GAHCHO KUÉ PROJECT ENVIRONMENTAL IMPACT STATEMENT
INFORMATION REQUEST RESPONSES

Information Request Number: AANDC_15

Source: Aboriginal Affairs and Northern Development Canada (AANDC)

Subject: Permafrost

EIS Section: Section 3: Project Description

Terms of Reference Section:

Preamble:

Reference. p. 3-104. "Permafrost development in the Fine PKC Facility and underlying talik is expected to occur over time."

Request

1. Please indicate whether any quantitative assessment of this process has been completed. Please supply details of such assessment for both Fine and Coarse PK storage facilities, including:

   a) Numerical modeling method

   b) Explicit statement of all assumptions used in modeling

   c) Statement of all thermal properties used in modeling

   d) Method for calculation of surface temperature of the fine PK

   e) Effect of climate change on the thermal regime of the fine PK

   f) Time required to establish permafrost in the PK and underlying talik

   g) Rate of annual freezing during period of permafrost aggradation

Response

a) Numerical modeling method

A thermal analysis of the proposed fine Processed Kimberlite Containment (PKC) Facility within Area 2 for the Gahcho Kué Diamond Project, NT was carried out (Appendix AANDC_15-1). The purpose of the analysis was to study the thermal conditions including progression of permafrost development within the Fine PKC Facility including climate change influences (global warming). The analysis was carried out using EBA Engineering Consultants Ltd.'s two-dimensional finite element computer model. The model simulates transient, two-dimensional heat conduction with change of phase for a variety of boundary conditions.

The thermal model was first calibrated to measured ground temperatures at the site.

A 1-D thermal model with a growing mesh feature was used to simulate the gradual placement of fine processed kimberlite (PK) and to predict the long-term thermal conditions.

b) Explicit statement of all assumptions used in modeling

The thermal analysis considered the following:

- An open talik (unfrozen zone) beneath Kennady Lake, including the lake-covered basin in Area 2 where fine processed kimberlite is proposed to be deposited into.
- The Soil profile considered a maximum of 15 m of fine processed kimberlite overlying 2 metre (m) thick layer of moraine blanket, overlying bedrock to the modelled depth of 100 m.
- The closure cover considered 2 m of mine rock or a combination of 1 m of mine rock overlying 1 m of coarse processed kimberlite.
- The initial temperatures below the lake varied between 1.0 and 2.5^{o}C in the top 50 m, and a thermal gradient of 0.017^{o}C/m below 50 m depth.
- Depositing of fine PK in Area 2 was from March Year 1 and end in July Year 5;
- The closure cover on fine PK was assumed to be placed between from August Year 5 to January Year 6;

- The initial temperature for the fine PK slurry coming from the process plant was assumed to be +15°C;
- The initial temperature for mine rock and coarse PK cover were assumed to be +5 °C; and
- Fine PK was assumed to be nearly saturated after placement.

A series of sensitivity analysis were carried out to investigate the impact of surface snow cover on the fine PK during the active fine PK discharge period (Stage 1). Mean monthly air temperatures measured at the Gahcho Kué station during 1998 to 2005 were assumed during the fine PK placement period (Stage 1). Three different climate conditions were considered in the after fine PK placement was concluded (Stage 2). The climate conditions considered were mean conditions and two climate change scenarios.

The cases analyzed are listed in Table 1.

Table 1: Summary of Cases in the Thermal Analysis

Case	Snow Cover Assumed	Air Temperature Conditions
Case 1	No snow cover in Stage 1 (March Year 1 to January Year 6); full seasonal snow cover in Stage 2 (After January Year 6)	Mean air temperatures
Case 2		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 3		Air temperatures considering climate change A2 (high green-house gas) scenario
Case 4	50% of seasonal snow cover in Stage 1 (March Year 1 to January Year 6); full seasonal snow cover in Stage 2 (After January Year 6)	Mean air temperatures
Case 5		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 6		Air temperatures considering climate change A2 (high green-house gas) scenario
Case 7	Full seasonal snow cover in both Stages 1 and 2	Mean air temperatures9
Case 8		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 9		Air temperatures considering climate change A2 (high green-house gas) scenario
Case 10 (Cover of 1 m mine rock over 1 m	50% of seasonal snow cover in Stage 1 (March Year 1 to January Year 6); full seasonal snow cover in Stage 2 (After January Year 6)	Air temperatures considering climate change A1B (moderate green-house gas) scenario

Table 1: Summary of Cases in the Thermal Analysis

Case	Snow Cover Assumed	Air Temperature Conditions
coarse PK)		

c) Statement of all thermal properties used in modeling

The thermal properties assumed in the thermal analysis are listed in Table 2.

Table 2 Material Properties Used in Thermal Analysis

Material	Water Content (%)	Bulk Density (Mg/m3)	Thermal Conductivity (W/m-°C)		Specific Heat (kJ/kg°C)		Latent Heat (MJ/m3)
			Frozen	Unfrozen	Frozen	Unfrozen	
Mine Rock Cover	4	2.17	1.7	1.8	0.79	0.87	28
Coarse PK Cover	10	2.04	1.6	1.2	0.86	1.05	62
Saturated Fine PK	63	1.63	2.5	1.0	1.26	2.07	210
Moraine Blanket	19	2.12	2.7	1.7	0.95	1.28	113
Bedrock	1	2.63	3.0	3.0	0.75	0.77	9

d) Method for calculation of surface temperature of the fine PK

The heat exchange at the ground surface is modelled with an energy balance equation considering air temperatures, wind velocity, snow depth, and solar radiation.

Climatic data required for the thermal analysis includes monthly air temperature, wind speed, solar radiation, and snow cover. Details of the climate parameters used to calculate the surface temperature are presented in EBA 2011 attached to this information request response.

e) Effect of climate change on the thermal regime of the fine PK

The effect of climate change on the thermal regime is a function of various assumptions and parameters. Ten cases were evaluated. A description of the climate change scenarios is presented In EBA 2011 attached to this information request response. A summary of the analysis results is presented in Table 3.

Table 3: Summary of Thermal Analysis Results

Case	Snow Cover Assumed	Air Temperature	Predicted Maximum Thickness of Permafrost in Fine PK after Mine Rock Cover Placement (m)	Predicted Years of Permafrost Presence in Fine PK after Mine Rock Cover Placement (years)	Predicted Long-term Seasonal Thaw Depth or Frost Penetration below Top of Mine Rock Cover over Fine PK (m)
Case 1	No snow in Stage 1; full seasonal snow cover in Stage 2	Mean	12.0	>100	2.3 to 2.4
Case 2		Mean+A1B Scenario	10.2	50	2.3 to 2.5
Case 3		Mean+A2 Scenario	10.1	45	2.3 to 2.6
Case 4	50% of seasonal snow cover in Stage 1 ; full seasonal snow cover in Stage 2	Mean	7.2	>100	2.3 to 2.5
Case 5		Mean+A1B Scenario	7.1	46	2.3 to 2.6
Case 6		Mean+A2 Scenario	7.0	35	2.3 to 2.7
Case 7	Full seasonal snow cover both in Stages 1 and 2	Mean	4.0	>100	2.5 to 2.6
Case 8		Mean+A1B Scenario	2.3	35	2.4 to 2.6
Case 9		Mean+A2 Scenario	2.2	30	2.3 to 2.7
Case 10 (Cover of 1 m mine rock over 1 m coarse PK)	50% of seasonal snow cover in Stage 1 ; full seasonal snow cover in Stage 2	Mean+A1B Scenario	7.1	55	2.3 to 2.5

The permafrost development and presence in the fine PK will depend on the actual climatic conditions, including the average thickness of snow cover over the fine PK surface. During the active placement of fine PK in Area 2, the snow cover will vary from location to location. Snow in some areas could be completely absent due to the placement of warm fine PK while full snow cover may exist in other areas. Cases 4, 5, 6 and 10 with an average 50% of seasonal snow cover are considered to be more representative of the actual conditions.

