Higher undrained shear strengths will be required to maintain the stability of additional lifts. These should easily be achieved as foundation materials freeze.

Geothermal modelling showed that even if the first lift of rockfill was placed during the summer, the foundation materials would freeze within about 270 days and are expected to remain frozen in perpetuity. In the case of winter placement of the first lift, the foundation is never expected to experience thawed conditions. Regardless, a check on the stability of the completed RSF with a gradually thawing foundation was conducted. Using a friction angle of 20° for the ice-rich sediments, a factor of safety against slope failure of 1.8 is predicted. Since any thawing of the foundation underneath the completed RSF would occur very slowly, the potential for thaw-generated excess pore pressures was considered low and not analyzed.

#### *6.2.1.4 Fully Thawed Foundation*

If the foundation materials were fully thawed, they would consolidate and gain strength. Using a friction angle of 28° for the fully thawed and consolidated ice-rich sediments, factors of safety against slope failure of 1.7 for lift no. 1 and 2.1 for the full height of the RSF were determined.

### 6.2.2 LONG-TERM SLOPE STABILITY

#### *6.2.2.1 Objectives*

The objectives of slope stability modelling for long-term conditions was to ensure that the factor of safety exceeds 1.5 under static conditions, and that under seismic loading the factor of safety is greater than 1.2. Additionally, a check was conducted to ensure that the stress condition in the foundation of the facility will not lead to creep rupture.

#### *6.2.2.2 Static Conditions*

As demonstrated previously, the factors of safety under static conditions exceed 1.5 under the full height of the proposed RSF, even when the unlikely scenario of thawing foundations is considered. Thus, the requirements for long-term stability under static loading conditions are satisfied.

#### *6.2.2.3 Seismicity & Psuedo-Static Conditions*

Golder (2004) reports that the peak ground acceleration (PGA) for the site has been estimated at 0.044 g for the 1:975-year event. This has been adopted for design in accordance with Canadian Dam Association safety guidelines. Common practice is to apply one-half of the expected PGA when carrying out a pseudo-static slope stability analysis. Consequently, the stability of the rock storage facility under a horizontal acceleration of 0.022 g was evaluated.

If the foundation is assumed to be partially thawed, the factor of safety under seismic loading is approximately 1.7, while if the foundation soils are fully thawed and consolidated, the factor of safety is approximately 2.0. These are well in excess of a factor of safety of 1.2 as recommended by the Canadian Dam Association and commonly adopted in engineering practice.

#### *6.2.2.4 Frozen Foundation*

If the ice-rich sediments in the foundation of the RSF remain frozen, the long-term stability of the facility may be governed by creep deformation. Using the creep strength assumptions for ice-rich materials at Diavik, a factor of safety of 1.6 was determined. The results imply that the specified creep rate (0.01) will not be exceeded, and the potential for creep rupture is low.

#### *6.2.2.5 Air Convection Cooling*

In cold climates, air convection can provide a cooling effect for embankments constructed of highly porous, poorly graded material such as gravel or crushed rock with a low fines and moisture content. Such a material allows convection of pore air to occur within the embankment. Saboundjian and Goering (2003) provide a description of the process.

During the winter, the surface of the embankment experiences very cold temperatures, while the lower portions of the embankment and its foundation are relatively warm. The result is an unstable air density gradient within the embankment, which can lead to circulation of the air and enhanced wintertime heat transfer.

In the summer, the surface of the embankment experiences relatively warm temperatures compared to the lower portions of the embankment and its foundation. In this case, the embankment air density gradients are stable and circulation will not occur. Thus, the embankment acts as a one-way heat transfer device that effectively removes heat from the embankment and foundation soil during the winter without re-injecting heat during the summer. This passive cooling effect can accelerate embankment freezing and prevent thaw of underlying permafrost.

Additional cooling may occur as a result of exposure to wind blowing air through the embankment, provided the mean annual air temperature is cooler than the average embankment temperature.

#### *6.2.2.6 Observations from Test Highway Embankments*

Saboundjian and Goering (2003) discuss the thermal performance of a highway test embankment constructed in Alaska.

The embankment was constructed to a thickness of about 3 m over ice-rich permafrost using granular material with approximately the following gradation:

| Sieve Opening (mm) | % Passing |
|---|---|
| 152 | 100 |
| 102 | 90 |
| 76 | 23 |
| 25 | 0.3 |

Temperatures were monitored throughout the embankment and embankment foundation between 1997 and 2001. The monitoring data confirmed that the process of air circulation during wintertime was occurring within the embankment, resulting in a depression of the mean annual temperature at the base of the embankment. The mean annual temperature at the base of the embankment was about 4°C cooler than at the surface. No such cooling effect was observed in an adjacent Control section that was constructed using minus 2" fill materials.

#### *6.2.2.7 Observations from Ekati Mine*

Anecdotal information suggests that rock piles placed at the Ekati mine are experiencing air convection cooling, resulting in temperatures at the base of the piles that are cooler than the mean annual air temperature. Interviews with Ekati personnel to learn more about the nature of the waste rock, rock placement schedule and techniques, and impacts of air convection cooling on ground thermal regime, should be conducted as part of final design of the Meadowbank rock storage facilities.

#### *6.2.2.8 Implications for Meadowbank Rock Storage Facilities*

The waste rock generated from the Meadowbank project may have a gradation similar to the materials used to construct the test embankment in Alaska and the waste rock pile at the Ekati mine, where air convection cooling has been observed. Consequently, air convection cooling could also occur within the Meadowbank rock storage facilities, resulting in cooler temperatures than predicted by the geothermal modelling completed to date. The results from Alaska suggest foundation temperatures beneath the Portage RSF could be as much as 4°C cooler than the mean annual air temperature. Faster rates of cooling and cooler temperatures within the RSF and its foundation will likely improve slope stability factors of safety over the values predicted from the slope stability modelling. Cooler temperatures should also reduce seepage quantities from the toe of the RSF, and possibly the rates of geochemical processes such as ARD and metals leaching.

# SECTION 7 • TAILINGS DIKE DESIGN ALTERNATIVES

A site selection study was conducted to identify the preferred storage location and deposition method for tailings at the Meadowbank site. Details of the selection process have been described previously, and are presented in:

- Golder Associates Ltd., Report on Evaluation of Tailings Alternatives, Meadowbank Project, Nunavut. October, 2005.
- Golder Associates Ltd., Report on Evaluation of Waste Rock Management Alternatives, Meadowbank Project, Nunavut. October, 2005.
- Golder Associates Ltd., Report on Alternative Waste and Water Management Plan, Meadowbank Gold Project, Nunavut. 7 March 2005.
- Golder Associates Ltd., Report on Mine Waste and Water Management, Meadowbank Gold Project, Nunavut. 5 March 2004.

The key criteria used to select the preferred tailings storage area are as follows:

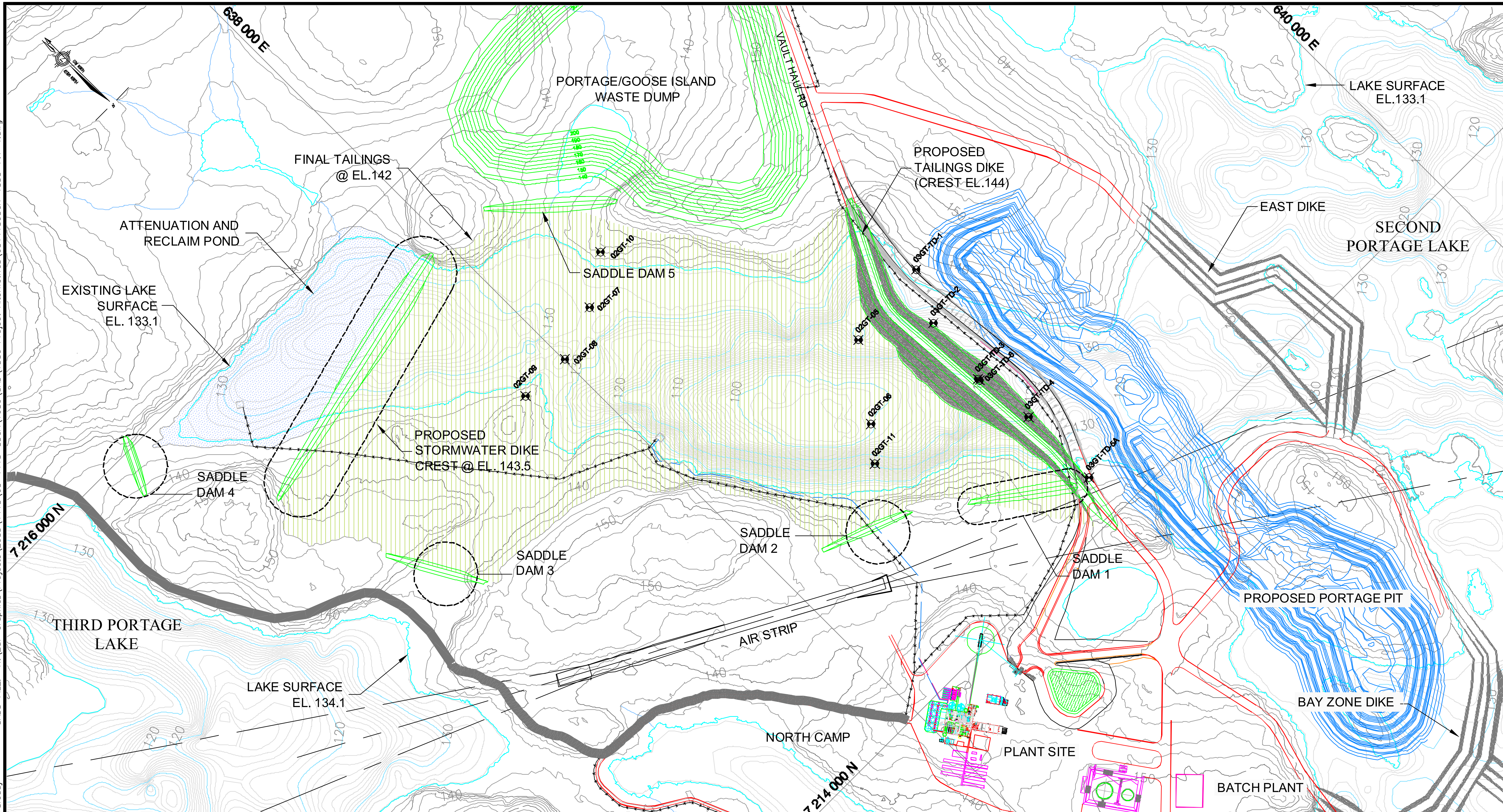
- the location should be within a catchment draining toward the open pits
- the facility must have the capacity to store the expected volume of tailings produced over the mine life
- the facility must have the potential to store increased volumes of tailings if mine is expanded
- the location must not preclude future mine expansion
- the facility must allow for collection and control of supernatant.

Based on the selection process, the preferred location for the tailings storage facility at the Meadowbank project is within the de-watered basin of the northwest arm of Second Portage Lake.

## 7.1 TAILINGS DIKE SITE CONDITIONS

The proposed tailings facility layout is shown on Figure 7.1 and the proposed tailings dike embankment is shown in plan on Figure 7.2 The site conditions along the proposed dike centreline are shown in Figure 7.3. This section was developed using the information obtained from geotechnical investigations conducted in 2002 and 2003, and presented in:

- Golder Associates Ltd., Report on 2003 Field Geotechnical Studies, Meadowbank Project, Nunavut. September, 2003.
- Golder Associates Ltd., Factual Report on Summer 2002, Geotechnical Drilling, Hydrogeological and Permafrost Investigations, Meadowbank Gold Project, Nunavut. 13 December 2002.
- Golder Associates Ltd., Report on Lake Bathymetry Survey, Meadowbank Project, Nunavut Territory. 15 November 2002.




CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-7.1-1.dwg

REVISION DATE: 05/10/19 11:45am By: sreddy

## NOTES

1) Contour information on land supplied by Cumberland Resources Ltd.
2) Contours below lake surface are based on bathymetric surveys by Golder Associates Ltd., 2002 and 2003.
3) Lake contours are based on surveyed lake surface elevations:
   - 2nd Portage Lake = 133.1 m
   - 3rd Portage Lake = 134.1 m
4) All elevations are in metres above mean sea level.

## LEGEND

| | |
|---|---|
| 02GT-05 | Golder borehole, 2002 |
| 03GT-TD-2 | Golder borehole, 2003 |
| | Creek/Stream |
| –x–x–x– | Powerline |

0 100 200 300 400 500
Scale in Meters

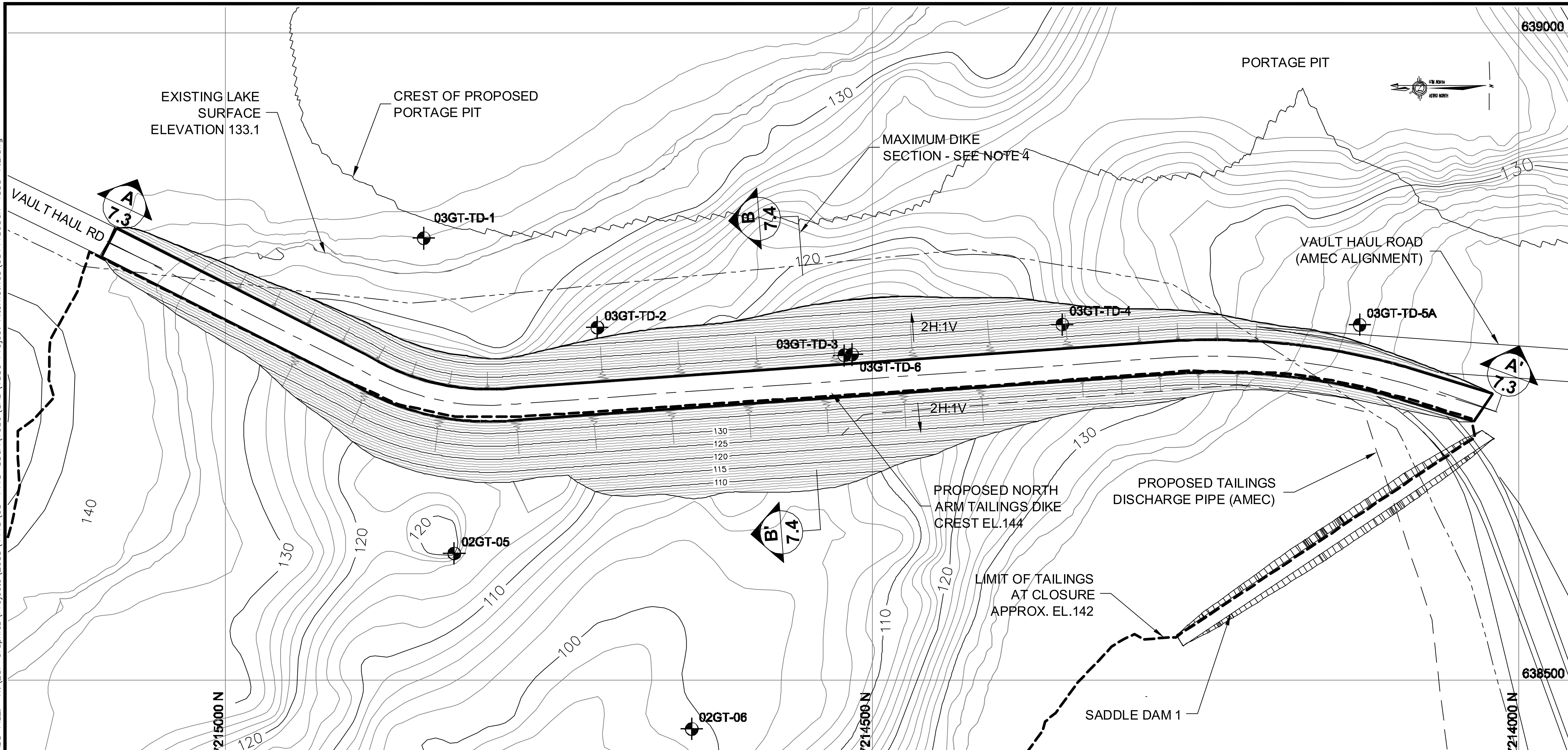
PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
**PROPOSED TAILINGS FACILITY LAYOUT**

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-7.1-1 |
| DESIGN | DAH | 10NOV03 | SCALE | AS SHOWN |
| CADD | RCR | 10NOV03 | REV. | 0 |
| CHECK | CJC | 13OCT05 | | |
| REVIEW | CJC | 17OCT05 | | |

**FIGURE 7.1**




CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-7.2.dwg

REVISION DATE: 05/10/18 2:15pm By: WLi

0 30 60 90 120 150
Scale in Meters

## NOTES

1) Contour information on land supplied by Cumberland Resources Ltd.

2) Contours below lake surface are based on bathymetric surveys by Golder Associates Ltd., 2002 and 2003.

3) Lake contours are based on surveyed lake surface elevations:
2nd Portage Lake = 133.1 m
3rd Portage Lake = 134.1 m

4) Basic Engineering Design includes 3 Alternatives for Typical Dike Section. See Figure 7.4.

5) All dimensions in metres.

6) All elevations in metres above sea level

## LEGEND

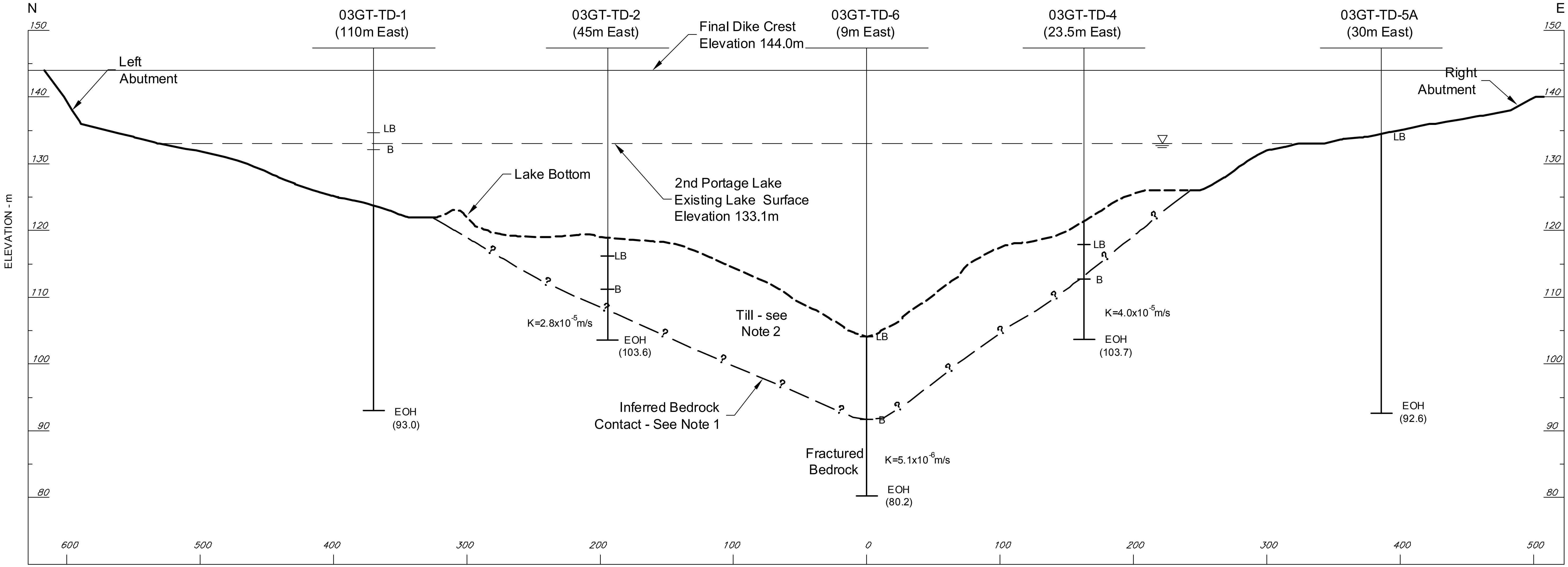
| | |
|---|---|
| 02GT-05 | Golder borehole, 2002 |
| 03GT-TD-2 | Golder borehole, 2003 |
| — — - — — | Powerline |

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
**PROPOSED TAILINGS DIKE PLAN**

| | | | |
|---|---|---|---|
| PROJECT | No. 05-1413-036A | | FILE No. 051413036A-1050-7.2 |
| DESIGN | DAH | 10NOV03 | SCALE AS SHOWN REV. 0 |
| CADD | RCR | 10NOV03 | |
| CHECK | CJC | 13OCT05 | FIGURE 7.2 |
| REVIEW | CJC | 18OCT05 | |

Golder Associates




A
7.2

## SECTION ALONG DIKE CENTRELINE

0 6 12 18 24 30

Vertical Scale 1:600

0 30 60 90 120 150

Horizontal Scale 1:3000(m)

## NOTES

1) Geological contacts are inferred. Actual contact locations are valid only at borehole locations. Variation from the inferred geological is expected between boreholes.

2) Foundation material recovered during drilling indicated a dense gravel till with cobbles and boulders. Few fines were recovered during drilling and sampling.

3) All elevations in metres above mean sea level.

## LEGEND

| | |
|---|---|
| — —?— — | Inferred Geological Contact |
| 03GT-TD-1 | Reverse Circulation Borehole Logged by Golder - 2003 |
| LB | Lake Bottom Location in Borehole Log |
| B | Bedrock Contact in Borehole Log |
| EOH (80.2) | End of Borehole at Elevation 80.2masl as Recorded in Borehole Log |

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**PROPOSED TAILINGS DIKE SITE CONDITIONS**

Golder Associates

| | | | |
|---|---|---|---|
| PROJECT | No. 05-1413-036A | | FILE No. 051413036A-1050-7.3 |
| DESIGN | DAH | 10NOV03 | SCALE AS SHOWN REV. 0 |
| CADD | RCR | 10NOV03 | |
| CHECK | CJC | 13OCT05 | **FIGURE 7.3** |
| REVIEW | CJC | 18OCT05 | |

REVISION DATE:05/10/18 1:13pm By: WLi CADD FILE: N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\1050\CAD\1300 Project Alternatives\051413036A-1050-7.3.dwg

- Golder Associates Ltd., Factual Report on Geotechnical Drilling, Hydrogeological, and Geophysical Investigations, Meadowbank Project, Nunavut Territory. 12 July 2002.

The boreholes drilled along the proposed alignment of the dike indicate the following:

- The maximum depth of foundation soil is approximately 18 m.
- The foundation soil consists of glacial till and possibly glacial outwash deposits. The till contains significant amounts of gravel, and cobbles. Based on samples collected from surface around the Meadowbank project site, the material could also contain significant silt or clay. Since water was circulated during drilling, very few fines were recovered.
- At the bedrock contact, there is a zone of highly fractured bedrock. This zone extends along most of the proposed alignment of the tailings dike.
- The zone of fractured bedrock is at least 10 m thick. None of the boreholes reached a less-fractured zone. However, based on results from drilling at nearby locations, the fractured zone may be less than 20 m thick.

In addition to the fractured surficial bedrock, the Second Portage Lake fault will underlie the tailings dike, and will cross the proposed dike alignment approximately perpendicularly. The fault is expected to be a relatively discrete structural feature, based on geotechnical drilling investigations. The hydraulic conductivity of the fault was measured as $5.1 \times 10^{-6}$ m/s.

## 7.2 DESIGN ALTERNATIVES

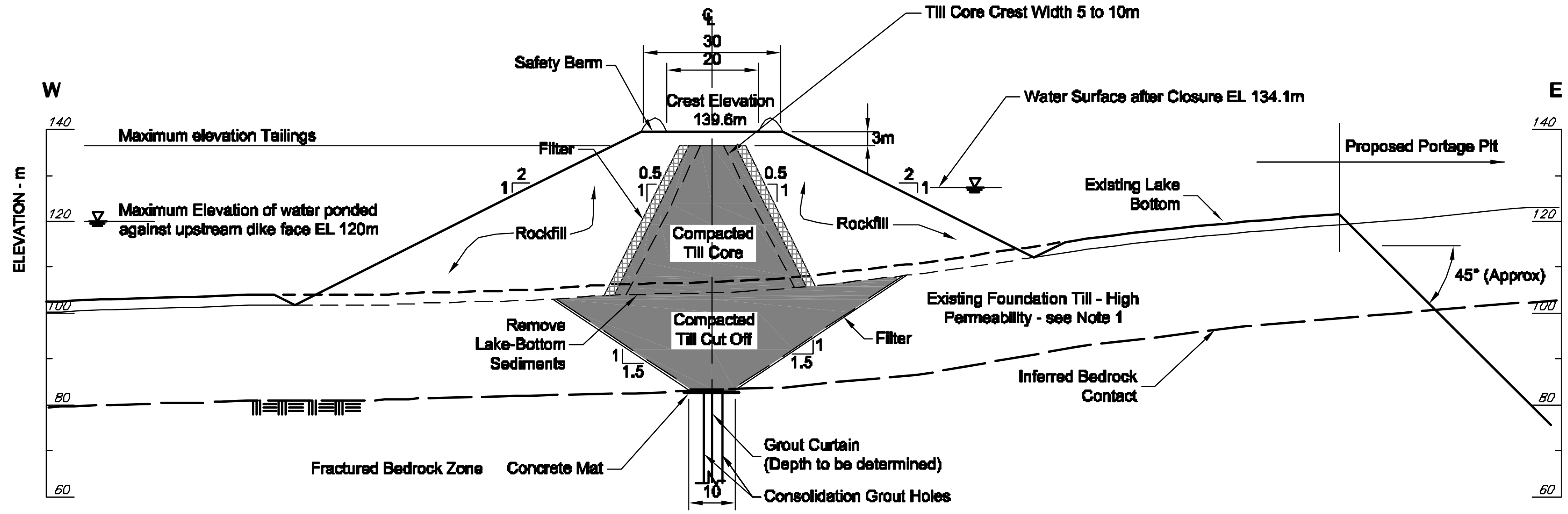
Due to the inability to recover the fine fraction of the foundation material during sampling, it is uncertain whether the in-situ till material along the alignment of the proposed tailings dike is of sufficiently low permeability and of sufficient extent to act as part of a seepage control blanket. This information might not be available until such time as the area has been dewatered. As such, three possible design cross-sections have been developed, as shown in Figure 7.4.

The first design alternative, the “full cutoff” design, includes a full cutoff through the foundation till materials to bedrock. In addition to the compacted till cutoff component, this design would include a pressure grouted curtain in the fractured bedrock.

