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B.6 – TERRAIN FEATURES

B.6.1 INTRODUCTION

Section 6 of the Proposal summarized the effects assessment conducted for terrain features at the Project. Terrain features were selected as a Valued Component (VC) by Casino Mining Corporation (CMC) for the Casino Project (the Project) because of their importance to regional and localized ecological processes. The Proposal defines terrain features as the geological surface features, topography, and layers of mineral and organic materials covering the underlying bedrock geology. The assessment focused on potential effects of the Project to three unique types of terrain features: thaw lakes (lakes found in thermokarst that develop in a depression and accumulate either permafrost melt water or rain water), pingos (mounds of earth-covered ice which grow as a result of periglacial processes), and tors (isolated pillar-like rock outcrops situated on ridges, associated with unglaciated terrain). The Proposal concluded that the potential effects of the Project on existing terrain features are considered to be adverse and irreversible; however, the adverse residual effect is considered Not Significant, since the effects will be on individual terrain features and localized to the Project footprint.

The effect of terrain instability on the project was assessment in Section 20 of the proposal. The terrain hazards assessment incorporated terrain mapping, terrain stability mapping and a preliminary assessment of potentially hazardous permafrost-related features. The overall potential effects of terrain instability, in particular permafrost degradation, on the Project is not considered significant. Even though the overall likelihood of occurrence has been determined to be HIGH and is likely to occur over the life of the Project, the consequence of the most likely event is considered to be LOW because Project components, activities and critical services are not anticipated to be interrupted for more than 24 hours with the implementation of proposed mitigation measures.

On January 27, 2015, the Executive Committee requested that CMC provide supplementary information to the Casino Project (YESAB Project No. 2014-0002) to enable the Executive Committee to commence Screening. The Executive Committee considered comments from various First Nations, Decision Bodies and regulators on the adequacy of the Project Proposal in the preparation of the Adequacy Review Report (ARR). CMC provided a Supplementary Information Report (SIR-A) on March 16, 2015. Subsequently, the Executive Committee issued a second Adequacy Review Report (ARR No.2) on May 15, 2015 following a second round of review. CMC is providing this Supplementary Information Report (SIR-B) to comply with the Executive Committee's Adequacy Review Report ARR No.2; CMC anticipates that the information in the two SIRs and in the Proposal, when considered together, is adequate to commence Screening.

The Executive Committee has eight requests related to information presented in Section 6 Terrain Features and Section 20 Effects of the Environment on the Project: Terrain Instability of the Project Proposal and Section A.6 Terrain Features of the SIR-A. These requests and the corresponding sections of the SIR where the responses can be found are outlined in Figure B.6.1-1.

Figure B.6.1-1 Requests for Supplementary Information Related to Terrain Features

Request #	Request for Supplementary Information	Response
R2-89	Clarification if permafrost berms will be used for tailing ponds and if so, how they will be managed to ensure they are secure.	Section B.6.2.1.1
R2-90	A description of the mitigations that will be used with respect to valley slopes and permafrost.	Section B.6.2.1.2
R2-91	A geothermal analysis and associated methodology that predicts response to the proposed TMF and associated infrastructure on	Section B.6.3.1.1

Request #	Request for Supplementary Information	Response
	permafrost conditions, considering the following: a. Heat generated from the waste rock and processed ore after disposal. b. Potential for solifluction, active layer detachment flows and similar mass wasting processes to occur at slope adjacent areas and embankments. c. Freezing and thawing of mine tailings and embankment soil. d. If the TMF is founded on permafrost soils that are too deep to excavate, creep deformation of those permafrost soils a result of the placement of the TMF should be considered. e. Characterization of the subgrade under any containment structures is critical. Issues of geothermal state (frozen or unfrozen), ground temperature, unfrozen water content, salinity, creep strength and others may be important as part of the assessment process. f. Effects of the proposed project on geothermal regime.	
R2-92	Additional details in relation to temperatures data, trends and ground temperature monitoring for the Freegold Road Extension including: a. A discussion regarding possible warming trend in the near surface based on the available ground temperature data. For example: Does the post 1994 ground temperature data exhibit any warming trend in the near surface temperatures? Is the active layer thickening? b. If thermistors were installed in 2011 and 2012, up to four years of ground temperature data has been collected. Please report on this data. c. If the 1994 thermistor cables are in the same location as the 2011 and 2012 thermistor cables. Please combine the data and provide some inferences as to long-term trends in mean annual ground temperatures. d. The installation of thermistor strings to monitor ground temperatures and develop “trumpet curves” is an appropriate development by CMC. These data should be used to establish baseline mean annual ground temperatures values.	Section B.6.4.1.1
R2-93	A reference to the legend used in the baseline terrain maps as well as a simpler interpretation (label) of the units, especially those with multiple capital letters and integers.	Section B.6.5.1.1
R2-94	A Hazard Map and associated methodology that: a. Predicts the type, nature, frequency and magnitude of all hazards in the study area. b. Where the study area is bound by moderate to steep slopes please modify the terrain map and the terrain stability map to include upslope areas (to the height of land). Note: In the case of the road, this only need apply to the side of the valley that supports the road. c. Where the study area is bound by moderate to steep slopes please increase the detail of the mapping to capture areas commonly associated with hazards such as gullies but not currently mapped. d. From the map above, if appropriate, identify specific risks to the project. e. From the map above, if appropriate, identify specific risks to the environment from the project. f. Based on the risk identified in response to the questions above, please provide general options and considerations for engineering design to mitigate the identified risks.	Section B.6.5.1.2
R2-95	Additional details in relation to terrain hazards assessment including: a. Table 1, Table 2, Figure 1, and Figure 2 referenced to in the Fluvial Geomorphology report.	Section B.6.6.1.1

Request #	Request for Supplementary Information	Response
	b. More detail on river ice buildup, ice jams, and thermokarst processes in relation to the proposed Freegold Road extension, Airstrip Access Road. c. Watershed characteristics (watershed area, watershed length, relief, and melton ratio) for each road crossing of a side channel feeding into the main valley and provide comment on dominant depositional process at each crossing. d. A correlation of lateral migration rate descriptors to an actual measured rate of migration (i.e. low = 0 to 0.1 m/year).	
R2-96	A soil erosion potential analysis for the LSA that includes the component of thermal erosion where permafrost is identified as being present.	Section B.6.6.1.2

B.6.2 PERMAFROST

B.6.2.1.1 R2-89

R2-89. Clarification if permafrost berms will be used for tailing ponds and if so, how they will be managed to ensure they are secure.

