BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

WOLFDEN RESOURCES INC.

HIGH LAKE TCF
FEASIBILITY DESIGN

HIGH LAKE PROJECT, NU

FINAL

PROJECT NO.: 0385-003-19
DATE: JUNE 28, 2007

DISTRIBUTION LIST:

WOLFDEN RESOURCES LTD.	2 COPIES
GARTNER LEE LTD.	2 COPIES
WARDROP ENGINEERING	1 COPY
NHC	1 COPY
BGC CALGARY	2 COPIES
BGC VANCOUVER	1 COPY

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
1605, 840 - 7 Avenue SW
Calgary, Alberta T2P 3G2
Tel.: (403) 250-5185
Fax: (403) 250-5330

Project No. 0385-003-19
June 28, 2007

Wolfden Resources Inc.
#401-1113 Jade Court,
Thunder Bay, Ontario
P7B 6M7

Attention: Mr. Andrew Mitchell, P.Geo. – Project Manager

RE: HIGH LAKE TAILINGS CONTAINMENT FACILITY, FEASIBILITY DESIGN
HIGH LAKE PROJECT, NU

Dear Andrew:

Please find attached our final version of the above referenced report for distribution to the High Lake project team. This report summarizes available information from geotechnical investigations conducted at various locations around High Lake and provides feasibility dam designs for the six noted dams.

Should you have any questions or comments regarding this report, please contact BGC at your convenience.

Regards,
BGC Engineering Inc.
per:

James W. Cassie, M.Sc., P.Eng.
Specialist Geotechnical Engineer

Attachment: Final Report

TABLE OF CONTENTS

1.0 Introduction 1
1.1 Background 1
1.2 Feasibility Design 1
1.3 Design Input from Other Consultants 2
1.4 Previous Tailings Work 3

2.0 Background Information and Project Design 4
2.1 Background Information 4
2.2 Climate and Climate Change 5
2.3 Project Design and Assessment 6
2.4 Project Layout 7

3.0 Tailings Containment Facility 8
3.1 Tonnages, Volumes and Overall Plan 8
3.2 Tailings Properties 9
3.3 Water Cover Requirements and Water Balance 10
3.4 Water Management and Discharge Methodology 10

4.0 Dam Foundation Conditions 11
4.1 Subsurface Investigations 11
4.2 Foundation Conditions 11
4.2.1 East Dam 11
4.2.2 Northeast Dam 13
4.2.3 Northwest Dam 15
4.2.4 Northwest Channel Dam 16
4.2.5 Polishing Pond Dam 17
4.2.6 Contact Lake Dam 19

5.0 Dam Design 20
5.1 Design Criteria 20
5.1.1 Consequence Categories 20
5.1.2 Specific Criteria 21
5.1.3 Freeboard and Height Rationale 22
5.2 Section Description and Elements 23
5.3 Liner System 24
5.3.1 Overview, Options and Longevity 24
5.3.2 Composite Liner Stability 26
5.4 Geothermal Design 27
5.5 Dam Geometry, Elements and Sections 29
5.5.1 Dam Geometry 29
5.5.2 Foundation and Abutment Preparation 30
5.5.3 Construction Materials 31

5.6 Stability Assessment 31
5.7 Seepage Potential 34
5.8 Cofferdams 35
5.8.1 Design 35
5.8.2 Stability 37
5.8.3 Cofferdam Seepage 39
5.9 Instrumentation 41
5.10 Water Conveyance Elements 41
5.10.1 Contact Lake Outflow Channel 41
5.10.2 Decant Siphons 42
5.11 Construction Plan Outline 42

6.0 Closure Design 45
6.1 Closure Plan Outline 45
6.2 Component Longevity 46
6.3 Spillway Design 47
6.4 Seepage Potential During Closure 48
6.5 Construction Plan Outline 48
6.6 Long Term Surveillance and Monitoring 49

7.0 Quantities and Costing Items 50
7.1 General 50
7.2 Main Dams 50
7.3 Cofferdams 52
7.4 Water Conveyance Elements 52

8.0 Final Design Process 53
8.1 General Requirements 53
8.2 Construction Phase 55
8.3 Monitoring 57
8.4 Operating Plans 58

9.0 Risk and Contingencies 58

10.0 Summary 61

11.0 Limitations and Closure 62

References 64

TABLES

Table 1: Seismicity Data (after NRC-GSC)....4
Table 2: Classification of Dam In Terms of Consequences of Failure (after CDA 1999)....20
Table 3: Dam Design Criteria (after CDA 1999)....21
Table 4: Summary of Dam Height Rationale....23
Table 5: Factors of Safety, Static Assessment (after CDA, 1999)....32
Table 6: Material Properties for Dam Stability Analysis....33
Table 7: Stability Analyses Results....33
Table 8: Material Properties for Cofferdam Stability Analyses....38
Table 9: Stability Analyses Results for Cofferdam at East Dam Location....39
Table 10 Stability Analyses Results for Cofferdam at North End of High Lake....39
Table 11: Seepage Analysis Input Material Properties....40
Table 12: Choice of Lower Permeability Sources and Resulting Seepage Quantity....40
Table 13: Quantity of Materials and Excavations for High Lake Dams....51
Table 14: Thermosyphon Quantities Required....51
Table 15: Quantity of Materials for the Cofferdams M^3....52

LIST OF FIGURES

Figure 1 Project Location Map
Figure 2 High Lake TCF Dam Locations
Figure 3 High Lake Project Area Layout
Figure 4 High Lake Storage Capacity Curve
Figure 5 East Dam Layout Plan
Figure 6 East Dam Longitudinal Section A
Figure 7 Northeast Dam Layout Plan
Figure 8 Northeast Dam Longitudinal Section A
Figure 9 Northwest Dam Layout Plan
Figure 10 Northwest Dam Longitudinal Section A
Figure 11 Northwest Channel Dam Layout Plan
Figure 12 Northwest Channel Dam Longitudinal Section A
Figure 13 Polishing Pond Dam Layout Plan
Figure 14 Polishing Pond Longitudinal Section A
Figure 15 Contact Lake Dam Layout Plan
Figure 16 Contact Lake Dam Longitudinal Section A
Figure 17 Effect of Thermosyphons on Dam Foundation Temperatures
Figure 18 Generalized Dam Section
Figure 19 East Dam Section B
Figure 20 Northeast Dam Cross Section B
Figure 21 Northeast Dam Cross Section C

Figure 22 Northwest Dam Cross Section B
Figure 23 Northwest Channel Dam Cross Section B
Figure 24 Polishing pond Cross Section B
Figure 25 Contact Lake Dam Crossing Section B
Figure 26 Typical Thermosyphon Details
Figure 27 Slope Stability Model and Typical Results
Figure 28 Cofferdam Typical Cross Section
Figure 29 North Cofferdam Longitudinal and Cross Sections
Figure 30 Northwest Channel Cofferdam Longitudinal and Cross Sections
Figure 31 East Cofferdam Longitudinal and Cross Sections
Figure 32 Cofferdam Seepage Model Geometry

APPENDICES

Appendix I Climate Change Design Criteria Memo
Appendix II High Lake Project Design Brief by nhc
Appendix III Geothermal Modelling Memo

LIMITATIONS OF REPORT

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

As a mutual protection to our client, the public, and ourselves, all reports and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this report or any data, statements, conclusions or abstracts from or regarding our reports and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval.

1.0 INTRODUCTION

1.1 Background

The High Lake Project, being developed by Wolfden Resources Inc. (Wolfden), is located in Nunavut within the High Lake greenstone belt, as shown in Figure 1. The proposed mining development encompasses two distinct components:

- The High Lake Property (polymetallic), located about 175 km to the east/southeast of Kugluktuk (formerly Coppermine) near the Kennarctic River; and
- A dock site located on Grays Bay in Coronation Gulf, approximately 50 km north of High Lake.

In addition to these two components, an all weather access road will be required between the proposed mine and port site. The Grays Bay Dock site will be used as a concentrate loading facility and supply dock. A 2,000 m gravel air strip is also proposed to be constructed at Sand Lake, approximately 12 km north of the mine site.

An Environmental Impact Statement (EIS) was filed with the Nunavut Impact Review Board (NIRB) in November 2006 to proceed with the High Lake Project. Wolfden (2006) notes that the High Lake Project includes two open pits (AB and D Zones), three underground mining areas (AB, D and West Zone) and a mill to process 4,000 tonnes of ore daily (with less ore being produced in the first year and final four years). The expected mine life is 14 years. High Lake will be used to store the tailings and consequently the elevation of High Lake will increase by approximately 5 m above the present day level. In order to store the tailings and accommodate the increased water level elevation, four dams will be constructed in topographic low points around the tailings containment facility (Wolfden, 2006).

1.2 Feasibility Design

BGC was retained to provide geotechnical and permafrost engineering input on the High Lake Project. In 2004, conceptual engineering studies and environmental baseline work were commenced, in addition to community consultation work. During that period, BGC undertook site visits to complete geomechanical core logging of the A/B Zone, geological mapping and reconnaissance and siting studies. Limited geotechnical site investigations were completed by BGC in 2004 and Wardrop in 2005, as reported in BGC (2006d). These boreholes were drilled with warm water. As such, these boreholes provided some preliminary subsurface information (including ground temperatures) but they were not able to assess ground ice conditions or the depth to frost-affected bedrock (FAB). A conceptual design for the Tailings Containment Facility (TCF) followed within BGC (2006b and 2006c). The conceptual design information was included within the Comprehensive Project Proposal that was submitted to the NIRB in November 2006.

Further geotechnical investigations were conducted in 2006 as reported in BGC (2007). As additional engineering input for the already submitted EIS, BGC was retained to provide a feasibility-level engineering design for the TCF, four containment dams, polishing pond and associated dam and the Contact Lake Dam, based on the investigations conducted between 2004 and 2006. An outline of the proposed feasibility engineering study scope was submitted to Wolfden on September 27, 2006. A meeting was held on October 17, 2006 in Calgary between BGC and Wolfden to review the proposed table of contents for the report. At that time, verbal authorization to proceed with the feasibility level engineering was provided by Mr. Andrew Mitchell of Wolfden. A budget outlining the costs of completing the feasibility level engineering was submitted to Mr. Mitchell on October 25, 2006. A project design basis memo was also provided to other design team member on October 25, 2006 to verify the design parameters.

The current report therefore provides design information for the High Lake TCF including the ground conditions observed at the dam locations, summarizes the design criteria used for the TCF and its related dams and spillways and provides designs and associated quantities for the noted structures. No design information is provided for the A/B Pit tailings deposition area within this current document. In addition, no costing information is supplied herein as all previous project costing has been done by others.

1.3 Design Input from Other Consultants

The High Project team consists of the following consultants and their roles:

- Wardrop Engineering - provided overall project planning, engineering and costing including the preparation of a prefeasibility study for the project and tailings pumping plan.
- EnvirAubé (sub-consultant to Wardrop) - provided recommendations on site water management and treatment of potentially mine affected drainage.
- Gartner Lee Ltd. – provided environmental related services including baseline conditions, preparation of overall EIA and permitting assistance. Gartner Lee was responsible for assessment of hydrogeological conditions and preparation of a water quality model for the site. In addition, Gartner Lee prepared a Preliminary Closure Plan for the site.
- Northwest Hydraulics Consultants (sub-consultant to Gartner Lee) – provided hydrological input and water balance assessment for the site and the TCF. In addition, nhc provided recommendations for the design of the closure spillway and the overflow location at the north end of Contact Lake.
- Lorax Environmental Services – provided geochemical assessment services including assessment of potential source terms for the site water quality model.

This team of consultants have produced numerous reports and documents relating to the High Lake Project and some have provided design inputs/assumptions for the report provided herein.

1.4 Previous Tailings Work

As noted, BGC (2006b) provided a conceptual design for the Tailings Containment Facility, including the following elements:

- compilation of site background information;
- assessment of potential tailings tonnages and volumes, including volume split between A/B Pit and other disposal areas;
- assessment of appropriate tailings disposal methodology;
- tailings area siting assessment;
- water cover requirements; and
- location of potential dams and conceptual design section.

Conventional tailings slurry was recommended as the preferred methodology, followed by its variant, thickened tailings. The need for water cover over the tailings (prevention of future geochemical concerns with sulphide tailings) was the driver for the methodology selection.

Five potential tailings disposal areas, in addition to the A/B Pit, were identified as potential storage areas but High Lake was recommended as the potential disposal location because of the following reasons:

- There is sufficient storage capacity for tailings solids.
- High Lake is located proximal to the plant site and A/B Pit.
- Natural poor water quality and current lack of aquatic life in High Lake minimize potential impacts from tailings deposition.
- Containment of majority of mine footprint within one watershed.

The tailings placed in High Lake will be covered with water to prevent oxidation of the potentially acid generating (PAG) tailings. Four dams would be constructed for containment around High Lake, as follows;

- Northwest Dam.
- Northwest Channel Dam.
- Northeast Dam.
- East Dam.

In addition, a polishing pond and associated dam is required downstream of the Northeast Dam. Treated water from High Lake and the polishing pond will flow down through a series of lakes and ponds before draining into the Kennarctic River. A small dam is also required directly north of Contact Lake to divert fresh water away from the High Lake TCF and into the Kennarctic River. Figure 2 illustrates the locations of the six dams around the High Lake TCF.

The proposed dams would be constructed of a rockfill embankment with an upstream sloping liner system. The liner folds under the centreline of the dam crest and will tie into intact bedrock via a cut off trench excavated beneath the dam. Since the foundation for each dam will be frozen, seepage will be completely minimized under each of the dams.

BGC (2006c) also discussed some supplemental issues related to the conceptual design of these dams. Further elaboration on these topics is included within the current design report.

2.0 BACKGROUND INFORMATION AND PROJECT DESIGN

2.1 Background Information

Section 2 of BGC (2006d) provides a compilation of existing physical conditions within the High Lake Project Area. The following main points are provided for completeness with the current report, not including climate data which is further reviewed in Section 2.2:

- The High Lake property is located approximately 175 km south/southeast of Kugluktuk at 67°22'N latitude and 110°50'W longitude, as shown on Figure 1.
- Lakes in the project area, including High Lake, drain to the Kennarctic River located directly along the eastern margin of the proposed mine area. The Kennarctic River drains north into Coronation Gulf.
- The project area is located within the Bear-Slave Upland of the Kazan physiographic region of the Canadian Shield; relief of up to 100 m is typical.
- The High Lake area was glaciated by the Keewatin section of the Wisconsin Laurentide Ice Sheet. Morainal deposits in the High Lake area are usually thin veneers, blankets and felsenmeer (boulder-field).
- As the glacial ice started to retreat, clay and silt marine sediments were deposited near the coast and in low areas connected to the sea such as the Kennarctic River Valley. Thinner, more mixed marine sediments were deposited in bedrock depressions.
- The High Lake region is located within the Archean Slave Province consisting of basement gneiss overlain by thick successions of greywacke, turbidites and basalt. The High Lake deposit is located within the High Lake greenstone belt comprised of mafic intermediate, and felsic volcanic rocks in the west and east, and a central domain of mixed volcanic and sedimentary rocks.
- Seismic hazards for the project area were recently estimated by Natural Resources Canada as outlined in the National Building Code (2005), and as summarized in Table 1.

Table 1: Seismicity Data (after NRC-GSC)

Locality	Ground Motion For Selected Probability Levels				
High Lake	Probability of Exceedance per annum	0.01	0.002	0.001	0.0004
	Probability of Exceedance in 50 years	40%	10%	5%	2%
	Peak Horizontal Ground Acceleration (g)	0.007	0.021	0.035	0.059

- Based on this data, and extrapolating for an extreme event, the 1:10,000 year return period event may be on the order of approximately 0.075g. This estimated seismic event is significantly larger than the value used in previous BGC reports.
- The High Lake Property is located in continuous permafrost. Site specific measurements for the West Zone reported in BGC (2006d) measured the base of the permafrost at about 440 m below ground surface (bgs). The geothermal gradient of the West Zone was approximated to be 1.6^{o}C/100 m depth.
- Active layer depths of approximately 1.5 to 3.5 m would be expected in ice-rich overburden materials and approximately 4 to 7 m in bedrock outcrops.
- BGC (2006a), located in Appendix XIV of BGC (2006d), notes that a through talik likely exists below High Lake, based on site specific permafrost measurements and two-dimensional geothermal modelling. A closed talik likely exists below the Kennarctic River and only slight variation to input assumptions result in the formation of a through talik beneath the river.
- Gartner Lee completed a hydrogeological assessment, provided in Volume 5, Section 2 of the EIS that noted the following main conclusions:
    - The groundwater quality in the High Lake talik generally meets the CCME guidelines for the protection of aquatic life with the exception of cadmium and copper. The quality of the groundwater within High Lake talik is similar to the surface water and with the exception of lower cadmium, copper and zinc concentrations and higher molybdenum values.
    - If a hydraulic connection exists through taliks, and assuming a higher water cover surface, deep groundwater flow from High Lake to the Kennarctic River would take 34 years while High Lake to Granite Lake (L4) would take over 100 years.

These bullets provide only selected points directly relevant to the High Lake TCF design provided herein.

2.2 Climate and Climate Change

At the current time, no long-term climate values are available specifically for the High Lake site. Five long-term climate stations are located several hundred kilometres either north or south of the High Lake site. As a result, it is necessary to estimate climate parameters for the High Lake site from these stations. RWDI (2006) estimated that the expected mean annual air temperature (MAAT) for the High Lake Project area is approximately -11.8^{o}C.

Based on regional correlations and some recent assessments done for the Hope Bay Gold Project, nhc devised for the following hydrological parameters for High Lake, which are provided in Volume 5, Section 1 of the EIS:

- Mean annual precipitation (MAP) – 280 mm, comprised of the following:
    - rainfall – 148 mm
    - snowfall – 132 mm (water equivalent).

- Mean annual lake evaporation – 240 mm (June 38 mm, July 104 mm, August 84 mm and September 14 mm).
- Runoff occurs from mid-June through to October (June 44%, July 28%, August 16%, September 9% and October 4%).
- Estimated 24-hour Probable Maximum Precipitation (PMP) – 158 mm.

In addition to the current "derived" (since they are not directly measured) climate parameters for the site, it is also necessary to address climate change parameters for the design of the tailings dams. Within Appendix I, BGC has prepared a summary of climate change design criteria for the site dams This memo reviews current amounts of measured warming in northern Canada, along with a summary of global warming allowances that have passed regulatory review of other northern projects. Various climate change forecasts based on general circulation and regional climate models are reviewed in the memo, which show significant variation. Based on the model forecasts, the measured site specific climate change amounts and recently permitted values for warming, BGC recommended that a warming value of 0.5^{o}C/decade be selected for the "base case" while 0.65^{o}C/decade be selected for the "high case" for the High Lake Project. In addition, it was recommended that a 25% precipitation increase over 100 years be allowed for; this total allowance translates into an increase in the snowfall by 25%.

2.3 Project Design and Assessment

Several other assessment reports have been prepared by the Project Team members that are directly relevant to the TCF design and brief summaries of that work are provided herein.

Wardrop (2006) provides a preliminary plan for the tailings pumping and discharge system into High Lake including the tailings overland pipeline (2,400 m of 200 mm diameter pipe) and the in-lake piping supported by floats (1,250 m long). Discharge of tailings will be below the water surface to prevent any ice entrapment in the tailings. Incremental discharge points on the pipe bottom will permit tailings placement at varying locations without having to move the pipeline. This will result in a relatively level tailings surface .Two discharge assemblies are proposed; one to the south end of the High Lake TCF for summer deposition and one to the north end for winter deposition.

Lorax (2006) provides a geochemical characterization of the waste rock and tailings for the project. Simulated tailings samples were tested for all three ore zones. Based on the net potential ratio (NPR), all three samples were designated as potentially acid-generating (PAG). Distilled water leachate tests from the tailing samples did not result in any parameters exceeding MMER guidelines but cadmium, copper, mercury and selenium concentrations were indicated to exceed CCME guidelines. Run-off dilution into High Lake would potentially mitigate the lab results in the actual pond performance. Lorax notes that tailings should be placed subaqueously to limit oxidation rates and metals release.

EnvirAubé (2006a and 2006b) reports on neutralization testing completed on water samples collected from High Lake, along with water management and treatment considerations. Neutralization tests were conducted with lime and ferric sulphate. The High Lake water was found to contain low total dissolved solids and therefore, this makes treating the high zinc concentration difficult. Options for treatment include a two step process in the main pond (raise the pH of the pond before dispersing ferric sulphate) or use of a polishing pond. The polishing pond can be used to treat almost any residual problem in the TCF supernatant water, subject to final design considerations such as pond size and depth.

Gartner Lee (2006) provided a water quality model for the High Lake tailings pond. Based on their assessment, no discharge of tailing water will occur until the end of Year 3. Following that time, active treatment of High Lake water will be required prior to discharge until Year 16 (2 years into closure). Following that, no treatment of High Lake water is forecast.

Nhc (2007) provided some hydrology and hydraulic design information for the current report, as attached in Appendix II. Where appropriate, their information is brought forward or referred to within this current report.

2.4 Project Layout

Figure 3 provides a view of the High Lake mine site. The High Lake Project includes two open pits (AB and D Zones), three underground mining areas (AB, D and West Zone) and a mill to process 4,000 tonnes of ore daily. Open pit mining will occur during the first four years using conventional drilling and blasting techniques. The waste rock and ore will be excavated and transported by truck to the process plant and surface rock piles while the excess mine rock will be stored near the open pits, directly proximal to High Lake. Therefore, any mine impacted seepage water would drain into the High Lake TCF.

The raw ore will be stock piled temporarily near the crusher before it goes through the various stages of crushing and grinding. The copper and zinc concentrate will be dried at the process plant, before being trucked to the dock site for shipment.

Tailings will be pumped to High Lake via a submerged pipeline to ensure the saturation of the tailings. Additional tailings will be stored in the AB Pit when mining is complete (and possibly the D Zone Pit as well) and backfilled with a mine rock cover. Supernatant water from the TCF will be reclaimed and used at the process plant or stored temporarily and released to the Kennarctic River in the spring or summer, when discharge criteria are met.

Infrastructure at High Lake will consist of maintenance shops, warehouses, accommodation facilities, the explosive storage and manufacturing facility, fresh process make-up and potable water supplies, sewage treatment and industrial (non-mining or processing) domestic waste disposal.

3.0 TAILINGS CONTAINMENT FACILITY

3.1 Tonnages, Volumes and Overall Plan

The following ore and tailings tonnages and storage capacities are provided for the High Lake Project:

- Total ore mined from A/B, D and West Zones – 18.2 million t.
- Mine Life – 14 years.
- Total concentrate produced – 2.0 million t.
- Total estimated tailings production – 16.2 million t.
- Estimated tailings dry density from BGC (2006b) – 1.3 to 1.43 t/m^3.
- Total tailings solids storage requirements – 11.3 to 12.5 (rounded to 12) million m^3.
- Tailings storage capacity back into A/B Pit (to Elev. 300 m) – 3.8 million m^3.
- Solids tailings storage requirement for High Lake TCF – 8.2 million m^3

Not taking into account the tailings beach slope, and using the lake bathymetry prepared by Gartner Lee previously and accounting for capacity lost due to the A/B waste dump, the tailings solids would fill High Lake to approximately Elevation 285 to 286, as shown on Figure 4. Allowing for the 2.5 m of water cover (for the reasons noted in BGC 2006b) over the tailings, the Full Supply Level (FSL) for the pond is set to Elevation 288.5 m. Nhc (2007) undertook a slightly different assessment but independently verified that an FSL of 288.5 m appears appropriate. Allowing for 1.5 m freeboard contingency storage (conceptual level estimates for PMP and wave height containment), the Maximum Water Level (MWL) is set at Elevation 290.0 m.

Tailings, at approximately 45% solids content, will be deposited into the High Lake TCF for Years 1 to 7, 10 and 14 and in the A/B pit for Years 7 to 10. Deposition into the A/B Pit will only occur after all the ore has been mined out. Supernatant water from the High Lake TCF and the A/B Pit will be recycled for use in the process plant. Yearly summer discharges will be required from the TCF to remove compliant water from the system. Losses of supernatant water into the recycle process water will be made up by use of fresh water received from Lakes L4 and L5 (GLL, 2006)

As noted in Wardrop (2006), the tailings will be pumped into High Lake using a 200 mm diameter pipeline. Two pipelines have been proposed for use; one during the mine operations and one as a stand-by line. Berms will be constructed on either side of the overland pipelines for protection and the pipelines will be placed on sand beds. In addition, leak and environmental protection will be installed. Catchment basins with liners will be constructed at low points. Discharge into the pit would likely occur from a tailings pipeline placed along a flatter grade of the pit haul road

The tailings deposited in High Lake will be pumped to the north end of High Lake in the winter and the south end in the summer to ensure solids will not exit to the Kennarctic River during the summer months. The tailings slurry will be deposited subaqueously to prevent the entrapment of ice within the tailings. The tailings deposition plan with moveable discharge points was designed to generate a relatively flat tailings surface (GLL 2006). This results in the efficient use of storage capacity and minimizes the final water cover depth.

3.2 Tailings Properties

Conventional slurry tailings will be produced and pumped into both the High Lake TCF and the A/B Pit after mining. The properties of the tailings produced will potentially impact both storage requirements (for solids and water) and deposition layout. Within the conceptual tailings work done under BGC (2006b), numerous assumptions based on experience were provided to facilitate the design work. Since that time, some metallurgical testing has been undertaken by SGS Lakefield and as such, bench-scale tailings have been produced. Following from those samples, which Wardrop has deemed to be “the best representative tailings samples to-date”, a geotechnical testing program was initiated by BGC which was undertaken by appropriate geotechnical laboratories in Thunder Bay and Mississauga. The following testing information is provided for tailings deposition planning within this current report:

- The bench-scale tailings grain size approximately meets the Wardrop tailings design curve. The D_{50} for the composite sample was about 70 μm while the Wardrop ‘s design D_{50} of 45 μm.
- Results from SGS Lakefield noted a specific gravity of 3.1 to 3.4 for the various fractions of the tailings samples.
- Results from TBT for the composite samples were 3.12 for the specific gravity values. This value is marginally higher than the value assumed in Table 3 of BGC (2006b).
- The Standard Proctir, Maximum Dry Density (SPMDD) for the tailings was 1.9 t/m^3 at an optimum moisture content of 15.5%.
- Two settling tests, drained and undrained, were performed on tailings samples placed initially at 45% solid content. The settled dry densities were 1.45 and 1.3 tlm^3 for the drained and undrained tests respectively. These values agree well with the estimated densities in Table 3 of BGC (2006b).
- Back-calculation of the respective void ratios (e) from the two settling tests provide values of 1.1 and 1.4 for the drained and undrained tests respectively. These values are approximately in agreement with the assumed void ratios noted in Table 3 of BGC (2006b).
- Consolidation test results on the tailings indicated a void ratio value of 0.78 under 50 kPa loading (~3 m of tailings), 0.75 under 200 kPa loading (~13 m of tailings) and 0.73 under 400 kPa loading (~26 m of tailings).

From these test results, it appears reasonable to use an initially settled dry density of 1.3 t/m^3 After some tailings are placed, the dry density would increase to approximately 1.7 to 1.8 t/m^3. As such, the storage volume calculation noted in Section 3.1 are conservative. The respective saturation water contents for each noted dry density are 42%, 27% and 23%.

3.3 Water Cover Requirements and Water Balance

Since the tailings placed in High Lake are acid generating, a water cover is needed to prevent oxidation of the tailings. The water cover will also prevent the tailings from becoming suspended by wave erosion, ice rafting and scouring. GLL measured ice thicknesses around the vicinity of High Lake in 2005 and 2006 and determined that the maximum ice thickness to be 2.2 m. There is the possibility that greater ice thicknesses could exist, but approximately 2.5 m of water cover is an adequate assumption to prevent the freeze back of the water cover to the underlying tailings.

Gartner Lee (2006) completed a detailed water balance based on 21 mine components. No discharge was required in the first three years of operation, while after that period, 400,000 to 1.5 million m^3 were estimated to be discharged yearly. Since the Polishing Pond only retains some 100,000 m^3 of water, numerous batches will need to be discharged from High Lake down to the Polishing Pond and then into the Kennarctic River by siphons.

3.4 Water Management and Discharge Methodology

Prior to the construction of some dam sites, cofferdams will need to be constructed on the upstream side of the proposed dam locations, as discussed further in Section 5.8. In addition to its cofferdam role, the dyke could also act as a filter berm during tailings placement. The northern portion of High Lake will be separated from the southern portion by a filter berm structure that will separate the solids and water. Therefore, the northern portion of High Lake will act as an internal polishing pond for the water before it is discharged to the external polishing pond. Water will be discharged from High Lake to the Polishing Pond by decant siphons during the summer (mid June to mid September). After being stored temporarily for potential treatment, the water will be transported by decant siphons to the appropriate drainage basin.

Nhc (2007), in Appendix II, provides an estimate of the siphon capacity required to discharge the 1:100 year surface runoff rate. Based on their assessment, a total discharge rate of 0.247 m^3/s would be required. This rate can be achieved with a single smooth pipe siphon with an internal diameter of 300 mm and a head difference of 3 m.

4.0 DAM FOUNDATION CONDITIONS

4.1 Subsurface Investigations

Limited geotechnical site investigations were completed by BGC in 2004 and Wardrop in 2005, as reported in BGC (2006d). The boreholes drilled did not determine the ground ice conditions or assess the proper FAB depth as they were drilled with warm water and not chilled brine. Four boreholes were drilled within the vicinity of High Lake in 2004. In addition, geophysical investigations at select dam sites were undertaken in 2004 as well. Five boreholes were drilled in the area of the TCF and the Polishing Pond in 2005, while three boreholes were drilled in the area of the plant site.

Six thermistors were installed in 2004 to determine the ground thermal regime at the Ulu Mine Site, within the proposed tailings dam foundations at High Lake, dock area and proximal to the West Zone ore body at High Lake. Six thermistors were installed in 2005 around the High Lake property, including the proposed dam locations, plant site and West Zone. Three of the thermistors installed were deep thermistors in the West Zone that were used in combination with the 2004 deep thermistor to define the depth of permafrost in the area.

Further geotechnical investigations were conducted by BGC in 2006 using chilled brine to collect subsurface information, such as ground ice conditions and depth to FAB. In 2006, 25 boreholes were drilled in the vicinity of the proposed tailings containment facility, plant site and Polishing Pond and eleven thermistors were installed. A surficial geological mapping program was also performed in 2006. The results from this program are provided in BGC (2007).

4.2 Foundation Conditions

The following sections outline the details of the proposed dam locations and the foundation conditions. The information was derived from the subsurface investigations conducted between 2004 and 2006 and the observations collected during the field mapping conducted in August 2006.

4.2.1 East Dam

The East Dam is located approximately 450 m to the northeast of the south end of High Lake as shown on Figure 2. The proposed dam alignment runs parallel to the long axis of High Lake and the alignment details are shown on Figure 5. The dam is located in a topographic low area with an undulating bedrock surface covered with a veneer of till or organic material. A seepage zone was noted immediately east of the downstream toe of the East Dam in the FAB. An outflow channel from High Lake to the Kennarctic River is located near the south abutment of the East Dam.

Frost affected bedrock and overburden were found on the flanks of the left abutment, but otherwise, the rock was noted to be fairly tight and massive. An occasional joint set perpendicular to the foliation was observed and a joint set with 10 m continuity that extended upstream and downstream of the dam location was also noted. The latter joint could potentially serve as a seepage conduit, if not properly mitigated. A potential low spot was observed in the vicinity of the left abutment, but it was completely closed off by bedrock so seepage should not be a problem. Frost affected bedrock was also observed in the vicinity of the right abutment. Otherwise, the bedrock was noted to be fairly massive with a veneer of organic or till material.

The geological mapping concluded that the foliation of the tuff in the vicinity of the East Dam was generally striking north and south and dipping between 66° and 80° to the west. The joint sets were found to have varying strikes, but typically dipped between 80° to 85°.

Five boreholes, BGC04-07, BGC06-05, BGC06-06, BGC06-24 and BGC06-25, were drilled within the proposed footprint of the East Dam. Figure 6 provides a longitudinal section of the East Dam, showing borehole information and preliminary dam design details.

A thin layer of peat (organic material) was found to be overlying frost affected tuff bedrock in all boreholes. Silty sand till was noted on the joint surfaces of the FAB and the ice content of the till typically ranged between 5 and 30%, if the ice was visible. The moisture content of the till was found to range between 6.7 and 19.8%. The depth to the top of intact rock ranged between 0.2 and 5.9 m bgs.

The bedrock encountered during the geotechnical investigation was found to be a light grey, fine grained, fresh to slightly weathered tuff. The unit was generally strong to very strong (R4 to R5) and was foliated between sub parallel and 30° to the core axis. Calcite and quartz infilling and iron oxidation were noted on the joint surfaces in addition to sulphide mineralization. Calcite veining and banding were also noted in the rock mass. Chloritic alteration was noted at BGC06-06 while at BGC06-25, the rock was noted to break easily along the foliation planes.

The RQD values typically ranged from good to excellent (RQD ranging between 75 and 100%) but there were several runs where the RQD was poor to fair (RQD ranging between 39 to 67%). At BGC06-25, the RQD ranged from fair to good (RQD values between 67 and 90%) and lower RQD values were noted between 10.4 and 15.1 m (RQD values between 52 and 59%). At BGC06-07, very poor rock (RQD 0% and close joint spacing) was recorded from 1.5 to 3.0 m bgs. Drill circulation was lost at a depth of approximately 4.5 m.

Thermistors BGC04-07, BGC06-05, BGC06-06 and BGC06-25 were installed within the proposed footprint of the East Dam. Thermistors BGC06-05 and BGC06-06 ceased working approximately two weeks after installation but no visible signs of damage were noted. Therefore, a thermistor was installed in BGC06-25.

The active layer depth at the East Dam appeared to be much deeper than the active layer at the other proposed dam sites. At BGC04-07, above 0°C temperatures were observed to a depth of approximately 7 m at the end of August 2006 while the active layer depth based on the August 2006 data was approximately 6.5 m at BGC06-25. This thawed layer typically cooled off at BGC04-07 as the winter progressed and was generally completely frozen by mid-December. The deep thaw depth was most likely due to the proximal flowing water from the outlet stream and High Lake along with the relatively high thermal conductivity of barren bedrock in the area.

The mean annual ground temperature (at approximately 25 m), was relatively stable at approximately -3.5^{o}C at BGC04-07 while the 20 m bead was stable at -2.7^{o}C at BGC06-25. The temperature at 25.0 m depth is significantly warmer (1.5^{o}C) than, the other proposed dam locations, which indicates the warming impact of the surface water flow in this area. No talik has been observed in the dam footprint to date.

4.2.2 Northeast Dam

The Northeast Dam is located approximately 40 m north of High Lake and is approximately 360 m in length. Figure 7 provides a plan view while Figure 8 provides a longitudinal section. The right abutment of the Northeast Dam is founded on massive and tight bedrock that is covered with a veneer of till. The eastern portion of the Northeast Dam traverses till veneer, bedrock and organic material into addition to two meltwater channels. The western portion of the Northeast Dam traverses a morainal blanket (approximate elevation of 286 m) and then rises in elevation to approximately 288 m as it crosses a bedrock knob. The left abutment, however, is founded on massive bedrock.

The eastern section of the proposed dam centreline crosses old fluvial channels and topographic low points that may act as potential seepage conduits. The channels vary from 1 to 3 m wide and are generally filled with alluvium and boulders. To the southeast of the Northeast Dam, a seepage zone filled with boulders was encountered during the field traverse. It is possible for water in the seepage area to flow either through the active layer or FAB out of High Lake or in a northerly direction to the downstream side of the Polishing Pond.

Four boreholes BGC04-03, BGC06-10, BGC06-11 and BGC06-12 were drilled within the proposed footprint of the Northeast Dam while BGC06-09 was drilled on the downstream side of the Northeast Dam. The geotechnical investigation in the vicinity of the Northeast Dam revealed that a layer of overburden up to 0.5 m thick was found to be overlying silt and sand till with some gravel. The ice content of the till ranged between 5 and 30% at BGC06-10 and 30 to 50% at BGC06-11. At BGC06-12, boulders were noted between 0.03 and 1.3 m bgs and a till matrix was encountered between the boulders. The estimated ice content of the till matrix ranged between 15 and 30%. The ice content at BGC06-09 ranged between 5 and 40%. The moisture content of the sand and silt till at BGC06-10 and BGC06-11 was found to range between 5 and 13% while the moisture content of the gravel and sand till encountered at BGC06-12 was determined to range between 3 and 11%.

Frost affected metavolcanic bedrock with sand till on the joint surfaces was encountered below the till and cobble layers. The depth to the top of intact bedrock ranged from 0.6 m at BGC06-11 to 3.4 m at BGC06-10.

Metavolcanic bedrock was encountered in all the boreholes drilled within the eastern section of proposed Northeast Dam footprint. The metavolcanic bedrock encountered in the vicinity of the proposed Northeast Dam footprint was dark green, strong to very strong (R4 to R5) and fresh to slightly weathered. Quartz and calcite infill with hematite and chloritic alteration on joint surfaces were noted. Quartz and calcite veins/veinlets were also observed. Quartz phenocrysts (1 to 5 mm in diameter) were noted in the core at BGC06-11. Porphyroblasts of feldspar, hornblende and pyroxene were noted in the core at BGC04-03.

The RQD in the vicinity of the Northeast Dam ranged from very poor to very good. At BGC04-03 several highly altered (chloritic gouge), rubble sections were encountered between 12.5 m depth and extending to a depth of 17.0 m. At BGC06-10 the RQD was very poor between 7.6 and 9.7 m (RQD ranging between 0 and 11%) and typically fair to excellent (RQD ranging between 58 and 97%) for the remainder of the rock. At BGC06-11 the RQD was very poor to fair (RQD ranging between 0 and 61%) between 32.5 and 35.2 m and 35.9 and 37.6 m. The RQD generally ranged from fair to excellent (RQD of 68 to 100%) in the core intervals not identified above. At borehole BGC06-12 very poor to poor RQD values (RQD ranging between 17 and 25%) were noted between 5.8 and 7.3 m while fair RQD values (RQD value of 56%) were noted between 2.8 m and 4.2 m. Excellent RQD (RQD ranging between 90 and 100%) was noted in the remainder of the core intervals.
During the geotechnical investigation it was noted that the bedding planes at BGC04-03 were steeply dipping to vertical. The geological field mapping indicated that steeply dipping joints to sub vertical joints, joints dipping approximately 50° and joints dipping approximately 25° had various strikes ranging between 004° and 170°.

The active layer thaw at BGC04-03, located on the till blanket about 90 m east of the left abutment, based on summer 2005 and August 2006 data, was recorded at a depth of approximately 1.8 m. The 10 m depth bead varied between -4.9^{o} and -7.0^{o}C and the 25 m bead was found to be non-functioning during the recorded interval. No talik was observed within the monitored 10 m depth.

The active layer thaw depth at BGC06-11, located in a melt water channel approximately 90 m northwest of the right abutment, based on the August 2006 data, was approximately 4.2 m. However, a full season of freezing and thawing will be required to accurately estimate the active layer depth at this location. At a depth of 25 m, the ground temperature was relatively stable at -4.2^{o}C during the recorded interval. No talik was recorded at this site to date.

4.2.3 Northwest Dam

The proposed Northwest Dam is located between High Lake and L-15 at the northwestern end of High Lake and is approximately 215 m in length. The right abutment of the Northwest Dam is located on fairly tight and massive bedrock. The topography between the proposed right dam abutment and dam apex decreases in elevation from around 290 to 283 m (High Lake surface elevation) and then increases in elevation to approximately 286 m in the vicinity of the dam apex. Till veneer and exposed bedrock cover the footprint of the proposed dam foundation on both sides of High Lake. Boulders up to 1 m in diameter were noted between High Lake and L-15. Between the dam apex and the left abutment, the proposed Northwest Dam footprint crosses organic, glaciofluvial and till material. At the left abutment, FAB and bedrock with a veneer of glaciofluvial or ablation till was noted. Potential active zone seepage concerns were also noted between the Northwest Dam and the Northwest Channel Dam. The rock in this area is frost jacked with a veneer of till.

Figures 9 and 10 provide plan and longitudinal section views of the proposed Northwest Dam. Two boreholes, BGC06-13 and BH-GT05-07 were drilled within the vicinity of the proposed Northwest Dam alignment.

Borehole BH-GT05-07 was drilled vertically within the island separating High Lake and L-15 with warm water and therefore, detailed information regarding ice content and FAB depth was not obtained. It was estimated that 2 m of overburden and FAB was present at this borehole location. At BGC06-13, a thin layer of organic material was found to be overlying FAB. The FAB was found to have 1 to 2 cm interbeds of silty sand till on the joint surfaces. The ice content of the till was estimated to be approximately 5%.

Metavolcanic bedrock was encountered in the boreholes drilled in the vicinity of the proposed Northwest Dam. The bedrock was described as massive, dark greyish green and strong to very strong rock (R4 to R5). The rock was fresh to slightly weathered and calcite and quartz infill were noted on the joint surfaces. Hematite alteration was prevalent throughout the rock mass. Sulphide mineralization was noted on some joint surfaces. Discontinuities consisted predominantly of cross joints at variable orientations. The foliation of the bedrock was found to strike approximately north/south and have a sub-vertical dip. Local areas of weak to intense silicification gave the rock a cherty character at BH-GT05-07.

Borehole BH-GT05-07 encountered a small section of chert between 15.5 and 16.9 m. The chert was described as a medium green to reddish brown, aphanitic, extremely hard, massive to brecciated rock that broke with conchoidal fractures. Discontinuities were generally cross joints at angles between 70 and 90 degrees to the core axis. The chert contained 2 to 3% quartz-calcite veinlets, stringers and fracture fillings.

The RQD typically ranged from fair to excellent (RQD values ranging between 50 and 100%) at BGC06-13. Very poor to poor RQD intervals were encountered between 3.4 to 5.4 m, 15.4 to 16.5 m and 17.8 to 20.8 m (RQD values ranging between 23 and 48%). Minor chloritic alteration was noted at 44.9 m. The RQD was poor to fair (RQD ranging between 50 and 57%) in the upper 10 m of BH-GT05-07 and good to very good (RQD ranging between 88 and 97%) below 10 m.

Thermistor BH-GT-05-07 was installed on the island located between High Lake and L-15. The active layer thaw at this location, based on summer 2005 and August 2006 data, was recorded at a depth of approximately 6.0 m. The active layer depth at this location appears to be larger than at other locations. This could be attributed to the proximal location of this borehole to surface water flows from both High Lake and L-15. The temperatures below 6 m depth are subzero and no talik is indicated.

The active layer depth at thermistor BGC06-13, based on the August 2006 data, was approximated to be 4.0 m but a full season of freezing and thawing will be required to accurately estimate the active layer depth at this location. The 25 m bead was relatively stable with temperatures ranging between -4.1^{o} and -4.3^{o}C during the recorded period and no talik has been observed at this location to date.

4.2.4 Northwest Channel Dam

The Northwest Channel Dam is located approximately 180 m south of L-15 and is approximately 115 m in length. The dam is located in a topographic low area with fluvial, felsenmeer and thin morainal material. In the right and left abutment areas some FAB with a veneer of ablation till was observed. The left abutment area showed evidence of periglacial influence and movement. Standing water on permafrost was noted in the area during the site investigation conducted in May 2006 but the area was dry during the geological mapping program conducted in late August.

Figures 11 and 12 provide plan and longitudinal section views respectively. Two boreholes, BGC06-15 and BGC06-16, were drilled within the proposed footprint of the Northwest Channel Dam.

In the vicinity of the proposed Northwest Channel Dam footprint, a thin organic layer was found to be overlying silty sand till and FAB with silty sand till on the joint surfaces. The depth to the top of intact rock ranged from 0.7 m to 2.7 m bgs. At BGC06-16, frozen organic soil was located over the FAB. The moisture content of the organic soil layer was determined to be approximately 72%.

The meta-volcanic bedrock encountered in the two boreholes was dark greyish green, very strong to extremely strong (R5 to R6), fresh to slightly weathered, moderately jointed with calcite and quartz infill on the joint surfaces. Quartz and feldspar phenocrysts and quartz and calcite veins/veinlets were observed in the rock mass. Chloritic alteration was noted in the rock mass. At borehole BGC06-16, minor hematite staining was noted. The foliation of the bedrock was found to have a strike between 155° and 175° with a vertical dip.

In BGC06-15, the RQD ranged between poor and good and the RQD values between 0.8 and 35.5 m were highly variable (0 to 99%) with at least half of the runs having an RQD less than 60%. The RQD between 35.5 m and 51.3 m was good to excellent (RQD ranging between 76 and 94%) with the exception of 43.4 and 43.6 m where the RQD was poor (48%). At 33.8 m, the rock was decomposed to soil and slickensides were visible. Between 49.7 m and 50.0 m, crushed rock coated with silty clay was visible. The RQD between 2.7 and 10.2 m at borehole BGC06-16 ranged very poor to poor (RQD ranging between 0 and 46%) as the rock was highly fractured. Below 10.2 m bgs, the RQD improved to good (85%). Sloughing was encountered in the borehole between 8.0 and 8.2 m.

A 50 m thermistor was installed in borehole BGC06-15. The active layer depth, based on the August 2006 data, was approximately 4.0 m. The 25 m bead was relatively stable at -4.2^{o} C during the recorded interval and no talik has been recorded at this location to date.

4.2.5 Polishing Pond Dam

The Polishing Pond Dam is located in between L30 and L29, approximately 350 m northeast of the north end of High Lake as shown on Figure 2. The proposed dam alignment trends east/west for approximately 120 m between lakes L29 and L30 and then trends north/south for approximately 240 m. The Polishing Pond Dam is located in fluvial or morainal material and ranges between 272 and 276 m in elevation as shown on Figure 13. Some surficial material in the vicinity of the Polishing Pond Dam was noted to have undergone periglacial movement (i.e., solifluction lobes).

Four vertical boreholes, BH-GT-05-08, BH-GT-05-09, BGC06-07 and BGC06-08 were drilled to approximately 20 to 25 m bgs within the proposed footprint of the Polishing Pond Dam. It should be noted that the drilling conducted in 2005 did not assess the ground ice conditions of the overburden or frost affected bedrock as it was drilled with warm water. The longitudinal section showing borehole information and preliminary dam design details for the Polishing Pond Dam is provided on Figure 14.

Generally, a thin peat layer was found to be overlying sandy silt till at the borehole locations. The ice content of the individual ice inclusions in the upper 0.6 m at BGC06-07 was found to range between 1 and 5% while the stratified ice content in the lower 0.8 m was found to range between 30 and 40%. The individual ice inclusion content was found to range between 3 and 35% at BGC06-08. The moisture content of the till overburden and till found on the frost affected bedrock joint surfaces was found to range between 7 and 23%. The depth to the top of intact bedrock was found to range between 1.4 and 3.6 m.

Metavolcanic bedrock was encountered in the boreholes drilled in the proposed footprint of the Polishing Pond Dam. The bedrock was light greyish green to dark greyish green, very fine grained, fresh to slightly weathered and strong to very strong rock (R4 to R5). Calcite infilling and iron staining were noted on the joint surfaces and healed calcite fractures were prevalent. Quartz and calcite veining were also common in addition to sulphide mineralization. Slight to strong pervasive epidote alteration was observed in the bedrock at BH-GT05-08 while a relict fault zone (partially healed with calcite and partially infilled with crush rock and fault gouge) was observed between 6.1 and 7.0 m at BGC06-08. An old shear zone healed with calcite was also encountered between 17.5 m and 18.2 m. At BH-GT-05-09, fault gouge was noted between 13.1 and 14.0 m while a dike was encountered between 14.0 and 16.9 m. Metavolcanic bedrock was encountered above and below the fault gouge and dike.

The RQD varied in the vicinity of the Polishing Pond Dam. The RQD values were poor to fair (RQD ranging between 29 and 51%) between 1.4 and 10.0 m and good to excellent (RQD between 75 and 100%) at greater than 10 m in depth at BGC06-07. Meanwhile, the RQD ranged between very poor to excellent (RQD values ranging between 0 and 97%) at BGC06-08. Very poor to poor RQD (RQD values ranging from 0 to 49%) was noted from 5.5 to 11.3 m, 17.5 to 19.0 m and 20.5 to 23.5 m. Very good RQD values (RQD ≥ 93%) with the exception of the upper 2 m of the bedrock, which had a RQD of 79% was encountered at BH-GT-05-08. The RQD was lower (minimum RQD of 40%) at BH-GT-05-09. The poor rock quality was due to highly altered sections with weak and friable rock material at two different depths (approximately 8 m and between 13 m and 14 m). These sections contained fault gouge and a high chlorite content.

The left abutment of the Polishing Pond Dam is founded on a 5 m high knob of sandy silt till with some gravel. Massive, rounded metavolcanic bedrock was noted between BGC06-07 and the dam apex. Downstream of the dam apex, 1.6 m of FAB was observed and the bedrock outcrop was imprinted with a veneer of glaciofluvial material and large rounded boulders.

The north/south trending portion of the Polishing Pond Dam was found to traverse an ancient channel and till blanket. Large quantities of boulders, up to 2 m in diameter, were encountered between the dam apex and the right abutment of the Polishing Pond Dam. The right abutment of the Polishing Pond Dam is to be founded on massive bedrock.

The active layer depth, based on the August 2006 data, was approximately 1.5 to 2.0 m in the proposed footprint of the Polishing Pond Dam. However, a full season of freezing and thawing will be required to accurately estimate the active layer depth at this location. No talik has been observed at this site to date.

4.2.6 Contact Lake Dam

The Contact Lake Dam is located approximately 300 m southwest of High Lake and is approximately 100 m in length. The purpose of the Contact Lake Dam is to divert clean runoff water from Contact Lake away from the TCF and into the Kennarctic River. An overflow channel will be constructed to divert the clean Contact Lake water to the Kennarctic River. The channel is to be located in an organic covered felsenmeer valley with massive bedrock on both sides. The bedrock along the shoreline of Contact Lake was found to be frost jacked.

The Contact Lake Dam is located in a topographic low point. The bedrock exposures were found to be highly weathered, gossanous and covered with felsenmeer (boulders up to 1 m in diameter) and fluvial material. The ground was also noted to contain some patterned ground likely indicative of ground ice. The left abutment area was located on till veneer and bedrock while the right abutment was located on massive bedrock with few joints and no frost jacking. The surficial material was classified as a till veneer. To the southeast of the left abutment area, the overburden material was highly weathered and the bedrock highly fractured.

Figures 15 and 16 shows the plan and longitudinal views of this dam. Boreholes BGC06-19 and BGC06-20 were drilled vertically within the vicinity of the Contact Lake Dam, as shown on the figures.

At borehole, BGC06-19, a thin organic layer was found overlying the FAB. The depth to the top of intact bedrock was found to be 1.2 m. Borehole BGC06-20, was drilled in the vicinity of the D-Zone Pit. During drilling, silt till was encountered over gravel and cobbles and frost affected meta-volcanic bedrock. The ice content of the overburden material ranged between 5 and 40%. The depth to intact bedrock was 5.1 m. The moisture content of the sand silt till found on the frost affected bedrock joint surfaces was found to range between 4 and 8%.

The metavolcanic bedrock encountered was grey to greenish grey, very strong (R5), fresh to slightly weathered and moderately jointed. Calcite and quartz infill were noted on the joint surfaces in addition to calcite and quartz veinlets. Hematite alteration and siliceous epidote alteration was also prevalent. Quartz phenocrysts were observed in the rock mass at BGC06-20 from 26.0 m to the end of the borehole. The joint sets in the vicinity of the Contact Lake Dam footprint are steeply dipping to vertical with strikes ranging between 80° and 175°.

At BGC06-19, the bedrock was found to have a good to excellent RQD rating (RQD values ranging between 81 and 98%) and below 15.6 m at BGC06-20, the bedrock had RQD values ranging between 68 and 100% with the exception of 23.0 to 23.5 m, 29.0 to 30.5 m and 37.9 to 38.5 m where the RQD was very poor (RQD values ranging between 0 and 20%).

Between 5.1 and 15.6 m at borehole BGC06-20, the RQD was very poor (0%) and decomposed rock (S5 to R0) was commonly noted between 12.1 m and 15.1 m. As indicated by the very poor RQD values, the rock was very broken between 5.6 and 12.1 m. Slickensides were noted on the decomposed rock between 14.2 and 15.1 m. The poor RQD values and decomposed rock were attributed to the proximity of the borehole to the D-Zone, where various geological processes likely resulted in the alteration weathering of the adjacent bedrock.

The active layer depth at BGC06-20, based on summer 2006 data, was approximately 2.0 m. A full season of freezing and thawing will be required to accurately estimate the active layer depth. The 25 m deep bead was relatively stable at -4.1^{o} C during the recorded interval. No talik has been observed at this location to date.

5.0 DAM DESIGN

5.1 Design Criteria

5.1.1 Consequence Categories

Some design criteria for dams, including tailings dams, are usually set relative to the failure consequence category for the dams. CDA (1999) presents the consequence categories for dams as noted in Table 2.

Table 2: Classification of Dam In Terms of Consequences of Failure (after CDA 1999)

Consequence Category	Potential Incremental Consequences of Failure	
	Life Safety	Socioeconomic, Financial & Environmental
Very High	Large number of fatalities	Extreme damages
High	Some fatalities	Large damages
Low	No fatalities anticipated	Moderate damages
Very Low	No fatalities	Minor damages beyond owner's property

The guidelines note that the "criteria which define the Consequence Categories should be established between the Owner and regulatory authorities, consistent with societal expectations." Within Nunavut, the CDA guidelines have been applied to establish consequence classifications for dams being permitted on other projects.

For the proposed High Lake tailings dams, no fatalities would be expected from a potential failure due to the remote location and the topography of the site. Depending upon the water quality within the TCF pond, moderate to large damages could be anticipated. The damages would potentially consist of remediation work, habitat compensation, fines and regulatory penalties, along with compensation payments to impacted stakeholders. Based on a subjective assessment of potential consequences, BGC classified the High Lake dams as high consequence dams while the Contact Lake Dam could be ranked as low consequence. This classification ranking was based on BGC's best judgement and does not reflect the views of the stakeholders or regulatory agencies. It is possible that a detailed review of the potential consequences could change these suggested consequence ranking.

5.1.2 Specific Criteria

Following from the noted consequence rankings, several design criteria fall out that would be appropriate for the design of the High lake tailings dams, as summarized in Table 3.

Table 3: Dam Design Criteria (after CDA 1999)

Consequence Category	Maximum Design Earthquake (MDE)		Inflow Design Flood (IDF)
	Deterministic	Probabilistic	
High	50 to 100% MCE**	1/1,000 to 1/10,000	AEP* between 1/1,000 and PMF
Low	Un-stated	1/100 to 1/1,000	AEP between 1/100 and 1/1,000

* AEP - annual exceedance probability
** MCE - maximum credible earthquake

As such, design criteria of 50% MCE (approximately) and PMF were chosen for design criteria for the high consequence dams around High Lake.

In addition, due to the proximity of nearby water bodies such as L15 and the Kennarctic River, the following dams were designed with as low as practical seepage potential during operations and during closure (period assumed to be 100 years for design basis):

- East Dam.
- Northwest Dam.
- Northwest Channel Dam.

The Northeast and the Polishing Pond Dams were designed to have as low as practical seepage during operations and partially into the closure period. It was deemed that only partial seepage cut off was required as the design criteria for the Contact Lake Dam. Seepage around this dam would be of minor consequence.

The dams will need to be constructed of local materials and the only potential sources are as follows:

- Esker sand, gravel and cobbles derived from Sand Lake esker to the north of the mine site.
- Rockfill from pit strippings or from specially developed quarries (dependent upon geochemical nature of the source bedrock).
- Processed crushed material from pit strippings or from specially developed quarries (dependent upon geochemical nature of the source bedrock).
- No appropriate fine-grained materials are available for the dam and as such, geosynthetic liners will be required for the water retaining element.

Since seepage must be absolutely minimized, the rockfill and liner dams will be constructed over a frozen foundation of permafrost bedrock. In addition, it should be noted that cut off trench excavation will need to occur likely in the winter such that seepage inflows are minimized due to frozen ground.

As noted earlier, water quality modelling by Gartner Lee indicates that discharge of tailings pond can occur in Year 16 of the mine (two years into closure). As such, this allowance becomes one of the important design considerations for the dams and the TCF.

5.1.3 Freeboard and Height Rationale

Since no spillways are proposed during operations, each High Lake dam will require additional freeboard height above the FSL to ensure floods and associated wave can be retained by the liner. The estimated freeboard amount is added to the FSL to determine the Maximum Water Level (MWL) for each dam.

Based on the 24 hour PMP of 158 mm, BGC (2006b) estimated the resulting flood volume for the TCF to be 380,000 m^3 while the flood volume for the Polishing Pond area was determined to be 7,600 m^3. The storage capacity curves for High Lake and the Polishing Pond indicated these flood volumes would result in a 0.4 m and 0.2 m increase in the water cover for the TCF and Polishing Pond, respectively.

The maximum wave heights for TCF and the Polishing Pond were also estimated within BGC (2006b). Using a maximum wind velocity of 28 m/s (RWDI, 2006) and fetch lengths of 2.1 and 0.26 km, wave heights of approximately 1.0 and 0.4 m were calculated for the TCF and Polishing Pond., respectively. These preliminary wave height estimates did not include any allowance for run-up.