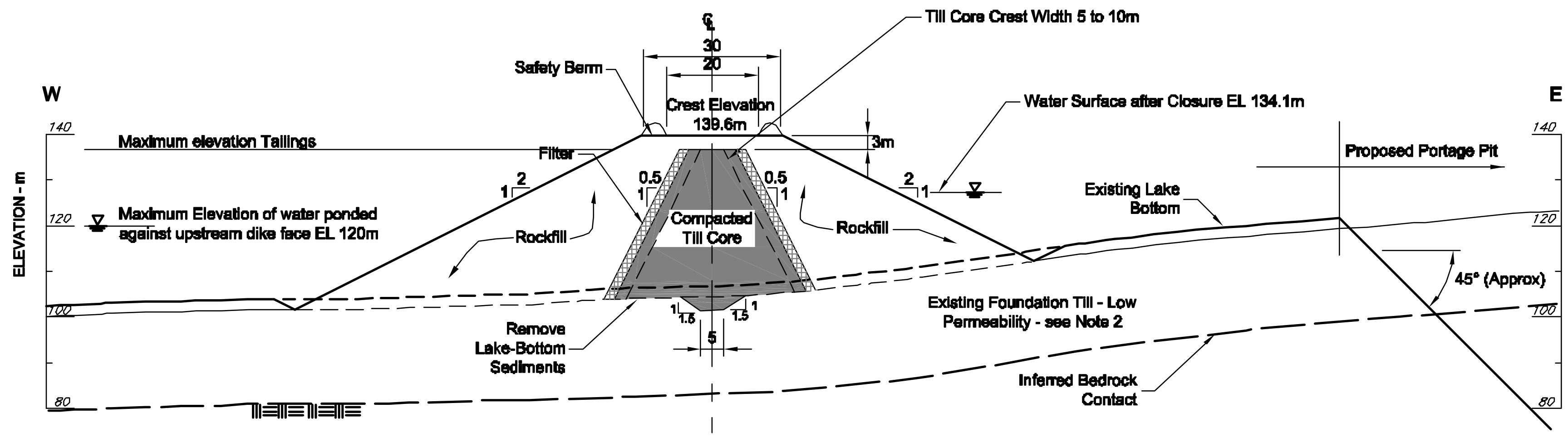
The second design alternative, the “partial cutoff” design assumes that the foundation till material has sufficiently low permeability, and is of sufficient lateral extent, that a full foundation cutoff is unnecessary. In this case, only a shallow key-in has been included in the section.

Current mine planning indicates that the north portion of Portage pit, closest to the proposed tailings dike, will be mined beginning in Year 4. Therefore, it is possible that the deposited tailings could act as a low-permeability upstream seepage blanket. This scenario was also considered in the seepage analyses.

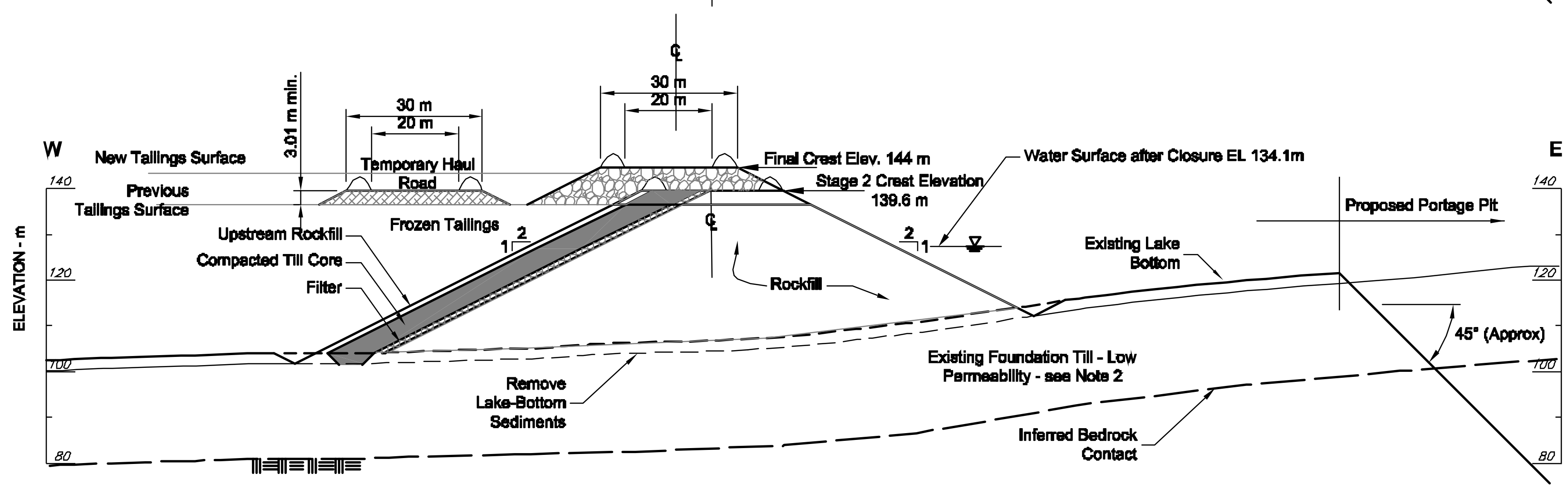
The third design alternative, “partial cutoff - alternative section,” is a modification of the partial cutoff’ design, with the seepage cutoff element (compacted till) being located on the upstream face of the embankment, overlying a full rockfill embankment structure.




SECTION - FULL CUTOFF




SECTION - PARTIAL CUTOFF




SECTION - PARTIAL CUTOFF ALTERNATIVE

## NOTES

1) Full Cutoff Design assumes that existing till material is highly permeable and requires foundation cut off structures.

2) Partial Cutoff Design assumes the existing till material is of sufficient areal extent and of sufficiently low permeability that foundation cut off structures are not required.

3) All dimensions in metres. All elevations in metres above mean sea level.

0 15 30 45 60 75
Scale in Meters

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
PROPOSED TAILINGS DIKE
DESIGN ALTERNATIVES
TYPICAL CROSS SECTIONS

Golder Associates

| PROJECT No. 05-1413-036A | | | FILE No. 051413036A-1050-7.4 |
|---|---|---|---|
| DESIGN | DAH | 10NOV03 | SCALE AS SHOWN REV. 0 |
| CADD | RCR | 10NOV03 | FIGURE 7.4 |
| CHECK | CJC | 13OCT05 | |
| REVIEW | CJC | 18OCT05 | |

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REVISION DATE:05/10/18 1:2pm By: WLi

In this case, the cross-section is similar to the partial cutoff, with similar material properties, assumptions for the foundation till materials and the seepage cutoff element. As with the partial cutoff, a shallow key-in at the toe of the upstream face is included. This alternative is considered to be feasible because the current mine plan indicates that the north portion of Portage pit, adjacent to the proposed tailings dike, will not be mined until Year 4. At the time of mining the North Portage area adjacent to the tailings dike, the tailings reclaim pond is expected to be some 200 to 300 m to the west of the dike. Consequently the tailings will then be acting as a low permeability seepage control blanket for the dike, in collaboration with the seepage cutoff element on the upstream dike face. The physical stability of the third alternative is considered to be at least equal to that of the first two alternatives, as the seepage cutoff element is no longer an integral component forming the core of the dike section, and the full dike section is constructed with coarse rockfill. The slope stability, seepage, and thermal characteristics of the structure will be assessed further in detailed engineering.

### 7.2.1 Proposed Tailings Dike Sections

The proposed full and partial cutoff dike cross-sections consist of:

- a rockfill element, constructed from run-of-mine waste rock, with the upstream and downstream faces designed at a 2H:1V slope
- upstream and downstream filter zones
- a low-permeability compacted till cutoff element, either as a core to the dike, or as an element on the upstream face
- a minimum crest width of 30 m.

Additionally, for the full cutoff design, the cross-section includes:

- a low-permeability compacted till cutoff through the foundation soil
- a pressure-grouted grout curtain through the fractured bedrock zone (at this time it has been assumed that the fractured bedrock is up to 20 m deep, based on available geotechnical drilling information along the dike alignment)

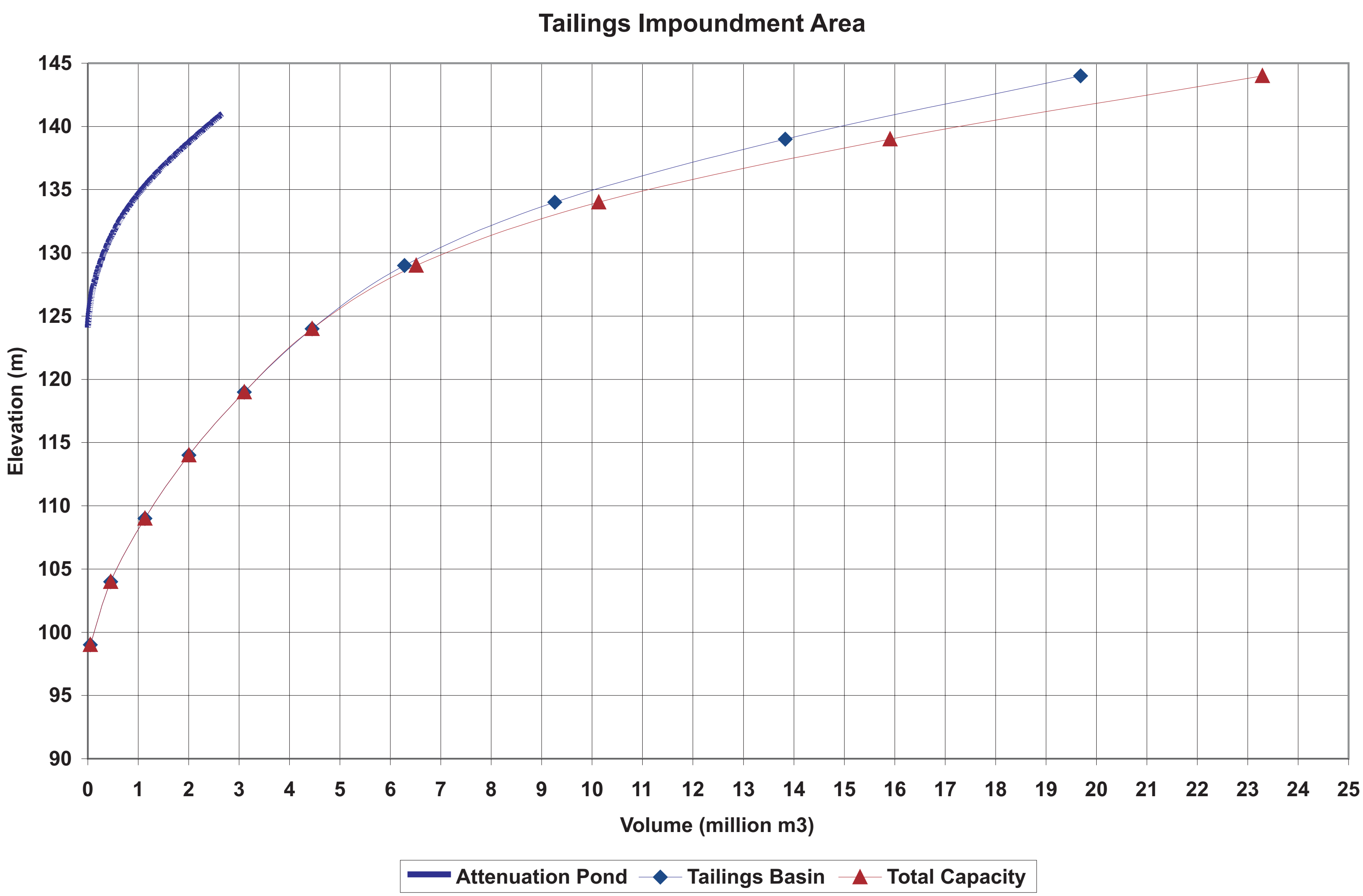
Design details for the proposed cross-sections are presented in the following sections.

### 7.2.2 Tailings Facility Design Capacity and Required Crest Elevation

The elevation of the crest of the dike has been selected to provide storage capacity for the presently known ore reserves, plus 3 m to provide freeze-thaw and traffic protection for the core.

The required capacity for storage of tailings is calculated using the total mass of tailings *(*21.9 Mt), and the predicted settled dry density (1.45 t/rn$^3$). This gives a total required volume of 15.1 Mm$^3$.

Figure 7.5 shows the storage capacity and elevation curve for the proposed tailings facility.




PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

**TAILINGS STORAGE FACILITY STAGE STORAGE VOLUME CURVE**

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | FIGURE 7.5 |
| DESIGN | CJC | 23SEP05 | SCALE NTS | REV. 0 |
| CADD | SS | 23SEP05 | **FIGURE 7.5** | |
| CHECK | CJC | 23SEP05 | | |
| REVIEW | CJC | 17OCT05 | | |

### 7.2.3 Proposed Construction Methodology

The tailings dike will be constructed under dry conditions after a portion of Second Portage Lake has been dewatered to elevation 105 m. The area will be dewatered once the East and Bay Zone dikes have been completed.

The tailings dike will be constructed to elevation 120 m in Years -2 and -1 of the mine life. Subsequently, by Year 2, the dike will be constructed to a crest elevation of 139.6 m, followed by a raise in Year 5 to a crest elevation of 144 m.

## 7.3 DESIGN BASIS & CRITERIA

Slope stability analyses were carried out for the full cutoff and partial cutoff design sections for the tailings dike. The section chosen for slope stability analyses was one that corresponds to the maximum height of the dike. The slope stability analyses were done for unfrozen conditions. If the dike and/or the foundation materials freeze, the strength of the materials would increase, and the slope stability of the dike would increase.

Stability analyses have been carried out for four stages, as follows:

- *End-of-Stage 1 Construction*: The first stage of the tailings dike would be constructed up to an elevation of 120 m. For the full cutoff design, it was assumed that the foundation soil is a permeable material. Strength of this material was assigned effective stress parameters. For the partial cutoff design, it was assumed that the foundation soil would be undrained, and the strength governed by the undrained shear strength of the material. A range of undrained strengths from 10 to 100 kPa was modelled for the foundation till to determine the minimum undrained shear strength required to achieve factor-of- safety design criteria. A potential upstream failure, through the foundation till layer, was modelled.
- *High Water Condition*: During the initial stages of mine life, water will be ponded against the upstream face of the tailings dike, at a maximum elevation of 120 masl. A potential downstream slope failure was modelled for this condition.
- *Potential Downstream Slope Failure*: This scenario was modelled for the completion of tailings deposition to an elevation of 136.6 m, consistent with the previous project objectives of a 10-year mine life and 13.7 $Mm^3$ of tailings. This condition has not been modelled for the shorter life of mine and increased tailings final surface elevation.
- *Closure*: After closure, portions of the Goose Island dewatering dike will be removed, and water will be allowed to flood the Portage pit area, up to elevation 134.1 (the elevation of Third Portage Lake surface). A possible downstream failure was modelled for this condition.

Material properties used in the analyses are summarized in Table 7.1.

*Table 7.1: Summary of Material Properties used in Slope Stability Analyses*

| Material | Unit Weight ($kN/m^3$) | Effective Stress Parameters: Cohesion, c (kPa) | Effective Stress Parameters: Angle of Internal Friction (°) | Undrained Strength Parameter, cu (kPa) | Basis for Property Selection |
|---|---|---|---|---|---|
| Till Core and Cutoff | 15.7 | 0 | 28 | n/a | Direct shear testing[1] |
| Rockfill | 18.6 | 0 | 40 | n/a | Previous experience with similar material |
| Overburden | 17 | 0 | 28 to 32 | 10 to 100 | Previous experience with material with similar grain size distribution |

**Notes: 1.** Golder geotechnical investigations. **2.** For till core material, assumed c'=0 for effective stress case.

For the Meadowbank site, the predicted PGA is 0.044 g for a seismic event with a return period of 975 years. The pseudo-static analyses have been done using a horizontal acceleration of 0.022 g. This value corresponds to one-half of the firm ground acceleration for the 1000-year return period event (USACE, 1984). The 1,000-year return period is considered appropriate, given that:

- the dike will be retaining water and tailings while personnel and equipment are working in the Portage pit
- the design life of the dike is less than 20 years.

## 7.4 SLOPE STABILITY

### 7.4.1 Results of Analyses for End-of-Construction Conditions

Slope stability analyses were carried out to evaluate the short-term, end of Stage 1 construction situation. For the full cutoff design, the foundation till material was assumed to be permeable. For the partial cutoff design, the foundation till was assumed to be undrained.

In both cases, the dike was modelled with a crest elevation of 120 m. This corresponds to the first stage of construction, to be completed in Year -1 of the mine life.

For the partial cutoff design case, the section was analyzed to determine the values of the undrained shear strength ($c_u$) which would yield factors of safety (FOS) of 1.0 and 1.3. A FOS of 1.3 is the minimum value required for the end of construction condition. A FOS of 1.0 is the value at which failure would begin to occur.

Table 7.2 presents the results of the end-of-construction conditions, and indicates that the Stage 1 dike will be stable for drained conditions with an associated FOS of 2.7.

***Table 7.2: Summary of End of Stage 1 Construction Stability Analyses***

| Condition | Strength Parameters | Minimum Calculated FOS | Required Undrained Shear Strength of Foundation Till to Achieve a FOS of 1.3 (kPa) |
|---|---|---|---|
| Drained | c', $\phi$ | 2.7 | - |
| Undrained | cu | See Note 1 | 60 to 70 |

**Notes: 1.** A factor of safety of 1.3 has been assume in order to calculate the minimum undrained shear strength of the foundation till to meet design requirements.

The analyses also indicate that, for undrained end of construction conditions, the minimum undrained shear strength of the foundation materials required to achieve a EQS of 1 .3 is about 60 to 70 kPa. The foundation soils that have been recovered during the geotechnical investigations carried out in other areas of the Meadowbank site indicate silty till material containing significant proportions of gravel and cobbles. Undrained shear strengths of this material are expected to be at least equal to or greater than 70 kPa, based on experience with similar materials at other sites. In the partial cutoff design case, undrained shear strength testing will be required during the detailed engineering design stage for the dike.

### 7.4.2 Results of Analyses for Long-Term, Steady-State Seepage Conditions

Slope stability analyses were done to evaluate the stability of the dike under long-term, steady-state seepage conditions, at three critical points in the life of the dike, and after closure. These were:

- In the early stages of mine life, free water ponded against the dike, with the water surface at approximately 120 masl. This situation was modelled under static and pseudostatic conditions.
- At the end of Year 10, deposition of tailings will be complete, and the tailings will be at their maximum elevation. This situation was modelled under static and pseudostatic conditions. This condition has not been modelled for the shorter life of mine and increased tailings final surface elevation.
- During closure of the facility, water will be allowed to flood the Portage pit side of the tailings dike. This situation was modelled under static and pseudostatic conditions.

The results of the long-term analyses are summarized in Table 7.3.

***Table 7.3: Summary of Long-Term Slope Stability Analyses***

| Failure Mode | Minimum Calculated Factors of Safety | | Yield Acceleration (g) |
|---|---|---|---|
| | Static (Minimum = 1.5) | Pseudostatic (Minimum = 1.2) | |
| High Water (Water at Elevation 120 m) | 2.0 | 1.8 | 0.21 |
| End of Deposition (Tailings at Elevation 136.6) | 2.3 | 2.2 | 0.41 |
| Closure | 4.9 | 4.3 | 0.43 |

**Notes: 1.** FOS = 1.5 is minimum specified for long-term – see Ref. 7. **2.** FOS = 1.2 is minimum specified for pseudostatic – see Ref. 7.

Based on the analyses, the dikes will be stable in the long term, for static and pseudostatic loading conditions.

## 7.5 SEEPAGE

Seepage analyses were carried out for the maximum section, for both the full and partial cutoff design cases. According to the current mining plan, the north portion of the Portage pit nearest the proposed tailings dike will not be mined until at least Year 4 of the mine life.

It is expected that seepage into the Portage pit for the "partial cutoff – alternative section" design will be similar to the partial cutoff design, with Year 3 tailings beach and reclaim pond 200 to 300 m back from the dike face. This situation was analysed considering the following:

- the foundation till is of higher permeability
- the dike cross-section includes a till core but no cutoff structures
- tailings have been deposited against the upstream face of the dike, and at a nominal slope into the impoundment
- the tailings pond is at a distance of 200 m from the face of the dike.

Material properties used in the analyses are presented in the Table 7.4.

***Table 7.4: Summary of Material Properties used in Seepage Analyses***

| Material | Hydraulic Conductivity (X $10^{-6}$ m/s) | Comments/Basis for Properties |
|---|---|---|
| Till Core and Cutoff (Cutoff is for Full Cutoff Design only) | 0.1 | • falling head tests from Dec 2002 geotechnical testing<br>• experience with materials with similar genesis and grain size distribution<br>• if till core and/or cutoff material is thawed after initial freezing, it is possible that the hydraulic conductivity of this material could increase, unless the upstream portion of the till is maintained in a frozen state. |
| Rockfill | 10,000 | |
| Foundation Till – Full Cutoff Design | 100 | • assumes material is free-draining |
| Foundation Till – Partial Cutoff Design | 0.1 | • assumes material is relatively low permeability |
| Grout Curtain – Full Cutoff Design only | 0.05 | • previous experience |
| Fractured Bedrock | 40 | • BH O3GT-TD-4 falling head packer test |
| Deeper Bedrock | 0.001 | • report on Hydrogeology Baseline Studies. |
| Tailings | 0.1 | • conservative estimate for fine-grained tailings, based on experience with similar materials, and published values (Vick 1990) |

Table 7.5 shows the seepage flux to the Portage pit west wall through the tailings dike.

*Table 7.5: Seepage Fluxes at the Portage Pit West Wall*

| Design | Flux ($m^3/s/m$) | Flow into Portage Pit (L/s) |
|---|---|---|
| Full Cutoff Design | $3.3 \times 10^{-5}$ | 26 |
| Partial Cutoff Design | $3.5 \times 10^{-5}$ | 28 |
| Partial Cutoff Design with Year 3 tailings beach (pond at 200 m from upstream dike face) | $9.0 \times 10^{-5}$ | 71 |
| Partial Cutoff Design with Frozen Core and Cutoff | $3.3 \times 10^{-5}$ | 26 |
| Full Cutoff Design with tailings beach at 100 m from upstream dike face | $1.5 \times 10^{-5}$ | 12 |

It is anticipated that the majority of the seepage flows will report to the pit dewatering system. This water would be returned to the tailings reclaim pond.

The seepage analyses show that the proposed designs are effective at controlling seepage through the tailings dike.

### 7.5.1 Tailings Dike Grout Curtain

As part of the evaluation of cutoff alternatives for the tailings dike, and to address some of the uncertainty associated with incomplete information relating to the foundation materials and the presence of the Second Portage Fault beneath the storage facility, estimates of quantities required for drilling and injection grouting and concrete cap for the full cutoff design were developed, and are presented in the following Table 7.6.

*Table 7.6: Drilling & Injection Grouting Estimates for the Tailings Dike*

| Item | Quantity |
|---|---|
| Number of Grout Curtain Holes | 800 |
| Total Drilling Length – Grout Curtain | 16,000 m |
| Volume of Grout – Grout Curtain | 1,650,000 L |
| Number of Consolidation Grouting Holes | 1,200 |
| Total Drilling Length – Concolidation Grouting | 6,000 m |
| Volume of grout – Grout curtanin | 250,000 L |

The quantities are based on the following assumptions.

- Foundation rock is characterized as highly fractured. Average conductivity from field tests is around 3 to 4 x $10^{-5}$ m/s in the upper 5 to 10 m of bedrock, which is equivalent to the hydraulic conductivity measured within the Second Portage Lake fault.

- Assume a nominal depth of treatment to 20 m in bedrock across the foundation. Note that the geotechnical drilling did not penetrate through the fractured bedrock layer.
- Estimates assume a single row grout curtain.
- Slope length along centreline of core trench: 1,200 m.
- Average hole spacing in completed curtain: 1.5 m.
- One upstream and one downstream row of consolidation grout holes.
- Average hole spacing in consolidation rows: 2 m.
- Depth of consolidation grout holes: 5 m.
- Assume 75 l/m grout admission, with 15% waste.

## 7.6 POST-CLOSURE THERMAL ANALYSES

The potential for acid generation and metal leaching from the tailings via seepage to the deep groundwater regime will be reduced by the development of a horizontally-continuous layer of frozen tailings across the tailings mass. This will limit the infiltration of air and water into the tailings.

A cover of ultramafic rock will be placed over the tailings, such that the active layer does not develop within the tailings mass, thereby limiting cryoturbation within the frozen tailings.

After closure, the tailings dike will need to act as a thermal barrier to limit the heat transfer from the lake water toward the tailings. The current analyses of the overall tailings facility predict that the tailings and the existing talik below the tailings storage facility will freeze in the long term.

A thermal model of the tailings dike was developed for the tailings dike to investigate whether the 0°C isotherm would lie within the tailings dike, or would penetrate into the tailings. Both steady-state and transient analyses were run.

### 7.6.1 Steady-State Analysis

A steady-state analysis of the post-closure dike configuration was performed using the following boundary conditions:

- Ground surface temperature = -11°C.
- Water temperature = +4°C.
- Geothermal flux at base of model = 0.05 1 W/m$^2$.

The ground surface temperature was applied over the surface of the tailings, and on the exposed portion of the tailings dike. The water table in the east side of the dike was assumed to extend horizontally through the rockfill, to the till core. Material properties used in the thermal analyses are shown in the Table 7.7.

***Table 7.7: Summary of Material Properties in Post-Closure Thermal Analyses***

| Material | Thermal Conductivity (kJ/day-m-°C) | | Volumetric Heat Capacity (kJ/m$^3$) | | Volumetric Water Content (%) |
|---|---|---|---|---|---|
| | **Frozen** | **Unfrozen** | **Frozen** | **Unfrozen** | |
| Compacted Till Seepage Cutoff Elements | 3.3 | 2.4 | 1.9 | 2.5 | 0.28 |
| Rockfill | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Foundation Till | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Fractured Bedrock | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Deep Bedrock | 3.5 | 3.4 | 2.39 | 2.4 | 0.02 |
| Tailings | 2.2 | 1.6 | 2.2 | 2.95 | 0.50 |

Figure 7.6 shows the results of the steady-state thermal analyses. The 0° isotherm is located within the tailings dike, indicating that the dike would be an effective thermal barrier between the lake and the tailings.