Permafrost berms are not proposed for the tailings management facility (TMF).

In relation to the TMF area, permafrost is discontinuous over the TMF embankment area, and is primarily present at the valley bottom, north-facing slopes and shaded areas. The ridges at higher elevations and upper slopes on the west abutment are southeast-facing, and are generally free of permafrost except for some local shaded areas. Permafrost is common in the northwest-facing east abutment area, where test pits were terminated at shallow depths in frozen colluvium and residual soils. Permafrost occurs as thin ice lenses in fine grained soils and as small ice wedges in broken rock.

Permafrost is abundant in the organic, silty colluvial apron of the Casino Creek and tributary valley bottoms. The overburden is generally saturated and frozen in these areas, with high ice contents. The site investigation data also indicated ground ice close to tributaries leading to Casino Creek. Alluvium lies at surface in very close proximity to Casino Creek, where it is not frozen as indicated by the presence of tall grasses and willows, and the absence of thick mosses. These areas are discontinuous and likely result from the historic shifting of the creek channel which acts to maintain a thawed region under the creek.

As it relates to construction of major infrastructure, thawing of ice-rich soils may lead to excessive settlements, and loss of strength. The ice-rich soils typically exhibit very low strengths when thawed, and flow even under very flat slopes. Two gelifluction lobes that were observed within the colluvial apron in the TMF embankment area are evidence of this potential for instability. Ice-rich soils also have the potential for long term creep displacements. Additionally, disturbance or removal of the vegetative cover may result in the melting of permafrost and the development of unstable conditions. Frozen overburden and bedrock that are underlying part of the tailings impoundment and embankments are expected to thaw over time, as the tailings and water stored in the TMF will act as a heat source.

Other mechanisms through which permafrost may impact the stability of mine infrastructure includes ground ice. Ground ice is not expected to be significant in bedrock which will likely provide a stable foundation for the embankments. Preferential seepage paths may develop when ice filled discontinuities thaw. If monitoring indicates that this is occurring, the bedrock may have to be steamed and grouted during foundation preparation.

Therefore, foundation preparation for the TMF embankments will involve the stripping of topsoil and vegetation and the removal of all talus boulders. The topsoil will be stockpiled for reclamation purposes. The underlying frozen soils will be excavated down to a competent, stable bedrock or non-frost susceptible overburden foundation. Ice-rich and frost-susceptible materials will be removed to spoil and are expected to be unsuitable for use as borrow in embankment construction. The ice-rich spoil material will be placed in the TMF impoundment.

The embankment footprint area that covers colluvial apron or other ice-rich overburden will be excavated to competent foundation, absent of frost susceptible soil. The removed material will be replaced with core, filter or shell zone material, depending on the location relative to the embankment. The average thickness of the colluvial apron is expected to be approximately 10 metres based on the findings of the site investigations.

A low permeability cut-off is required beneath the core zone of the Main Embankment and West Saddle Embankment at locations where no colluvial apron or other ice rich soil is present, to provide an effective seepage control barrier. The seepage cut-off trench will extend through the foundation soils and key into competent bedrock, at an average depth of about three meters for both the Main and West Embankment.

Further details on the foundation preparation of the TMF embankment are provided in Appendix A.4D.

B.6.2.1.2 R2-90

R2-90. A description of the mitigations that will be used with respect to valley slopes and permafrost.

Engineering considerations to be incorporated into detailed design with respect to permafrost are described below.

Access Road

- In areas where the alignments traverse areas of known or suspected ice-rich soils, permafrost degradation effects can be mitigated by constructing the road/air strip on an embankment of non frost susceptible fill.
- The natural vegetation cover of sphagnum moss should be kept in place, wherever possible, to provide the maximum protection to the thermal regime. Winter construction is preferred in these areas.
- For summer construction, woven geotextile may need to be laid over thaw unstable ground, prior to placement of the fill.
- To mitigate sedimentation and erosion in areas of silty and organic soils (e.g., colluvial aprons and organic swamps on the flood plains of major watercourses), such soils should be left in place, wherever possible, with the surface cover of sphagnum moss intact and the road constructed on an embankment of non-frost susceptible fill.
- Develop robust erosion and sediment control plans in any areas where soils are to be disturbed.
- In areas where solifuction is particularly prevalent (e.g., moderate, north-facing colluvial slopes), the road should be constructed on an embankment that effectively buttresses the natural slope.
- Where the access road alignment traverses a solufuction lobe in, the alignment may need to be re-routed slightly upslope or downslope.
- Minimize cut slopes to mitigate the risk of permafrost degradation.
- Detailed drainage design for the road should consider the shallow permafrost table in the north-facing colluvial mid-slopes and the colluvial aprons.

Airstrip

- Complete additional boreholes along the airstrip alignment as part of the detailed design to further investigate the extent of ice-rich soils and to facilitate the installation of thermistors.
- Incorporate additional measures into the detailed design of the airstrip to management expected surface and shallow subsurface water flows and limit long-term thaw and/or creep settlements and displacements associated with the presence of ice-rich soils and massive ground ice (e.g., flattening or buttressing the side slopes of the embankment).
- Implement drainage measures to prevent water ‘ponding’ at the upslope toe of the embankment.
- Monitor the performance throughout the design-life of the airstrip against to-be-determined performance criteria.