After combining the requirement for freeboard from the PMP and estimated wave heights, it was determined that the 1.4 and 0.6 m increase in freeboard was required. Therefore, to be conservative, the "rounded" freeboard values were estimated to be 1.5 and 1.0 m for the TCF and Polishing Pond, respectively.
Table 4 below summarizes the dam height rationale for the High Lake and Polishing Pond dams:

Table 4: Summary of Dam Height Rationale

Aspect	High Lake Dams	Polishing Pond Dam
Tailings Solids Elevation	Elev. 286 m	N/A
Water Cover Depth	2.5	N/A
FSL	Elev. 288.5 m	Elev. 277.4 m
Freeboard Amount	1.5	1.0 m
MWL	Elev. 290.0 m	Elev. 278.4 m
Crest Cover Layer	0.6	0.6 m
Top of Physical Crest	Elev. 290.6 m	279.0 m

The Contact Lake Dam height was based on simplifying assumptions, rather than detailed hydrology. The current elevation of Contact Lake is 293.4 m. It was assumed that Contact Lake would rise by 1 m to a FSL of 294.4 m. A further allowance of 1.5 m gives a MWL of 295.9 m. The total dam height will be 296.5 m, which is an additional 0.6 m above the MWL. Detailed hydrology and water balance for this dam should be undertaken during final design of this dam.

No allowances for dam settlement were made in this current design due to the relatively low dam heights, bedrock foundation and the proposed use of rockfill. During final design, it is possible that a small allowance could be selected within the freeboard allowance, if deemed so appropriate.

5.2 Section Description and Elements

Section 5.1 laid out the appropriate dam design criteria for the TCF dams. Due to the similar ground conditions and the availability of construction materials at site, the six dams have a proposed similar design. This concept is a rockfill dam located over top of frozen foundation (not the same as a frozen core dam) and significant elements are as follows:

- All dams will comprise a rockfill embankment section which provides for a stable and robust design able to withstand seismic deformations and overtopping, if these events occur.
- The water retaining element will be an upstream sloping geomembrane (GM) that folds back on itself under the centreline of the dam crest and ties into intact, frozen bedrock. This is done to ensure seepage cut off through the FAB unit located between overburden and intact bedrock.

- The cut off trench depth varies between 2 and 6 m below the original ground surface, with the exception of Contact Lake where a 1 m cut off trench depth has been assumed (subject to further investigation).
- Bedding/cover layer and transition zone materials are located around the liner to protect it and control seepage, in the very unlikely event that such an issue occurs.
- Riprap material will be placed on the upstream slope to prevent erosion from wave and ice action.
- Crushed material will be placed on the dam crests for trafficability and access.

Additional discussion on the liner system and geothermal design of the dams is provided in Sections 5.3 and 5.4, respectively. These two sections provide rationale required to confirm the geometry of the dams to meet the noted design criteria. Section 5.5 then provides dam specific details on the proposed designs.

5.3 Liner System

5.3.1 Overview, Options and Longevity

Within the dams around High Lake, a liner system is required to retain water for the design life of the dams, nominally set at 100 years. Geosynthetic materials are a required component due to a lack of any low-permeability natural materials at site. Potential GM liner materials include the following:

1. High density polyethylene - HDPE.
2. Linear low density polyethylene - LLDPE.
3. Polypropylene - PP.
4. Geosynthetic clay liner - GCL.
5. Bituminous geomembranes - BGM.

Benson (2000) reviews the general advantages and disadvantages of each liner type, while Reddy and Butul (1999) review failure mechanisms within liner systems. Bouazza (2002) provides a comprehensive review of GCL design and performance issues. Some general comments relative to northern projects on these GM materials are as follows:

- HDPE has a long and proven track record, including use in Canada's north with extrapolated values of longevity of several hundred years.
- Both LLDPE and PP have been used in "recent" dam designs in northern environments including the Pogo Mine in Alaska and the new dam at Colomac Mine in the NWT. Both LLDPE and PP have better elongation properties than HDPE and are viewed as "more flexible" for cold weather installation.
- GCL's are overlapped panels and are not a liner of continuous confirmed integrity. They are generally used in combination with a primary liner such as a frozen core or other primary liner within selected dams in the north.

- BGM's have been used in Europe for decades in dams and waste isolation projects and have recently been installed at the Diavik Mine site.

In addition, as noted earlier, the potential for any seepage through the High Lake dams (not including the Contact Lake Dam) must be completely minimized. As such, a high-quality composite liner system consisting of two liners (a primary and a secondary) is recommended. The primary liner should be able to fulfill its intended role of complete water retention. The secondary liner is redundant and only fulfills its role should imperfections in the primary liner result in some seepage. Hence, the primary and secondary liners should have complimentary (and different) properties. The two recent dam examples noted earlier used the following liner systems:

- The Pogo Mine RTP Dam (approximately 27 m high) liner system consists of a textured 60 mil (1.5 mm) LLDPE GM underlain by a GCL, as reported in Davies and Veillette (2006). This liner was installed on 3H:1V slope.
- The new dam at Colomac Mine used a liner system of protective geotextile, 60 mil PP GM underlain by GCL. This liner system was installed at 3:1 steepening to 2.5:1.
- Hayley et al. (2004) notes the Waste Rock Dam at Ekati Mine contains a composite liner of three components; a 542 g/m^2 non-woven geotextile, a 40 mil PP GM followed by a GCL.

For the High Lake Dams, either of the following composite liner systems are proposed:

- 60 mil HDPE GM over GCL.
- 60 mil LLDPE GM over GCL.

PP GM's were excluded from the final option list due to the lack of texturing available on the surface. This GM feature allows for the proper and safe installation of the liner, especially in cold regions where overnight condensation and frost accumulation are typical occurrences. BGM's were excluded from final consideration due to their lack of northern track record and from their point specific quality assurance (QA) program. It is possible that these GM's could be considered during final design, should some of the noted issues be resolved.

Bouazza (2002) notes that small penetrations and defects (including open holes up to 30 mm size) can be effectively sealed by the bentonite within GCL's. In addition, he notes that they can maintain their hydraulic integrity over the long term. As such, the GCL characteristics are complementary to the synthetic GM proposed.

The other component of the liner system includes the bedding and covering materials around the dual liner. Two potential materials are available for construction at the High Lake site:

1. Screened sand derived from the Sand Lake esker, approximately 12 km north of the site. This source would likely result in durable, rounded sand and gravel particles but screening of top size fractions would be required.

2. Processed crushed material, likely with a top size of 20 mm, could be produced by drill and blasting of clean quarry rock, followed by crushing. These crushed materials would produce angular particles and generally it is not possible to produce any significant amounts of fines within these produced aggregates. Additional crushing and screening may be required to produce fines if required for appropriate gradation specifications. Use of a crushed product may necessitate the use of a protective geotextile layer.

Appropriate filter criteria will be applied to the particle size distribution required for the transition layers located both below and above the liner bedding layer.

The composite liner needs to be connected to the underlying intact bedrock in order to complete the water retention element within the dam. The final bedrock surface can be undulating and irregular, dependent upon the exposed bedrock surface and the drilling practices undertaken. The simplest connection detail consists of a layer of bedding sand coupled with the placement of thermosyphons evaporators which will freeze the sand bedding layer. This layer will act as an effective hydraulic barrier.

The issue of GM longevity is also germane to the discussion of liner options within these dams. A detailed review of this topic is provided in Section 3.0 of BGC (2006c), but a brief summary is provided herein for completeness. Studies on the cold temperature longevity of liners have not been done but the published literature at warmer temperatures was reviewed as guidance for this project. Extrapolation of data provided within Koerner et al. (2005) and Rowe (2005) estimated that the service life for HDPE geomembrane is possibly greater than 500 years for lower temperature applications. The extrapolation of engineering data by scientific methods is necessary since liners have only been in use for decades and hence, no real long-term field data actually exists. Limited information exists on the longevity of other GM materials.

5.3.2 Composite Liner Stability

Notwithstanding stability concerns related to the earthern materials in the dams, the liner system must also be stable in the long term. Bouazza (2002) provides the following comments that are pertinent to GCL's and GCL-GM systems:

- The interface frictional resistance between GCL and soil and GCL and GM must be high enough to resist shear stresses generated during the structure lifetime.
- Reinforced (needle-punched or stitch bonded) GCL's showed a greater internal peak strength due to the presence of the fibres. There are no known cases of slope failures due to internal shear failure of reinforced GCL's.
- Laboratory testing has indicated that bentonite expulsion from a GCL (with a mass of unit area < 220 g/m^2) on proximal GM can result in a reduction of the frictional resistance.
- He reports on full scale field trials reported in Daniel et al. (1998) that noted that all geosynthetic configurations on test slopes inclined at 3H:1V performed satisfactorily.

Some recent references on shear strength properties for GM's include the following:

- Russell et al. (1998) reports on shear strength testing of HDPE and PP GM's against three different non-woven geotextiles. Large strain interface friction angle values varied from approximately 10.5^o to 14.4^o for geomembrane to geotextile surfaces. Significantly higher peak values were recorded.
- McCartney et al. (2005) presents the results of 87 tests of textured HDPE GM's and needle-punched GCL's with non-woven carrier geotextile. Peak friction angles of approximately 19° to 31° were recorded while large displacement values of 12° to 19° were noted.
- Blond and Elie (2006) report on laboratory testing of textured HDPE and LLDPE on clean sand (SP according to USC) with normal loads up to 140 kPa. Peak values ranged from 26° to 36° while residual values ranged from 17° to 33°.

Within the proposed liner system for the High Lake dams, the following elements and their respective frictional values are as follows (from top to bottom):

1. Cover layer (sand with some gravel) to GM (HDPE or LLDPE) – 17-18° for smooth and 28-30° for textured.
2. GM to GCL geotextile interface – 10.5^o to 14° and 12° to 19° already referenced for textured GM's for residual values. Peak friction angles of approximately 19° to 31° and 26° to 36° were recorded. Lower values were noted from smooth GM's.
3. Interfacial shear strength of the GCL – not considered herein due to implied use of needle-punched or stitch-bonded GCL to negate this issue.
4. GCL geoxtile to bedding layer (sand with some gravel) – 26° to 30° for non-woven and 23° to 26° for woven.

As such, it appears that the GM-GCL interface shear strength would govern the stability and this aspect is reviewed in later stability evaluations.

5.4 Geothermal Design

The proposed dam design requires that the dam geometry be such that the foundation bedrock below the centre of the dam remains frozen to limit the potential under-seepage amount below the dam. To facilitate this occurrence, the liner (a composite liner as previously noted) within the dam first heads towards the upstream reservoir in order to create some distance between the warm water surface and the frozen substrate of the cut off trench. The liner then folds back towards the dam center where the liner attaches to intact bedrock within the cut off trench. In order to determine the dam configuration (e.g., crest width, need for thermosyphons etc.), it is necessary to undertake a two dimensional (2D) geothermal analysis to access the heat flow within the dam section.

Thermosyphons are hollow steel pipes which are used to passively transfer heat from warm ground to colder air. The pipes contain pressurized gas (CO_2 or ammonia) that evaporates when heated by the ground around the evaporator section. The gas rises as it vaporizes where it losses its heat by condensation in the radiator section exposed to cold surface air temperatures. As such, the pipes are able to transfer heat (due to the evaporation and condensation cycle) when the external air temperature is colder than the ground temperature where the evaporator section is located. The pipes only work during cold periods (the winter) and they do so passively without mechanical assistance or power inputs. Thermosyphons can be installed vertically inclined or horizontally and their use within rockfill dam was recently reviewed in Hayley et al. (2004). Additional information on thermosyphons is provided in Section 6.2.

Appendix III contains the memo that details the modelling process, calibration, design inputs and results from the geothermal modelling undertaken. The significant design criteria and inputs are summarized below:

- The foundation beneath the dam must remain "frozen" for the design period, which typically includes the operational life (14 years) and the closure period (100 years).
- The "frozen" criteria is specifically a temperature of -2°C rather than just 0°C. This criteria has been used on other northern dam designs and allows for a safety factor due to issues related to freezing point depression and unfrozen water content at subzero temperatures.
- One dimensional (1D) geothermal analyses were undertaken to validate derived climate parameters to actual subsurface temperatures measured at High Lake.
- Global warming values of 0.5^{o}C/decade and 0.65^{o}C/decade were applied for the design basis.

The geothermal modelling demonstrated that the impoundment of a reservoir at the FSL of 288.5 m would result in thawing dam foundations in less than 10 years, if no thermosyphons were used. Therefore, to meet the stated design criteria for the dam foundations, it was necessary to place horizontal thermosyphons within the cut off trench below the dam. The dam cross-section modeled consisted of a minimum 10 m wide crest along with seven thermosyphons in a 12 m wide cut off trench below the centerline of the dam. Each modelled thermosyphon had a radiator surface area of 58.5 m^2 (three radiators at 19.5 m^2 each). For calibration, the Waste Rock Dam at the Misery site at Ekati Mine includes a total of 13 thermosyphon loops within their key trench (Hayley et al. 2004).

For the noted geometry, 2D modelling indicated that use of the thermosyphons would maintain dam internal and foundation temperatures below the -2°C design criteria. Figure 17 displays the internal dam temperatures for 20 and 120 year time periods for Run 3 (0.5^{o}C/decade global warming) showing that the foundation and majority of the dam section remains subzero. Additional plots of modelling results for other cases are provided in the noted appendix. Even for the worst case global warming value, and accumulated snow at the toe, the proposed dam geometry meets the required foundation temperature over the long term.

Therefore, the East, Northwest and Northwest Channel Dams will require thermosyphons for the operations and for the closure period, if the seepage potential must be completely minimized for those periods. The Northeast and Polishing Pond Dams require thermosyphons for the operations phase and partially into the closure phase, dependent upon the associated supernatant water quality and the allowance for seepage potential (pond discharge is proposed for Year 16 as noted earlier). No thermosyphons are currently forecast for the Contact Lake Dam, but their potential need will be evaluated further during later detailed design.

The geothermal results provided herein are based on one typical geometry reflected in the model geometry and on assumed (correlated) thermal properties for the five dams. During the later final design phase, dam specific geothermal analyses will be required to optimize the dam geometry and the number and extent of the thermosyphons in order to achieve the most economical design for each dam.

5.5 Dam Geometry, Elements and Sections

5.5.1 Dam Geometry

The geothermal analysis revealed that a minimum dam crest width of 10 m, in combination with a 12 m wide cut off trench and seven thermosyphons, is required to meet the -2°C criteria. Each thermosyphon has a radiator area of 58.5 m^{2}. The actual dam crest will be slightly wider as the riprap layer needs to be installed onto the upstream slope. Figure 18 provides a generalized view of the proposed dam cross-section.

As reviewed earlier, the majority of the dams are founded on permafrost bedrock with no currently indicated taliks under the dam footprints. Downstream slopes have been selected at 2H:1V (27°) while the upstream slopes have been specified at 3H:1V (18°). The upstream slope was flattened to allow for easier placement of the geomembrane liner and its associated bedding material. Stability analyses for the dams, including inclusion of a liner element, are reviewed in detail within Section 5.6.

Based on a physical crest elevations noted in Section 5.1.3, the dams around High Lake vary from 4.6 to 8.6 m higher than the natural ground elevations below the proposed crests. The Polishing Pond Dam varies from 5 to 7 m above natural ground surface. From the noted crest elevations, the following dam crests lengths result:

- Northwest Dam – 245 m.
- Northwest Channel Dam -141 m.
- Northeast Dam - 320 m.
- East Dam -230 m.
- Polishing Pond Dam - 390 m.
- Contact Lake Dam has - 74 m.

Based on the drilling results, in combination with interpretations of expected subsurface conditions, the following cut off trench depths are estimated for each dam:

- The Northwest Dam trench varies between 4 and 10 m for most of the dam length and tapers off near the abutments.
- The Northwest Channel Dam trench varies between 3 and 6 m for most of the dam length and tapers off near the abutments.
- The Northeast Dam trench varies between 4 and 8 m deep for most of the dam length and tapers off near the abutments.
- The Polishing Pond Dam trench varies between 6 and 7 m for most of the dam length and tapers off near the abutments.
- The East Dam trench varies between 3 and 7 m in depth for most of the dam length and tapers off near the abutments.
- The Contact Lake Dam trench depth is assumed to be 1 m deep, subject to further investigation and design assessment.

Plans and longitudinal views of each dam have been provided previously as Figures 5 to 16. Cross-sections for each dam are provided within Figures 19 to 25. Figure 26 provides typical installation details for the thermosyphons within the cut-off trench.

5.5.2 Foundation and Abutment Preparation

Foundation preparation will include stripping the entire footprint of the dam to remove vegetation, loose boulders, organic material and ice-rich overburden. For planning purposes, a 1 m depth is assumed to be excavated from the foundation footprint. After the prepatory work is completed, it would be necessary to remove the frozen overburden and FAB within the cut off trench down to the intact bedrock by drilling and blasting. Compressed air will be used to clean off the surface of the bedrock so a detailed inspection can be completed by a geotechnical engineer. Since some of the excavated material will contain ground ice, it should be placed away from nearby water bodies as the material thaws.

The proposed excavation depth of the cut off trench ranges between 2 and 6 m, but the depths will be checked during construction. It should be noted that no ice filled or open joints should be visible in the base of the excavation trench. A levelling lift of sand (at subzero temperatures) will be placed on top of the intact bedrock surface, directly below the liner.

Appropriate depth excavations and connection details will be required at all abutment areas, both to install the liner and the thermosyphons. Some further investigation is recommended at the abutments, as detailed in Section 8.1.

5.5.3 Construction Materials

The construction materials required for the dams include riprap, rockfill transition and bedding materials. All materials placed within dams require appropriate geochemical characterization. consist of riprap, rockfill, geomembrane liner (LLDPE) and processed material. The riprap material and rockfill could be produced from the local mine operations (clean NAG rock) or from a local esker.

The riprap material should not exceed 600 to 800 mm in diameter (mean diameter of 400 mm) and needs to be sourced from durable lithologies. The riprap provides protection to the dam against wave and ice erosion. The riprap should be placed in lifts not exceeding 1 m on the upstream side of the dams. The final surface should be tight and compact.

Broadly graded blasted rockfill with a maximum particle size of 600 mm (mean diameter of 300 mm) should be used for the dam embankment. The rockfill provides the support material for the embankment and it needs to be hard and durable, as well. The rockfill should be placed in compacted lifts of 1 m.

The composite liner will be composed of a 60 mil (1.5 mm) textured geomembrane (HDPE or LLDPE) in combination with an appropriate needle-punched GCL.

Processed sand and gravel that acts as the protective layers (transition and bedding layers) for the liner may be found in local eskers or produced by crushing and screening blasted bedrock. The transition material should have a maximum particle size of 200 mm while the bedding material should have a maximum particle size of 20 mm or less. It is also possible that a 10 mm minus sand could be produced from the esker. The bedding and transition material should be compacted and placed in 0.3 m lifts. These materials will need to be properly designed to meet filter criteria with proximal materials.

As noted above, the earthfill construction materials will be produced from the mining operations or from granular sources. Therefore, quarry and borrow development permits will be required to exploit the identified materials, along with appropriate geochemical work. During final design, appropriate grain size specification for each material will be developed.

5.6 Stability Assessment

Stability assessments for dams on permafrost may comprise the following three elements:

- Limit equilibrium method (LEM) to quantify the Factor of Safety (FS) against global instability.
- Liquefaction assessment for dams on loose and saturated soils.
- Creep analysis for dams on ice-rich material for the High Lake dams.

For the High Lake dams, only the LEM component is appropriate and reviewed herein.

Stability analyses were undertaken for the dams to quantify the minimum FS. This value is defined as the factor required to reduce the mobilized shear strength parameters (of the soil or rock) of a potential sliding mass into a state of limiting equilibrium (CDA 1999). A simpler definition notes that the FS is the ratio between the forces resisting movement of a body (e.g., shear strength of the soil) to the forces acting on that body (e.g., soil weight).

CDA (1999) provides guidelines for a minimum FS for static assessments for three different loading conditions: steady state seepage with maximum storage pool, full or partial rapid drawdown and end of construction. Based on these guidelines, Table 5 below outlines the following criteria.

Table 5: Factors of Safety, Static Assessment (after CDA, 1999)

Loading Conditions	Minimum Factor of Safety	Slope
Steady state seepage with maximum storage pool	1.5	Downstream
Full or partial rapid drawdown	1.2 to 1.3	Upstream
End of construction before reservoir filling	1.3	Downstream and Upstream

Pseudo-static seismic stability analysis is also required for the dams. Based on precedent, the minimum FS required for a pseudo-static analysis is at least 1.1. The analysis was carried out using 0.037g seismic acceleration, approximately 50% of the MCE value. No liquefaction assessment was undertaken due to the bedrock conditions in the dam foundation.

The stability analyses were conducted using the commercially available software SLOPE/W under license from Geo-Slope International of Calgary, AB. The Morgenstern-Price method was used to conduct the analyses.

The dam geometry that was modeled is shown in Figure 27. The dam has side slopes of 3:1 on the upstream side and 2:1 on the downstream side. As is shown on the figure, the dam crest was 10 m wide and the height was 7.5 m.

The material properties assigned to the different materials used in the analysis are summarized in Table 6 as follows:

Table 6: Material Properties for Dam Stability Analysis

	Material Properties		
Material	**Friction Angle**	**Cohesion (kPa)**	**Unit Weight (kN/m^3)**
Waste Rock/Rockfill/Riprap	Shear/Normal Function	0	20
Transition Material	32°	0	20
Liner/Soil Interface	Varied from 12 to 18°	0	20
Liner Bedding Material	32°	0	20
Bedrock	Impenetrable		
Water	N/A	N/A	9.8

Material properties were estimated from sources such as Bowders et al. (1996). The composite liner interface friction angle was estimated to be between 12° and 18° for a textured geomembrane liner as noted previously. The friction angle of the rockfill was found to vary with the effective confining pressure (Leps, 1970, Marsal 1973 and Williams 2000). The shear normal function was used to model the rockfill so that SLOPE/W would not return surficial shallow failures as the critical cases.

Table 7 below details the minimum FS calculated for the dams. As noted, the friction angle for the interface between the liner elements was varied to examine its effect on the stability of the dams.

Table 7: Stability Analyses Results

	Liner Interface Friction Angle = 18°		**Liner Interface Friction Angle = 14°**		**Liner Interface Friction Angle = 12°**	
	Upstream Side	**Downstream Side**	**Upstream Side**	**Downstream Side**	**Upstream Side**	**Downstream Side**
End of Construction	**1.4**	**2.0**	**1.3**	**2.0**	1.2	**2.0**
Static FS	**1.7**	**2.7**	**1.5**	**2.7**	**1.5**	**2.7**
Pseudo-Static FS	**1.4**	**2.0**	**1.3**	**2.0**	**1.2**	**2.0**
Rapid Drawdown (acceleration = 0 G) with coupled seepage analysis	**1.4**	**N/A**	**1.3**	**N/A**	**1.2**	**N/A**

As shown in Table 7, the dam meets an acceptable FS for all cases with the exception of the end of construction case on the upstream side where the liner interface friction angle was 12°.

5.7 Seepage Potential

Dams are designed to control seepage, but are not meant to completely stop all seepage. That concept being stated, relatively low head dams constructed on continuous permafrost likely have the lowest seepage potential (in fact, they may even have no seepage) of any dams constructed.

As noted earlier, it is expected that water within the TCF would not be amenable to discharge until at least two years into closure. Therefore, the potential for water seepage out of the High Lake TCF needs to be assed. Seepage could occur through two possible components:

1. Through, under or around containment dams.
2. Through shallow groundwater seepage in active zones located proximal to dams and the elevated TCF pond shoreline.

The discussion within the following section reviews the seepage potential during the mine operations phase. The seepage potential during closure is discussed further in Section 6.4. In addition, Section 9.0 further discusses risks and contingencies, including dam seepage.

Mechanisms for seepage in dams comprise the following three elements:

- Through the water retaining element (e.g. the liner);
- Through the abutments; and
- Through the foundation zone.

Assuming that the foundation remains frozen and the abutment areas are properly constructed, seepage is only possible through the composite liner element. Imperfections and defects in GM's can lead to leakage through the liners. BGC (2006c) noted this potential seepage mechanism and provided some seepage estimates based on leakage through a single liner. The total theoretical leakage quantity, noting the numerous assumptions made in the previous analysis, varied from 151 m^3/month in Year 1 to 835 m^3/month in Year 4 and beyond. These calculated values were based on published case histories from landfills extended for assessment of the potential leakage quantities from the noted dams with single liners.

As noted in Section 5.3.1, a composite liner system is recommended for the High Lake dams, not including the Contact Lake Dam for which a single liner system will suffice. Composite liners will reduce liner leakage from the noted theoretical values. Recent work by Rowe and Brooker (2001), Foose et al. (2001) and Weber and Zornberg (2005) indicates that that placing a GCL in contact with another GM reduces the seepage rate by several orders of magnitude over the primary liner only. As such, any potential seepage quantity (if any) should be significantly less than the previously-quoted theoretical quantities. As demonstrated within the geothermal modelling, the very minor amount of seepage that actually occurs would likely freeze within the body of the dam.

In the natural areas proximal to the dams around the TCF, some seepage could occur through the active layer around the shoreline of High Lake. The terrain around High Lake is classified mostly as a till veneer or blanket overlying undulating bedrock. An active layer of 2 to 5 m was noted during previous site investigations. To prevent any active layer seepage from occurring, the ground surface elevation must be higher than 293.5 m. Potential areas of active layer seepage were identified in three areas at the north end of High Lake and two areas at the south end of High Lake.

Where potential for active layer seepage exists, it will be necessary to undertake mitigation of this potential mechanism. The typical mitigation measure consists of placing some fill onto the permafrost terrain. The fill placement moves the active layer up and away from the underlying materials causing the permafrost at depth to cool (sometimes referred to as aggradation). The previous active layer zone does not thaw in subsequent years and begins to act as a hydraulic barrier due to its subzero condition. Approximately 2.5 to 3 m of rockfill will be required to aggrade the permafrost, depending upon the design period required for seepage prevention. This period would be approximately 16 years following construction since discharge compliant water is forecast by then. Geothermal modelling by BGC estimated that 2.5 m of rockfill would remain subzero for 30 years from its initial placement, even allowing for global warming.

Should the permafrost aggradation berms not be appropriate, other potential mitigation measures for active layer seepage could include the following:

- Small saddle dams could be constructed across low points to collect seepage water, before being pumped back.
- Toe ditches and ponds could be constructed (in ice-free materials) to collect any seepage, before being pumped back.
- Seeping active layer materials could be excavated and replaced with lower permeability materials (or GCL's) to control the seepage quantity.

5.8 Cofferdams

5.8.1 Design

To construct the required cut off trenches below the natural elevation of High Lake, the surface elevation of High Lake on the upstream side of the dams needs to be lowered. This could be accomplished by constructing cofferdams on the upstream side of selected High Lake dams and by pumping the excess water back into High Lake. Water seeping under the cofferdams will also need to be pumped back during construction of the main dams.

In order for construction to proceed in the dry for the dams in the vicinity of the TCF, three cofferdams are required in High Lake for the following main dams.

- East Dam
- Northwest Channel Dam
- Northeast Dam/Northwest Dam

These proposed cofferdam locations are shown on Figure 2.

In addition to cofferdams, it may be necessary to lower the elevation of Lake L-15 (located adjacent to the Northwest Dam) to ensure the cut off trench at the Northwest Dam could be excavated and backfilled without the presence of water. Gartner Lee estimated the total volume of water in Lake L-15 is 76,440 m^3, of which some portion may have to be pumped out.

The bathymetry and topography were assessed in the vicinity of the TCF dams to determine the preferable cofferdam locations. It would be desirable to place the cofferdams in shallow water (depths up to 1 to 2 m) with a flat down stream slope ensuring a low hydraulic head of water on the upstream side of the cofferdam. Also, by constructing the cofferdams in shallow water, less rockfill and impervious material needs to be utilized during the construction of the cofferdams.

The bathymetry in the vicinity of the Northwest Channel Dam was noted to be flat. The water depth on the upstream side of the Northwest Channel Dam was determined to be approximately 1 m. Meanwhile, the bathymetry at the north end of High Lake undulated and was noted to range between 278 and 281 m. The water depth on the upstream side of the cofferdam at the north end of High Lake was found to be approximately 2 m. The bathymetry in the vicinity of the East Dam ranged between 1 and 3 m, with the bathymetry fairly level between the upstream face of the East Dam and the upstream face of the rockfill material utilized in the cofferdam construction.

The cofferdams should be composed of a minimum 6 m wide rockfill crest (allows vehicle access) on the downstream side and a 3 m wide low-permeability material zone on the upstream side. Figure 28 shows a conceptual cofferdam design. The cofferdams should be a minimum of 284.6 m in elevation or 1.5 m above the natural High Lake elevation to ensure they would not be breached during the PMP or by wind and wave action.

The rockfill should form an underwater natural angle of repose of approximately 1.3 to 1.4H: 1V as shown by previous cofferdam construction case studies. The rockfill material should be as broadly graded as possible with a maximum particle size of 600 mm (mean particle size of 300 mm).

The rockfill should be dumped on the material crest or in the vicinity of the cofferdam abutments and pushed over the crest by a bull dozer in large quantities into High Lake to ensure particle sorting does not occur. Pushing rockfill material over the edge into High Lake would also enable surficial slope failures to occur and displaces the soft sediments found at the bottom of High Lake. In the longer term, pushing the rockfill material over the dam crest increases the strength of the rockfill material.

Low-permeability material such as till strippings (derived from site development), glaciofluvial material from Sand Lake or processed rockfill could be placed on the upstream side of the cofferdam materials in order to minimize the seepage potential. This material should also be pushed over the rockfill crest by a dozer and placed underwater. Depending on the slope length/water depth conditions, an excavator with an extended boom may also be required to ensure that impervious material are properly placed along the upstream toe of the cofferdam. Further discussions on appropriate low-permeability materials is provided in Section 5.8.3.

Figure 29 to 31 provide plan and section views of all three proposed cofferdams. Additional design input is provided in the following two sections.

5.8.2 Stability

Cofferdam stability analyses were undertaken for the required cofferdams at the north end of High Lake and at the East Dam. The bathymetry at these locations was determined to be the least favourable for cofferdam construction due to the water depth and slope of the lake bed.

Cofferdams are temporary structures used for a limited time period during construction of the permanent structure. As such, they usually have a very limited design life. This fact directly impacts the appropriate FS for the design basis. The criteria established by CDA (1999) could be used as a screening level design criteria but a lower FS may also be acceptable.

Stability analyses were conducted using the commercially available software SLOPE/W under license from Geo-Slope International of Calgary, AB. The Morgenstern-Price method was used to conduct the analyses.

The grid and radius method were used to develop potential slip surfaces within the potential cofferdams. Only deep seated failures that intersected the upstream low-permeability material and the lakebed sediments or till were considered. Surficial failures in the low-permeability material were not considered.

The rockfill material placed on the downstream side is approximately 6 m wide with assumed angle of repose slopes of 1.4H:1V (i.e., 35°) on both the upstream and downstream side. Meanwhile, the low-permeability material placed on the upstream side is required to be 3 m wide, with an assumed angle of repose upstream slope of 2.8H: 1V (i.e., 20°). It should be noted that during construction of the cofferdams, the water level will be the same on both sides of the crest (i.e. at original lake level). Upon cofferdam completion, the water on the downstream side can be pumped out to achieve “dry” conditions for construction of the TCF dams.

The material properties assigned to the different materials used in the analysis are summarized in Table 8 below:

Table 8: Material Properties for Cofferdam Stability Analyses

	Material Properties		
Material	**Friction Angle**	**Cohesion (kPa)**	**Unit Weight (kN/m^3)**
Dumped Waste Rock/Rockfill	Shear/Normal Function	0	20
Dumped Impervious Material	20°	0	19
In-situ Lakebed Sediments	20°	0	18
In-situ Till (sand/silt)	33°	0	19
Water	N/A		9.8

The determination of the lakebed sediment and glacial till properties were reviewed previously in the A/B Toe Dike Conceptual Design (BGC, 2006) and the strength parameters for both these geological units were also utilized in the cofferdam stability analyses. It should be noted that no current subsurface information is available from beneath the cofferdams and ground conditions were assumed.

Two scenarios were analysed; one assuming that the lakebed sediments would not be displaced during the end dumping of the fill materials and another assuming the lakebed sediments were displaced.

Cross sections was produced through the cofferdam centreline at both the north end of High Lake and near the East Dam. Different cofferdam heights and foundation bathymetry were used. Slope stability analyses were conducted to determine the FS for deep seated failures that intersect the impervious material and sediments (either lakebed or till) at the bottom of High Lake. The bathymetry information used was previously collected by Gartner Lee Ltd.

In the analyses conducted with the lakebed sediments, the lakebed sediments were assumed to be approximately 2 m thick while the till layer was estimated to be 5 m thick. In the analyses with no lakebed sediments, the till was assumed to be approximately 7 m thick. The thickness of the lakebed and till sediments was extrapolated from the 2006 geotechnical investigation program conducted in the A/B Toe Dike area. It should be noted that the thickness of the lakebed sediments and till may be different in the vicinity of the proposed cofferdams. No boreholes were drilled in either of these areas during any previous geotechnical investigations. Therefore, the overburden information collected from the A/B toe dike area was extrapolated and assumed for the stability analysis provided herein.

Table 9 below details the minimum FS calculated for the cofferdam in the vicinity of the East Dam for both static and seismic cases, while Table 10 details the results for the north end of High Lake.

Table 9: Stability Analyses Results for Cofferdam at East Dam Location

	Factor of Safety (with lakebed sediments)	Factor of Safety (no lake bed sediments)
Static FS	1.1	**1.7**
Pseudo-Static analysis using 0.037 g	< 1.0	**1.4**

As shown above, the minimum FS for the East Dam cofferdam is met only when the lakebed sediments were assumed to be missing or were displaced.

Table 10 Stability Analyses Results for Cofferdam at North End of High Lake

	Factor of Safety (with lakebed sediments)	Factor of Safety (no lakebed sediments)
Static FS	**1.5**	**2.5**
Pseudo-Static analysis using 0.037 g	**1.3**	**2.0**

As shown in Table 10 above, the minimum FS for the static and pseudo-static analyses for the cofferdam at the north end of High Lake is achieved when lake bed sediments are present or displaced. Depending upon the actual extent and strength of the lake bed sediments, it may be necessary to ensure their removal (or displacement) during cofferdam construction. Alternatively, a small rockfill berm could be placed on the upstream side to restrain the low permeability material and enhance stability. Before any further assessment work, it is necessary to collect geotechnical information for each of the three noted cofferdam locations.

5.8.3 Cofferdam Seepage

Seepage analyses were undertaken for the cofferdams to determine appropriate materials for construction in order to yield acceptably low seepage so as to permit dam construction. The commercially available program, SEEP/W, was used to model the seepage of water through the cofferdams. The cofferdam geometry that was modeled is shown in Figure 42. The geometry consisted of a 6 m wide berm of rockfill to 1.5 m above the current level of high lake. The rockfill had side slopes of 1.4:1 (H:V). A 3 m wide zone of lower permeability material was placed on the upstream side of the rockfill and was modeled with slopes of 3:1 (H:V). A thin layer of till, underlain by bedrock, was modeled beneath the cofferdams.

Table 11 shows the material properties for the dam construction and foundation materials. The associated hydraulic conductivity for each material is noted. It should be noted that the hydraulic conductivity of the low permeability material zone is dependent upon the source of material chosen. A sensitivity analysis was performed to examine the impact of the different lower permeability materials on the expected seepage quantity. It should be noted that hydraulic conductivities of the foundation materials assume thawed conditions.

Table 11: Seepage Analysis Input Material Properties

Material	Hydraulic Conductivity (cm/s)
Rockfill	1
Low Permeability Material*	1 to 1 x 10^{-5} (see note)
Till	1 x 10^{-4}
Bedrock	1 x 10^{-5}
Note: Conductivity of the low permeability material is dependent on the source of the material.	

Table 12 shows a list of the potential sources of lower permeability material along with an approximate permeability and the resulting calculated rate of seepage per metre of dam length. It should be noted that the length of the Northeast, East and Northwest Channel Cofferdams are approximately 100, 70 and 60 m, respectively.

Table 12: Choice of Lower Permeability Sources and Resulting Seepage Quantity

Source of Material and Description	Approximate Hydraulic Conductivity Range (cm/s)	Resulting Seepage Quantity (US gpm/m of dam length)
Strippings: silt/sand, some gravel and cobbles	10^{-3} to 10^{-5}	0.5 – 0.005
Sand Lake Esker: gravel, sand and trace silt	10^{-1} to 10^{-3}	44 – 0.5
Processed material (-20 mm): gravel, sand with limited fines	1 to 10^{-1}	4000 - 44

It is clear from the results presented in Table 12 that the processed material cannot be used for the lower permeability zone since the expected quantity of seepage may range as high as 4000 US gpm per m of dam length. If material from the Sand Lake Esker is used as the low permeability zone, the calculated seepage quantity for the 100 m long north cofferdam may range from 50 to 4400 US gpm. If strippings from the dam footprints are used for the lower permeability zones, the calculated seepage quantity for the 100 m long north cofferdam may range from 0.5 to 50 US gpm. However, the quantity of strippings from the footprint of the dam may not be enough for construction of the lower permeability zone. In addition, strippings may be too variable in terms of grain size to actually be useable.

As such, appropriate material sources need to be developed before any further design work can proceed.

5.9 Instrumentation

The dams and associated ponds will require instrumentation to monitor their actual performance upon first filling and throughout their design lives. Important performance indicators for the dams are as follows:

- Retained water pond elevation and its variation through the year.
- Thermal regime within the dams and foundation zones.
- Initial settlement, if any, of the dam embankment section.

To monitor these performance indicators, the following specific instrumentation will be required:

- Pond levels in both High Lake and Contact Lake can be manually monitored using staff gauges or continuously using submerged pore pressure transducers.
- At least two vertical and two horizontal thermistors will be required to measure active layer depths on the dam, assess internal dam temperatures and confirm that cooling is occurring at depth due to the thermosyphons. These can be read manually at appropriate increments or they can be read continuously with dataloggers.
- At least two settlement points should be installed onto each dam crest to assess dam settlement over the first few years upon inundation. Appropriate benchmarks are required at each dam to facilitate the noted survey work.

Detailed designs for the instrumentation arrays would be provided within the final design task.

5.10 Water Conveyance Elements

5.10.1 Contact Lake Outflow Channel

Section 3 of nhc (2007) provides the design basis and details for the Contact Lake outlet channel required to divert fresh water down to the Kennarctic River. Details of the outlet channel are as follows:

- Outlet channel consists of 5 m wide broad-crested weir.
- Channel designed to pass PMP flow with a design peak flood of 1.0 m^3/s.
- Flow depth in the channel would be shallow.
- A rockfill dike would be required along the first 180 m of the outlet channel to constrain the channel flow.
- Some erosion protection riprap would be required at the channel entrance and along the rockfill dike.

Figures 10 and 11 within nhc (2007) provide plan and section views of the outlet channel. Four recommendations for final design of the channel were also provided.

5.10.2 Decant Siphons

Decant siphons pipes will be used to transfer the batch water over the Northeast Dam and the Polishing Pond Dam before discharge to the environment. Nhc (2007), provided in Appendix II, estimated the potential June discharge quantity of approximately 0.25 m^3/s based on the 1:100 year run-off. For that estimated maximum discharge quantity, nhc provided the following siphon specifications:

- Single smooth pipe.
- Length – 40 m.
- Head difference – 3 m.
- Internal pipe diameter – 300 mm.

These specifications will result in a discharge quantity of 0.25 m^3/s or approximately 650,000 m^3/month. These siphon pipes need to be steel, or adequate plastic thickness, to resist the suction pressures generated within the pipe. One siphon will be required at each of the two dams. It is also recommended that a spare siphon pipe be available for back-up purposes.

Gartner Lee (2006) estimated that between 400,000 and 1.5 million m^3 of water will need to be discharged to the Polishing Pond (and beyond) each year over the Northeast Dam. If so required, the pond water will then be treated, either in the TCF pond or in the Polishing Pond, before being discharged to the Kennarctic River. Discharge will only be able to occur during the warm months. The proposed siphon sizing by nhc (2007) appears adequate to meet the expected water quantities.

It should be noted that BGC has not undertaken any design of the Polishing Pond based on settling and treatment design criteria. Peak hydrological events and treatment retention times in the Polishing Pond will dictate the final design for the overall Polishing Pond and associated decant system.

5.11 Construction Plan Outline

Within the construction phase, the following major tasks are envisioned within the construction plan:

1. Find and develop appropriate quarries and borrow sources for construction materials.
2. Build cofferdams within High Lake, possibly with allowance to remove lakebed sediments by suction dredge.
3. Pump out water located between the cofferdams and the proposed dam footprints.
4. Pump down Contact Lake.
5. Construct the main dams, including the cut off trenches in the “dry”.
6. Construct the overflow spillway from Contact Lake.

Initially, construction materials for the cofferdams and initial sections of the main dam would have to sourced and quarry and borrow development would need to be initiated. Materials for the cofferdams would consist of run-of-mine (ROM) rockfill derived from pit strippings or from special quarries, along with the low-permeability material likely derived from esker sources or from overburden stripping at dam sites. In addition, appropriately sized haul roads would need to be constructed from quarry and borrow areas to the abutment areas of all cofferdams.

Cofferdam construction should commence in the late summer or fall because the fill placement into the lake needs to occur within ice-free conditions. In addition, the cofferdams need to be completed before the cut off trench excavation begins in early winter. Construction of the cofferdams should commence with the stripping of organic material, overburden and loose boulders in all abutment areas. Any stripped materials should be stockpiled for possible use in the low-permeability zone on the cofferdams or placed in appropriate storage areas.

As noted, it may be necessary to remove soft lakebed sediments with a suction dredge. If this step is deemed necessary, sediment disposal areas will be required.

The construction of the cofferdams could commence from either abutment (or possibly both) where trucks would dump the rockfill and a dozer would push the dumped rockfill into the water. As the length of the cofferdam crest increases, the haul trucks could dump the rockfill material on the cofferdam crest before the dozer pushes the material over the edge. This would continue until the rockfill crest is the desired 6 m minimum width with approximately 1.4H:1V side slopes. After the rockfill crest has advanced some distance, and allowing for traffic issues on the rockfill crest, the low-permeability zone material can be placed on the upstream side of the cofferdam. The low-permeability material should be dumped on the rockfill crest and pushed by a dozer into the lake.

Once construction of the cofferdams is completed, and the appropriate crest elevations have been surveyed, the lake water can be pumped from the downstream side of the cofferdam to the upstream side. There is approximately 24,000 m^3, 1100 m^3 and 100 m^3 of initial water on the downstream side of the Northeast, Northwest Channel and East Cofferdams, respectively. Seepage water through the cofferdams would add to the pumping requirements. Appropriately sized pumps and associated power supply or generators would be needed to dewater the toe area of the cofferdams and also to pump back seepage water on an on-going basis. The cofferdams and associated pumping system would remain in place until the following spring or summer when the construction of the all dams around High Lake has been completed.

In addition, it may be necessary to pump down the water levels in both L15 and Contact Lake to construct the Northwest and Contact Lake Dams. Appropriate pumping plans would need to be developed for both lakes.

Due to the permafrost existence below the High Lake dams, the construction of these dams typically occurs during the winter months to take advantage of the cold temperatures and prevent any foundation warming. Again, before the winter construction season begins, it will be necessary to ensure that appropriate quantities of liner materials, bentonite for the GCL and instrumentation are delivered to site. In addition, appropriate amounts of rockfill, bedding and transition materials should be prepared and ready for the initial placement portions.

Dam construction will commence with the stripping of the vegetation, overburden and loose rock to a depth of approximately 1 m below the entire footprint for all dams. This surficial stripping would be best accomplished in the early fall due to the greatest depth of active layer occurrence. Stripping should be pushed completely outside the footprint or disposed in an appropriate storage area.

In the early winter, excavation of the cut off trench and abutments needs to occur. The trench excavation is expected to range between 2 and 6 m in depth and must be done by drilling and blasting to remove frozen overburden and FAB. The complete bottom surface of the trench need to be cleaned of all materials, including frozen rock, dust and snow so that the trench surface can be properly inspected. Air lances driven by compressors and extensive hand-labour are required to complete this task.

Following acceptance of the intact bedrock surface in the trench, the levelling layer of sand is placed on the undulating exposed bedrock surface. This layer is then followed by placement of the composite liner flap onto the trench bottom followed by a liner protection layer and the thermosyphon evaporator pipes. Appropriate backfill is placed in the trench and on the upstream side of the dam so that the liner can also be raised incrementally by appropriate welding techniques. Liner welding can be undertaken at cold temperatures but experienced contractors and appropriate northern placement methods have been employed on other projects already. Once the trenches have been excavated and backfilled, it is possible that pumping at the toes of the cofferdams could be discontinued.

Following from the cut off trench work, the appropriate backfill materials are placed into the embankment section on the downstream side of the liner. This will require the hauling, placement and compaction of rockfill, transition and bedding materials within winter temperatures. Snow removal during the winter can be a significant concern. Access to air lances and compressors will be required.

When the downstream embankment is completed to the top liner elevation, the second section of the composite liner is installed on the slope to the crest. Following appropriate QA/QC tests on the liner, a cover layer is carefully placed over the liner, along with the additional upstream slope materials including transition and riprap. Placement of crush material on the dam crest would be the final construction tasks. This upstream side would be completed before spring thaw so that the dams would be ready for use in the following spring melt.

Instrumentation may be placed in the dam as construction proceeds upward. In some cases, drilling will be done later to provide vertical boreholes for the installation of appropriate instrumentation.

Construction of the Contact Lake overflow spillway would also likely occur in the winter. Road access to the overflow location and the sourcing of appropriate backfill and erosional protection materials would be one of the initial tasks. Some drilling and blasting would be required to excavate the proper spillway section since the ground would be frozen. Bedding and/or riprap materials would be placed before the spring run-off occurs.

This section has provided a very general overview of the steps that will be required to build the dams. In final design, it will be necessary to formulate a detailed description of work staging, resources and constraints such that appropriate mobile equipment, manpower and resources are sourced to undertake the work. Construction of the stated number of cofferdams and dams will be challenging within a one winter construction period, unless significant preparatory work and significant site resources are provided.

6.0 CLOSURE DESIGN

6.1 Closure Plan Outline

A water cover is proposed for long term storage of the tailings in High Lake. The water cover depth needs to prevent remobilization of tailings by wind induced wave action, ice plucking and scouring.

To facilitate the water cover, a spillway must be constructed to maintain the FSL of 288.5 m and pass the design flood. The proposed spillway is proposed to be located adjacent to the Northeast Dam and will be founded mostly in bedrock. The spillway will be designed to pass the PMP, which should ensure the long term safety of the dams located around the TCF.

The spillway located adjacent to the Northeast Dam will discharge to the Polishing Pond area. After the water in the Polishing Pond has reached an acceptable quality, the pond would be breached so that a flow-through system is in place. The discharge water quality must meet the regulated discharge criteria.

Construction of the spillway will depend on the water quality of High Lake at closure. If the water found in the tailings containment exceeds discharge limits, it would be required to treat the water in the Polishing Pond and wait for the water in the TCF to meet discharge requirements. The sludges that accumulate in the Polishing Pond would be removed and placed within the TCF. The TCF water quality at closure was designed to be suitable for discharge without treatment. However, some water treatment may be required for the first few years of closure.

When the TCF water quality meets the appropriate guidelines, the spillway will be built and the Polishing Pond breached. The spillway invert will have the appropriate amount of freeboard to ensure that overtopping and erosion of the perimeter containment dams, does not occur.

6.2 Component Longevity

In order for the dams to function in the long term, two main components need to perform over the long term, as noted below:

1. The composite liner needs to retain water (to continue to cover the tailings).
2. The foundation must remain frozen due to the operation of the thermosyphons (to completely limit any under seepage potential).

The issue of GM longevity has been reviewed in detail in BGC (2006c) and a summary is provided in Section 5.3.1 of the current report. This review summarizes that HDPE should have a service life exceeding 500 years for low temperature applications. That section also notes the long term usefulness of GCL's that includes bentonite (natural, low permeability clay when hydrated).

As noted in the design criteria for the dams, it may be necessary for the thermosyphons to operate for more than 100 years, which raises the obvious topic of their longevity. Yarmak (2007) notes that the first commercial systems installed in the 1960's are still in service. Sorensen et al. (2003) notes that approximately 124,300 thermosyphons were installed on the Trans Alaska Pipeline System (TAPS), which was completed in 1977. Jardine (2007) notes that the oldest thermosyphons in Canada were installed in 1987 and are still operating today. As such, a 20 to 40 year time frame for thermosyphon longevity has been demonstrated.

By way of northern example, the Giant Mine is Yellowknife has recently undertaken the assessment of numerous remediation options for the arsenic trioxide residue located in shallow stopes under the mine site. The current "leave-it-in" option will require the active freezing of the stopes containing the residue. A super-cooled liquid will be circulated through a series of underground pipes to freeze the designated areas around and within each of the stopes. Following this active freezing phase, the frozen blocks will be maintained through the use of thermosyphons in the long term. Noel and Hockley (2004) review the results of an experimental, 100 m deep thermosyphon that has been installed at Giant Mine as part of this assessment project.

Within the topic of longevity comes potential failure modes that could potentially lead to poor performance, or loss of any performance, of these passive heat exchangers. The following "failure mechanisms" are possible:

- "Gas topping" – Occurs when non-condensing gas collects at the top of the thermosyphons. Really only an issue for thermosyphons charged with ammonia, as noted in Sorensen et al. (2003). Potential problems do not exist for thermosyphons charged with CO_2 or other high-pressure gases (Jardine et al. 1992).
- Radiator damage due to vehicle impact – A puncture in the thermosyphon can occur. Any hole and the associated gas recharge can be easily repaired. The installation of protective bollards could mitigate this issue.
- Radiator puncture due to bullets (i.e., vandalism) – Jardine et al. (1992) notes that only one pipe had been shot at in 30 years of experience, and the bullet did not penetrate the steel wall, even though standard wall pipe was used. Any necessary repair could be done as for a puncture.
- Corrosion of the evaporator and radiator pipes – Radiators and riser pipes can be coated to prevent corrosion or the pipe wall thickness increased, if deemed necessary. Corrosion of the evaporator should not be an issue since it will be located within frozen ground.

Monitoring and potential maintenance of the thermosyphons will be required in the long term. Monitoring inspections with an infrared camera will be required, followed by any necessary puncture repair and/or gas recharging. This can usually be done by a small crew in a day or so typically.

6.3 Spillway Design

Section 2.23 of nhc (2007) provides a design for the spillway required at closure of the TCF. The purpose of the spillway is to convey extra pond water, in excess of the 2.5 m cover depth, to the environment. Implicit within this action will be the realization of compliant discharge water within the pond.

Details of the spillway design are as follows:

- Spillway located at left abutment of the Northeast Dam, so that the spillway is independent from the dam. In addition, the spillway end terminates closer to Lake L30, part of the natural drainage system for the local area.
- The inlet elevation for the spillway coincide with the reservoir FSL of 288.5 m.
- Design flood for the spillway was the 24 hour PMP.
- Inflow peak flow of 3 m^3/s used for design.
- Spillway width of 5 m selected for practical reasons, including removal of snow if required.
- Maximum computed water depth over the sill elevation was 0.46 m, much less than the dam freeboard amount of 1.5 m.

Figures 6, 7 and 8 within nhc (2007) provide plan and section views of the proposed spillway, which is required only for the closure phase of the project. Figure 7 indicates that 3 to 4 m deep cuts are typically required, indicating excess channel capacity available should some ice-blockage occur from fall water flows.

The first portion of the spillway appears to be situated over exposed bedrock with the lower section located in thin till over bedrock and some thicker overburden units near the discharge end. Since the structure is not required until 14 years after mining begins, site investigation and final design of the spillway can occur at the a later time. As such, detailed design of this spillway has not been provided herein.

6.4 Seepage Potential During Closure

Seepage potential during operations was reviewed in Section 5.7. After two years of closure, it is possible that the TCF water could meet discharge compliant criteria, and as such, some dam seepage may be allowable (as long as the water cover depth is not reduced).

BGC (2006c) analyzed the dams at closure, assuming the foundations thawed in the long term, even though the geothermal modelling reviewed herein predicts that this would not be the case. If the dam foundations were to thaw, the hydraulic conductivity of the underlying foundation would increase. In situ testing by Gartner Lee indicated an average hydraulic of 6.3×10^{-7} cm/s for bedrock below High Lake. Based on this assumed value for the dam foundations, the total seepage quantity was estimated to be 86 m^3 /month for the four dams located around the TCF. However, if the seepage path was increased by constructing a 30 m low permeability berm on the upstream side of the dam, the estimated seepage could be lowered to 31 m^3 / month.

The estimated seepage quantities are likely too small to be an issue with respect to retention of the tailings water cover depth over the long term.

6.5 Construction Plan Outline

The spillway at the Northeast Dam (and related discharge channel down through the Polishing Pond) is not required until after operations cease in Year 14. As such, no detailed site investigation, final design or related construction plan is currently required for the spillway. The most important aspect to implementation of the spillway will be the indications that the water quality within the High Lake TCF are compliant with discharge criteria and that the water can be discharged to the nearby receiving environment. In addition, the role of the Polishing Pond needs to be considered in relation to the initiation of discharge through the spillway. The relatively small capacity of the Polishing Pond may be able to retain small on-going discharge quantities, but it would not be able to retain a flood event when one occurs.

The basic outline of the spillway construction plan would include the following components:

- Ensure that road access to the construction site is available.
- Quarry and stockpile appropriate bedding and riprap materials near the spillway location (it is possible that riprap could possibly be screened from the blasting muck created from the channel excavation).
- Either lower the upstream pond level or construct a small cofferdam at the inlet end to prevent channel inundation during construction.
- Ensure adequate level of survey control for construction.
- Drill and blast bedrock and excavate overburden to create channel design grade and width.
- Place bedding and riprap over any exposed overburden located within the channel walls and invert.
- Construct breach and associated discharge channel through Polishing Pond Dam.
- Remove cofferdam at spillway inlet or let pond water rise to inlet elevation.

6.6 Long Term Surveillance and Monitoring

The main water retention dams and closure spillway will require surveillance, monitoring and maintenance over the long term to ensure the safety of these dams for the closure. It is important to note that the closure phase dams will have different “operational” constraints placed on them and an appropriate operations, maintenance and surveillance (OMS) Manual specifically for the closure phase should be developed. Some of the important aspects to be monitored included the following:

- Site climatic conditions including temperature, rainfall and accumulated snowfall on the ground.
- Water levels retained behind dams.
- Internal and foundation temperatures beneath retention dams.
- Movement and deformations within the dams.
- Indications of seepage from visual observations or impacted water quality results on nearby water bodies.
- Assessment of thermosyphons operations including visual observation and infrared scanner surveys.
- Assessment on durability of erosional protection measures against water, ice and wind forces.

At the current time, it is assumed that a combination of remote instrumentation (possibly connected by wireless methods for download) coupled with yearly site inspections (by appropriate engineering personnel) will be required. It is possible that new technology within the next two decades will facilitate the more efficient collection of the appropriate monitoring information.

Following from collection of surveillance data, it is possible that isolated maintenance of some elements of the dams or spillway may need to be undertaken. As such, Wolfden would then need to either store at site, or mobilize to site (depending upon possibility of fixed wing or helicopter access), the appropriate mobile equipment, supplies and resources to undertake the work. In addition, camp accommodations and related infrastructure (power, water, communications, etc.) would also be required.

The noted aspects could be documented with an OMS Manual and Emergency Preparedness Plan (EPP) prepared specifically for the closure phase of these structures. Since these documents will not be prepared for perhaps 15 years, it is important that the High Lake operation ensure that adaptive management is adopted and used to learn important lessons about the TCF design and performance. As such, best "learned" practices can be applied for final design, construction and "operation" of the closure structures.

7.0 QUANTITIES AND COSTING ITEMS

7.1 General

The quantity estimates for the six main dams, three cofferdams and two spillways dams are provided within this section. The quantities provided are for in-place, bank volumes for excavation and fill materials and do not provide an allowable for bulking or contingency. In addition, the liner quantities do not include overlap or waste.

It should be noted that BGC's work scope included the preparation of construction quantities only. Costing of these capital works is to be done by other consultants. In addition, no operating or closure costs were prepared by BGC.

In addition, it is possible that any of the noted quantities could change during final design or for practical construction requirements to be assessed later.

7.2 Main Dams

For each dam, the excavation and fill volumes were estimated by multiplying the area of selected cross sections by the appropriate incremental length of the dam. These estimates were checked by calculating a three-dimensional overall dam volume using AutoCAD.