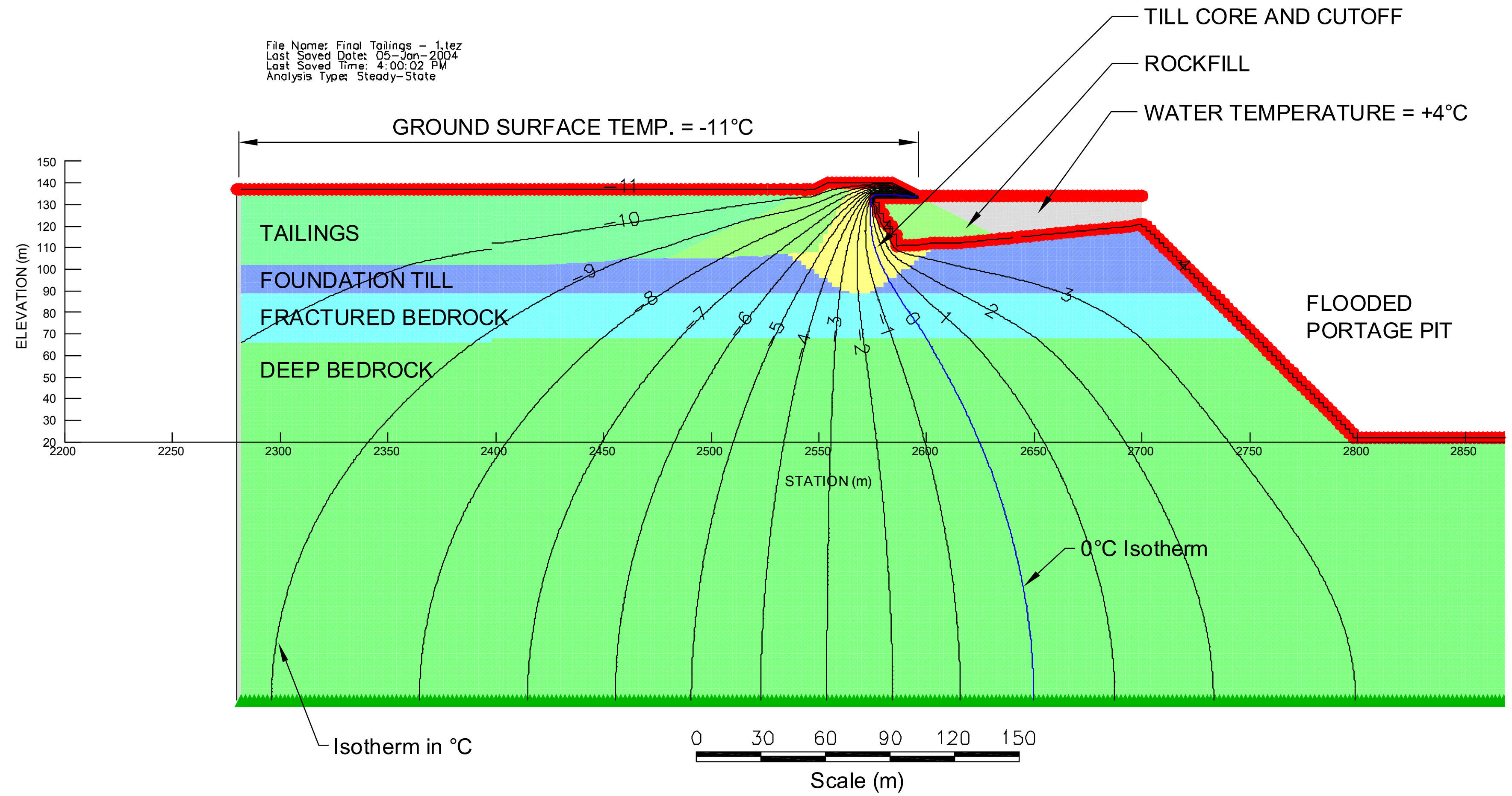
### 7.6.2 Transient Analysis

The tailings dike area was also analyzed for the transient thermal case, for:

- the case where no variation from the current climate patterns is anticipated
- the case where there will be a 5.5°C increase in average air temperature over the one- hundred years following closure of the mine.

The purpose of the transient model was to assess the potential for seasonal variations in temperature to affect the till core of the dike, particularly the top portion of the core. Given that the hydraulic conductivity of the till could increase if thawed after being frozen, it was also important to assess the potential for thawing due to climate change. The material thermal properties used in the transient analyses were the same as those used in the steady-state analysis.

Other parameters used in the analyses are shown in Table 7.8.




## MATERIAL PROPERTIES

| Material Type | Thermal Conductivity (J/sec-m-°C) | | Volumetric Heat Capacity (J/m³-°C)(x 10 6) | | Volumetric Water Content |
|---|---|---|---|---|---|
| | Frozen | Unfrozen | Frozen | Unfrozen | |
| Till Core & Cutoff | 3.3 | 2.4 | 1.9 | 2.5 | 0.28 |
| Rockfill | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Foundation Till | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Fractured Bedrock | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Deep Bedrock | 3.5 | 3.4 | 2.4 | 2.4 | 0.02 |
| Tailings | 2.2 | 1.6 | 2.2 | 2.95 | 0.5 |

## NOTES

1) Analyses done using TEMP/W TM Software.

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
POST-CLOSURE THERMAL MODELLING FULL CUTOFF TAILINGS DIKE - STEADY STATE ANALYSIS

Golder Associates

| | | | | |
|---|---|---|---|---|
| PROJECT No. | 05-1413-036A | | FILE No. | 051413036A-1050-7.6 |
| DESIGN | DAH | 23DEC03 | SCALE AS SHOWN | REV. 0 |
| CADD | RCR | 23DEC03 | FIGURE 7.6 | |
| CHECK | CJC | 13OCT05 | | |
| REVIEW | CJC | 18OCT05 | | |

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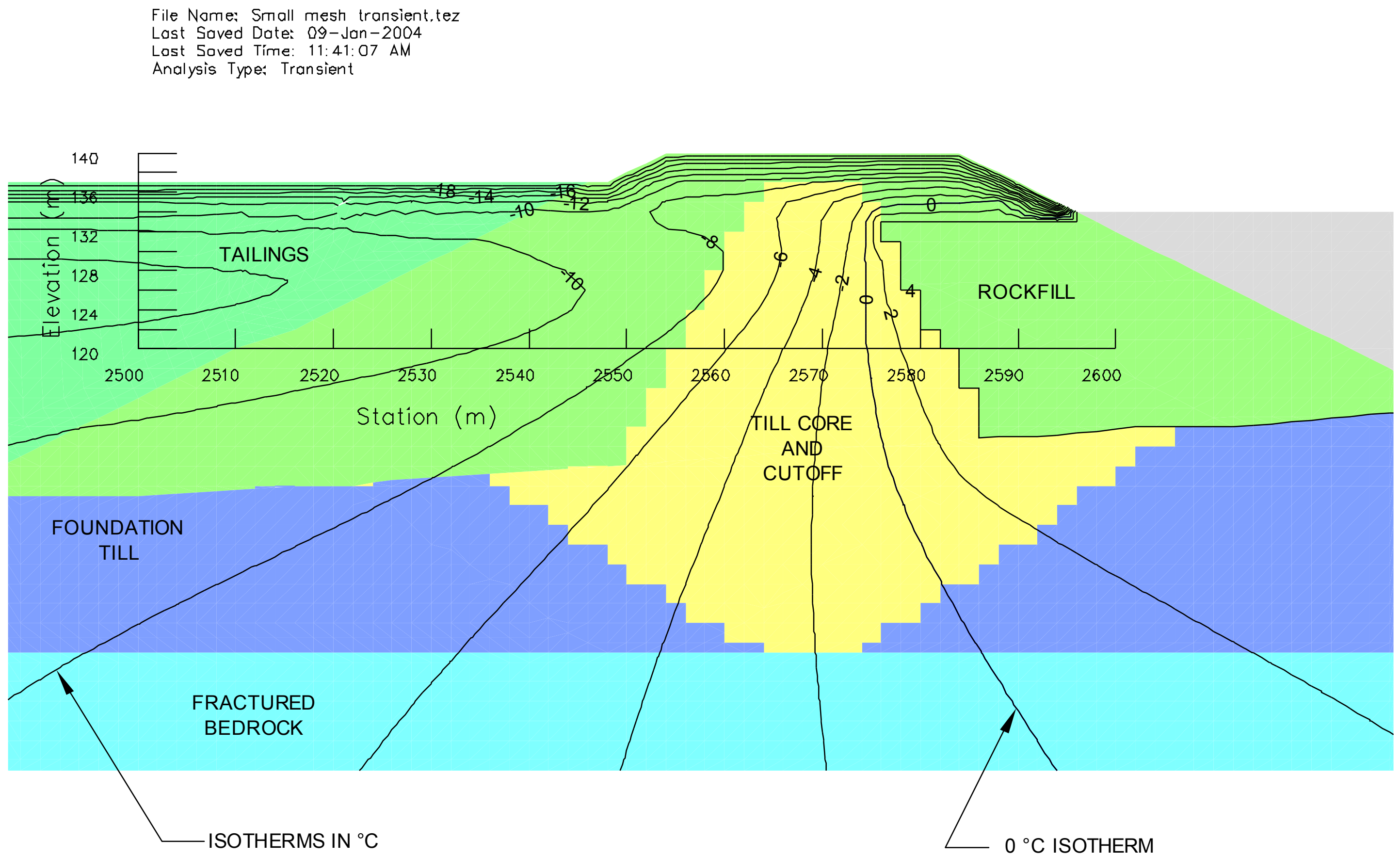
***Table 7.8: Summary of Modelling Parameters for Post-Closure Transient Thermal Modelling***

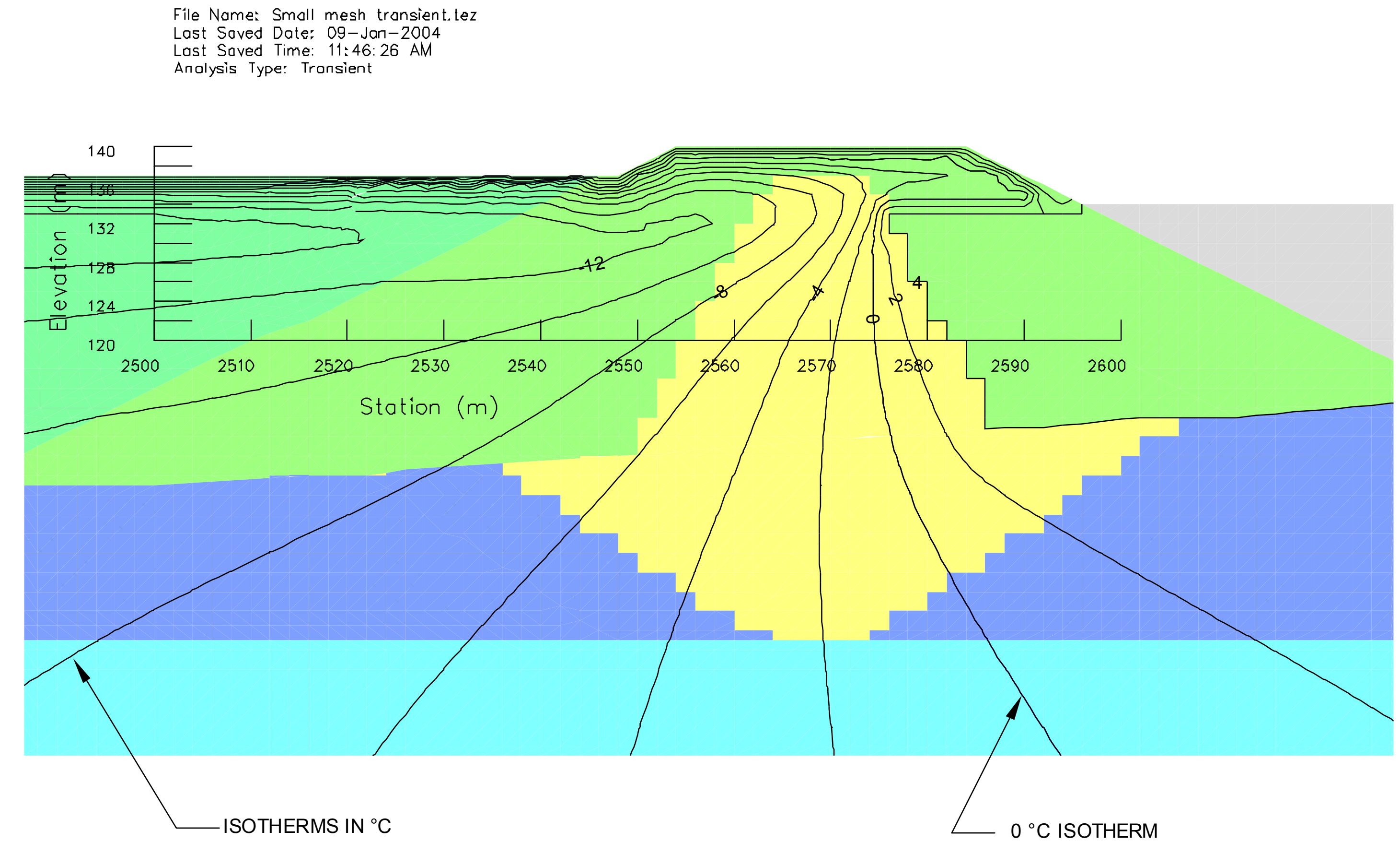
| Parameter | Conditions Used in Model |
|---|---|
| Initial Conditions | Post-Closure steady-state conditions assumed. |
| Boundary Condition Functions | • For tailings surface and exposed portion of tailings dike, a function assuming no snow cover was used.<br>• For climate change, a linear warming trend of 5.5°C over 100 years was used.<br>• A constant temperature of +4°C was used for water. |
| Time steps | Ten-day time steps used. |
| Total duration of modelling | Ten years for transient modelling not including climate change. Duration chosen to be sufficient to allow stabilization of 0°C isotherm below active layer.<br>For climate change, 100 years was used. |

Figure 7.7 summarizes the results of the transient thermal modelling without including for climate change, and shows the isotherms for January and August. Figure 7.8 shows the results for the transient thermal modelling including the effects of climate change.

The figures indicate that the active layer does not penetrate into the till core, and the till core will remain frozen.




**THERMAL REGIME IN JANUARY**




**THERMAL REGIME IN AUGUST**

**MATERIAL PROPERTIES**

| Material Type | Thermal Conductivity (J/sec-m-°C) | | Volumetric Heat Capacity ($J/m^3$-°C)(x $10^6$) | | Volumetric Water Content |
|---|---|---|---|---|---|
| | Frozen | Unfrozen | Frozen | Unfrozen | |
| Till Core & Cutoff | 3.3 | 2.4 | 1.9 | 2.5 | 0.28 |
| Rockfill | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Foundation Till | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Fractured Bedrock | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Deep Bedrock | 3.5 | 3.4 | 2.4 | 2.4 | 0.02 |
| Tailings | 2.2 | 1.6 | 2.2 | 2.95 | 0.5 |

0 5 10 15 20 25
Scale in Meters

## NOTES

1) Analyses done using TEMP/W ™ Software.
2) All dimensions are in metres. All elevations in metres above sea level.

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
**POST-CLOSURE THERMAL MODELLING FULL CUTOFF TAILINGS DIKE - TRANSIENT ANALYSES**

Golder Associates

| PROJECT No. 05-1413-036A | | FILE No. 051413036A-1050-7.7 |
|---|---|---|
| DESIGN | DAH | 23DEC03 |
| CADD | RCR | 23DEC03 |
| CHECK | CJC | 13OCT05 |
| REVIEW | CJC | 18OCT05 |

SCALE AS SHOWN REV. 0

**FIGURE 7.7**

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By: WLi

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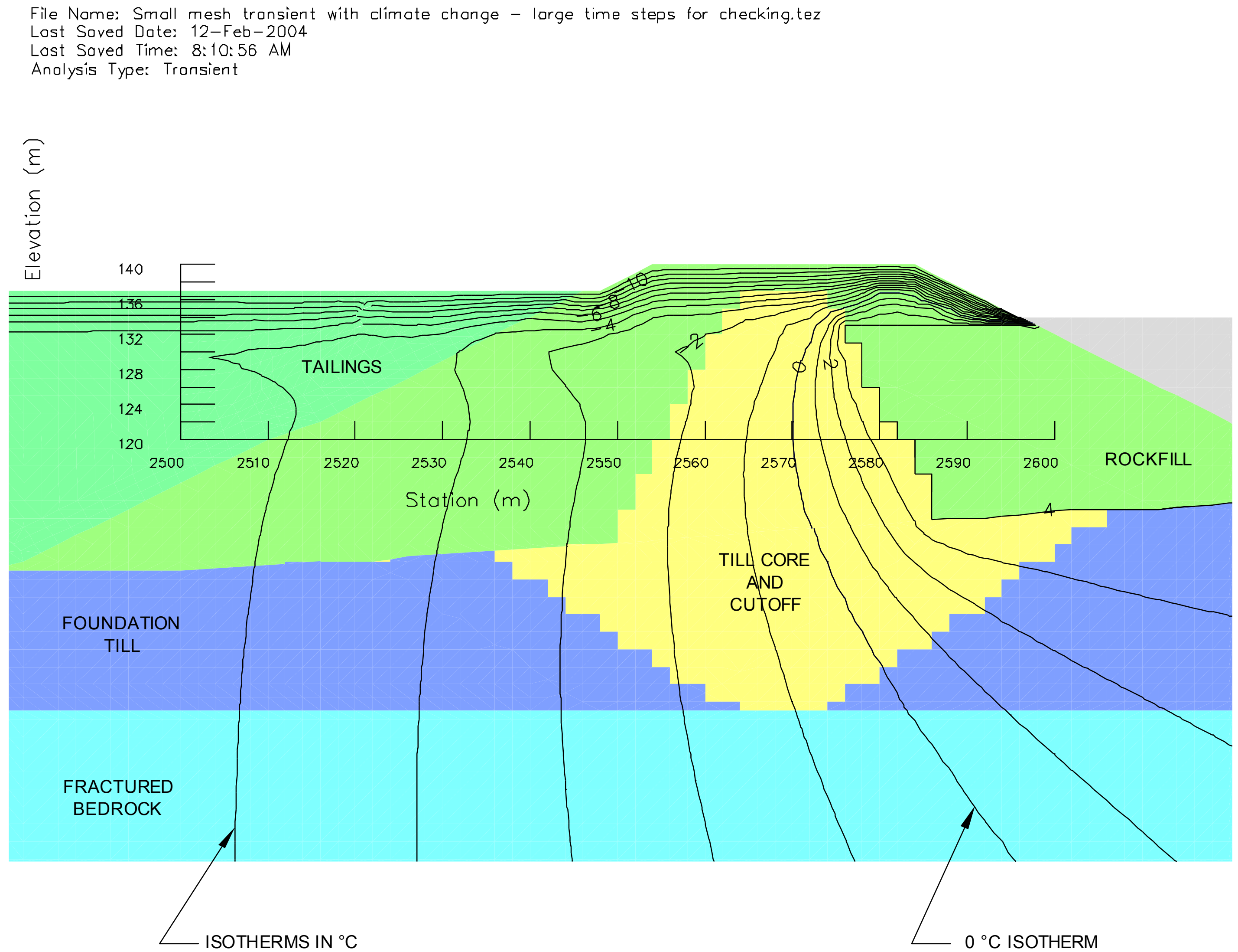
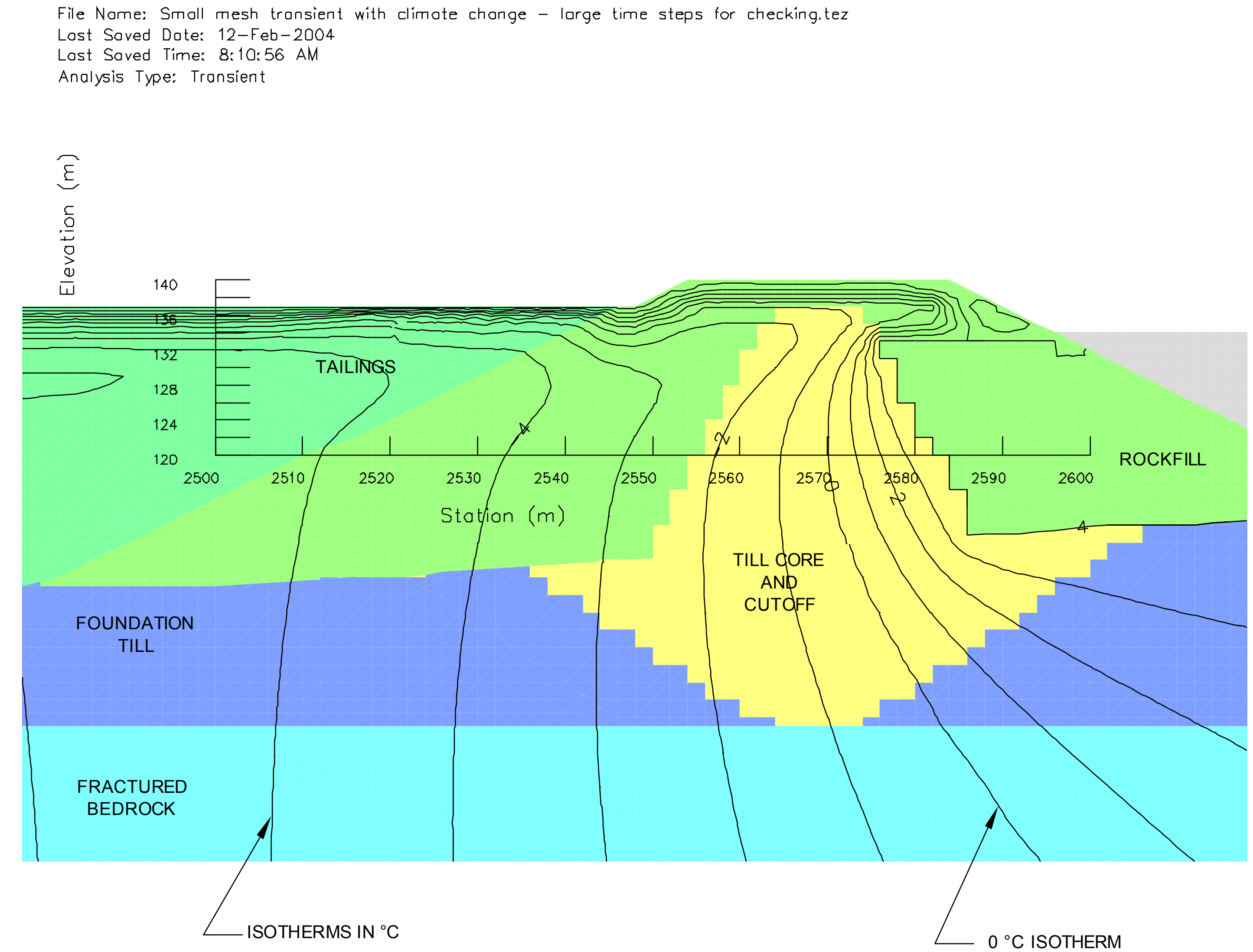



**CLIMATE CHANGE YEAR 100**
**JANUARY**




**CLIMATE CHANGE YEAR 100**
**AUGUST**

**MATERIAL PROPERTIES**

| Material Type | Thermal Conductivity (J/sec-m-°C) | | Volumetric Heat Capacity (J/m³-°C)(x 10 6) | | Volumetric Water Content |
|---|---|---|---|---|---|
| | Frozen | Unfrozen | Frozen | Unfrozen | |
| Till Core & Cutoff | 3.3 | 2.4 | 1.9 | 2.5 | 0.28 |
| Rockfill | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Foundation Till | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Fractured Bedrock | 3.3 | 2.8 | 2.4 | 2.6 | 0.12 |
| Deep Bedrock | 3.5 | 3.4 | 2.4 | 2.4 | 0.02 |
| Tailings | 2.2 | 1.6 | 2.2 | 2.95 | 0.5 |

0 5 10 15 20 25
Scale in Meters

## NOTES

1) Analyses done using TEMP/W TM Software.
2) All dimensions are in metres. All elevations in metres above sea level.

PROJECT
CUMBERLAND RESOURCES LTD.

TITLE
POST-CLOSURE THERMAL MODELLING
FULL CUTOFF TAILINGS DIKE - TRANSIENT ANALYSES
INCLUDING CLIMATE CHANGE EFFECTS

Golder Associates

| PROJECT No. 05-1413-036A | | FILE No. 051413036A-1050-7.7 |
|---|---|---|
| DESIGN | DAH | 10FEB04 |
| CADD | SRR | 10FEB04 |
| CHECK | CJC | 13OCT05 |
| REVIEW | CJC | 18OCT05 |

SCALE AS SHOWN REV. 0

**FIGURE 7.8**

# SECTION 8 • PROCESS SELECTION

## 8.1 GOLD RECOVERY

Comparative scoping level capital cost estimates were developed for three process flowsheet options based on a plant throughput of 7,500 t/d:

- Base Case – whole ore leaching
- Option 1 – flotation concentrate leach
- Option 2 – flotation concentrate and tailings leach.

The trade-off study indicated that the Meadowbank deposits are more economically amenable to whole ore cyanidation than to the more-complex bulk sulphide flotation and concentrate cyanidation flowsheet used in the prefeasibility study. Subsequently, whole ore cyanidation was selected as the basis for the current feasibility study. A simplified flow diagram is shown in Figure 8.1.