Permafrost is expected to thaw under climate change scenarios A1B or A2. The air temperatures considered in the moderate (A1B) climate change scenario represents reasonably conservative cases. The permafrost is calculated to thaw after 55 years under Case 10 with a closure cover of 1 m of mine rock and 1 m of coarse PK.

f) Time required to establish permafrost in the PK and underlying talik

Permafrost in the fine processed kimberlite establishes quickly in the fine processed kimberlite placed above the water level; however layers of unfrozen and frozen fine processed kimberlite exist in the earlier years. After approximately 20 years the permafrost in the upper portion of the fine processed kimberlite is continuous to the maximum thicknesses listed in Table 6. The original talik below the fine PKC facility does not freeze back in either the mean climate or climate change conditions.

g) Rate of annual freezing during period of permafrost aggradation

The rate of annual freezing varies over time as shown in the figures in the EBA 2011.

References

EBA 2011. Technical Memo - Thermal Analysis of the Proposed Fine PK facility in Area 2, Gahcho Kue Diamond Project, NT. Submitted to De Beers Canada, December 13, 2011

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TECHNICAL MEMO

ISSUED FOR REVIEW

TO:	Andrew Williams, De Beers Veronica Chisholm, De Beers	**DATE:**	December 13, 2011
C:	Wayne Corso, JDS Dan Johnson, JDS		
FROM:	Hongwei Xia, EBA Gordon Zhang, EBA Bill Horne, EBA	**EBA FILE:**	E14101143
SUBJECT:	Thermal Analysis of the Proposed Fine PK Facility in Area 2, Gahcho Kué Diamond Project, NT		

This "Issued for Review" document is provided solely for the purpose of client review and presents our findings and recommendations to date. Our findings and recommendations are provided only through an "Issued for Use" document, which will be issued subsequent to this review. You should not rely on the interim recommendations made herein. Once our report is issued for use, the "Issued for Review" document should be either returned to EBA or destroyed.

1.0 INTRODUCTION

EBA Engineering Consultants Ltd. operating as EBA, a Tetra Tech Company (EBA) was retained by JDS Energy & Mining Inc. (JDS) to conduct thermal analyses for the proposed fine PK facility within Area 2 for the Gahcho Kué Diamond Project, NT. The purpose of the analyses was to study the thermal conditions including progression of permafrost development within the fine PK facility over time under assumed climate conditions, including considering climate change (global warming) scenarios. This memo summarizes the methodology, input data, and results of the thermal analyses.

2.0 PROJECT DESCRIPTION

2.1 Site Condition

A site investigation was carried out for the AMEC 2005 study for the Gahcho Kué project. Detailed site conditions in the mine site area were described in AMEC (2005) and De Beers (2010). Generally, seven main geological units were identified within the Gahcho Kué mine site area: moraine veneer (till thickness < 1 m), moraine blanket (till thickness > 1 m), glaciolacustrine deposits, glaciofluvial deposits, organic deposits, esker outwash deposits, and bedrock.

Shallow lakebed sediments at the Gahcho Kué area range from soft, predominantly silty material containing some sand and traces of clay that grade into dense sandy silt with some gravel. Bedrock encountered in boreholes drilled within the proposed dyke areas for the 2005 AMEC study was generally described as medium-coarse grained granite to highly foliated granite gneiss.

2.2 Ground Temperature and Permafrost Condition

A total of 42 thermistor cables were installed on site during the AMEC 2004 site investigation. The majority of the mine site area includes glacial veneer and blanket with the mean annual permafrost temperatures of -0.5°C to -2.5°C. The highest soil temperatures (-0.5°C) correspond to regions that possess dense polar birch vegetation, while the lowest temperatures (-2.5°C) are encountered within glacial veneers or blankets with minimum snow cover, which correspond to areas with no shrub vegetation. Wet areas within peat bogs and peat veneers have mean annual soil temperatures from -1.0°C to -1.5°C, due to the low thermal resistance of saturated moss. Areas with a mean annual soil temperature above 0°C (up to +1.5°C) (permafrost free) could be encountered within the tall shrub terrain along creeks in the glaciofluvial deposits and on lake banks. The development of positive temperatures is a result of snow accumulation in tall shrubs.

The thickness of the active layer within the moraine veneer and blanket is expected to vary from 2.6 to 3.2 m and 1.6 to 2.5 m, respectively. Glaciofluvial sand and silt have the thinnest active layer thickness (1.0 to 2.0 m) of the mineral soils within the study area. The main factors that determine a relatively shallow active layer are the high moisture content and insulating effect of the moss cover. The maximum thickness of the active layer (3.7 to 4.0 m) is estimated to occur in exposed bedrock areas. Deep seasonal thaw in this terrain is a result of very low moisture retention within the bedrock. A deep active layer is also expected in eskers, where the thickness of the active layer would be in the range of 3.0 to 3.4 m. Organic soils (peat) have the shallowest active layers (0.4 to 0.9 m).

Three deep GTCs were installed to the estimated permafrost thickness (AMEC 2005). Based on measured soil temperatures from three deep boreholes, the permafrost thickness is estimated to be ranging from 120 m to 310 m, and the thermal gradient is estimated to be 1.7 ^{0}C /100 m. The high degree of variability in permafrost thickness between the boreholes can be explained by the locations of the boreholes. The shallower permafrost depth is considered as a result of the warming effect of a large water body such as Kennedy Lake.

It is expected that an open talik (unfrozen zone) currently exists beneath Kennady Lake, including the lake-covered basin in Area 2 where fine PK is proposed to be deposited into.

3.0 THERMAL ANALYSIS MODEL AND CLIMATIC DATA

3.1 General

Analyses were carried out using EBA's proprietary two-dimensional finite element computer model, GEOTHERM to estimate the permafrost behavior in the proposed fine PK facility. The model simulates transient, two-dimensional heat conduction with change of phase for a variety of boundary conditions. The heat exchange at the ground surface is modelled with an energy balance equation considering air temperatures, wind velocity, snow depth, and solar radiation. The model facilitates the inclusion of temperature phase change relationships for soils, such that any freezing depression and unfrozen water content variations can be explicitly modelled. The model has been verified by comparing its results with closed-form analytical solutions and many different field observations. The model has successfully formed the basis for thermal evaluations and designs of tailings dykes, dams, foundations, pipelines, utilidor systems, landfills, and ground freezing systems in both arctic and sub-arctic regions.

3.2 Climatic Data Input for Thermal Model

Climatic data required for the thermal analyses includes monthly air temperature, wind speed, solar radiation, and snow cover. A meteorological station on Gahcho Kué was operated from August 1998 to September 2005. The seven years of climate data from the Gahcho Kué station are not enough to describe the local long-term temperature condition. De Beers (2010) described a study of climate condition for Gahcho Kué based on the five nearby climate stations (located within 300 km of the Gahcho Kué climate station) where the long-term climate data are available. The study indicated that the available climate data between the Lupin combined (Lupin station and Contwoyto Lake) and the Gahcho Kué exhibits a good linear relationship. Moreover, the Lupin A Station elevation of 490 m and Contwoyto Lake Station elevation of 451 m are also close to that of the Gahcho Kué climate station at an elevation of 430 m, therefore, long-term mean monthly air temperatures for Gahcho Kué in this study were estimated based on the relationship between Lupin combined and Gahcho Kué station.

Long-term mean wind speed data is not available for the Gahcho Kué site. Monthly wind speeds have been estimated by interpolating the monthly data proportional with latitude, from Fort Reliance and Lupin/Contwoyto Lake for the climate normal period of 1961 to 1990. Lupin/Contwoyto Lake is located approximately 100 km north of Gahcho Kué and Fort Reliance is located approximately 200 km south of Gahcho Kué. Monthly snow depths for Gahcho Kué have been predicted using the same method. Daily solar radiation is available for only a limited number of sites in the arctic. Based on their similar latitudes, the mean daily solar radiation from Baker Lake, located approximately 650 km east of Gahcho Kué, for the climate normal period of 1951 to 1980 (Environmental Canada 1982) was used for Gahcho Kué in this study.

The mean climatic data estimated for Gahcho Kué in this study are summarized in Table 1.