Table 13: Quantity of Materials and Excavations for High Lake Dams

Material	East Dam	Northeast Dam	Polishing Pond Dam	Northwest Dam	Northwest Channel Dam	Contact Lake Dam
GCL Area (m^2)	4800	10600	8500	6500	3700	0
Membrane Liner Area (m^2)	4800	10600	8500	6500	3700	1500
Bedding (m^3)	4500	9700	8200	6100	3500	1600
Transition (m^3)	9500	20000	14800	13100	6500	1700
Rockfill (m^3)	23500	22100	22700	27700	9500	800
Riprap (m^3)	4400	7500	5500	5500	2400	700
Total Fill (m^3)	**41900**	**59300**	**51200**	**52400**	**21900**	**4800**
Stripping Beneath Dam Footprint (m^3)	6700	9400	8200	7400	3400	1900
Trench Excavation (m^3)	4100	13200	7800	16600	5000	0 (Subject to later assessment)
Total Excavation (m^3)	**10800**	**22600**	**16000**	**24000**	**8400**	**1900**

Besides the neat quantities mentioned in Table 13, powdered bentonite is required to seal overlap seams in the GCL. Manufacturer installations guidelines should be followed when formulating and purchasing the appropriate quantity.

The estimated quantities for the proposed thermosyphon arrangement are shown in Table 14.

Table 14: Thermosyphon Quantities Required

Dam	Length of Cut off Trench (m)	Length of 2.5" Steel Pipe Req'd (m)[1]	Thermosyphons per Dam[2]	Radiators per Thermosyphon	Radiators per Dam
Northwest Chanel Dam	157	156	14	3	42
Northwest Dam	273	272	14	3	42
Polishing Pond Dam	409	408	14	3	42
Northeast Dam	335	334	14	3	42
East Dam	241	240	14	3	42
Total	1415	1410	70		210

[1]Assuming 1 m space at location where thermosyphons meet under dam
[2]Each radiator is 19.5 m^2 for a total area of 58.5 m^2 per thermosyphon.

7.3 Cofferdams

The estimated quantities for the three cofferdams are shown in Table 15:

Table 15: Quantity of Materials for the Cofferdams M^3

Materials	East Cofferdam (M^3)	Northeast Cofferdam (M^3)	Northwest Channel Cofferdam (M^3)
Rockfill	1300	4500	700
Low Permeability Material	1000	2300	500
Total Quantity	**2300**	**6800**	**1200**

Appropriately sized pumps, and associated power and discharge lines, will be required for the cofferdams. Estimates of the required size and capacity is assumed to be done by others. In addition, no current estimate are made relative to the need for lakebed sediments removal.

7.4 Water Conveyance Elements

The following quantities are estimated for the three water conveyance elements within this noted design.

Siphon Pipes - Operations

- Two or three 40 m long smooth pipes (plastic or steel) with an internal diameter of 300 mm.
- Associated values and couplings to change the siphons.

Contact Lake Outlet Channel - Operations

- Approximately 4500 m^3 of fill for surface water deflection berm.
- Approximately 1500 m^3 of riprap for erosion protection on the inlet and the deflection berm.

Northeast Dam Spillway - Closure

- Approximately 5000 m^3 of excavation for the channel. Based on visual assessment (subject to actual site investigation), proportioned as 3400 m^3 in bedrock and 1600 m^3 in overburden.
- Approximately 750 m^3 of riprap for channel protection, subject to actual site investigation.

To reiterate, numerous assumptions were made to estimate these quantities. Site investigation and further design will certainly change the values quoted herein.

8.0 FINAL DESIGN PROCESS

8.1 General Requirements

The current report outlines the proposed feasibility level design for the High Lake TCF dams and spillways. Before construction can proceed, and assuming receipt of appropriate regulatory approvals, the dams and associated spillways must proceed to the final design process. This final stage contains several steps including the following:

- additional site investigations and sampling;
- site surveying;
- materials testing;
- related analyses and optimizations; and
- related documentation including the final design report, drawings and technical specifications and associated construction and operations plans and manuals.

As such, the following section notes some of the significant tasks recommended for final design.

Site investigation and instrumentation:

- Abutment areas for all cofferdams should be mapped. If bedrock is not directly exposed, test pits should be excavated to review near surface conditions at those areas.
- Additional boreholes and thermistors need to be drilled to further investigate the subsurface conditions and talik potential under the dam footprints. In addition to potential shallow boreholes at dam abutment areas (where bedrock is not exposed), the following minimum investigation requirements are summarized below for each of the main dams:
    - East Dam – two to four boreholes including one thermistor cable on the upstream side.
    - Northeast Dam – two to four boreholes including two thermistor cables in the depression feature and on lake shoreline.
    - Northwest Dam – two boreholes and two thermistors to check for lake taliks.
    - Northwest Channel Dam – one borehole (perhaps angled across the dam axis).
    - Polishing Pond Dam – two to three boreholes on south arm and one additional borehole near BGC06-08.
    - Contact Lake Dam – two more boreholes angled across the dam axis.
- Within some of these deeper boreholes, undertake “water-take testing” within highly fractured bedrock zones at depth.
- Boreholes and/or in situ testing (cone penetration testing for example) needs to be undertaken at all three proposed cofferdam locations (and related A/B Toe Dike location). In addition, some in situ testing should be undertaken to assess the hydraulic conductivity of overburden and FAB units located on the bottom of High Lake below the proposed structures.
- Investigation of appropriate esker deposits should be undertaken to assess the grain size distribution for possible construction use.

Topography, bathymetry and site climate:

- Detailed topographic surveys should be undertaken at all dam and spillway locations to facilitate the final design process. These surveys should be able to produce elevation contours to approximately 0.5 m intervals.
- Benchmarks should be installed at each dam and spillway location to facilitate the later construction operation.
- Detailed bathymetric surveys should be undertaken at all three proposed cofferdam locations (and associated A/B Toe Dike location) and the upstream side of the East Dam and a portion of the Northeast Dam. These surveys should be able to produce elevation contours to approximately 0.5 m intervals.
- Detailed topographic surveys at all proposed borrow and quarry areas should be undertaken to facilitate borrow and quarry development plans.
- Assessment of High Lake wind velocities and directions.

Testing of subsurface materials or construction materials:

- Any samples collected from the bottom of High Lake should be tested for geotechnical parameters, including strength and hydraulic conductivity if samples are appropriate.
- Samples collected from esker borrow sites should be tested for particle size analysis, durability and aggregate soundness tests. In addition, the material could also be tested for hydraulic conductivity if it is proposed for cofferdam use.
- Samples of dam construction materials and bedrock should be tested to determine actual thermal properties as input for later geothermal analyses.
- Samples of all proposed dam construction materials should be tested for further geochemical characterization.
- The interface friction angle of composite liner materials needs to be tested.

Analyses and assessments:

- Confirm ore/tailings tonnages and the possible use of D Zone Pit for tailing containment.
- Confirm pond rise due to floods and wave action on dams for all three retained ponds.
- Detailed assessment of foundation preparation measures.
- The final arrangement of the East Dam could possibly be straightened, depending upon the design of the cofferdam on the upstream side.
- Dam specific geothermal analyses are required to validate the various dam geometries. In addition, geothermal analyses should optimize thermosyphons details and configuration.
- Stability analyses with the measured interface shear strength for the composite liner should be done.
- Further stability and seepage assessments of cofferdam designs should be completed when additional in situ testing and lab testing results are available.

- Finalize design for required Polishing Pond retention time along with details for water conveyance using decant siphons.
- Assessment of instrumentation details and data collection systems.

Documentation:

- Final design report outlining design criteria for each dam, along with tender-ready design drawings and technical specifications.
- Finalization of hydrology and related dam design for the Contact Lake Dam needs to be undertaken relative to the other High Lake and Polishing Pond dams.
- Preliminary Quality Assurance/Quality Control (QA/QC) Plan for construction of the dams.
- Preliminary Operations, OMS Manual and EPP required for later operations of the facility.

All final design documentation should be stamped by a professional engineer registered to practice in Nunavut. Following an appropriate tendering and bidding phase, if Wolfden chooses this approach, construction of the dams could begin.

8.2 Construction Phase

To facilitate the proper construction of the required structures in High Lake, construction supervision and field engineering oversight will be required by the design engineers. This step is required to ensure that the design concept and related design criteria are met within the finally constructed dams, which will certainly encounter some conditions that have not been identified to-date.

There are two components to the construction monitoring phase, undertaken by the design engineers:

1. Implementation of the QA/QC Plan and related construction monitoring process.
2. Documentation of “as-constructed” conditions and preparation of “as-built” reports and related drawings.

During construction, a QA/QC Plan is required to control and document the construction activities to ensure good performance of the as-built structures. The plan is a combined effort of the owner’s design engineer (typically responsible for QA) and the owner’s contractor (typically responsible for QC). This plan provides protocols to detail verification measures used to measure the quality of work performed and responsibilities regarding “acceptance” of conditions and materials. In addition, field engineering staff may be called upon to take and interpret any on-going monitoring data and related engineering and safety assessments of temporary structures.

Quality control measures relative to the High Lake structures could include some of the following tasks:

Cofferdams

- Crest location of cofferdams.
- Rockfill and low-permeability material grain size assessments.
- Removal of sediments from lakebed (if so required).
- Remote or diving inspection of lake bed sediments during placement of the fill.
- Remote measurement of underwater fill slopes.
- Quantification of seepage through cofferdams and reassessment of stability and pump-back quantities.
- On-going assessment of cofferdam stability and safety.

Main Dams

- Construction of test fills to confirm lift thickness and compaction requirements (size of compactor and number of passes) for the various fill materials.
- Surface and subsurface water management and potential control measures.
- Stripping depth and extent of dam foundations and abutments to ensure the removal of unsuitable foundation materials.
- Field inspection of intact bedrock within the bottom of the cut off trench and verification of final depth of excavation.
- Verification of material gradations and moisture content, placement technique and density of all engineered materials within the dam section.
- Verification of thermosyphons installation methods, materials and related welding.
- Verification and testing of composite liner components within the dams. Possible use of leak detection surveys on the in-place liner. Elevation survey to confirm top of liner elevation.
- Sampling and geochemical testing of all fill materials placed within the dam.
- Assessment of riprap size and diameter ratio, quality (lithology) and placement finish.

Overflow Spillway

- Confirm location, width and inlet elevation.
- Ensure appropriate sub-grade conditions.
- Review appropriateness of any erosional protection measures placed.

In addition to implementation of the QA/QC Plan by field engineers, it is also usually their responsibility to read any instrumentation installed during the geotechnical investigation programs. In addition, field engineers need to ensure that appropriate survey control and data collection is being undertaken by the project surveyors.

After construction, as-built reports need to be prepared by the "engineer of record" to document the as-built structure conditions and to verify that the design objective(s) had been achieved with each structure. These as-built reports typically contain QA/QC results as tested, verification of technical standards met and decisions made relative to field design changes undertaken. These reports are required for both project documentation and submission to appropriate regulatory agencies.

8.3 Monitoring

During operations and closure, the dam and spillways will require an appropriate inspection and monitoring program, comprised of the following major components:

- On-going inspection of dam/spillway conditions by site staff.
- On-going instrumentation monitoring by site staff.
- Annual inspections and performance assessments by engineering consultants.
- Periodic dam safety reviews, in accordance with the Canadian Dam Association (CDA) guidelines.

It is important to monitor the performance of the dams, especially following first filling of the reservoir (may take several years, dependent upon yearly climatic conditions). The monitoring will include thermal regime, settlement, seepage and climate related data.

Visual inspection would be undertaken for the following important observations:

- Evidence of surface cracking, bulging, depressions, sinkholes and erosion.
- Reservoir water level.
- Evidence of seepage, new seepage areas or changes in seepage areas.
- Upstream slopes affected by ice scour and plucking.
- Associated water quality monitoring of any seepage and spillway discharge.

Instrumentation for these dams would likely consist of three main components:

- Thermistors to monitor geothermal regime with and beneath dams.
- Settlement points to monitor dam settlement in the first few years after construction.
- Pore pressure transducers to monitor upstream pond levels.

The data can be collected at discrete times using manual methods or dataloggers can be utilized to collect continuous monitoring data for thermistors and pore pressure transducers. Detailed site climate data should also be collected during the operation of the proposed mine to compliment the site instrumentation data collected for the dams. A snow cover survey should also be completed near the end of each winter in the vicinity of the dams.

Annual inspections of the dams and spillways will be performed by an external geotechnical consultant as usually required by the Nunavut Water Board License for mines. Dam safety reviews (DSR'S) will be required every 7 years as the dams were classified as High Consequence Dams.

Some additional detail relative to dam monitoring is also provided in the next section.

8.4 Operating Plans

Within the operating period for the High Lake TCF, it is important that the mine staff are familiar with design criteria and operating constraints. As such, CDA (1999) recommends that an OMS Manual be prepared that outlines the following main information:

- design criteria;
- inspection requirements;
- monitoring frequency; and
- maintenance requirements for each dam.

The document allows the dam operators to operate the dams in a safe manner, maintain it in a safe condition and monitor performance well enough to provide early signs of distress (CDA, 1999). A preliminary OMS Manual could be prepared as part of the final design for the dams; this manual could then be expanded in the future to meet the complete needs of the site operators.

In addition to the manual, CDA (1999) also recommends the preparation of an EPP for the site operators. The primary purpose is to identify potential emergencies so they can be managed in the future. The EPP describes the procedures and actions in case of an emergency and provide measures for situations where the consequence of potential damages could be reduced. The EPP will also list the various individuals responsible for the actions and agencies to be notified. Again, a preliminary EPP could be prepared as a portion of the final design process, which could be completed later during operations.

9.0 RISK AND CONTINGENCIES

The information supplied herein provides for the feasibility level design of the containment dams and related spillways around the High Lake TCF. As with all engineered structures, there are some potential risks that may potentially occur. The following section therefore attempts to outline some of the potential risks and the design measures or potential mitigation plans that could be implemented to address the potential concerns.

Risk #1 – Seepage through dams

Potential seepage through the liner is addressed by selection of a composite liner to absolutely minimize the potential for leaks due to imperfections and defects. The appropriate QA/QC Plan, plus the potential use of a leak detection survey on the GM, would ensure the lowest practical number of liner defects. In addition, any minimal seepage that does occur would likely freeze within the void space of the downstream rockfill due to the subzero temperatures caused by the use of thermosyphons in the cut off trench.

Abutment seepage is usually managed by the appropriate excavation depth and liner embedment to low permeability materials. This mitigation step is dependent upon selection of appropriate abutment locations, detailed site investigations and construction inspection by experienced engineering personnel. If some seepage still occurs, three potential mitigation options are as follows:

1. The simple option consists of placing additional fill on the crests and abutment areas to force the aggradation of permafrost into the seepage areas. The lowering of the ground temperature will reduce or stop the seepage. This approach was undertaken on the tailings dams at Lupin Mine when the dam has some initial seepage problems after they were constructed.
2. Secondly, it may be possible to place some GCL on the ground surface in order to reduce the hydraulic gradient at the abutment area. In order for this approach to work, it would be necessary to install the GCL below FSL which would require pond lowering or placement in the winter time after pond ice has been removed.
3. The more complex option consists of the installation of additional thermosyphons into the seepage area to cool the ground and control the seepage.

Seepage through the foundation is extremely unlikely due to the low temperatures created by the thermosyphons in the trench. Further site investigation and assessment of water takes within bedrock will determine if any leakage could result within fractured rock zones at depth.

Therefore, design elements, site investigation details or potential mitigation plans are in-place to deal with all three potential seepage mechanisms.

Risk #2 – Later identification of taliks under dams

BGC has drilled a number of boreholes and installed some thermistors into each of the proposed dams. There is still the potential of talik existence below the proposed footprints of selected dams so additional site investigation will be required before final design. If a talik is actually identified, two potential options exist for their mitigation within the dam construction period. Firstly, it is possible that winter stripping and foundation preparation could freeze-back the talik if enough time is available for freeze-back to occur. Secondly, the thermosyphons could be used to freeze-back the talik, as was done at the Panda Diversion Dam at Ekati Mine.

Risk #3 – Failure of individual thermosyphons

Thermosyphons “fail” due to gas-topping or due to the loss of refrigerant in the pipe, due to puncturing from vehicle impacts or vandalism and their longevity has been reviewed in Section 6.2. At the current time, seven thermosyphons loops are required for each cut off trench. As such, the “failure” of one pipe within an overall system of seven would likely have minimal short term impacts on the heat extraction ability of the system. Regular monitoring and related maintenance would be required in any thermosyphons radiator found to be inoperative.

Alternatively, if the retained water reaches a discharge compliant state, it is possible that the thermosyphons could be decommissioned. Thereafter, the dam foundations would warm up, followed by the creation of under-seepage flowing through warmed bedrock. If no environmental impacts were forecast to result from this seepage, and the dam remained stable along with the water cover depth, then there would be no future requirement for the thermosyphons to operate.

Risk #4 – Composite liner failure due to instability

The composite liner may become unstable if inappropriate liner materials (low interface shear strength) were chosen or if bentonite expulsion occurred from the GCL onto the GM surface. This first issue has been dealt with using a detailed review of available technical information to ensure proper material selection. Bold and Elie (2006) noted that the selection of proper asperity height for textured GM's is critical. In addition, material specific interface shear testing has been recommended within the final design task to ensure a long-term stable design.

Risk #5 – Overtopping of dams

The High Lake dams have been designed with enough contingency storage to retain the PMP, an event by definition as "beyond imagination". As such, an extremely conservative design assumption has been used. Secondly, experience has shown that rockfill dams are usually able to resist overtopping, even though they are not explicitly designed to do so, without catastrophic failure occurring.

Therefore, it is extremely unlikely that these dams will be overtopped. And if such an unlikely event occurs, it is possible that the dams will remain stable, although discharge of some water would occur. If discharge were to occur during the closure phase, the water may be discharge compliant with little to minor environmental impacts (in relation to the "natural damage" being caused by a PMP event).

Risk #6 – Lack of tailings storage capacity

It is conceivable that an incorrect tailings density or poor operation of the tailings deposition could result in higher than expected, or more variable, tailings solids level. For selected high points in tailings, Nanisivik has previously used small explosive charges to liquefy tailings and decrease their elevation. For an overall higher tailings surface, it would be necessary to either optimize the 2.5 m of water cover (based on the operating experience of water cover depth to reservoir water quality results, especially in the spring break-up period) or to raise the containment dams.

Obviously, this potential problem would not "instantly" occur and Wolfden would have years of operating experience and monitoring data to forecast the potential occurrence of this risk. Options for additional tailings storage capacity are reviewed under Risk #7.

Risk #7 – Identification of additional ore reserves

A number of mining projects will increase their ore reserves over feasibility level estimates. As such, it is possible that additional ore and associated tailings could be produced over the mine life. If this occurs, a number of options exist for the containment of additional tailings:

- Raise the existing dams using the downstream construction approach.
- Place tailing solids behind a retention dike proximal to, or within High Lake to store tailings above the lake level. These tailings would then be frozen in-place with a permafrost aggradation cover for closure. This approach was undertaken at Nanisivik Mine with sulphidic tailings.
- Place tailings within the mined-out D Zone Pit.
- Assess the use of paste backfill into the various underground stopes.

For any option, additional engineering and environmental impact assessment, along with appropriate permitting, would be required to appropriately assess the option.

As noted, seven potential risks have been reviewed within this section; it is possible that other risks do exist with the facility design.

10.0 SUMMARY

The information provided herein provides for the feasibility level design of six dams and associated spillways around the High Lake TCF. Geothermal analyses, using conservative values of global warming and snow accumulation, have provided a dam geometry including thermosyphons to keep the foundation bedrock frozen for 100 years. In addition, a high-quality composite liner has been proposed as the water retaining element in the dams. These two design features should ensure that seepage from the TCF is completely minimized.

The design features for the Contact Lake Dam are different than the other dams, because seepage under the Contact Lake Dam would have minor consequences.

Seven selected potential risks for the facility were reviewed. For each risk, design elements, inspection protocols or mitigation plans are provided for mitigation.

Numerous recommendations for final design are provided in Section 8.0. Plans should be initiated to undertake the noted work within an implementation schedule that meets Wolfden's requirements for design and construction.

During final design, it is possible that design details, materials and arrangements could change in response to practical constraints such as constructability, construction schedule and costs. Any design changes would still need to meet required and noted design criteria for the structures.

Design recommendations provided herein are based on the assumption of adequate and appropriate construction monitoring by BGC's staff. This step is critical in realizing the design intent on the actually constructed structures.

11.0 LIMITATIONS AND CLOSURE

The report provided herein provides a feasibility design for six dams located around the High Lake TCF. In some cases, design input and plans have been submitted by third-parties. BGC has not independently verified this work and BGC has assumed it to be accurate. In addition, interpretations have been made with respect to subsurface conditions and potential variations exist from these interpretations. Before construction of any of the noted structures, the final design requirements must be undertaken by appropriate engineering professionals.

Recommendations provided herein are based on the findings of geotechnical investigations and interpretations of that information. If conditions other than noted are encountered during subsequent phases of the project, BGC should be notified of such changes and be given an opportunity to review and possibly revise their recommendations, if necessary. As such, the recommendations provided herein may not be valid if an adequate level of field monitoring and construction inspection is not provided.

We trust the enclosed report meets your requirements and thank you for the opportunity to be of service to Wolfden Resources Inc. Should you have any questions, or require any other services, please contact any of the undersigned at your convenience.

BGC Engineering Inc.

Per:

Eric Niven, M.Sc., E.I.T.
Engineer-in-Training

James W. Cassie, M.Sc., P.Eng.
Specialist Geotechnical Engineer

Reviewed by:

Holger Hartmaier, M.Eng., P.Eng.
Senior Geotechnical Engineer

REFERENCES

BGC Engineering Inc. 2006a. High Lake and Area Talik Assessment, High Lake Project, NU. Memo prepared for Wolfden Resources Inc., August 2, 2006, 16 pages plus figures.

BGC Engineering Inc. 2006b. Conceptual Design, Tailings Containment Facility, High Lake Project, NU. Report prepared for Wolfden Resources Inc., August 28, 2006, 39 pages plus figures.

BGC Engineering Inc. 2006c. Supplemental Information on Tailings Dam Design, High Lake Project, NU. Memo prepared for Wolfden Resources Inc., October 13, 2006, 16 pages.

BGC Engineering Inc. 2006d. 2004-2005 Geotechnical Investigations Report, High Lake Project, NU. Report prepared for Wolfden Resources Inc., October 23, 2006, 38 pages plus figures and appendices.

BGC Engineering Inc. 2006e. Conceptual Design Outline - A/B Waste Dump Toe Dike, High Lake Project, NU. Memo prepared for Wolfden Resources, October 19, 2006, 27 pages plus figures.

BGC Engineering Inc. 2007. 2006 Geotechnical Investigation Program, High Lake Project, NU. Report prepared for Wolfden Resources Inc., March 26, 2007, 42 pages plus figures and appendices.

Benson, C.H., 2000. Liners and covers for water containment. Proceedings of the 4th International Geotechnical Forum, Japanese Geotechnical society, Kyoto, Japan, May 2000, pp. 1-40.

Blond, E. and Elie, G., 2006. Interface shear-strength properties of textured polyethylene geomembranes. Sea to Sky Geotechnique 2006 Conference, Vancouver, BC, pp. 898-904.

Bouazza, A., 2002. Geosynthetic clay liners. Geotextiles and Geomembranes, Vol. 20, pp. 3-17.

Bowders, J.J., Tan, J.P., Daniel, D.E. 1996. Expanded clay and shale aggregates for leachate collection systems. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Volume 123, Issue 11, pp. 1030-1034.

Canadian Dam Associates, 1999. Dam Safety Guidelines. Twelve section, January 1999.

Davies, M.P. and Veillette, M.F., 2006. Pogo Project Alaska – tailings and water management for a cold regions mine. Sea to Sky Geotechnique 2006 Conference, Vancouver, BC, pp. 1024-1032.

Gartner Lee Limited 2006. High Lake Project - Water Quality Model. Report prepared for Wolfden Resources Inc.

EnvirAubé 2006a. High Lake Laboratory Neutralization Tests. Report submitted to Wolfden Resources and Gartner Lee, October 2006.

EnvirAubé 2006b. Water Management and Treatment at the High Lake Mine Site. Report submitted to Wolfden Resources and Gartner Lee, October 2006.

Foose, G.J., Benson, C.H., and Edil, T.B. 2001. Predicting Leakage Through Composite Landfill Liners. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 6, pp. 510 – 520.

Hayley, D.W., Seto, J.T.C., Grapel, C.K., Cathro, D.C. and Valeriote, M.A., 2004. Performance of Two Rockfill Dams with Thermosyphons on Permafrost Foundations, Ekati Diamond Mine, NT. Proceedings of the 57th Canadian Geotechnical Conference, Quebec, Session 5F.

Jardine, J., 2007. Personal Communication. March 16, 2007.

Jardine, J.D., Long, E.L. and Yarmak, E., 1992. Thermal analysis of forced-air and thermosyphons cooling systems for the Inuvik airport expansion: Discussion. Canadian Geotechnical Journal, 29, pp. 998-1001.

Jones, D. R. V. and Dixon, N. 1998. Shear strength properties of geomembrane/geotextile interfaces. Geotextiles and Geomembranes, Volume 16, pp. 45 – 71.

Leps, T.M. 1970. Review of shearing strength of rockfill. Proceedings ASCE Journal of Soil Mechanics and Foundation Engineering Division, 96, SM4: 1159-1170.

Lorax Environmental Services Inc., 2006. Geochemical Characterization and Source Loading Study High Lake Project. Report submitted to Wolfden Resources and Gartner Lee, October 2006, 14 sections plus appendices.

Koerner, R.M., Hsuan, Y.G. and Koerner, G.R., 2005. Geomembrane lifetime predictions: unexposed and exposed conditions. GRI White Paper #6, produced for the Geosynthetic Institute, June 7, 2005, 19 pages.

Marsal, R.J. 1973. Mechanical Properties of Rockfill. In Embankment Dam Engineering ed. Hirshffeld and Poulos.

McCartney, J.S., Zornberg, J.G. and Swans, R.H., 2005. Effect of geomembrane texturing on GCL-geomembrane interface shear strength. Proceedings of the Geo-Frontiers 2005 Conference, Geotechnical Special Publication No. 142, Waste Containment and Remediation, Austin, Texas, January 24-26, 2005.

Noel, M. and Hockley, D., 2004. Thermal analysis of an experimental thermosyphons installed at the Giant Mine in Yellowknife, NT, Canada. 57th Canadian Geotechnical Conference, Quebec City, Session 1G, pp. 9 to 16.

Reddy, D.V. and Butul, B., 1999. A comprehensive literature review of liner failures and longevity. Report submitted to Florida Centre for Solid and Hazardous Waste Management, University of Florida, July 12, 1999, 146 pages.

Rowe, R.K., 2005. Long-term performance of containment barrier systems. Geotechnique, 55, No. 9, pp. 631-678.

Rowe, R.K. and Booker, J.R. 2001. Theoretical solutions for calculating leakage through composite liner systems. In Developments in Theoretical Geomechanics (eds D.W. Smith and J.P. Carter). Balkema, Rotterdam, pp. 589 – 602.

Russell, D., Jones, V. and Dixon, N., 1998. Shear strength properties of geomembrane/geotextile interfaces. Geotextiles and Geomembranes, Vol. 16, pp. 45-71.

RWDI Air Inc. 2006. High Lake Climate Assessment, Updated Report. Submitted to Gartner Lee Ltd., Calgary, AB, 53 pages.

Sorensen, S., Smith, J. and Zarling, J., 2003. Thermal performance of the TAPS heat pipes with non-condensable gas blockage. Proceedings of the Eighth International Conference on Permafrost, 21-25 July 2003, Zurich, Switzerland, A.A. Balkema Publishers, pp 1097 to 1102.

Wolfden Resources, 2006. High Lake Project Proposal. Prepared for the Nunavut Impact Review Board. November 15, 2006, Volume 1 through Volume 9.

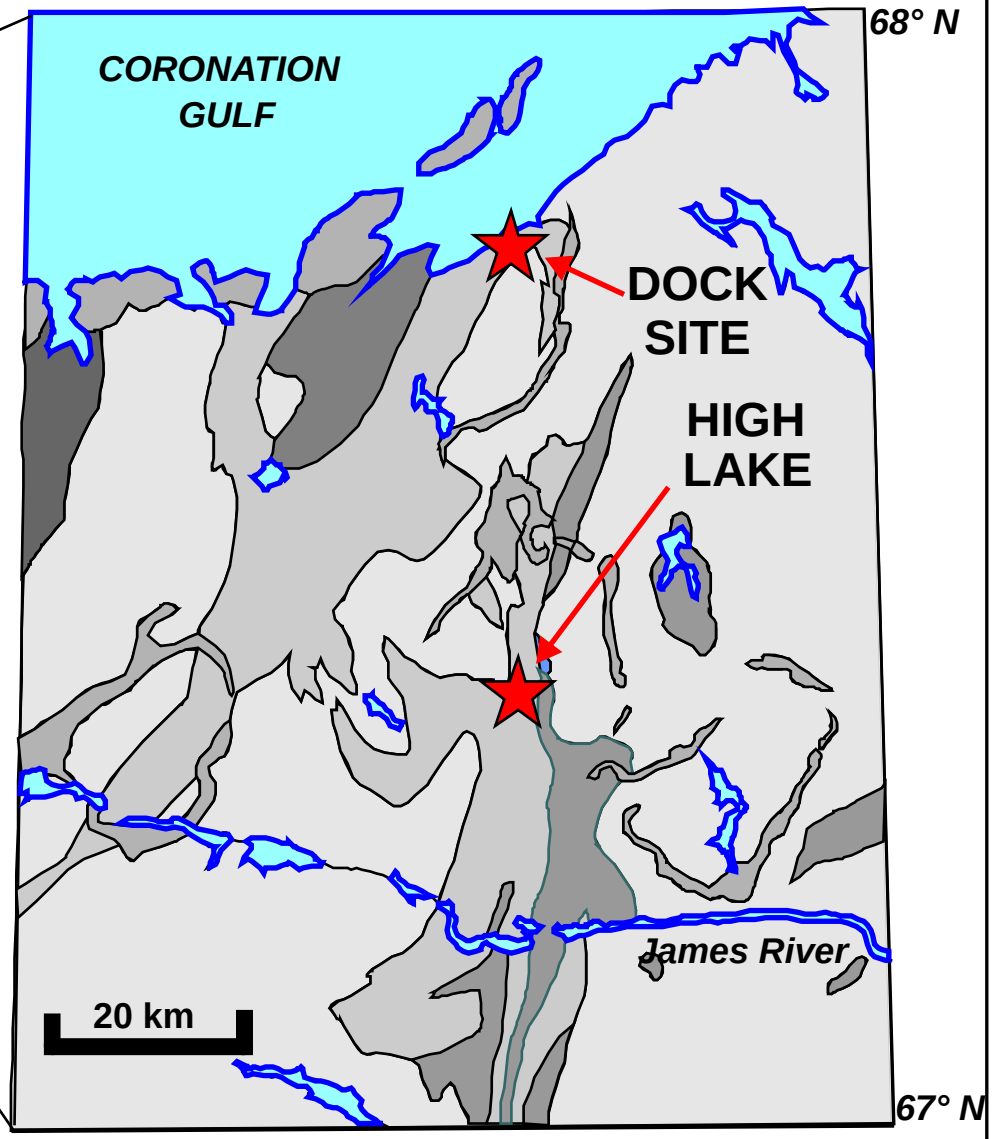
Wardrop Engineering Inc., 2006. High Lake Tailings Disposal. Report submitted to Wolfden Resources, June 7, 2006, 7 pages plus appendices.

Weber, C.T., and Zornberg, J.G. (2005). Use of GCL's to control leakage through geomembrane defects under high hydraulic heads. Proceedings of the NAGS 2005 Geosynthetics Conference. North American Geosynthetics Society. Las Vegas. NV. December 14 – 16, pp. 1 – 8 (CD-ROM).

Williams, D.J. 2000. Assessment of Embankment Parameters. In Slope Stability in Surface Mining. Society for Mining, Metallurgy and Exploration, Inc. (SME), Littleton Colorado pp. 275-284.

Yarmak, E., 2007. Personal Communication. March 14, 2007.

FIGURES



DATE: MAY 2007	DRAWN SLF

REFERENCED DRAWING DESCRIPTION

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

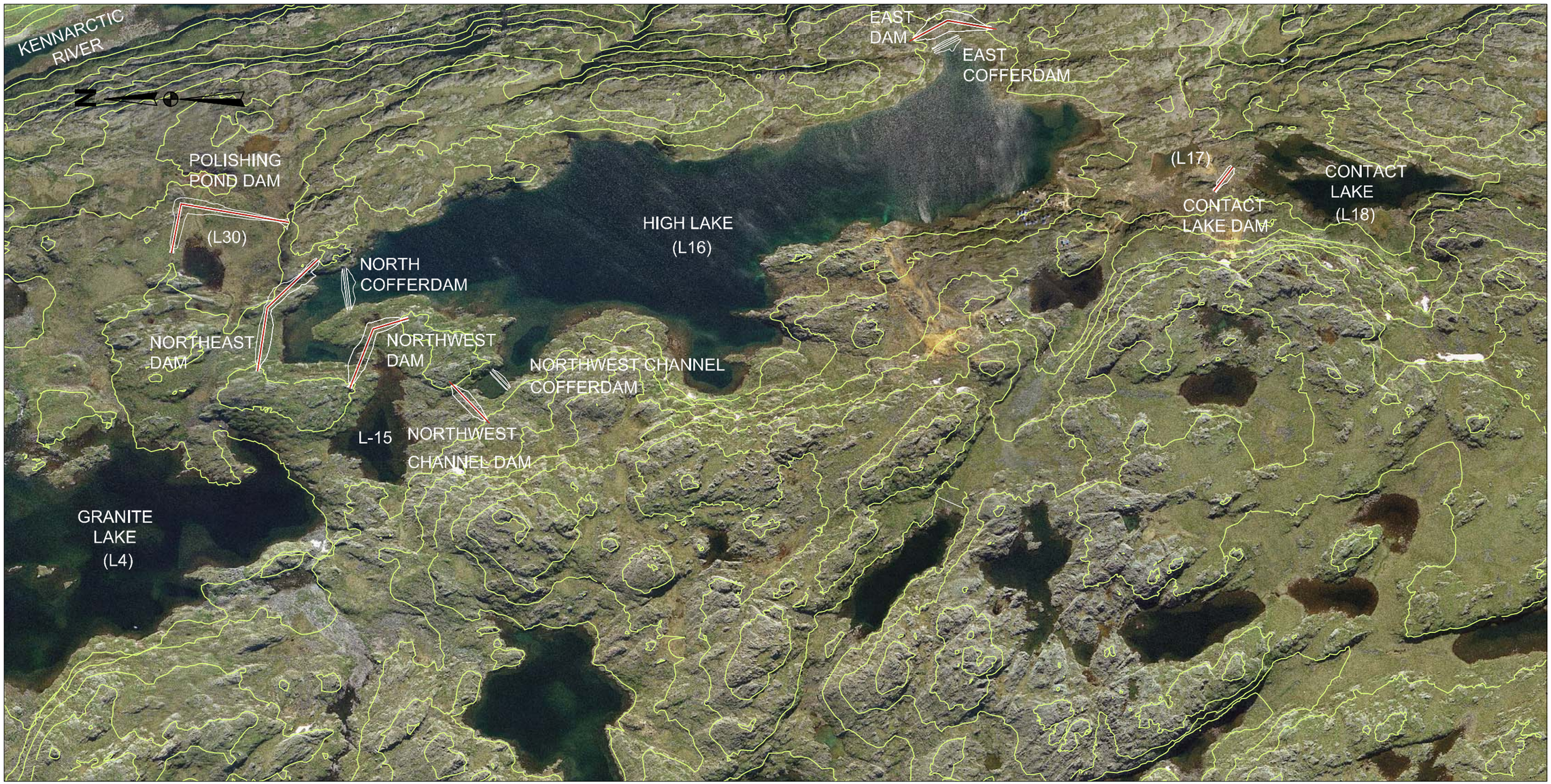
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
Calgary, Alberta Phone: (403) 250-5185

CLIENT WOLFDEN Resources Inc.

PROJECT
HIGH LAKE TCF
FEASIBILITY DESIGN REPORT

TITLE
PROJECT LOCATION MAP

PROJECT No.	FIGURE NO.	REV.
0385-003-19	1	0



NOTE: L NUMBERS REFER TO GLL'S LAKE NUMBERING SYSTEM

200 0 200 400 600

metres

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	MSR
DESIGNED:	EBN
CHECKED:	JWC
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

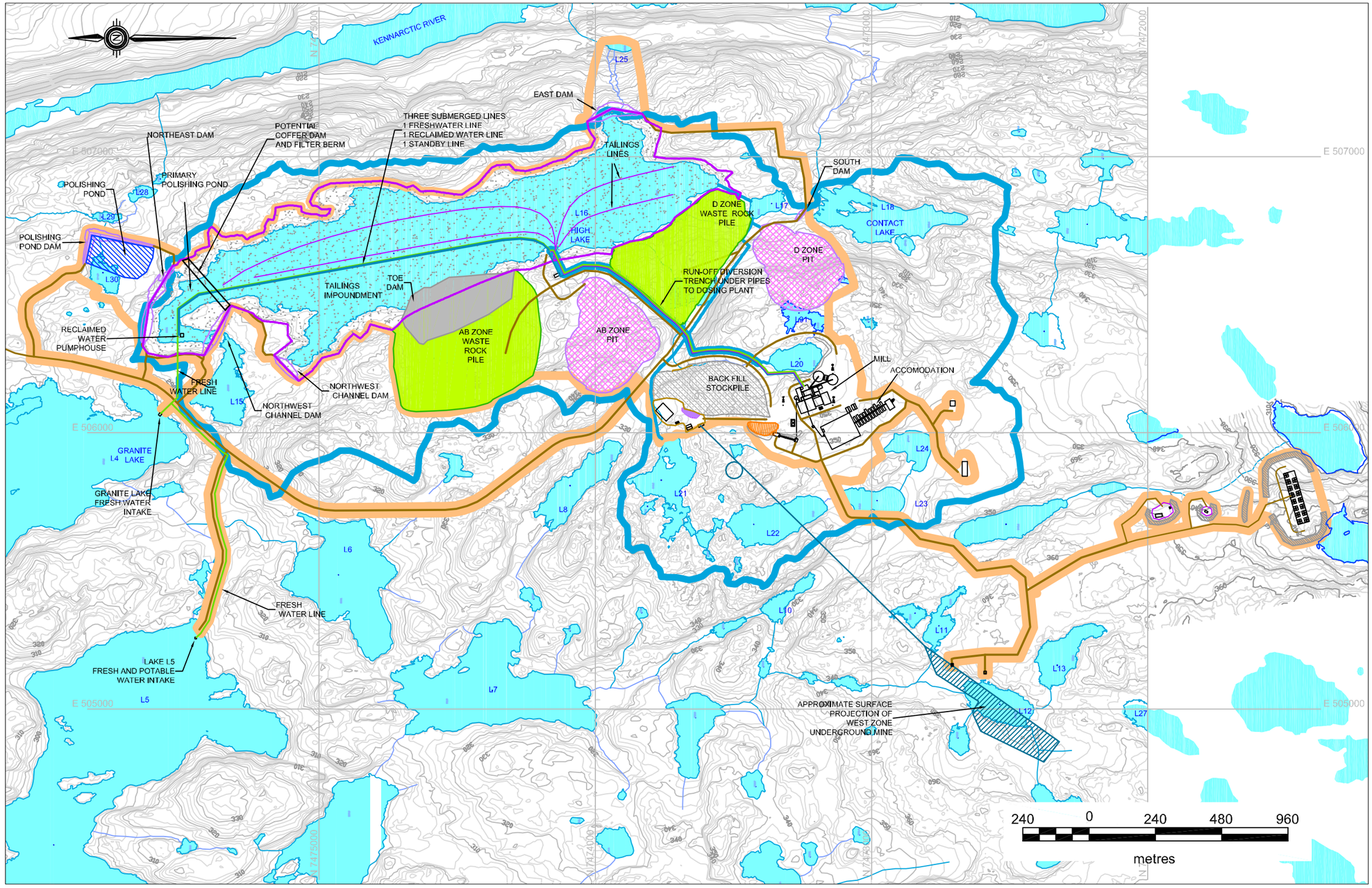
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: HIGH LAKE TCF DAM LOCATIONS

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	2	

K:\Projects\0385 Wolfden Resources\003 HL Prefeasibility Study\19 2006 Dam Design\3 Report\Graphics\Drawings\0385-003-19 DamLocations(2).dwg Layout: High Lake Site Plan Plot Date: Jun 27 07 Time: 4:43 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	MSR
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

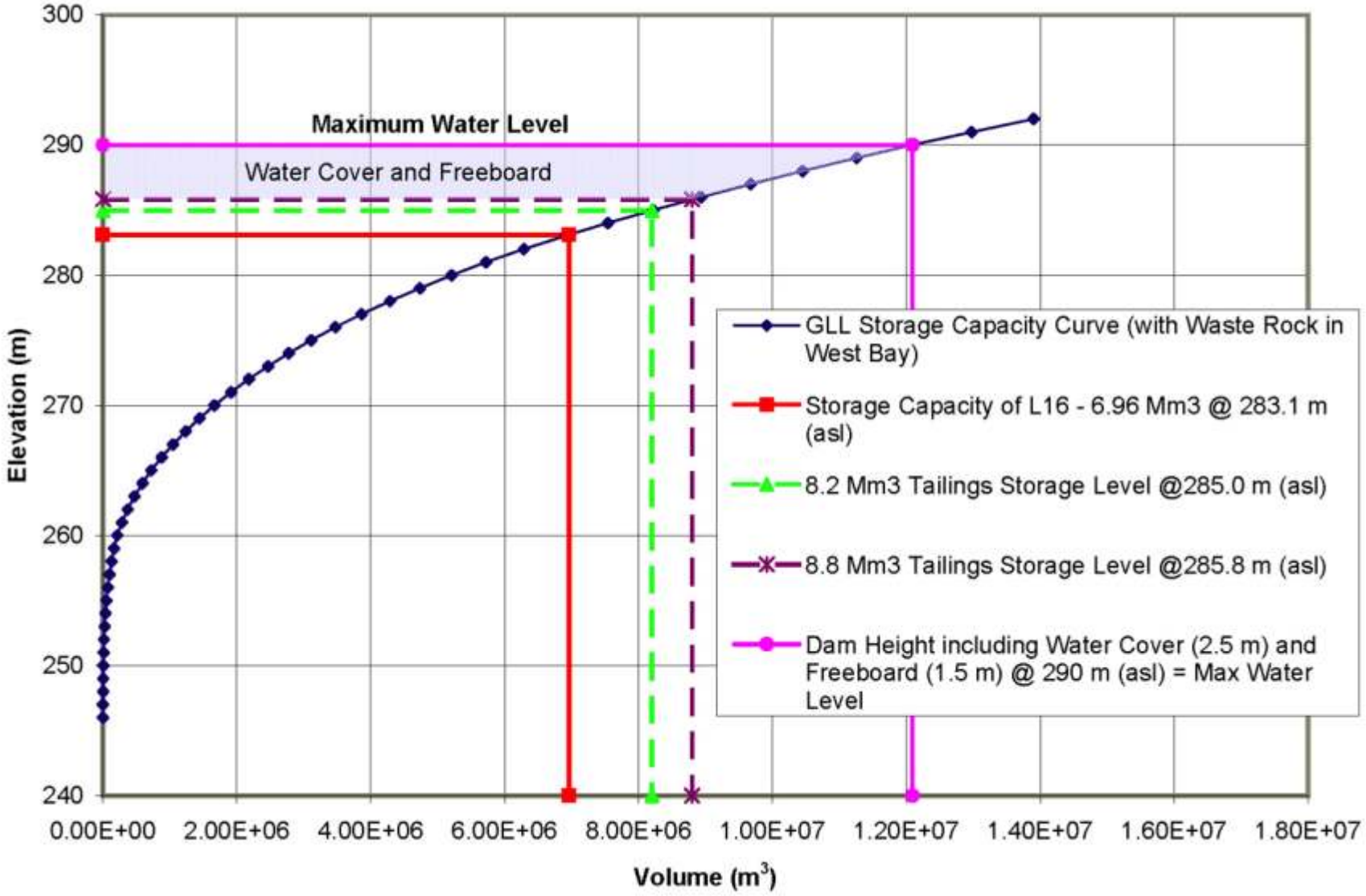
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: HIGH LAKE PROJECT AREA LAYOUT

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	3	

X:\Projects\0385 Wolfden Resources\003 HL Prefeasibility Study\19 2006 Dam Design\3 Report\Graphics\Drawings\0385-003-19 TopoApril2007.dwg Layout: Figure 3 Plot Date Jun 27 07 Time: 4:24 PM



DATE: MAY 2007	DRAWN SLF	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY Calgary, Alberta Phone: (403) 250-5185	PROJECT HIGH LAKE TCF FEASIBILITY DESIGN		
REFERENCED DRAWING DESCRIPTION			TITLE HIGH LAKE STORAGE CAPACITY CURVE		
AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.		CLIENT WOLFDEN Resources Inc.	PROJECT No. 0385-003-19	FIGURE No. 4	REV. 0

7474100 7473900

N

LEGEND

- BOREHOLES WITH THERMISTOR
- BOREHOLES WITHOUT THERMISTOR
- POTENTIAL ACTIVE LAYER SEEPAGE ZONE

507200

270 280 290 288.5

EAST DAM

BGC06-06 BGC06-24 BGC04-07 BGC06-05 BGC06-25

B 19 A 6

FULL SUPPLY LEVEL 288.5m

HIGH LAKE

NOTE: BOREHOLE LOCATIONS ARE APPROXIMATE.

20 0 20 40 60 metres

7474100 7473900 UTM NAD 83 ZONE 12N

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:1000
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

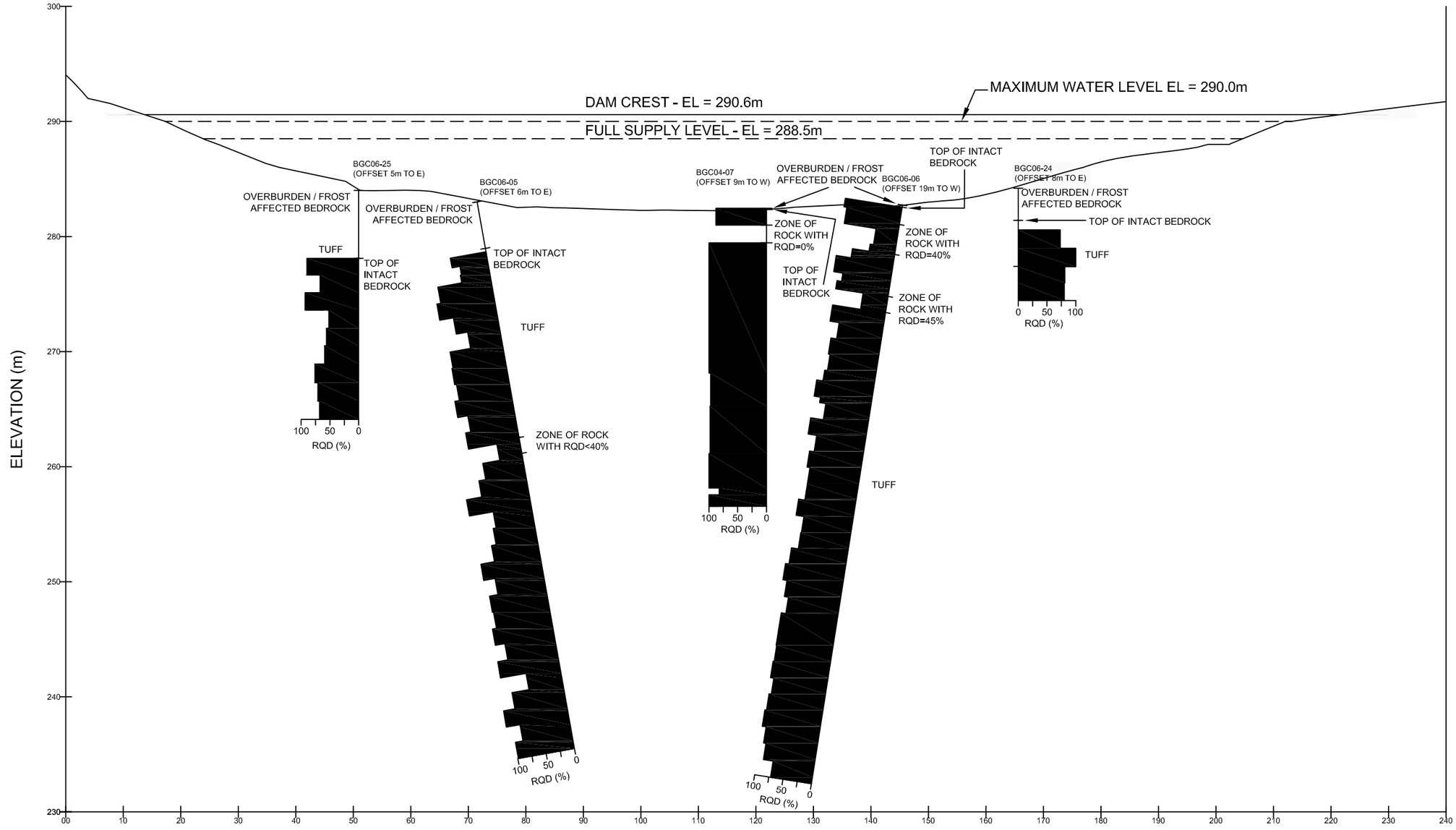
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: EAST DAM LAYOUT PLAN

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	5	0

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: EAST DAM Plot Date Jun 27 07 Time: 4:34 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

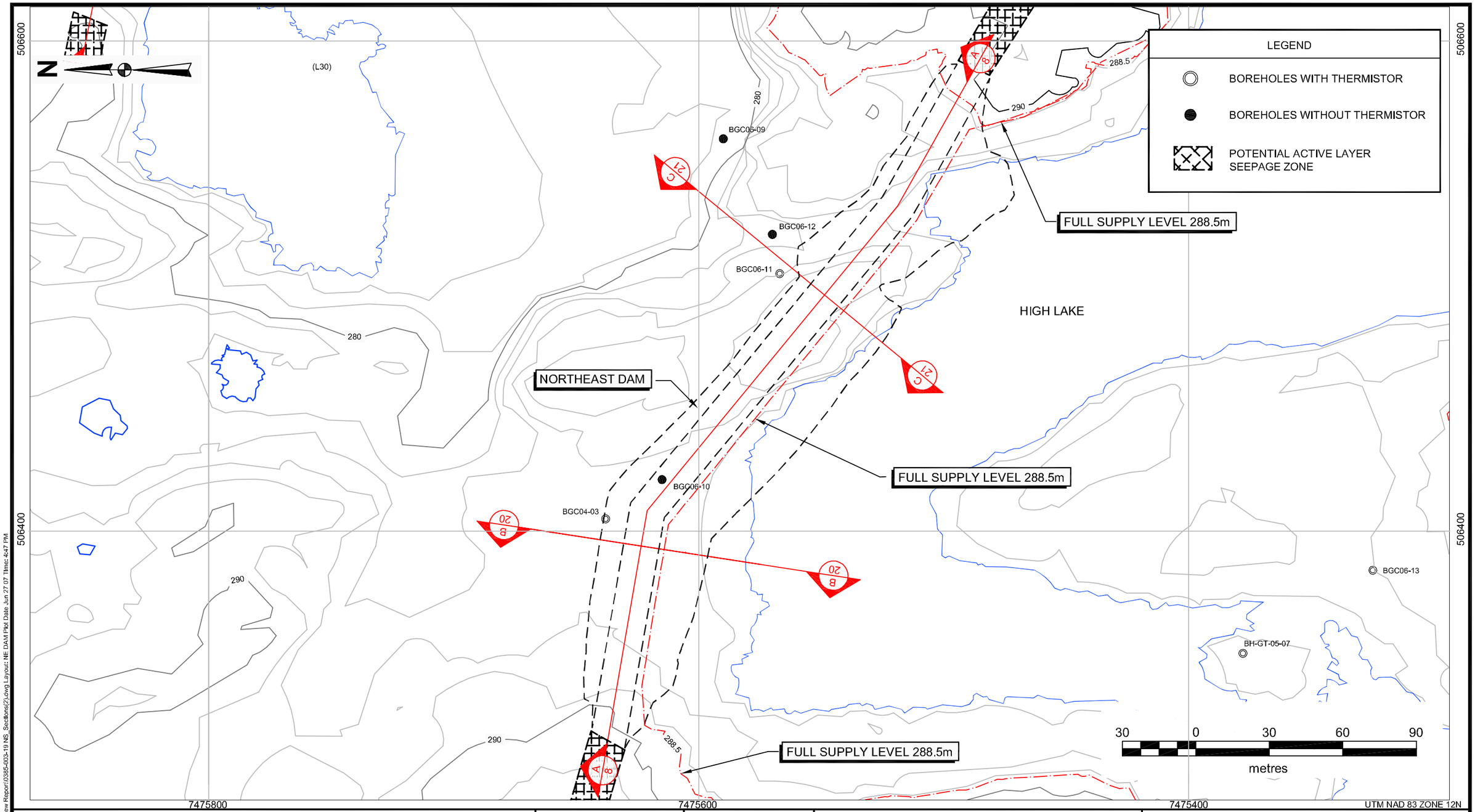
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: EAST DAM LONGITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	6	0

X:\Projects\0385\003\10\dwg\0385-003-10 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:1500
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

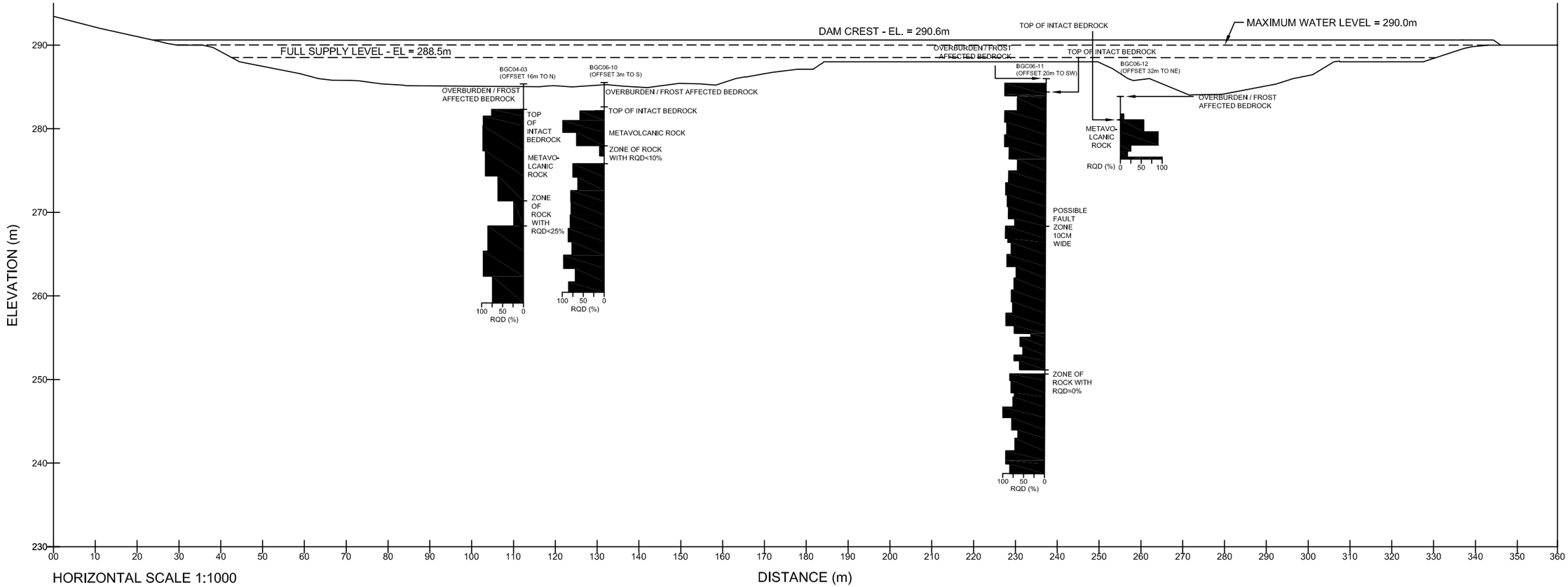
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHEAST DAM LAYOUT PLAN

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	7	0

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: NE DAM Plot Date: Jun 27 07 Time: 4:47 PM



HORIZONTAL SCALE 1:1000
VERTICAL SCALE 1:500

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHEAST DAM LONGITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	8	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

7475500

7475300

506400

506400

N

LEGEND

BOREHOLES WITH THERMISTOR

POTENTIAL ACTIVE LAYER SEEPAGE ZONE

FULL SUPPLY LEVEL 288.5m

FULL SUPPLY LEVEL 288.5m

BGC06-13

BH-GT-05-07

HIGH LAKE
L-16

NORTHWEST DAM

L-15

B 22

B 22

A 9

A 11

288.5

290

290

290

20 0 20 40 60

metres

NOTE: BOREHOLE LOCATIONS ARE APPROXIMATE.