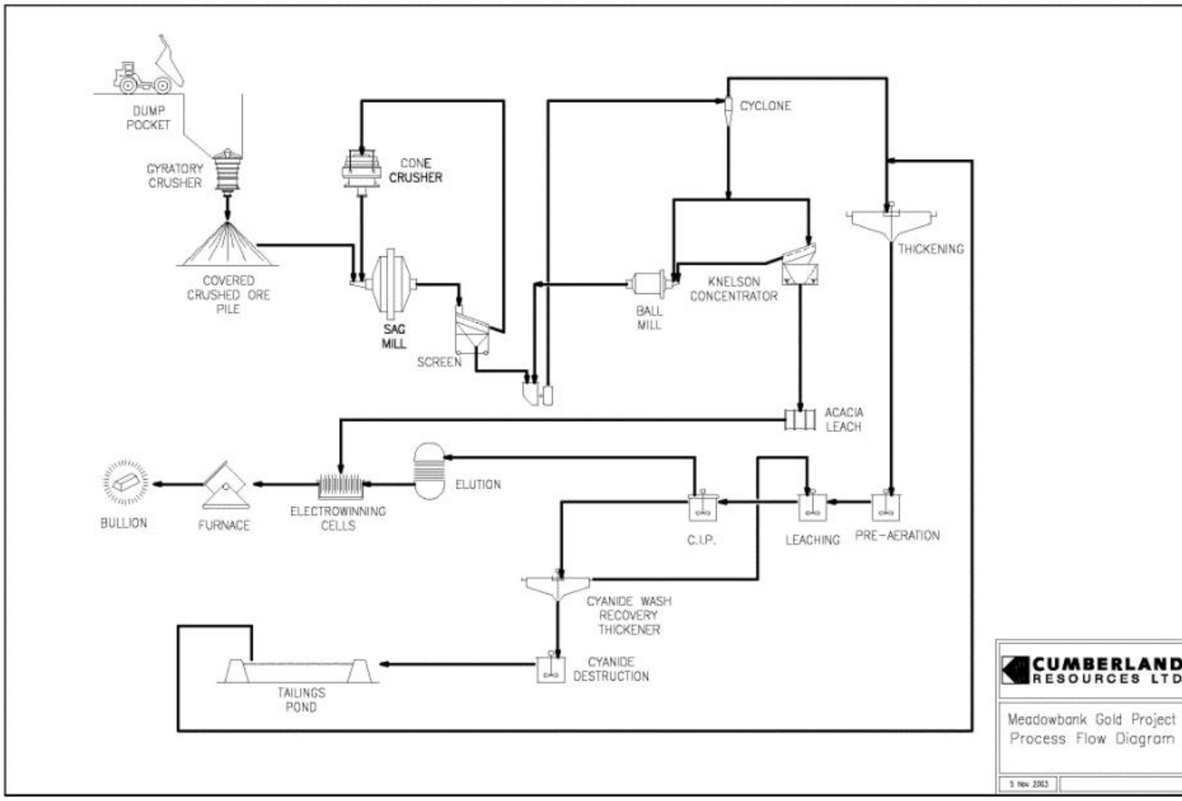
The selected gold recovery process uses a traditional cyanide leach process, which generates a cyanide concentration of approximately 200 mg/L cyanide in solution, following the recovery of precious metals. The cyanide content of the process solutions will be reduced to approximately 2 to 5 mg/L using a patented INCO $SO_2$/air process. Because of the short- to mid-term residual reactivity resulting from the destruction process, solutions from cyanide destruction cannot be recycled immediately. The process solutions must be aged for complete cyanide destruction and to reduce chemical oxygen demand. The aging process is expected to require up to two months in a natural setting, a timeframe consistent with those at other gold processing operations that use this approach. The large inventory of solution will also provide a form of “chemical inertia” to the recirculating process water chemistry and reduce the impact of variable sulphide mineralogy within the mined ores. It has been shown that changes in solution chemistry can affect the overall extraction of gold from the ores, owing to the presence of oxidation products from the sulphide mineral phase when present in high concentrations.

## 8.2 TAILINGS PROCESSING

Three scenarios were considered for the deposition and storage of ground tailings from the gold recovery and cyanide recovery processes:

- filtering out the process tailings solids and stacking the resulting filter cake into tailings piles
- thickening/filtering the tailings slurry to a very high density, disposing of the resulting slurry without solution recovery, and recycling the filtrate solutions
- directly placing the tailings slurry either subaerially or subaqueously within an impoundment to permit solids to settle and process solutions to decant for re-use.

***Figure 8.1: Simplified Flow Diagram for Proposed Meadowbank Process***




In all three scenarios, a pond of process solution would need to be maintained to provide sufficient aging and volumes of stored process water. In the third option, process solids and process solutions would be stored within the same facility. In the first two options, the solids would be placed and stored separately from the process solutions; the impact on closure would be far greater than for the combined placement concept in option 3 because of the space required for the separate types of storage.

The option of combined tailings solution and solids placement has been selected for the feasibility study. The process would operate at a solids concentration of 45% to 55% (by weight), which corresponds to the product stream from the gold recovery plant. Recycling the solutions will allow for management of water quality within the process and minimize the impact of any process solution spillage on the surrounding surface and groundwater.

## SECTION 9 • WATER MANAGEMENT & TREATMENT

A staged water management strategy has been designed for the Meadowbank project (central Portage mining area) based on the use of Second Portage Arm (see Figure 9.1) for the tailings storage facility. Initially, the eastern end of Second Portage Arm will be used for tailings discharge, the central area will serve as a reclaim pond, and the western end will be used as a stormwater attenuation pond until Year 5. After Year 5, mining of the Goose Island pit will be complete, and the pit will be operated as the attenuation storage facility. The former attenuation storage facility at the northwest end of Second Portage Arm will be used to manage reclaim water. At the end of mining, the process plant will be converted to water treatment, and the remaining water in the reclaim pond will be treated and released.

A site-wide water balance has been developed to evaluate the interaction between the various mine components as these relate to water consumption and use. The water balance allows the evaluation and prediction of water requirements for the mill process, tailings pond, re-watering of the open pits at closure, among other considerations. The model takes into account average annual climate data as well as predicted storm events to allow the appropriate sizing of water storage and conveyance structures. In the long term, the water balance model will be used to assess the predictions made for the mine during the feasibility studies against actual site conditions experienced during operations. This will allow appropriate mitigative measures to be identified at an early stage if it becomes apparent that alterations to the mine water management plan are required.

The type of treatment will depend on the quality of water to be discharged. Preliminary analysis indicates that levels of dissolved copper, zinc, and nickel may be elevated and need to be removed through a lime treatment process. Another possibility is to collect the storm runoff water separately and pump it to Third Portage Bay, west of the plant site, after Year 6 to serve as a settling pond. Having no contact with the tailings slurry or reclaim water, the runoff water may not need to be treated before discharge, reducing capital and operating costs. Further laboratory testing is required before design is finalized.

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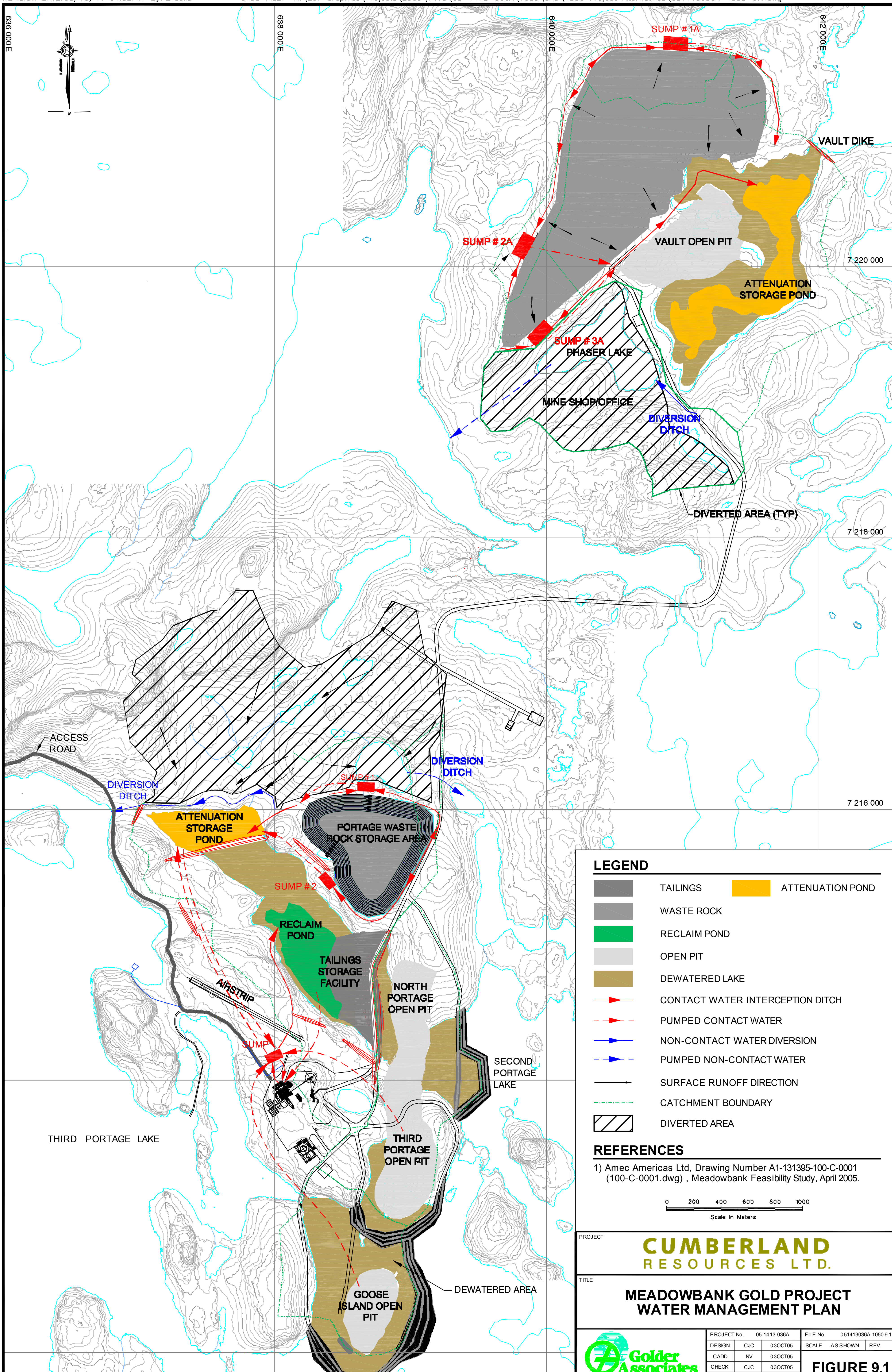


## SECTION 10 • WORKFORCE CONSIDERATIONS

The Meadowbank project is being planned as a fly-in/fly-out mining operation, similar to other northern mines such as Lupin, Diavik, Ekati, and Polaris. On-site accommodations will be provided for approximately 250 people on bi-weekly rotations. Personnel will be transported to and from site by air service. The community of Thompson, Manitoba, is currently considered the point of origin for personnel based in the South and for air freight. Some smaller aircraft may be used to transport mine personnel residing in local northern communities where suitable commercial air service is not available.

Negotiations for the Inuit Impact and Benefit Agreement (IIBA) are ongoing and address some of the following opportunities:

- jobs
- training
- preferential hiring programs
- project financing
- new business and contract arrangements
- participation in monitoring activities and dispute resolution.

To the extent that workers can be hired from the local population, fly-in/fly-out arrangements could be scaled back. During the 2002 field season, Cumberland was one of the largest private employers in Baker Lake, with local residents comprising 54% of the project's workforce. Similar employment averages have been maintained since 1995, when exploration activities began.

## SECTION 11 • ENERGY SOURCES

Typically and traditionally, remote northern mining projects use on-site, diesel-generated power for electrical supply unless they are close to a grid supply (within 100 km). This is usually based on considerations of proven technology, reliability, cost, and practicality. In the case of the Meadowbank project, the nearest grid is far to the south. Power for the community of Baker Lake itself is in fact supplied from diesel generators.

Other recent projects in northern Canada have considered wind, solar, and hydrogen fuel cell technologies but have found them to be lacking, even as supplemental sources to reduce diesel consumption and attendant air emissions. Alternative energy sources are briefly discussed below.

### 11.1 WIND POWER

This technology generally involves relatively high capital costs and is only effective under very specific wind conditions. The key parameter is sustained average wind speed: speeds above 8 m/s are deemed excellent and those below 4 m/s unacceptable. Wind speed at the Meadowbank site is variable and averages 4.8 m/s annually to a height of 10 m above the ground and slightly greater above 10 m (note that “average” is not necessarily “sustained”). At Baker Lake, the average wind speed is 5.9 m/s.

Wind power offers no significant economic advantages for the Meadowbank project because the variable wind speeds would not meet the steady demand of the process plant and related facilities. The only gains would be small reductions in air emissions associated with a limited wind power installation to supplement diesel-based power generation.

### 11.2 SOLAR

Conversion of solar radiation to electrical power or for use in direct heat exchange tends to be expensive and to have minimal benefit in winter months. Some limited use of solar heat exchange for building heating may be feasible in the spring and fall. This could be investigated during detailed design if the other anticipated sources of waste heat prove to be unavailable or inadequate.

### 11.3 HYDROGEN

Although hydrogen fuel cells are emission free, the technology is not yet proven and the costs are very high, particularly for remote sites. In addition, an economic source of hydrogen would need to be identified.

### 11.4 HYDROELECTRIC POWER

In spite of the potential advantages to the project of this type of power supply, no suitable site has been identified for the establishment of hydroelectric power-generating facilities.

## 11.5 OPTIONS TO REDUCE POWER CONSUMPTION

The project is designed to limit power use, diesel consumption, air emissions, and costs. Design concepts to further these objectives are listed below.

- use glycol heat exchangers to convert heat extracted from the diesel generating sets for heating buildings
- heat the process plant complex with excess heat generated by the process equipment
- minimize power losses and waste by using automated power plant management controls
- generally use high-efficiency electric motors
- use high-efficiency lighting such as metal halide lamps
- monitor and control building heating.

These and other refinements will be adopted as detail design proceeds.

# SECTION 12 • TRANSPORTATION

Cumberland has considered various options for shipping project consumables to site. These materials will consist predominantly of diesel fuel and process supplies such as steel and reagents. Transport alternatives all generally consist of shipping during summer months from southern ports to a location in the vicinity of Baker Lake, as well as overland via an all-weather road to site (see Figure 12.1).

## 12.1 SUMMER SHIPPING OPTIONS

The prefeasibility study evaluated shipping options from eastern ports and also from southern railheads. Four options were considered and compared:

- *Deception Bay* – Use nickel ore carriers from the Raglan project to backhaul supplies, with transshipment at Deception Bay and onward shipment by tug and barge to Baker Lake. This option was not deemed suitable by the shipping companies that were approached for options and pricing.

- *Rankin Inlet* – Use a deep-sea shipping service from eastern ports to a future common user dock and storage facility at Melvin Bay, with tug and barge shipment to Baker Lake. This option was discounted because there is no firm indication that the required facility would be built in time to service the project.

- *Chesterfield Inlet (Schooner Harbour)* – Use deep-sea shipping to an anchorage in Schooner Harbour with lightering up Chesterfield Inlet by tug and barge. This would be less efficient and cost effective than direct barge shipment to Baker Lake because no trans-shipment facilities are available, and Chesterfield Inlet is distant (approximately 170 miles east) from Baker Lake.

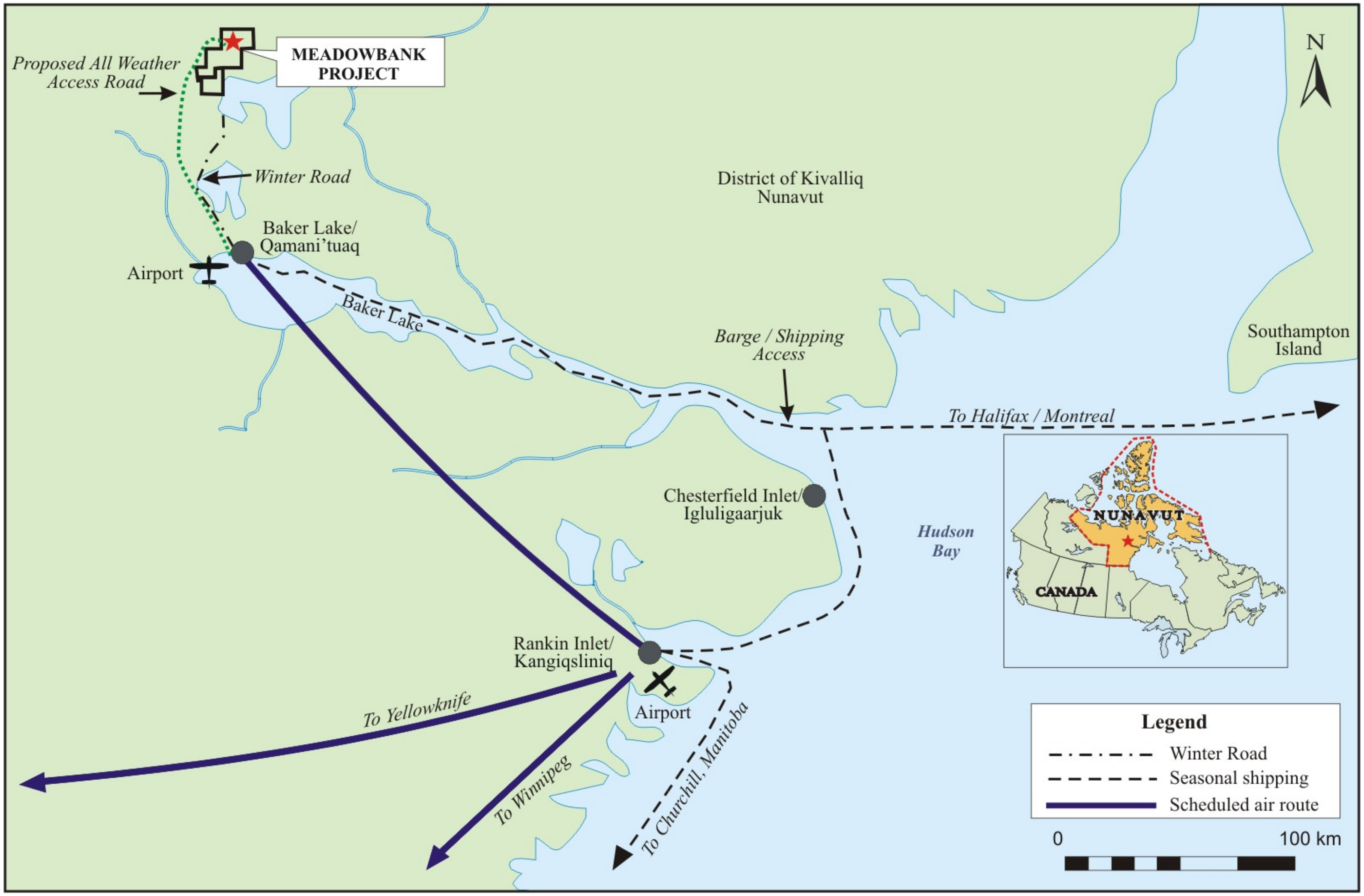
- *Direct Tug & Barge Service* – Use a 6,000 to 8,000 DWT barge from Montreal or Halifax through Chesterfield Inlet to Baker Lake. At high water, a barge should be capable of carrying about 6,000 tonnes of cargo safely through the most constrained part of the inlet. Chesterfield Inlet is a 124 mile long, salt-water channel typically used by shallow draft barges and small vessels but not by deep-sea vessels. Depending on the type of vessel used and whether it is ice-strengthened, the shipping season ranges from about 2.5 months to 4 months.

Based on the pricing and equipment availability enquiries conducted for the prefeasibility study, direct shipping using adapted tug and barge equipment is considered the best option for the project.

## 12.2 ACCESS ROAD

Initial selection annual re-supply requirements at the mine site are estimated to be 20,000 to 30,000 tonnes, including 10,000 to 15,000 tonnes of process and mining consumables (reagents, tires, lubricants, mill steel, explosives). Options for haulage during winter from temporary storage at Baker Lake were investigated by soliciting budget quotes from experienced northern logistics companies. Two fundamental options are evident:

***Figure 12.1: Marine & Overland Transportation Options***



- use of tractor-trailer units on a maintained ice road or permanent all-weather road
- all-terrain tracked or low-pressure-tired equipment towing trailers or sleds.

The feasibility evaluation of the project considered the following alternative access options to the project:

- an ice road
- a seasonal land road
- a permanent all-weather road.

These are discussed in the following sections. Based on the feasibility evaluation of the alternatives, the preferred option is the permanent all-weather access road.

## 12.3 ICE ROAD

Tractor-trailers have been used to haul large volumes of freight and fuel over ice roads to service several large during construction projects and operations. For example, Robinson Enterprises Limited hauled more than 100 ML of fuel and 20,000 tonnes of dry goods over ice roads in 1997. Conventional trucks have been used for winter road haulage out of centres such as Yellowknife for several decades; these haulage fleets demobilize each season for southern use.

In 1993 and 1994 an experimental winter road was constructed between Rankin Inlet and Arviat. Maintaining driveable conditions was found to be very difficult because of snow drifting. Consequently, concern has been expressed that winter road construction and operation between Baker Lake and the Meadowbank site may not be feasible given the commonly inclement winter conditions. Balloon-tired, all-terrain articulated trucks have been used successfully in the vicinity of Baker Lake for the last 20 years or so, and have the advantage of not requiring a cleared roadway. While these vehicles are slower and considerably more expensive to purchase, minimal additional equipment and effort is needed to form and maintain a trafficable trail.

Two transportation contractors provided detailed plans and pricing for operating tractor-trailers or a fleet of all-terrain trucks over a conventional winter road, both following the same route from Baker Lake to Meadowbank. In both cases, the transportation fleet would remain captive at Baker Lake from year to year. The comparison is detailed in Table 12.1.

*Table 12.1: Tractor-Trailer vs. All-Terrain Vehicle Operations – Winter Road*

| Aspect | Tractor-Trailer | All-Terrain Vehicle | Comment |
|---|---|---|---|
| Technical | 28 day preparation and 75 day haulage | 135 day haulage season | Tractor-trailer option requires support fleet, so shorter season is desirable to reduce operating costs |
| | Method well precedented at planned scale | Little precedent at planned scale | No fundamental reason for ATV not to succeed |
| | Experienced companies available and credible | Local operators need to build infrastructure and demonstrate management capability | 2004 advanced exploration will test ATV and locally based operator further |
| Cost | Similar within 10% | | Comparable to other projects/estimates |
| Environmental | Quote based on building snow/ice base over portages | Same approach | No permanent roadway construction across portages |
| | Risk of accidents and spills may be higher due to higher speed | Risk of mishaps/spills due to operation in poor visibility difficult to quantify but considered significant | Likely to be mitigated through good training and management for both options |
| | Shorter season may reduce effects on terrain | Longer period to mid-May may affect thaw and vegetation response | No reported effects of limited ATV operations in recent years |
| | Uses ½ the fuel of alternate | Uses 2 times the fuel of alternate | May be a significant difference in air pollution |
| | Wide roadway likely affects/influences fauna movements | Narrower, somewhat less distinct track may have less adverse impact on fauna | |
| Community | Fewer work-hours | More work-hours, longer period of winter operations | |
| | Smaller proportion of local labour hire | Relatively high use of local labour | Both depend on availability of trained staff |
| Regulatory | Likely more regulatory process required to permit | Local operator possesses permit for current level of ops; may be easier to scale up | Cumberland must verify PEL claim that sufficient permitting is in place for full scale operation |
| Overall Benefit | Less employment and less synergy with current methods of transport in region | Higher employment and more synergy | Assumedoverall cost is similar for both quotes at current level of accuracy |

Currently, an ice trail is used to service the project site from approximately January to May over a period of approximately 122 days. The practical period of use, accounting for white-out conditions, is estimated to be about 90 days. A seasonal ice road would have a limited and low environmental impact. However, there would be risks associated with the transport of fuel and other chemicals required for the mining project in the event of an accident on the ice. Based on the present project requirements, the shipment schedule will require the acquisition of at least 23 Foremost Delta 3 all-terrain transport units to complete the transport activities within the prescribed safe operating period for the winter ice road. Due to the required fleet size, and associated risk, the ice road alternative is not considered to be a viable alternative.

### 12.4 SEASONAL LAND ROAD

As an alternative to the winter ice road, preliminary consideration was given to provide a seasonal land road to maximize the safe operating period up to the observed freezing period of 243 days from October 1 to May 31 each year. Although the observed freezing period is approximately 243 days, travel along the route would be unlikely before November of each year to allow sufficient frost penetration into the soils to carry the applied loads. Therefore, the operational period for this alternative would be on the order of about 213 days, not accounting for white-out conditions. A seasonal land road access will be limited to operate during extended seasonal frozen ground conditions and not operate during seasonal thaw conditions, spring freshet or summer stream flow periods.

It is envisaged that a seasonal land road would require some local ground improvement using materials available along the route, but water course crossing structures would not be constructed. A preferred seasonal land route would limit water course crossings to locations having less than 2 m of water, and would not require the construction of bridges or culverts as travel would only be during frozen conditions. Therefore, seasonal land road access will be limited to operate during extended seasonal frozen ground conditions and not operate during seasonal thaw conditions, spring freshet or summer stream flow periods.

Advantages of a seasonal road are:

- reduced fuel storage requirement at Meadowbank
- reduce number of haul units required
- use more economical conventional haul units instead of costly ATVs
- reduced transport costs Baker Lake to Meadowbank
- reduced construction equipment rental costs
- reduced environmental impact risks by not hauling fuel and reagents on ice surface
- unlimited load weight capability
- increased reliability for the delivery of supplies.

It is understood that the seasonal land route will not consider the use of thaw stable road embankments and water crossing structures. Thaw settlement should be expected for thin embankment fills constructed over soft subgrade soils or organic deposits. It is envisaged that a typical road structure for a capital cost-effective season land road will be less than a permanent all-weather road. However, the season land road will require more operational maintenance, particularly during the seasonal thermal transition periods.

## 12.5 ALL-WEATHER LAND ROUTE

As an alternative to the winter ice road and seasonal land road, consideration was given to a permanent all-weather access road. The all-weather access road would require the construction of bridge structures for water course crossings.

Construction of an all-weather land road will require the development of suitable borrow deposits and rock quarries along the route for the preparation of the sub-base and for surfacing materials. The travel surface would be 10 m in width and nominally 1.5 m in height above the original ground to preserve permafrost in the sub-grade. Surfacing would be crushed 3" minus rock. The bridges would be single-lane prefabricated logging road style structures supported on rock fill cribs.

Advantages of an all-weather road are:

- reduced laydown area required at Baker Lake
- reduced explosives and reagent storage at Baker Lake
- reduced fuel storage requirement at Meadowbank
- reduced transport fleet required
- reduced capital cost of transport fleet using conventional tractor trailer units instead of ATVs
- reduced freight costs Baker Lake to Meadowbank
- reduced equipment rental costs
- rapid delivery of critical spares (air freight to Baker Lake then overland transport)
- reduced risk of fuel and reagent spills on lake ice
- greater reliability of freight delivery schedules
- reduced airstrip length at Meadowbank
- enhanced alternate medivac capability
- reduced impact on permafrost in comparison to seasonal road effect.

## 12.6 PREFERRED ALTERNATIVE

Based on environmental, technical, and economic considerations, the all-weather land route is the preferred alternative.

Once the preferred alternative was defined, an additional evaluation of routing alternatives was undertaken.