Table 1: Mean Climatic Conditions at Gahcho Kué Used in Thermal Analyses

Month	Estimated Mean Monthly Air Temperatures at Gahcho Kué (1971 to 2000) [(a)] (°C)	Measured Monthly Air Temperature at Gahcho Kué (1998-2005) [(b)] (°C)	Estimated Monthly Wind Speed at Gahcho Kué I[(c)] (km/h)	Estimated Monthly Snow Cover at Gahcho Kué [(d)] (m)	Estimated Daily Solar Radiation at Gahcho Kué [(e)] (W/m^2)
January	-28.5	-27.8	14	0.37	9.1
February	-27.0	-26.3	11	0.45	38.7
March	-23.7	-21.8	12	0.51	119.5
April	-14.2	-13.3	13	0.49	206.4
May	-3.1	-4.4	13	0.28	259.7
June	7.7	7.7	12	0	252
July	12.6	13.5	12	0	226.4
August	10.5	10.4	14	0	160.8
September	3.8	4.4	17	0	124.9
October	-6.5	-5.3	17	0.05	41.3

Table 1: Mean Climatic Conditions at Gahcho Kué Used in Thermal Analyses

Month	Estimated Mean Monthly Air Temperatures at Gahcho Kué (1971 to 2000) [(a)] (°C)	Measured Monthly Air Temperature at Gahcho Kué (1998-2005) [(b)] (°C)	Estimated Monthly Wind Speed at Gahcho Kué I[(c)] (km/h)	Estimated Monthly Snow Cover at Gahcho Kué [(d)] (m)	Estimated Daily Solar Radiation at Gahcho Kué [(e)] (W/m^2)
November	-18.5	-15.7	15	0.17	14.4
December	-25.5	-24.1	13	0.29	3.7
Annual	**-9.4**	**-8.6**			

Notes:

(a) Based on measured monthly air temperatures at Lupin/ Contwoyto Lake station for the periods of 1971 to 2010, measured air temperatures at Gahcho Kué station for the period of 1998 to 2005

(b) Based on measured temperature data at Gahcho Kué station (1998-2005)

(c) Based on measured data at Fort Reliance and Lupin/Contwoyto Lake station for the period of 1961 to 1990

(d) Based on measured data at Fort Reliance and Lupin/Contwoyto Lake station for the period of 1961 to 1990

(e) Based on measured data at Baker Lake station (1951-1980)

3.3 Climate Change Projection

The historical air temperature data at Lupin/ Contwoyto Lake for the period of 1959 to 2005 indicated that the long-term climatic trend at Lupin/ Contwoyto is warming. Based on the observed warming trend in the historical air temperatures and state-of-practice, the thermal evaluations for this project should consider the long-term effects of climate change (or global warming).

The Adaptation and Impacts Research Section (AIRS) of Environment Canada recently produced a report (Environment Canada 2009) summarizing findings from the most recent modelling assessment for the Arctic. AIRS adopted an ensemble approach (multi-model means/medians) to reduce the uncertainty associated with any individual model. Model validation over the historical period from 1971-2000 was first used to identify those models which best reproduced the mean annual temperature of this period against the National Centre for Environmental Prediction global gridded dataset. Subsequently, only the four best-agreement models were used to produce the final ensemble projections. The four best ranking models within each sector were then used as an ensemble to produce projections of temperature change in the 2020s, 2050s, and 2080s for both the 'A1B' (middle of the road emission), and 'A2' (high emission) scenarios. CSA (2010) adopted the climate change projections in Environment Canada (2009).

The Gahcho Kué site (63° N 109° W) is located at the arctic zone C1 in Environment Canada (2009) and CSA (2010). The predicted mean temperature changes from 1970-2000 baseline under the moderate green-house gas emission scenario in zone C1 (CSA 2010) are presented in Table 2. These rates of the predicted temperature change were applied in the thermal evaluations. Table 3 summarizes the estimated monthly air temperatures Gahcho Kué during the period of 1971 to 2000, and in 2020 considering the rates of the projected climate changes in the period of 2011 to 2040.

Table 2 Predicted Seasonal Air Temperature Changes in Zone C1 (CSA 2010)

Period	Predicted Seasonal Air Temperature Changes from 1971-2000 Baseline under Moderate (A1B) Green-house Gas Emission Scenario (°C)				Predicted Seasonal Air Temperature Changes from 1971-2000 Baseline under High (A2) Green-house Gas Emission Scenario (°C)			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
2011–2040	1.9	1.0	0.8	1.3	2.2	1.0	0.9	1.4
2041–2070	4.2	2.1	1.8	2.7	4.9	2.0	1.8	2.8
2070-2100	6.3	2.8	2.4	3.4	8.9	3.5	3.0	4.7

Table 3: Estimated Monthly Air Temperatures at Gahcho Kué

Month	Estimated Mean Monthly Air Temperature at Gahcho Kué (1971-2000) (°C)[1]	Estimated Mean Monthly Air Temperature at Gahcho Kué in 2020 Based on Projected Climate Change and 1971-2000 Air Temperatures (°C)[2]
January	-28.5	-26.9
February	-27.0	-25.4
March	-23.7	-22.8
April	-14.2	-13.3
May	-3.1	-2.2
June	7.7	8.4
July	12.6	13.3
August	10.5	11.2
September	3.8	4.9
October	-6.5	-5.3
November	-18.5	-17.4
December	-25.5	-23.9
Annual	**-9.4**	**-8.3**

1. Based on measured monthly air temperatures at Lupin/ Contwoyto Lake station for the periods of 1971 to 2010, measured air temperatures at Gahcho Kué station for the period of 1998 to 2005
2. Based on Lupin/ Contwoyto Lake station for the periods of 1971 to 2000, adjusted to Gahcho Kué plus climate change estimate under moderate (A1B) green-house gas emission scenario

4.0 CALIBRATION THERMAL ANALYSIS

A total of 42 thermistor cables were installed at the Gahcho Kué site including three deep thermistors (up to 250 m). Based on the thermistor location and reliability of the measured ground temperature data, the measured ground temperature data at MPV-04-194C was used to calibrate the thermal model. The latest measured ground temperature data at MPV-04-194C is on August 11, 2004. The borehole location of MPV-04-194C is shown in Figure 1.

The soil profile at MPV-04-194C for the calibration thermal analysis consisted of 2.0 m moraine blanket overlying bedrock based on information in AMEC (2005).

The material properties used in the analysis are presented in Table 4. The index soil properties were estimated from borehole logs and past experience with similar soils. The soil thermal properties were determined indirectly from well-established correlations with soil index properties (Farouki, 1986; Johnston, 1981)

Table 4: Material Properties Used in Thermal Calibration Analysis for MPV-04-194C.

Material	Water Content (%)	Bulk Density (Mg/m^3)	Thermal Conductivity (W/m-°C)		Specific Heat (kJ/kg°C)		Latent Heat (MJ/m^3)
			Frozen	Unfrozen	Frozen	Unfrozen	
Moraine Blanket	14	2.17	2.5	1.8	0.90	1.16	89
Bedrock	1	2.63	3.0	3.0	0.75	0.77	9

Table 5 compares the predicted and measured ground temperatures on May 1, 2004 and August 11, 2004 at MPV-04-194C.

Table 5: Measured and Predicted Ground Temperatures at MPV-04-194C.

Depth below Ground Surface (m)	Measured on May 1, 2004 (°C)	Predicted on May 1, 2004 (°C)	Measured on August 11, 2004 (°C)	Predicted on August 11, 2004 (°C)
-0.5	-8.5	-8.7	5.5	7
-2.5	-6.5	-6.3	-1	-1.1
-5	-4.5	-4	-3	-2.7
-7.5	-3.25	-2.8	-3.4	-3.2
-10	-2.6	-2.3	-3.2	-3
-12.5	-2.5	-2.4	-3.1	-2.7
-15	-2.5	-2.6	-2.8	-2.65
-17.5	-2.6	-2.7	-2.75	-2.63
-20	-2.75	-2.7	-2.75	-2.6

Good agreement was obtained between the measured and predicted ground temperature data, which suggests that the input parameters are reasonable and can be used in the thermal evaluations for other locations at the mine site.

5.0 THERMAL ANALYSIS FOR FINE PK FACILITY

5.1 Analysis Assumptions and Cases

The purposes of the thermal evaluation are to investigate the permafrost development in the fine PK after deposited in Area 2 and the long-term thermal conditions under long-term climatic conditions while considering the climate change scenarios.