Mine Site

- The surface water management strategies implemented should prevent water accumulating in the natural terrain adjacent to the proposed facilities in areas of known or suspected ice-rich soils. Ditching at the toe of embankments should be avoided in areas of known or suspected ice-rich soils.
- Ice-rich portions of the colluvial apron deposits within the proposed footprint area of the tailings embankment will need to be removed prior to the construction of the embankment, and replaced with non-frost susceptible fill.
- Additional site investigation is required in order to enhance the understanding of the ground conditions at the proposed embankment site and to facilitate a reasonably accurate estimate of the volume of unsuitable material needing to be removed, spoiled and replaced.
- In areas mapped “potentially unstable” and “unstable”, the natural vegetation cover should be kept in place to provide the maximum protection to the thermal regime. For summer construction, a woven geotextile may need to be laid over thaw unstable ground, prior to placement of fill. In areas where vegetation needs to be removed, winter construction is recommended for the initial lifts.

To prevent impacts due to permafrost degradation on the short term and long term stability of proposed mine infrastructure, the footprints of the mine infrastructure will be stripped of the surficial soils that may otherwise contribute to instability. In general, construction and site preparation techniques on permafrost require frozen, organic and ice-rich colluvium and residual soils to be ripped, blasted and/or excavated to competent, non-frost susceptible bedrock for subgrade preparation. All ice-rich overburden and heavily weathered rock will be removed to prevent potential thaw-settlement resulting from melting permafrost. The exposed bedrock will provide a thaw-stable foundation for mine infrastructure.

In support of future refinement in the Project design and future construction activities, ground temperature data are currently being collected at a number of locations across the site using thermistor strings and data loggers that were installed in vertical drillholes. Continued monitoring in the operations phase will allow for identification of real-time changes in permafrost conditions that may be connected with climate change. The need for additional mitigations for permafrost degradation to ensure the stability of the slopes of the upper Casino Creek valley will be assessed in detailed design taking into account the additional ground temperature data currently being collected.

During operations, monitoring of site facilities will include vibrating wire type piezometers installed in the embankment fill, foundations and tailings deposit to measure pore water pressures during initial placement, throughout operations and postclosure. The piezometers will be distributed throughout the various foundation and fill zones to provide a spectrum of monitoring data. Thermistors may be required to determine the temperature profile to supplement piezometer data. The piezometer and thermistor leads will be appropriately routed to read-out panels for ease of monitoring. Movement monuments will be installed on the embankment crest following the completion of selective embankment raises to monitor deflections along the slope and crest of the embankment. Periodic surveying of the monument locations will provide early warning of movements and possible acceleration of movement which often occurs prior to failure.

Valley slopes in the area of the tailings management facility no excavated to bedrock are known to be primarily comprised of colluvial veneer. The nature of colluvium, i.e. material that has been transported down slopes, causes local variations in the composition. The downslope migration also causes organic material to be included in the deposit at some locations. The organic content generally increases down-slope. On north facing slopes, the colluvial veneer is mostly frozen.

Climate warming may lead to thawing of the north facing valley slopes, and the thawing may be exacerbated, to some extent, by the placement of tailings and PAG waste rock. Thaw flows and solifluction lobes may develop locally (particularly in the restricted north-facing slopes). The impacts of thawing of the frozen north slopes will be contained within the TMF, and retained by the TMF embankment, which is constructed on competent bedrock. Additionally, CMC will prepare a Permafrost Management Plan (PMP) that will be submitted as part of the Quartz Mining Licence application. Other requirements for definition of permafrost management and site preparation details as part of the Quartz Mining Licence application include the Site Characterization Plan (soil and bedrock section), Environmental Monitoring, Surveillance and Reporting Plan (terrestrial monitoring section), Mine Development and Operations Plan (site preparation section), Mill Development and Operations Plan (site preparation section), Heap Leach and Process Facilities Plan (site preparation and construction quality assurance/quality control section), Tailings Management Plan (site preparation and construction quality assurance/quality control section), and in the Waste Rock and Overburden Management Plan (foundation conditions and construction quality assurance/quality control section).

B.6.3 THERMAL EROSION MODELING

B.6.3.1.1 R2-91

R2-91. A geothermal analysis and associated methodology that predicts response to the proposed TMF and associated infrastructure on permafrost conditions, considering the following:

a. Heat generated from the waste rock and processed ore after disposal.

b. Potential for solifluction, active layer detachment flows and similar mass wasting processes to occur at slope adjacent areas and embankments.

c. Freezing and thawing of mine tailings and embankment soil.

d. If the TMF is founded on permafrost soils that are too deep to excavate, creep deformation of those permafrost soils a result of the placement of the TMF should be considered.

e. Characterization of the subgrade under any containment structures is critical. Issues of geothermal state (frozen or unfrozen), ground temperature, unfrozen water content, salinity, creep strength and others may be important as part of the assessment process.

f. Effects of the proposed project on geothermal regime.

Further geothermal analysis has not been conducted for the proposed TMF, for reasons described below.

Geotechnical site investigation programs were conducted in the area of the TMF in 1993, 1994, 2010, 2011 and 2012. The programs included drillholes and test pits to investigate the geotechnical characteristics and foundation conditions. The programs included 27 geotechnical drillholes in the TMF area, in situ packer, falling head permeability tests, shut-in pressure tests, groundwater monitoring well, test pit samples with subsequent laboratory testowork for particle size, moisture content, Atterberg limits, specific gravity, flexible wall permeability triaxial shear and compaction tests. Further details on the site investigation results are provided in Appendix A.4D.

The results of the geotechnical site investigation programs indicated that permafrost is discontinuous over the TMF embankment area, and is primarily present at the valley bottom, north-facing slopes and shaded areas. The ridges at higher elevations and upper slopes on the west abutment are southeast-facing, and are generally free of permafrost except for some local shaded areas.

Permafrost is common in the northwest-facing east abutment area, where test pits were terminated at shallow depths in frozen colluvium and residual soils. Permafrost occurs here as thin ice lenses in fine grained soils and as small ice wedges in broken rock.