## 12.7 PERMANANT LAND ROUTE ALTERNATIVES

Once the preferred access method was decided on, three alternative land routes were identified and evaluated for consideration within an access route corridor ranging between about 5 and 25 km wide.

Their general location relative to the winter ice road, estimated route length, and number of water crossings are summarized in Table 12.2 and are shown on Figure 12.2.

***Table 12.2: Comparison of All-Weather Road Alternatives – Location, Length & Water Crossings***

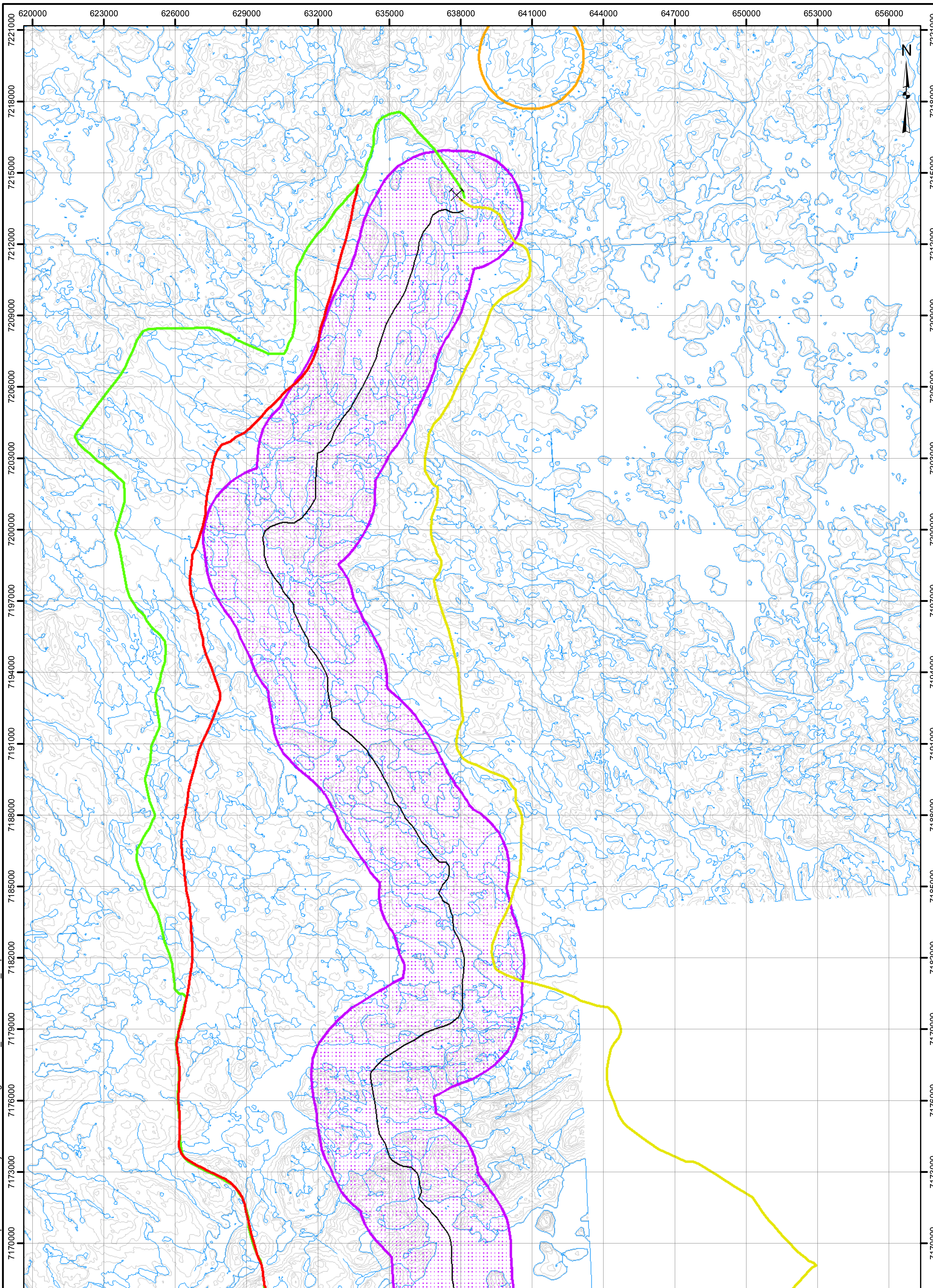
| Route Name | Location Relative to Winter Ice Road | Estimated Length (km) | Estimated Number of Water Crossings |
|---|---|---|---|
| Green | Most westerly access route, up to 13 km west of the winter ice road and following high ground relief. | 115 | 19 |
| Red | West of ice road, within Green route alignment, up to 11 km west of the winter ice road and following low ground relief. | 95 | 23 |
| Yellow | East of ice road, up to 15 km west of the winter ice road and following low ground relief. | 96 | 27 |

Initial field investigations involved preliminary route assessment from helicopter and air photo interpretation. The initial investigations also involved the collection of hydrology data during low and peak flow periods at stream crossings along the various routes. Based on the initial investigations, the Green route was selected as the preferred route alternative.

## 12.8 PREFERRED OPTION – GREEN ROUTE

Based on the assessment, the Green route was selected as the preferred option. The route length, as measured from the proposed Baker Lake marshalling area to the Meadowbank project site, is approximately 115 km. Detailed air photo interpretation was carried out for the Green route. Air photo coverage is shown on Figure 12.3 along with the proposed route alignment. Initially, 23 stream crossings were identified along the proposed Green route. This number was increased to 25 during the air photo interpretation study. The subsequent ground mapping program resulted in a reduction in the number of required stream crossings to approximately 19.

In general, the regional setting for the study area comprises poorly-drained low lying to moderate topographic relief resulting from post-glacial activities. The study area is surfaced with numerous water bodies and stream channels, organic filled depressions, glacial till sheets, limited granular deposits and exposed bedrock outcropping with coarse grained weathered block fields. The assessment indicated that surficial materials are potentially better drained along the Green route than for the other proposed routes. The Red and Yellow routes are shorter road lengths as they are located in lower ground relief and require a number water course crossings.




**LEGEND**

- Meadowbank Project
- Winter Road
- Proposed Seasonal Road
- Proposed Seasonal Road
- Proposed Seasonal Road
- Winter Road - 5 km buffer
- Vault - Local Study Area
- Watercourse
- Waterbody
- Contour (10 m interval)

3,000 1,500 0 3,000 Metres

Scale - 1:150,000

**REFERENCE**

Cumberland Resources Ltd.

Datum: NAD 83 Projection: UTM Zone 14

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**MEADOWBANK PROJECT**
**ALTERNATIVE ACCESS ROUTES**
**1:150,000 Mapsheet 1 of 2**

Golder Associates
Burnaby, B.C.

| PROJECT No. 05-1413-36A | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | CJC | 14 Oct. 2005 | **FIGURE 12.2** | |
| GIS | CDB | 14 Oct. 2005 | | |
| CHECK | CJC | 14 Oct. 2005 | | |
| REVIEW | | | | |

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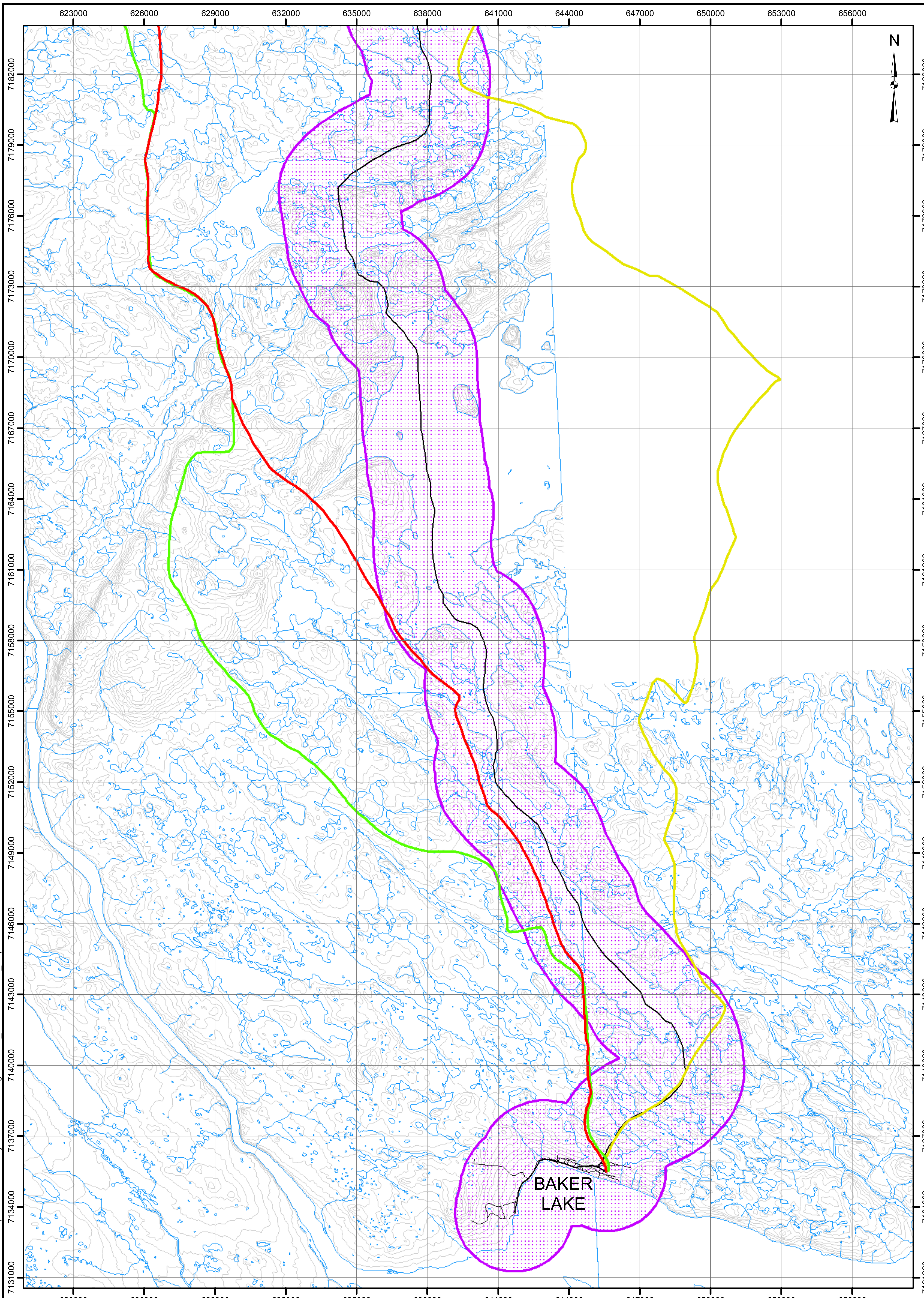


**LEGEND**

- Meadowbank Project
- Winter Road
- Proposed Seasonal Road
- Proposed Seasonal Road
- Proposed Seasonal Road
- Winter Road - 5 km buffer
- Vault - Local Study Area
- Watercourse
- Waterbody
- Contour (10 m interval)

3,000 1,500 0 3,000 Metres

Scale - 1:150,000

**REFERENCE**

Cumberland Resources Ltd.

Datum: NAD 83 Projection: UTM Zone 14

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**MEADOWBANK PROJECT**
**ALTERNATIVE ACCESS ROUTES**
**1:150,000 Mapsheet 2 of 2**

| PROJECT No. 05-1413-036A | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | CJC | 14 Oct. 2005 | | |
| GIS | CDB | 14 Oct. 2005 | | |
| CHECK | CJC | 14 Oct. 2005 | | |
| REVIEW | | | | |

Golder Associates
Burnaby, B.C.

**FIGURE 12.2**

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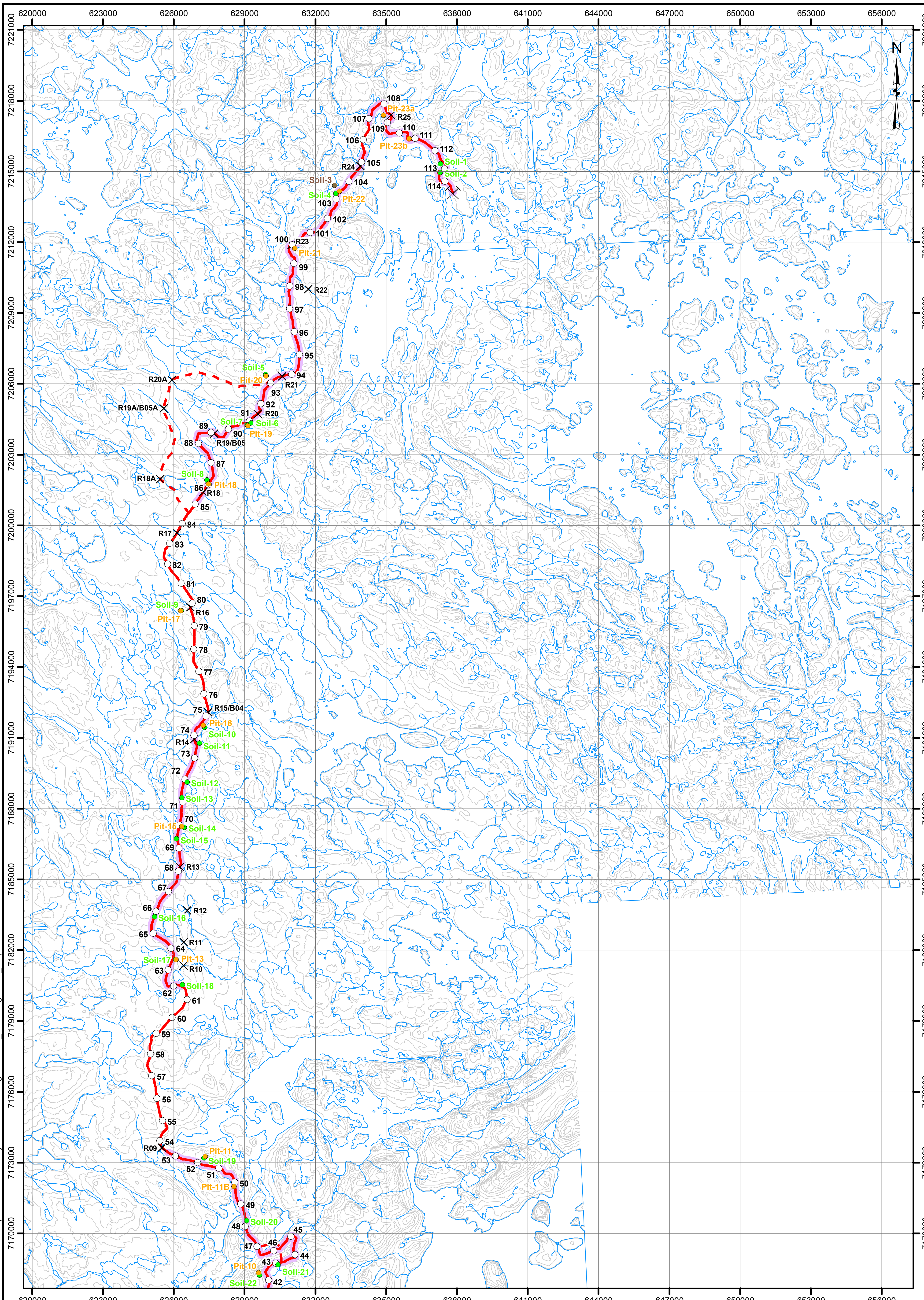


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**LEGEND**

| | | | |
|---|---|---|---|
| × | Meadowbank Project | | Proposed Route |
| | Approximate Location of Potential Rock Quarry Site | | Proposed Alternate Route |
| | Approximate Location of Hand-Dug Soil Pit | | Foot Traverse |
| | Approximate Location of Glaciofluvial Gravel Deposit | × | Stream Crossing |
| | Kilometre Marker | | Watercourse |
| | | | Waterbody |
| | | | Contour (10 m interval) |

3,000 1,500 0 3,000 Metres

Scale - 1:150,000

**REFERENCE**

Cumberland Resources Ltd.

Datum: NAD 83 Projection: UTM Zone 14

PROJECT

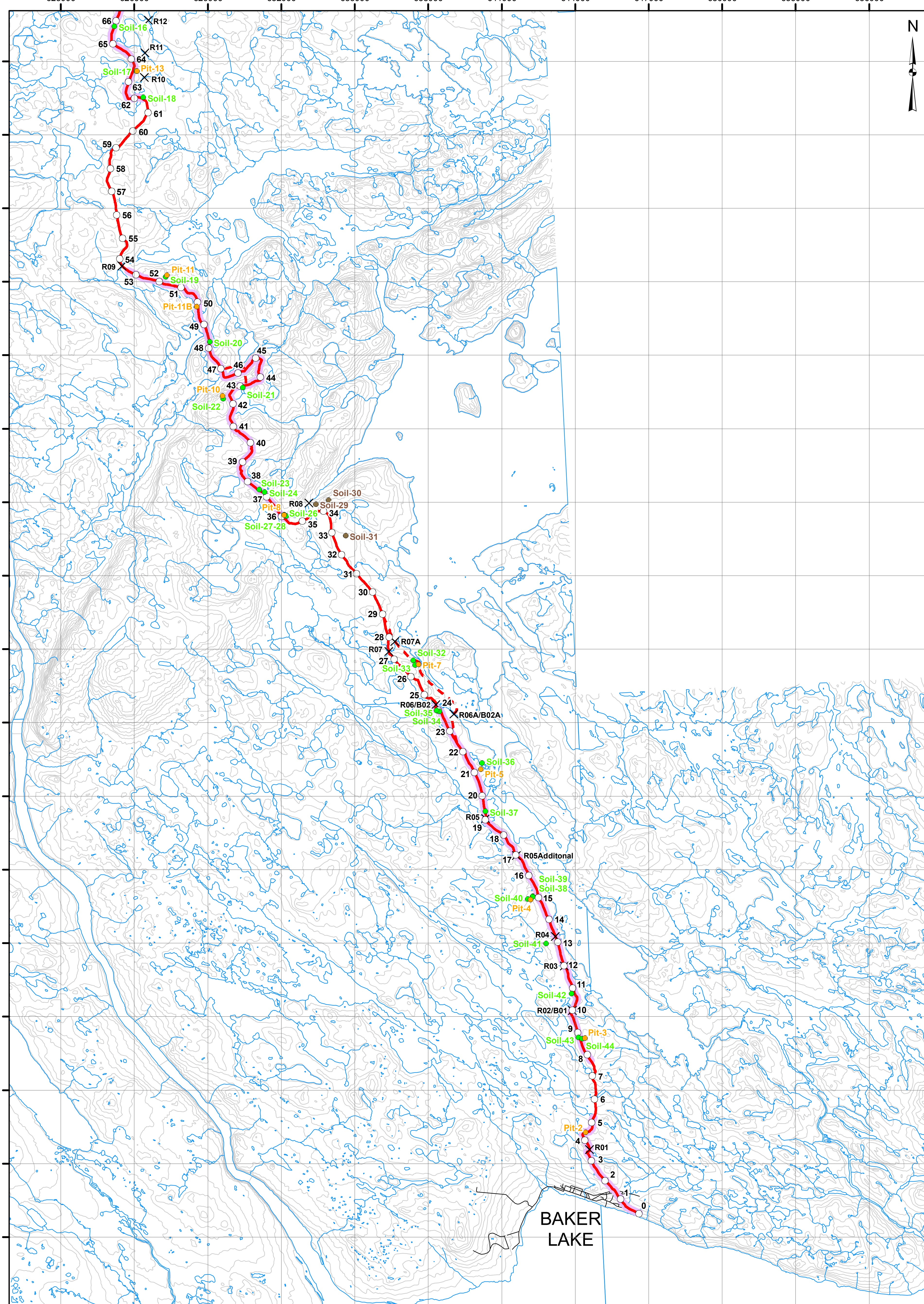
**CUMBERLAND RESOURCES LTD.**

TITLE

**ROUTE ALIGNMENT AND SOIL AND ROCK SAMPLING SITES 1:150,000 Mapsheet 1 of 2**

Golder Associates
Burnaby, B.C.

| PROJECT No. 05-1413-036A | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | KD | 31 Aug. 2005 | **FIGURE 12.3** | |
| GIS | CDB | 31 Aug. 2005 | | |
| CHECK | CJC | 31 Aug. 2005 | | |
| REVIEW | | | | |




N:\Bur-Graphics\Projects\2005\1413\05-1413-036A\GIS\aprs\1050\1300 Project Alternatives\figure-12-03_route-alignment_map-02.mxd

**LEGEND**

- Meadowbank Project
- Approximate Location of Potential Rock Quarry Site
- Approximate Location of Hand-Dug Soil Pit
- Approximate Location of Glaciofluvial Gravel Deposit
- Kilometre Marker
- Proposed Route
- Proposed Alternate Route
- Foot Traverse
- Stream Crossing
- Watercourse
- Waterbody
- Contour (10 m interval)

3,000 1,500 0 3,000 Metres

Scale - 1:150,000

**REFERENCE**

Cumberland Resources Ltd.

Datum: NAD 83 Projection: UTM Zone 14

PROJECT

**CUMBERLAND RESOURCES LTD.**

TITLE

**ROUTE ALIGNMENT AND SOIL AND ROCK SAMPLING SITES 1:150,000 Mapsheet 2 of 2**

Golder Associates Burnaby, B.C.

| PROJECT No. 05-1413-036A | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | KD | 31 Aug. 2005 | | |
| GIS | CDB | 31 Aug. 2005 | | |
| CHECK | CJC | 31 Aug. 2005 | | |
| REVIEW | | | | |

**FIGURE 12.3**

Occurrences of geomorphic and periglacial processes and surficial materials along the access road route were mapped to identify site conditions, natural hazards, and possible aggregate sources to be considered during engineering design and construction. The results of the office-based assessment were field verified by eight walking traverses along selected sections of the route, observations at eleven locations associated with potential bedrock quarry sites and, terrain observations along the road route from a helicopter. In addition, bedrock sampling for geochemical analysis was carried out at a series of possible rock quarry sites. Selected soil samples were collected for geochemical and geotechnical characterisation. Samples of potential borrow and quarry material was collected for initial assessment of acid rock drainage (ARD) potential.

The results of the air photo interpretation, mapping, and sampling program were presented in a report:

- Golder Associates Ltd., Report on Air Photo Interpretation, Site Reconnaissance, Mapping, and Sampling: Tehek Lake Access Road, Meadowbank Gold Project, Nunavut. October 2005.

### 12.8.1 Test Pitting & Soil Sampling

To assess ground conditions and permafrost depths, 44 hand-dug soil pits were excavated along the proposed route and locations are shown on Figure 12.3. Samples of overburden material were collected from all 44 test pits. A selected number of samples were submitted for additional laboratory testing. Table 12.3 describes the samples collected, and the conditions observed in the field.

The area has low relief, and is generally gently- to moderately- sloping with short, steep slopes occurring locally on some bedrock surfaces. The terrain is dominated by undulating and irregular bedrock surfaces, veneers and blankets of till and/or weathered (frost-shattered) bedrock (felsenmeer), and discontinuous organic veneers. Occasional marine (beach) deposits and very small glaciofluvial deposits are present locally. Periglacial processes present in the area are typical of areas underlain by continuous permafrost, although their surface expression is subdued due to the relatively thin cover of overburden and locally well-drained site conditions. Terrain features and geomorphic processes associated with excess ground ice are limited. Previous field studies in the Baker Lake area and the Meadowbank project site, which included the installation of thermistor cables, indicated that the depth of annual thaw is on the order of 1.5 to 2 m. Shallow, hand-dug soil pits excavated in late July 2005 indicate thaw to depths of 1 m or less on imperfectly- to poorly-drained upland till surfaces at this time of year.

Physical weathering (frost wedging and frost shattering) will occur on exposed bedrock surfaces and in areas of rubbly, weathered bedrock. Freezing induced displacement of soil (frost creep, frost heave, frost jacking, and frost sorting) is expected to occur along the road alignment, although the displacements are likely restricted to poorly-drained surficial materials such as fine-grained glacial tills. Thaw induced displacement of soils (possible solifluction and thaw consolidation/settlement) are expected to occur locally, but are expected to be restricted to the finer, grained soils and to steeper slopes. Thaw settlement and consolidation of finer, grained tills following road construction or surface disturbance should be expected to occur along portions of the road underlain by native till materials.

*Table 12.3: Characteristics of Soil Sample Test Pits*

| Site | Depth (m) | Soil Type | Comments |
|---|---|---|---|
| Soil-1 | 0-0.4 | Brown silt, some clay, gravel and sand | Wet |
| Soil-2 | 0-0.3 | Light brown silty Sand and Gravel | Dry |
| Soil-3 | | Sand, some gravel | No sample |
| Soil-4 | | Till | No sample |
| Soil-5 | 0-0.3 | Grey brown Silt, some clay, fine gravel and sand | No GPS point |
| Soil-6 | 0-0.3 | Till | |
| Soil-7 | 0-0.3 | Light brown Silt, some sand, clay and gravel | |
| Soil-8 | 0.4-0.6 | Grey sandy Silt with gravel | No GPS point |
| Soil-9 | 0-0.3 | Till | Very stiff and hard to dig |
| Soil-10 | 0-0.3 | Till | Small holes showing trace of melted ice, soil around the hole is swelling, not able to dig deeper |
| Soil-11 | | Till | Dry, no sample |
| Soil-12 | | Till | Dry, no sample |
| Soil-13 | | Till | Dry, no sample |
| Soil-14 | 0-0.5 | Light brown sandy Silt, some clay and gravel | Softer in the bottom than Soil-8 |
| Soil-15 | | Plastic Till | Wet, no sample |
| Soil-16 | | Till | Wet, no sample |
| Soil-17 | 0-0.35 | Till | Drier than others places, no trace of permafrost |
| Soil-18 | 0-0.3 | Brown silty Sand mixed with weathered rock | Very difficult to dig deeper, to much rocks |
| Soil-19 | 0-0.4 | Till | Very stiff at the bottom, no trace of permafrost |
| Soil-20 | | Dark brown clayey Silt, some sand and gravel | |
| Soil-21 | | Till | Permafrost at 0.6-0.7 m |
| Soil-22 | 0-0.5 | Dark brown clayey Silt, some sand and gravel | Soft at the base of pit, sandier at the surface |
| Soil-23 | 0-0.3 | Brown Silt, some gravel, trace of sand and clay | No sample, rock at 0.3 m |
| Soil-24 | 0-0.7 | Wet till | |
| Soil-25 | | Sand and Gravel | No sample |
| Soil-26 | 0-0.05 | Weathered reddish rock | |
| Soil-27 | 0.4-0.5 | Silty gravel | |
| Soil-28 | 0-0.4 | Silty sandy Gravel | |
| Soil-29 | 0-0.5 | Sand and Gravel | |
| Soil-30 | 0-0.6 | Sand and Gravel | |
| Soil-31 | | Sand and Gravel | No sample |
| Soil-32 | 0-0.05 | Till | Poorly-drained (type 4) |
| Soil-33 | 0-0.45 | Ablation till | Sand and Gravel, well drained (type 2) |
| Soil-34 | 0-0.5 | Grey clayey Silt, some sand and gravel | Permafrost at 0.5m |
| Soil-35 | 0-0.5 | Grey brown Silt, some gravel, clay and sand | |
| Soil-36 | 0-0.5 | Till | Poorly-drained |
| Soil-37 | | Dark brown clayey Silt, some sand and gravel | |
| Soil-38 | 0-0.3 | Sand, some gravel | Nbn (permafrost classification), below 0.3 cm |
| Soil-39 | | Peat | Soft and wet peat over frozen peat, Vx (permafrost), no sample |
| Soil-40 | | Sandy till | Seems to have lost the sample |
| Soil-41 | | Sand | |
| Soil-42 | | Grey clayey Silt, some sand and gravel | |
| Soil-43 | 0-0.3 | Grey sandy Silt, some gravel | Permafrost at 0.7 m, visible ice, inclusion of ice |
| Soil-44 | 0-0.5 | Sand and Gravel | Collapsing hole, could not excavate deeper than 0.7 m deep |

A geophysical ground penetration radar (GPR) survey has recently been completed along the proposed route by Golder Associates, to evaluate areas of potential snow drifting, snow pack, and to refine the proposed route alignment based on actual site conditions. In addition to the GPR survey, electromagnetic terrain conductivity (EM31) surveys were carried out at specific locations, in particular at potential bridge abutments, to evaluate the potential for massive ice formation.