The following schedules and assumptions for the fine PK to be deposited in Area 2 were adopted in the thermal analyses:

- Start depositing fine PK in Area 2 from March 2015 and end in July 2019;
- Place mine rock cover on fine PK from August 2019 to January 2020;
- The base elevation of the fine PK was assumed to be 414 m, and the top final elevation to be 429 m (the maximum height of the final fine PK is 15 m);
- The thickness of the mine rock cover was assumed to be 2 m;
- The initial temperature for the fine PK slurry pumping out from the process plant was assumed to be +15°C;
- The initial temperature for mine rock cover was assumed to be +5 °C; and
- Fine PK was assumed to be nearly saturated after placement.

A series of sensitivity analyses were carried out to investigate the impact of the fine PK surface snow cover during the active fine PK discharge period on the progression of permafrost development in the fine PK. The analyses were carried out in two stages according to the snow cover depths assumed. Stage 1 analyses simulated the period of actively placing fine PK and mine rock cover in Area 2 (i.e. from March 2015 to January 2020). Stage 2 analyses simulated the conditions after the completion of placing mine rock cover over the final fine PK in Area 2 (i.e. after January 2020). Three snow cover depths were simulated in the Stage 1 analyses, which include: a) no snow cover, b) 50% of seasonal snow cover, and c) full seasonal snow cover. A full seasonal snow cover was simulated in the Stage 2 analyses.

In each sensitivity study, mean monthly air temperatures measured at the Gahcho Kue station during 1998 - 2005 were used in the Stage 1 analyses. Three different climate conditions were considered in the Stage 2 analyses (i.e. mean and two climate change scenarios). Table 6 summarizes the cases run in the thermal analyses.

Table 6: Summary of Cases in the Thermal Analyses

Case	Snow Cover Assumed	Air Temperature Conditions
Case 1	No snow cover in Stage 1 (March 2015 to January 2020); full seasonal snow cover in Stage 2 (After January 2020)	Mean air temperatures
Case 2		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 3		Air temperatures considering climate change A2 (high green-house gas) scenario
Case 4	50% of seasonal snow cover in Stage 1 (March 2015 to January 2020); full seasonal snow cover in Stage 2 (After January 2020)	Mean air temperatures
Case 5		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 6		Air temperatures considering climate change A2 (high green-house gas) scenario
Case 7	Full seasonal snow cover in both Stages 1 and 2	Mean air temperatures
Case 8		Air temperatures considering climate change A1B (moderate green-house gas) scenario
Case 9		Air temperatures considering climate change A2 (high green-house gas) scenario

5.2 Material Properties for Thermal Analyses

The original soil profile similar to that used in the calibration analysis was adopted in the thermal analyses.

The index properties for the fine PK slurry and mine rock cover have been estimated from limited available information and past experience. The soil thermal properties were determined indirectly from well-established correlations with their index properties. Table 7 summarizes the material properties used in the thermal analyses.

Table 7: Material Properties Used in Thermal Analyses

Material	Water Content (%)	Bulk Density (Mg/m3)	Thermal Conductivity (W/m-°C)		Specific Heat (kJ/kg°C)		Latent Heat (MJ/m3)
			Frozen	Unfrozen	Frozen	Unfrozen	
Mine Rock Cover	4%	2.17	1.7	1.8	0.79	0.87	28
Saturated Fine PK	63%	1.63	2.5	1.0	1.26	2.07	210
Moraine Blanket	19	2.12	2.7	1.7	0.95	1.28	113
Bedrock	1	2.63	3.0	3.0	0.75	0.77	9

5.3 Results and Discussions

A 1-D thermal model with a growing mesh feature was used to simulate the gradually placement of fine PK in Area 2 and to predict the long-term thermal conditions after the mine rock cover is placed over the final fine PK surface. Nine cases were evaluated. A summary of the analysis results is presented in Table 8.

Table 8: Summary of Results of Thermal Analyses

Case	Average Snow Cover Assumed	Air Temperature Conditions	Predicted Maximum Thickness of Permafrost in Fine PK after Mine Rock Cover Placement (m)	Predicted Years of Permafrost Presence in Fine PK after Mine Rock Cover Placement (years)	Predicted Long-term Seasonal Thaw Depth or Frost Penetration below Top of Mine Rock Cover over Fine PK (m)
Case 1	No snow in Stage 1; full seasonal snow cover in Stage 2	Mean	12.0	>100	2.3 to 2.4
Case 2		Mean+A1B Scenario	10.2	50	2.3 to 2.5
Case 3		Mean+A2 Scenario	10.1	45	2.3 to 2.6
Case 4	50% of seasonal snow cover in Stage 1 ; full seasonal snow cover in Stage 2	Mean	7.2	>100	2.3 to 2.5
Case 5		Mean+A1B Scenario	7.1	46	2.3 to 2.6
Case 6		Mean+A2 Scenario	7.0	35	2.3 to 2.7
Case 7	Full seasonal snow cover both in Stages 1 and 2	Mean	4.0	>100	2.5 to 2.6
Case 8		Mean+A1B Scenario	2.3	35	2.4 to 2.6
Case 9		Mean+A2 Scenario	2.2	30	2.3 to 2.7

As illustrated in Table 8, the permafrost development and presence in the fine PK will depend on the actual climatic conditions, including the average thickness of snow cover over the fine PK surface. The snow cover thickness assumed during the active fine PK placement will have a great impact on the predicted permafrost growth within the fine PK. During the active placement of fine PK in Area 2, the snow cover will vary from location to location over the fine PK surface. It is expected that snow in some areas could be completely melted due to the placement of warm fine PK while full snow cover in other areas may exist. As a reasonable simplification, the cases with an average 50% of seasonal snow cover would be more representative to the actual conditions.

There are some uncertainties in the future air temperature projections at the project site. The air temperature conditions considering the moderate (A1B) climate change scenario would represent reasonably conservative cases.

Figure 2 shows the predicted thermal conditions of the fine PK during the initial fine PK placement in Area 2 for Case 4. Similarly, Figures 3 and 4 present the predicted thermal status of the fine PK during later stages of the active fine PK placement for Case 4.

Figure 5 presents the predicted thermal conditions of the fine PK during the period of Year 2025 to Year 2035 for Case 5. Figure 6 shows the predicted thermal conditions of the fine PK during the period of Year 2040 to Year 2071 for Case 5. It is predicted that no permafrost will exist after Year 2066 for Case 5. Figures 7 and 8 show the predicted seasonal frost penetration into the fine PK in Year 2081 and Year 2119, respectively, for Case 5.