Permafrost is abundant in the organic, silty colluvial apron of the Casino Creek and tributary valley bottoms. The overburden is generally saturated and frozen in these areas, with high ice contents. Massive ice layers were encountered in the colluvial apron in DH11-23A. The massive ice was also identified in the ground penetrating radar (GPR) data in more than half of the survey line length along the valley bottom. The GPR data also indicated ground ice close to tributaries leading to Casino Creek. Alluvium lies at surface in very close proximity to Casino Creek, where it is not frozen due to the presence of a talik (permanently unfrozen ground). Permafrost is also absent in localized areas along Casino valley as indicated by the presence of tall grasses and willows, and the absence of thick mosses. These areas are discontinuous and likely result from the historic shifting of the creek channel which acts to maintain a thawed region under the creek.

This information lead to the following conclusions on the impact of permafrost:

- Thawing of ice-rich soils may lead to excessive settlements, and loss of strength. The ice-rich soils typically exhibit very low strengths when thawed, and flow even under very flat slopes. Two gelifluction lobes that were observed within the colluvial apron in the TMF embankment area are evidence of this potential for instability. Ice-rich soils also have the potential for long term creep displacements.
- Disturbance or removal of the vegetative cover may result in the melting of permafrost and the development of unstable conditions. Frozen overburden and bedrock that are underlying part of the tailings impoundment and embankments are expected to thaw over time, as the tailings and water stored in the TMF will act as a heat source. It is therefore recommended that all ice-rich overburden encountered during construction be removed along the entire foundation of the TMF embankments.
- Ground ice is not expected to be significant in bedrock which will provide a stable foundation for the embankments. Preferential seepage paths may develop when ice filled discontinuities thaw.
- Permafrost has an important effect on hydrogeology. Saturated frozen soil and rock have a much lower permeability when frozen compared to a thawed or unfrozen state. In situ hydraulic conductivity test results showing very low hydraulic conductivities potentially indicate frozen soil or rock.

Mitigation measures incorporated into the design of the TMF embankment are as follows:

- Bedrock may have to be steamed and grouted if ground ice is significant in bedrock.
- Permafrost and frost susceptible materials should be avoided when sourcing core zone borrow materials.

Recommendations for future studies include:

- Thermistors installed during the 2011 and 2012 site investigations will provide a better understanding of the thermal regime in the bedrock.
- Additional site investigations will be required to confirm the characteristics of the overburden and bedrock, and the extent of permafrost within the TMF embankment area.
- Thermal modelling may also be required to predict the effect of the proposed TMF on foundation conditions, depending on the results of the additional site investigations and the thermistor monitoring.

Geothermal analyses are an important part of the design process. If foundation conditions are suspected to be susceptible to the effects of thermal erosion, after the removal of permafrost to non-frost susceptible bedrock, additional site investigation and detailed thermal analysis will be completed and additional mitigations measures will be applied if required.

Results of on-going geothermal analysis will be incorporated into the Permafrost Management Plan that will be submitted as part of the Quartz Mining Licence application. Other requirements for definition of permafrost management and site preparation details as part of the Quartz Mining Licence application include the Site Characterization Plan (soil and bedrock section), Environmental Monitoring, Surveillance and Reporting Plan (terrestrial monitoring section), Mine Development and Operations Plan (site preparation section), Mill Development and Operations Plan (site preparation section), Heap Leach and Process Facilities Plan (site preparation and construction quality assurance/quality control section), Tailings Management Plan (site preparation and construction quality assurance/quality control section), and in the Waste Rock and Overburden Management Plan (foundation conditions and construction quality assurance/quality control section).

B.6.4 GROUND THERMAL CONDITION AND PERMAFROST TEMPERATURE MONITORING

B.6.4.1.1 R2-92

R2-92. Additional details in relation to temperatures data, trends and ground temperature monitoring for the Freegold Road Extension including:
a. A discussion regarding possible warming trend in the near surface based on the available ground temperature data. For example: Does the post 1994 ground temperature data exhibit any warming trend in the near surface temperatures? Is the active layer thickening?
b. If thermistors were installed in 2011 and 2012, up to four years of ground temperature data has been collected. Please report on this data.
c. If the 1994 thermistor cables are in the same location as the 2011 and 2012 thermistor cables. Please combine the data and provide some inferences as to long-term trends in mean annual ground temperatures.
d. The installation of thermistor strings to monitor ground temperatures and develop “trumpet curves” is an appropriate development by CMC. These data should be used to establish baseline mean annual ground temperatures values.

The introduction to request R2-92 in ARR-2 comments on the ground temperature data, trends and ground temperature monitoring for the Freegold Road Extension, however, questions a. through d. relate to thermistors installed in and around the mine site. To clarify, a geotechnical site investigation is *planned* for the Freegold Road Extension and may include the installation of thermistors to monitor ground temperature, but has not yet been completed. The plan includes installation of thermistors in the swamp areas on the valley floors where the permafrost table is expected to be close to ground surface and the potential is greater for massive ground ice. The thermistor data for these areas will be used to analyze the permafrost conditions and design the insulating embankment upon which the road is to be constructed. The plan also includes installation of thermistors at several bridge sites to determine the permafrost conditions and to investigate the possibility of frost jacking of piles.

The responses to questions a. through d. as they relate to thermal monitoring around the mine site are provided below:

a. Six thermistor strings were installed in drillholes in June through August 1994. Data at each of these locations was only manually downloaded once or twice per month until December 1994 or January 1995. All of the six 1994 thermistor strings have been reportedly damaged or lost and none are currently functioning (Appendix 7C). The available ground temperature readings for thermistor cables installed in 1994 are provided in Figure B.6.4-1 through Figure B.6.4-6, for each sampling month. Temperatures below zero were recorded in the deposit area at 94-321, 94-331, and 94-334, and downstream of the proposed TMF Embankment at 94-349. Recorded temperatures were above zero at sensors 94-344 and 94-355 located in Casino Creek Valley.