### 12.8.2 Summary of Rock Sampling

Sources of granular aggregate are relatively small in spatial extent, and are scarce along the proposed road alignment. It is expected that rock quarries will be developed along the road to provide a source of material for processed aggregates. An initial assessment of some proposed quarry sites has been undertaken to assess the potential for environmental effects associated with the aggregate sources proposed for road construction.

The local bedrock consists of rocks of igneous, metamorphic, volcanic, and sedimentary origin. Individual bedrock types tend to extend over large distances along the road route. Samples were collected from 20 potential quarry sites located along the proposed route. The criteria for selecting potential rock quarry sites were:

1. areas of exposed bedrock ideally 200 x 200 m in extent
2. moderate relief (i.e., 5 m to 10 m or more from bottom to top of outcrop)
3. sites located away from surface waters
4. avoidance of areas that are heavily mineralised
5. avoidance of outcrops with deep, extensive, and open fractures/joints
6. avoidance, if possible, of areas with deeper overburden (>0.5 m)
7. avoidance of lee slopes (S, SSE, and SE) when possible
8. well-spaced sites (5 km to 10 km apart), supplementary and closer site if only small outcrops are available.

Three composite rock samples weighing 3 to 5 kg each were collected at each potential quarry site situated within 1 km on either side of the proposed access road. Quarry sites and sample locations are shown on Figure 12.3. A total of 53 samples were collected from 18 possible quarry sites. Most quarry site outcrops consisted of one relatively homogeneous rock type.

The suite of chemical analyses performed by CEMI includes whole rock and elemental solid phase chemistry, acid-base accounting (ABA) and analysis of metal leaching potential (shake flask extraction). Acid base accounting results were compared to guidelines presented by INAC (1992) for Northern mine sites.

### 12.8.3 Geology

Table 12.4 summarizes the lithology, sulphides, and iron staining of samples collected from each of the eighteen sample locations.

***Table 12.4: Rock Sample Location & Lithology***

| Station ID | Primary Lithology | Visible Sulphides | Iron Staining | Notes on Texture, Fabric, Weathering |
|---|---|---|---|---|
| 2 | Granite | None | None | Medium-grained, fresh to slightly weathered |
| 3 | Granite | None | traces on fracture surfaces | Medium-grained, fresh to slightly weathered |
| 4 | Granite-Granodiorite | None | None to trace | Fine- to medium-grained, fresh locally up to 0.5 cm weathering rind |
| 5 | Granite | None | None to trace on some fractures | Fresh, weakly foliated |
| 7 | Granite | None | Traces of iron staining, mostly on fractures | Fresh, fine- to medium-grained, weakly foliated |
| 8 | Quartzite | None to very minor | Iron staining on some surfaces | Fresh, fine- to medium-grained, weakly foliated |
| 10 | Granite/ Gneiss/ Quartzite | None | None to trace | Fresh, medium-grained |
| 11 | Felsite | None | None to trace | Fresh to slightly weathered, fine grained |
| 11B | Andesite | - | - | Moderately weathered, fine-grained |
| 13 | Metawacke | None | None to trace | Fresh to slightly weathered, fine-grained |
| 15 | Metawacke | None | None to trace | Fresh to slightly weathered |
| 16 | Metawacke | Trace | Trace | Slightly weathered |
| 17 | Mafic wacke/granite gneiss | None | Trace | Slightly weathered |
| 18 | Mafic Volcanic | None | Minor to trace | Slightly weathered |
| 19 | Granite | None to trace | None to trace | Fresh to slightly weathered |
| 20 | Granite | None | Traces on fracture surfaces | Fresh |
| 21 | Granite | None | Trace | Fresh |
| 22 | Granite | None | Trace | Fresh, weakly foliated |

None of the samples exhibited visible sulphides in greater than trace amounts, and iron staining was generally minor.

Results of whole rock and elemental analyses confirm an abundance of aluminosilicate minerals within the majority of the rock types. Aluminosilicates, such as feldspar and mica, which are typically present in the rock types being studied, provide some amount of acid neutralization potential, although they are less reactive (slower reaction kinetics and lower buffering pH) than carbonate minerals such as calcite or dolomite.

As shown in Table 12.5, ABA results indicate that all samples are non-acid-generating, based on their neutralization potential ratio (NPR above 2 as per INAC (1992) guidelines), or based on their very low sulphide sulphur content.

Rock leachate pH values range from acidic to alkaline. Six of 24 samples are outside of the freshwater CEQG range for pH. The following metals exceed the freshwater CEQG for at least two samples: aluminum, arsenic, chromium, copper, and selenium. These exceedances do not necessarily imply non-compliance of actual on-site drainage water quality. Concentrations of these constituents are expected to decrease with time, as soluble salts are flushed from the excavated rock.

***Table 12.5: Summary of Analytical Results***

| Station | Sample ID | Rock Type | CCME Exceedances | ARD Potential (INAC, 1992) |
|---|---|---|---|---|
| 2 | P2-2 | Granite | Al, Cu | NPAG |
| 3 | P3-2 | Granite | Al, Cu, Se | NPAG |
| 4 | P4-2 | Granodiorite | Cu, Se | NPAG |
| 5 | P5-2 | Granite | Al, Cu, Se | NPAG |
| 7 | P7-2 | Granite | Al, Cu, Se | NPAG |
| 8 | P8-2 | Quartzite | pH, Cu, Se | NPAG |
| | P8-3 | | pH, Al, Cu, Se | NPAG |
| 10 | P10-2 | Granite / Gneiss / Quartzite | pH, Al, Cu, Se | NPAG |
| | P10-3 | | pH, Al, Cu, Se | NPAG |
| 11 | P11-2 | Felsite | Al, As, Cu, Se | NPAG |
| | P11-3 | | Al, Cu, Se | NPAG |
| 11B | P11b-2 | Andesite | Al, Cu, Se | NPAG |
| | P11b-3 | | Al, As, Cu, Se | NPAG |
| 13 | P13-2 | Metawacke | Al, Cu, Se | NPAG |
| 15 | P15-2 | Metawacke | Al, Cu, Se | NPAG |
| | P15-3 | | Al, Cu, Se | NPAG |
| 16 | P16-2 | Metawacke | Cu, Se | NPAG |
| 17 | P17-2 | Mafic wacke/ Granite gneiss | Cr, Cu, Se | NPAG |
| | P17-3 | | Cr, Cu, Se | NPAG |
| 18 | P18-2 | Mafic Volcanic | Cu, Se | NPAG |
| 19 | P19-2 | Granite | Se | NPAG |
| 20 | P20-2 | Granite | pH, Al, Cu, Se | NPAG |
| 21 | P21-2 | Granite | pH, Al, Cu, Se | NPAG |
| 22 | P27-2 | Granite | pH, Al, Cu, Se | NPAG |

Although quarry sites 8, 10, 21, and 22 have a sulphide content that is expected to be too low to generate ARD, consideration should be given to avoiding these quarry sites as a precautionary measure. The quality of runoff contacting the open quarry sites and the excavated rock should be monitored during construction to document the effect of exposure of the quarry rock on receiving water quality.

## 12.9 STREAM CROSSINGS

The terrain conditions at the stream crossing locations, as best as can be determined from the air photo interpretation and through field verification, are listed below. The kilometer distances indicated are measured from the Baker Lake marshalling area at Km 0 (see Table 12.6).

Initially 23 stream crossings were estimated, but this number was increased to 25 during the air photo interpretation. However, on further inspection of the air photos, the route alignment was adjusted where possible to reduce the number of stream crossings required to approximately 19.

***Table 12.6: Terrain Conditions at Stream Crossings***

| Stream Crossing Number | Terrain Conditions | Notes | km |
|---|---|---|---|
| R01 | Unconsolidated materials form both sides of the crossing. Bedrock is exposed a short distance south and north of the crossing. Road construction on the approaches could provide ample rock for crossing construction. Organic veneers and poorly-drained tills are present along the stream edge. The crossing may move closer to the lake if road location to south changes. | Crossing conditions are better closer to the lake as some bedrock is exposed on the north side of the crossing. | 3.5 |
| R02/B01 | No air photo coverage. Ground photos indicate blocky-rubbly frost shattered bedrock at the crossing. | Bedrock near surface; check grades. | 10 |
| R03 | Crossing appears to be on poorly-drained till. There is a possibility that the crossing could be located on bedrock a short distance to the west, or this rock could be exploited for crossing materials. | Field verify conditions. | 12 |
| R04 | Crossing appears to be on poorly-drained till. There is a possibility of locating the crossing on bedrock a short distance to the west. Ground photos indicate organic soils at the crossing location. | Field verify bedrock. | 13 |
| R05 | There are two possible crossings at this location (east and west of a small lake). Both crossings are on till or weathered bedrock. The east crossing appears better drained, there is a very slight chance there is exposed bedrock on the north side of the east crossing. Rounded/sub-rounded boulders visible in the stream channel in the ground photos suggest that till may underlie the stream/crossing. Poorly-drained tills are present on the approaches to the crossing. | Original (west) crossing location okay – broad and low flows after freshet; no change. | 17 to 19 |
| R06/B02 | The stream on the eastern side of this crossing location is narrower but the western side appears to have exposed bedrock on both sides of the stream. Frost shattered bedrock is present at the east end of the stream so bedrock may be near surface. Ground photos indicate areas of blocky, rubbly frost shattered bedrock, and possibly gently dipping bedrock locally in the stream channel. | Current location is near west end of stream. | 24 |
| R07A | There is bedrock exposed along most of the north side of this crossing but the south side is dominated by till or weathered bedrock. Moving the crossing location west may provide some bedrock for the south approach as well as a narrower crossing. | Check alternative route. | 27.5 |
| R07 | This is the alternative route location described above. | | 28 |

*Table 12.6 – Continued*

| Stream Crossing Number | Terrain Conditions | Notes | km |
|---|---|---|---|
| R08 | Till or weathered bedrock. The south side of the crossing appears better drained than the north side. Exposed bedrock is available to the south of the crossing. There may areas of frost shattered bedrock on the south side of the crossing that may provide reasonable foundation opportunities. | Not part of the current road route, which uses an alternate high ground alignment to the west of R08. | 34 |
| R09 | There appear to be bedrock outcrops at this location on the stream that may provide favourable foundation conditions. | | 54 |
| R10/B03 | Primarily unconsolidated materials (till) – poorly-drained till likely dominates. Could exploit exposed bedrock by moving towards west or on green route or to the east. | Crossing excluded from revised route alignment. | 63.5 |
| R11 | Bedrock is present on the south side of crossing. Mainly unconsolidated materials (till) on north side but may be bedrock locally. | Crossing excluded from revised route alignment. | 64 |
| R12 | Unconsolidated materials (till) dominate this crossing. | Crossing excluded from revised route alignment. | 66 |
| R13 | Unconsolidated materials (till) dominate this crossing. | | 68 |
| R14 | Poorly- to imperfectly-drained tills dominate the approaches to this crossing. Rubbly, frost-shattered bedrock is present along the stream. | | 74 |
| R15/B04 | Bedrock and frost shattered bedrock dominate on both sides of this crossing. | Check rock at abutments. | 75 |
| R16 | Unconsolidated materials (till) dominate both sides of this crossing. Some exposed bedrock may be present a short distance west. | Shift route slightly west. | 80 |
| R17 | Unknown conditions, no air photo coverage. Ground photo suggests there may be exposed bedrock or frost shattered bedrock to west. | Field verification required, no air photos. | 83.5 |
| R18 | Unknown conditions – no air photos or ground photos. | Field verification required, no air photos. Two route options available (R18A). | 86 |

*Table 12.6 – Continued*

| Stream Crossing Number | Terrain Conditions | Notes | km |
|---|---|---|---|
| R19/B05 | Ground photos indicate areas of frost shattered bedrock (angular rock fragments) that would provide a more favourable crossing location. Avoid areas possibly underlain by till (i.e., rounded/sub-rounded boulders in stream). Approaches are dominated by poorly-drained till deposits. Gradients are quite gentle in this area so there may be an opportunity to shorten the route between kilometre 89 and kilometre 87 to reduce road construction across poorly-drained till deposits. | Two route options available (R19A/B05A). | 89 |
| R20 | Poorly-drained tills (terrain types 4 and 6) dominate this crossing (see photos D-c-1 to D-c-4 on the traverse photos CD). Rock quarry site 19 is about 0.5 kilometres southeast. | Two route options available (R20A). | 91.5 |
| R21 | Poorly-drained tills are present at the immediate crossing (terrain type 6), areas of blocky to rubbly frost-shattered bedrock and small bedrock outcrops are present on the approaches to the crossing (see photo D-a-1 on the traverse photos CD, the crossing area is on the right hand side of this photo). | Field verification required; shift to green route between R21 and R22. | 93.5 |
| R22 | Ground photos indicate unconsolidated materials but there may be localised areas of frost shattered bedrock (upstream areas) that could provide more favourable ground conditions for the approaches and the crossing. The air photos indicate opportunities for bedrock approaches on at least one side of the crossing depending on exact route selection. | Crossing excluded from revised route alignment. | 98 |
| R23 | Rubbly, frost-shattered bedrock is present at the crossing. Areas of poorly- to imperfectly-drained tills are present on the approaches to the crossing. | | 100 |
| R24 | The crossing site is dominated by blocky to rubbly, frost-shattered bedrock limited areas of till may be present in meadow area upstream of crossing (see photos C2-1 and C2-2 on accompanying traverse photos CD). | | 105 |
| R25 | Air photo review indicates that the crossing site is dominated by bedrock outcrops, areas of frost-shattered bedrock and till veneers may be present locally. | | 109 |

### 12.9.1 Stability Discussion

The terrain along the proposed road route does not show any obvious features or processes that preclude the development of the access road, provided appropriate permafrost engineering design methods that account for specific site conditions are used. However, where possible the road should be located on well-drained (dry), granular soils. Sites underlain by fine-grained, poorly-drained, ice-rich, frost-susceptible tills should be avoided where possible, as these soils may require significant ground treatment. There are one or two possible landslides adjacent to the northern portion of the route, but none were observed on the route itself.

Table 12.7 summarizes the susceptibility of various terrain types identified in the mapping to periglacial processes.

***Table 12.7: Evaluation of Terrain Susceptibility to Periglacial Processes***

| Active Layer Process | Description | Susceptibility | | |
|---|---|---|---|---|
| | | **Low** | **Moderate** | **High** |
| Physical weathering of *in situ* materials | Rockfall or Minor Rock Displacement<br>Frost Shattering<br>Frost Wedging | Non-bedrock areas<br>Bedrock areas with slope gradients typically < 60%<br>Rubbly gravely beach ridges and veneers (gWrv) | Bedrock areas with slope gradients typically > 60% | Observed rockfall areas |
| Freezing-induced displacements of soils | Frost Creep<br>Frost Jacking<br>Cryoturbation | Felsenmeer ($rD_b$)<br>Bedrock (R)<br>Flat, thin till veneers or organic veneers<br>Rubbly gravely beach ridges and veneers (gWrv) | Similar terrain as “High” but no sign of lateral movement | Thick till or organics ($M_w$, $M_b$, $O_w$, $O_b$)<br>Terrain showing signs of lateral movement (e.g. solifluction lobes)<br>Patterned ground |
| Thaw-induced displacements of soils | Thaw Settlement<br>Thaw Slumping | Felsenmeer ($rD_b$)<br>Bedrock (R)<br>Flat, thin till veneers or organic veneers<br>Rubbly-gravely beach ridges and veneers (gWrv) | Thin till or organics ($M_x$, $M_v$, $O_x$, $O_v$) | Thick till or organics ($M_w$, $M_b$, $O_w$, $O_b$)<br>Polygons including obvious patterned ground<br>Settlement, slopes typically <10% gradient<br>Slumping, slopes typically >10% gradient |

Some of the identified ground conditions will require conventional cold climate, or permafrost, engineering practices to be used.

Table 12.8 summarizes general engineering and construction methods to consider during the detailed design phase and to be used during the construction phase to manage ground stability in permafrost terrain.

Additional field inspection may be necessary to assess specific, poorly-drained areas (i.e., till deposits), and to assess local variations in permafrost conditions.

***Table 12.8: Engineering & Construction Methods Based on Sensitivity to Freeze/Thaw Induced Displacements***

| Sensitivity to Ground Disturbance | Facility Type | Engineering/Construction Methods Based on Sensitivity to Ground Disturbance |
|---|---|---|
| Sensitive to Settlement or Heave | Bridge abutments, heated structures, water retaining structures, fuel storage tanks, machine foundations, and cut slopes. Structures will likely include modular units on grade supported foundations or skids. | *Appropriate engineering design:*<br>- Excavate ice rich soils<br>- Excavate to bedrock<br>- Use thaw stable fills<br>- Manage drainage<br>- Fill to preserve permafrost<br>- Insulate/Ventilate/Refrigerate<br>- Realign/Relocate if necessary<br>- Flatten cut slopes. |
| Moderately Sensitive to Settlement or Heave | Ditches, cut slopes, building pads, explosives, and storage pads. | *Appropriate engineering design:*<br>- Excavate ice rich soils as required, or accept slight increase in annual maintenance associated with controlled subsidence<br>- Use thaw stable fills<br>- Manage drainage<br>- Fill to preserve permafrost<br>- Insulate<br>- Realign/Relocate if necessary. |
| Insensitive to Settlement or Heave | Site roads, soil stockpiles, and dry freight storage areas. | *Appropriate engineering design:*<br>- Fill to preserve permafrost<br>- Use thaw stable fills where possible<br>- Annual maintenance<br>- Control drainage<br>- Insulate where possible. |

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# APPENDIX A

## Tailings Site Selection

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**REPORT ON**

# EVALUATION OF TAILINGS MANAGEMENT ALTERNATIVES MEADOWBANK GOLD PROJECT NUNAVUT

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2 Copies - Golder Associates Ltd., Burnaby, BC

October 6, 2005 05-1413-036A/3000

## EXECUTIVE SUMMARY

A series of Technical Meetings were held in Baker Lake on June 2 and 3, 2005 to review the Draft Environmental Impact Statement (DEIS) for Cumberland Resources Limited (CRL), Meadowbank Gold Project. Following the technical meeting, a list of commitments by CRL was prepared, which would either be addressed as soon as possible or appear in the Final Environmental Impact Statement. This report responds to Items #5 and #26 from this list which requested additional information relating to the decision matrix used to evaluate tailings disposal options.

Items #5 and #26 from this list specifically requested that:

1) Revised wording for the elimination of options be provided;
2) Clarification be provided regarding the decision matrices for the Portage Waste Rock pile and Tailings Impoundment Area (as it relates to the possible effects on all affected fish-bearing lakes) – to be provided to parties as soon as possible;
    a) The rationale for selecting the various factors, sub-indicators, relative weightings and the ranking of the various options needs to be supported with scientific evidence. The various options need to be clearly described with supporting rationale for each component.

Two reports have been issued previously describing the evaluation process used to select the most appropriate tailings facility:

- Golder Associates Ltd., Report on *Alternative Waste and Water Management Plan, Meadowbank Gold Project, Nunavut*, March 7, 2005.
- Golder Associates Ltd., Report on *Mine Waste and Water Management, Meadowbank Gold Project, Nunavut*, March 5, 2004.

The objectives of those reports was to identify the most appropriate method for disposal of tailings for the Meadowbank Project based on an evaluation of technical, environmental and economic considerations. The requirements are that the facility have minimal net adverse effects on the environment, now and in the future, be technically sound with the minimal potential for failure and economic. Further clarification of the methodology used to select the tailings facility has been requested, and the objective of this document is to provide this clarification.

The process used to select the tailings management system involved:

- Identifying potential tailings storage locations and technologies;
- Developing a list of key site selection criteria that all facilities needed to meet; and
- Developing a site specific, decision matrix model to evaluate, rank, and select the best overall tailings management facility.

This approach, known as a Multiple Accounts Analysis (MAA), is commonly used as a decision making tool for the selection of tailings and waste management facilities. An important aspect of the decision matrix methodology is that it requires all factors be weighed in the final outcome, rather than allowing a single factor to dictate the overall outcome.

The decision matrix model considered factors in three primary categories:

- Environmental;
- Operational; and
- Economic.

Each category was subdivided to consider other sub-indicators. Weighting factors were assigned to each sub-indicator and to the overall factors.

Initially, seven potential tailings management areas were identified. Three of these were excluded from further consideration based on a series of pre-screening criteria. Four potential tailings management areas were carried further for analysis using a decision matrix approach.

| Location | Disposal Type |
|---|---|
| Second Portage Arm | Sub-aerial Paste or Dry Stack |
| Second Portage Arm | Sub-aerial Slurry |
| North of Second Portage Arm | Sub-aerial Slurry |
| North of Second Portage Arm | Sub-aerial Paste or Dry Stack |

The sites were evaluated using the decision matrix model.

The results of the decision matrix analysis indicate that the most appropriate tailings management option for the Meadowbank Project, based on environmental, operational, and economic considerations, is the disposal of tailings into the natural rock basin of the northwest arm of Second Portage Lake.

Three sensitivity analyses were carried out. Firstly, each of the individual weighting factors was set to 1, assigning equal weighting to each individual sub-indicator. Secondly, only environmental factors and long term (post-closure) impacts were considered, at the exclusion of operating and economic indicators. Finally, environmental factors specifically relating to impacted lakes and fish habitat were weighted as highly as possible within the decision matrix so that the contribution of these sub-indicators towards on-land disposal options ranged between 31% and 35% of the total environmental score, while the contribution to disposal options in Second Portage Lake were reduced to between 13% and 17% of the overall total score.

The sensitivity analyses showed that when economic factors were removed from consideration, and operational factors reduced in terms of relative importance leaving environmental factors as having the greatest contribution to the overall decision analysis, the preferred option continues to be disposal in the northwest arm of Second Portage Lake, using permafrost encapsulation as the control strategy for acid mine drainage and metal leaching.

A case study of the oxidation of exposed, sub-aerial mine tailings from Rankin Inlet, Nunavut, at sub-zero temperatures is presented. The tailings are acid generating and metal leaching, with saline pore waters. A remediation program begun in 1991 consisted of depositing the tailings into a drained rock basin, with the expectation that permafrost would aggrade into the facility. This is similar to the recommended option for tailings management at the Meadowbank project. A series of thermistors installed in the Rankin Inlet test area indicated that freeze-back of the tailings was occurring more rapidly than predicted. There was no indication of heating by tailings oxidation, despite the reactive nature of the pyrrhotite rich tailings. The results of the laboratory and field investigations indicated that prospective sites for permafrost encapsulation of tailings should have a mean annual air temperature colder than about -6ºC. The mean annual air temperature at the Meadowbank Project is -11.3ºC. Based on the results presented in the case study, permafrost encapsulation of tailings disposed in a drained rock basin, such as the northwest arm of Second Portage Lake, is a preferred method of disposal in permafrost regions.

## TABLE OF CONTENTS



### LIST OF TABLES

## LIST OF FIGURES

## 1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Cumberland Resources Ltd. (CRL) to identify and select an appropriate tailings storage facility for the Meadowbank Gold Project in Nunavut. The project is located approximately 70 km north of Baker Lake, Nunavut (see Figure 1).

Two reports have been issued previously describing the evaluation process used to select the most appropriate tailings facility:

- Golder Associates Ltd., Report on *Alternative Waste and Water Management Plan, Meadowbank Gold Project, Nunavut*, March 7, 2005.
- Golder Associates Ltd., Report on *Mine Waste and Water Management*, *Meadowbank Gold Project, Nunavut*, March 5, 2004.

The objectives of those reports was to identify the most appropriate method for disposal of tailings for the Meadowbank Project based on technical, environmental and economic considerations. The requirements are that the facility have minimal net adverse effects on the environment, now and in the future, be technically sound with the minimal potential for failure and economic. Further clarification of the methodology used to select the tailings facility has been requested, and the objective of this document is to provide this clarification.

A Multiple Accounts Analysis (MAA), or decision matrix method of analysis, was used to evaluate tailings disposal alternatives and to select the best tailings storage facility for the Meadowbank Project.

A series of Technical Meetings were held in Baker Lake on June 2 and 3, 2005 to review the Draft Environmental Impact Statement (DEIS) for Cumberland Resources Limited (CRL), Meadowbank Gold Project. During these sessions, the Department of Fisheries and Oceans (DFO) and other stakeholders requested additional clarification regarding the decision matrix method used to select the Tailings Impoundment Area for the project. The following report has been prepared to explain in more detail the evaluation process used to select the tailings storage facility for the proposed Meadowbank Gold Project. The decision matrix used to identify the most appropriate tailings management site based on environmental, engineering, and economic considerations is presented and explained in greater detail. In some cases the weightings and scoring of sub-indicators used to arrive at the final site selection have been modified to reflect on-going refinements to the mine model.