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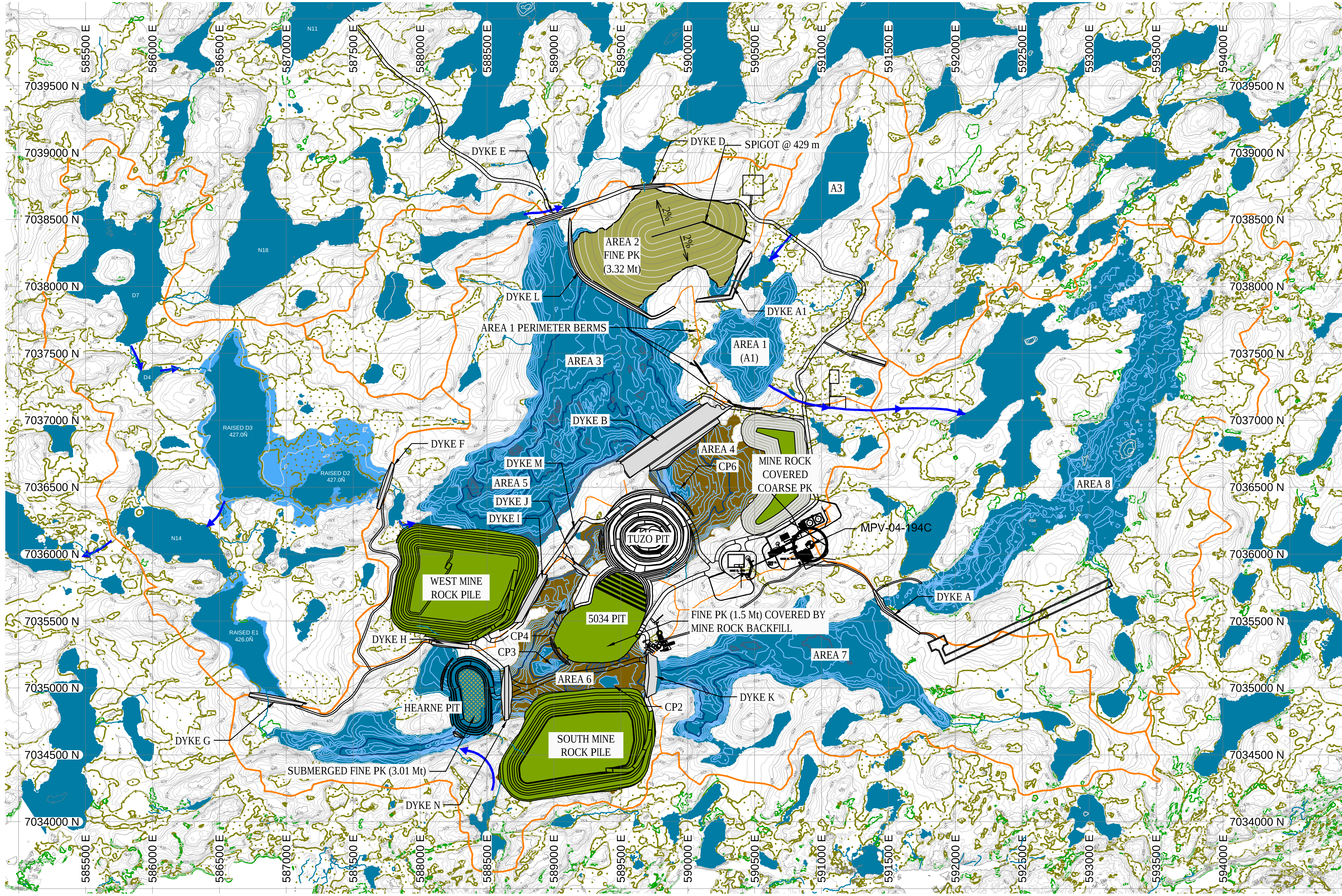
FIGURES



STATUS
ISSUED FOR REVIEW

LEGEND:

- EXISTING GROUND CONTOURS 5 m INDEX - 1 m INTERMEDIATE
- BATHYMETRY CONTOURS 5 m INDEX - 1 m INTERMEDIATE
- CATCHMENT BOUNDARY
- DRAINAGE FLOW DIRECTION
- MARSH AREA
- SCRUB
- LAKE/POND
- DRAINED AREA
- MINE ROCK
- BOREHOLE

ZONE 12, UTM NAD83 PROJECTION CENTRED ON 111Á

0 — 1 000 m
Scale: 1: 30 000

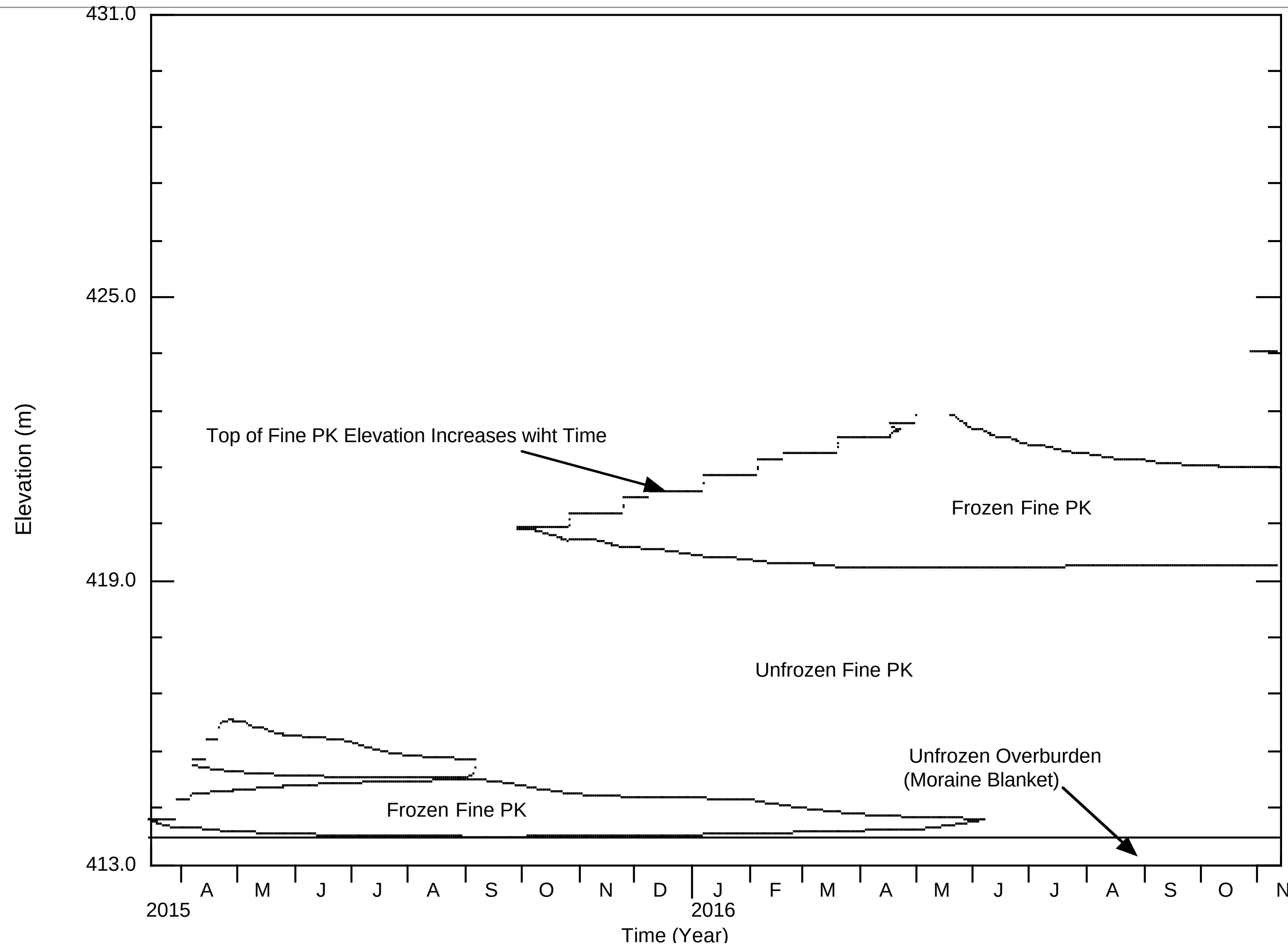
CLIENT
DE BEERS CANADA
MOUNTAIN PROVINCE DIAMONDS INC.
eba A TETRA TECH COMPANY

GAHCHO KUE FINE PK THERMAL ANALYSIS
NWT, CANADA

OPTION 2 FINE PK DISPOSAL PLAN
GENERAL SITE LAYOUT

PROJECT NO.	DWN	CKD	REV	
E14101143	EL	GZ	0	Figure 1
OFFICE	DATE			
EDM	October 3, 2011			

Q:\Edmonton\Drafting\CIVIL3D\E141\E14101143\Production Drawing\Thermal Analysis Memo\E14101143_FIG 1_R0.dwg [FIGURE 1] December 12, 2011 - 2:27:48 pm (BY: LEE, ELVIN)