The Executive Committee has requested that temperature data from 1994 thermistor sites be compared against adjacent locations with existing data sets, such as at 94-349 and DH12-03, to assess impacts of recent climate warming. While the two thermistor strings 94-349 and DH12-03 are the closest together of the 1994 and more recent thermistor installations, they are located approximately 260 m apart and on opposite sides of Casino Creek valley. The inferred base of permafrost at 94-349 was 29 mbgs based on the available 1994 data (Figure B.6.4-5). The inferred base of permafrost at DH12-03 is 43 mbgs based on data collected from 2012 to 2014 (Figure B.6.4-7). Since comparison of the two data sets shows the opposite trend as would be expected due to climate warming, impacts of recent climate warming are unable to be inferred by their comparison. Unfortunately, no other 1994 thermistor locations are proximal to locations where temperature data has been more recently recorded.

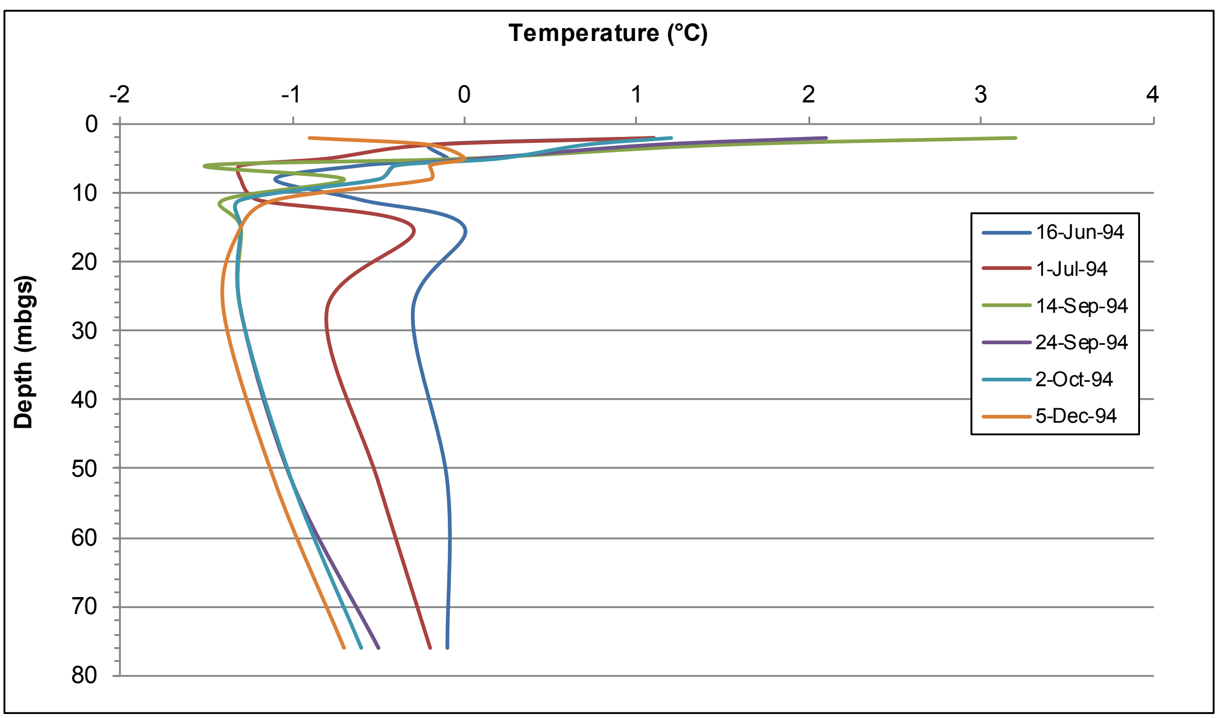

Figure B.6.4-1 Ground Temperature with Depth at 94-321

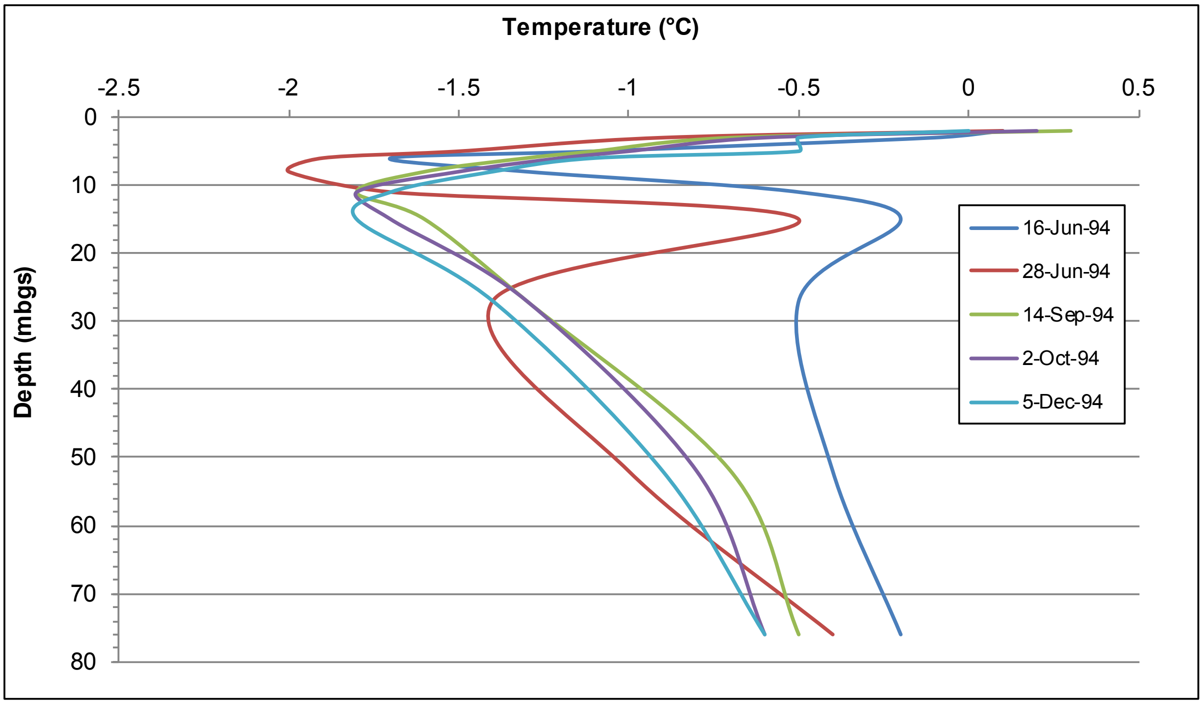

Figure B.6.4-2 Ground Temperature with Depth at 94-331

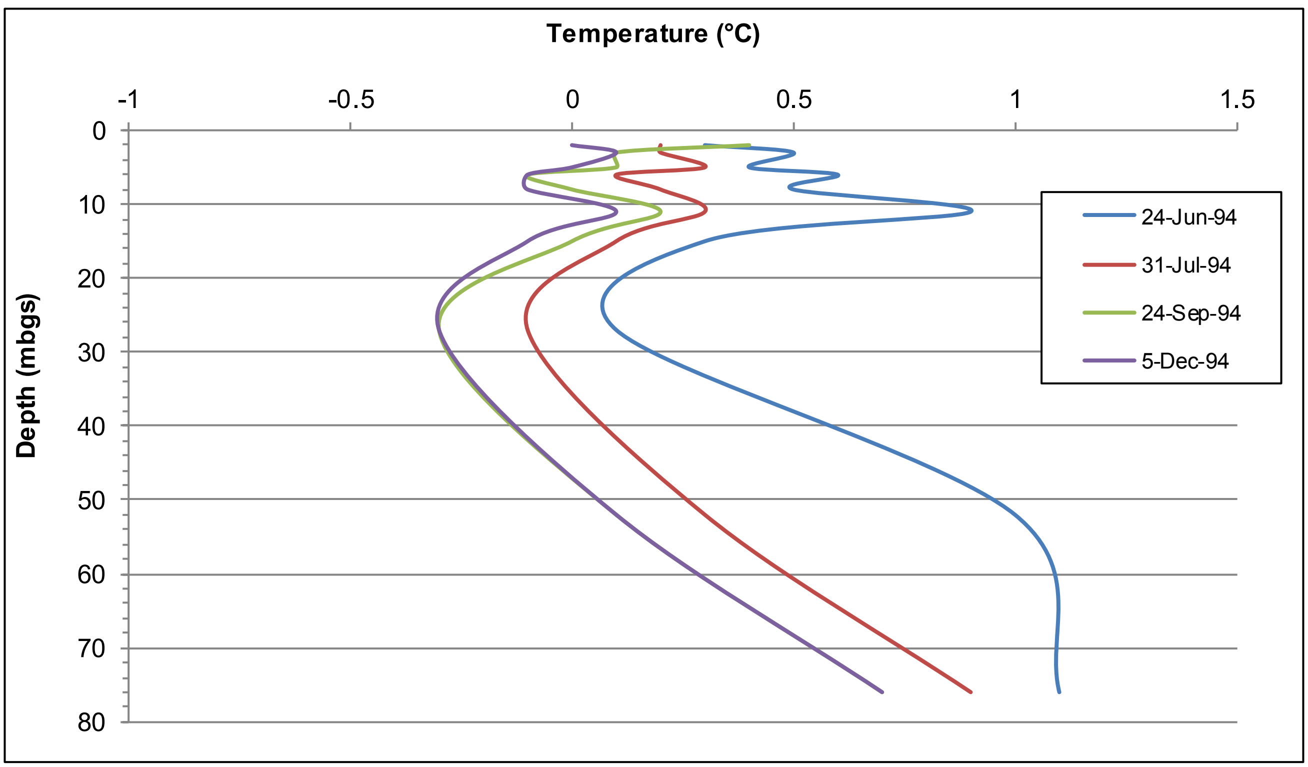

Figure B.6.4-3 Ground Temperature with Depth at 94-334