The primary objectives for a tailings storage facility were that the facility would:

- have a low long-term environmental impact;
- provide reliable containment; and
- be operational on a year round basis, during mining operation.

### 1.1 Physical Setting

The site area consists of low, rolling hills with numerous small lakes. Laterally extensive deposits of glacial till cover the area, with thicknesses typically of 2 m to 4 m. Bedrock consists of a sequence of Archean greenstone (ultramafic and mafic flow sequences) and metasedimentary rocks.

The Meadowbank project is located in an area of low seismicity.

**Table 1-1: Peak Horizontal Ground Accelerations for Meadowbank Site**

| Return Period of Seismic Event (years) | Peak Horizontal Ground Acceleration (g) |
|---|---|
| 100 | 0.018 |
| 200 | 0.025 |
| 475 | 0.034 |
| 975 | 0.044 |

Source: Seismic Risk Calculation for Meadowbank Project Site, Geological Survey of Canada, Natural Resources Canada, Sidney, B.C., July, 2003.

The site has vegetation cover interspersed with bedrock outcrops and continuously aggrading surfaces. The vegetation includes; lichens, mosses, shrubs, heaths, grasses and sedges (CRL 2003).

No vital caribou areas or protected wildlife areas have been identified in close proximity to the site (CRL 2003). The area is not regularly used for hunting due to its remoteness from Baker Lake and relatively low abundance of wildlife (CRL 2003).

Water quality in the lakes is excellent. However, the lakes are nutrient poor and are classified as ultra-oligotrophic and hence have low fish productivity (CRL 2003).

The annual average temperature is about -11.3ºC, based on site data collected between 1997 and 2004 and an annual precipitation of less than 200 mm (AMEC, 2005). Long-term temperature trends collected over 50 years at Baker lake, when applied to the Meadowbank Project site, suggest a mean annual air temperature of -12.8ºC. The depth of permafrost is estimated to range from about 450 m to about 550 m, but varies based on proximity to lakes. Taliks typically are located beneath bodies of water that exceed 2 m to 2.5 m depth of water. The depth of the active layer ranges from about 1.3 m in areas of shallow overburden, up to 4 m adjacent to lakes.

### 1.2 Planned Mining Operations

The project consists of several gold bearing deposits within reasonable proximity to one another. Mining of the deposits will primarily be performed as a truck and shovel, open pit operation. Ore is to be transported to a central plant site for processing.

A site plan is shown in Figure 2. The mine plan estimates that 22 million tonnes of ore will be processed over the mine life of approximately 8.4 years. The total volume of settled tailings is estimated to be 15 million cubic metres.

### 1.3 Decision Matrix Models

Decision matrix types of analyses are also sometimes referred to as Multiple Accounts Analyses (MAA) or alternatives analyses. These types of analyses have been used as site selection tools for tailings facilities and other mining related decision processes including at: Zortman and Landusky Mine Sites, Montana (Shaw *et.al.*, 2001), Red Dog Mine, Alaska (Northern Liner, 2005), and Questa Molybdenum Mine, New Mexico (Molycorp Watch Project). Numerous papers have been published on the subject of Multiple Accounts Analyses such as: Robertson and Shaw (1998 and 1999); Caldwell and Robertson (1983); Vick (1990); Brown (2002); and the Decision Makers Field Guide (2005).

Similar types of analyses are also used in the fields of risk assessment, risk management, selection of the best available technologies or options for environmental remediation projects, resource planning, and sustainable development (Canter, 1985; International Atomic Energy Agency, 2000; CH2MHill, 2004, Robson Valley Land and Resource Management Plan, 1999).

### 1.4 Meadowbank Tailings Selection Process

The tailings selection process for the Meadowbank project involved three main steps:

- developing a list of key site selection criterion;
- identifying potential tailing storage facilities and deposition methods; and
- developing a decision matrix model to evaluate potential storage facilities.

The site selection process was based on a decision matrix model to assess alternatives.

### 1.4.1 Initial Site Selection Criterion

A list of initial site selection criterion that any tailings storage facility for the Meadowbank mine site must meet was developed. This list was used as an initial screening tool, and any locations that did not meet these criteria were eliminated from further analysis. The following key site selection criteria were utilized:

- The site was required to have sufficient volume to store planned volume of tailings;
- The site required the potential to provide additional capacity for tailings storage;
- The location would accommodate mine expansion;
- The location is within catchments of the open pits; and
- The site allows control and collection of the tailings supernatant.
- Low potential for failure of the containment facility

### 1.4.2 Potential Tailing Storage Facilities

Potential tailings storage facilities were identified in the area of the proposed mine site (Figure 3), along with appropriate deposition methods for each location. The tailings facility locations and deposition methods are intimately linked throughout the analyses; in some cases the deposition method can alter the responses to each of the sub-indicators.

All locations and methods that met the initial criterion proceeded to the next phase of analyses which involved the use of the decision matrix.

### 1.4.3 Meadowbank Decision Matrix Model

The development of the decision matrix model for the Meadowbank Project first involved developing a site specific list of criteria that would be utilized to evaluate and rank the facilities. The criteria covered three main areas:

- environmental factors;
- operational factors; and
- economic factors.

Each of the factors was further subdivided into sub-indicators, in order to evaluate specific aspects. Weightings were assigned to each factor and sub-indicator.

Each tailings facility option was then evaluated based on the sub-indicator and a relative score was assigned. These scores were then multiplied by the weighting factors and summed to give the overall score. The options were then ranked according to the overall score, with the highest score indicating the preferred option.

Quantitative methods were utilized to assign the relative scores where possible, however some sub-indicators necessitated the use of qualitative assessment. Judgement and perception of the individual conducting the analyses is inevitably a part of any such decision making system, both in the assignment of qualitative scores and of weighting factors.

The weighting factors were specifically designed to place a higher significance on the environmental factors, and less on the operational and economic factors.

Some sub-indicators, such as the potential for the tailings facility to generate acid rock drainage (ARD), were divided into two components: the potential for impact during mine construction and operation, and the potential for long-term impact, after mine closure. In these cases the long-term sub-indicator was generally assigned a higher weighting than the short term operation sub-indicator.

## 2.0 MEADOWBANK DECISION MATRIX METHOD OF ANALYSIS

This section will explain in greater detail the decision matrix component of the site selection analyses, and each of the sub-indicators used in the selection process, under the three primary categories of environmental, operational, and economic factors. Sub-indicators were chosen to evaluate a wide spectrum of potential impacts, without double counting impacts.

### 2.1 Environmental Factors

The European Commission published a Report on Best Available Techniques (BAT) reference document for Management of Tailings and Waste-Rock in Mining Activities (2004). This document was developed in response to a Communication from the European Commission COM(2000) 664 [COM(2003) 319 final, 2.6.2003] on the 'Safe Operation of Mining Activities' that was a follow-up action to tailings dam bursts that occurred in Aznalcollar and Baia Mare. The follow-up measures included an elaboration of the BAT Reference Document based on an exchange of information between European Union's Member States and the mining industry. The document was developed in response to the Commission's initiative and in anticipation of the proposed Directive on the management of waste from extractive industries (European Commission, 2004). The following key environmental issues or impacts associated with tailings facilities were listed in this document:

- Site specific issues relating to facility location and relative land take;
- Potential emissions of dust and effluents during operation (to air, land and water) and their impact;
- Potential emissions of dust and effluents after closure (to air, land and water) and their impact;
- ARD and metal leaching generation, release and impact;
- Potential releases due to failures of facilities (i.e., burst or collapses of tailing management facilities); and
- Site rehabilitation and aftercare to minimize environmental impacts.

In accordance with the intention to utilize Best Available Techniques to respect environmental considerations, a list of sub-indicators was developed and used to evaluate the various tailings options. These sub-indicators are presented in the following table and are described briefly in subsequent sections.

**Table 2.1: Environmental Sub-Indicators**

| | Sub-Indicators |
|---|---|
| Environmental Factors | Sub-catchment area |
| | Footprint area |
| | Potential for generating dust during operation |
| | Potential for generating dust after closure |
| | Potential for Acid Rock Drainage (ARD) generation during operation |
| | Potential for ARD generation after closure |
| | Potential for metal leaching (ML) during operation |
| | Potential for ML after closure |
| | Potential for seepage to impact groundwater during operation |
| | Potential for seepage to impact groundwater after closure |
| | Potential for geotechnical hazards [1] |
| | Lake area impacted |
| | Number of lakes impacted |
| | Visual impact |
| | Impact on fish and fish habitat |

Note:
[1] Includes consideration of foundation conditions, impact of seismicity, and height of structure.

### 2.1.1 Sub-Catchment Area

A catchment is an area of land bounded by natural high points (hills, ridges and mountains). Surface water (rainfall and runoff) flows down through the catchment area and into one low point (a creek, river or bay). Catchment areas may be further divided into sub-catchments; typically each sub-catchment area will have homogeneous physical characteristics.

Sub-catchment area for the purpose of this evaluation was defined as the primary portion of the watershed that would be impacted by the deposited tailings. The total sub-catchment area (hectares) was used to assign the relative scores and determine the impact of each option. Options having lower sub-catchment areas are preferable to those with greater areas, and hence were assigned a relatively higher score.

### 2.1.2 Footprint Area

The footprint area of the tailings storage facility is defined as the area covered by the deposited tailings both on land and in water. The total footprint area, in hectares, was used to assign the relative scores and judge the impact of each facility location. The site having the smallest footprint area was given the highest relative score, and the other options were assigned a lower score, relative to their footprint area.

### 2.1.3 Potential for Generating Dust During Operations

The relative potential for each facility and tailings deposition method to generate dust during mine operation was qualitatively judged and a value of low, moderate, or high was assigned. This factor is dependent on the method of tailings deposition selected and the relative exposure of the site to wind. In assessing this indicator, a tailings site having the lowest topographic profile, or within an area of low topographic relief, would have a high relative value assigned representing a more desirable site. A site having high topographic profile, and located in an area exposed to wind, would be assigned a low relative value, representing a less desirable site.

At the Meadowbank Project site, the prevailing wind direction is from the northwest, averaging about 20 km/h to 30 km/h. The maximum daily wind gust recorded at the Meadowbank climate station was 83 km/h. A tailings facility located on-land and substantially exposed above ground would have the potential for on-going dust generation during operations and during closure. The dispersion of dust could potentially result in deposition in lakes and on land down wind of the source. A facility located topographically as low as possible would be preferable in that the potential for on-going dust generation and down-wind dispersion over water and land would be reduced.

### 2.1.4 Potential for Generating Dust After Closure

The relative potential for each facility to generate dust after closure was qualitatively judged and a value of low, moderate, or high was assigned. This factor is dependent on the planned method for closure, grain size of cover material, including methods of erosion protection, topographic profile, and exposure of the site to wind. A facility that as part of the closure plan is to be covered, thus reducing or eliminating the potential for dust, either by a rock, soil or vegetative cap, or underwater, would have a high relative value assigned. A facility that remained exposed after mine closure would have a low value assigned.

### 2.1.5 Potential for Acid Rock Drainage (ARD) Generation During Operation

Geochemical testing has shown that tailings at Meadowbank contain metal sulphides and will have the potential to generate ARD. The relative potential for each facility to generate ARD during mine operation was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition and the planned method of operation that may minimize the generation of ARD.

Sulphides oxidize when exposed to oxygen and air, which in turn creates an acidic metal-laden leachate and can be generated over a prolonged period of time if acid buffering minerals are not present. The rate of generation of ARD is accelerated with fine particles as the surface area potentially exposed to oxygen is much greater, which is typically the case when dealing with tailings and processed mine waste. Other factors that may increase the rate of ARD generation are: high oxygen concentration, high temperature, low pH, and bacterial activity (European Commission, 2004).

Tailings deposition methods that reduce or prevent the generation of ARD would receive a higher score. For example, methods that reduce or eliminate exposure to oxygen, such as through the use of submerged tailings facilities, or permafrost encapsulation would receive a higher relative score, in comparison to facilities where tailings are exposed to oxygen (i.e., aerial). Alternatively, facilities that mix acid generating tailings with buffering agents would receive a higher score in comparison to the same facility with insufficient buffering agents. Facilities that maintain tailings at low temperatures and in a frozen state through permafrost encapsulation would receive a high score.

### 2.1.6 Potential for ARD Generation After Closure

The relative potential for each facility to generate ARD after closure was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition, and the planned method for closure which may reduce or control generation of ARD. As discussed in the previous subsection, facilities that in the long term control factors that lead to acid generation, would receive a relatively higher score in comparison to facilities that do not control these factors. Deposition and maintenance of a submerged facility, a lined and dry facility, or a permafrost encapsulated facility would receive higher scores, in comparison to above ground facilities exposed to air and precipitation.

### 2.1.7 Potential for Metal Leaching (ML) Generation During Operation

Geochemical testing has shown that tailings generated at Meadowbank will have the potential to generate ML. The impact of metals released into the environment may be toxic, but depends on many factors including: concentration, pH, temperature, and water hardness (European Commission, 2004). Figure 4 schematically shows some of the primary geochemical and physical processes and their interaction that may lead to the generation of ARD and the potential release of metals (ML).

The relative potential for each facility to generate ML during mine operation was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition and the planned method of operation that may minimize the generation of ML. Facilities that reduce or eliminate the generation and/or transmission of soluble metals to the environment (i.e., hydraulic containment) would receive a high relative score, in comparison to facilities that do not control metal leaching.

Metals may leach from tailings irrespective of the pH, therefore controlling the flux of water through and out of the tailings facility may have the most significant impact on reducing the release of constituents. Consequently, management strategies that limit infiltration of water into the tailings facility, and limit the ability for tailings to come into contact with natural water sources such as groundwater, surface water, and precipitation, through the use of permafrost encapsulation, low permeability cover systems, containment berms and diversion ditches, are preferable.

### 2.1.8 Potential for ML Generation After Closure

The relative potential for each facility to generate ML after closure was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition, and the planned method for closure which may reduce or control generation and migration of ML. The evaluation of this sub-indicator is the same as discussed in the previous subsection.

### 2.1.9 Potential for Seepage to Impact Groundwater During Operation

The relative potential for seepage from each facility to impact groundwater resources during operation was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition, the planned method of operation, including any steps that will be taken to control groundwater discharges, and groundwater flow paths and flow rates of the site (i.e., groundwater discharge or recharge area). Facilities that produce low rates of seepage and seepage with low levels of contamination would receive a high relative score in comparison to facilities that are expected to generate high quantities of seepage with a high concentration of contaminants (including metals and low pH).

One method of reducing the potential for groundwater impact may be achieved by controlling the flux of water through the facility. During operation flow through the facility may be controlled by the surrounding berms and liner or low permeability boundary. Facility liners may be man-made or natural, such as low permeability rock, till, clay, permafrost, or synthetic materials (i.e., high density polyethylene). Materials such as sands and gravels, or highly fractured rock are highly conductive and would not reduce the flux through the facility.

At the Meadowbank Project site, the hydraulic conductivity of the bedrock is on the order of $10^{-8}$ m/s, while that of the overburden materials is on the order of $10^{-6}$ to $10^{-5}$ m/s. Consequently, a naturally contained basin facility underlain by bedrock would be preferable to an engineered facility underlain by till.

#### 2.1.10 Potential for Seepage to Impact Groundwater After Closure

The relative potential for seepage from each facility to impact groundwater resources after closure was qualitatively judged and a value of low, moderate, or high was assigned. This factor is primarily dependent on the method of tailings deposition, planned methods to control groundwater discharges, and the planned closure method, as discussed in the previous section. Facilities that generate low rates of seepage and seepage with low levels of contamination would receive a high relative score in comparison to facilities that are expected to generate high quantities of seepage with higher concentration of contaminants.

#### 2.1.11 Potential for Geotechnical Hazards

The relative potential for geotechnical hazards to exist at each facility was qualitatively judged and a value of low, moderate or high was assigned. The assessment considered foundation conditions, seismic activity, and height and type of structure. Tailings facilities may be constructed using very high dams, and very long perimeter dykes. These may contain large quantities of mobile tailings that can be released to the environment if the retaining structures fail either through the man-made perimeter dikes and dams, or failure through the foundation materials due to low strength.

If the tailings are deposited on-land, within a storage facility, the facility will require the construction of several kilometers of dikes. The dikes will be engineered structures constructed with processed materials. The performance and stability of these structures will depend on the foundation conditions, foundation preparation, fill materials, and quality of the construction. Experience at the site have shown that the till materials can be problematic to construct with, having high moisture content and low strength. Consequently, there is a higher inherent risk associated with failure of an engineered structure constructed on weak soils. This risk increases with the length of the structure.

It is desirable from an environmental perspective to minimize the reliance on engineered structures.

Facilities constructed at higher relative elevations will have a greater relative potential energy compared with facilities constructed at lower elevations. Consequently, there is a greater risk associated with facilities at higher elevations as a breach and release of tailings from these facilities will move to an elevation having a lower potential energy. Such a failure could result in the release of tailings to the environment. If the site was located directly upslope of a fish bearing lake then there is the potential for damage to fish stocks not only in that lake but also to downstream habitat and fish stocks. The use of natural depressions at lower relative elevations considerably reduces the reliance on engineered structures, and hence the geotechnical and environmental risks associated with these structures.

#### 2.1.12 Lake Area and Habitat Quality Impacted

The expected quality (i.e., low, medium, high) of lake area impacted by each of the tailings facilities (tailings deposition and reclaim water) was determined and was used to assign the relative scores and judge the impact of each facility location. The facility with the lowest relative quantity of high quality habitat area impacted would receive a higher score, relative to a facility that impacts a greater amount of high value habitat area. Because of the greater relative importance of this metric, a weighting factor was applied.

#### 2.1.13 Number of Lakes Impacted

The number of lakes that each option would impact was tallied and used to assign the relative scores for this sub-indicator. A facility that impacted only one lake would receive a higher score in comparison to a facility that impacted three lakes.

#### 2.1.14 Visual Impact

The relative visual impact for each facility was qualitatively judged and a value of low, moderate, or high was assigned. This factor considered such items as height, shape, and contrast with the surrounding terrain. A facility with a low profile and that would blend in with the surrounding area would receive a higher relative score than a facility with a high topographic relief, that did not blend into the surrounding terrain.

### 2.2 Operational Factors

Table 2.2 presents a list of the sub-indicators that were used to evaluate the operational factors for the tailings options under consideration. The following subsections briefly describe each of these sub-indicators and how they were evaluated.

**Table 2.2: Operational Sub-Indicators**

| | Sub-Indicators |
|---|---|
| Operational Factors | Ease of operation |
| | Distance from mill |
| | Potential for delays due to freezing |
| | Construction risk |
| | Disposal system has precedent in arctic environment |

### 2.2.1 Ease of Operation

The relative ease of operation of each facility was qualitatively judged and a value of low, moderate, or high was assigned. Various factors were considered including such items as: number of personnel, energy requirements, and mechanical components. For example, a gravity drain system may be judged as being easier to operate than a system that required three pumping stations. In this case the gravity system would receive a relatively higher score than the alternative system. Another example would be a facility that requires multiple tailings discharge locations may be less desirable than a facility with a single discharge point, especially considering the Arctic climate.

### 2.2.2 Distance from Mill

The nominal distance from the mill to the proposed tailings discharge location was determined. This value was used to assign a relative score for each tailings facility based on the proximity to the mill. The facility closest to the mill would receive the highest relative score, and the facility located furthest from the mill would receive the lowest relative score. Increased distance results in higher pumping power requirements, higher risk of pipe blockage either due to freezing or sanding, and increased pipe maintenance. It is also recognized that reduced distance from the mill allows more frequent inspections and facilitates maintenance.

### 2.2.3 Potential for Delays due to Freezing

The relative potential for delays to be caused due to freezing that would impact mining processing operations was qualitatively judged and a value of low, moderate, or high was assigned. This considered various factors including; deposition method, tailings transport method, and ability to operate a reclaim pond. Facilities that were judged as being more susceptible to freezing that could then cause delays within other portions of the plant received a relatively low score, whereas facilities that were less subject to freezing received a relatively high score.

For example a facility that required multiple pumping stations or a longer pipeline for transport of tailings and reclaim water would likely be more susceptible to freezing and therefore cause delays than a system that required only one pump, and transport length was shorter.

### 2.2.4 Construction Risk

The relative potential for delays or problems to occur during construction was qualitatively judged and a value of low, moderate, or high was assigned. Various factors including: type of construction, likely construction schedule, and site conditions, were taken into account. Facilities that utilized local materials that can be placed on a year round basis received a higher score. In comparison, facilities that required a large number of components to be imported, and that could only be delivered by ship and during summer months when the port is open and free of ice, received a lower score.

### 2.2.5 Disposal System has Precedent in Artic Environment

The relative precedent for use of each of the proposed tailings deposition methods was qualitatively judged based on the evaluators’ experience and published literature, and a value of low, moderate, or high was assigned. Facilities that have been successfully built and operated in arctic climates received relatively higher scores then facilities that have not been built or rarely built in arctic climates. A list of various tailings management systems used in Arctic or cold climate regions are shown in Table 2.3. The list is not comprehensive but is intended to provide the reader with additional background as to which management strategies are commonly used in the north.

**Table 2-3**
**Tailings Deposition Methods in Arctic or Cold Climates**

| *Mine Name* | *Owner* | *Location* | *Tailings Disposal Method* | *Notes* |
|---|---|---|---|---|
| Ruttan Mine | Hudson's Bay Mine & Smelting | Northern Manitoba | Sub-aqueous slurry | |
| Thompson Mine | Inco | Manitoba | Sub-aqueous slurry | |
| Nanisivik Mine | Breakwater Resources Ltd | Nunavut | Sub-aqueous slurry | - initial deposition in lake until filled |
| Red Dog Mine | Teck Cominco | Alaska | Sub-aqueous slurry | |
| Voisey's Bay | Inco | Newfoundland (Labrador) | Sub-aqueous slurry | - under construction, to be completed in late 2005 |
| Colomac Mine | Comaplex Minerals Corp. | Northwest Territories | Sub-aqueous slurry and sub-aerial slurry | - into a lake with dams |
| Doris North Project | Miramar Hope Bay Ltd. | Nunavut | Sub-aqueous slurry | - planned |
| Key Lake | Cameco | Northern Saskatchewan | Sub-aqueous slurry | - initially in on land containment facility now in mined out flodded pit |
| Rabitt Lake | Cameco | Northern Saskatchewan | Sub-aerial slurry, will be sub-aqueous at closure | - in open pit with a drainage layer surrounding tailings (wall and base) |
| Copper Cliff Mine | Inco | Sudbury | Sub-aerial slurry | |
| FlinFlon | Hudson's Bay Mine & Smelting | Northern Manitoba | Sub-aerial slurry | |
| Kidd Creek Mine | Falconbridge (Falconbridge-Noranda) | Timmins | Sub-aerial slurry | - Thickened to 60-65% deposited from center in a cone |
| Nanisivik Mine | Breakwater Resources Ltd. | Nunavut | Sub-aerial slurry | - later stage deposition in cells above lake<br>- permafrost encapsulation |
| Fort Knox and True North | Kinross Gold Corporation | Alaska | Sub-aerial slurry | - in dammed valley, closure will be: sub-aqueous using engineered wetlands |
| Rankin Inlet | Asamera Minerals Inc. | Nunavut | Sub-aerial slurry in pit | as remediation, permafrost encapsulation |
| Lupin Mine | Echo Bay Mines Ltd. | Nunavut | Sub-aerial slurry | - deposited in cells, saturated final cover, and paste for underground backfill, permafrost encapsulation |
| Ekati Mine | BHP | Northwest Territories | Thickened tailings (50%) - sub aerial and sub-aqueous | - in dammed lake with lake level raised<br>- non acidic generating |
| Polaris Mine | Teck Cominco (formerly Cominco) | Cornwallis Island, Nunavut | Thickened tailings | - deposition in lake |
| Greens Creek Mine | Hecla Mining Company | Alaska | Sub-aerial dry stack | |
| Raglan Mine | Falconbridge (Falconbridge-Noranda) | Quebec | Sub-aerial dry stack | - permafrost encapsulation |
| La Coipa | Mantos de Oro (Placer Dome) | Chile | Sub-aerial dry stack | - Tailings are filtered to recover excess water as well as residual cyanide and metal credits |
| Pogo Gold Mine | Teck Cominco and Sumitomo Metal Mining | Alaska | Sub-aerial dry stack in valley impoundment and underground paste backfill | - final permitting and construction |
| Mineral Hill Mine | Triako Resources Limited | Montana | Sub-aerial dry stack | - in the planning stages |
| Met Site, Kidd Creek Mine | Falconbridge (Falconbridge-Noranda) | Timmins | Sub-aerial paste (thickened) | - radius of the conical pile is 1.2km and the height of the cone is 25m. The height of the cone increases by 0.2m/y and by closure the height is expected to be 29m |
| Colstrip power plant | LLC, Portland General Electric Company, Puget Sound Energy, PacifiCorp, AVISTA Corporation and NorthWestern Energy LLC | Montana | Sub-aerial paste | - for fly ash disposal |
| Snap Lake | De Beers Canada | Northwest Territories | Sub-aerial paste and paste backfill underground | - non acidic generating are placed on land |
| Kubaka Mine | Omolon Mining Company (operators facility is a joint venture) | Russia | Tailings facility as consisting of two levels; Partially dry tailings in the upper level, and lower level holding the liquid tailings | - permafrost as containment |
| Colomac Mine | N.W.T. | Northwest Territories | Sub-aqueous slurry | |
| Illinois Creek | Quest Capital Corp. | Alaska | Tailings slurry | final closure |
| Ryan Lode | Bartholome | Alaska | Lined earthen Dam with reclaimed water system | final closure |
| Nixon Fork | St. Andrews Goldfields LTD | Alaska | Lined earthen Dam with reclaimed water system | inactive |
| Julietta | Bema | Russia Far east | Paste tailings 85-90% soilds in to surface facility | |
| Kumtor | Cameco, Kyrgyz Govt | Kyrgyzstan | Sub- aerial | |
| Con | Miramar | Yellowkife | Sub aerial | |
| Giant | Diand (formerly Royal Oak) | Yellowkife | Sub aerial | |
| Pogo | Teck Cominco (formerly Cominco) | Alaska | Dry Stack | |
| Kemess | Northgate | BC | De-watered slurry | |
| Huckleberry | Imperial Metals Corporation | BC | De-watered slurry | |
| Mount Polley | Imperial Metals Corp. | BC | Tailings slurry | |
| Diavik | DDMI, Rio Tino | NWT | Fine Pk as sub-aerial slurry into HDPE and coletanche bitumenous lined containment, coarse pk trucked moist and dumped (stacked) in till lined containment | |
| Snap lake | Debeers | NWT | Paste tailings on surface into cells | - under constrcution |

## 2.3 Economic Factors

The economic factors influencing each of the tailings options were considered. The following table presents the sub-indicators that were used to evaluate the economic factors for the tailings options under consideration based on an assessment of the present value of costs.