7475500

7475300

UTM NAD 83 ZONE 12N

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: 1:1000

DATE: MAY 2007

DRAWN: CJT

DESIGNED: ACJ

CHECKED: ACJ

APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

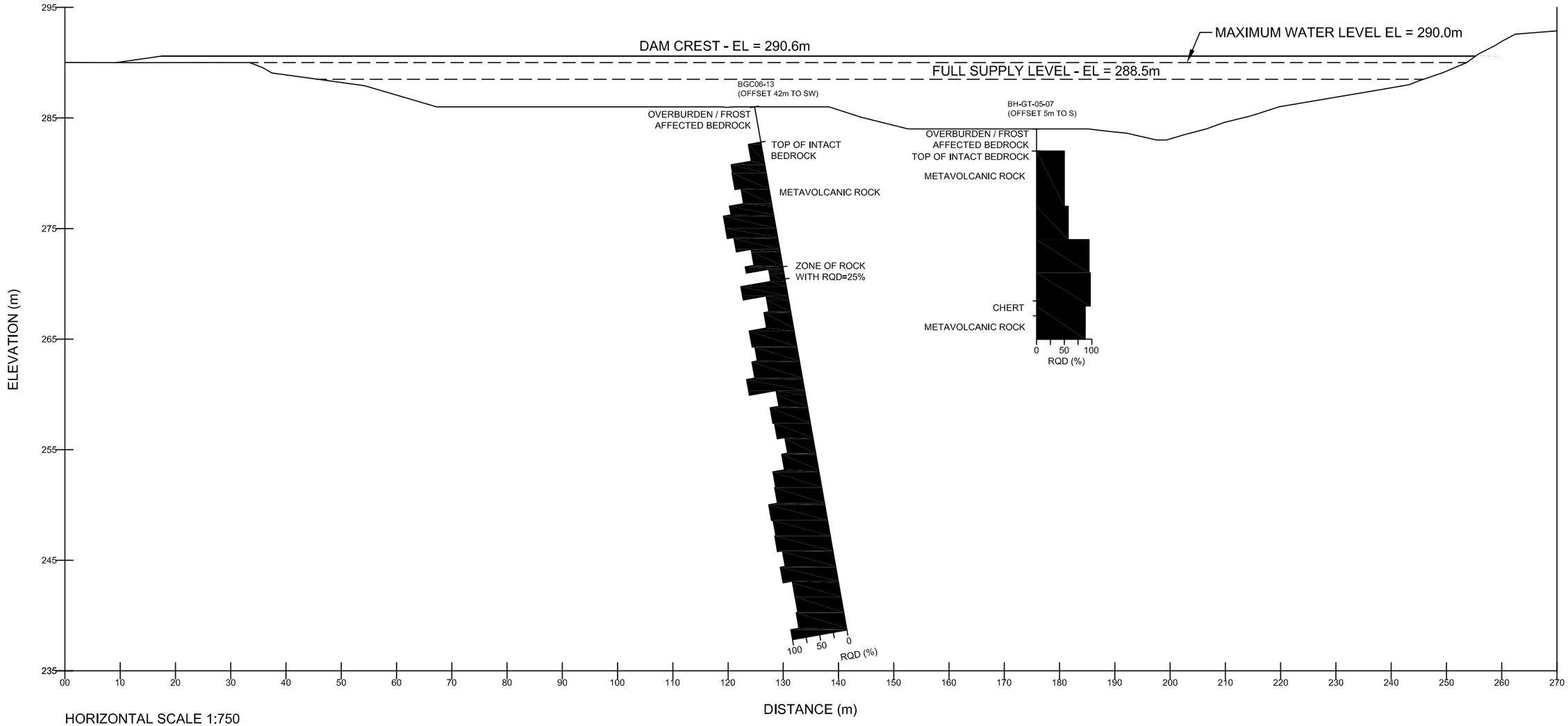
TITLE: NORTHWEST DAM LAYOUT PLAN

PROJECT No.: 0385-003-19

FIGURE No.: 9

REV.: 0

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: NW DAM Plot Date: Jun 27 07 Time: 4:46 PM



HORIZONTAL SCALE 1:750
VERTICAL SCALE 1:375

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

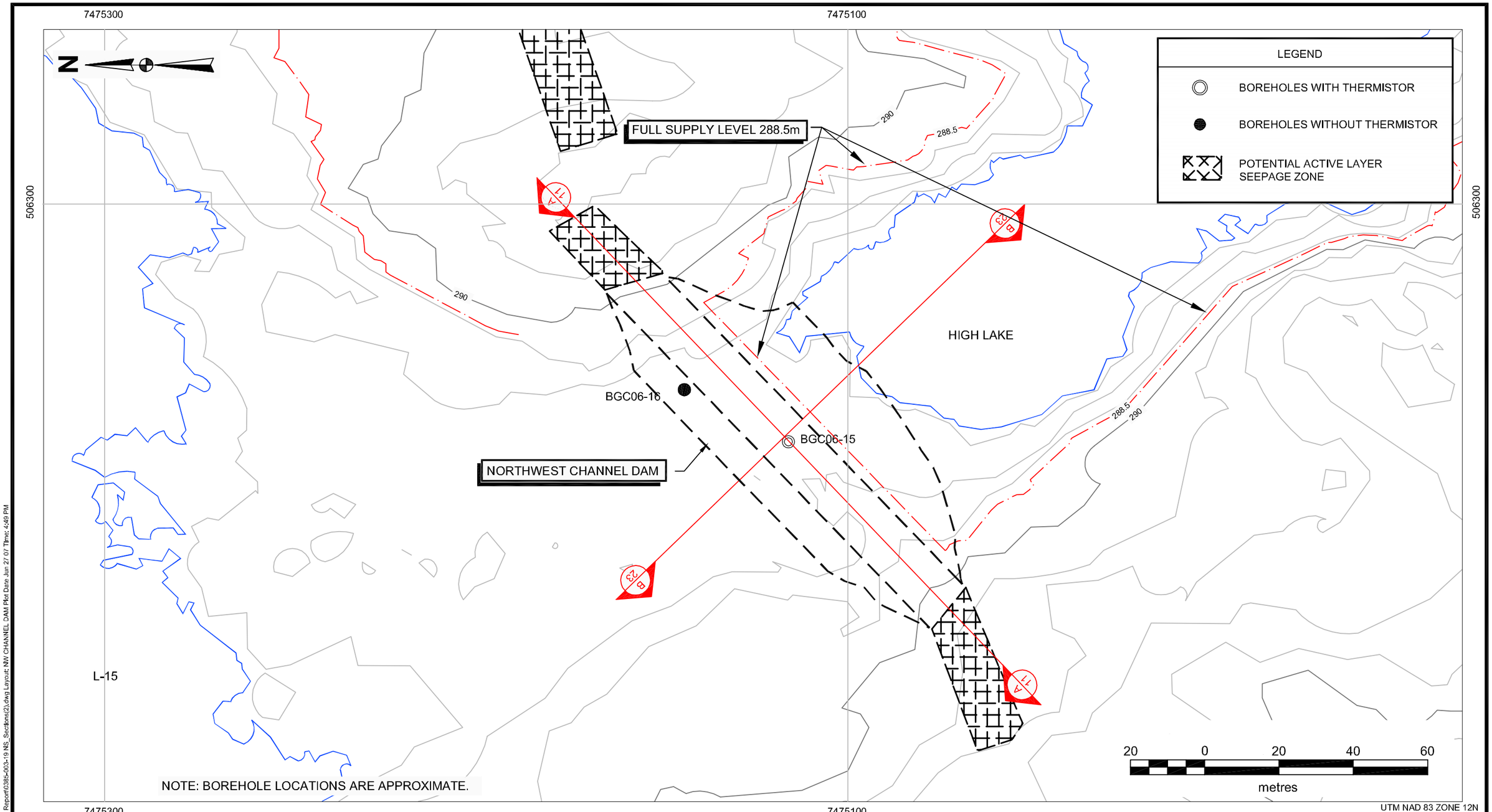
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHWEST DAM LONGITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	10	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date: May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:1000
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

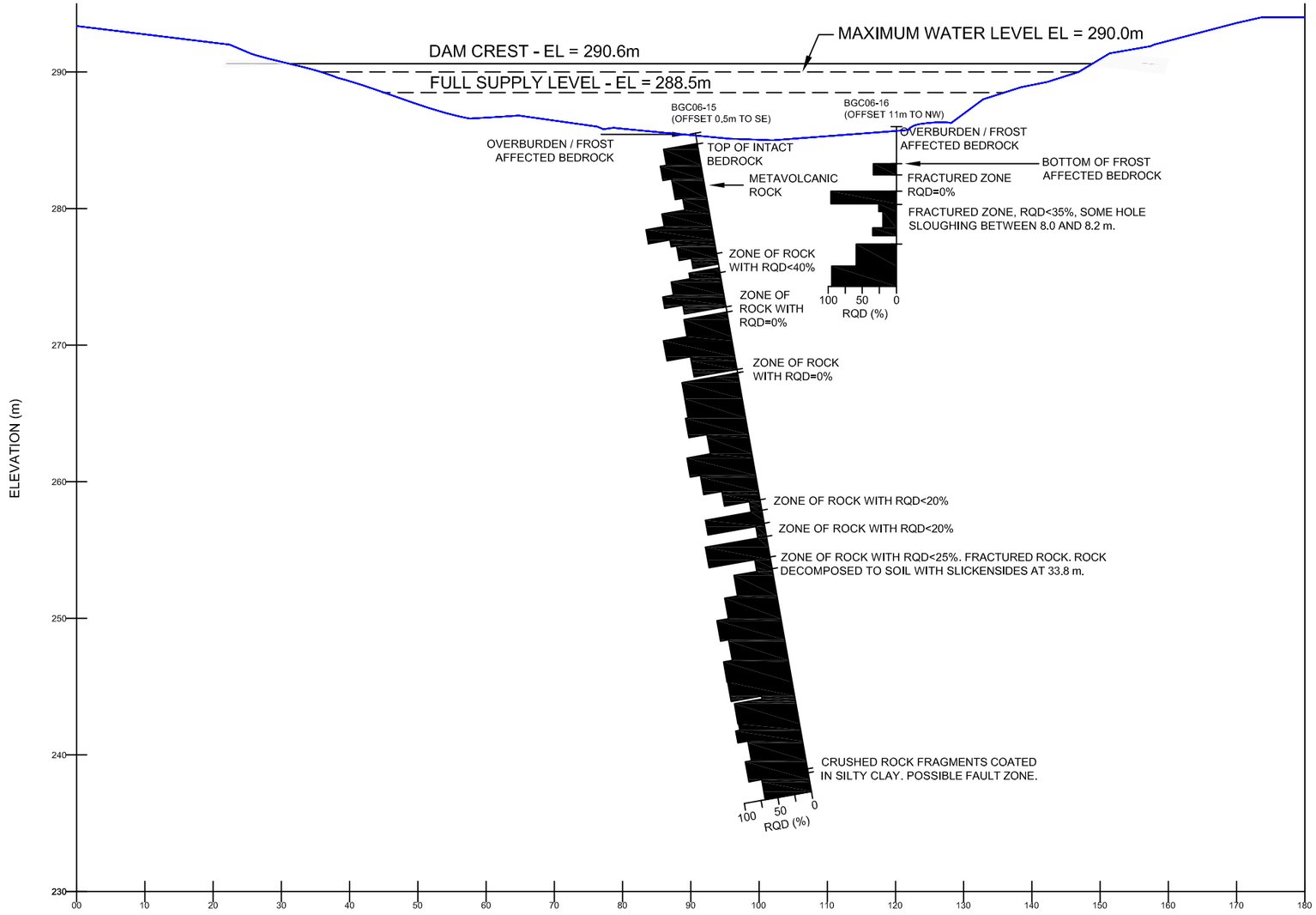
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHWEST CHANNEL DAM LAYOUT PLAN

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	11	0

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: NW CHANNEL DAM Plot Date Jun 27 07 Time: 4:49 PM



HORIZONTAL SCALE 1:600
VERTICAL SCALE 1:300

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHWEST CHANNNEL DAM
LONGITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	12	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

7475900 7475700

N

LEGEND

BOREHOLES WITH THERMISTOR

BOREHOLES WITHOUT THERMISTOR

270

270

BGC06-08

BH-GT-05-08

506700 506700

POLISHING POND DAM

277.4

290

280

BGC06-07

B 24

FULL SUPPLY LEVEL 277.4m

BH-GT-05-09

A 14

FULL SUPPLY LEVEL 277.4m

(L30)

20 0 20 40 60

metres

7475900 7475700 UTM NAD 83 ZONE 12N

NOTE: BOREHOLE LOCATIONS ARE APPROXIMATE.

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:1000
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

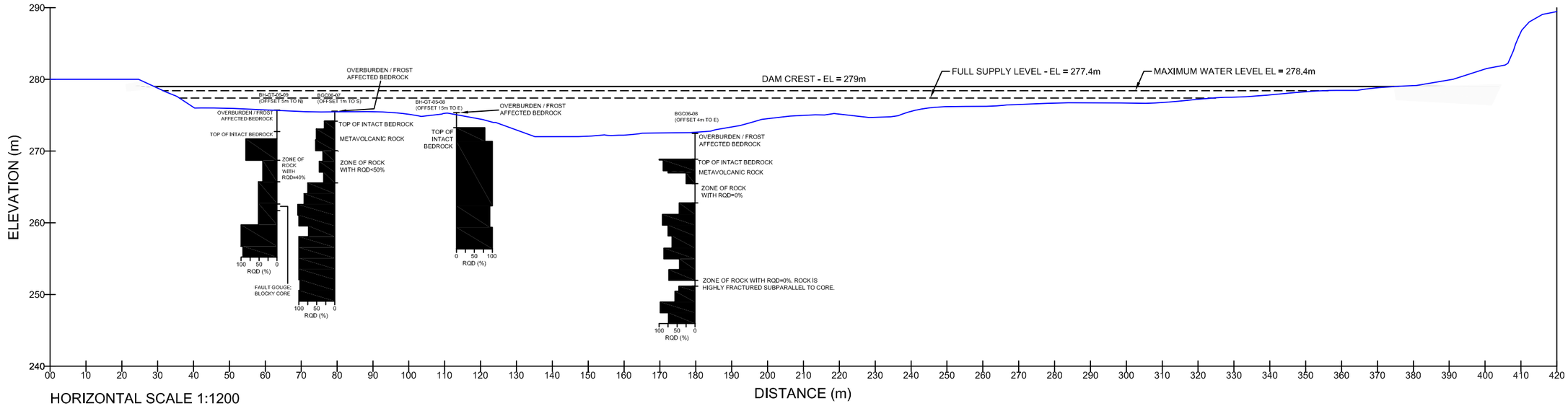
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: POLISHING POND DAM LAYOUT PLAN

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	13	0

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: P_POND DAM Plot Date: Jun 27 07 Time: 4:50 PM



HORIZONTAL SCALE 1:1200
VERTICAL SCALE 1:600

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: POLISHING POND LONGITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	14	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

7473400

7473200

N

PROPOSED OUTFALL CHANNEL LOCATION

LEGEND

BOREHOLES WITH THERMISTOR

BOREHOLES WITHOUT THERMISTOR

290

ABUTMENT AREA TOPOGRAPHY TO BE CHECKED. POSSIBLE EXTENSIONS REQUIRED.

A 16

B 25

L-17

506800

BGC06-19

CONTACT LAKE

BGC06-20

CONTACT LAKE DAM

300

20 0 20 40 60

metres

DRAFT

NOTE: BOREHOLE LOCATIONS ARE APPROXIMATE.

7473400

7473200

UTM NAD 83 ZONE 12N

K:\Graphics\Projects\0385\003\19\Graphics\New Report\0385-003-19 NS_Sections(2).dwg Layout: CONTACT LAKE DAM Plot Date Jun 27 07 Time: 4:51 PM

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	ACJ
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

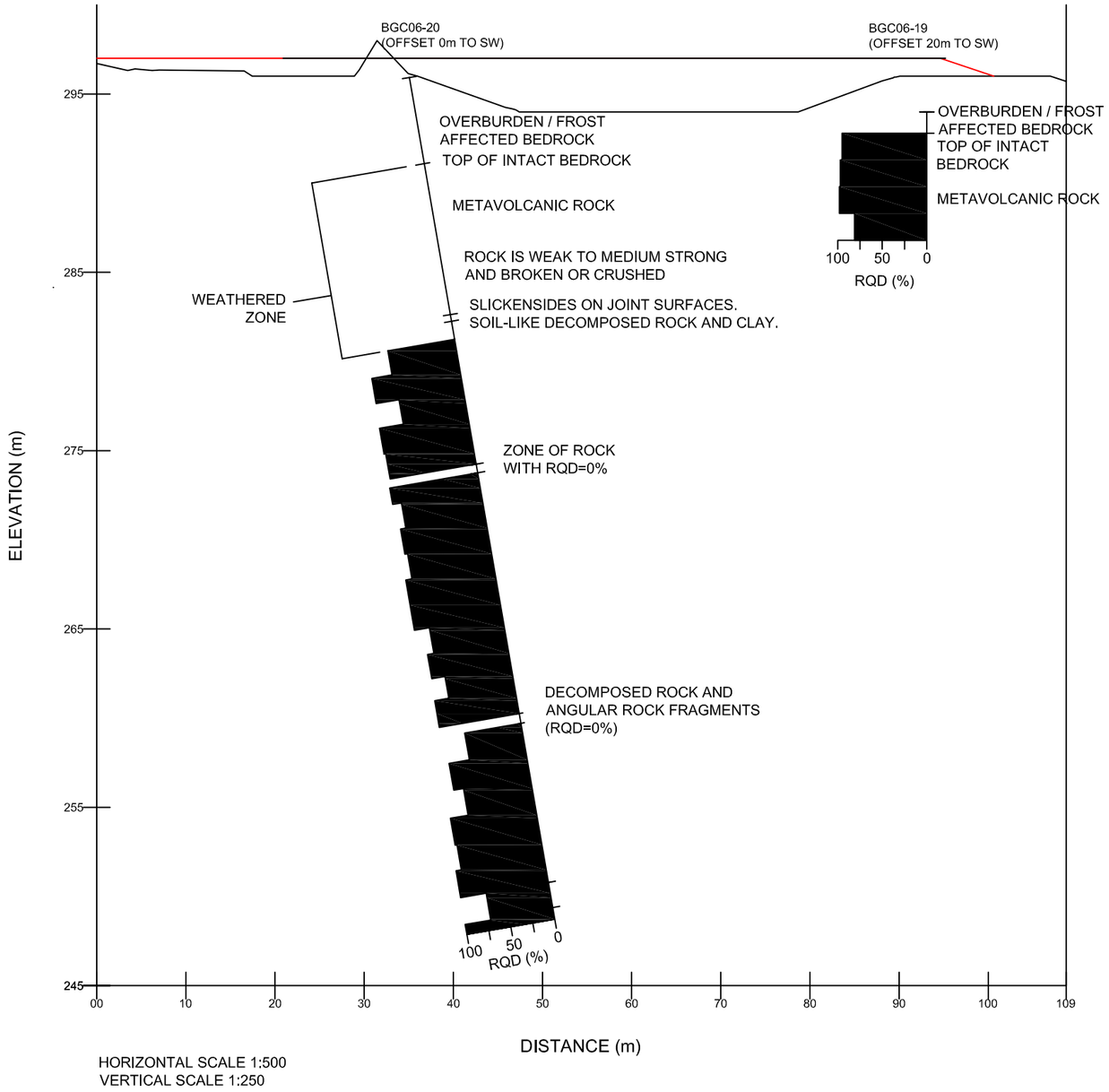
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: CONTACT LAKE DAM LAYOUT PLAN

PROJECT No.:	FIGURE No.	REV.:
0385-003-19	15	0



HORIZONTAL SCALE 1:500
VERTICAL SCALE 1:250

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

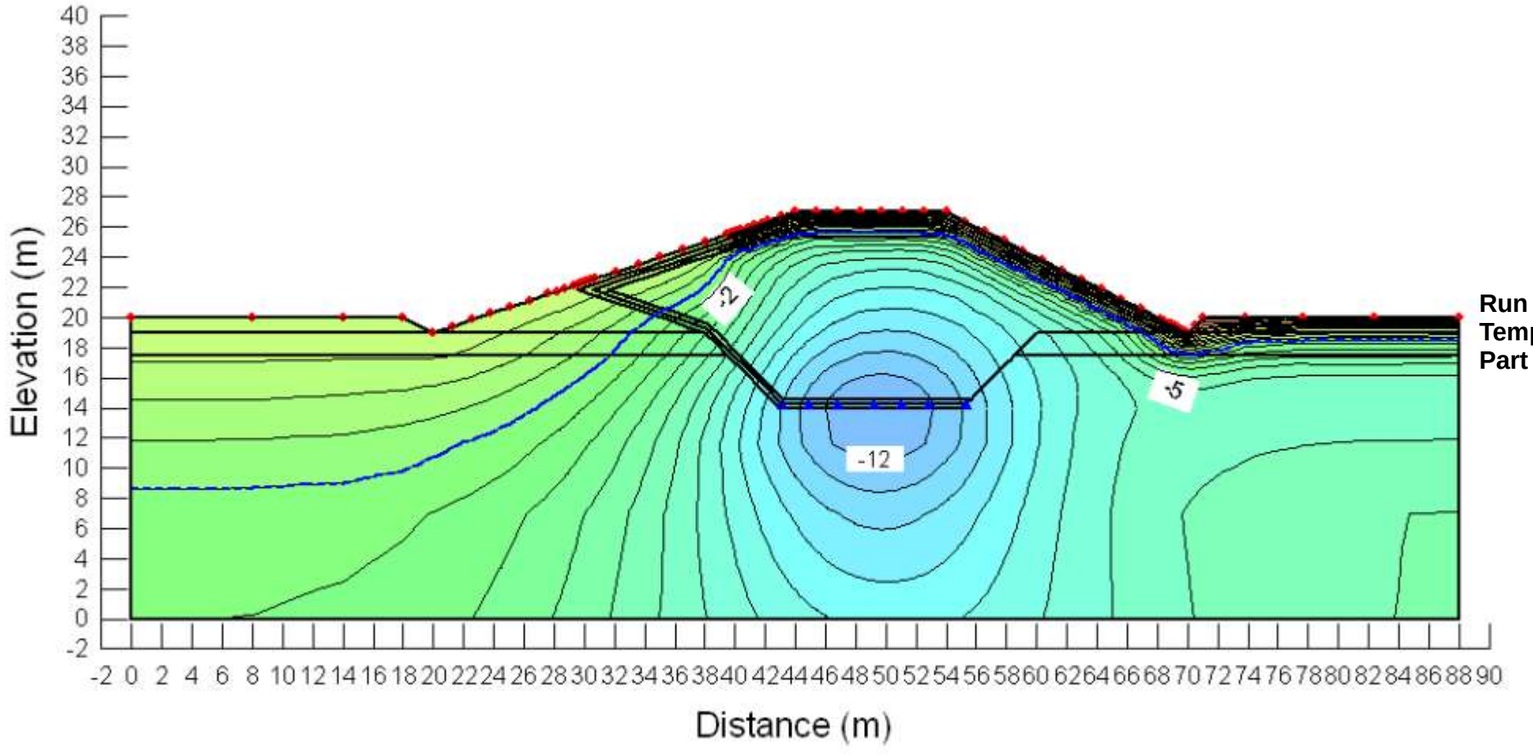
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

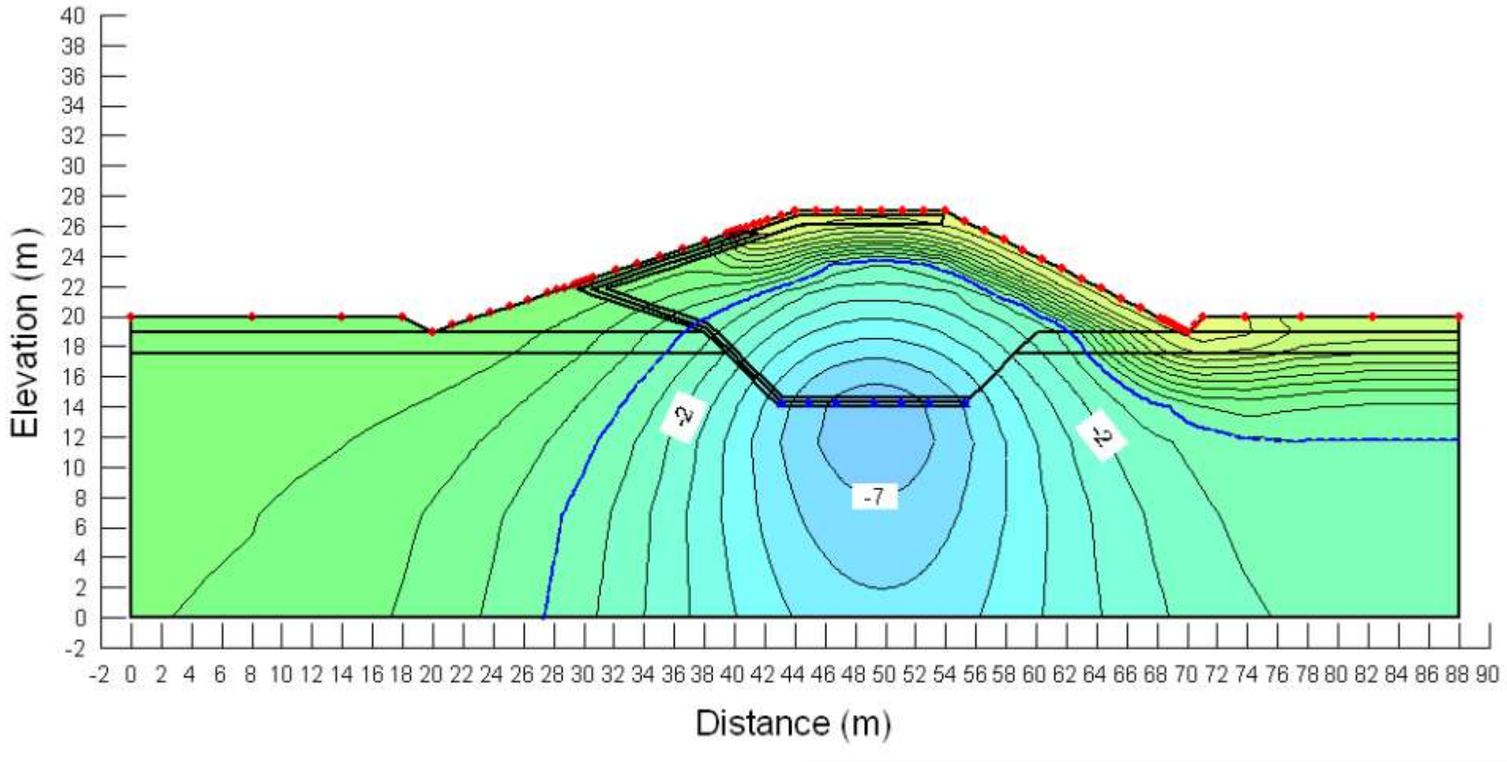
TITLE: CONTACT LAKE DAM LONGNITUDINAL SECTION A

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	16	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE OF HL (P) Plot Date May 4 07 Time: 1:29 PM



Run 3 Dam Foundation Temperatures During Warmest Part of Year 20



Run 3 Dam Foundation Temperatures During Warmest Period of Year 120

CLIENT:

WOLFDEN Resources Inc.

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA STATEMENTS CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECKED	APPROVED
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	SLF
DESIGNED:	EBN
CHECKED:	EBN
APPROVED:	JWC

PROJECT

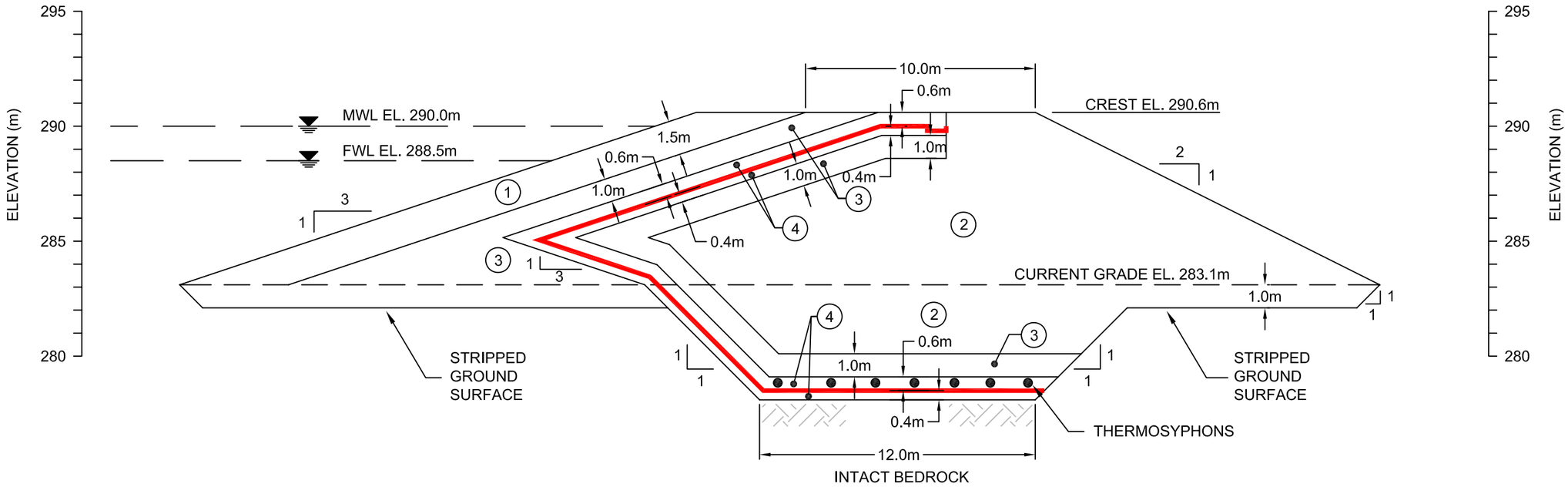
HIGH LAKE TCF FEASIBILITY DESIGN

TITLE

EFFECT OF THERMOSYPHONS ON DAM FOUNDATION TEMPERATURES

PROJECT No.	FIGURE No.	REV.
0385-003-19	17	0

BGC Engineering Inc.
AN APPLIED EARTH SCIENCES COMPANY
Calgary Alberta
Phone: (403) 250-5185



4 0 4 8 12

metres

LEGEND

1. RIPRAP (600mm)
2. ROCKFILL (600mm)
3. TRANSITION MATERIAL (200mm)
4. BEDDING MATERIAL (20mm)
5. COMPOSITE LINER

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: CJT
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

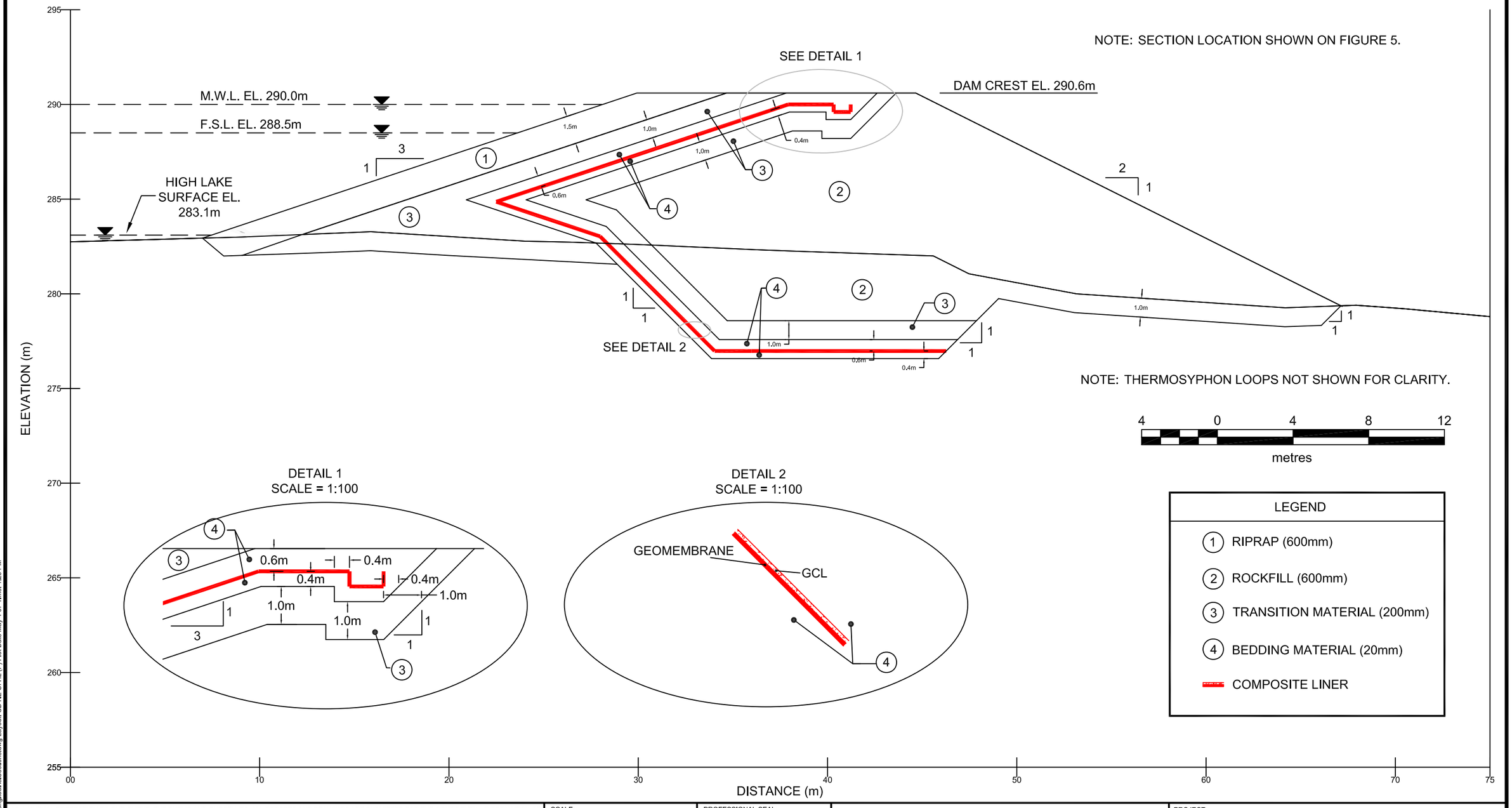
PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: GENERALIZED DAM SECTION

PROJECT No.: 0385-003-19
FIGURE No.: 18
REV.: 0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

NOTE: SECTION LOCATION SHOWN ON FIGURE 5.



NOTE: THERMOSYPHON LOOPS NOT SHOWN FOR CLARITY.

4 0 4 8 12

metres

DETAIL 1
SCALE = 1:100

DETAIL 2
SCALE = 1:100

LEGEND

1. RIPRAP (600mm)
2. ROCKFILL (600mm)
3. TRANSITION MATERIAL (200mm)
4. BEDDING MATERIAL (20mm)
5. COMPOSITE LINER

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	ACJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

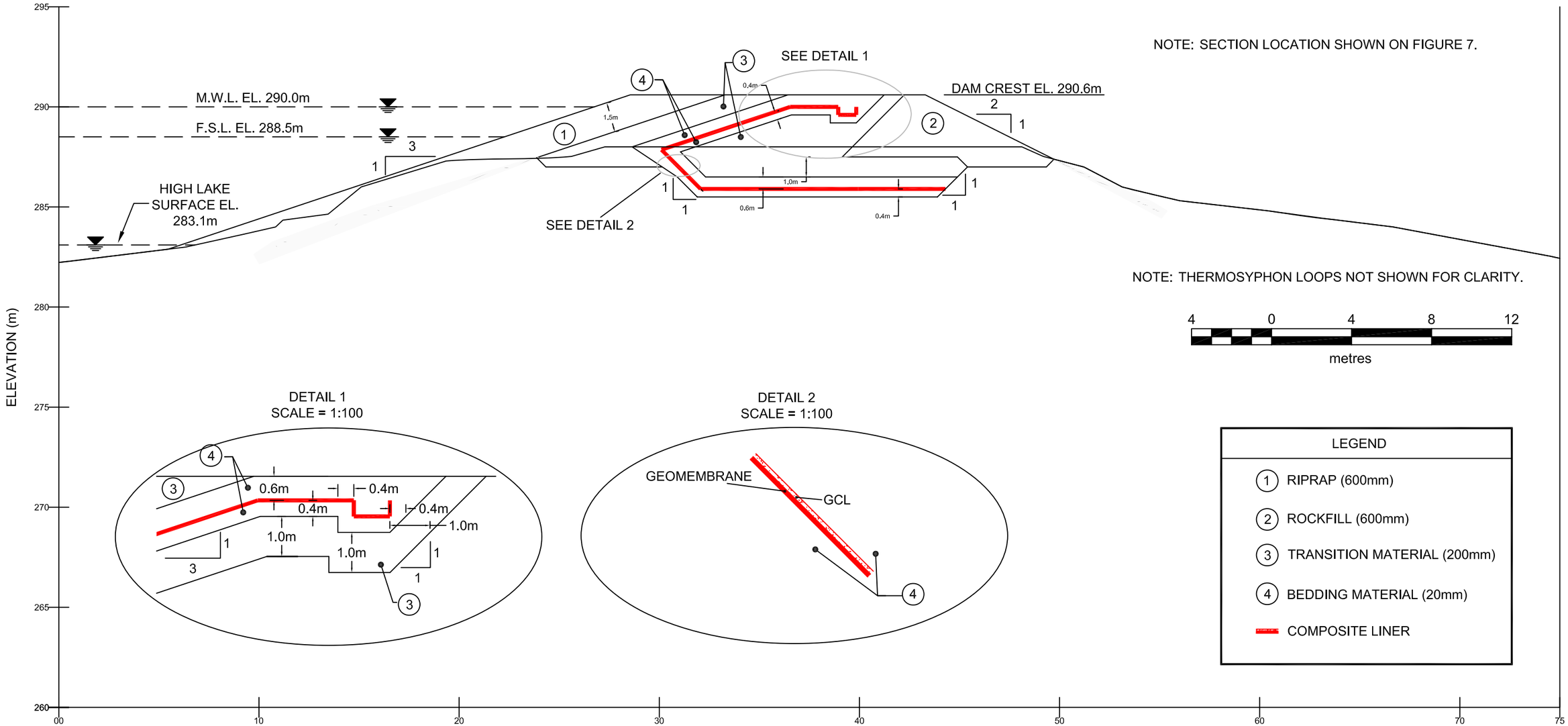
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: EAST DAM SECTION B

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	19	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

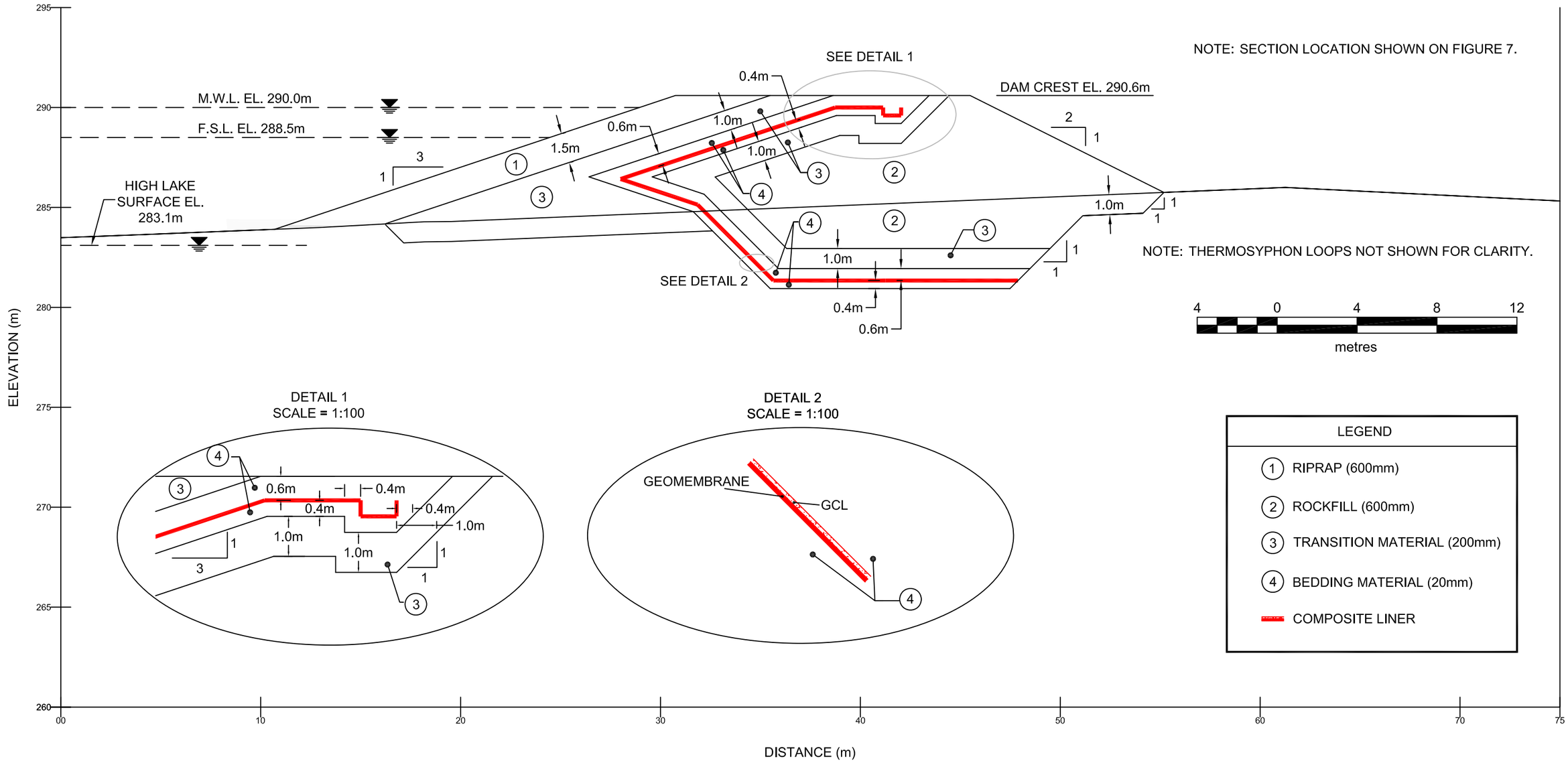
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHEAST DAM CROSS SECTION B

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	20	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date: May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

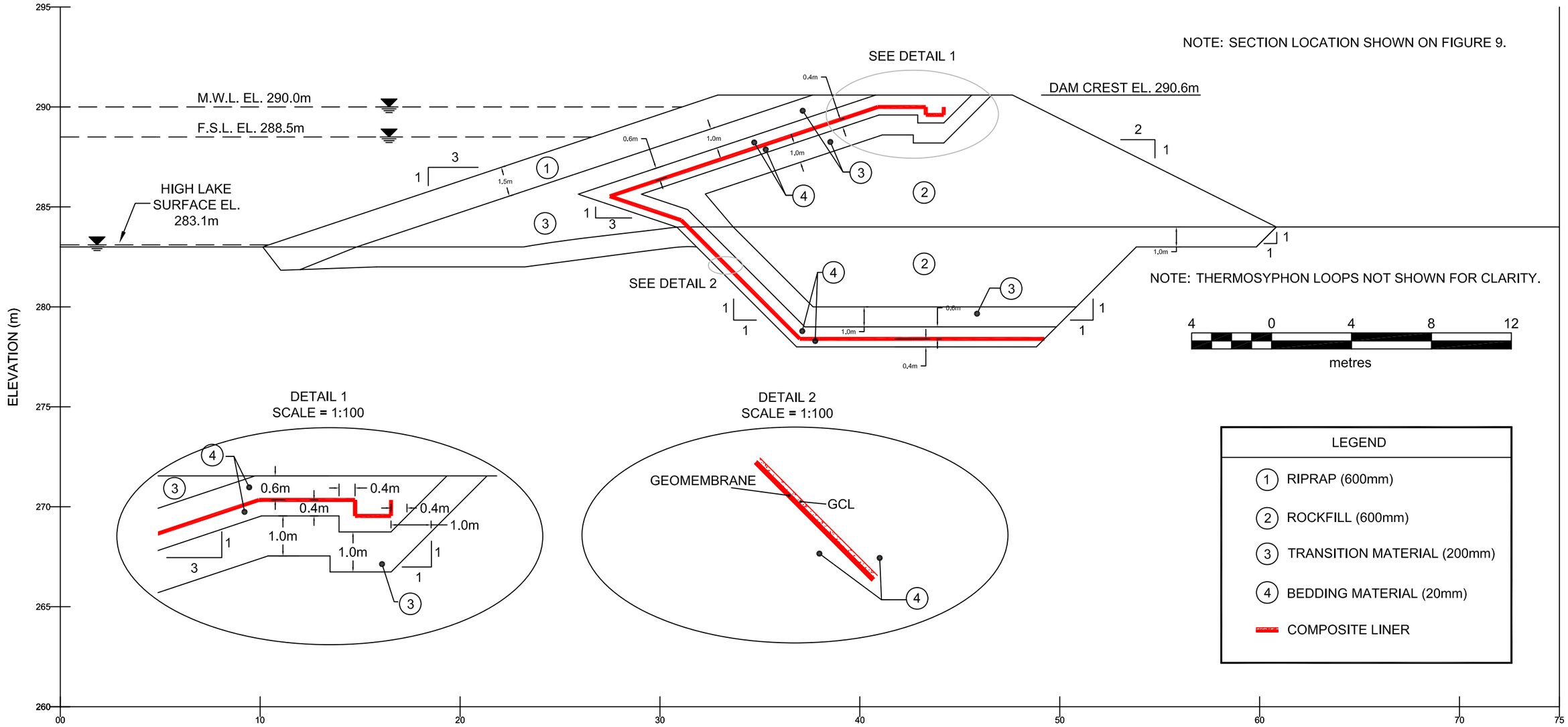
PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHEAST DAM CROSS SECTION C

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	21	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date: May 4 07 Time: 1:29 PM

NOTE: SECTION LOCATION SHOWN ON FIGURE 9.



NOTE: THERMOSYPHON LOOPS NOT SHOWN FOR CLARITY.

4 0 4 8 12
metres

DETAIL 1
SCALE = 1:100

DETAIL 2
SCALE = 1:100

LEGEND

1. RIPRAP (600mm)
2. ROCKFILL (600mm)
3. TRANSITION MATERIAL (200mm)
4. BEDDING MATERIAL (20mm)
5. COMPOSITE LINER

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

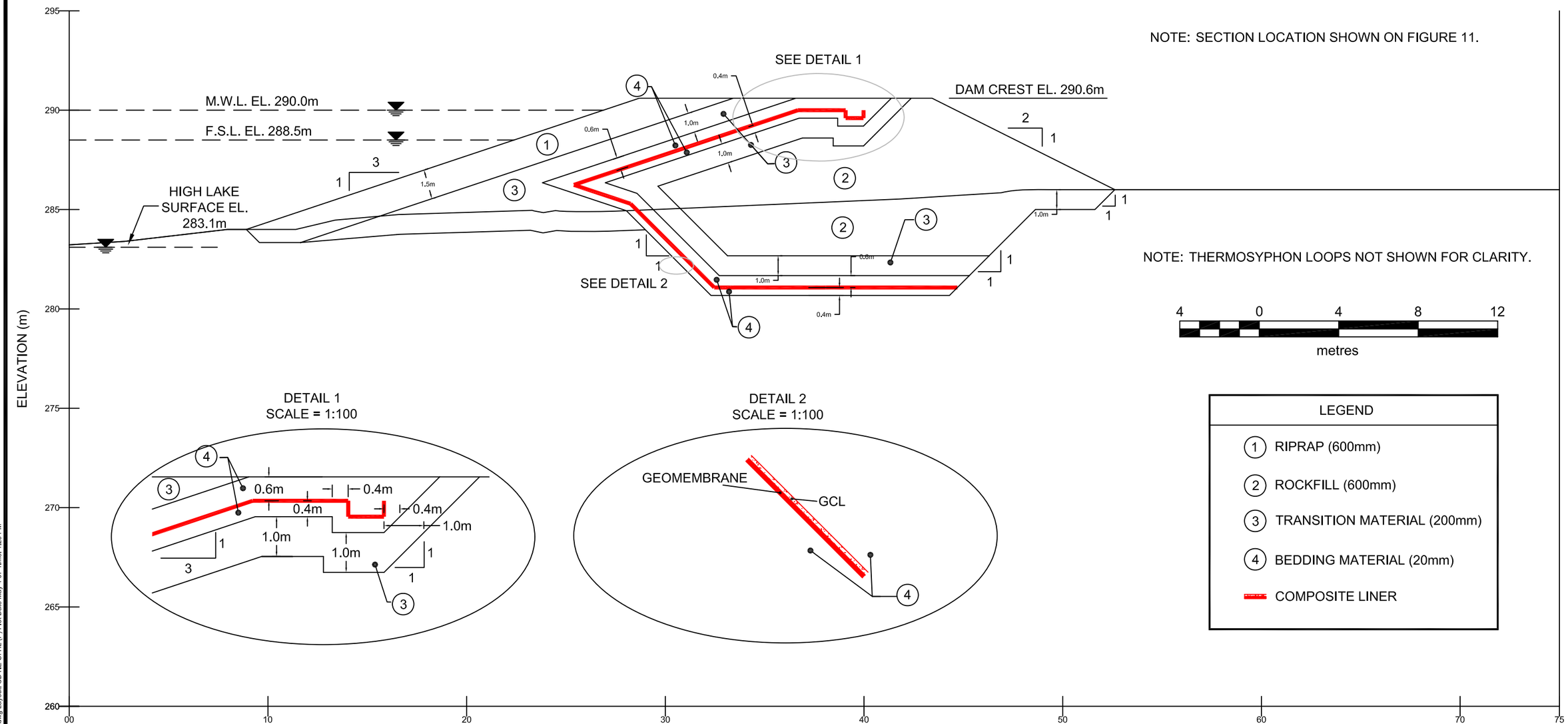
TITLE: NORTHWEST DAM CROSS SECTION B

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	22	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

NOTE: SECTION LOCATION SHOWN ON FIGURE 11.

NOTE: THERMOSYPHON LOOPS NOT SHOWN FOR CLARITY.