NOTES

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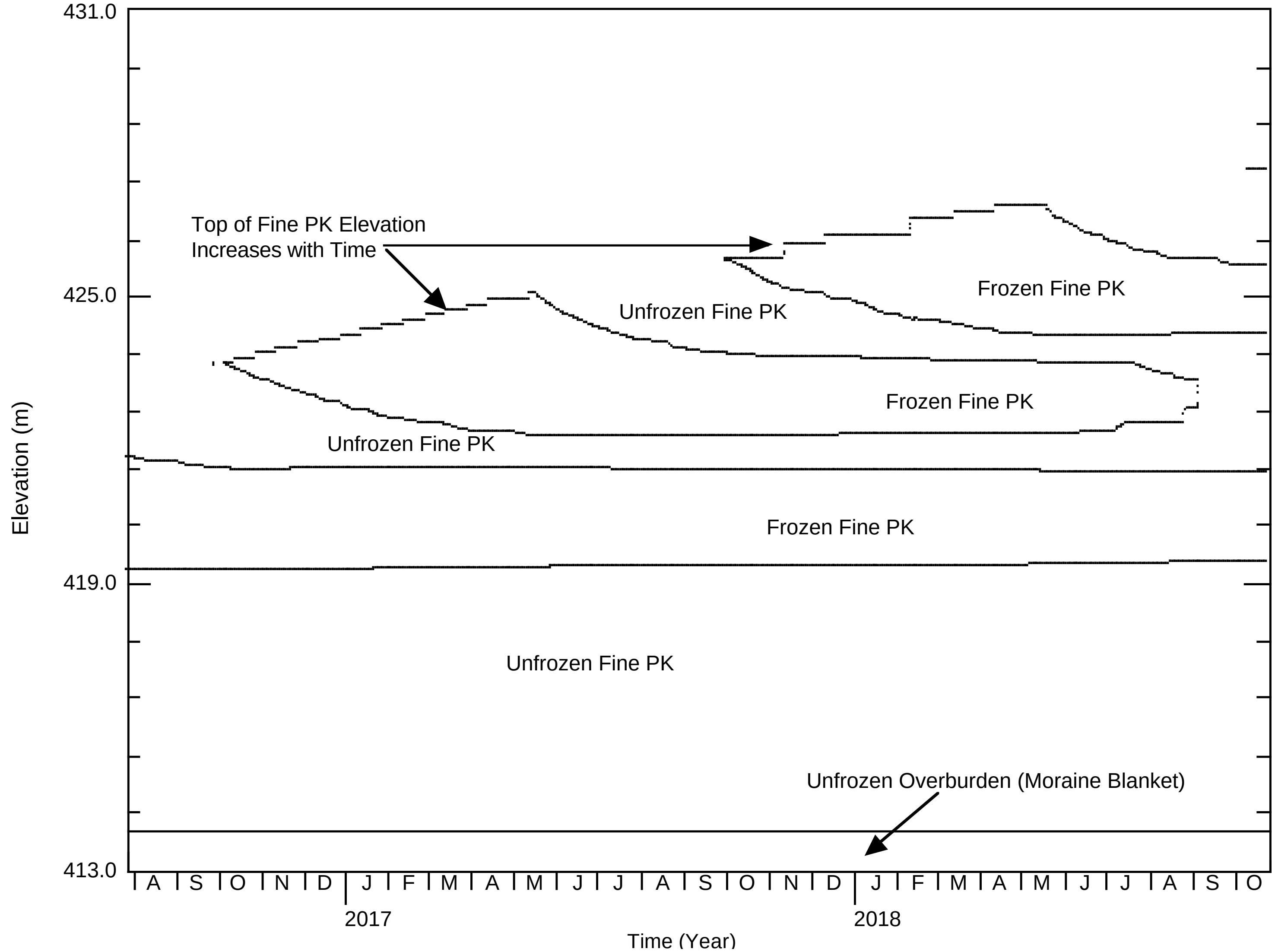
Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Conditions within Fine PK in Area 2 for Case 4 in Stage 1 (from March 2015 to November 2016)

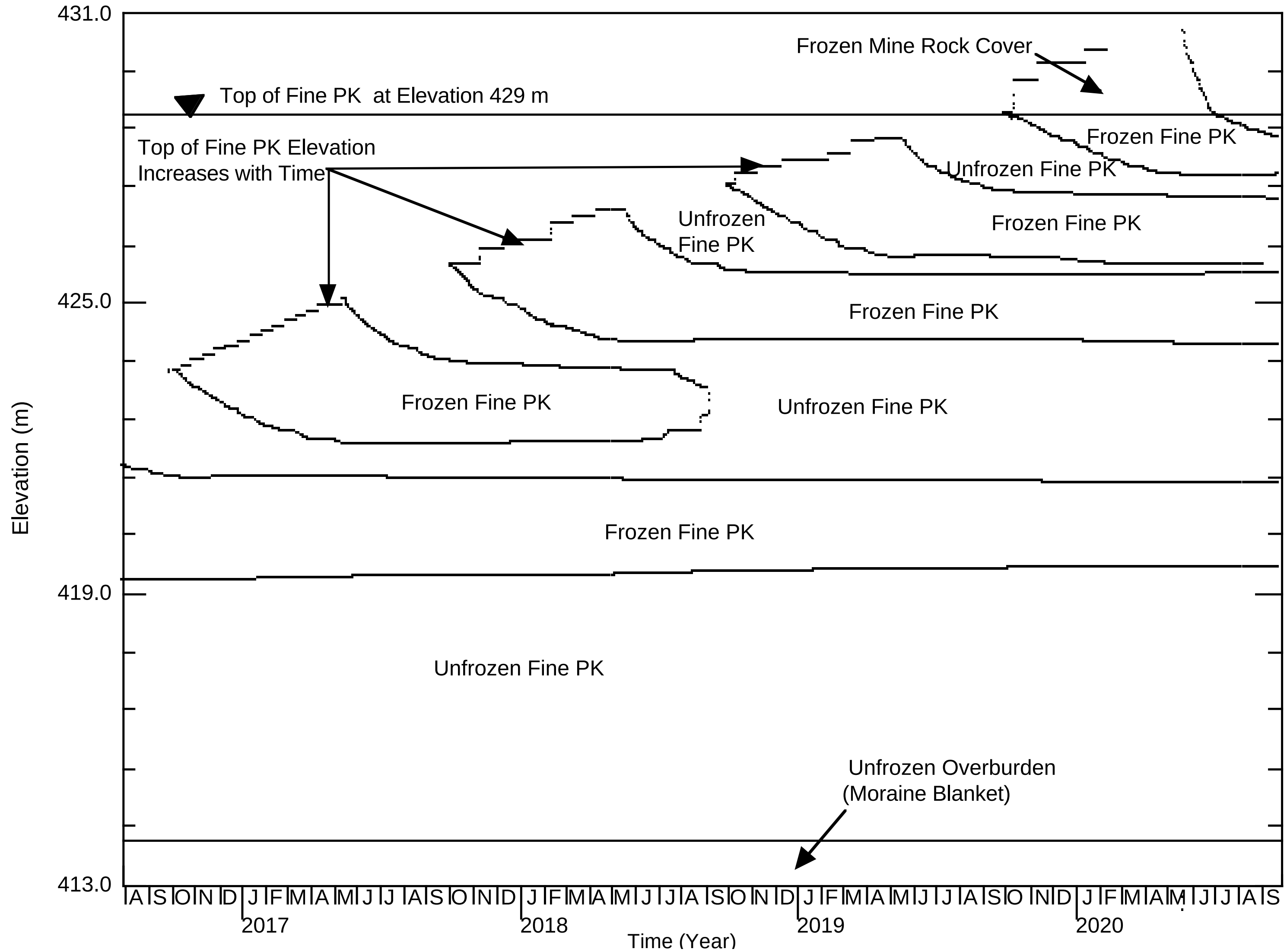
PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		

OFFICE	DATE
EBA-EDMONTON	Dec. 12, 2011

Figure 2



NOTES	CLIENT	Gahcho Kue Fine PK Thermal Analysis, NWT, Canada
	JDS Energy & Mining Inc.	Predicted Thermal Conditions within Fine PK in Area 2 for Case 4 in Stage 1 (from April 2017 to October 2018)
STATUS ISSUED FOR REVIEW	eba A TETRA TECH COMPANY	PROJECT NO. E14101143; DWN HX; CKD GZ; APVD; REV; OFFICE EBA-EDMONTON; DATE Dec. 12, 2011; Figure 3



NOTES

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JDS Energy & Mining Inc.