**Table 2.4: Economic Sub-Indicators**

| | Sub-Indicator |
|---|---|
| **Economic Factors** | Total present value of costs (initial costs + delayed costs) |

Previously, (Golder, 2004) two sub-indicators, overall present value cost and initial capital costs, were considered in the evaluation of the economic factors. This has been revised to consider only the total present value cost as a sub-indicator of economic factors. This reduces the influence of economic factors on the results of the decision making process.

The total present value costs for each facility were estimated and used to rank the facilities. This value includes initial construction costs, facility operational costs over the ten-year mine life, and closure costs. An 8% interest rate was used for these calculations. The resulting total costs were then ranked and scored, with the lowest cost allocated the highest score.

## 2.4 Weighting Factors and Scoring

The contributions of the three primary categories were assigned weightings so that the overall contribution of the primary categories to the outcome of the decision matrix was as follows.

**Table 2.5: Contribution of the Primary Categories to Weighting Factors Used in the Decision Matrix**

| Primary Category | Contribution to Overall Weighting[1] |
|---|---|
| Environmental | 55% |
| Operational | 33% |
| Economic | 12% |

### 2.4.1 Scale Factor

In order to separate the best alternatives from the worst, a scaling, or scoring factor was applied ($S_{IND}$). Each sub-indicator was assigned a score between 1 and 9 points, similar to the system described by Robertson and Shaw (1999). The scores provide a relative ranking between the options with the 'best' option receiving a score of 9, and the 'worst' a score of 1. All subsequent options were then compared to the 'best' option and assigned a lower relative score.

An example of the scoring method is presented in Table 2.6.

**Table 2.6: Example of Scoring System used in the Decision Matrix**

| Option | Distance to Mill | Points | Notes |
|---|---|---|---|
| A | 1 km | 9 | 9 points awarded for the facility located closest to the mill (BEST) |
| | | 8 | |
| | | 7 | |
| | | 6 | |
| C | 2 km | 5 | 9 points x 1 km (BEST)/2 km = 5 points |
| | | 4 | |
| B | 3 km | 3 | 9 points x 1 km (BEST)/3 km = 3 points |
| | | 2 | |
| | | 1 | |

### 2.4.2 Relative Weighting Factor

Each sub-indicator of the primary categories was assigned a relative weighting factor ($W_{IND}$) to introduce a value bias between the individual sub-indicators, based on the relative subjective importance of one indicator versus another. A higher weighting factor indicates a perceived greater relative value or importance between sub-indicators. For example, the relative importance of the impact of a disposal on fish and fish habitat is considered greater than the visual impact of the facility. Consequently, the sub-indicator of fish and fish habitat has been given a relative weighting factor that is four-and-a-half times greater than the weighting factor for visual impact. The weighting factors are shown below in Table 2.7.

Calculations

The cumulative score for each of the primary categories was determined as the sum of the products of the sub-indicator weightings and relative scores.

$$OptionScore = \sum \left(W_{IND} \times S_{IND}\right)_{Environment} + \sum \left(W_{IND} \times S_{IND}\right)_{Operations+} + \sum \left(W_{IND} \times S_{IND}\right)_{Economic}$$

The resulting option score based on qualitative and quantitative inputs provides a means to evaluate the relative ranking of the various options considered. The method is transparent, and allows stakeholders the opportunity to assess the relative weightings and scaling factors based on personal preference. A significant aspect of the decision matrix methodology is that it requires all factors be weighed in the final decision, rather than allowing a single factor to dictate the overall outcome.

The following table presents the weighting factors for the sub-indicators in each of the primary categories as well as the maximum possible value and maximum possible score that could potentially be achieved.

**Table 2.7: Weighting Factors for Sub-Indicators**

| Factor | Sub-Indicator | Relative Weighting | Max, Possible Score | Max. Possible Weighted Score[1] | Max. Possible Category Score[1] |
|---|---|---|---|---|---|
| Environmental | Sub-catchment area | 1 | 9 | 9 | 603 |
| | Footprint area | 1 | 9 | 9 | |
| | Potential for generating dust during operation | 6 | 9 | 54 | |
| | Potential for generating dust after closure | 4 | 9 | 36 | |
| | Potential for Acid Rock Drainage (ARD) generation during operation | 5 | 9 | 45 | |
| | Potential for ARD generation after closure | 7 | 9 | 63 | |
| | Potential for metal leaching (ML) during operation | 2 | 9 | 18 | |
| | Potential for ML after closure | 5 | 9 | 45 | |
| | Potential for seepage to impact groundwater during operation | 5 | 9 | 45 | |
| | Potential for seepage to impact groundwater after closure | 6 | 9 | 54 | |
| | Potential for geotechnical hazards [2] | 5 | 9 | 45 | |
| | Lake area impacted | 5 | 9 | 45 | |
| | Number of lakes impacted | 4 | 9 | 36 | |
| | Visual impact | 2 | 9 | 18 | |
| | Relative loss of high value fish habitat | 9 | 9 | 81 | |
| Operational | Ease of operation | 9 | 9 | 81 | 351 |
| | Distance from mill | 8 | 9 | 72 | |
| | Potential for delays due to freezing | 10 | 9 | 90 | |
| | Construction risk | 4 | 9 | 36 | |
| | Disposal system has precedent in arctic | 8 | 9 | 72 | |
| Economic | Total present value of costs (initial cost + delayed costs) | 15 | 9 | 135 | 135 |
| **TOTAL** | | | | | **1089** |

Notes:

[1] Values represent the maximum score, if each sub-indicator assigned a maximum scoring factor of 9 points.

[2] Includes consideration of foundation conditions, impact of seismicity, and height of structure.

# 3.0 ANALYSIS OF POTENTIAL TAILINGS STORAGE SYSTEMS

## 3.1 Alternative Control Strategies For Mine Waste Disposal At The Meadowbank Project

The generation of metal leachate in acidic drainage is a concern for mining projects. In evaluating the potential control strategies for the disposal of the mine waste at the Meadowbank Project, consideration was given to control strategies that are effective in cold regions. Many reports have been prepared that relate to the disposal of mine waste in cold regions. Under the Mine Environment Neutral Drainage (MEND) program some relevant reports are:

**Table 3.1: Reports Relating to Disposal of Mine Waste in Arctic**

| MEND Project | Title | Year |
|---|---|---|
| 6.1 | Preventing AMD by Disposing of Reactive Tailings in Permafrost | 1993 |
| 1.61.1 | Roles of Ice, in the Water Cover Option, and Permafrost in Controlling Acid Generation from Sulphide Tailings | 1996 |
| 1.61.2 | Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements | 1996 |
| 1.61.3 | Column Leaching Characteristics of Cullaton Lake B and Shear (S) – Zones Tailings Phase 2: Cold Temperature Leaching | 1997 |
| 1.62.2 | Acid Mine Drainage Behaviour in Low Temperature Regimes – Thermal Properties of Tailings | 1998 |
| W.014 | Managing Mine Wastes in Permafrost Zones, Summary Notes MEND Workshop | 1997 |
| 5.4.2d | MEND Manual, Volume 4 – Prevention and Control, Chapter 4.8 Permafrost and Freezing | 2001 |
| 1.61.4 | Covers for Reactive Tailings Located in Permafrost | 2004 |

Common control strategies for the prevention or reduction of acid mine drainage are:

1. Control of acid generating reactions;
2. Control of migration of contaminants; and,
3. Collection and treatment.

In assessing the overall control strategies for the Meadowbank Project, an emphasis has been placed on methods that satisfy items 1 and 2 in the above list, which then has an impact on item 3, collection and treatment, by potentially reducing the requirements for these activities.

Dawson and Morin (MEND 1.61.2, 1996) list various acid mine drainage control strategies.

**Table 3.2: Acid Mine Drainage Control Strategies of the Arctic**

| Strategy | Tailings | Waste Rock |
|---|---|---|
| Freeze Controlled | • Total or perimeter freezing options can be considered<br>• Can freeze up to greater than 15 m annually if freezing in thin layers<br>• Process chemicals could cause high unfrozen water contents | • Requires considerable volumes of non-acid waste rock for insulation protection<br>• Better understanding of air and water transport through waste rock required for reliable design |
| Climate Controlled | • May not be a reliable strategy for saturated tailings | • Requires control of convective air flow through waste rock, infiltration control with modest measures and temperature controls<br>• Better understanding of waste rock air, water, and heat transport for reliable design |
| Engineered Cover | • Special consideration for freeze-thaw effects<br>• Availability and cost of cover materials are major impediments | |
| Subaqueous Disposal | • Special considerations for winter ice conditions and pipeline freeze-up | • Very difficult to dispose of waste rock beneath winter ice |
| Collection and Treatment | • Costly to maintain at remote locations<br>• Long term maintenance cost | |
| Segregation and Blending | • Tailings are normally geochemically homogeneous | • May be very effective<br>• Research and development on-going |

Reference: (MEND 1.61.2, 1996)

The Meadowbank Project is located within the zone of continuous permafrost, and has a mean annual air temperature of about -11.3 degrees C. The project area is underlain by permafrost to depths between 450 m and 550 m based on thermal data collected from the site since 1996.

<u>Freeze Control Strategies:</u> Freeze control strategies rely on the immobilization of pore fluids to control acid mine drainage reactions, and the potential migration of contaminated porewater outside of the impoundment area. The climate conditions at the Meadowbank Project site are amenable to freeze control strategies, and hence should be taken advantage of. In addition to immobilization of pore fluids, permafrost can reduce the hydraulic conductivity of materials by several orders of magnitude. Consequently, freeze control strategies are effective methods for preventing the migration of

contaminants through materials. At the Meadowbank Project, the hydraulic conductivity of the bedrock is already low, on the order of $10^{-8}$ m/s. The implementation of a freeze control strategy would result in even lower hydraulic conductivities if tailings were disposed of within a bedrock basin. According to Dawson and Morin, above, freeze control strategies for waste rock dumps can only be effective if sufficient quantities of non-acid generating waste rock are available for use as a cover and insulation protection. Based on the production forecast schedule for the Meadowbank Project, there will be sufficient ultramafic rock, which is not only non-acid generating, but also acid neutralizing with a buffering capacity up to 5 times greater than the other rock types at the project. Consequently, a freeze control strategy for the waste rock dumps in the Portage area, using ultramafic rock as a cover and insulating layer, is a preferred alternative.

Climate Control Strategies: Cold temperatures reduce the rate at which oxidation occurs. The low net precipitation in permafrost regions limits infiltration of water into waste rock and tailings disposal areas. Consequently, the climate of the Meadowbank Project area will act as a natural buffer to the production of acid mine drainage and metal leachate. According to Dawson and Morin (1996) these strategies are best applied to materials placed at a low moisture content to reduce the need for additional controls on seepage and infiltration. Consequently, this strategy is considered to be effective for waste rock, but not tailings. The arid climate at the Meadowbank Project is therefore ideally suited for climate control strategies for use with the waste rock piles.

Engineered Covers: In general, the objectives of engineered covers are to minimize infiltration of water into the disposal facility, and to create a physical barrier to the diffusion of oxygen into the facility, either waste rock or tailings. In temperate climates, dry covers consist of a layer of fine grained material between two coarse grained layers. In permafrost regions, freeze-thaw cracking due to annual freeze-thaw processes is a concern, resulting in damage to the cover layers and a reduction in the effectiveness of the barrier system. Consequently, materials having a low susceptibility to freeze-thaw damage are desirable. At the Meadowbank Project there is a substantial shortage of thaw-stable soils. Consequently, the development of an appropriate cover design using natural materials available at the site would require significant processing to achieve the requirements for the cover materials. Alternatives to natural materials are manufactured materials, such as geosynthetics or geomembranes. However the costs associated with transporting these materials to site, and the construction of the man-made cover system, are prohibitive.

Subaqueous Disposal Strategies: In temperate regions, the disposal of waste rock and tailings beneath a water cover is a suitable method for disposal as this inhibits the ability of sulphides within the waste materials, either tailings or waste rock, to oxidize. In permafrost regions, additional considerations include the ability to dispose of tailings and waste rock under ice during the ice covered water period of the project. At the Meadowbank Project, ice on the lakes can continue in to July. Consequently, the free-ice period for subaqueous disposal strategies would be limited to a time period of about 3 months. It is notable however, that mines such as Polaris have successfully operated underwater tailings disposal.

Blending and Segregation: Blending and segregation of waste materials consists of combining acidic and alkaline materials to achieve a net neutral waste product producing non-acidic leachate. This approach requires substantial quantities of non-acid generating waste rock to blend with the acid generating rock. At the Meadowbank Project, there are sufficient quantities of non-acid generating waste rock such that this strategy appears desirable. However, in comparison with a total freeze control strategy, there does not appear to be any significant advantage to this method. Furthermore, this type of approach would likely require substantial planning, stockpiling, and re-handling of material; more so than for the freeze control alternative.

### 3.1.1 Summary

A review of control strategies for mine waste disposal, both waste rock and tailings, in cold regions has been presented. The following lists aspects of the project that must be considered in selecting an overall waste management philosophy:

- The Meadowbank Project site is located in the zone of continuous ‘dry’ permafrost;
- The permafrost is classified as ‘dry’, having ice content of less than 10% based on regional permafrost classification maps;
- The permafrost is continuous, with permafrost up to 450 m to 550 m deep based on thermal data collected from the site;
- The mean annual air temperature at the site is about -11.3 degrees C;
- The project site is considered to be arid and dry, with mean annual precipitation on the order of about 290 mm (rainfall and estimated snowfall);
- There is a shortage of naturally occurring thaw-stable materials at the site;
- Most of the waste rock that will be produced during mining is potentially acid generating;
- However, there are sufficient quantities of acid-neutralizing ultramafic waste rock material at the site for use as a cover of waste rock piles and tailings; and
- All of the tailings are acid generating and metal leaching.

Based on the summary of conditions at the site, the following strategies for waste management are appropriate from a technical perspective.

Waste Rock Disposal Alternatives

Waste rock should be disposed of on-land using a total freezing control strategy, followed by a convective insulating cover of acid-neutralizing waste rock. The waste rock will freeze with time, encapsulating the potentially acid generating waste material within permafrost. The waste rock could be placed in a heaped dump construction in lifts of about 2 to 3 m to allow freezing during placement. The cover material would be coarse to allow the development of convective cooling during winter, and insulation through trapped air within voids during the summer. Given the high evaporation rate and low annual average precipitation at the site, the average annual infiltration into the pile is expected to be low. Freeze and climate control strategies for potentially acid generating rock are shown on Figure 5.

Tailings Disposal Alternatives

Due to the arid climate and permafrost environment, tailings should be disposed of in a manner that encourages total freezing as a control strategy. Subaerial disposal is preferred, given the length of time that water at the site is ice covered, allowing the tailings to be frozen in thin layers rather than one thick layer in order to maximize the total frozen thickness. This can be accomplished through the use of slurry pipelines. The tailings will eventually become encapsulated by permafrost, thus limiting oxygen diffusion and water infiltration into the pile, thereby limiting the generation of acid mine drainage. This is shown conceptually on Figure 6.

If disposed of on-land a system of containment dikes would need to be constructed. The dike system would contribute to perimeter freezing of the tailings pile. However, there are insufficient quantities of natural materials available to construct such a dike system. Ideally, disposal of the tailings into a rock basin within permafrost would be the most suitable control strategy. Freezing of the tailings pile would then occur during deposition of the thin layers into the basin, and from the perimeter of the basin which would already be frozen. The hydraulic conductivity of the thawed bedrock at the site is on the order of $10^{-8}$ m/s. Permafrost can reduce the hydraulic conductivity of a material by as much as several orders of magnitude. Consequently, an additional advantage to disposal within a naturally occurring bedrock basin followed by total freezing is that the ability for constituents to migrate out of the facility is substantially restricted. The use of the naturally occurring bedrock and permafrost as the control mechanism to inhibit the onset of acid mine drainage, to restrict the potential release of constituents to the environment, and to restrict infiltration into the pile is preferred over other alternatives that rely on the construction of kilometres of engineered dikes constructed with man made and processed materials, such as clay liner systems, which have hydraulic conductivities that are higher than the bedrock in the Meadowbank Project area. Furthermore, the use of engineered structures carries with it an inherent risk of failure. It is therefore desirable to minimize the reliance on engineered structures.

Capping of the tailings storage facility would consist of the placement of a coarse convective insulating layer of ultramafic rock over the facility to a minimum depth of about 2 m. This thickness is consistent with other cover designs over reactive tailings in the north. During winter convective heat transfer developed within the coarse cover material will transfer heat out of the tailings pile; during the summer trapped air within the voids will act as insulation. This will limit the depth of annual thaw penetration to within the acid-neutralizing ultramafic waste rock. During detailed design, a detailed cover design will be developed that will consider the addition of a fine grained layer of soil material as a base layer to the coarse rock cover. This layer would retain moisture within it resulting in a reduction in the thickness of the active layer. It is possible that this layer could consist of till material dozed in a thin layer over the tailings facility. There are sufficient quantities of till material that will be produces during pre-mining and pre-stripping that could be stockpiled and used for this purpose.

### 3.2 Tailings Disposal Systems Considered

Initially seven potential tailings storage sites were identified. These are listed in Table 3.3 along with the disposal methodology for each site, and are shown on Figure 3.

**Table 3.3: Summary of Potential Tailing Storage Options**

| Option | Location | Disposal Type |
|---|---|---|
| A | Second Portage Arm and North Portage Pit | Sub-aqueous Slurry |
| B | Second Portage Arm | Sub-aerial Paste or Dry Stack |
| C | Second Portage Arm | Sub-aerial Slurry |
| D | Third Portage Lake | Sub-aqueous Slurry |
| E | East from Vault Haul Road | Sub-aerial Slurry |
| F | North of Second Portage Arm | Sub-aerial Slurry |
| G | North of Second Portage Arm | Sub-aerial Paste or Dry Stack |

These options were then compared to the site selection criteria (described in Section 1.4), as a pre-screening process, prior to conducting the overall decision matrix analysis. Based on the pre-screening assessment, only four of the initial seven options met the site selection criteria. These are shown in Table 3.4. Options B and C require draining of the northwest arm of Second Portage Lake. Options F and G are on land. Note that all options require that the northwest arm of Second Portage Lake be diked and nearly completely drained. The full pre-screening matrix is shown in Table 3.5.

**Table 3.4: Options Evaluated Using the Decision Matrix**

| Option | Location | Disposal Type |
|---|---|---|
| B | Second Portage Arm | Sub-aerial Paste or Dry Stack |
| C | Second Portage Arm | Sub-aerial Slurry |
| F | North of Second Portage Arm | Sub-aerial Slurry |
| G | North of Second Portage Arm | Sub-aerial Paste or Dry Stack |

**Table 3.5: Tailings Site Selection Pre-Screening**

| | | Option A | Option B | Option C | Option D | Option E | Option F | Option G |
|---|---|---|---|---|---|---|---|---|
| | | 2nd Portage Arm and North Portage Pit | Second Portage Arm | Second Portage Arm | Third Portage Lake | East of Second Portage Arm | North of Second Portage Arm | North of Second Portage Arm |
| | | Sub-aqueous slurry | Sub-aerial Paste or Dry Stack | Sub-aerial Slurry | Sub-aerial Slurry | Sub-aerial Slurry | Sub-aerial Slurry | Sub-aerial Paste or Dry Stack |
| | | **Construction** – Dewater Second Portage Arm by 28 m (El. 105m ASL) to allow construction of dike. Construct and maintain pipeline. | **Construction** - Dewater Second Portage Arm by 38 m (El. 95m ASL) and allow base to freeze. Build water management pond near mill or in 3rd Portage Arm. Construct and maintain pipeline. | **Construction** - Dewater Second Portage Arm by 28 m (El. 105m ASL) to allow construction of dike. Construct and maintain pipeline. | **Construction** – Place silt curtain to control sediment dispersion or other sediment control and install and maintain pipeline. | **Construction** – build conventional tailings containment berms on frozen ground; install and maintain pipeline. | **Construction** – build conventional tailings containment berms on frozen ground; install and maintain pipeline. | **Construction** – build minor containment berms on frozen ground; install and maintain pipeline. |
| | | **Operation** - Place tailings in Second Portage Arm until Year 6, then North Portage Pit. Use water above tailings for reclaim. Transport tailings by pipeline. | **Operation** - Place thickened/paste tailings to 4 to 7 m above current lake level such that tailings freeze each year. Transport tailings by pipeline for paste, or by truck for thickened. | **Operation** - Place slurry to 7 m above current lake level. Maintain water management and reclaim pond at west end of lake. Transport tailings by pipeline. | **Operation** – deposit tailings into 3rd Portage Lake. Reclaim from Second Portage Arm (water management pond) and 3rd Portage Lake. Transport tailings by pipeline. | **Operation** - Place tailings slurry on surface. Use Second Portage Arm for water management, plus reclaim from tailings area. Allow tailings to freeze each year. Transport tailings by pipeline. | **Operation** - Place tailings slurry on surface. Use Second Portage Arm for water management and reclaim water, plus reclaim from tailings area. Allow tailings to freeze each year. Transport tailings by pipeline. | **Operation** - Place thickened/paste tailings on surface. Use Second Portage Arm or Third Portage Arm for water management and reclaim water. Allow tailings to freeze each year. Transport paste tailings by pipeline, or truck thickened tailings. |
| **Key Indicators** | **Sub-Indicators** | **Closure** – Submerged tailings: Tailings remain submerged and thawed. Long term metal leaching potential. | **Closure** – Permafrost encapsulation: Place ultramafic capping layer to maintain tailings frozen below active layer and to shed water. | **Closure** – Permafrost encapsulation: Place ultramafic capping layer to maintain tailings frozen below active layer and to shed water. | **Closure** – Submerged tailings: Tailings remain submerged and thawed. Long term metal leaching potential. | **Closure** – Permafrost encapsulation: Place ultramafic capping layer to maintain tailings frozen below active layer and to shed water. | **Closure** – Permafrost encapsulation: Place ultramafic capping layer to maintain tailings frozen below active layer and to shed water. | **Closure** – Permafrost encapsulation: Place ultramafic capping layer to maintain tailings frozen below active layer and to shed water. |
| Site Selection Criteria | Sufficient volume to store planned volume of tailings | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | Potential for increased capacity | No | Yes | Yes | Yes | Yes | Yes | Yes |
| | Location enables mine expansion | No | Yes | Yes | Yes | Yes | Yes | Yes |
| | Impoundment is within catchment of open pits | Yes | Yes | Yes | No | No | Yes | Yes |
| | Allows control/collection of supernatant | Yes | Yes | Yes | No | Yes | Yes | Yes |
| | Potential candidate for tailings storage facility | **No** | **Yes** | **Yes** | **No** | **No** | **Yes** | **Yes** |

### 3.3 Description of Tailings Deposition Methods

The tailings deposition methods considered for use at the Meadowbank Project are:

- Sub-aqueous Slurry;
- Sub-aerial Slurry;
- Sub-aerial Dry Stack; and
- Sub-aerial Paste.

The following subsections provide a brief summary of each of these technologies.

#### 3.3.1 Sub-Aqueous Slurry

This method of tailings deposition, involves the direct placement of tailings slurry into a body of water. The water body may consist of a natural lake, river, or other body of water, within an on-land flooded containment facility, or within a flooded pit. This type of tailings deposition method is commonly used in combination with wet ore mineral processing techniques. Slurries typically have solids contents between 20% and 40%, but may range between 5% and 50%. Tailings slurries are typically transported in pipelines or open channels to the containment area. Slurries may be deposited from a single point or multiple locations.

Sub-aqueous deposition implies that all tailings are deposited under water. This is primarily used when tailings have a high potential to produce ARD or severe dust problems. After slurry deposition, solids settle out and the supernatant water can then be decanted and recycled for use within the plant.

Engineered containment structures are built to control the area over which tailings are placed. These structures may consist of dykes or dams, and may be constructed using upstream, downstream or center line construction methods (Figure 7). Figure 8 shows a typical tailings dam structure and the associated water cycle (European Commission, 2004).

As part of this type of tailings management facility, diversion structures are commonly constructed to redirect natural surface water away from the tailings storage facility.

The following are examples of mines that use this type of tailings deposition: Hudson's Bay Ruttan Mine, Manitoba; Inco's Thompson Mine, Manitoba; Nanisivik Mine (initial deposition), Nunavut; Polaris Mine Nunavut ; and the Red Dog Mine, Alaska.

### 3.3.2 Sub-Aerial Slurry

Sub-aerial slurry deposition is generally the same as the sub-aqueous method of tailings deposition, but in this case the tailings are not all deposited under water. In general, the resulting density of the tailings when a sub-aerial method of deposition is used is greater than when sub-aqueous methods are used as settlement of the deposit is promoted through drainage and evaporation from the tailings beach.

Additional thickening techniques, often using chemical additives, may be employed to increase the solids content above 50% (typically 50% – 60%), thus improving storage efficiency.

Water within this type of facility may also be decanted and recycled for use within the plant.

As part of this type of tailings management facility, diversion structures are commonly constructed to redirect natural surface water away from the tailings storage facility.

The following are examples of mines that use this type of tailings deposition: Inco’s Copper Cliff Mine, Ontario; Hudson’s Bay Flin Flon, Manitoba; Kidd Creek Mine, Ontario; and Nanisivik Mine (later stage), Nunavut.

### 3.3.3 Sub-Aerial Dry Stack

An alternative to slurry type tailings deposition systems is called “dry stack”. This method uses mechanical devices, such as high capacity vacuum and pressure belt filters, to dewater the tailings. The resulting tailings have about 50% to 70% solids, and are not able to be pumped. Instead they are transported by truck or conveyor system. It is important to note that these tailings are not truly “dry”, but rather have moisture contents several percentage points below saturation.

Typically, these tailings are then placed, spread, and compacted to form an unsaturated, dense and stable mound. No additional containment structures are required such as dykes or dams.

This type of facility may be advantageous if the mine is:

- Located in an arid regions, where water conservation is a driving factor, and where subsequent saturation by precipitation is not an issue;
- Located in a high seismic area;
- In a region where water handling is difficult; and
- Limited by available space for disposal of tailings.