LEGEND

1. RIPRAP (600mm)
2. ROCKFILL (600mm)
3. TRANSITION MATERIAL (200mm)
4. BEDDING MATERIAL (20mm)
5. COMPOSITE LINER

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

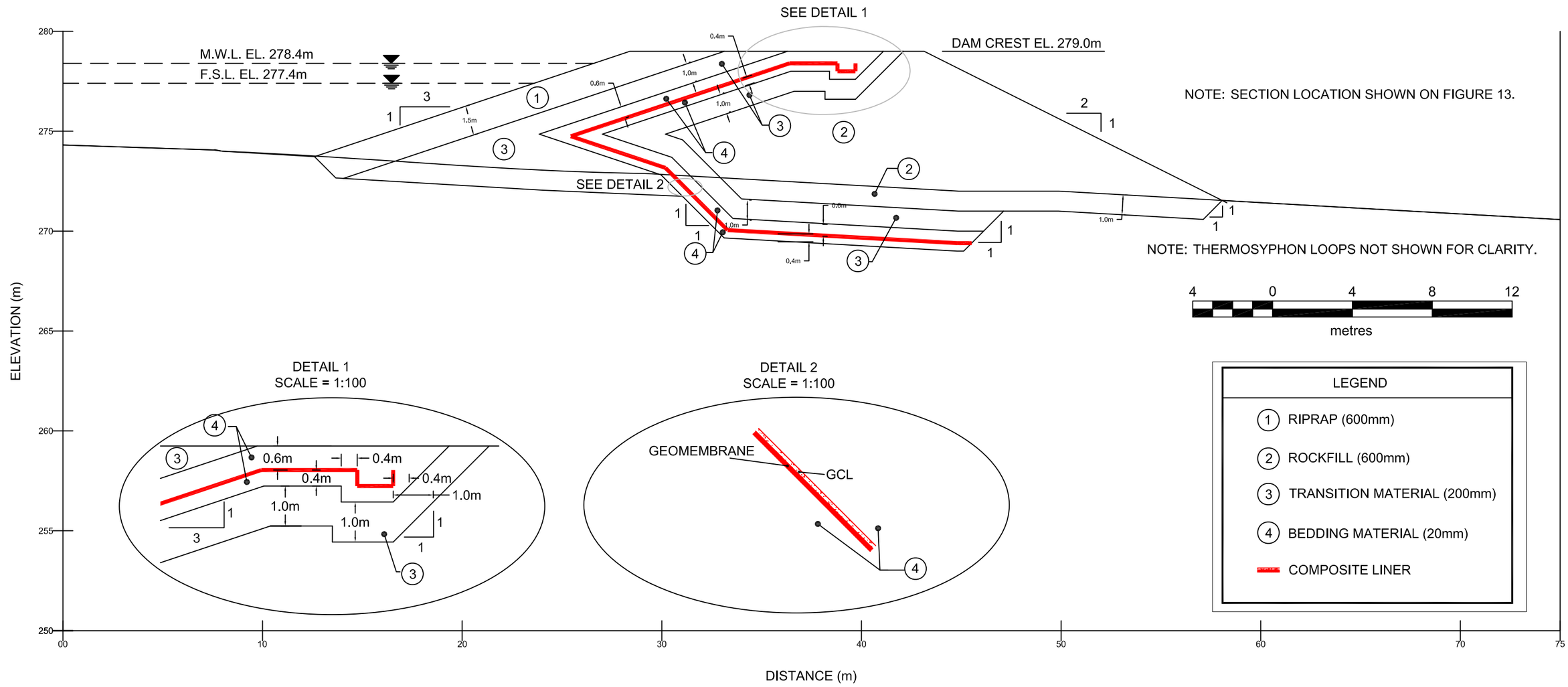
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHWEST CHANNEL DAM CROSS SECTION B

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	23	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

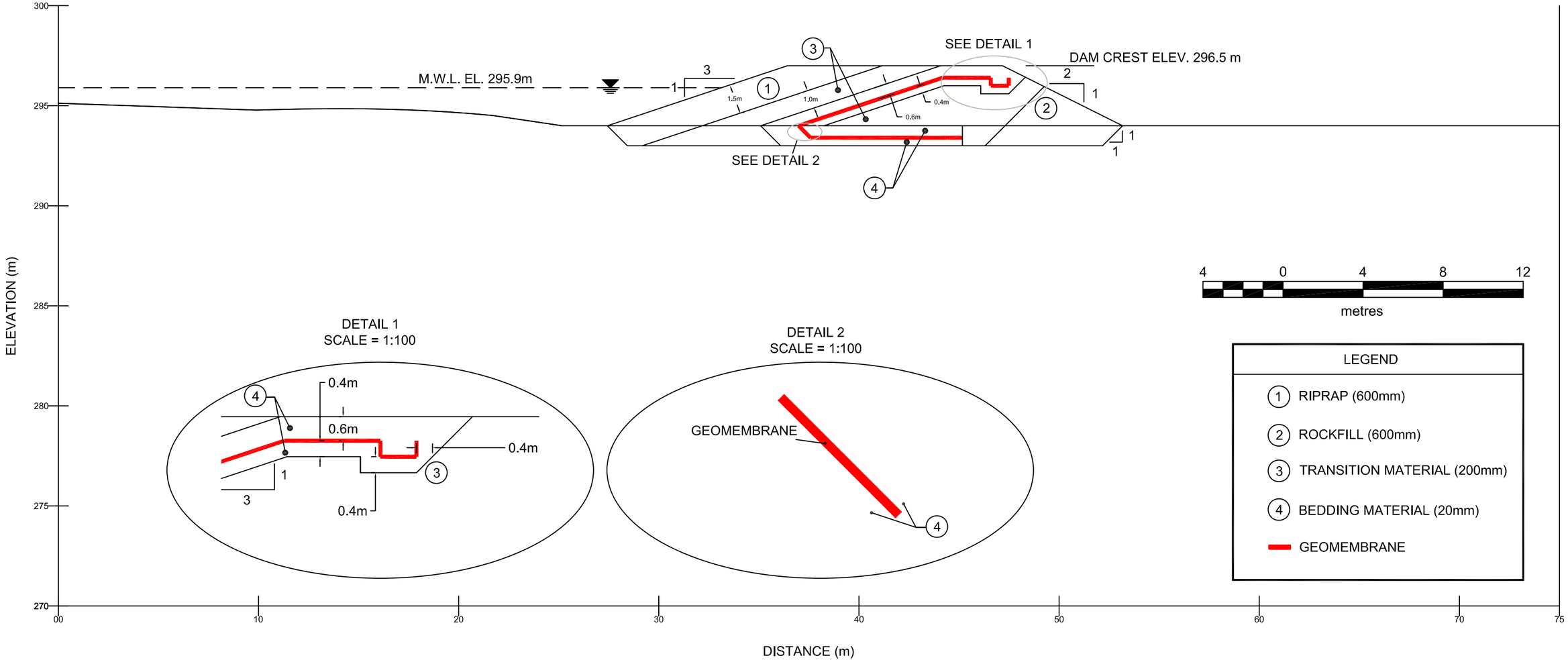
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: POLISHING POND CROSS SECTION B

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	24	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: ACJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

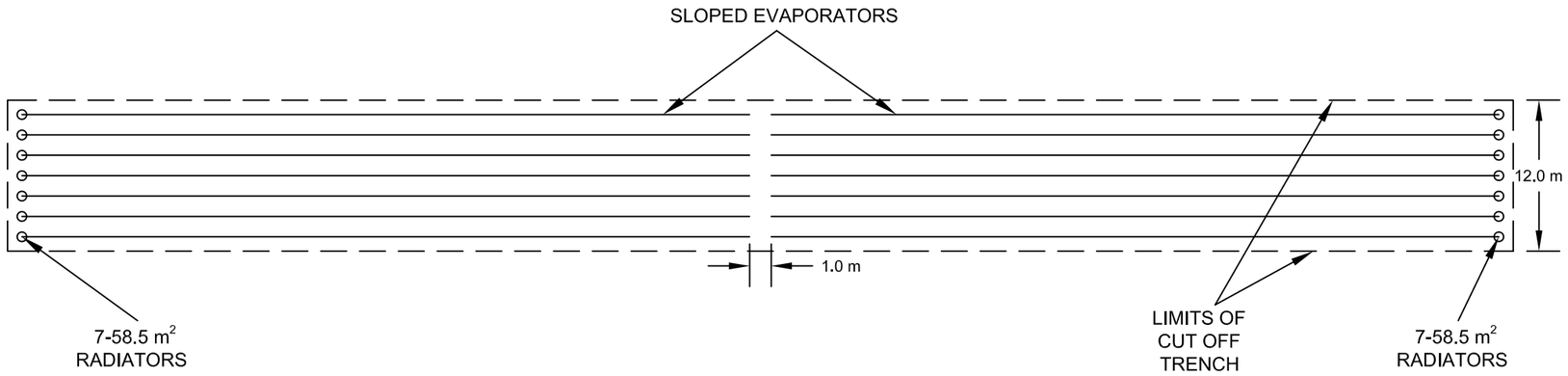
PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: CONTACT LAKE DAM CROSS SECTION B

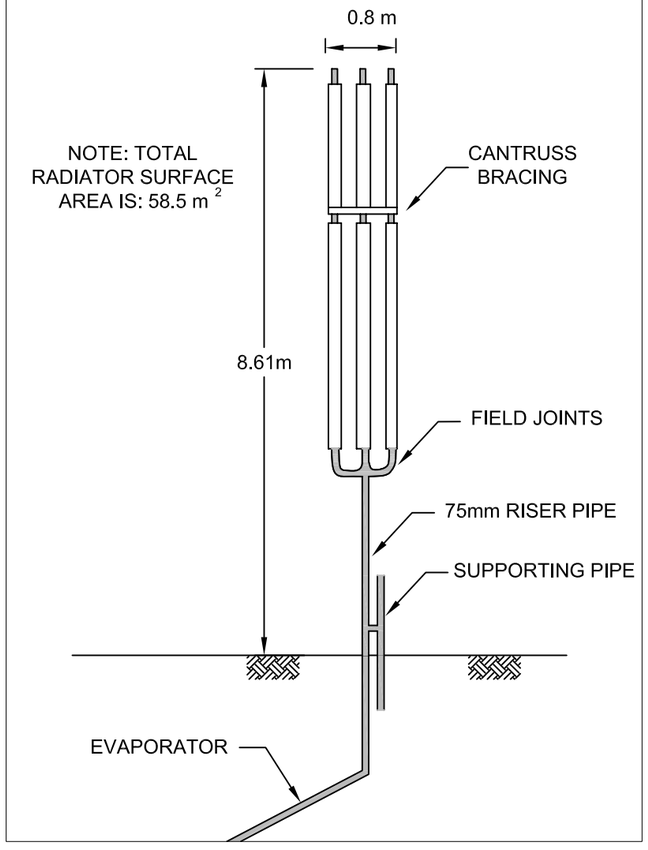
PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	25	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

DETAIL 1 - THERMOSYPHON EVAPORATORS (PLAN VIEW)
(NOT TO SCALE)



DETAIL 2 - THERMOSYPHON RADIATORS
(NOT TO SCALE)



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	NTS
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	AJ
CHECKED:	EN
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

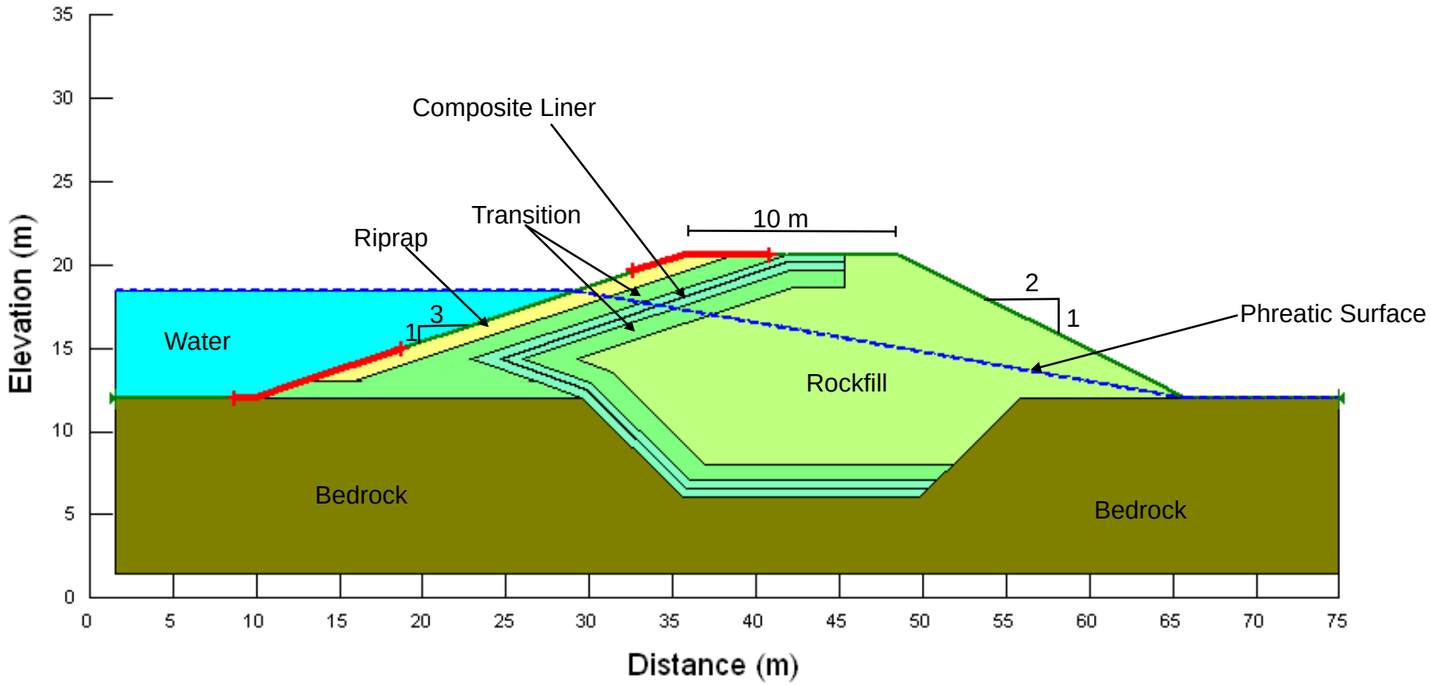
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: TYPICAL THERMOSYPHON DETAILS

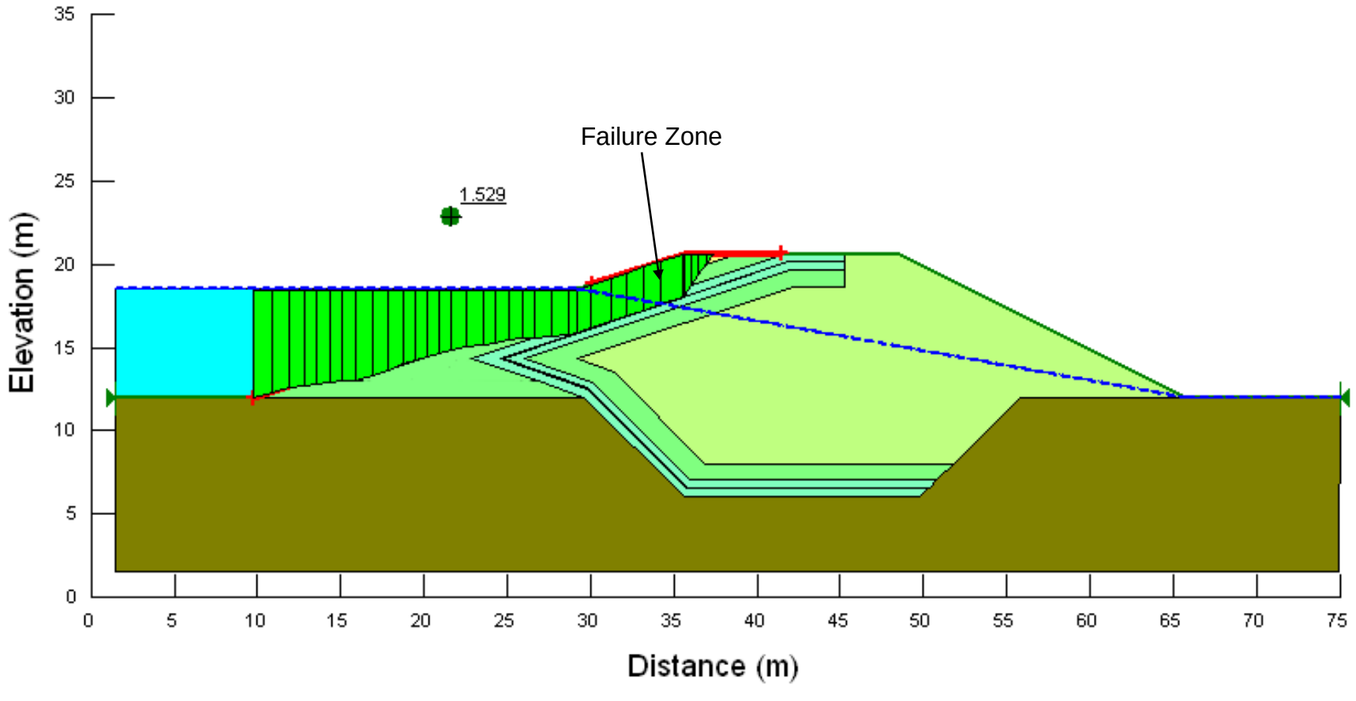
PROJECT No.:	FIGURE No.	REV.:
0385-003-19	26	0

K:\Projects\0385 Wolfden Resources\003 HL Prefeasibility Study\19 2006 Dam Design\3 Report\Graphics\Drawings\0385-003-19_DETAILS_ap.dwg Layout: Layout1 Plot Date: Jun 27 07 Time: 4:52 PM



Slope Stability Model

Upstream slope, static loading
phi=14° for liner/soil interface.



CLIENT:

WOLFDEN Resources Inc.

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA STATEMENTS CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECKED	APPROVED
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	SLF
DESIGNED:	EBN
CHECKED:	EBN
APPROVED:	JWC

PROJECT

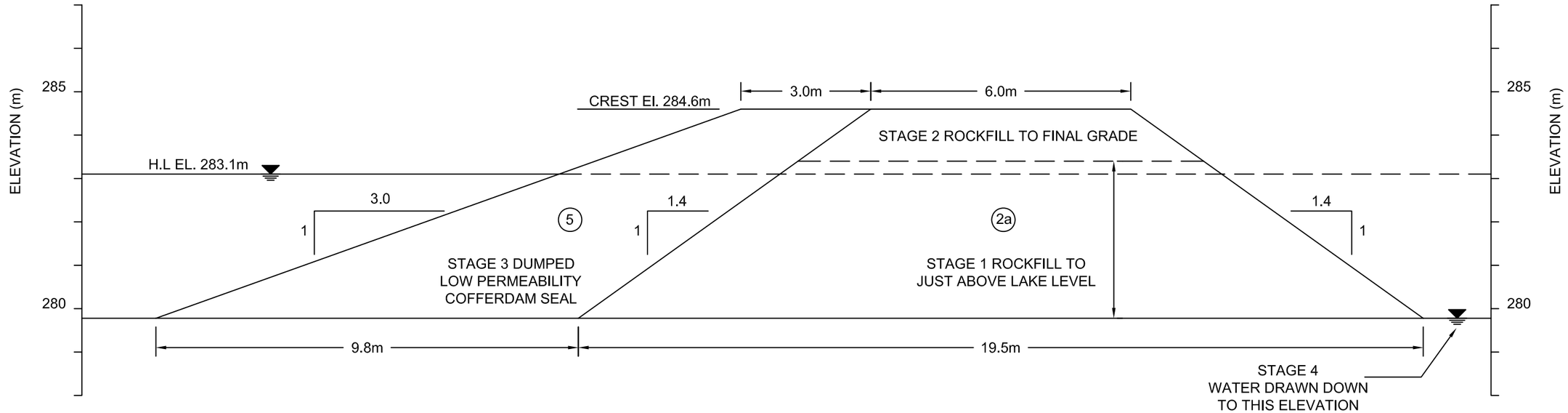
HIGH LAKE TCF FEASIBILITY DESIGN

TITLE

SLOPE STABILITY MODEL AND TYPICAL RESULTS

PROJECT No.	FIGURE No.	REV.
0385-003-19	27	0

BGC Engineering Inc.
AN APPLIED EARTH SCIENCES COMPANY
Calgary Alberta
Phone: (403) 250-5185



2 0 2 4 6

metres

LEGEND	
2a	DUMPED ROCKFILL (600mm)
5	DUMPED MATERIAL (20mm)

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	CJT
DESIGNED:	AJ
CHECKED:	EBN
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: COFFERDAM TYPICAL CROSS SECTION

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	28	0

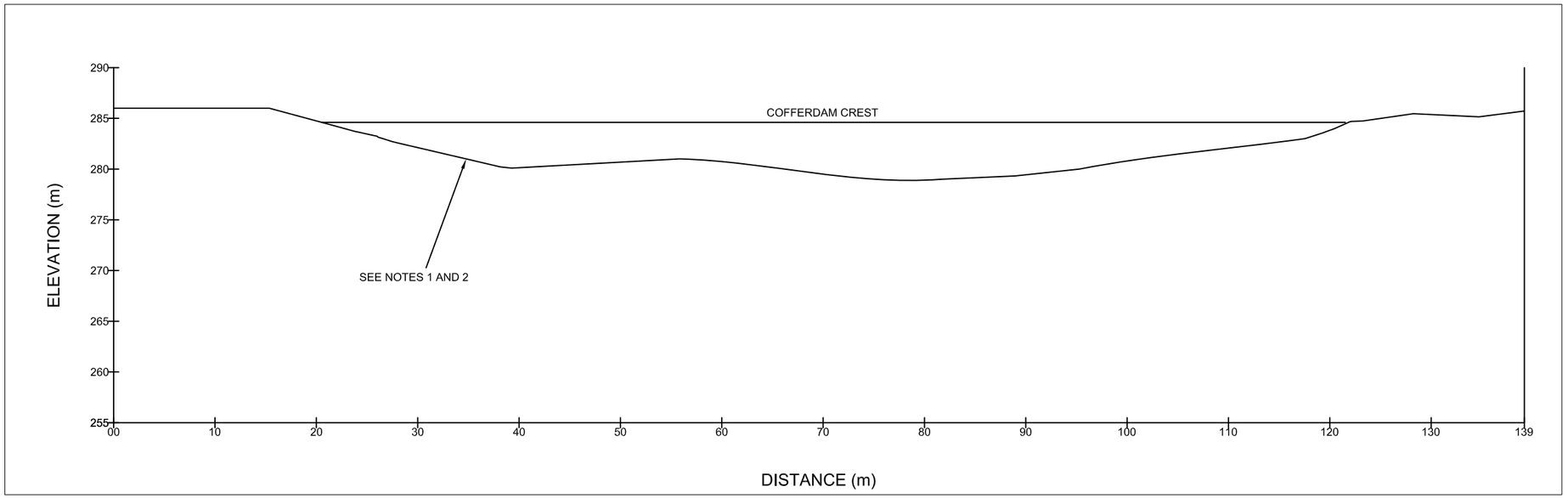
X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

NOTES:

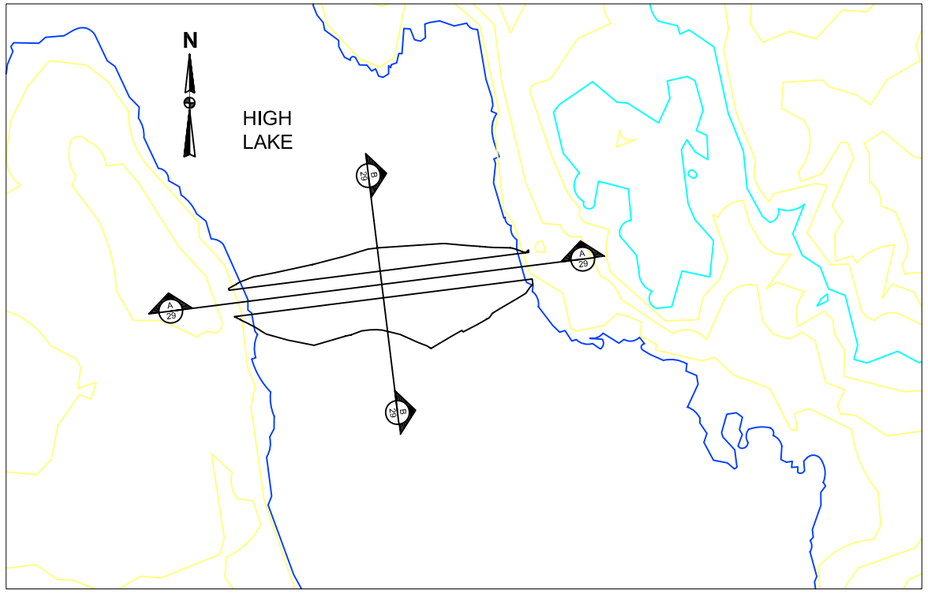
1. COFFERDAM FOUNDATION TOPOGRAPHY BASED ON BATHYMETRIC CONTOURS DERIVED FROM GLL BATHYMETRIC SURVEY.

2. FOUNDATION PREPARATION MEASURES MAY INCLUDE LOCAL REMOVAL OF SOFT LAKEBED SEDIMENTS, AS DIRECTED BY ENGINEER DURING CONSTRUCTION.

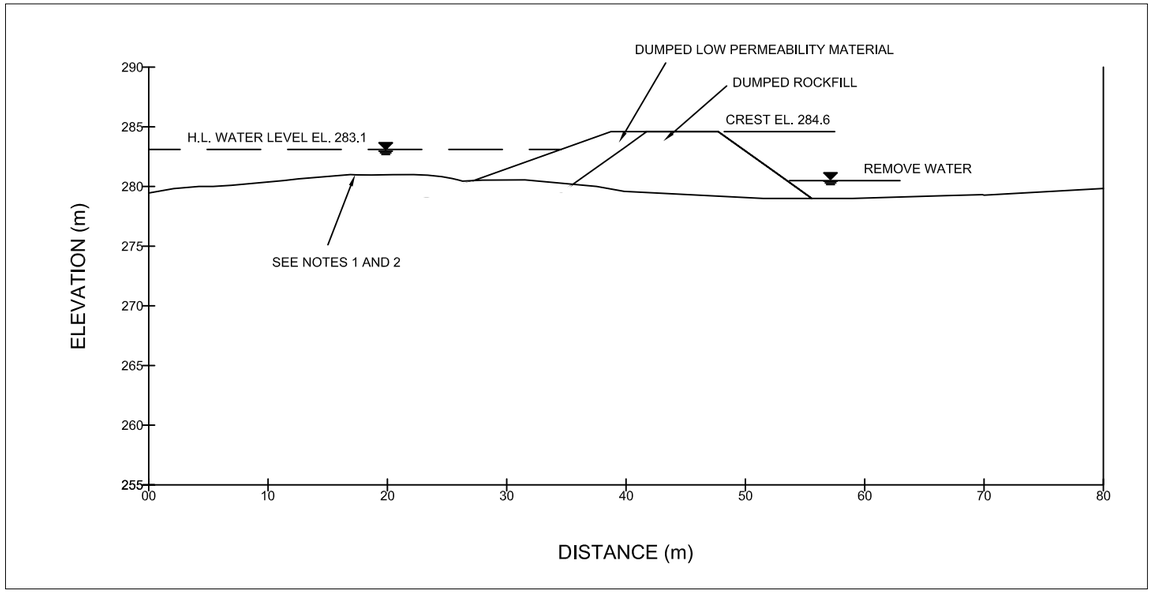
LONGITUDINAL SECTION A



PLAN VIEW



CROSS SECTION B



AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	AJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

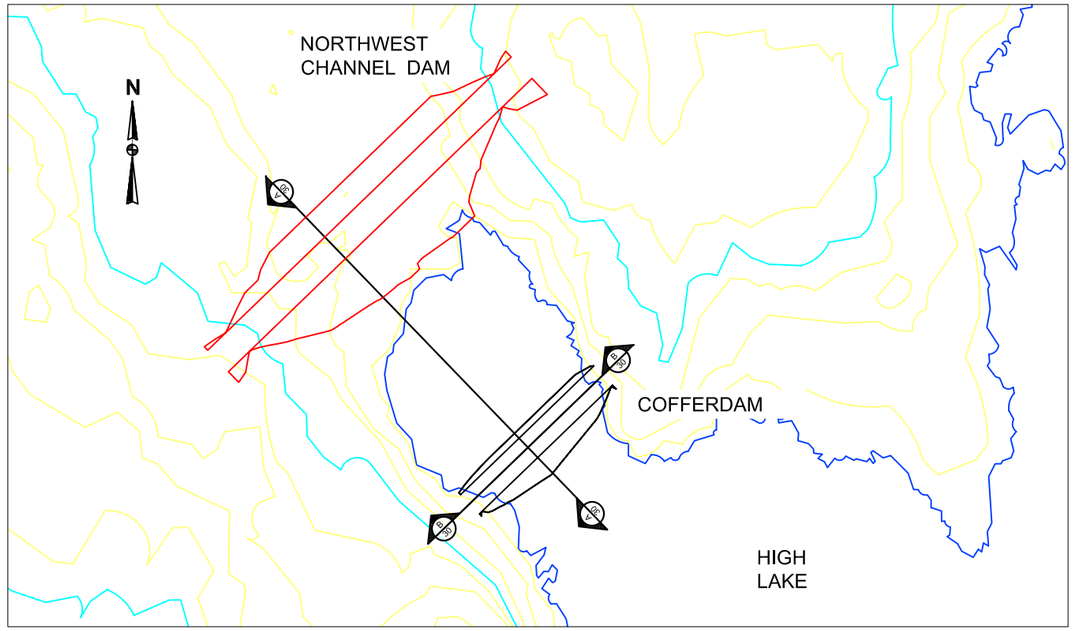
PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTH COFFERDAM LONGITUDINAL AND CROSS SECTIONS

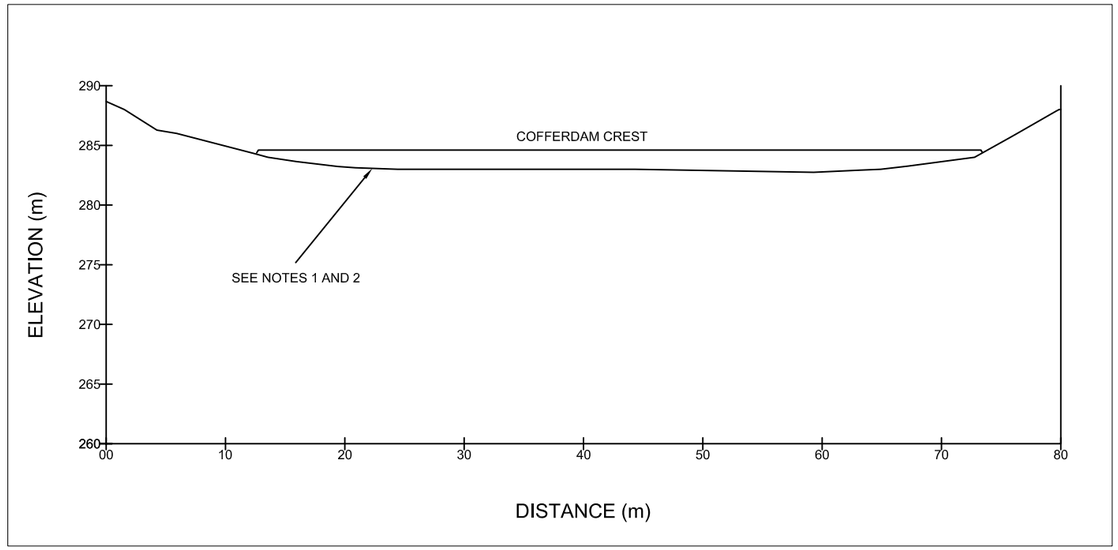
PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	29	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

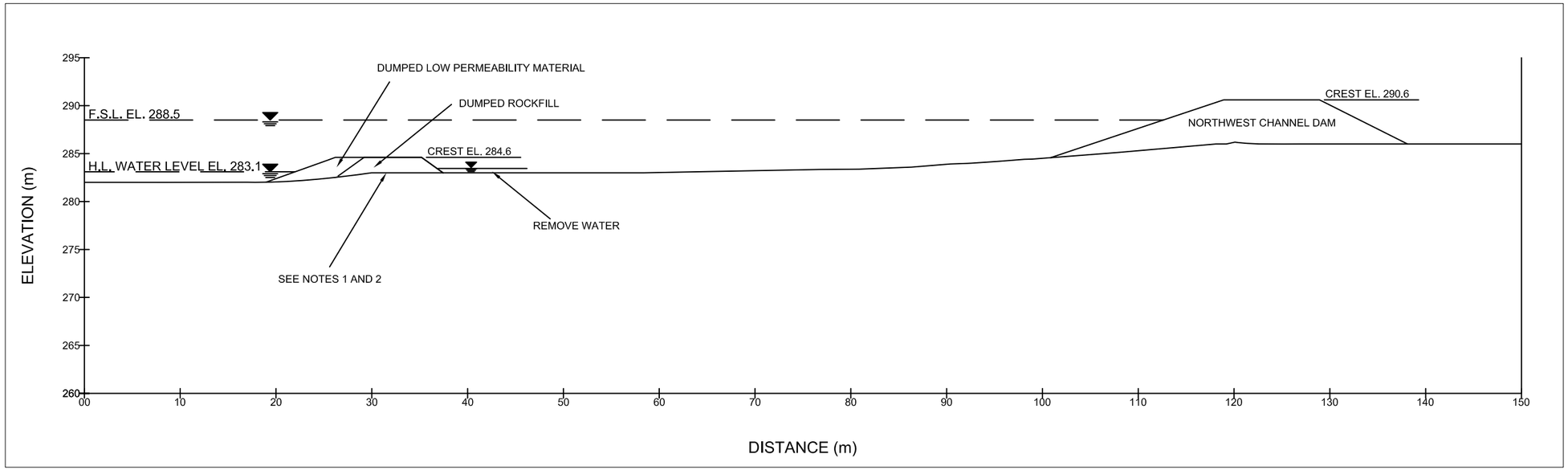
PLAN VIEW



LONGITUDINAL SECTION B



CROSS SECTION A



NOTES:

1. COFFERDAM FOUNDATION TOPOGRAPHY BASED ON BATHYMETRIC CONTOURS DERIVED FROM GLL BATHYMETRIC SURVEY.

2. FOUNDATION PREPARATION MEASURES MAY INCLUDE LOCAL REMOVAL OF SOFT LAKEBED SEDIMENTS, AS DIRECTED BY ENGINEER DURING CONSTRUCTION.

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAY 2007
DRAWN: ASP
DESIGNED: EBN
CHECKED: AJ
APPROVED: JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: WOLFDEN Resources Inc.

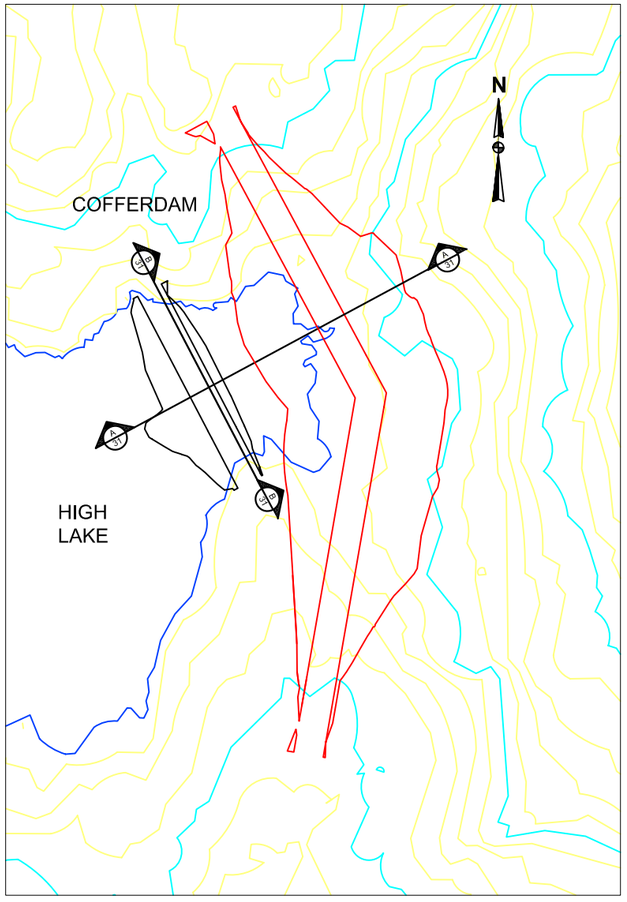
PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: NORTHWEST CHANNEL COFFERDAM LONGITUDINAL AND CROSS SECTIONS

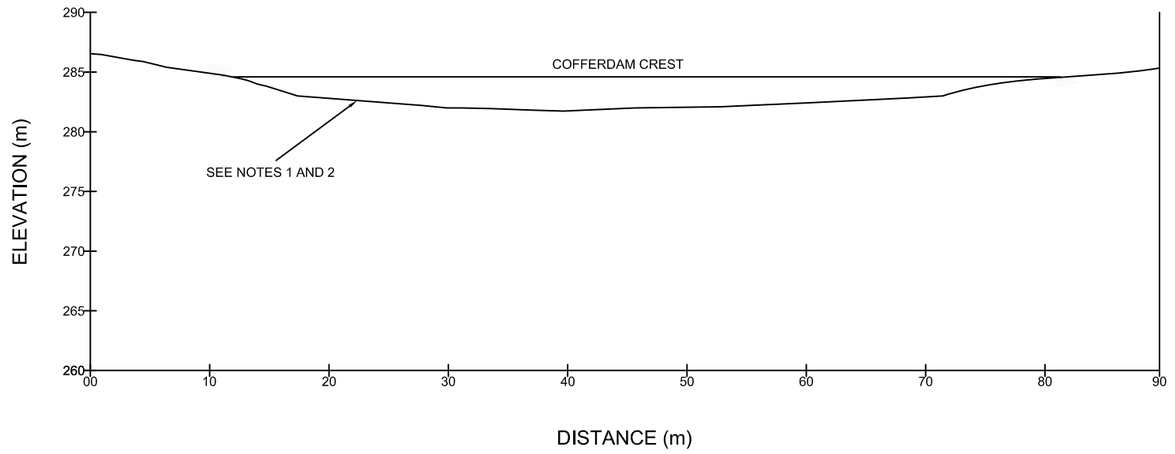
PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	30	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM

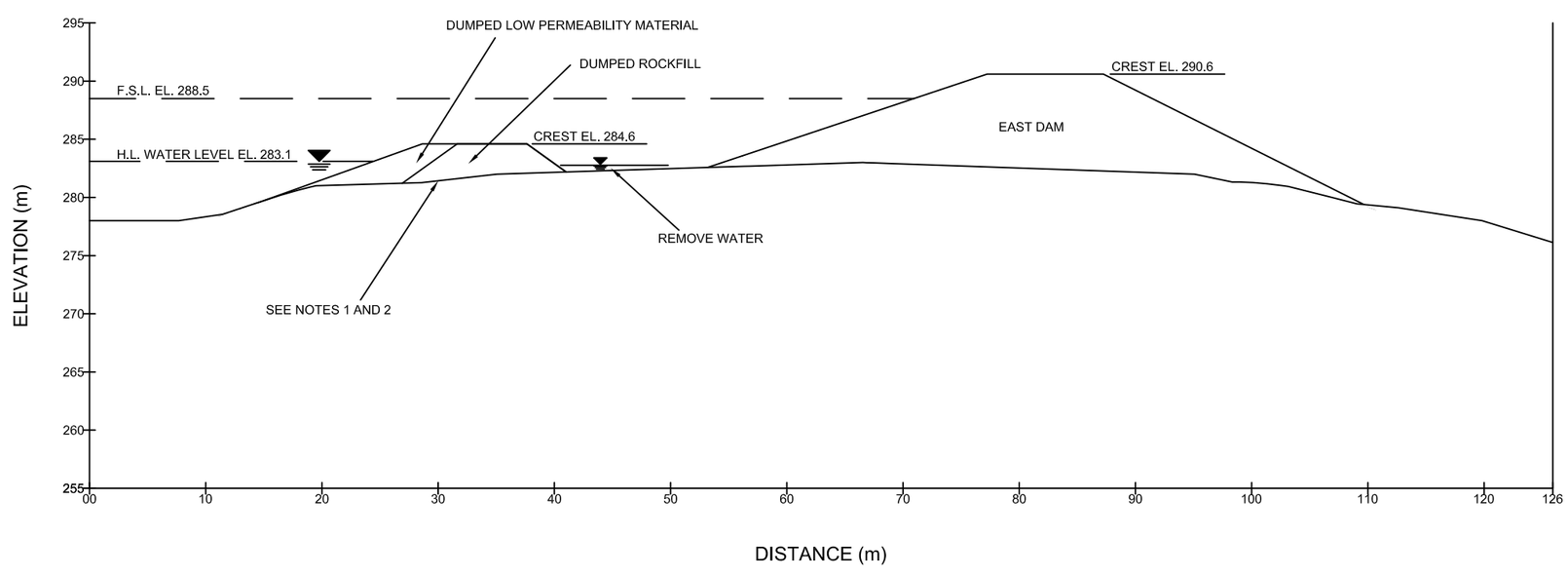
PLAN VIEW



LONGITUDINAL SECTION B



CROSS SECTION A



NOTES:

1. COFFERDAM FOUNDATION TOPOGRAPHY BASED ON BATHYMETRIC CONTOURS DERIVED FROM GLL BATHYMETRIC SURVEY.

2. FOUNDATION PREPARATION MEASURES MAY INCLUDE LOCAL REMOVAL OF SOFT LAKEBED SEDIMENTS, AS DIRECTED BY ENGINEER DURING CONSTRUCTION.

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAY 2007
DRAWN:	ASP
DESIGNED:	EBN
CHECKED:	AJ
APPROVED:	JWC

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

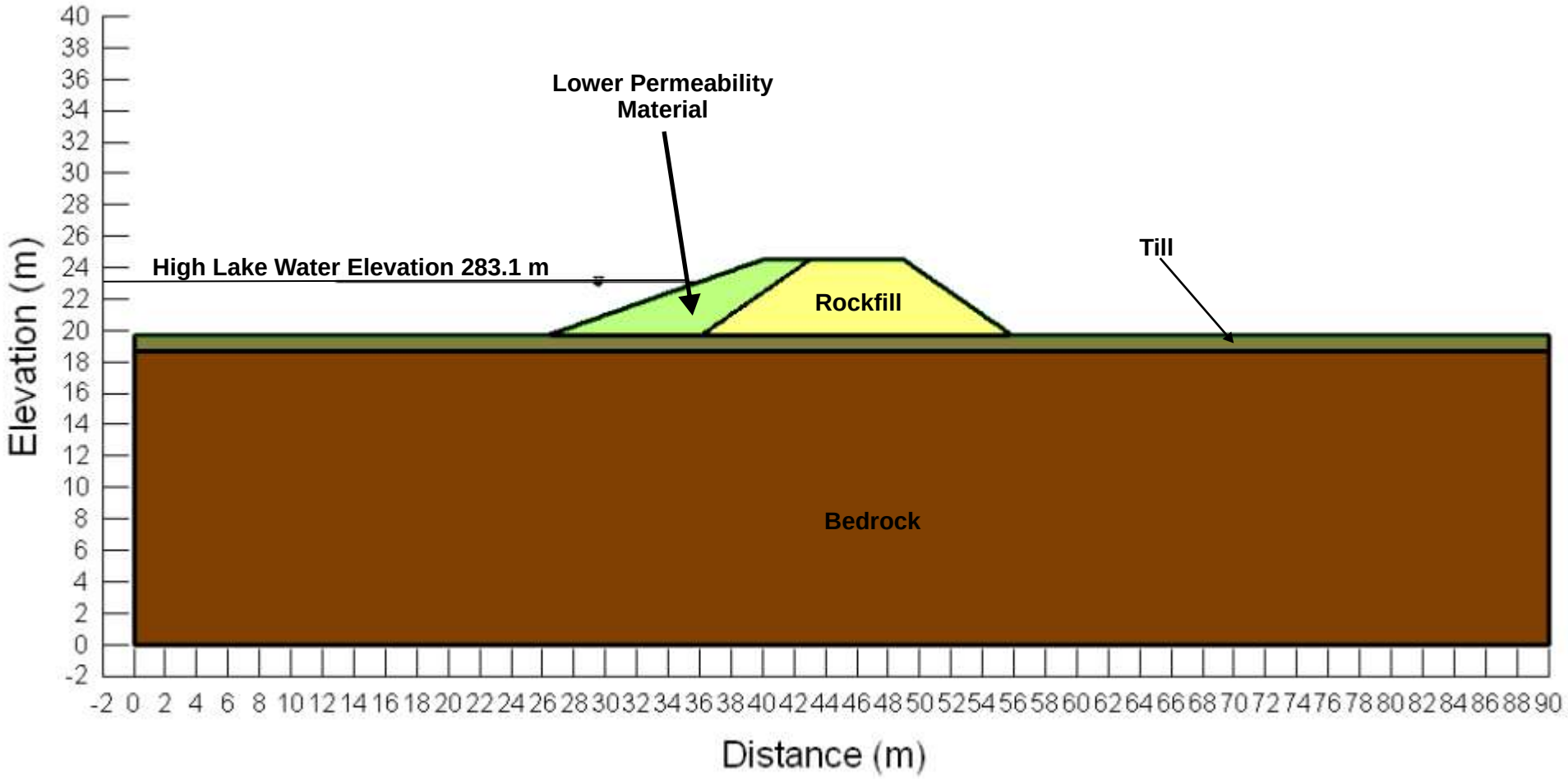
CLIENT: WOLFDEN Resources Inc.

PROJECT: HIGH LAKE TCF FEASIBILITY DESIGN

TITLE: EAST COFFERDAM LONGITUDINAL AND CROSS SECTIONS

PROJECT No.:	FIGURE No.:	REV.:
0385-003-19	31	0

X:\Projects\0385\003\19\dwg\0385-003-19 LongitudinalSections.dwg Layout: CD NE Of HL (P) Plot Date May 4 07 Time: 1:29 PM



DATE: MAY 2007	DRAWN SLF

REFERENCED DRAWING DESCRIPTION

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
Calgary, Alberta Phone: (403) 250-5185

CLIENT WOLFDEN Resources Inc.

PROJECT HIGH LAKE TCF FEASIBILITY DESIGN

TITLE COFFERDAM SEEPAGE MODEL GEOMETRY

PROJECT No.	FIGURE No.	REV.
0385-003-19	32	0

APPENDIX I
CLIMATE CHANGE DESIGN CRITERIA MEMO

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
1605, 840 – 7 Avenue S.W., Calgary, Alberta, Canada. T2P 3G2
Phone (403) 250-5185 Fax (403) 250-5330

PROJECT MEMORANDUM

To:	**Wolfden Resources/Gartner Lee/ Wardrop Engineering**	**Fax No.:**	**by email**
Attention:	**Andrew Mitchell/Eric Denholm/Phil Davis**		
From:	**Jim Cassie, P.Eng.**	**Date:**	**March 30, 2007**
Subject:	**Climate Change Design Criteria Proposed Tailings Dams, High Lake Project, NU**		
No. of Pages (including this page): 13		**Project No:**	**0385-003-19.3**

1.0 INTRODUCTION

Wolfden Resources Inc. (Wolfden) is proceeding with the permitting and potential development of their High Lake Project in Nunavut, situated about 550 km by air northeast of Yellowknife, NT. At the mine site, several tailings dams are proposed to be designed and constructed on continuous permafrost. As outlined in BGC (2006), these dams are designed to have the foundation under the dam remain frozen either for their operational life, and potentially into their closure phase as well.

Climate change, and more specifically, global warming, is an on-going phenomena in the world. For a variety of reasons, the effects of global warming are magnified at northern latitudes. In order for the design of the High Lake tailings dams to proceed, climate change design criteria and associated duration periods need to be selected.

The selection of appropriate design criteria for dams, including climate change parameters over some future time period, need to made within the overall context of the "Precautionary Principle". Environment Canada (2005) outlines the tenets of the principle as follows:

> "The precautionary approach/precautionary principle is distinctive within science-based risk management. It recognizes that the absence of full scientific certainty shall not be used as a reason to postpone decisions when faced with the threat of serious or irreversible harm. However, guidance and assurance are required as to the conditions governing the decisions that will be made. Guidance and assurance are particularly needed when a decision must be made regarding a risk of serious or irreversible harm about which there is significant scientific uncertainty. The precautionary approach/precautionary principle primarily affects the development of options and the decision phases, and is ultimately guided by judgement, based on values and priorities."

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Therefore, it is necessary to ensure that impacts from climate change, and more specifically, global warming, are accounted for in the design and the potential impacts of the High Lake Project. The application of the Precautionary Principle is specified within the Nunavut Impact Review Board (NIRB) Terms of Reference issued for Environmental Impact Statements.

Therefore, the following memo outlines some climatic information relative to the High Lake site, as context for some later interpretations regarding climate change design parameters. Global warming allowances for other recent northern projects are also reviewed. The memo also provides a recommended warming allowance for the High Lake site, where the critical engineered structures, the tailings dams, will be located. Related climate change topics such as the potential variation in precipitation and evaporation are also reviewed briefly.

2.0 NORTHERN LATITUDE CLIMATE CHANGE

Recent pronouncements by the Arctic Climate Impact Assessment (ACIA), a four-year study of the Arctic by international scientists, noted some of the following conclusions:

- In Alaska, Western Canada, and Eastern Russia, average winter temperatures have increased as much as 3 to 4°C in the past 50 years and are projected to rise 4 to 7°C over the next 100 years.
- Arctic summer sea ice is projected to decline by at least 50 percent by the end of this century
- Many coastal towns and facilities around the Arctic face increasing risks from erosion and flooding due to rising sea levels, decreased sea ice and thawing coastal permafrost.
- Over the next 100 years, climate change is predicted to accelerate, contributing to major physical, ecological, social, and economic changes.

Within Canada, Environment Canada (1995) noted that mean annual temperatures within the Mackenzie Valley have increased by 1.7^{o}C over the last century. Burn (2002) noted that near surface permafrost in the Mackenzie Delta has warmed rapidly in response to regional climate warming. Beilman et al. (2000) indicated that the southern limit of permafrost in Western Canada has moved northward by 39 km on average.

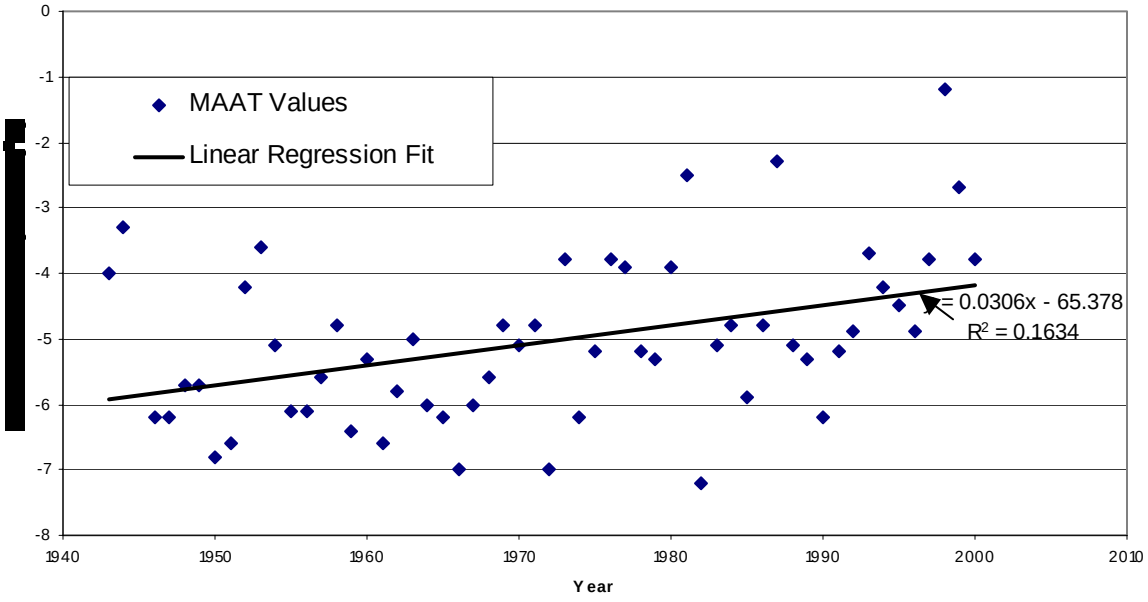
Alternatively, some records for the eastern Arctic and northern Quebec (Allard et al. 1995) showed cooling occurring over the same time period in which Mackenzie Valley warming had been documented. That observation has recently been superseded by Allard et al. (2002) that noted that permafrost warming is now occurring in northern Quebec, beginning with summer temperatures in 1993 and winter temperatures in 1995.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

There is still on-going debate in both the scientific and the public circles on whether climate change is a natural phenomena, is caused by anthropogenic ("man-made") inputs to the atmosphere, or some combination of the two. Anthropogenic climate warming is caused by "greenhouse gases" such a carbon dioxide (CO_2), methane (CH_4) and water vapour. These gases trap the Earth's outgoing radiation, and hence, warm the planet. Both carbon dioxide and methane are generated by industrial activity and the use of fossil fuels. Anthropogenic contrarians, such as Baliunas et. al. (2002) and Patterson (2003), suggest that variations in the Sun's energy output cause the increasing temperatures. The rising temperatures then raise the concentration of carbon dioxide in the atmosphere, rather than the other way around.

Regardless of the causes, warming air temperatures are occurring in the western Canadian Arctic. Figure 1 shows almost 60 years of recorded air temperatures at Yellowknife (62°27'N) along with a linear regression line fitting to the noted data points.

Figure 1 60 Years of Yellowknife Temperatures

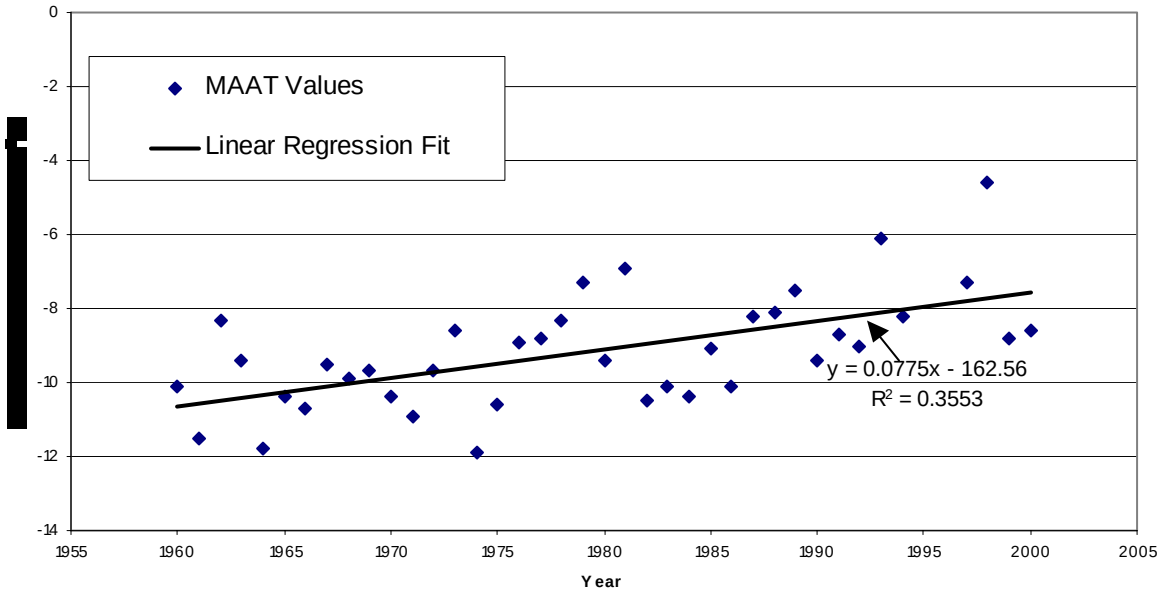


A warming trend of approximately 0.3°C/decade is indicated over the long period shown on Figure 1. If the regression were limited to a later time period (post-1970 for example), then higher warming values may have been indicated.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Figure 2 displays the data for Inuvik, in the Mackenzie Delta at 69°18'N.

Figure 2 40 Years of Inuvik Temperatures



Based on 40 years of records, and a coefficient of determination of 0.36 (i.e. 36% of the data is explained by the linear fit model), a warming trend of 0.77°C/decade is indicated by the air temperature history. Regardless of the air temperature trends, warming in the underlying permafrost has been measured, as noted earlier in Burn (2002).

For the eastern Arctic, the warming indications are not quite so obvious. Linear regression of only 14 data points from the Nanisivik A Station (Baffin Island) provided a warming trend of 0.6°C/decade with a coefficient of determination of only 0.22 (i.e. only 22% of the data is explained by the linear fit). For the Resolute Station (Cornwallis Island), with 52 data points and hence a much larger sample population for statistical assessment, a warming of only 0.1°C/decade was indicated but the coefficient of determination was only 0.04. Hence, the Nanisivik and Resolute weather stations do not indicate any statistically significant warming within the data sets analysed (up to 2000). It is possible that eastern Arctic warming may be indicated on other Nunavut or northern Quebec locations or in more recent data (after 2000).

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

3.0 HIGH LAKE PROJECT

The High Lake property site is located at 67°22'N latitude. No long term climate measurements are available for either site but Table 1 summarizes the mean annual air temperature (MAAT) data for nearby climate stations, in relation to the High Lake site:

Table 1 - Summary of MAAT Data from Nearby Stations

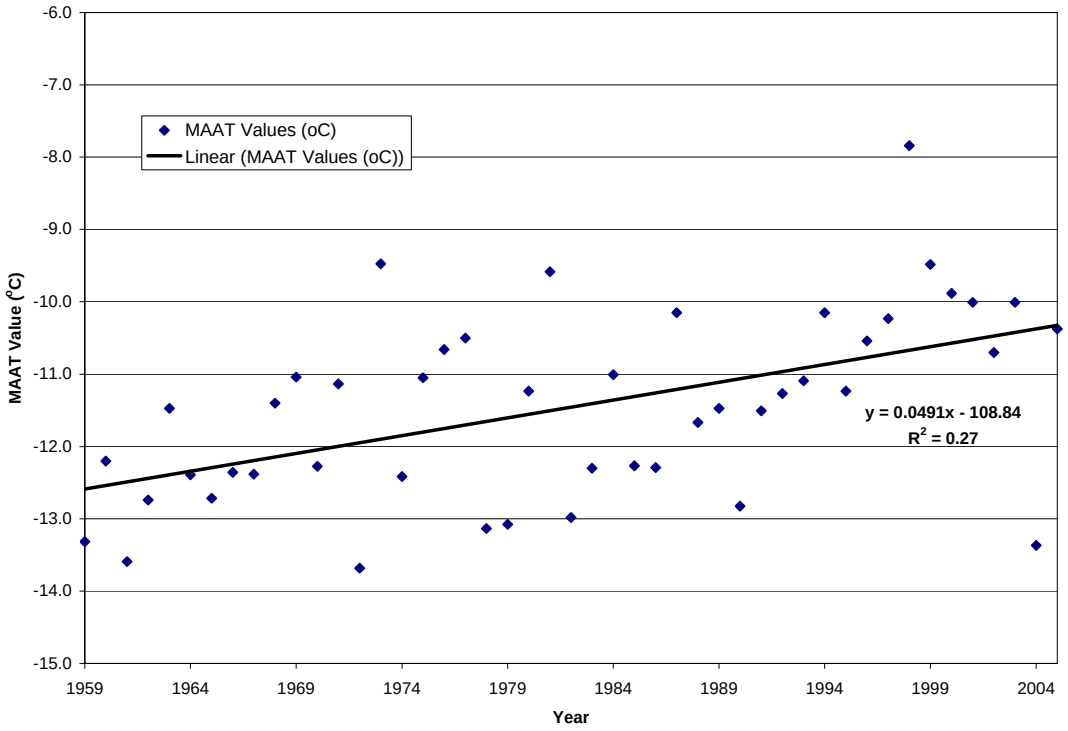
Station Name	Distance/Direction from High Lake	Period of Record	MAAT
Cambridge Bay	300 km NE	1929-2004	-14.7^{o} C
Coppermine	200 km WNW	1933-1977	-11.4^{o} C
Kugluktuk	200 km WNW	1978-2004	-10.4^{o} C
Contwoyto Lake (65.48^{o}N)	280 km S	1959-1981	-11.9^{o} C
Lupin (65.76^{o}N)	200 km S	1982-2005	-11.0^{o} C

As a result, it is estimated that the MAAT values for the High Lake site will be approximately -11° to –12°C. RWDI (2006) estimated the MAAT for the High Lake as –11.8^{o}C. In addition, RWDI (2006) estimated the 2 year return period total precipitation to be 309 mm/year (adjusted).

The climate data available from the Contwoyto Lake and Lupin are from two different, but relatively close stations. Both are located around the large lake and provide a long term climate station in relative proximity to High Lake. The MAAT values are similar (-11.9^{o} versus -11.0^{o}C) along with the standard deviation values from the data (1.16^{o} versus 1.24^{o}). If the data is combined from the two proximal stations, a 46 year period of record is available for potential assessment of climate warming; the results are displayed on Figure 3:

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Figure 3 Long Term Temperatures for Combined Station



The 46 years of data from the combined station indicates a potential warming amount of 0.49°C/decade, but again with a low correlation coefficient.

RWDI (2006) reviewed climate data from several proximal weather station (including Lupin and Contwoyto) and provided the following two conclusions regarding climate change observations for the High Lake "Project Area":

- Annual mean temperatures have increased by 0.01°C/year to 0.02°C/year between 1933 and 2002.
- Mean annual precipitation amounts have increased by about 0.7 mm/year in the same time frame.

In addition to climate change amounts, it is also necessary to discuss the relevant time periods relative to the mine phases in which to apply the various climate change parameters:

1. Construction – two years from 2008 to 2010.
2. Mining – 14 years from 2010 to 2024.
3. Reclamation and monitoring – 7 years from 2024 to 2031.
4. Closure – past 2031.

Both the amount and time period will be important as design criteria, along with the potential differing design intent of each dam structure within the operations and closure phases.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

4.0 OTHER NORTHERN MINING PROJECTS

Numerous other new mine and closure projects in the north have been submitted for regulatory review and permitting within the last few years. As such, these projects had to undertake some form of climate change review and proposed global warming values in their regulatory submissions. As such, these other northern projects can provide some valuable information and context for the topic of allowances made to account for the precautionary principle. Table 2 therefore summarizes the climate warming values used for the variously noted projects:

Table 2 Summary of Climate Warming Parameters for Northern Mines

Project	Latitude	Mean Annual Air Temperature	Global Warming Allowances as Design Criteria	Project Status
Polaris Mine Closure, NU	76°N north of Resolute	-16.5°C	Best estimate MAAT increase; 3.0°C/100 years High sensitivity; 5.1°C/100 years	Permits received Closure work completed Active monitoring
Nanisivik Mine Closure, NU	73°N north end of Baffin Island	-15.1°C	Best estimate MAAT increase; 2.8°C/100 years High sensitivity; 5.0°C/100 years	Permits received Closure work almost completed
Doris North Mine, NU (2 year mine life)	67.5°N	-12.0°C	Discussed worst case of 5.3°C warming over the next century. Used simplying assumption of 6.5°C over next century for thermal modelling of dams.	NIRB approval provided in September 2006.
Jericho Mine, NU (8 year mine life)	65.8°N	-11.1°C	High sensitivity value was used for final dam design	Mine now operating
Meadowbank Mine, NU (8 year mine life)	65°N north of Baker Lake	-11.3°C	5.5°C warming over 100 years	NIRB approval provided in August 2006.

As such, global warming amounts ranging from approximately 5° to 6°C/100 years have been selected for design and received regulatory approval on selected northern projects. The 100 year time frame from closure should also be noted as important.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Some of High Lake's structures may be required to perform their design function for more than 100 years. Any climate predictions beyond a 100 year period, and some may argue a 50 year period, contain so much uncertainty as to be useless. Monitoring and design criteria reassessments would be required in the future for all noted structures.

5.0 CLIMATE CHANGE FORECASTS

Any selection of appropriate climate change parameters for the future is done on the basis of complex, atmospheric general circulation models (GCM's) that attempt to forecast future changes in greenhouse gases (based on proposed society's response) and their impact on the climate. These computer models are highly complex and require extensive amounts of computer power and time to simulate long time periods. In order to simplify the models, the horizontal resolution of the models is limited (Plummer et. al 2006). As such, finer scale resolution is provided through the use of limited-areas regional climate models (RCM's). It should be noted that these models are complex, but that does not necessarily imply accuracy in terms of all elements of the climate (e.g., temperature, precipitation, evaporation, etc.)