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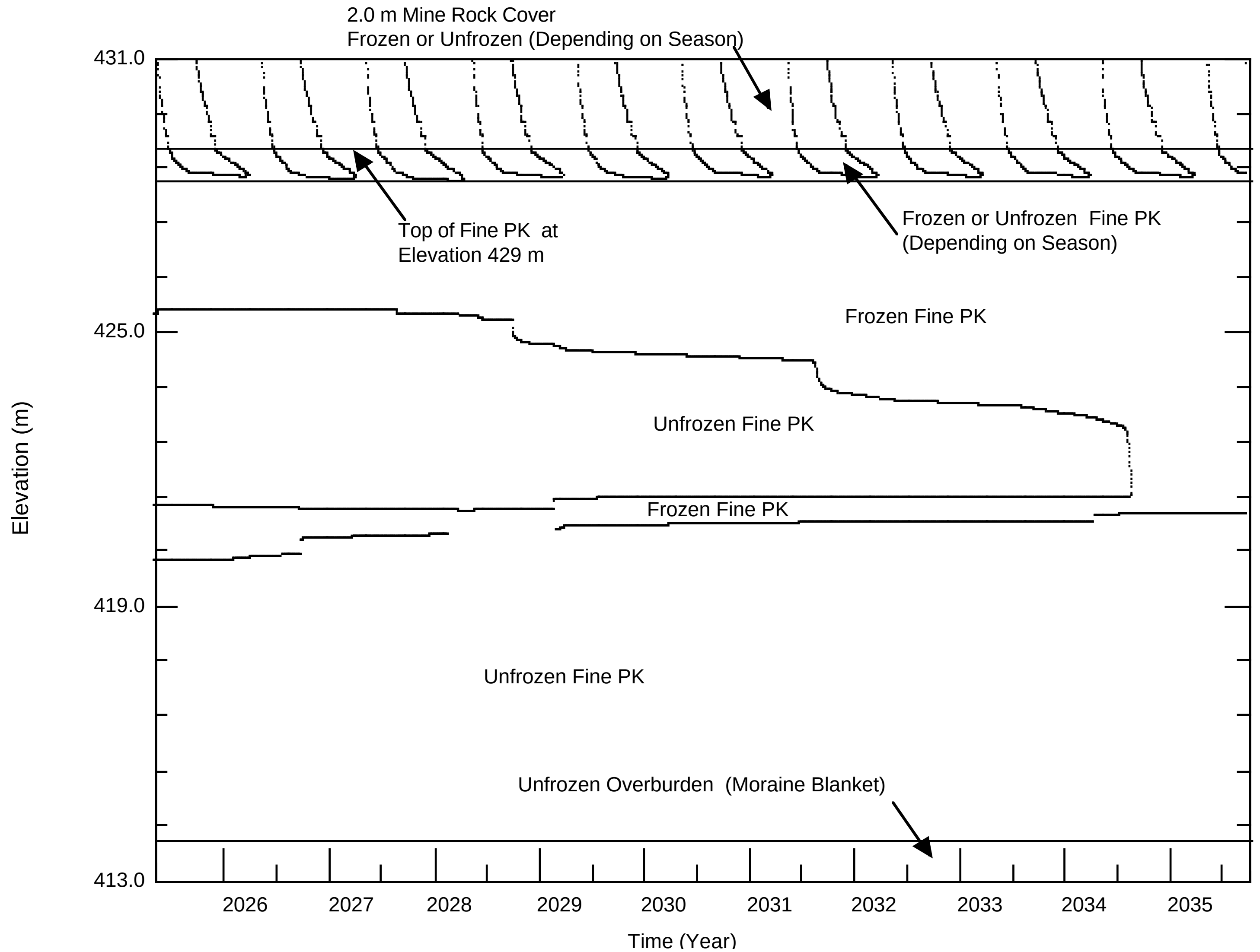
Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Conditions within Fine PK in Area 2 for Case 4 in Stage 1 (from April 2017 to September 2020)

PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		
OFFICE	DATE			
EBA-EDMONTON	Dec. 12, 2011			

Figure 4



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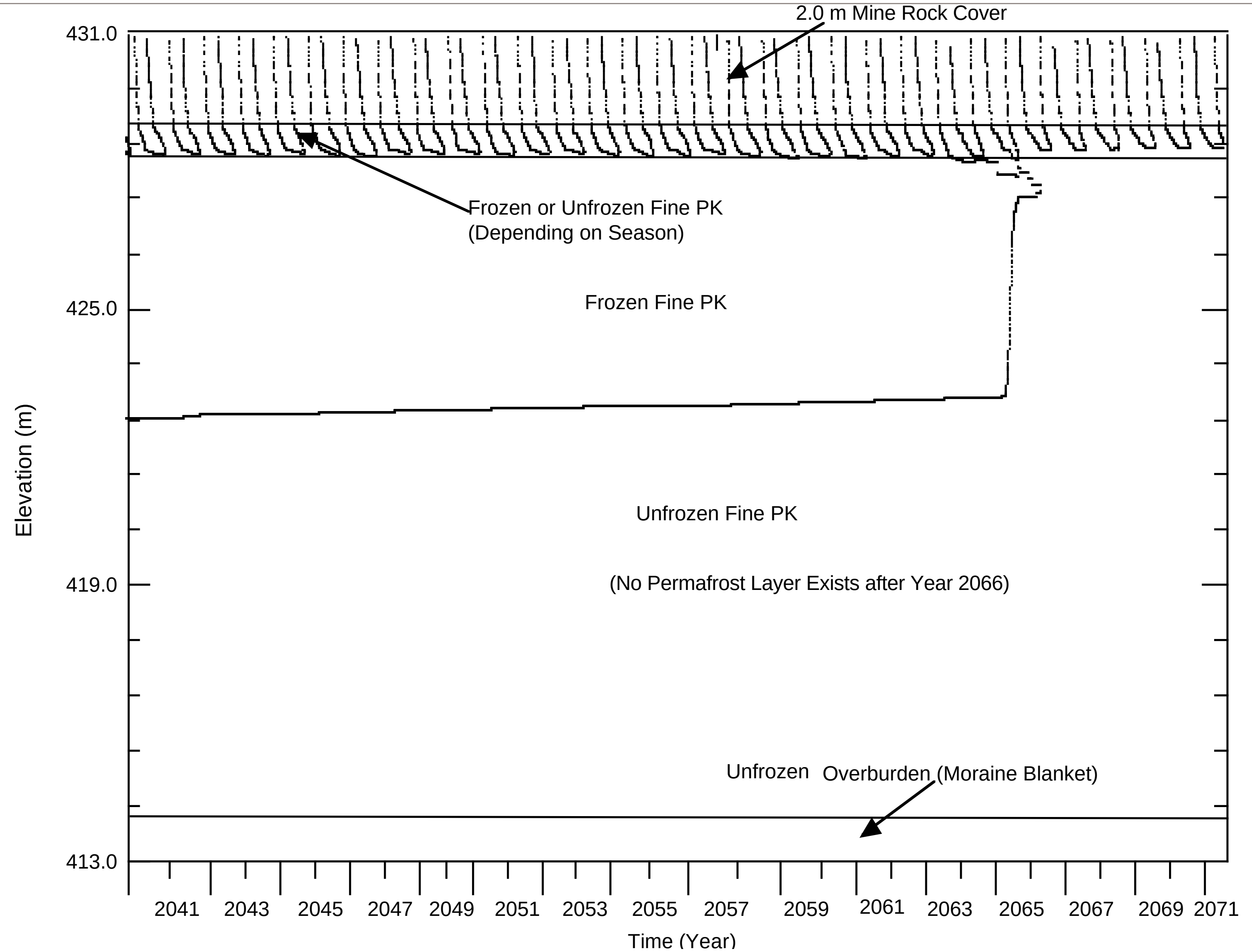
Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Conditions within Fine PK in Area 2 for Case 5 under A1B Climate Change Scenario (from Year 2025 to 2035)

PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		
OFFICE	DATE			
EBA-EDMONTON	Dec. 12, 2011			