Environment Canada (1998) has published guidelines as a consistent basis for planning and impact assessment for long-term projects in the North. Based on increasing concentrations of greenhouse gases, and using GCM's, the IPCC (1995) estimates a range of estimated global warming values. Often quoted scenarios are the "Best Estimate" and the "High Sensitivity" values of 2.0^{o}C and 3.5^{o}C for the global temperature warming between 1990 and 2100. These global increases are then converted into regional warming values, based on the use of GCM's.

Environment Canada (1998) provides values for the expected temperature increases by season, latitude and decade. The following limitation is noted though with the temperature increase values provided:

> "…they can be considered nominal temperature change scenarios for northern North America to the north and west of Hudson's Bay (emphasis by BGC). There is still considerable uncertainty on both the direction and magnitude of impact of global warming in the northeastern part of North America."

These guidelines, although noted as only appropriate for the Western Arctic, has been used for numerous projects in the Eastern Arctic as well.

Tables 3 and 4 therefore provide the interpolated temperature increase values proposed for High Lake site, based on the only currently published guidelines for temperature increases in the North.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Table 3 Best Estimate Global Warming Estimates for High Lake

BEST ESTIMATE CASE											
	60°N Latitude					70°N Latitude					67.3°N Latitude
Year	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	Annual
2000	0.5	0.4	0.1	0.1	0.3	0.5	0.4	0.1	0.1	0.3	0.3
2100	5.0	3.9	1.5	1.2	2.9	6.0	4.2	1.0	1.1	3.1	3.0
Difference					2.6					2.8	2.8

Table 4 High Sensitivity Global Warming Estimates for High Lake

HIGH SENSITIVITY CASE											
	60°N Latitude					70°N Latitude					67.3°N Latitude
Year	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	Annual
2000	0.8	0.6	0.2	0.2	0.5	1.0	0.7	0.2	0.2	0.5	0.5
2100	8.8	6.9	2.6	2.0	5.1	10.5	7.2	1.8	2.0	5.4	5.3
Difference					4.6					4.9	4.8

As a result, the mean annual temperatures increases of 2.8°C and 4.8°C for the Best Estimate and the High Sensitivity cases respectively, would be applied to the "current" MAAT value of –11.8°C. As a result, the Best Estimate MAAT would be equivalent to –9°C and the High Sensitivity MAAT would be –7°C by 2100.

RWDI (2006) undertook a review of proposed climate change parameters from GCM's extracted from the Canadian Institute for Climate Studies (CICS) at the University of Victoria. It should be noted that results provided herein are results for a specific cell encompassing all of Nunavut and not for the High Lake area specifically. For four different scenarios and seven different models, the following climate change parameters were predicted, on average, by the Year 2080:

- 5.7°C total average change in the air temperature (0.076°C/decade).
- 23% total increase in precipitation (3%/decade).
- 0.21 mm/day increase in evaporation.

Again, these estimated values are representative of the entire territory and not just the High Lake site.

Plummer et al. (2006) presented the recent results from the Canadian RCM, which was broken down into 11 climatic regions. For the Eastern Arctic region (appears equivalent to Nunavut), the following climate change estimates were made for the climate means from 1971-1990 to 2041-2060 (70 year duration):

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

- The air temperature was forecast to increase by 3.6°C (average) to 4.3°C (high amount) over the 70 year duration. This increase corresponds to 0.051°C/decade to 0.061°C/decade.
- The total annual precipitation (seasonally precipitation amounts were also variable) was estimated to increase by 12.75% (average) to 18.75% (high amount) over the modelled 70 year duration.

As such, two different models over similar time periods appear to provide different results.

Increasing precipitation resulting from global warming should increase the probability of greater snow cover. Increasing snow cover represents additional insulation on the ground and hence, permafrost warming would occur. It should be noted that climate models appear to have difficulty is accurately predicting precipitation changes in the future. Increasing air temperatures is expected to increase the evaporation in northern areas.

6.0 CONCLUSIONS

The currently available information provides five varying estimates of climate warming; 0.1°-0.2°C/decade to 0.49°C/decade from actual measured temperatures and 0.48°C/decade to 0.76°C/decade based on climate change models. Based on these values, and on the precedents with respect to the other northern mining projects, it is recommended that a warming allowance of 0.5°C/decade be applied as the "base case" and 0.65°C/decade for the "high case" for the High Lake Project. Some judgement will need to be applied to their application, based on the potential consequences and impacted predicted for this amount of warming. Thermal Factors of Safety will be employed during the design of the dams, and therefore, some additional conservatism will be applied to the noted warming value.

Two climate models estimated 18%, 26% and 33% precipitation increase over a 100 year period. As such, it is recommended that a total precipitation increase of 25% over 100 years be allowed for, including the increase in snowfall amounts by 25%.

7.0 LIMITATIONS AND CLOSURE

This memorandum provides a review of climate change information collected and modelling undertaken by third-parties, separate from BGC Engineering Inc. (BGC). As such, BGC has not independently verified the work and it is assumed accurate, although numerous assumptions (and associated limitations) are generally required to simplify natural complexity. As such, judgement has been applied to the information reviewed and the recommendations made herein. Variations from the noted conclusions are possible.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

This memorandum was prepared by BGC Engineering Inc. (BGC) for the account of Wolfden Resources Inc. The material in it reflects the judgement of BGC staff in light of the information available to BGC at the time of memorandum preparation. Any use which a Third Party makes of this report, or any reliance on decisions to be based on it are the responsibility of such Third Parties. BGC Engineering Inc. accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this memorandum. All memorandums and drawings are submitted for the confidential information of our client for a specific project and authorization for use and/or publication of data, statements, conclusions or abstracts from or regarding our memorandums and drawings is reserved pending BGC's written approval.

We trust that the information contained within memorandum meets your present requirements. Should you have any questions regarding the information and recommendations contained herein, please contact BGC at your convenience.

Respectfully submitted;
BGC Engineering Inc.
per:

James W. Cassie, M.Sc., P.Eng.
Specialist Geotechnical Engineer

Reviewed by:

Ron Coutts, M.Sc, P.Eng.
Specialist Geothermal Engineer

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

REFERENCES

Allard, M., Fortier, R., Duguay, C. and Barrette, N. 2002. A trend for fast climate warming in northern Quebec since 1993: impacts on permafrost and man-made infrastructure. American Geophysical Union 2002 Fall Meeting, San Francisco, December 2002.

Allard, M., Wang, B. and Pilon, J.A. 1995. Recent cooling along the southern shore of Hudson Strait, Quebec, Canada, documented by permafrost temperature measurements. Arctic and Alpine Research, Vol. 27, p. 157-166.

Arctic Climate Impact Assessment 2004. http://usinfo.state.gov/gi/Archive/2004/Nov/08-21489.html. Web site accessed December 2005.

Baliunas, S., Patterson, T. and MacRae, A., 2002. Climate change is natural. Article published in the Globe and Mail, November 19, 2002, page A21.

Beilman, D.W., Vitt, D.H. and Halsey, L.A. 2000. Localized Permafrost Peatlands in Western Canada: Definitions, Distributions and Degradation. Arctic, Antarctic and Alpine Research, Vol. 33, No. 1, p. 70-77.

BGC Engineering Inc. 2006. Supplemental Information on Tailings Dam Design, High Lake Project, NU. Memorandum submitted to Wolfden Resources Inc., October 13, 2006, 13 pages.

Burn C.R. 2002. Recent permafrost warming in Northwest Canada. American Geophysical Union 2002 Fall Meeting, San Francisco, December 2002.

Environment Canada 1995. The State of Canada's Climate; Monitoring Variability and Change. Environment Canada State of the Environment Report, Ottawa, Canada.

Environment Canada 1998. Climate change impacts on permafrost engineering design. Published by the Environmental Adaptation Research Group, AES, Environment Canada. Funded by the Panel on Energy Research and Development (PERD). March 1998, 42 pages.

Environment Canada 2005. http://www.ec.gc.ca/econom/pp_e.htm. Web site accessed December 2005.

IPCC 1995. Climate change 1995: the science of climate change – technical summary. Cambridge University Press, Cambridge, UK.

Natural Resources Canada. 1995. Canada – Permafrost 1995. The National Atlas of Canada, 5th Edition. Published by the National Atlas Information Service, Canada Centre for Mapping, Geomatics Canada and the Terrain Sciences Division, Geological Survey of Canada, Natural Resources Canada 1995.

Patterson, T., 2003. Kyoto science disputed. Article in the National Post, July 14, 2003.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

Plummer, D.A., Caya, D., Frigon, A., Cote, H., Giguere, M., Paquin, D., Biner, S., Harvey, R. and De Elia, R., 2006. Climate and Climate Change over North America as Simulated by the Canadian RCM. Journal of Climate, Volume 19, pages 3112 to 3132.

RWDI Air Inc. 2006. High Lake Climate Assessment. Report submitted to Gartner Lee Limited, March 7, 2006, 53 pages.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

APPENDIX II
HIGH LAKE PROJECT DESIGN BRIEF BY NHC

HIGH LAKE PROJECT
HIGH LAKE OUTLET SPILLWAY
AND
CONTACT LAKE DIVERSION

DESIGN BRIEF

PRELIMINARY

Submitted to:

Wolfden Resources Inc.
and
BGC Engineering Inc.

Submitted by:

Northwest Hydraulic Consultants Ltd.
Edmonton, Alberta

Prepared By:

E.K. Yaremko, P.Eng.

May 2007

ref. 6971/5585

1. INTRODUCTION

1.1 Background

The Wolfden Resources Inc. High Lake Project being developed in Nunavut will utilize High Lake as the tailings pond facility. Associated with the development of this facility is a series of six dams surrounding High Lake (see Figure 1), two of which will be involved with passing (spilling) or diverting of flows. Specifically:

- Northeast Dam - The East Dam at the southeast corner of High Lake will permanently close off the natural outlet; there is some belief that during extreme high runoff periods the level of High Lake could result in some outflow at the north end of the lake. The Northeast Dam will block off this overflow route but lake outflow during the 14-year mine life and post-mine period will flow past this dam. A syphon will be used to bypass flow during the 14-year mine life and a fixed-crest, ungated spillway will be provided for the post-mine period.

- Contact Lake Dam – A small sub-basin drains into High Lake via two small lakes, one of them being Contact Lake. A dam will be constructed at the outlet of this lake and lake inflow will be permanently diverted directly into the Kennarctic River via a secondary outlet from the lake.

  The Northwest and Northwest Channel dams are retention dams that are meant to block potential outflow routes from High Lake. One consequence of this will be permanent diversion of the Lake L15 basin into Granite Lake.

- A polishing pond will be established behind the Polishing Pond Dam. This dam will be breached at the end of mine life to re-establish surface flow from High Lake to the Kennarctic River. Flow past the dam during mine life will be via a siphon.

1.2 Objectives

The objectives of the work summarized by this report were as follows:

- Syphon designs for both the Northeast and Polishing Pond dams.
- Spillway design for the Northeast Dam - for closure only.
- Diversion outlet and channel associated with the Contact Lake Dam.
- Assessment of Probable Maximum Precipitation (PMP) pond rise and wave height during storm events.

1.3 Background Information

- "High Lake TCF Feasibility Design. Draft", BGC Engineering Inc. April 30, 2007.
- "High Lake Project, Volume 5.2, Surface Water Hydrology"; Gartner Lee Ltd./Northwest Hydraulic Consultants Ltd., May 2006.
- "High Lake Project Proposal, Volume 1, Environmental Assessment"; Gartner Lee Ltd. November 2006.
- High Lake water balance modelling; summary notes to file.
- "Rainfall Frequency Atlas for Canada"; Hogg and Carr. 1985

2. NORTHEAST DAM

2.1 Basis for Design

Figure 2 provides a more detailed view of Northeast and Polishing Pond dams. Figure 3 provides the proposed design dam section. It is noted that the pond Full Supply Level (FSL) will be Elev. 288.5 m (current lake level is Elev. 283.1 m) and dam crest level Elev. 290.6 m.

The FSL has been established on the basis that the final maximum level of deposited tailings shall have a minimum water cover depth of 2.5 m. The expected annual tailings tonnage will be in the order of 1.1 tonnes. The anticipated destination of tailings slurry over the 14 years of mine life is:

- High Lake Year 1-6
- AB Pit Year 7 – August of Year 10
- High Lake September Year 10 - June Year 12
- D Pit July Year 12 - Year 14[1]

The anticipated 14 year distribution of tailings delivered to the various destinations is shown by Table 1.

[1] Note that D Pit tailings deposition would be a decision made at some point during mine life - it is possible that the final period would have deposition continue into High Lake.

Table 1
Annual Delivery of Tailings

Year	Tonnes
1	980146
2	1309000
3	1295000
4	1287000
5	1287000
6	1307000
7	1304000
8	1311000
9	1306000
10	1300000
11	1097000
12	1099000
13	1099000
14	372817

Based on Tables 1 and 2, the expected total mass of tailings to be delivered to the High Lake TCF for the years indicated is 10.09 Mm^3. For a dry density of 1.3 t/m^3, the total volume would be 7.8 m^3. From Figure 3, displacing this volume of lake water would result in High Lake rising to Elev. 285.0 m. Allowing for 2.5 m of ice thickness plus 0.5 m to ensure a secure clearance of the ice cover bottom and potential non-uniform distribution of tailings deposition, a pond (FSL) of Elev. 288.0 m seems appropriate. However, an additional allowance of 0.5 m is recommended in the event that the quantity of tailings destined for pit D is instead directed to High Lake. This confirms the appropriateness of the adopted FSL, Elev. 285.5 m.

2.2 Mine Operation Period

2.2.1 Water Balance Model

A water balance model was developed for the purpose of predicting the rate of tailings infilling of the High Lake TCF, Pit A/B and Pit D. It is assumed that all dams are in place at the beginning of mine operation, which will raise the tailings storage availability from 7 Mm^3 that it is currently to about 11 Mm^3 at FSL Elev. 288.5 m. Tailings are deposited in High Lake at the beginning of the project until Pit A/B is available for deposits beginning in Year 7. Tailings are again routed to High Lake once Pit A/B has been filled, beginning in September of Year 10 to June of Year 12. Natural surface runoff and tailings will fill the lake until its level approaches FSL, after-which spill past the Northeast Dam would commence,

assuming decanted water meets the approved level of quality.

For average years of runoff, the water balance model shows that the FSL would be reached during Year 3 – sooner if years of above average runoff occur. Subsequent years will require spilling natural inflow past the Northeast Dam and Polishing Pond Dam using a system of siphons. Spilling would occur only during the open water season which is normally June through the middle of October. Additional pre-emptive releases would be required during the summer to provide capacity for mining inputs that continue through the winter months. This additional drawdown is distributed through the summer months in the same monthly distribution as natural runoff.

2.2.2 Syphon Design

As outlined above, water spilled from the High Lake TCF during the summer will be comprised of four possible sources:

- the annual surface runoff that enters the lake;
- a volume of water that represents the dislocation of lake storage by tailings;
- tailing slurry water minus water reclaimed for processing;
- miscellaneous mine water discharges (grey water, underground mine water, etc.)

Table 2 provides the range of annual depth of precipitation probabilities adopted for the project, while Table 3 provides the percentage distribution of summer runoff.

Table 2
Annual Precipitation Probabilities

Return Period (Years)	(mm)
2	280
5	320
10	344
20	360
50	380
100	394

Table 3
Monthly Runoff Distribution

Month	Runoff (%)
June	44
July	28
August	16
September	19
October	3

Figure 4 shows the High Lake drainage area – the L15 and Contact Lake basins have been removed to reflect the fact that their runoff would be diverted. The various sub-areas are shown which reflect different mine development component characteristics within the basin. Table 4 provides a summary of these sub-areas and their adopted runoff coefficients.

Table 4
High Lake Basin Sub-Areas

Sub-Area	Drainage Area (m^2)	Runoff Coefficient
High Lake	824,694	.60
High Lake area with elevated metals	49,456	.60
High Lake natural area with low metals	453,827	.24
AB zone waste dump	202,709	.24
DP zone waste dump	42,147	.24
DPT zone waste dump	20,656	.24
DT zone waste dump	67,094	.24
D Pit	72,310	Pit walls: .80 June; .60 July-October
AB Pit	94,058	As-above
L17 local runoff	32,964	.60
L 21 local runoff	120,572	n/a
L21 thru L24 land	483,393	.60
Upper L19 and L17	195,384	.60
High Lake ore stockpile	4,218	.24
Backfill stockpile	61,955	.24
Natural residual L20 drainage	170,250	.60
Project roads	22,904	.85
Project buildings	26,596	.85

Surface runoff – From Table 2 and applying the runoff coefficients in Table 4, the mean annual runoff volume is 303,769 m^3. From Table 3, the highest monthly rate of runoff would occur in June when 44 percent, or 133,658 m^3 would runoff into the lake - the average rate for the 30 days would be 0.052 m^3/s. The corresponding 100-year rate would be 0.072 m^3/s.

Water displacement – From Table 1, the highest annual tailing deposit would be 1,309,000 tonnes in Year 2. This amount of displacement would have to be accommodated in the tailings pond in the summer previous, with spillage mimicking the natural inflow pattern. The volume of displacement for this amount of settled tailings would be about 1Mm^3, assuming a dry density of 1.3 m^3/tonne. June would have to accommodate 44 percent of this volume, or 440,000 m^3 and a discharge rate of 0.17 m^3/s.

Tailings slurry-water - A tails water contribution of 0.005 m^3/s was provided by BGC Engineering.

The siphon capacity would be as follows:

• 100-year June runoff	0.072 m^3/s
• June displacement spillage	0.170 m^3/s
• Tails water	0.005 m^3/s
• Mine Water	The mine water contribution can be assumed to be negligible
Total	0.247 m^3/s

A single smooth pipe siphon 40 m long, having a head difference of 3 m and an internal diameter of 300 mm would have a capacity of 0.25 m^3/s. Rates during the remaining summer months would be proportional to the runoff distribution in Table 3, so a siphon of this size would suffice for all months as the outflow discharge could be increased to accommodate any shortage of outflow during June. The siphon would be required for all years of mine operation but only for the periods indicated previously would the High Lake TCF be receiving both surface runoff and tailings.

The same siphon design would also apply to the Polishing Dam operation: length of syphon of 40 m; 400 mm internal diameter; smooth pipe; head difference of 3 m.

2.2.3 Spillway Design

Basis for design - A spillway will be provided at the Northeast Dam at the end of mine life. This outlet will be required to convey all outflows from High Lake, but

the basis for its design will be the Probable Maximum Flood (PMF) hydrograph.

Areas – It is assumed that for a short-duration, high intensity rainfall event the contributing area will be 1.7 km^2, including the lake area itself (adjusted for A/B stockpile) and surface area along the lake margins. It is further assumed that a string of lakes L21 to L24 would sufficiently hold up the Probable Maximum Precipitation (PMP) runoff into High Lake until the runoff from the lake margin areas is completed. The net contributing area for spillway design is then the value indicated above. This area has been taken to be impermeable so has a runoff coefficient of 100 percent.

Storm Rainfall – The time of concentration is very short, probably much less than an hour. However, the lake can absorb the volumes of very short events with insignificant rises in level. Table 5 provide estimates for the 100-year and PMP amounts:

Table 5
Extreme Rainfall Estimates

Duration (hrs)	100-year (mm)	PMP (mm)
24	40	150
6	23	80
1	13	50

The 100-year amounts have been based on the Rainfall Frequency Atlas of Canada - the PMP amounts, by applying the Hershfield statistical equations.

Inflow hydrographs – Figure 5 provides estimated inflow hydrographs. For all hydrographs, the time to peak is assumed to be one hour. The time to drop is also taken as one hour – in the 24-hour and 6-hour events, the peak flow persists for most of the period.

The critical event is linked to spillway design. Even the 24-hour event produces a lake-level rise of less than 0.5 m, even with zero outflow. So it should be possible to have a relatively small spillway with the outflow spread over a period of several days.

Spillway design – A spillway width of 5 m has been adopted. A narrower width would be possible given the relatively small discharges associated with this outlet but for practical reasons – eg. construction and snow cleaning equipment access – this width is considered appropriate. As well, for reasons of conservatism, the PMF inflow peak of 3 m^3/s has been used for design, even though the routed 24-hour hydrograph produces a lower peak. Maximum computed depth over the

spillway sill level of Elev 288.5 m was 0.46 m.

Design basis for spillway:

- The spillway structure location has been selected to be independent of the dam itself – it has been located to the left of the left abutment of the dam as shown in Figure 6;

- It is possible that much of the spillway will be constructed within bedrock, but this will have to be confirmed at the final design stage.

- The downstream end of the spillway terminates near L30, which makes up part of the Polishing Pond - the alignment of the channel is in-line with the natural flow system; and,

- It is assumed that the material over which the spillway will be constructed and water would be conveyed is durable and would not significantly deteriorate with time.

Figure 7 provides a design drawing of the spillway crest; Figure 8 provides selected section views of the spillway at the locations shown in Figure 6.

Ice - It can be expected that the level of the TCF will have receded to the spillway invert level prior to freeze-up in October, so the risk of ice build-up at the spillway entrance is not considered to be an issue. Even if a late fall runoff event occurred, the volume of water entering the pond would not raise it significantly and the thickness of an ice cover on the spillway would be minor.

In some circumstances, winds during the freshet period could push ice into the entrance and block it off. However, the spillway entrance is located in a sheltered area, away from any influence of a south-north wind fetch.

The process of 'ice plucking' has resulted in rock armour being pulled off a slope, such as the upstream side of a dam. For this to occur, there would have to be a situation where the TCF level dropped dramatically during the winter and this would never be the case for this pond.

Slope Protection - For a south wind velocity of 75 km/hr and fetch length of 2.1 km, a wave height of about 1.0 m can be expected. This will require 500 mm diameter (nominal) rock for protection. The protection should cover the range Elev.'s 284.5 to 291.5 m.

3. CONTACT LAKE DAM

3.1 Basis for Design

Figure 1 identifies the proposed dam location; Figure 9 provides the design dam section - note that dam height is 3 m. The purpose of this dam is to block the natural outflow from Contact Lake and redirect it to the Kennarctic River. Normally, lake outflow exits into Lake L17 - a small lake- and ultimately into High Lake.

Lake parameters of interest are as follows:

- drainage basin area: 370,000 m^2 (0.37 km^2)
- lake surface area: 50,000 m^2 (0.05 km^2)
- net basin area: 320,000 m^2 (0.32 km^2)

Ground contours and lake boundary shown in Figure 10 indicate the existence of a secondary outlet channel at the northeast corner of Contact Lake that flows to the Kennarctic River. The primary outlet to L17 is also shown. From a site visit of the lake, it was confirmed that at some lake level, the secondary channel begins operating.

Contours suggest that the bed level at the entrance to the primary outlet channel and late summer lake level is about Elev. 293.4 m and the ground level at the entrance to the secondary channel is about Elev. 294.0 m.

Figure 11 provides a ground profile along the secondary outlet channel. The first 160 m has a drop of 15 m, followed by a drop of 30 m in 50 m and 50 m in the remaining 500 m. The ground characteristics are not well defined but likely consist of frost-jacked bedrock. In the first 160 m, there would be shallow flow over bouldery-rocky terrain, much like the primary outlet channel. Beyond the 160 m point, flow becomes confined within an gully-like feature. Figure 11 also provides cross sections based on the contour plan at the locations indicated.

The purposed top-of-dam level is Elev. 296.5 m, or 3.1 m above the primary lake outlet level, and 2.5 m above the secondary channel outlet level (see Figure 9).

Runoff time of concentration for the 0.32 km^2 basin and storm rainfall runoff is likely less than 1 hr. Assuming a hydrograph time base of 2 hrs, 100 percent runoff coefficient, a 1 hr, 50 mm PMP depth of rainfall and no lake outflow, lake level would rise 0.30 m. The corresponding 24 hr, 150 mm PMP lake rise would be 0.9 m. A summary of this is provided in Table 6.

For a MAP depth of 280 mm, 44 percent June runoff and 60 percent runoff coefficient, the runoff volume would be 39,424 $m^{3,}$ with a corresponding lake level rise 0.73 m, assuming no lake outfall.

Table 6
Inflow Peaks, Contact Lake

	Precipitation (mm)	Routed Peak (m^3/s)	Volume (m^3)	Lake Level Rise (m)
PMP (1 hr)	50	1.0	18,500	0.34
PMP (24 hr)	150	0.60	48,000	0.90
MAP	280	0.12	39,424	0.73

3.2 Outlet Design

Routing of the PMP 1- and 24- hours hydrographs resulted in the outflow peaks shown in Table 6. A design flood peak of 1.0 m^3/s is considered appropriate for design of the Contact Lake outlet. The outlet would consist of a 5 m wide broad-crested weir that has an invert level of Elev. 293.4 m. Flow depth would average 0.30 m, leaving 0.30 m to the current secondary outflow level[2]. The design approach is to encourage shallow surface flow along the current path of the secondary channel. Because of the ground slope in the first 180 m of channel length, it would be necessary to provide a rock dike along the left (north) side in order to contain flow along that side (Figure 11, B-B).

Because much of the diversion route has experienced long term shallow flow, it is expected that a degree of self-armouring has occurred at the surface. Given the small flow depth at the PMF, flow velocities will be small and likely not much different than occurs presently.

Erosion and scour protection must be provided at the channel entrance in the form of a layer of 300 mm (nominal) riprap rock embedded along the invert and banks of the entrance. This armour would not be required should durable rock be encountered within the outlet section,

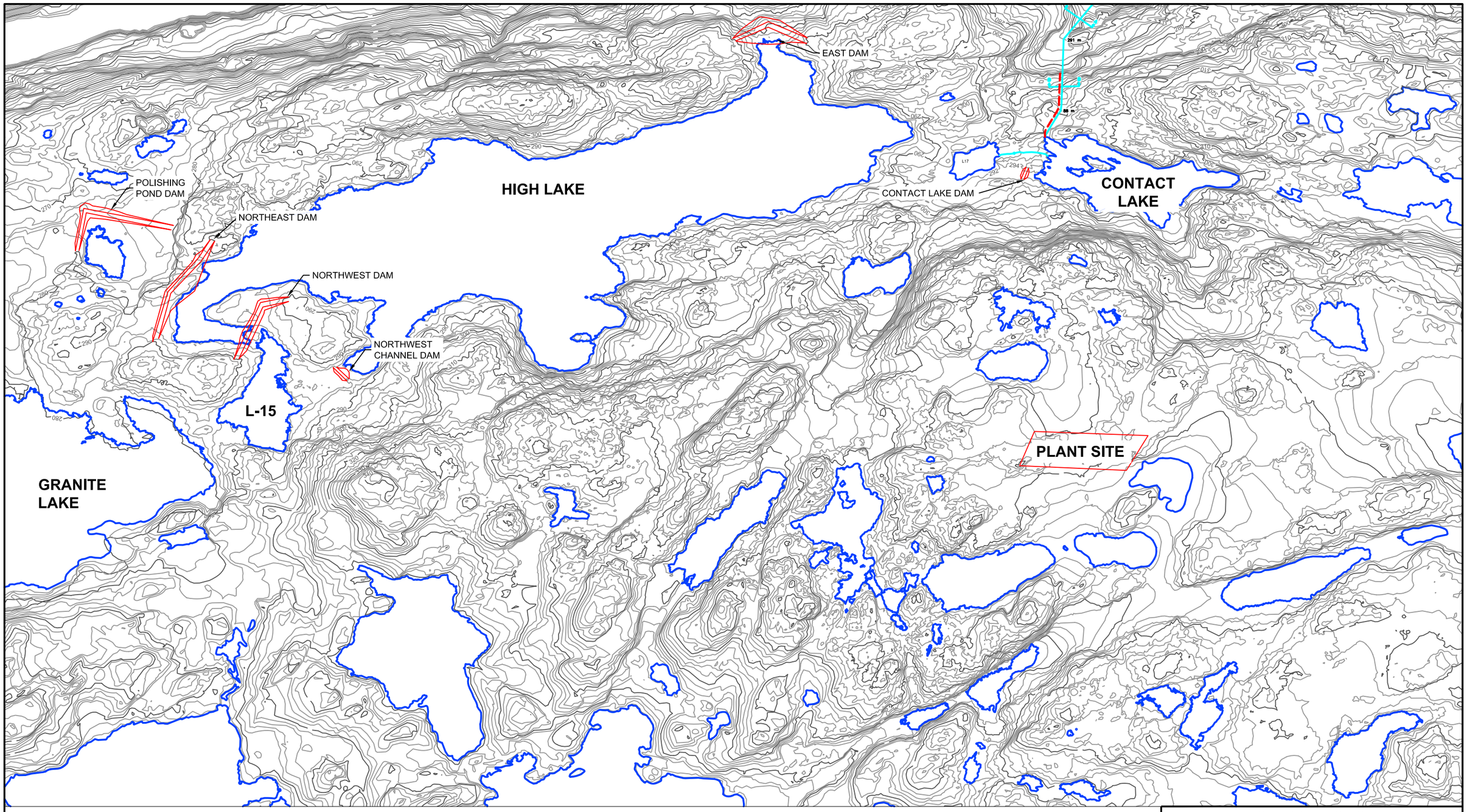
Rock riprap armour would be continued along the 180 m confinement dike.

[2] Note that these elevations have been based on a contour plan that does not provide much detail in the area of interest. A site survey will be required at the final stage of design.

3.3 Information Required for Final Design

- Bathymetry of lake bed fronting the proposed new lake outlet.
- Ground levels above lake level in area surrounding north and east boundary of lake: lake bathymetry and ground levels surveyed with sufficient density to enable generation of 0.1 m contour intervals.
- Ground levels in 60 m width centered along proposed diversion channel centerline sufficient to generate 0.1 contour intervals.
- Characterization of surface material at proposed diversion outlet and channel to establish durability of material.

FIGURES



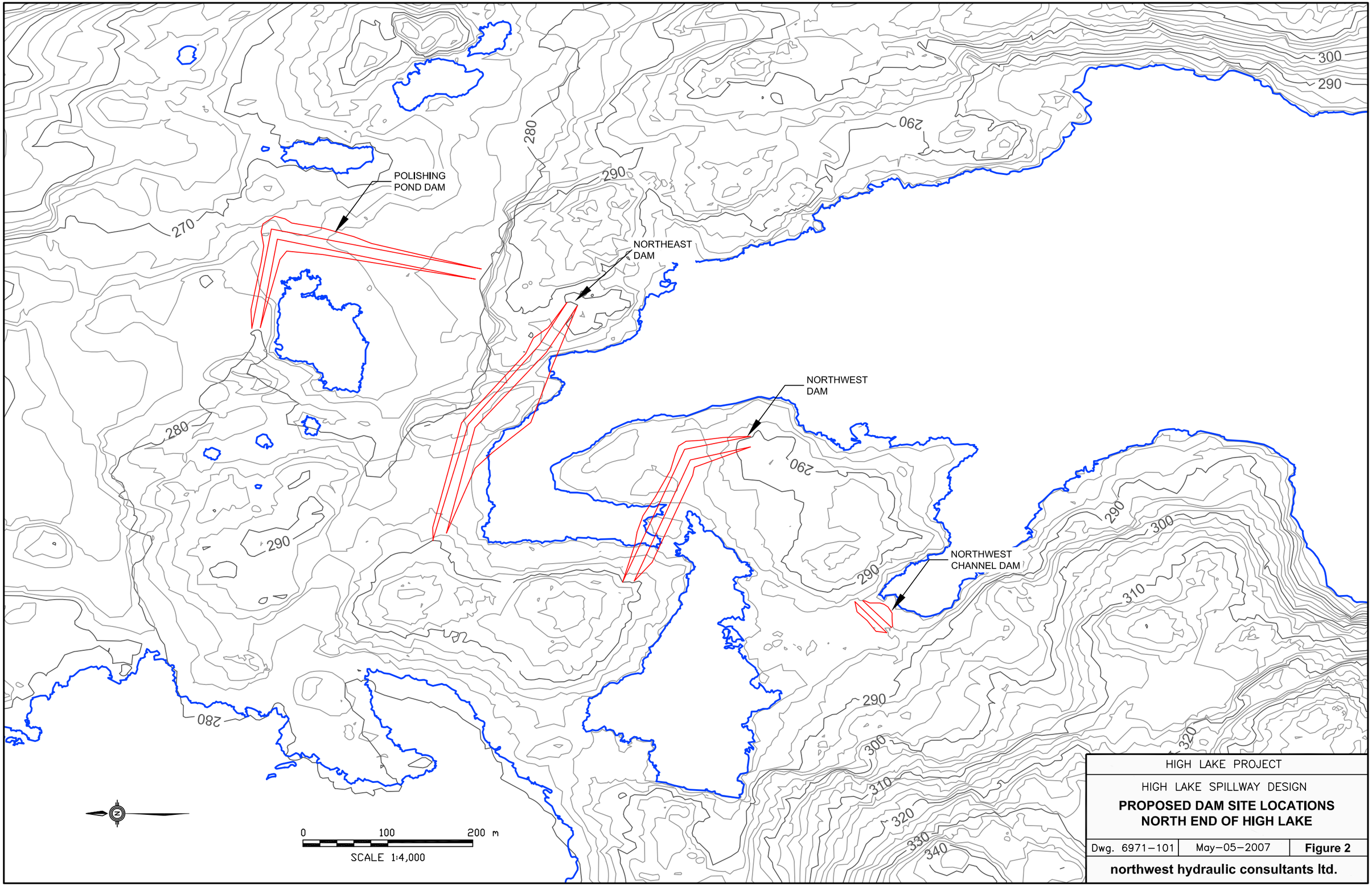
HIGH LAKE PROJECT

HIGH LAKE SPILLWAY DESIGN

HIGH LAKE LOCATION PLAN

Dwg. 6971-101	May-05-2007	**Figure 1**

northwest hydraulic consultants ltd.



HIGH LAKE PROJECT

HIGH LAKE SPILLWAY DESIGN

PROPOSED DAM SITE LOCATIONS
NORTH END OF HIGH LAKE

Dwg. 6971–101	May–05–2007	**Figure 2**

northwest hydraulic consultants ltd.

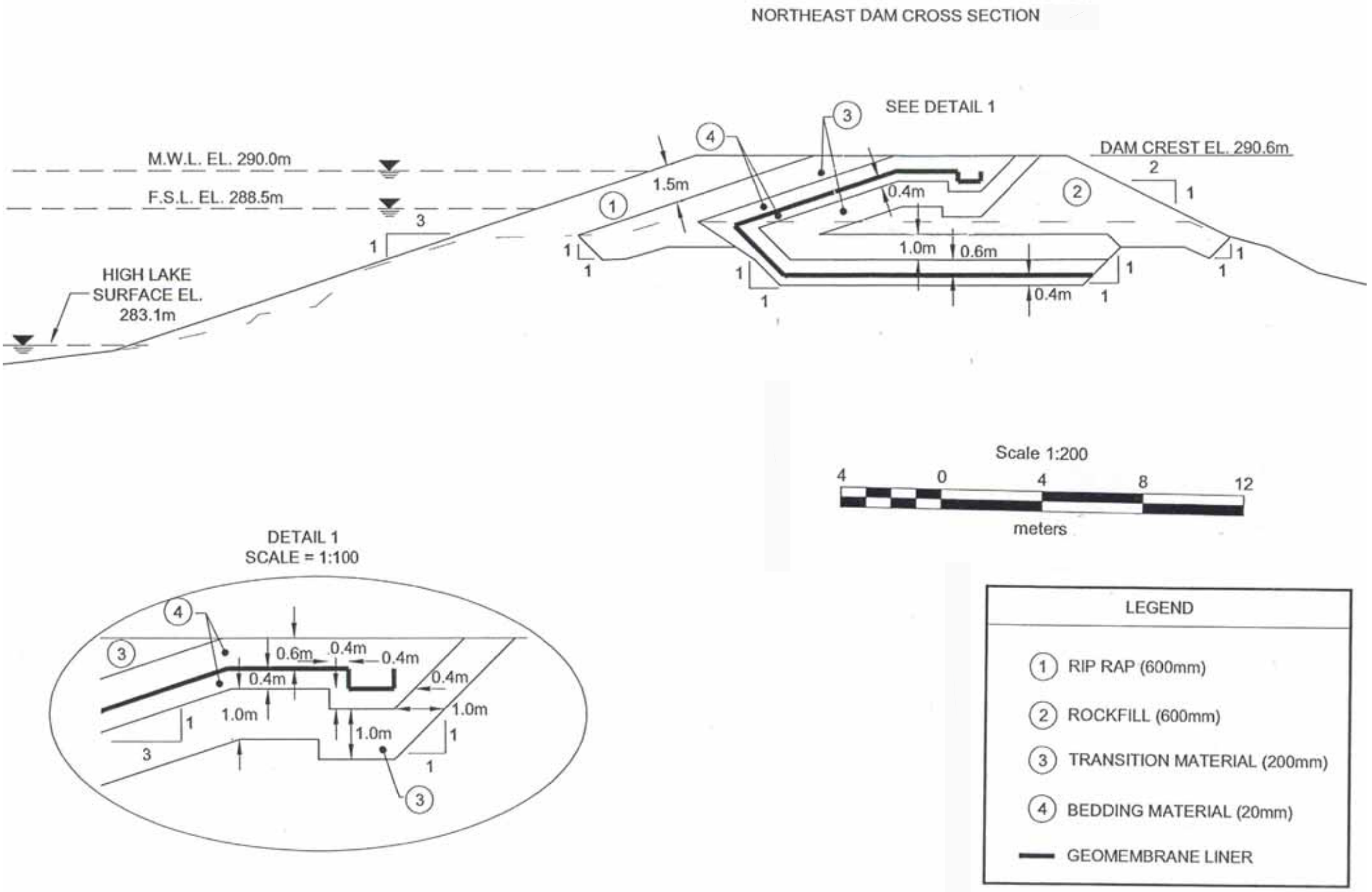


Figure 3 Proposed Northeast Dam Cross Section

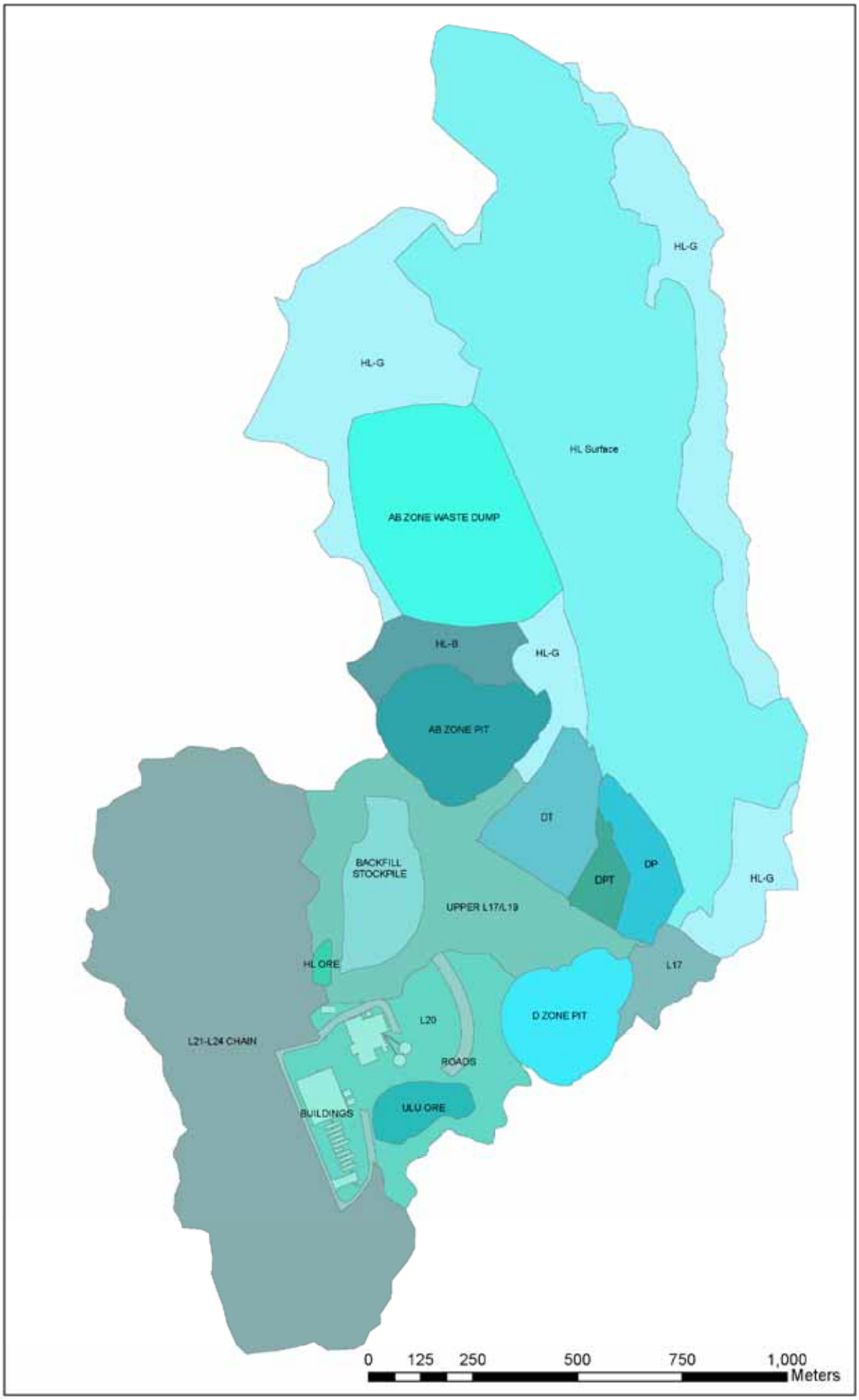
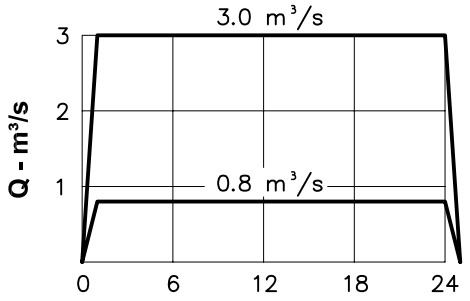


Figure 4 Highlake Sub-basins

RISE IN LAKE LEVEL FOR ZERO OUTFLOW

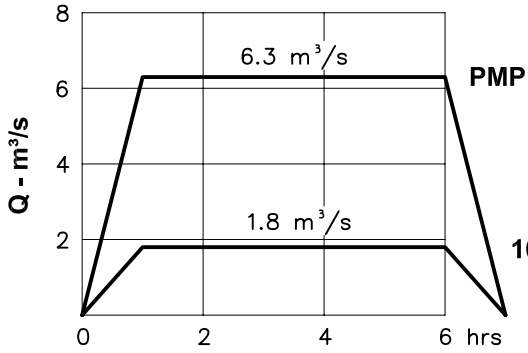
24-hr PRECIPITATION EVENT



PMP ——————————— 0.46 m

100-YEAR FLOOD ——————— 0.12 m

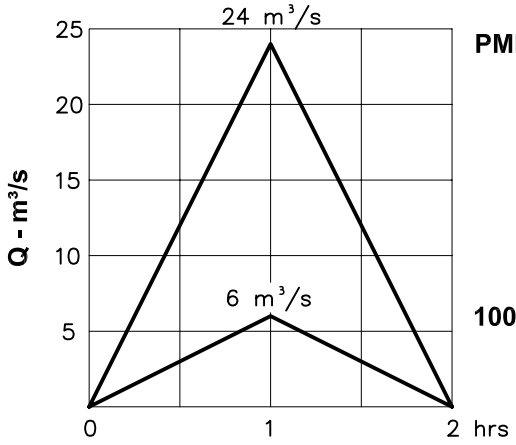
6-hr PRECIPITATION EVENT



PMP ——————————— 0.24 m

100-YEAR FLOOD ——————— 0.07 m

1-hr PRECIPITATION EVENT



PMP ——————————— 0.15 m

100-YEAR FLOOD ——————— 0.04 m

VOLUMES (m^3)	100-YEAR FLOOD	PMP
24 hr	70,000	260,000
6 hr	39,000	136,000
1 hr	22,000	87,000

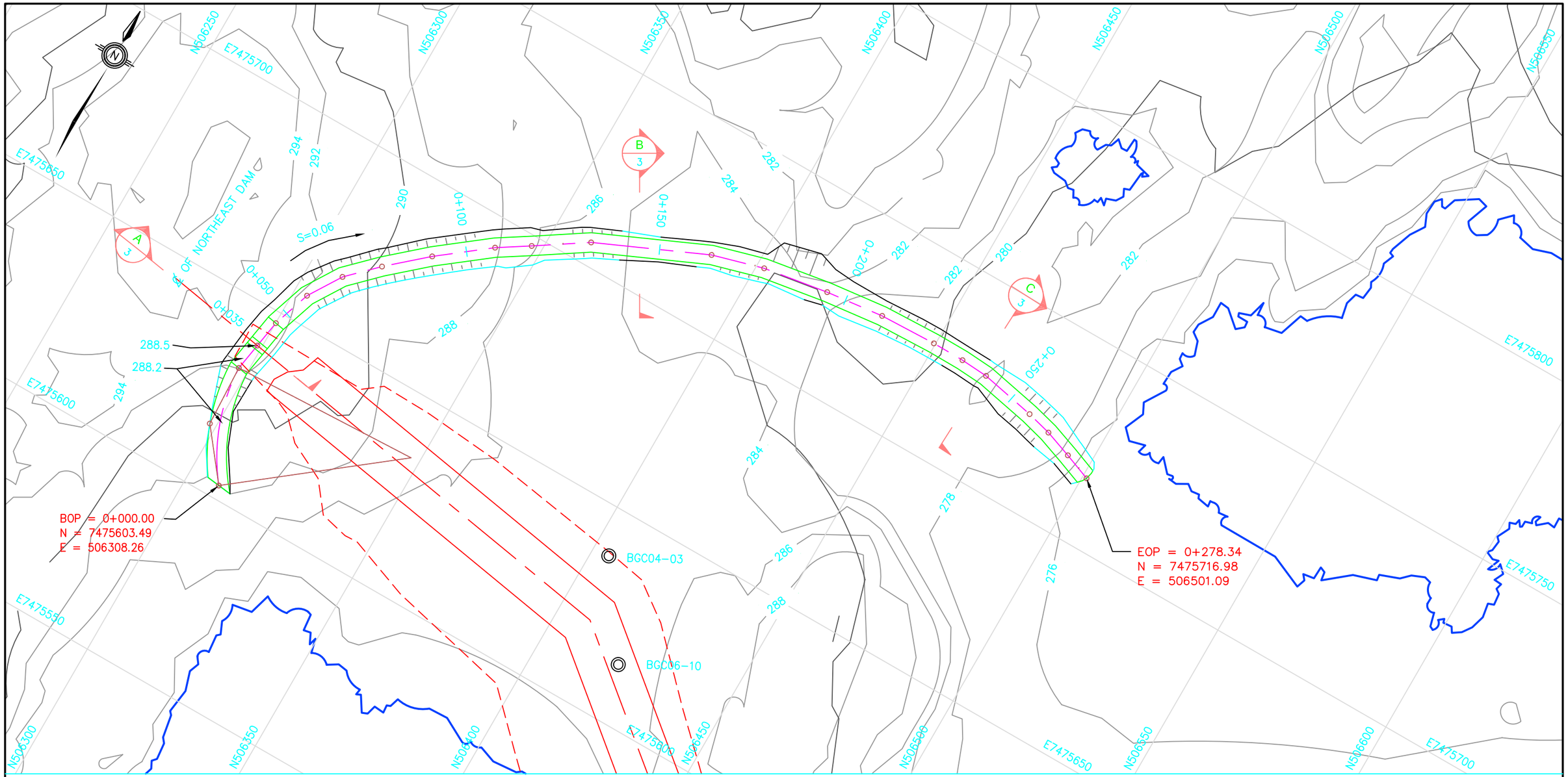
HIGH LAKE PROJECT

HIGH LAKE SPILLWAY DESIGN

HIGH LAKE FLOOD HYDROGRAPHS

Dwg. 6971–105	9 May 2007	**Figure 5**

northwest hydraulic consultants



PLAN
1:1000

20 0 20 metres
SCALE 1:1000

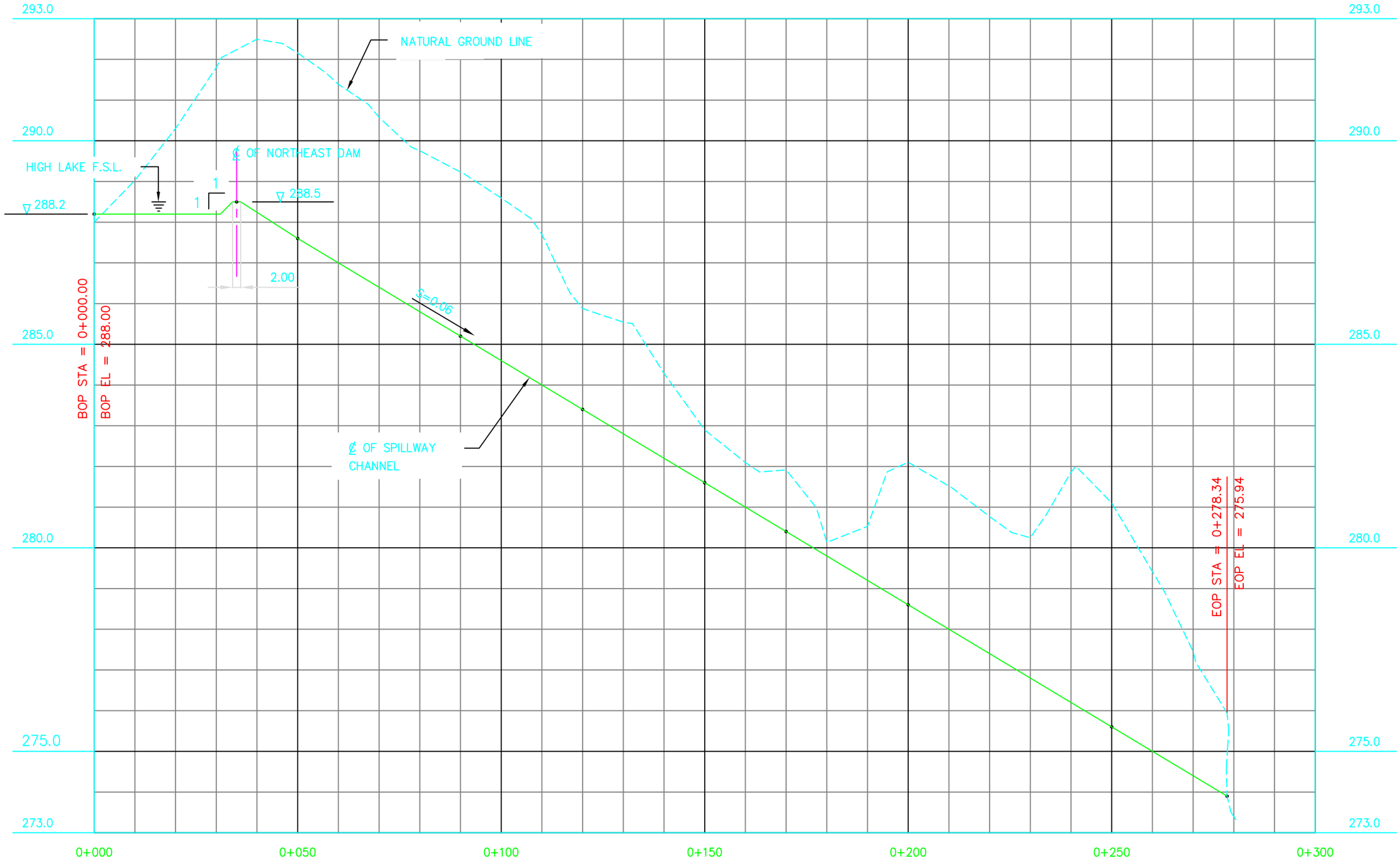
HIGH LAKE PROJECT

NORTH EAST DAM SPILLWAY

SPILLWAY SITE PLAN

Dwg. 6971-102	May-05-2007	**Figure 6**

northwest hydraulic consultants ltd.



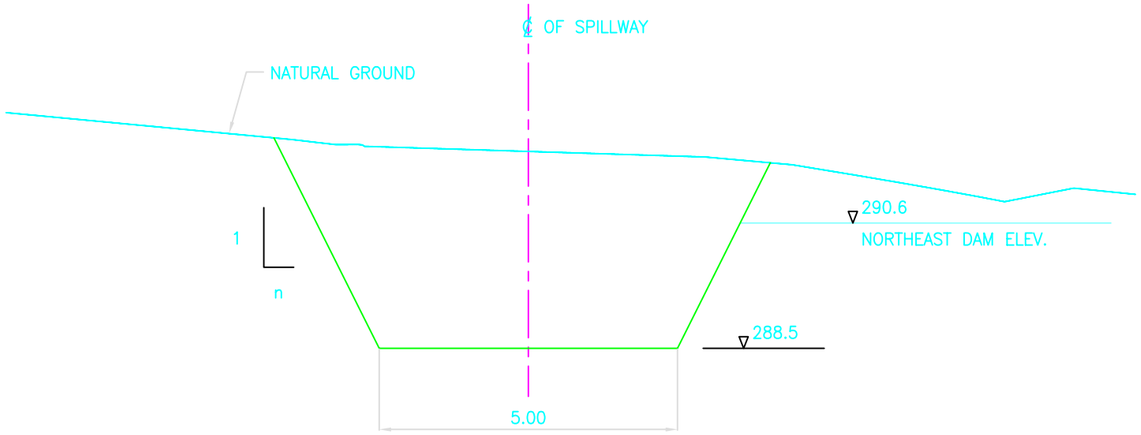
PROFILE
HOR. 1:1000
VER. 1:100

20 0 20 metres
SCALE 1:1000

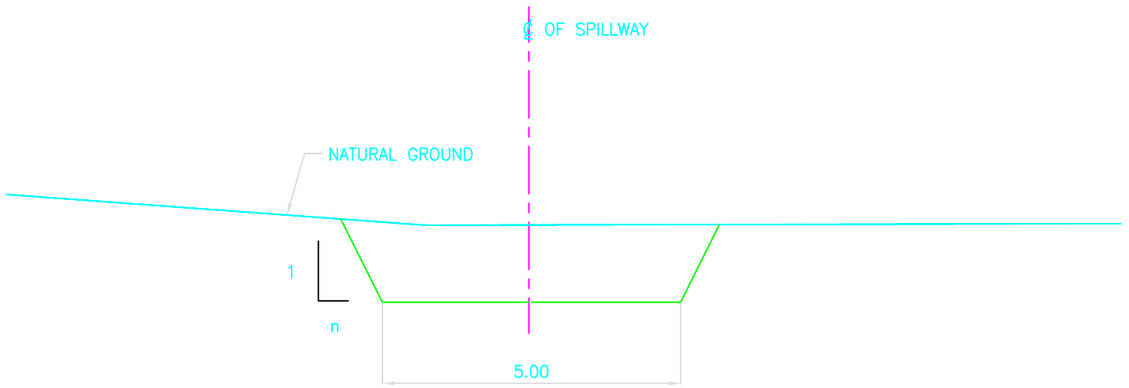
HIGH LAKE PROJECT
NORTH EAST DAM SPILLWAY
PROFILE

Dwg. 6791-103	May-05-2007	**Figure 7**

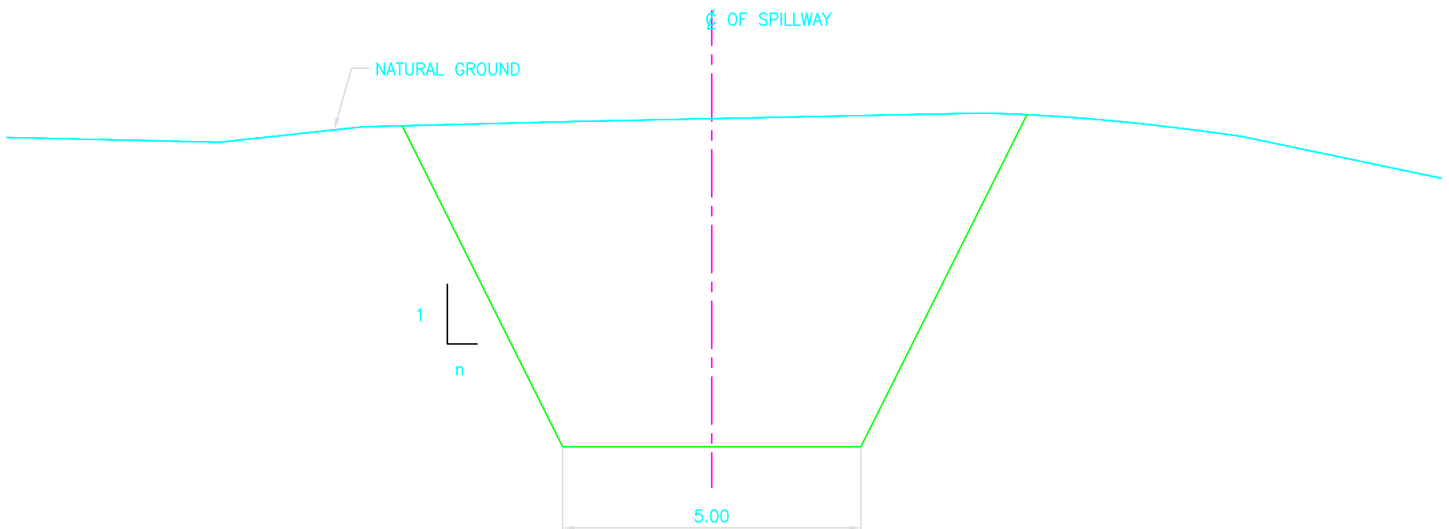
northwest hydraulic consultants ltd.



SECTION A
1:100
1



SECTION B
1:100
1



SECTION C
1:100
1

SIDE SLOPES	
MATERIAL	**n**
TILL AND FROST–JACKED BEDROCK	1
BEDROCK	10

2 0 2 metres

SCALE 1:100

HIGH LAKE PROJECT

NORTH EAST DAM SPILLWAY

CROSS SECTIONS

Dwg. 6971–104	May–05–2007	**Figure 8**

northwest hydraulic consultants ltd.

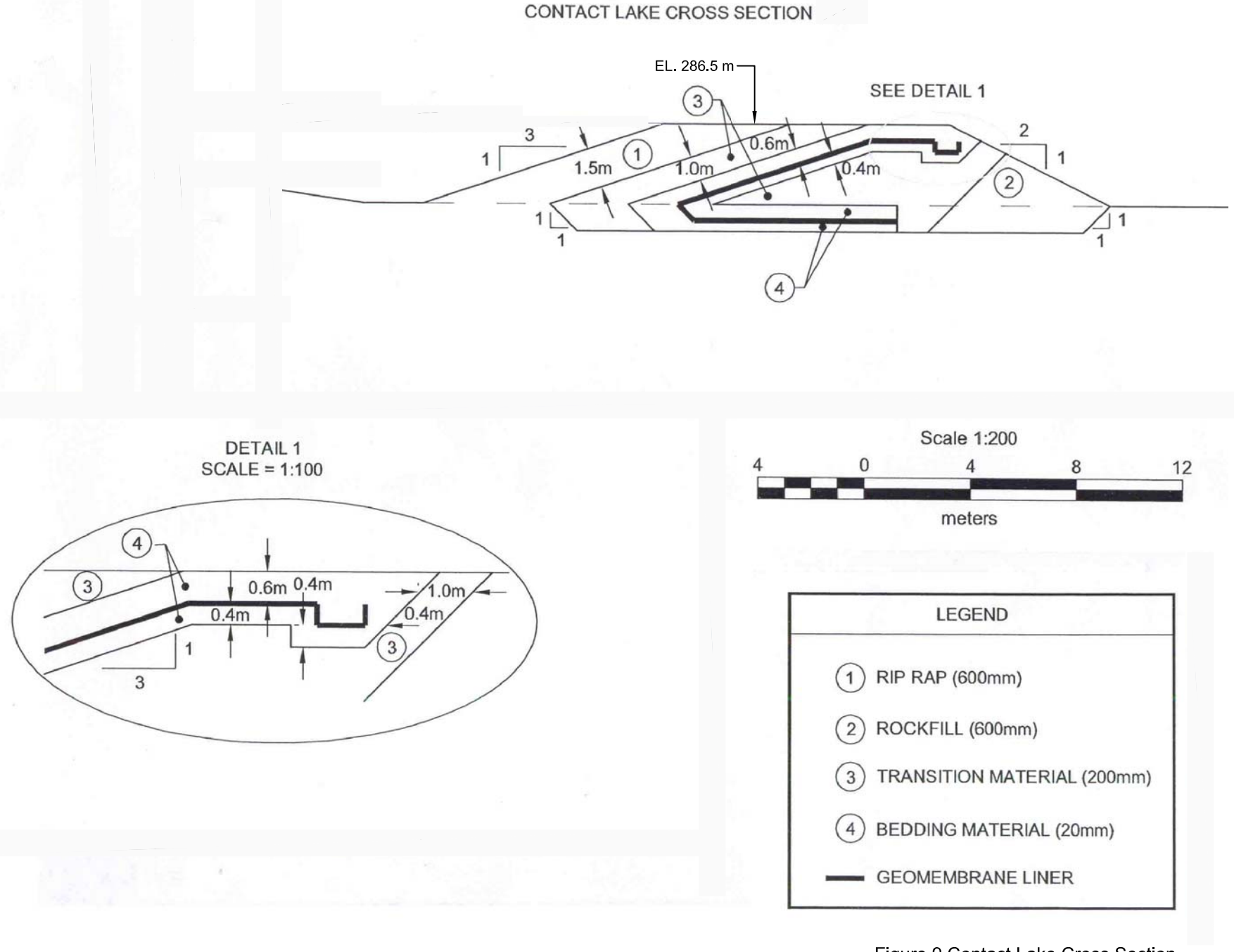


Figure 9 Contact Lake Cross Section

KENNARTIC RIVER

702 m

522 m

291 m

SECONDARY OUTLET CHANNEL
TO BECOME PERMANENT
PLENARY OUTLET CHANNEL

EAST DAM

B

B

88 m

CONTAINMENT DIKE

HIGH LAKE

PLENARY
OUTLET

CONTACT LAKE
L18

L17

294

292

CONTACT LAKE DAM

0 100 200 m

SCALE 1:4,000

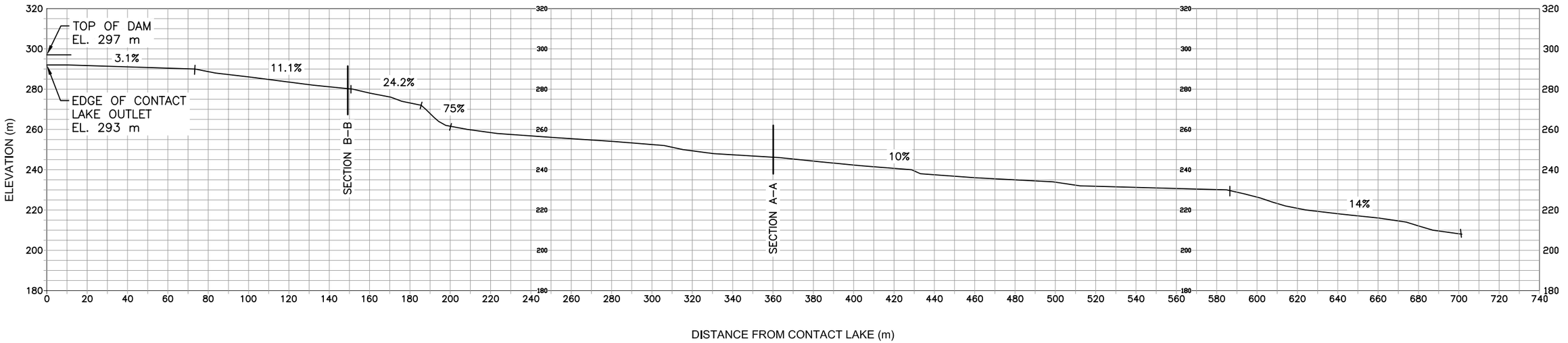
HIGH LAKE PROJECT

HIGH LAKE SPILLWAY DESIGN

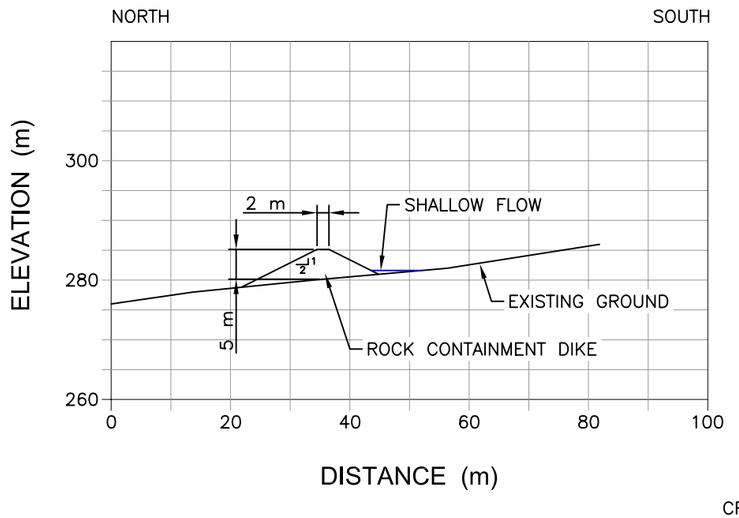
CONTACT LAKE SITE PLAN

Dwg. 6971–101	May–05–2007	**Figure 10**

northwest hydraulic consultants ltd.

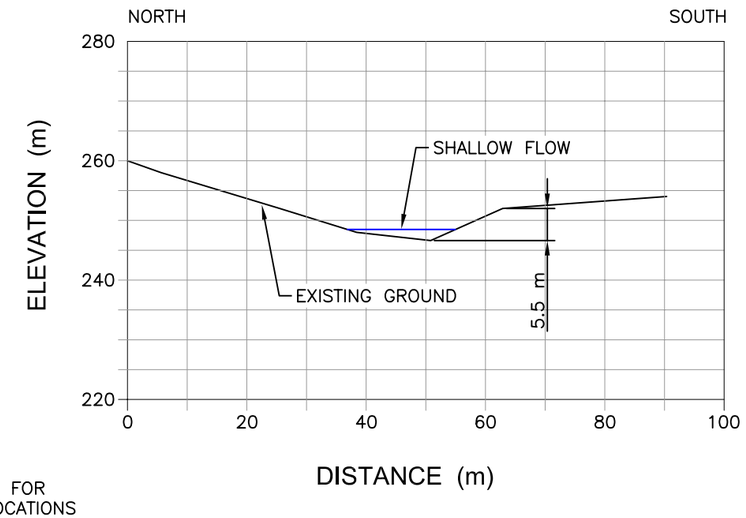


PROFILE OF SECONDARY OUTLET CHANNEL



CROSS SECTION ON B-B

SEE FIGURE 10 FOR
CROSS SECTION LOCATIONS



CROSS SECTION ON A-A

HIGH LAKE PROJECT		
HIGH LAKE SPILLWAY DESIGN **NEW PRIMARY OUTLET CHANNEL PROFILE AND SECTIONS**		
Dwg. 6971–101	May–05–2007	**Figure 11**
northwest hydraulic consultants ltd.		

APPENDIX III
GEOTHERMAL MODELLING MEMO

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
1605, 840 – 7 Avenue S.W., Calgary, Alberta, Canada. T2P 3G2
Phone (403) 250-5185 Fax (403) 250-5330

PROJECT MEMORANDUM

To:	**File**	**Fax No.:**	**by email**
From:	**Eric Niven/Ron Coutts**	**Date:**	**April 26, 2007**
Subject:	**High Lake Project, NU, Geothermal Modelling of Tailings Dams**		
No. of Pages (including this page): 30		**Project No:**	**0385-003-19**

1.0 INTRODUCTION

Wolfden Resources Inc. (Wolfden) is proceeding with the permitting and potential development of their High Lake Project in Nunavut, situated about 550 km northeast of Yellowknife, NT. At the mine site, several tailings dams are proposed to be designed and constructed on continuous permafrost. As outlined in Tailings Containment Facility Conceptual Design Report (BGC 2006a), these dams are designed to have the foundation under the dam remain frozen either for their operational life, and potentially into or throughout their closure phase as well. Since the dam design will incorporate a composite liner system consisting of a geomembrane (GM) in contact a geosynthetic clay liner (GCL), having the dam foundation remain frozen will completely minimize under-seepage below the dams.

The tailings dams will be located around High Lake, which will become a tailings containment facility (TCF) when the mine begins operations. There are some nearby lakes (L15 for example) and the Kennarctic River adjacent to High Lake where the potential for impacts from seepage under and through the dams must be absolutely minimized. Therefore, the dams that prevent seepage into these neighbouring lakes and rivers (East Dam, Northwest Dam and Northwest Channel Dam) must be designed for as low a volume of seepage as is practicable. The remaining dams (Polishing Pond Dam, Northeast Dam and Contact Lake Dam) may be allowed some minor seepage amount, possibly during the operations and/or the closure phase. The High Lake Mine will have a mine life of 14 years and is being designed with a closure period of 100 years.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

2.0 GEOTHERMAL ASSESSMENT

2.1 Background and Objectives

As a basis for the geothermal design, it is required that the tailings dams maintain a maximum temperature of -2°C within the center of the dam and in the foundation underlying the cut-off trench below the dam. This criterion is a safety factor that allows for freezing point depression and unfrozen water content at sub-zero temperatures. This -2° criterion appears to be the accepted standard of practice for dams in the north including Ekati (Hayley et al., 2004). This ensures the continuity of the water retaining elements comprised of the dam liner and underlying permafrost. A geothermal modelling assessment was conducted to evaluate future temperatures in the dam under the following conditions:

- Expected internal dam temperatures in the absence of climate warming and without the aid of thermosyphons.
- The effect of moderate and extreme climate warming on the temperatures within the interior and foundation of the dam.
- The expected decrease in internal dam temperatures if thermosyphons were installed in the cut-off trench.
- The effect of snow drifting on the downstream face of the dam on the dam temperatures.
- The effect of three consecutive extreme warm years during the operating phase of the dams.

Following from these conditions, an appropriate geothermal design for the various dams could be formulated to facilitate the feasibility level design.

2.2 Modelling Overview

To meet the objectives outlined earlier, geothermal modelling of a two-dimensional (2D) cross-section through a typical containment dam was required to estimate the expected long-term temperatures in the internal area of a dam. Two software programs, THERM2 and TEMP/W, were employed to complete the geothermal modelling. Each tool has specific strengths that were utilized.

THERM2, developed by Nixon Geotech Ltd., provides a rigorous surface energy balance (SEB) calculation that computes energy fluxes at the ground surface based on climate data such as snow depth, wind speed, solar radiation and evapotranspiration. Use of the SEB calculation negates the need for empirical n-factors to determine ground surface temperatures and allows sensitivity analyses on climatic factors to be performed, such as was done for snow depth variability in this work. Furthermore, THERM2 has a climate warming feature which allows for a constant rate of air temperature increase to be specified. THERM2 is a finite difference program that requires the domain geometry to be discretized using rectangular finite difference cells, which can be problematic for complex geometries such as the dam cross-section. Furthermore, THERM2 is a command-line software program with no graphical input or output capability, rendering it difficult to show contour plots of results.

TEMP/W is a commercially available Windows-based finite element geothermal model. As such, it allows graphical input and output and generation of the finite element mesh can accommodate any domain geometry such as dam cross-sections. The main shortcoming with excusive use of TEMP/W is the lack of a SEB calculation based on monthly climate data as implemented by THERM2.

To provide computed ground temperatures based on surface energy balance flux calculations, one-dimensional (1D) analyses using THERM2 were completed to provide temperature at the ground surface as a function of time. The properties of the material (soil or rock) at the ground surface affect the energy flux across the ground surface boundary. Therefore, it was necessary to calculate the ground surface temperature function for each surficial material type that would exist across the dam cross-section. These surface material types included the following:

- native terrain characterized by undisturbed silty sand (no organic peat layer);
- unsaturated rockfill shell on the downstream face of the dam; and
- disturbed terrain downstream of the dam characterized by a silty sand layer to surface (no organic peat layer) that has been disturbed by construction activities such that it has a slightly lower summer albedo (reflectivity) and lower evapotranspiration relative to undisturbed terrain.

The ground surface temperature functions (one per surficial soil type, three in total) were then used to define the surface temperature boundary condition in the subsequent 2D analyses of the dam cross-section using TEMP/W.

It should be noted that before the 2D TEMP/W analyses were started, 1D TEMP/W analyses were done using identical conditions as were used in the 1D THERM2 models, but with the ground surface temperature boundary conditions set to the ground surface temperatures computed from the 1D THERM2 runs. This was done for quality control reasons to check that the temperatures computed by TEMP/W were the same as those from THERM2. This check also verified that the material properties and boundary conditions were correctly transferred from the THERM2 model to the TEMP/W model. Results of these analyses are presented in later sections.

After verifying the TEMP/W model in 1D, a variety of 2D dam cross-section analyses were completed to compute the effects on long-term dam core temperatures caused by changes to the dam geometry, climate warming, thermosyphons and snow drifting on the downstream slope of the dam. Results of these analyses are discussed herein.

3.0 MODEL DEFINITION

3.1 Domain Geometry

A generic soil profile for undisturbed terrain was developed after reviewing the borehole logs from the site. This generic soil profile was used for calibrating the THERM2 model to ensure that the model-computed mean annual ground temperature at depth matched that observed in the field. The generic soil profile consisted of 1 m thick silty sand till overlying 1.5 m of frost fractured bedrock overlying intact bedrock. It should be noted that, at most of the dam locations, there was only a very thin veneer of organic peat cover (if there was any at all) with a thickness of 0.1 m. Therefore, the generic 1D soil profile did not include an organic peat layer.

3.2 Discretization

The discretization of the 1D soil profile using rectangular finite difference cells is shown in Figure 1. The 1D grid extended to 23 m depth. As shown in the figure, smaller cells were used near the surface to properly model the large temperature gradients near the surface.

Temporal discretization (time step size) was determined automatically by THERM2 to satisfy finite difference stability constraints. Time steps were nominally about 40 minutes each. However, data was only saved to disk on every 120th time step, or about every 3 days of simulation time.

The 2D geothermal model mesh was designed to represent a “typical” conceptual dam cross section through the tallest part of the dam. The typical cross-section was constructed assuming the parameters shown in Table 1. Also shown in Table 1 is the conceptual design geometry of the tailings containment facility (TCF) dams and the Polishing Pond Dam.

Table 1: Comparison of Modeled Cross-Section With TCF Dams and Polishing Pond Dam

	TCF Dams	Polishing Pond Dam	Modeled Cross-Section
Height of crest above natural ground surface (m)	4.6 – 8.6	5.0 – 7.0	7.0
Maximum depth of cut-off trench below natural ground surface (m)	5.0-6.0	3.5	6.0
Width of crest (m)	10.0	10.0	10.0
Width of cut-off trench (m)	12.0	12.0	12.0
Height of reservoir above natural ground surface (m)	5.4	3.4 – 5.4	5.5

The modeled cross-section compares well with the expected dam geometries. The model geometry is also shown in Figure 2. It should be noted that specific geothermal analyses for selected dam geometries may have to be done as a part of the final design process.

Discretization of the 2D dam cross-section into finite elements for the TEMP/W analyses is shown in Figure 3. The side boundaries are considered to be sufficiently far enough away from the dam such that they had no effect on the computed temperatures within the dam. It should be noted that the upstream face of the dam is on the left hand side of the figure. Therefore, the left boundary is closer to the dam than the right boundary because only constant thermal boundary conditions were applied upstream of the dam (representing water temperature).

The TEMP/W analyses were temporally discretized using a specified time step size of 5 days. TEMP/W uses an implicit formulation which allows significantly larger time step sizes than THERM2. A time step size of more than 5 days would be unacceptable because it would not adequately capture the seasonal temperature variation of the applied surface temperature boundary conditions.

3.3 Material Properties

Table 2 lists the properties of the materials used in the modelling. These properties were estimated from appropriate values of porosity and saturation combined with values for unfrozen water content and thermal conductivity of geologic materials published by Andersland and Ladanyi (2004).

There are some slight differences regarding material property input requirements between THERM2 and TEMP/W. THERM2 internally computes the unfrozen gravimetric water content function and therefore requires only that the A and B parameters in Table 1 be specified in the input file. TEMP/W requires that an unfrozen volumetric water content function be specified as a lookup table which is calculated using following equation and the values in Table 1.

$$W_u = A\,(-T)^{B}/w_{tot} \qquad [1]$$

Where:

- W_u is the unfrozen volumetric water content (fraction of total water content).
- A is the gravimetric unfrozen water content at -1°C.
- B is the exponent in the power law function.
- T is the temperature in °C (negative).
- w_{tot} is the total gravimetric water content.

Table 2 shows the soil and rock material properties used in the TEMP/W analysis. Slightly different values for the unfrozen water content “A values” for unsaturated silty sand and unsaturated rock shell were used in the THERM2 and TEMP/W analyses. These changes were made to simulate a more appropriate normalized water content function. Since the changes are small, they did not create any significant difference in the computed temperatures as evidenced by the temperatures computed by 1D TEMP/W analyses which matched almost exactly those computed by THERM2. Comparison of the 1D THERM2 and TEMP/W analyses are presented later.

Table 2: Soil & Rock Material Properties

Material	Porosity (m^3/m^3)	Saturation (m^3/m^3)	Grav. Moisture Content (g/g)	A[1]	B[1]	Unfrozen Thermal Cond. (W/°C)	Frozen Thermal Cond. (W/°C)	Dry Density (kg/m^3)
Silty Sand Till	25%	40%	5.0%	0.020	-0.8	2.3	2.3	2000
Sat. Filter Material	25%	100%	12.5%	0.020	-0.8	1.9	2.6	2000
Unsat. Filter Material	25%	40%	5.0%	0.020	-0.8	1.8	1.8	2000
Intact Bedrock	2%	100%	0.8%	0.001	-1.0	2.2	2.2	2617
Fractured Bedrock	5%	100%	2.0%	0.002	-1.0	3.0	3.0	2537
Sat. Rock Shell	25%	100%	12.5%	0.020	-1.0	2.1	2.8	2000
Unsat. Rock Shell	25%	40%	5.0%	0.001	-1.0	1.6	1.6	2000

[1] A & B refer to coefficients in unfrozen water content function $Wu = A(-T)^B$.

3.4 Climate Data Used in 1D THERM2 Analysis

Climate data used in the THERM2 analyses was obtained from RWDI (2006) and various Environment Canada Weather stations including Contwoyto Lake, Kugluktuk, Coppermine, Lupin, Cambridge Bay, Ulu and High Lake, as summarized in Table 3.

Table 3: Climate Data for THERM2 Geothermal Analysis

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg.
Mean monthly air Temperature[1] (°C)	-30.1	-30.2	-27	-17.8	-6.2	4.4	10.1	8.3	2	-8.2	-20.6	-26.8	-11.8
Mean monthly snow depth[2] (cm)	28	33.5	37.5	39.5	29	5	0	0	0.5	8	17	23	18.4
Mean monthly wind speed[3] (kmph)	20.7	20.1	18.4	16.9	17.3	16.8	17.1	18.5	19.6	20.2	18.9	19.8	18.7
Mean monthly solar radiation[1] (W/m^2)	2.2	21.1	87.6	185.5	251.8	268	214.5	138.5	71.7	33	4.5	0	106.5

[1]Source: RWDI (2006)
[2]Source: Environment Canada Website (Mean of Kugluktuk and Cambridge Bay snow depth data)
[3]Source: Environment Canada Website (Mean of Kugluktuk and Cambridge Bay wind speed data)

As previously mentioned, THERM2 was used to calculate ground surface temperatures for the native undisturbed terrain, disturbed terrain, and the unsaturated rock fill shell of the dam. These computed ground temperature boundary conditions were then applied to the appropriate surface nodes in the 2D TEMP/W model.

3.5 Ground Surface Boundary Conditions Used in 1D THERM2 Analysis

Ground surface boundary condition properties used in the THERM2 surface energy balance calculations are shown in Table 4. Of particular note is the difference between the surface energy balance properties used to represent the undisturbed and the disturbed terrain. The undisturbed terrain is considered to reflect slightly less light during the summer and sustains lower vegetation cover as a result of construction disturbance. The net result is that higher summer energy influx occurs over the disturbed terrain relative to the undisturbed terrain and is considered conservative because it does not account for re-growth of the vegetation cover which would reasonably be expected to occur within 10 years after construction.

Table 4: Ground Surface Boundary Conditions for THERM2 Geothermal Analysis

Property	Value
Snow Thermal Conductivity[1] (W/(m.C))	0.120
Summer Albedo – Undisturbed Terrain	0.25
Summer Albedo – Disturbed Terrain & Rock Shell	0.20
Winter Albedo	0.85
Evapotranspiration Factor – Undisturbed Terrain	0.50
Evapotranspiration Factor – Disturbed Terrain & Rock Shell	0.30
Greenhouse Factor	0.83
Last Snow Day	152
First Snow Day	277
[1] Value obtained via model calibration with observed mean annual ground temperature.	

3.6 Other Boundary Conditions Used in 1D and 2D Analysis

Climate warming rates of 0.050° and 0.065°C/yr were used in climate warming analyses to represent moderate and extreme climate warming rates, respectively. The rational for selection of these climate warming rates was documented separately by BGC (2006B). As before, THERM2 was used to obtain the ground surface temperature boundary conditions for use in TEMP/W.

For the analysis of increased snow depth on the downstream face of the dam possibly caused by drifting snow, the mean monthly snow depth was increased by 50% and THERM2 was used to compute the ground surface temperature on the rock fill surficial material. As before, these THERM2-computed ground surface temperatures were input to TEMP/W as the temperature boundary condition on the downstream face of the dam.

Side and bottom boundary conditions in all modelling runs (1D and 2D) were zero-energy-flux. A geothermal gradient was not applied to the bottom boundary because it was considered unnecessary as its effect would be negligible on the computed temperatures at the relatively shallow depth of the dam core.

3.7 Initial Conditions and Model Calibration

The ground temperatures at a depth reasonably close to the depth of zero annual temperature amplitude (nominally 8 to 10 m) were obtained from borehole thermistor strings installed at several locations at the site.

The thermistor data showed that the ground temperature at depth (GTAD) was not consistent across all the High Lake dam locations. In general, thermistor temperatures at depth at the dam sites ranged from -3.5° to -5°C. It should be noted that the East Dam, Northwest Dam and the Northwest Channel Dam, where the GTAD is approximately -4°C, are to be designed for as low seepage as is practicable. Therefore, an initial ground temperature of -4°C was used in the modelling.

It should be noted, that to obtain appropriate computed ground temperature values from THERM2, it is necessary to calibrate the model such that under the specified climatic conditions, the model will compute a long term GTAD that is consistent with that temperature as measured in the field. As previously mentioned, the GTAD used for the modelling was -4°C. Using the undisturbed terrain soil profile, multiple 1D THERM2 analyses were performed and the thermal conductivity of the snow was varied to find the snow conductivity that resulted in a long term computed GTAD matching that measured from the field. As well, the computed and measured actual active layer depths were compared to ensure that they were approximately equal. In fact, the calculated active layer depth exactly matched the measured active layer depth from one site thermistor. As shown in Table 3, the calibrated snow conductivity thus found was 0.120 W/m°C, which is within the range of published values for snow thermal conductivity (Andersland and Ladanyi 2004).

3.8 Transfer of THERM2 Ground Surface Temperatures to TEMP/W

Use of ground surface temperature boundary conditions computed by THERM2 in the TEMP/W model is only valid if all of the other modelling inputs, such as material properties, are identical in the two models. To verify that TEMP/W would compute the same thermal response as THERM2, and by implication verify that the TEMP/W model input was correctly specified, the thermal history from both models was compared for the case of a 1D undisturbed terrain analysis.

Figure 4 shows the comparison trumpet curves for the THERM2 1D model and the TEMP/W 1D model. As is shown in the chart, an excellent match between the two 1D models was achieved thus verifying that the transfer of the ground surface temperature boundary conditions from THERM2 to TEMP/W was successful. In addition, both of the model predictions matched the GTAD of approximately -4°C measured at the dam sites.

3.9 Boundary Conditions Specific to the 2D Analysis

The lake was assumed to have a constant temperature of +4°C and as such, the lake bottom and upstream slope of the dam, up to the expected full supply level of the reservoir, were specified with constant temperature boundary conditions. This is considered somewhat conservative as it does not account for winter ice on the lake which would provide for additional heat removal during the winter where the ice contacts the upstream face of the dam.

3.10 Thermosyphon Boundary Conditions for 2D Analysis

TEMP/W has the ability to model thermosyphons as a boundary condition at individual nodes. Each thermosyphon node represents a single horizontal thermosyphon installed with the thermosyphon axis perpendicular to the plane of the cross-section. Thermosyphons remove heat from the ground when the air temperature (radiator end of the thermosyphon) is less than the ground temperature around the buried (evaporator) portion of the thermosyphon. The heat removal rate of a thermosyphon is generally linearly proportional to the temperature differential between the air and the ground. Horizontal thermosyphons are modeled in TEMP/W using a nodal heat flux boundary condition at a specified node. The flux applied to the thermosyphon node is calculated using the following equation:

$$Q = P\ (T_g - T_{air}) \qquad [2]$$

Where:

- Q is the nodal heat flux in watts (W).
- P is the effective conductance of the thermosyphon in W/°C.
- T_g is the ground temperature in °C.
- T_{air} is the air temperature in °C.

Haynes and Zarling (1988) developed an empirical relationship for P as a function of wind velocity and radiator surface area. The following equation is valid for thermosyphons installed at angles of inclination greater than 5 degrees relative to horizontal, referred to here as vertical thermosyphons, and horizontal thermosyphons:

$$P_V = (2.54 + 4\ V_w^{0.62})\ A \quad [3a]$$

$$P_H = 0.66\ P_V \quad [3b]$$

Where:

- P_v and P_H are the effective conductance of vertical and horizontal thermosyphons, respectively, in W/°C.
- V_w is the wind velocity in m/s.
- A is the surface area of the radiator in m^2. A radiator area of 58.5 m^2 was used to model three 19.5 m^2 radiators attached to each thermosyphon.

Using Equations 2 and 3, the total heat extraction rate from the above-ground condenser section of the thermosyphon can be calculated. This heat extraction rate is then divided by the length of the buried condenser section to determine the heat removal rate per unit length of the thermosyphon, which is then applied to a thermosyphon node in TEMP/W. The monthly mean wind speed, as outlined in Table 3, was used in the modelling.

4.0 MODELLING RESULTS

4.1 Base Case

Run 1: Base Case (GTAD = -4°C; no climate warming; no thermosyphons)

The base case model was run for 50 years using 5 day time steps. The base case assumes an initial GTAD of -4°C and does not consider the effects of climate warming. In addition, the base case did not consider thermosyphons or snow drifting on the downstream side of the dam.

Figure 5 shows the calculated temperature at two nodes beneath the dam centerline over time. At the base of the cut-off trench, beneath the centerline of the dam, the temperature is calculated to be -0.7°C after 50 years. At the base of the model (20 m below ground surface), beneath the centerline of the dam, the temperature is calculated to be -0.4°C after 50 years. Figure 5 also shows that the temperature of the cut-off trench is warmer than the -2°C criteria after approximately 10 years. Figure 6 shows contours of the dam temperatures during the warmest period of Year 30 for Run 1. Figure 7 shows contours of the dam foundation temperatures during the warmest period of Year 50 for Run 1.

Thus, the base case model (Run 1) indicates that even when climate warming is not considered, the internal dam temperatures do not meet the -2°C criteria and that this geometry is not suitable for the design criteria noted.

4.2 Effect of Climate Warming

Run 2: (GTAD = -4°C; global warming = 0.05°C/yr for 120 years; no thermosyphons)

Run 2 is similar to the Run 1 base case. The only difference is that a global warming factor of 0.05°C/yr was applied to the model, which was subsequently run for 120 years. All other conditions and input data were kept the same as in the base case.

Figure 8 shows the calculated temperature at two nodes beneath the dam centerline over time. As expected, the foundation temperatures are warmer than the design criteria in approximately 9 years. At the base of the cut-off trench, beneath the centerline of the dam, the temperature is calculated to be +3.4°C after 120 years. At the base of the model (20 m below ground surface), beneath the centerline of the dam, the temperature is calculated to be +3.1°C after 120 years. As such, this geometry again does not meet the noted design criteria. Figure 9 and Figure 10 show contour plots of the dam temperatures during the warmest period of Year 20 and Year 120 respectively.

4.3 Effect of Thermosyphons

Run 3: (GTAD = -4°C; global warming = 0.05°C/yr for 120 years; with thermosyphons)

Run 3 is similar to Run 2 in that the model was run with the same boundary conditions and time frame as Run 2. The only difference is that thermosyphons were applied to the model in order to examine their effects on dam temperatures. The thermosyphons were applied to nodes located at the base of the cut-off trench. In total, seven thermosyphons were applied to the model at a spacing of approximately 2.0 m.

Figure 11 shows the temperatures beneath the dam centerline at the base of the model. The warmest temperature measured at that node at the base of the model was -5.3°C after 120 years. Figure 12 and Figure 13 show contour plots of the dam temperatures in Years 20 and 120, respectively. Figure 13 shows that the maximum thaw depth below the dam centerline was calculated to be 3.4 m. Therefore, the elevation of the maximum thaw depth location is 287.2 m, which is lower than the full supply level of 288.5 m. The -2°C isotherm is approximately 2.5 m below the zero degree isotherm.

4.4 Effect of Snow Drifting on Downstream Slope of Dam

Run 4: (GTAD = -4°C; global warming = 0.065°C/yr for 120 years; with thermosyphons; snow depth increased by 50% on downstream side of dam to account for snow drifting)

Run 4 represents the worst case scenario geothermal model. The dam geometry remains the same as in previous runs. However, the climate warming rate has been increased to 0.065°C/year and the snow depth has been increased by 50% on the downstream slope of the dam to account for snow drifting. The same thermosyphon boundary condition was applied as in Run 3.

Figure 14 shows the temperatures beneath the dam centerline at the base of the model. The warmest temperature measured at that node at the base of the model was -3.7°C after 120 years. Figure 15 and Figure 16 show contours of the dam temperatures after 20 and 120 years, respectively. Figure 16 shows that the maximum thaw depth below the dam centerline was calculated to be 5.5 m. Therefore, the elevation of the maximum thaw depth location is 285.1 m, which is lower than the full supply level of 288.5 m. The -2°C isotherm is approximately 2.5 m below the zero degree isotherm.

4.5 Effect of Three Extreme Warm Years During Operations

Run 5: (GTAD = -4°C; global warming = 0.05°C/yr for 120 years; with thermosyphons; three extreme warm years were modeled)

Run 5 examines the effect of three extreme warm weather years during Years 10, 11 and 12 of mine operations. Figure 17 shows the air temperature profile used in Run 5. As is shown on the figure, the air temperature was increased by 5°C for each of the three years starting in Year 10. The 5°C increase in temperature was selected as the approximate difference between the mean and extreme maximum temperature data derived from Lupin Mine as summarized in RWDI (2006). As well, the ground surface boundary temperatures (for each terrain unit – rock shell, undisturbed ground and disturbed ground) were also increased by 5°C for each of the three years starting in Year 10 in the same manner.

Figure 18 shows the temperature beneath the dam centerline at the base of the model. The extreme warm years have an immediate impact on the dam temperatures. Temperature increases of approximately 2°C were calculated. However, when the temperature profile returned to normal, the dam temperatures quickly cooled over a period of about 10 years at the base of the model. At no time were the dam temperatures in the core trench or base of the model above the -2°C criteria. In addition, the 120 year calculated dam temperatures are unchanged from those calculated in Run 3. It is important to note that the thermosyphons themselves are primarily responsible for the immediate increase in internal dam temperatures as a result of the three extreme warm years. If the thermosyphons were not installed, then there would not be an immediate impact from three warm years at the depth of the cut-off trench. In fact, three extreme warm years would have little impact on the ground temperatures at that depth away from the thermosyphons. Figure 19 and Figure 20 show the dam temperatures during the warmest period of Years 12 (during the third consecutive extreme warm year) and 120, respectively.

5.0 CONCLUSIONS

The results have shown that impoundment of a reservoir at the full supply level of 288.5 m on the upstream side results in a thawing foundation in less than 10 years. Geothermal modelling has indicated that thermosyphons will be necessary to reduce the ground temperature in the cut-off trench and foundation to acceptable levels. A conceptual cross section was modeled with seven thermosyphons in a 12 m wide cut-off trench below the centerline of the dam. The results indicated that use of the thermosyphons in the cut-off trench will be required to maintain temperatures below the -2°C required threshold for long term design. However, it should be noted that the 0°C isotherm was calculated to be at a lower elevation than the maximum supply level and the -2°C isotherm at an even lower elevation. Hence, any potential seepage through liner imperfections would likely freeze within the pore spaces of the dam materials.

As noted earlier, there is a requirement for the East Dam, Northwest Dam and Northwest Channel Dam to be designed for as low seepage as is practicable. Thus, those dams will require thermosyphons for the operations and for closure period (i.e. 120 years). The Northeast Dam, Contact Lake Dam and Polishing Pond Dam may be allowed some minor seepage amount, possibly during the closure phase and will require thermosyphons for the operations phase and partially into the closure phase.

It should be noted that dam specific geothermal analyses will be required later during the final design phase. This step will be required to assess dam specific geometries and materials and to optimize the number and size of the thermosyphon radiators and evaporators in order to achieve an economical design for each dam.

6.0 LIMITATIONS AND CLOSURE

This memorandum was prepared by BGC Engineering Inc. (BGC) for the account of Wolfden Resources Inc. The material in it reflects the judgement of BGC staff in light of the information available to BGC at the time of memorandum preparation. Any use which a Third Party makes of this report, or any reliance on decisions to be based on it are the responsibility of such Third Parties. BGC Engineering Inc. accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this memorandum. All memorandums and drawings are submitted for the confidential information of our client for a specific project and authorization for use and/or publication of data, statements, conclusions or abstracts from or regarding our memorandums and drawings is reserved pending BGC's written approval.

We trust that the information contained within memorandum meets your present requirements. Should you have any questions regarding the information and recommendations contained herein, please contact BGC at your convenience.

Respectfully submitted
BGC Engineering Inc.
per:

Eric Niven, M.Sc., E.I.T.
Geotechnical Engineer

Ron Coutts, M.Sc., P.Eng.
Senior Geothermal Engineer

James W. Cassie, M.Sc., P.Eng.
Specialist Geotechnical Engineer

REFERENCES

Andersland, O.B. and Ladanyi, A. 2004. Frozen Ground Engineering; Second Edition. John Wiley and Sons and the American Society of Civil Engineers, 363 pages.

BGC Engineering Inc. 2006a. Tailings Containment Facility Conceptual Design Report. Report submitted to Wolfden Resources Inc., August 28, 2006.

BGC Engineering Inc. 2006b. Climate Change Design Criteria; Proposed Tailings Dams; High Lake Project, NU. Draft memorandum submitted to Wolfden Resources Ltd., Gartner Lee Ltd., and Wardrop Engineering Ltd., December 5, 2006, 13 pages.

BGC Engineering Inc. 2007. 2006 Geotechnical Investigation Program. Report submitted to Wolfden Resources Inc., January 23, 2007.

Hayley, D.W., Seto, J.T.C., Grapel, C.K., Cathro, D.C. and Valeriote, M.A., 2004. Performance of Two Rockfill Dams with Thermosyphons on Permafrost Foundations, Ekati Diamond Mine, N.T. Proceedings of the 57th Canadian Geotechnical Conference, Quebec, Session 5F.

Haynes, D.F. and Zarling, J.P. 1988. Thermosyphons and Foundation Design in Cold Regions. Cold Regions Science and Technology. Vol. 15. 251-259.

RWDI, 2006. High Lake Climate Assessment. Report submitted to Gartner Lee Ltd., March 7, 2006.

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

FIGURES

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

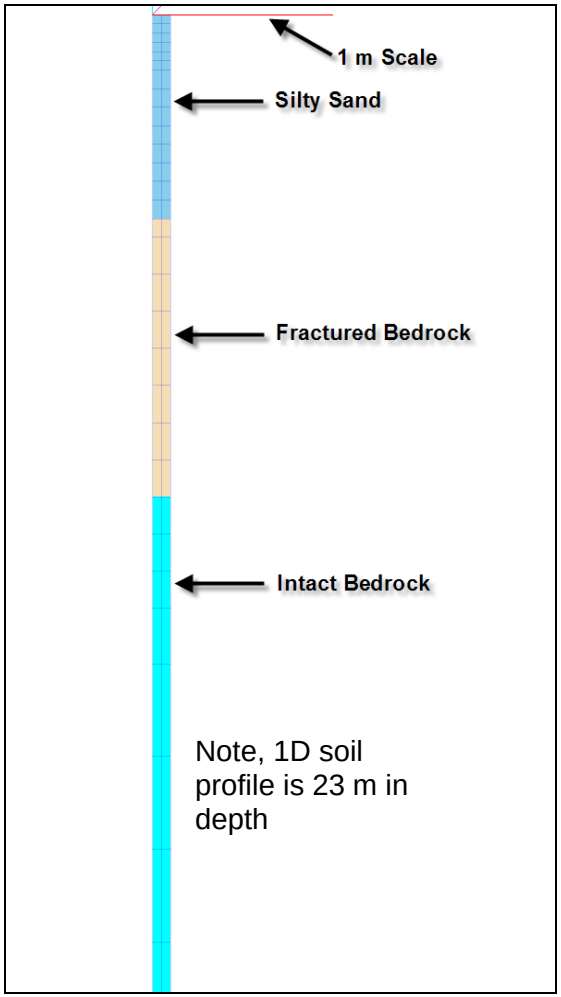


Figure 1: Near-Surface Soil Profile for 1D THERM2 Analyses

This communication is intended for the use of the above named recipient. Any unauthorized use, copying, review or disclosure of the contents by other than the recipient is prohibited.

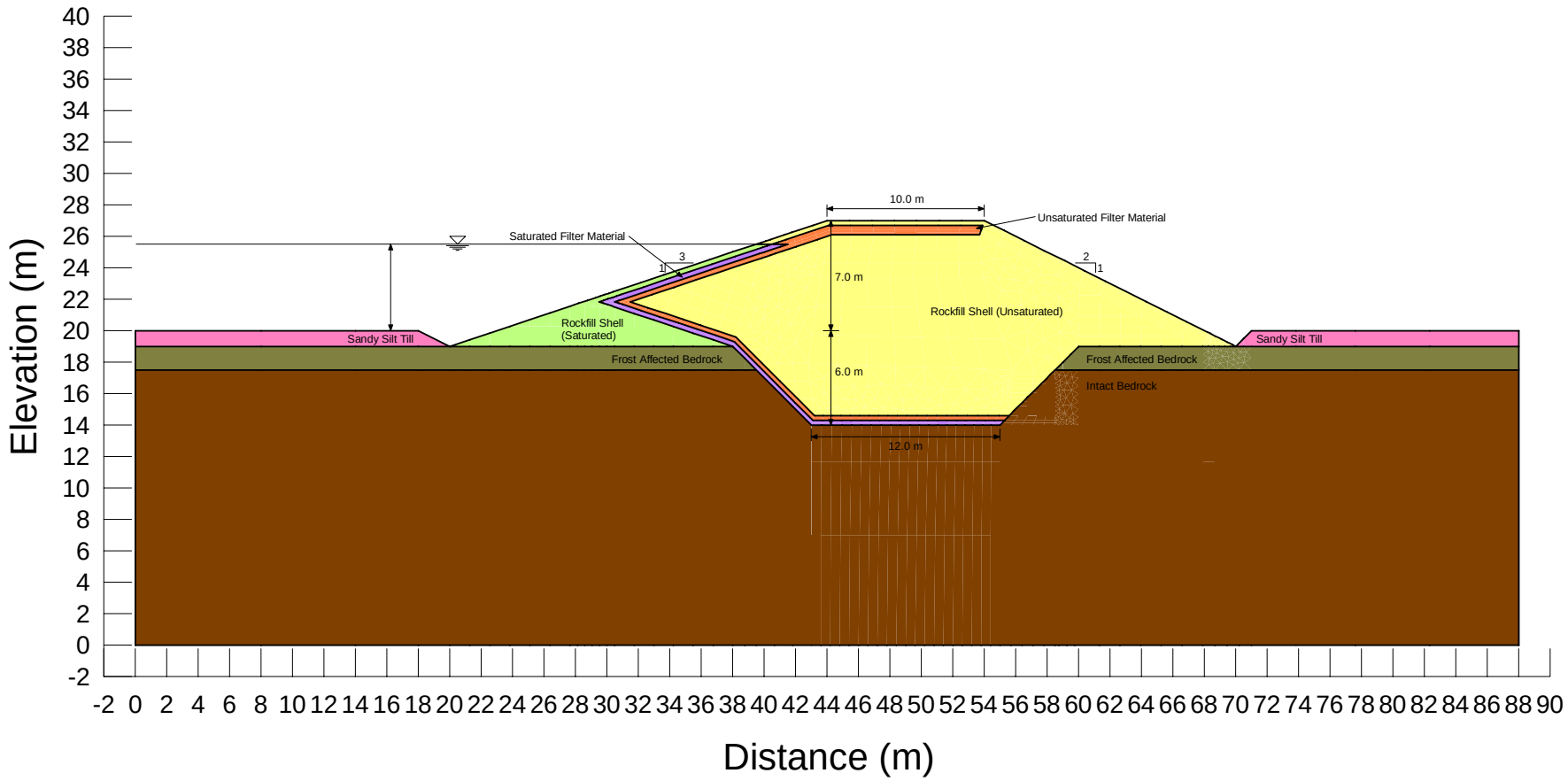


Figure 2: Typical Cross Section Used For Geothermal Modelling

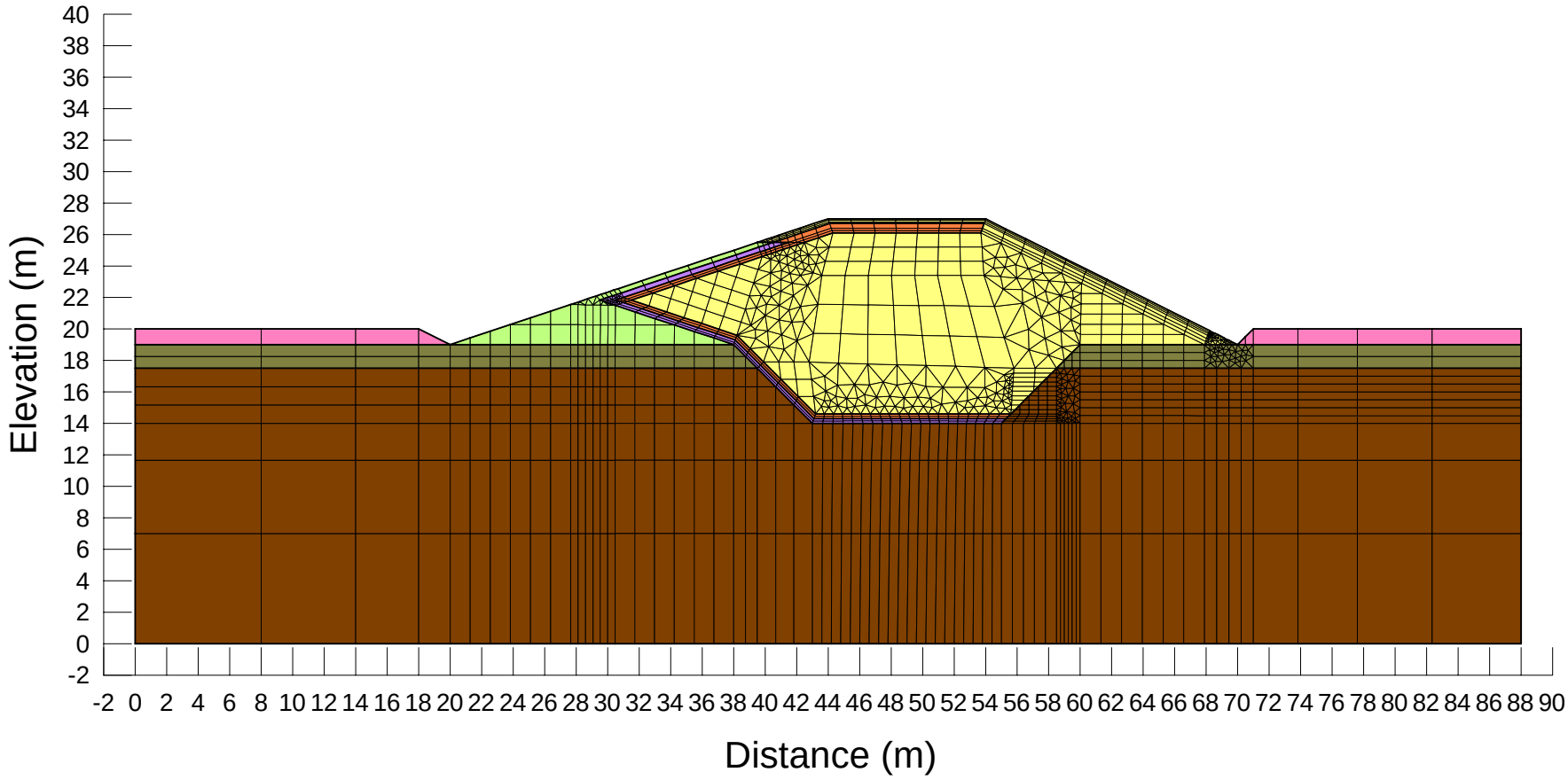


Figure 3: 2D TEMP/W Finite Element Mesh Used for Geothermal Modelling

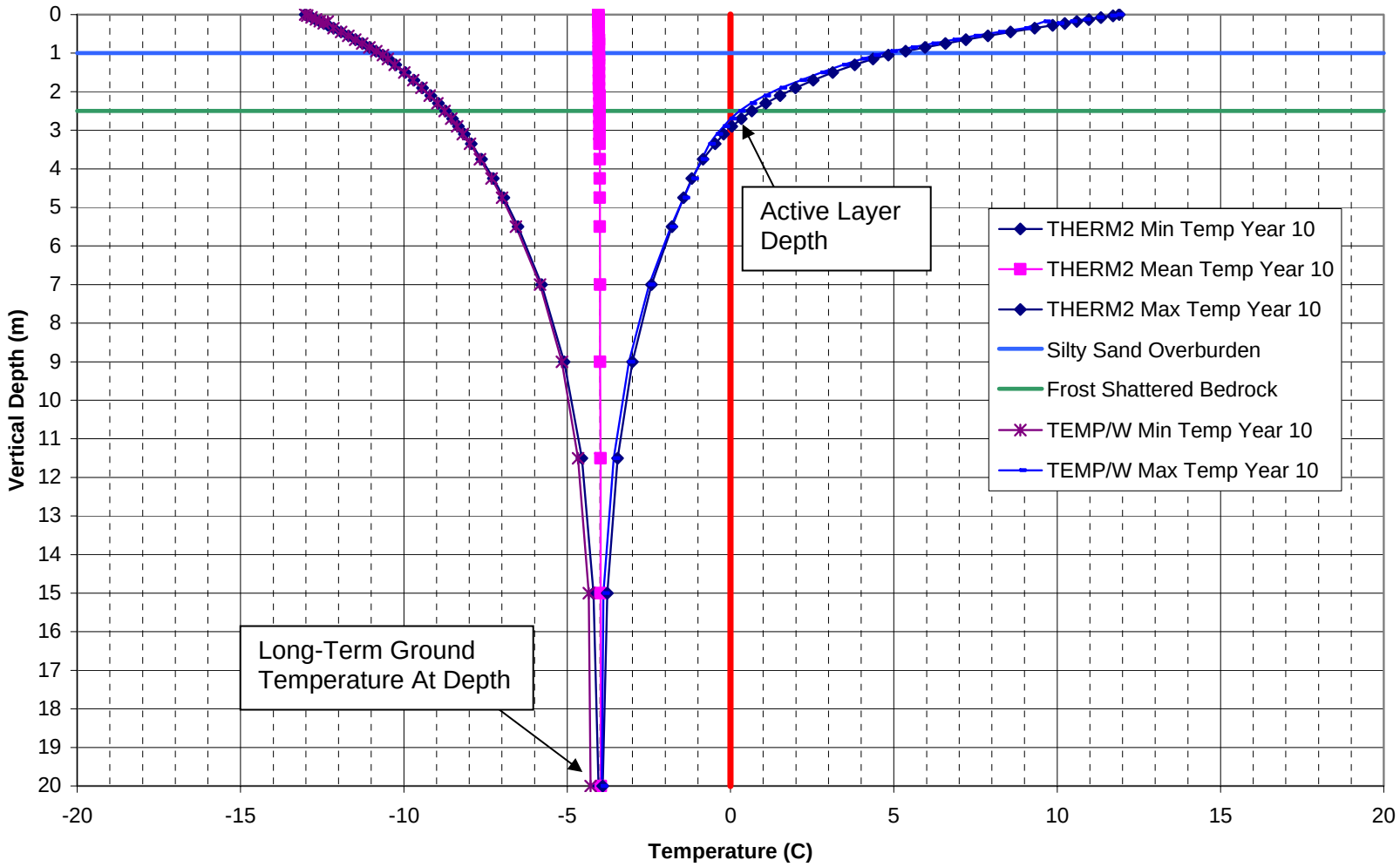


Figure 4: Comparison of THERM2 and TEMP/W Calibration Models

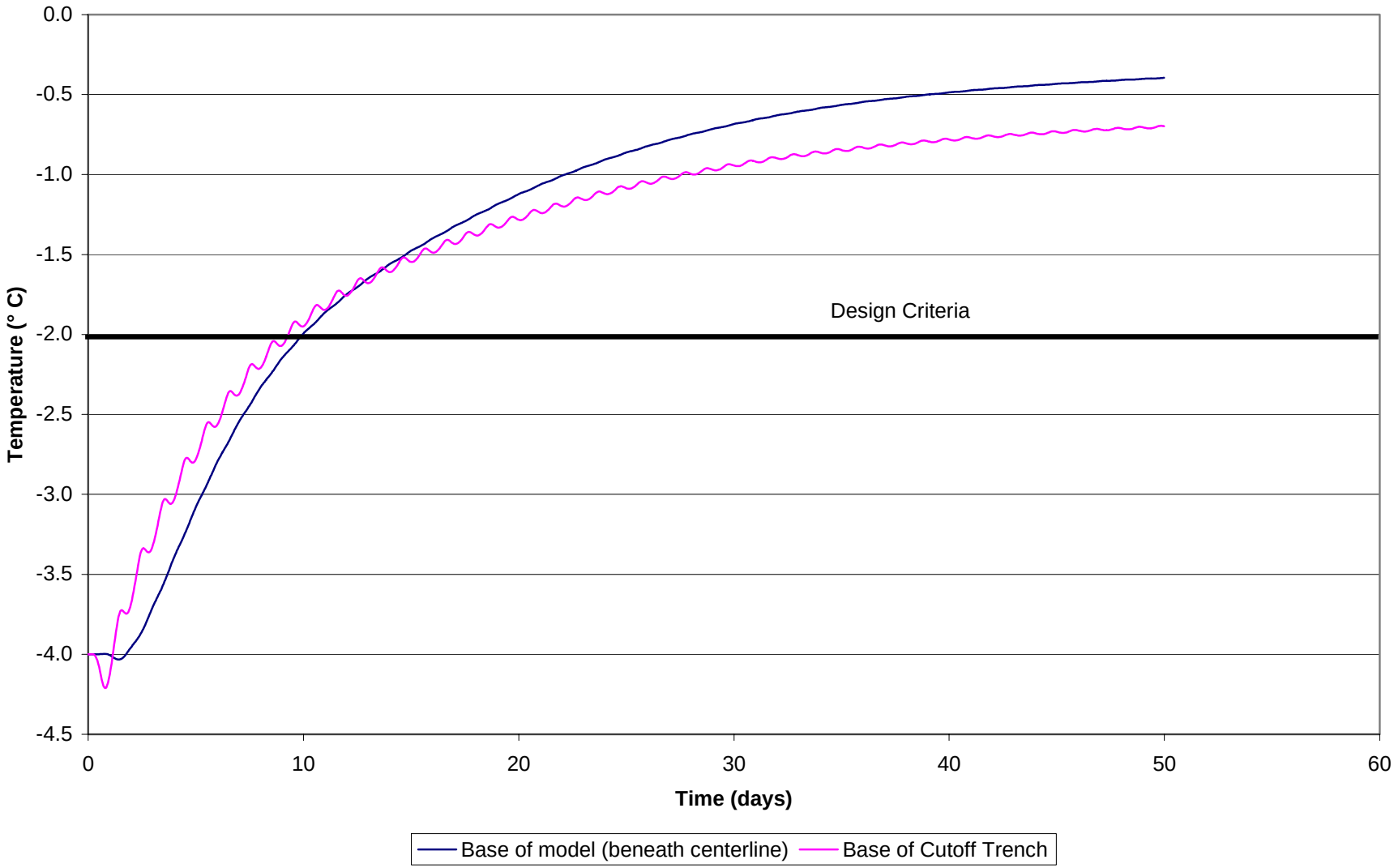


Figure 5: Temperature Versus Time at Two Nodes Beneath the Dam Centerline (Run 1: GTAD = -4°C; No Thermosyphons, No Climate Warming)