Figure 5



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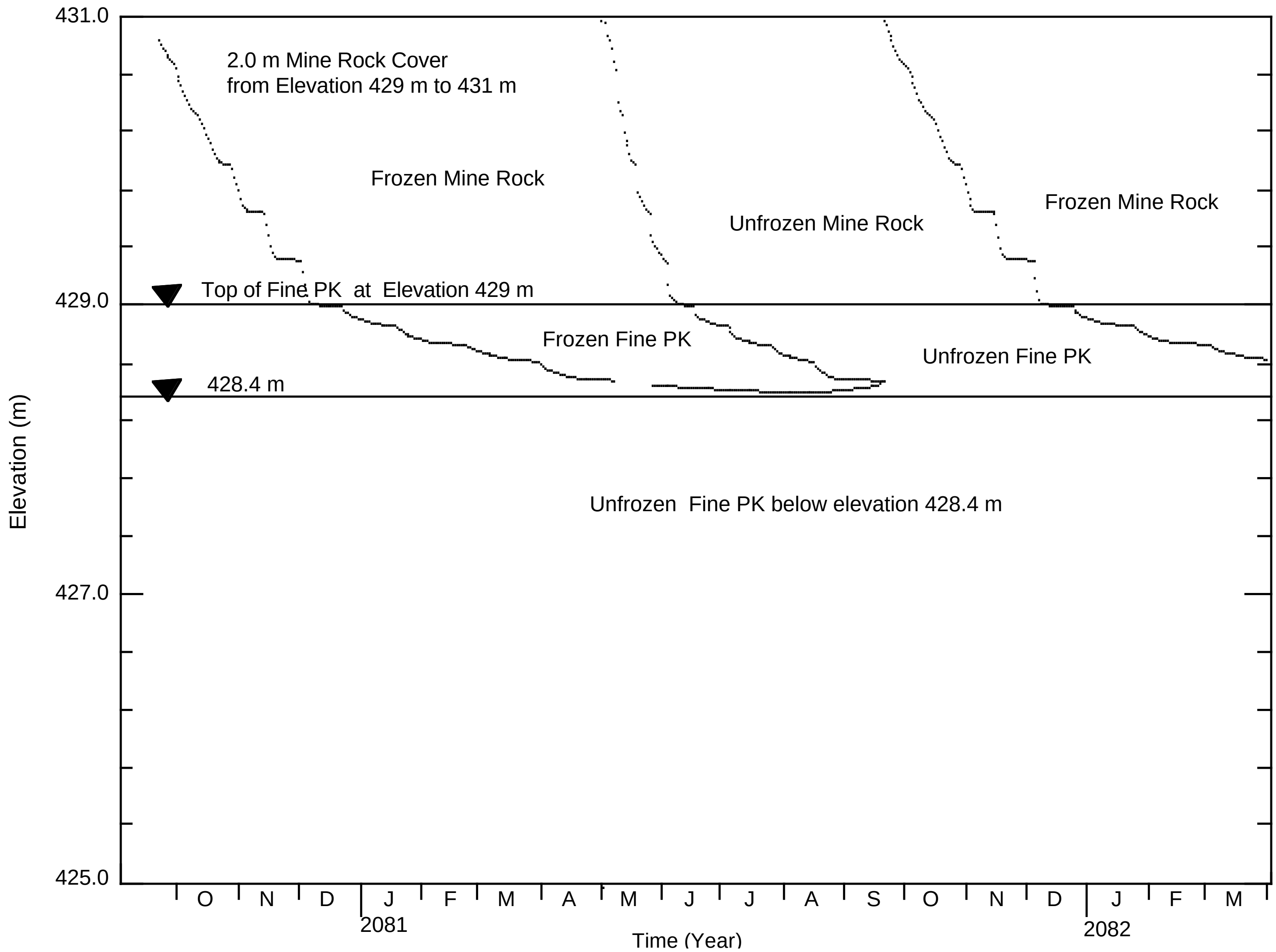
Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Condition within Fine PK in Area 2 for Case 5 under A1B Climate Change Scenario (from Y2040 to Y2071)

PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		
OFFICE	DATE			
EBA-EDMONTON	Dec. 12, 2011			

Figure 6



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Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Condition within Fine PK in Area 2 for Case 5 under A1B Climate Change Scenario (Y2081)

PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		

OFFICE	DATE
EBA-EDMONTON	Dec. 12, 2011

Figure 7

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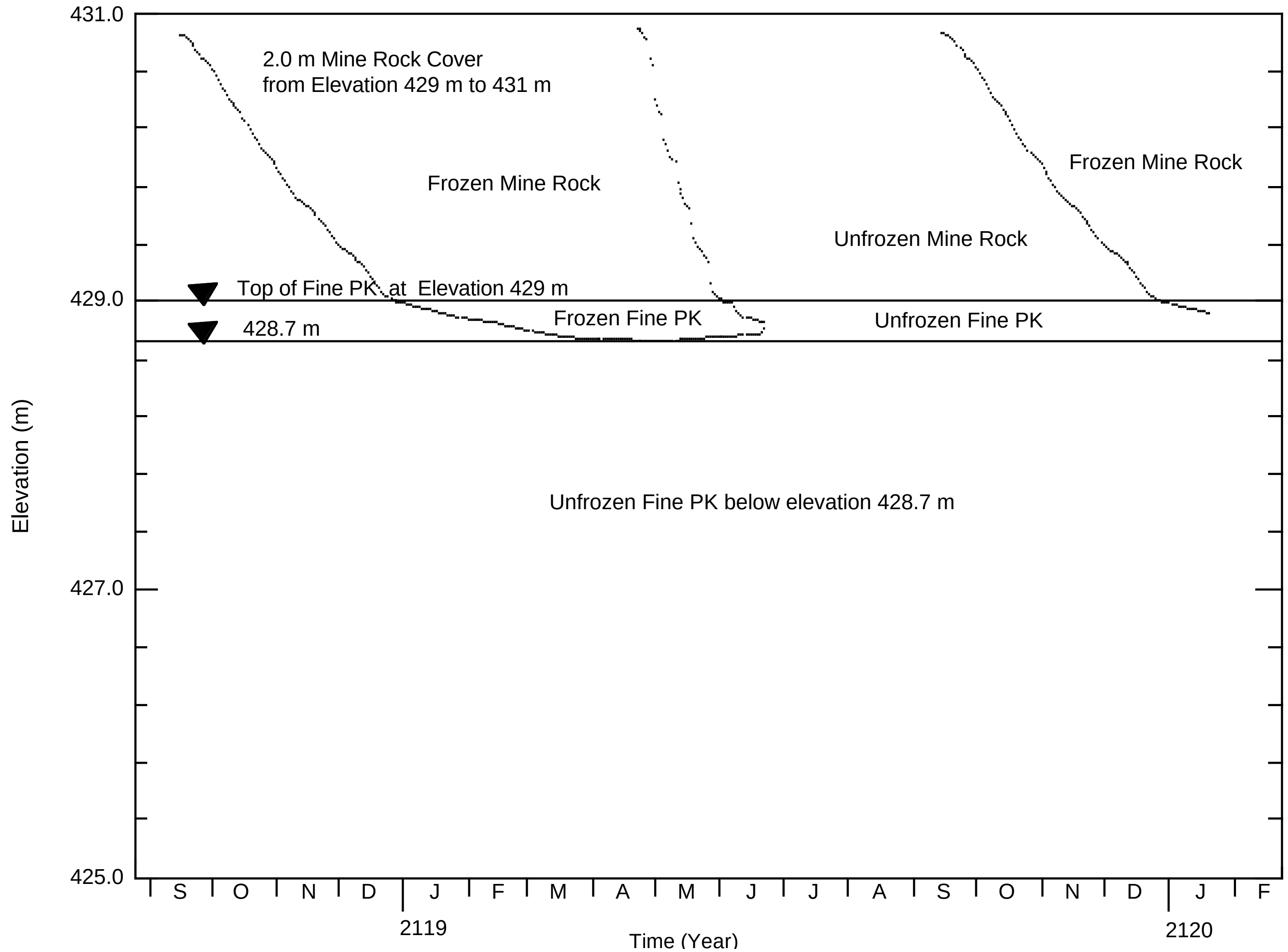

NOTES

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Gahcho Kue Fine PK Thermal Analysis, NWT, Canada

Predicted Thermal Condition within Fine PK in Area 2 for Case 5 under A1B Climate Change Scenario (Y2119)

PROJECT NO.	DWN	CKD	APVD	REV
E14101143	HX	GZ		

OFFICE	DATE
EBA-EDMONTON	Dec. 12, 2011

Figure 8