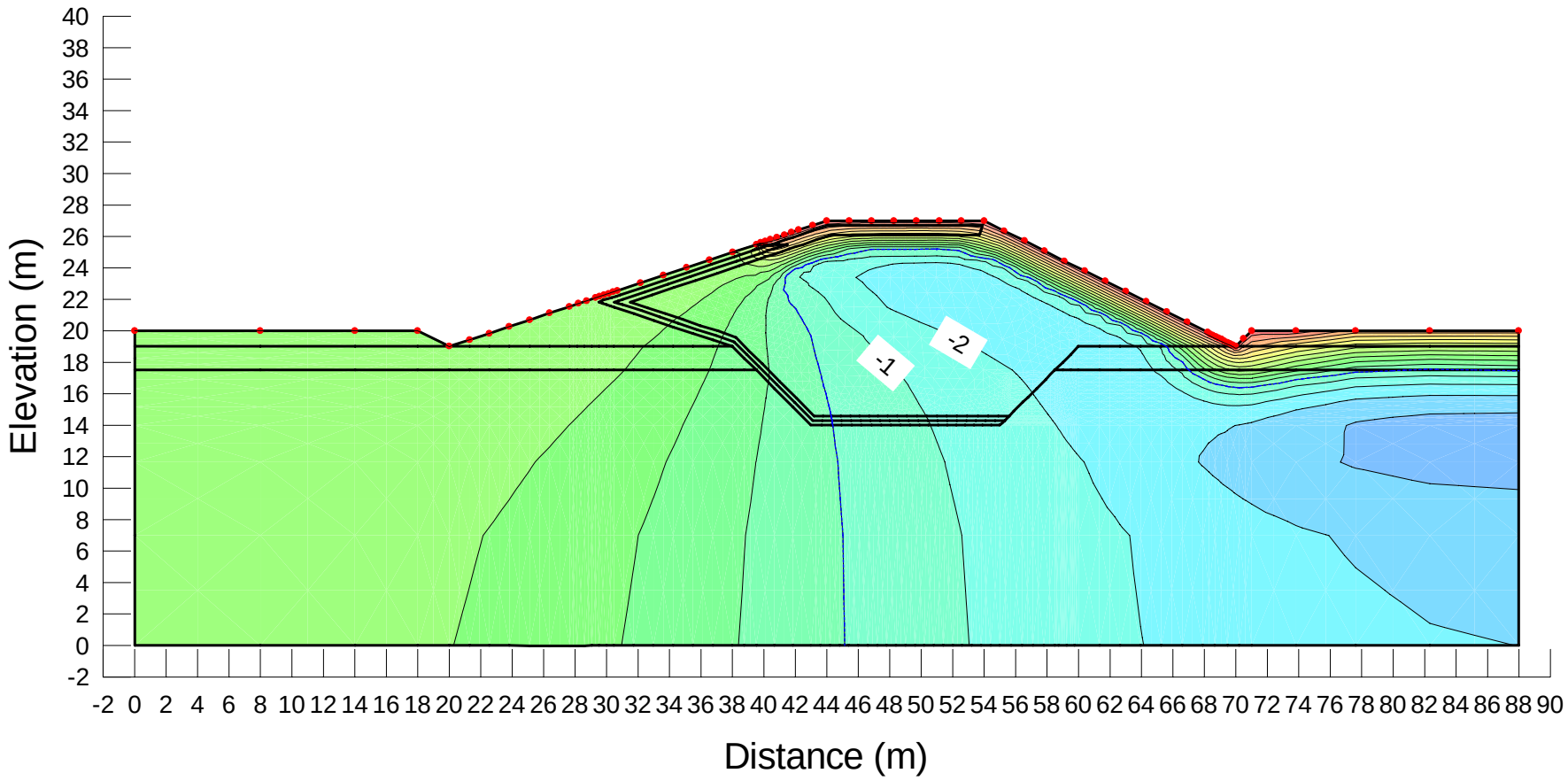


Figure 6: Run 1 Dam Temperatures During the Warmest Period of Year 30

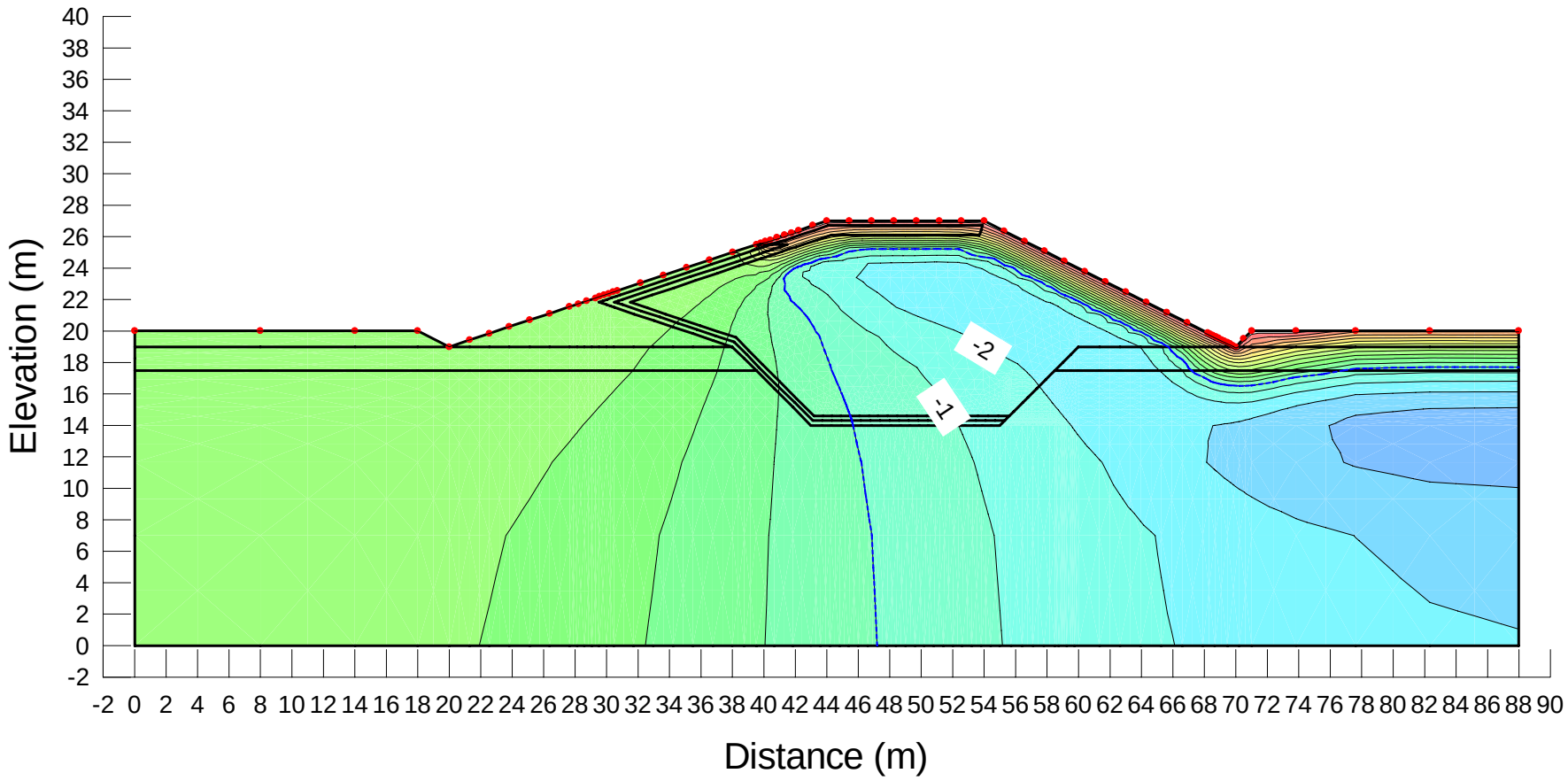


Figure 7: Run 1 Dam Temperatures During the Warmest Period of Year 50

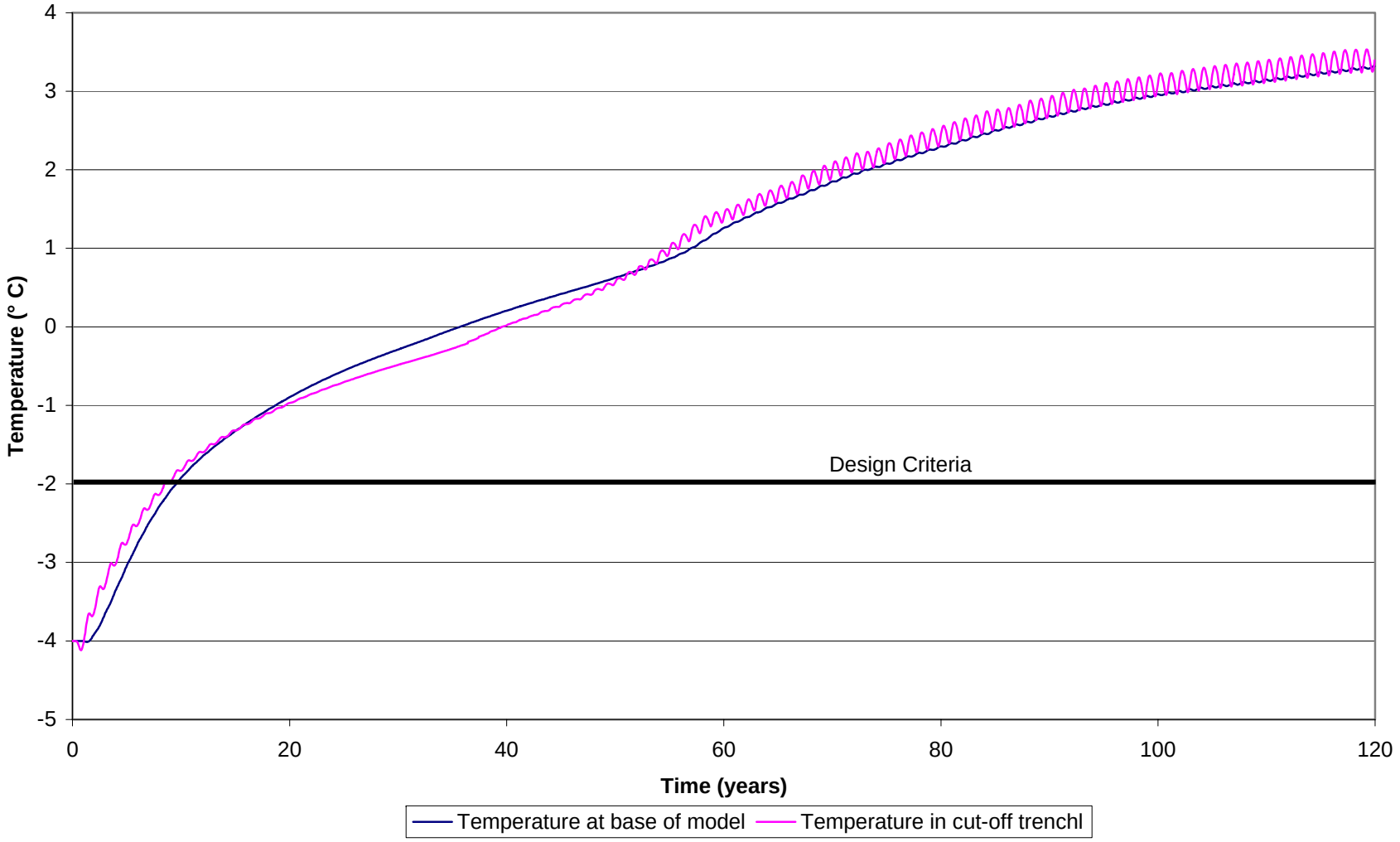


Figure 8: Temperature Versus Time At Two Nodes Beneath The Dam Centerline (Run 2: GTAD = -4°C; Global Warming Of 0.05°C/Year)

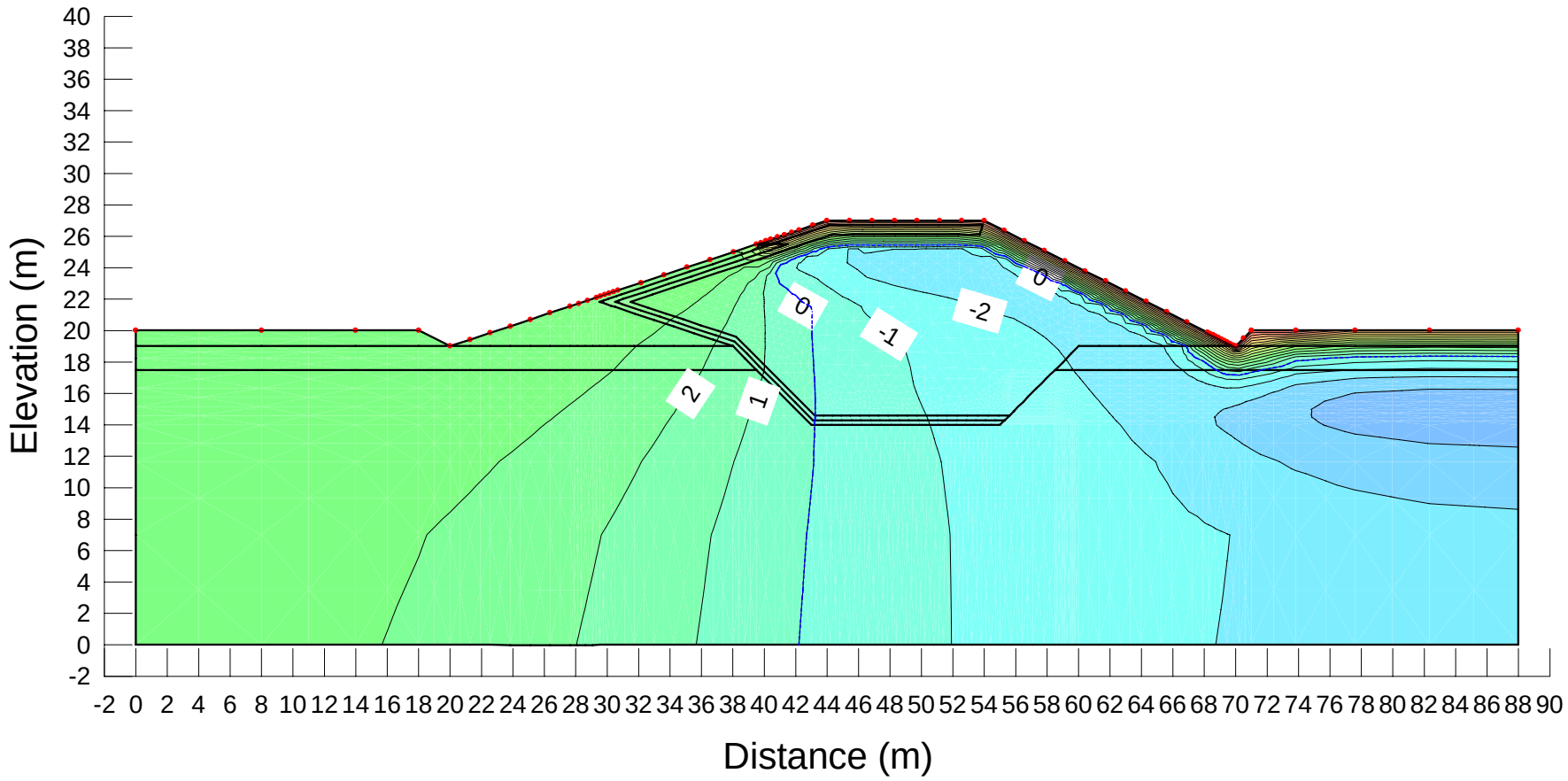


Figure 9: Run 2 Dam Foundation Temperatures During Warmest Period Of Year 20

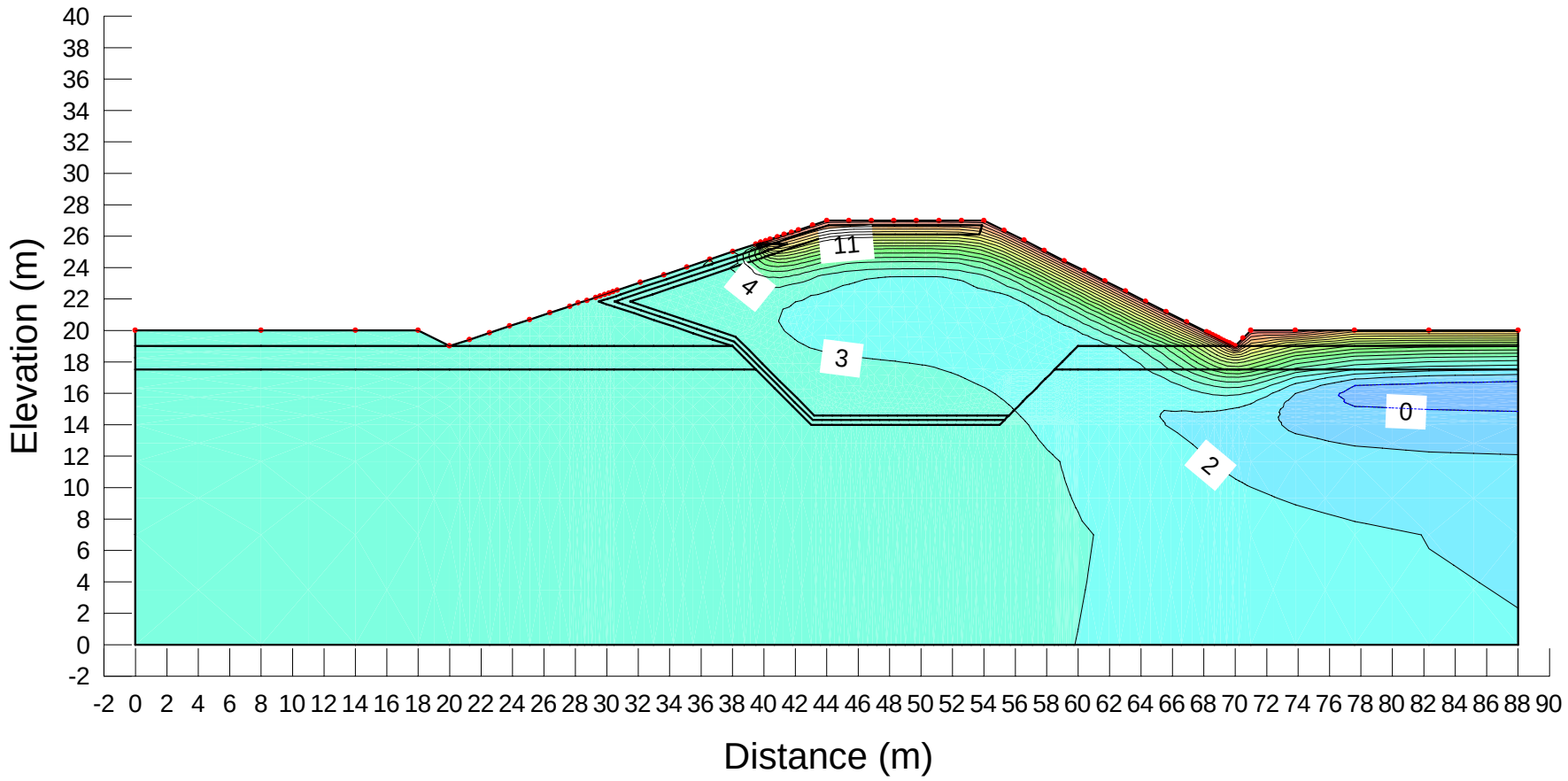


Figure 10: Run 2 Dam Foundation Temperatures During Warmest Period of Year 120

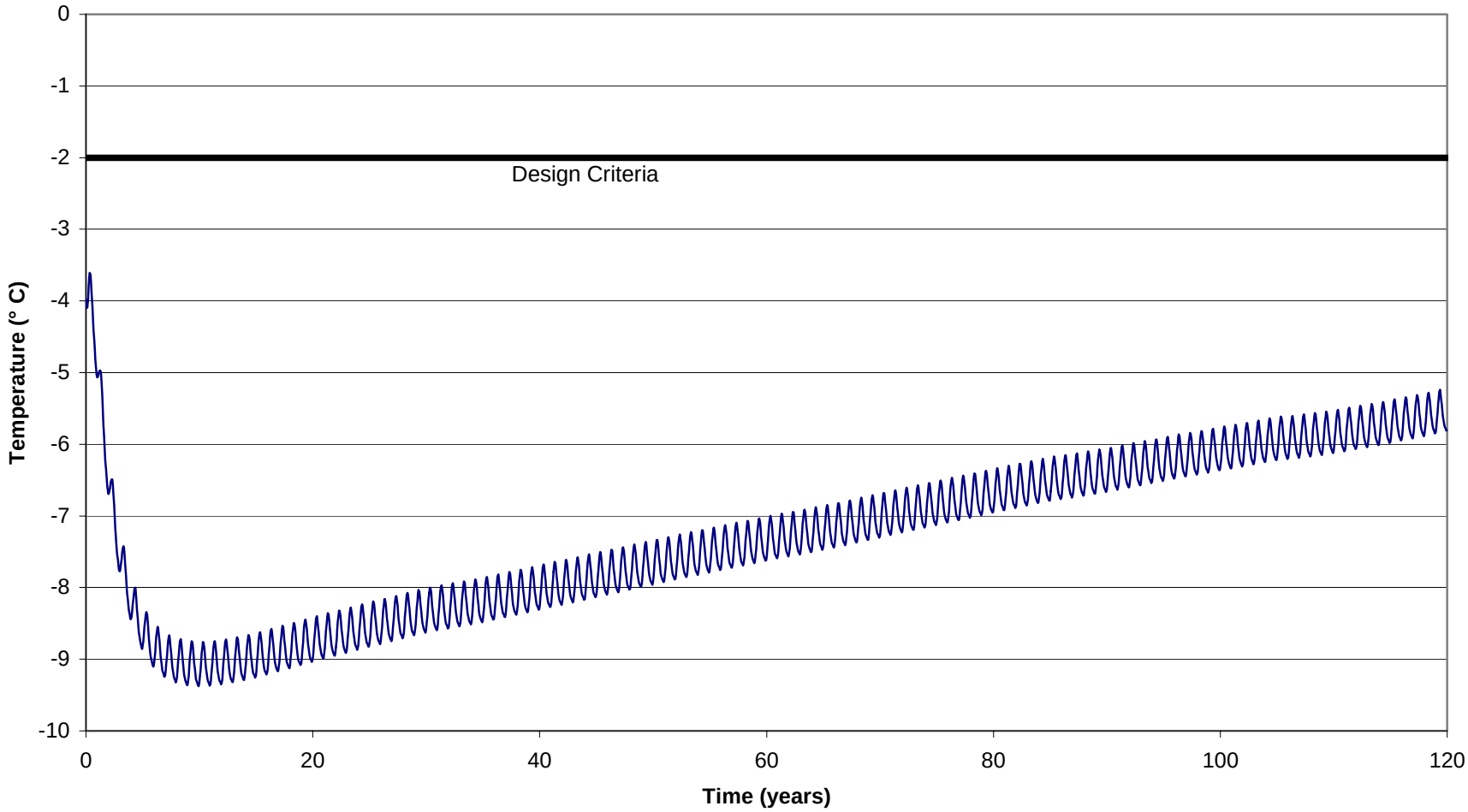


Figure 11: Run 3: Temperature Versus Time Beneath the Dam Centerline at the Base of the Model (Run 3: GTAD = -4°C; Climate Warming of 0.05°C/Year; With Thermosyphons)

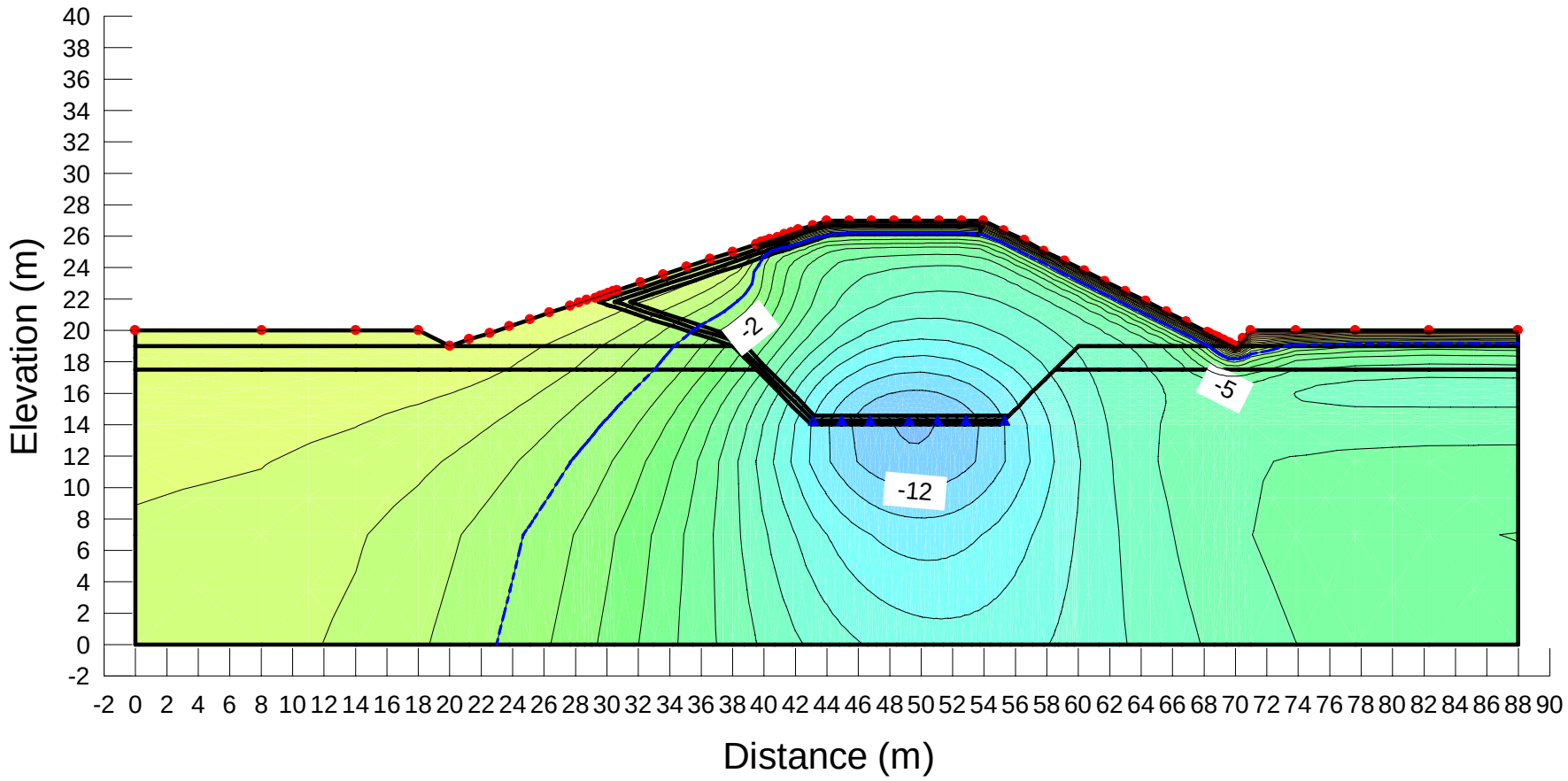


Figure 12: Run 3 Dam Foundation Temperatures During Warmest Part of Year 20

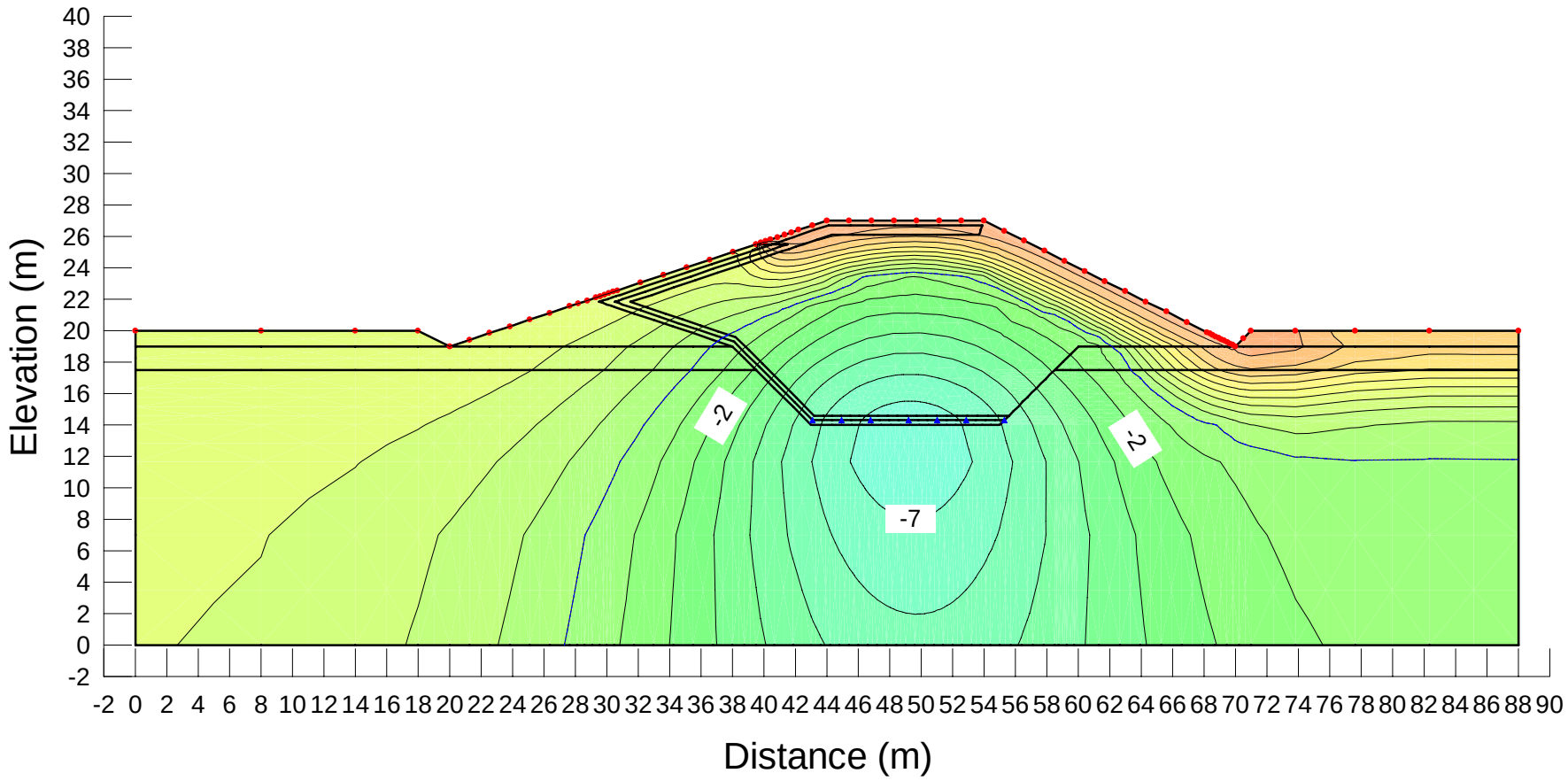


Figure 13: Run 3 Dam Foundation Temperature During Warmest Period Of Year 120

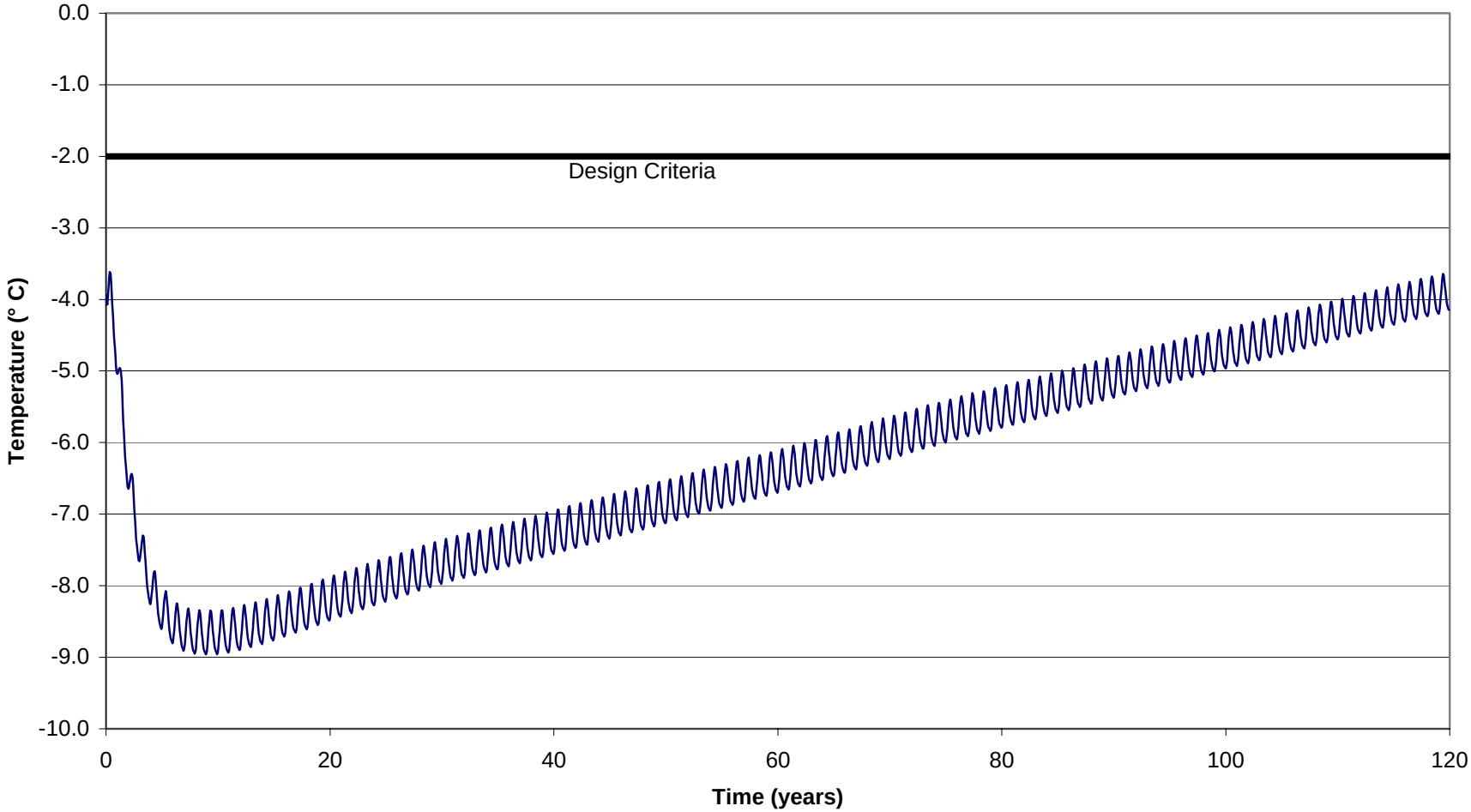


Figure 14: Run 4: Temperature Versus Time Beneath the Dam Centerline at the Base of the Model (Run 4: GTAD = -4°C; Climate Warming of 0.065°C/Year; Snow Depth Increased By 50% on Downstream Side of Dam; With Thermosyphons)

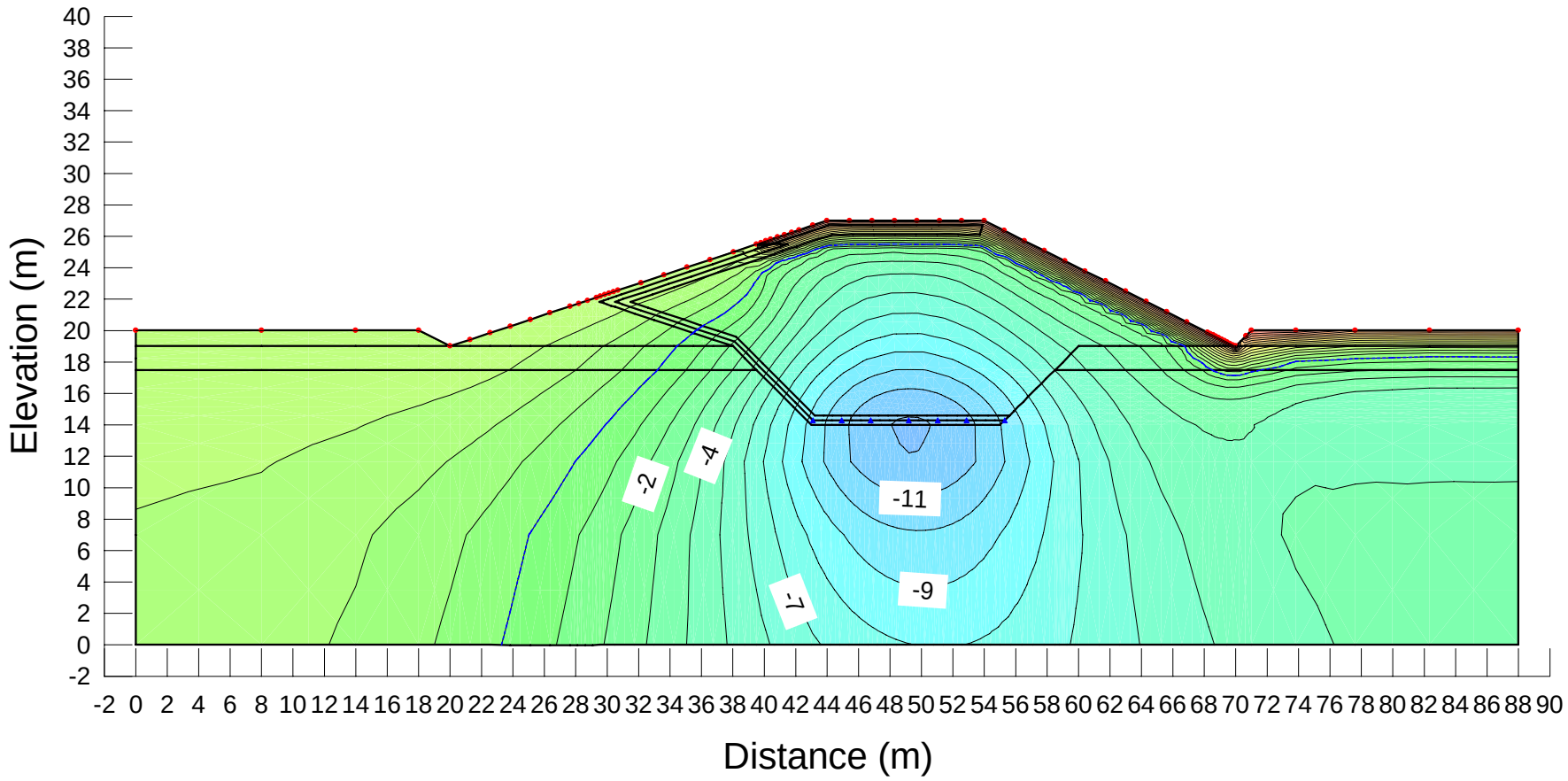


Figure 15: Run 4 Dam Foundation Temperatures During The Warmest Period Of Year 20

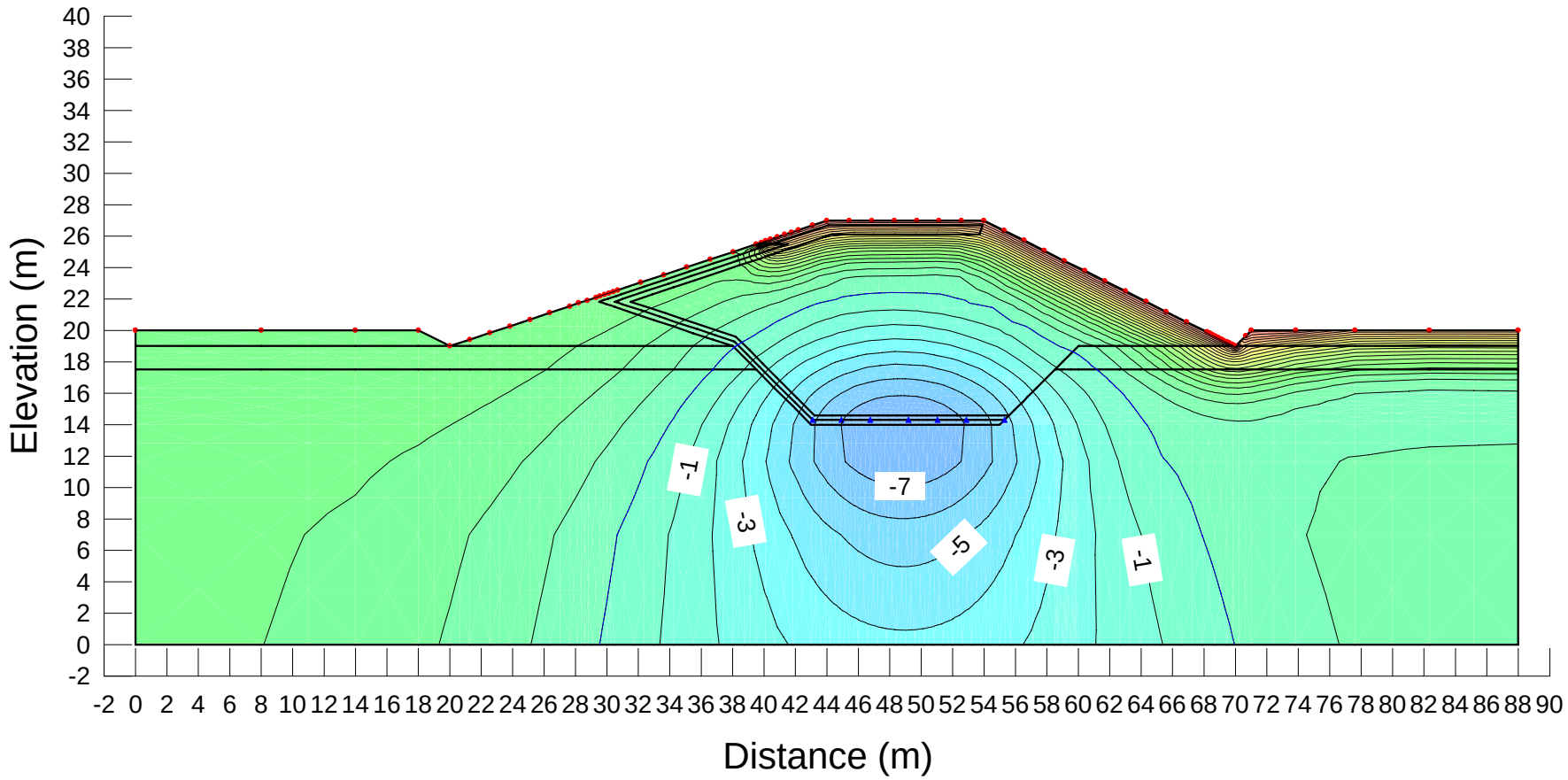


Figure 16: Run 4 Dam Foundation Temperatures During the Warmest Period of Year 120

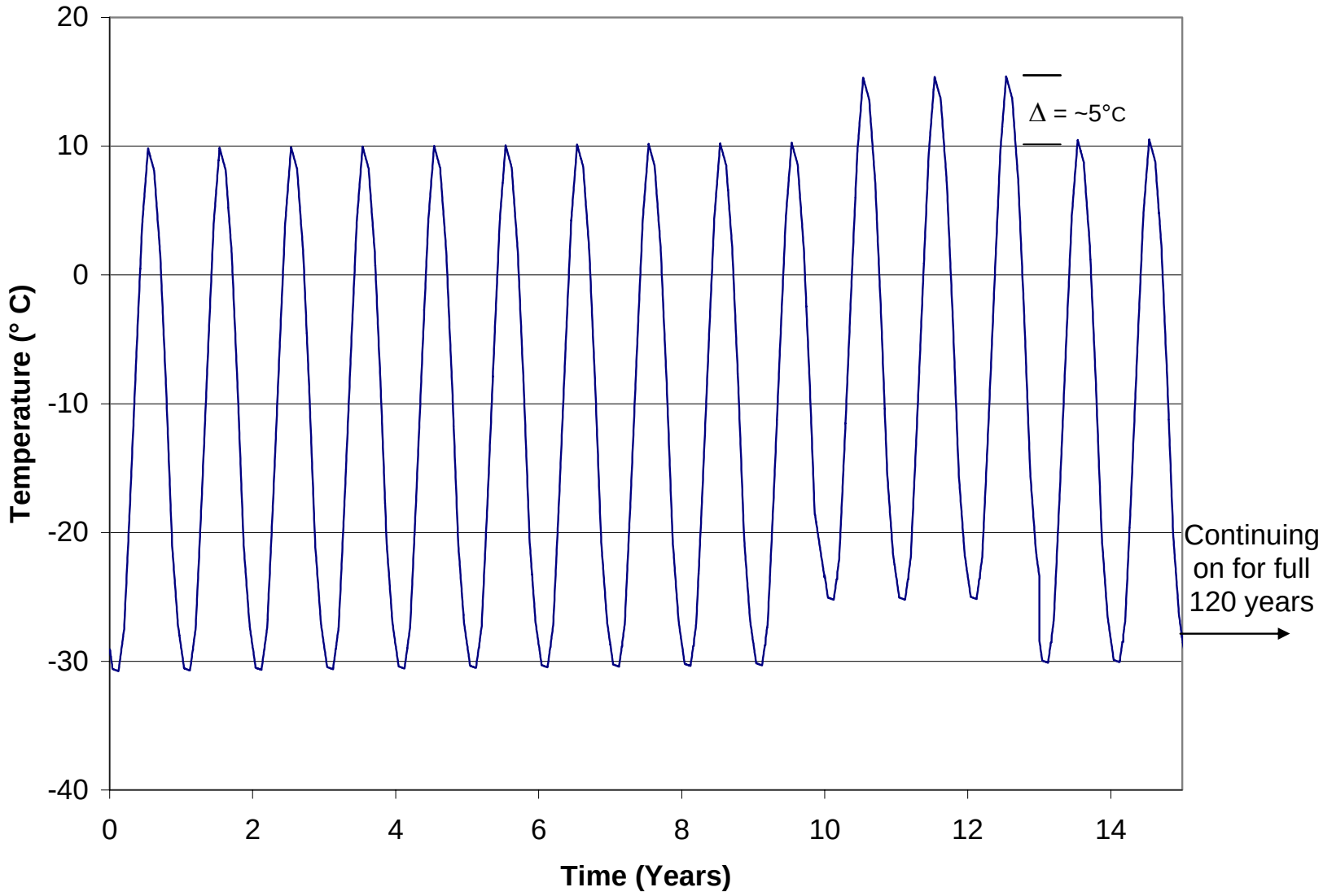


Figure 17: Air Temperature Versus Time Showing the Three Consecutive Warm Years

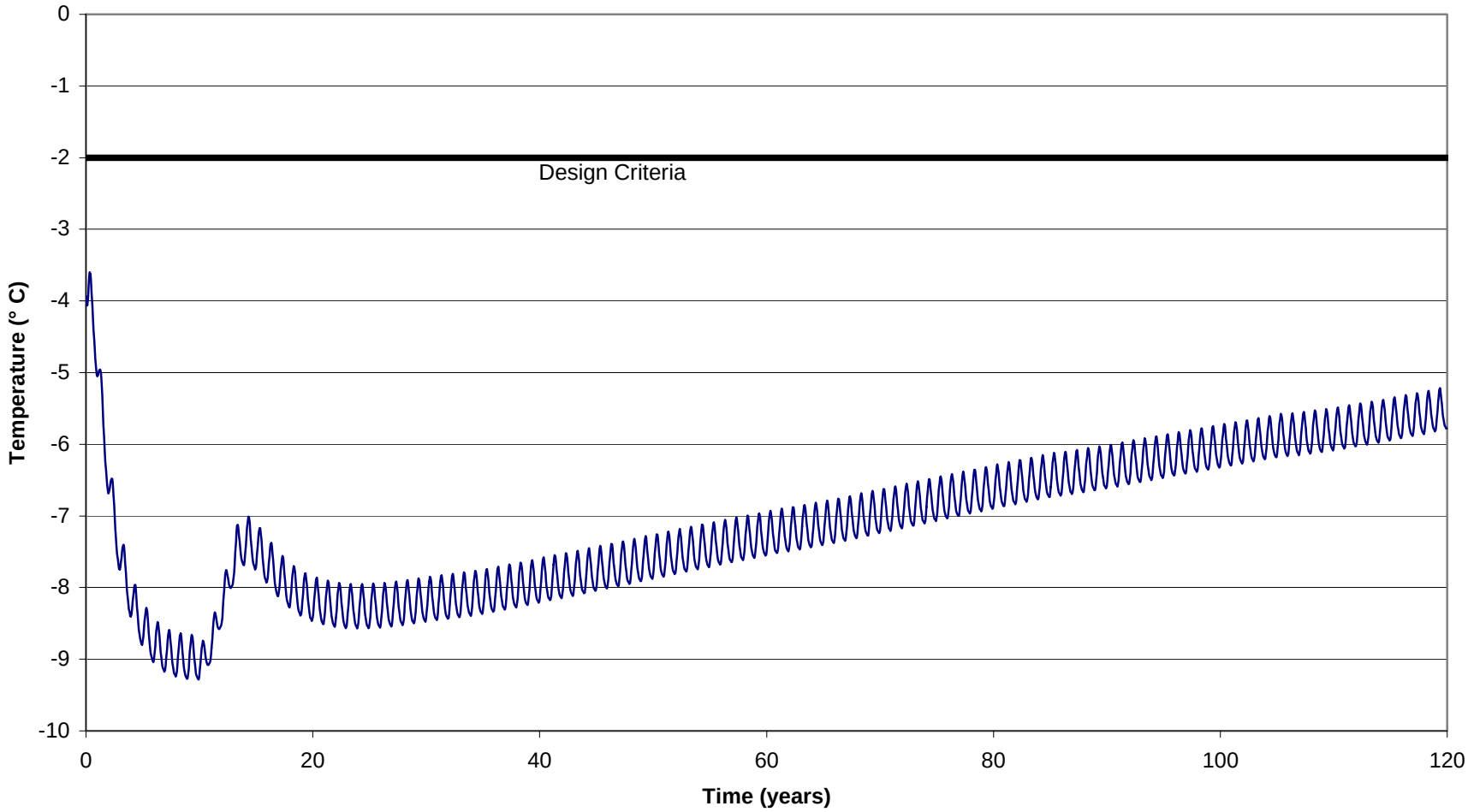


Figure 18: Run 5: Temperature Versus Time Beneath the Dam Centerline at the Base Of The Model (Run 5: GTAD = -4°C; Climate Warming Of 0.065°C/Year; With Thermosyphons; With 3 Extreme Warm Years During Operations)

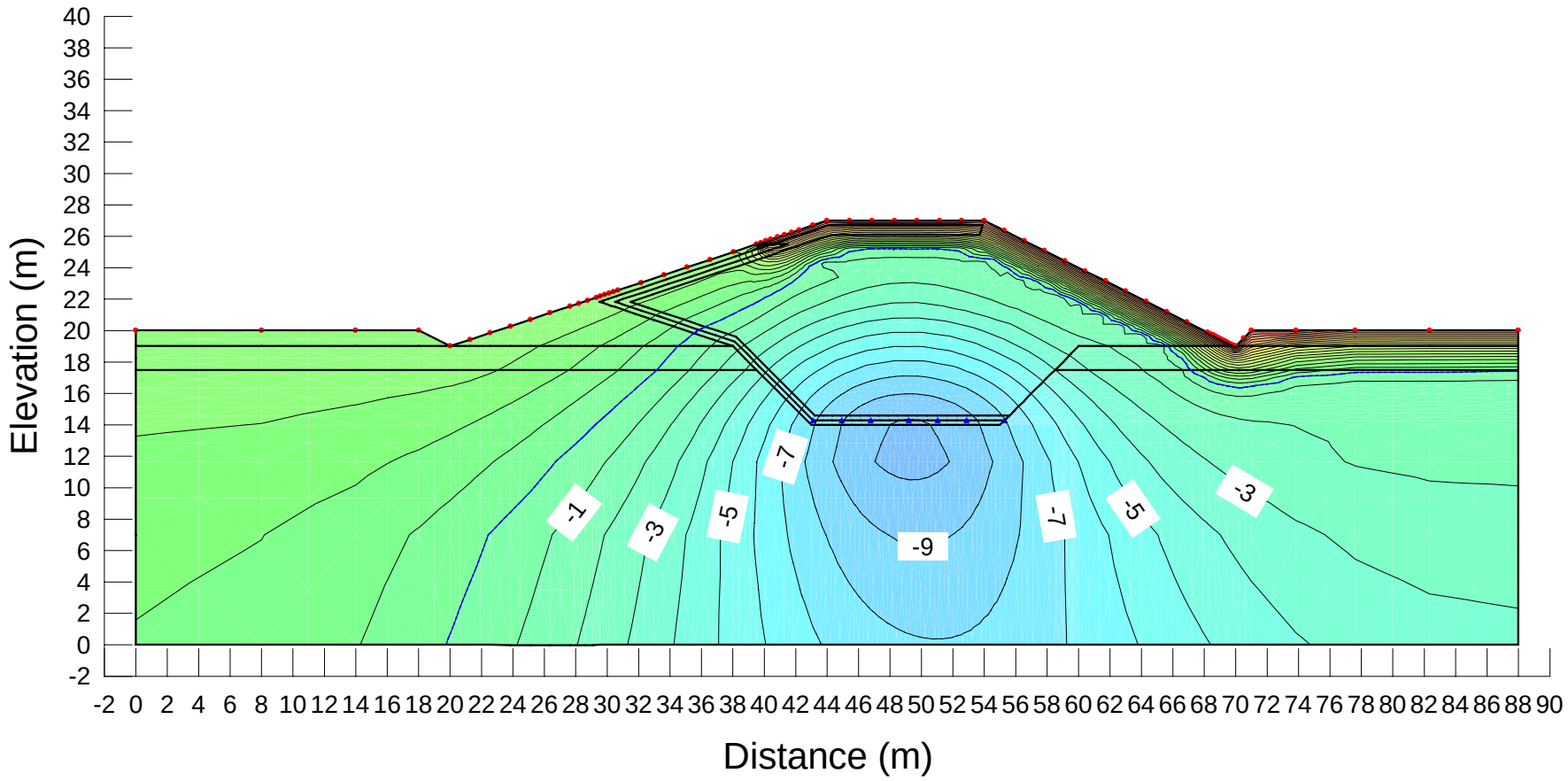


Figure 19: Run 5 Dam Foundation Temperatures During The Warmest Period of Year 12 (During the Three Extreme Warm Years)

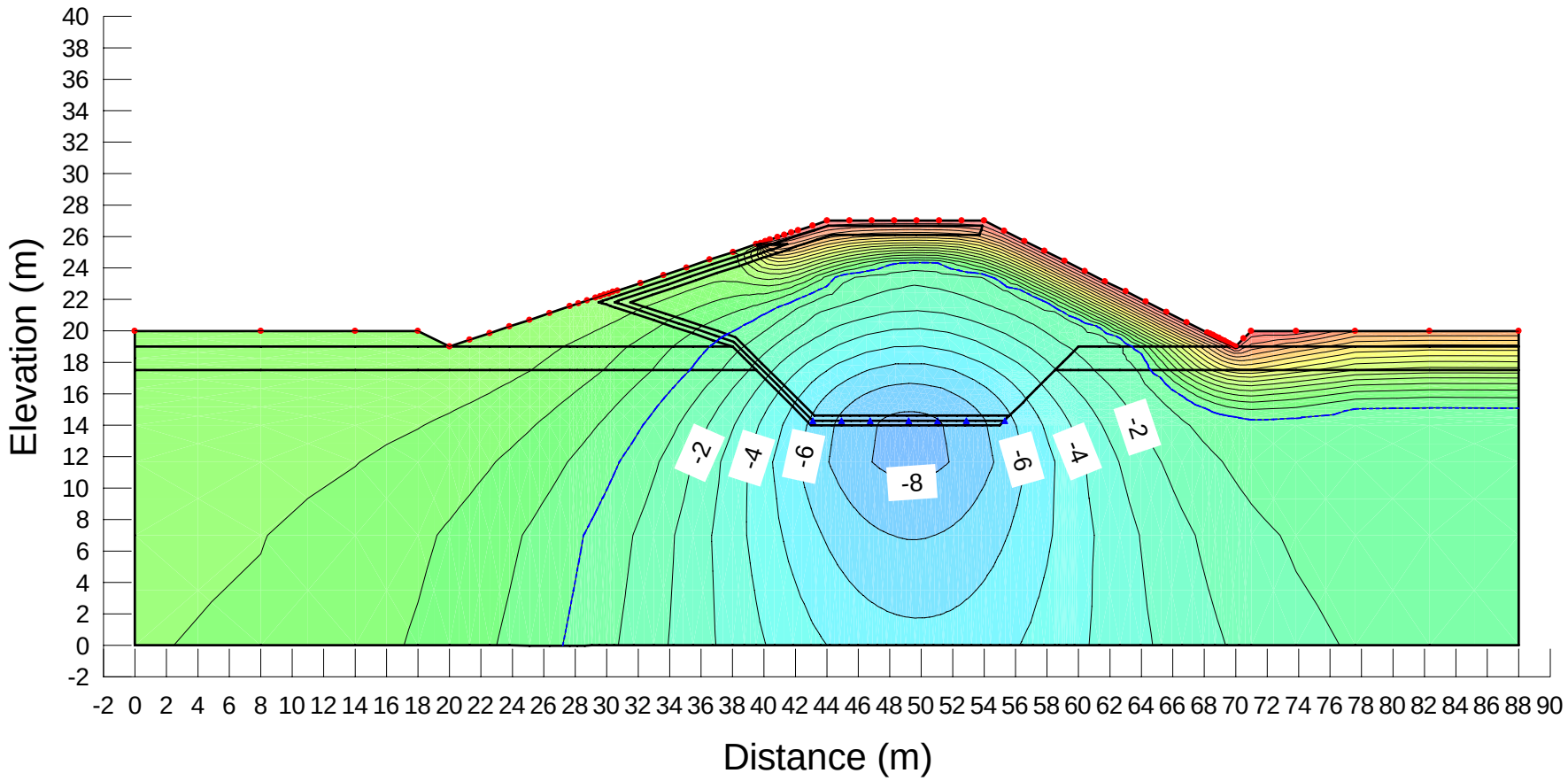


Figure 20: Run 5 Dam Foundation Temperatures During the Warmest Period of Year 120