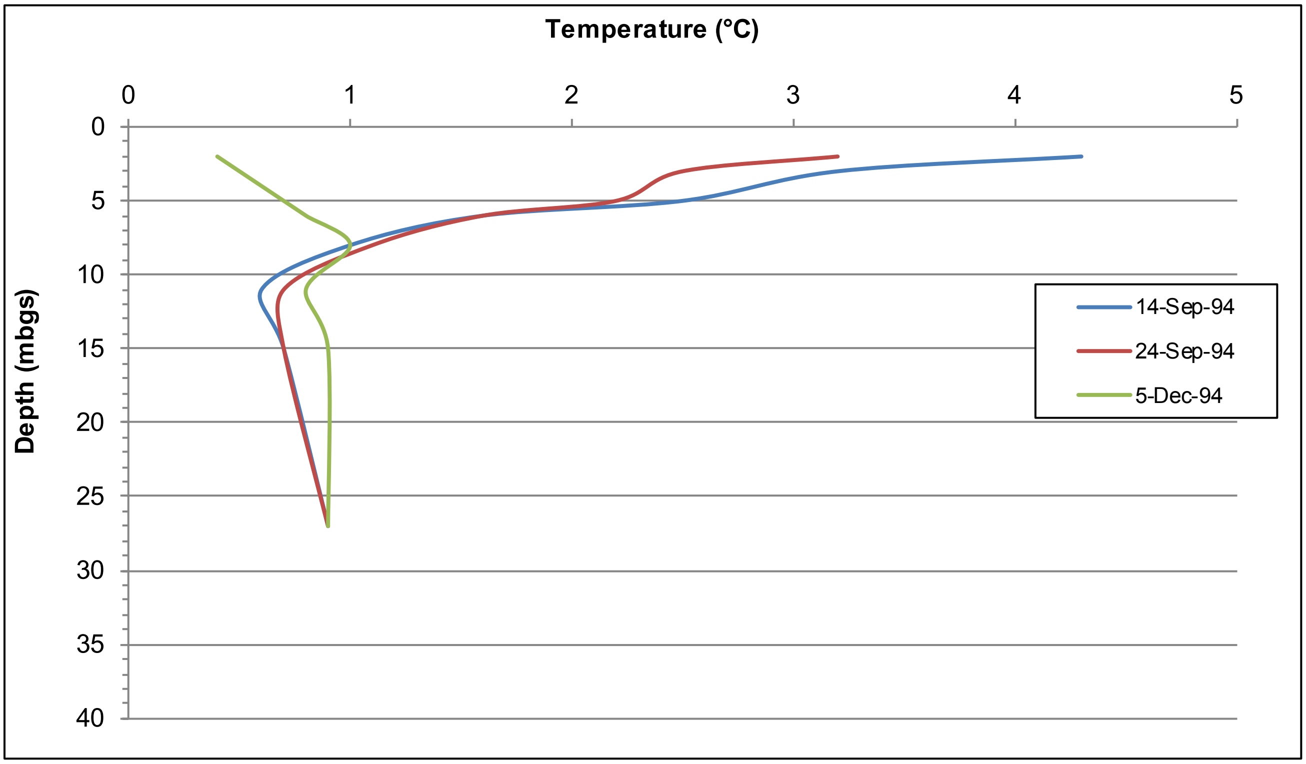

Figure B.6.4-4 Ground Temperature with Depth at 94-344

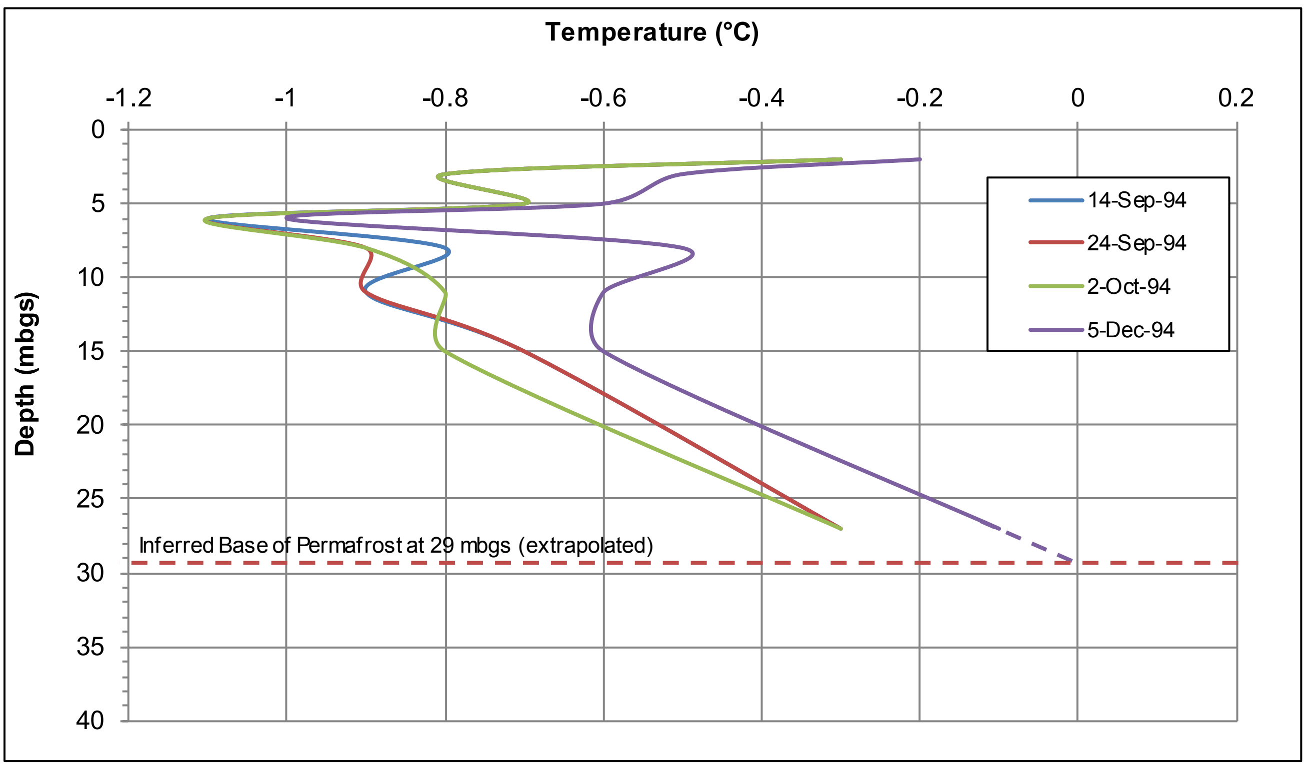

Figure B.6.4-5 Ground Temperature with Depth at 94-349

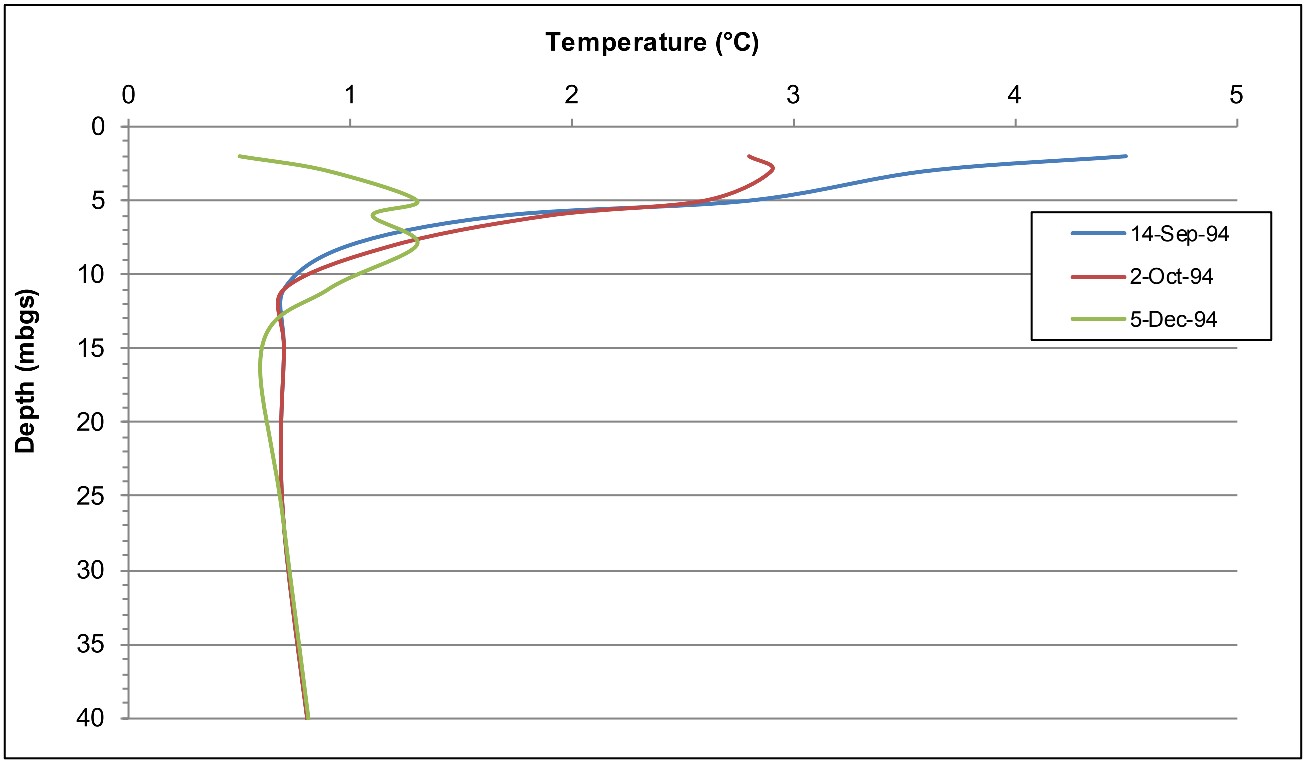

Figure B.6.4-6 Ground Temperature with Depth at 94-355

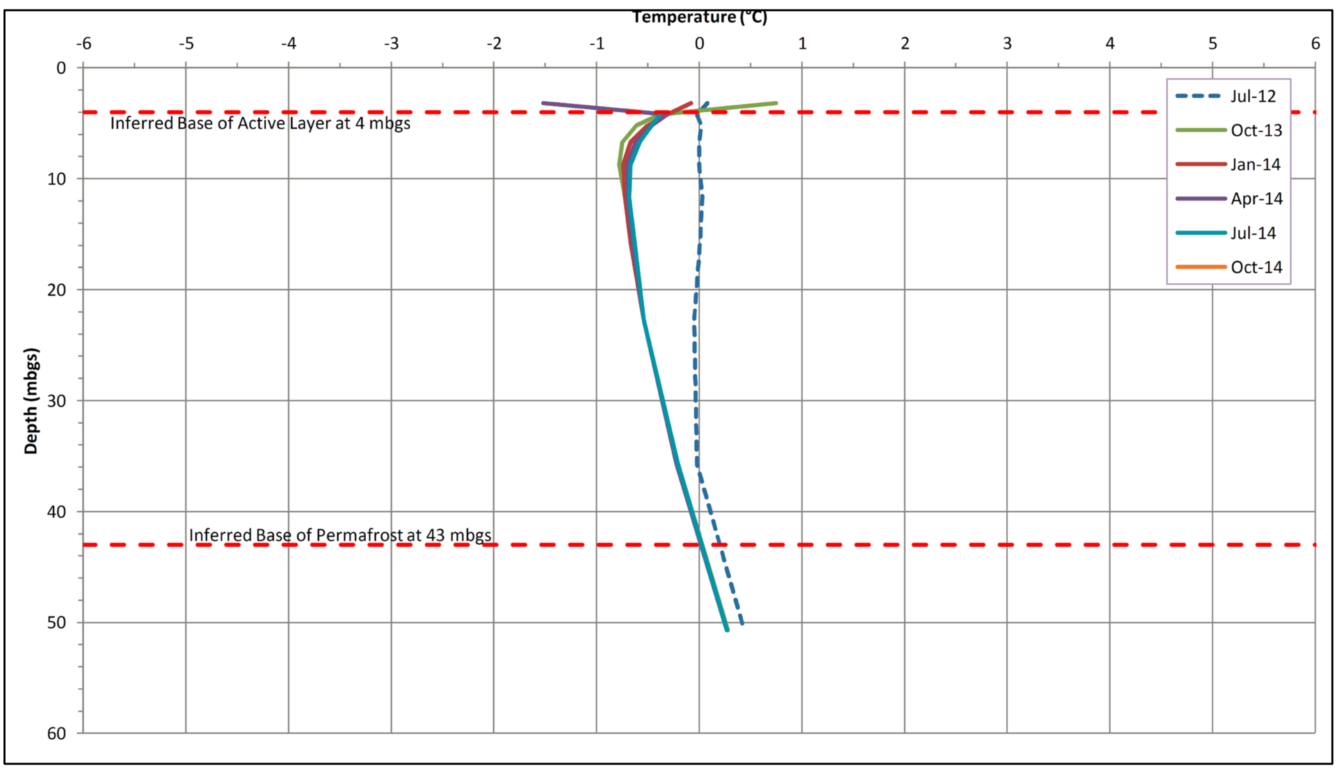

Figure B.6.4-7 Ground Temperature with Depth at DH12-03

b. Updated thermistor data is provided in the 2013-2014 Groundwater Data Report, provided in Appendix A.7M, specifically Appendix D of that report.

c. The locations of all installed thermistors are shown in Figure B.6.4-8. No 1994 thermistor locations are proximal to locations where temperature data has been more recently recorded. Therefore, inferences as to long-term trends in mean annual ground temperatures are not possible.

d. Hydrogeology data in and around the mine site, including continuous groundwater level and ground temperature monitoring, and groundwater quality sampling continues to be collected as part of the on-going environmental monitoring program. Baseline studies will be updated and provided in the applications for Quartz Mining and Water Use Licences.

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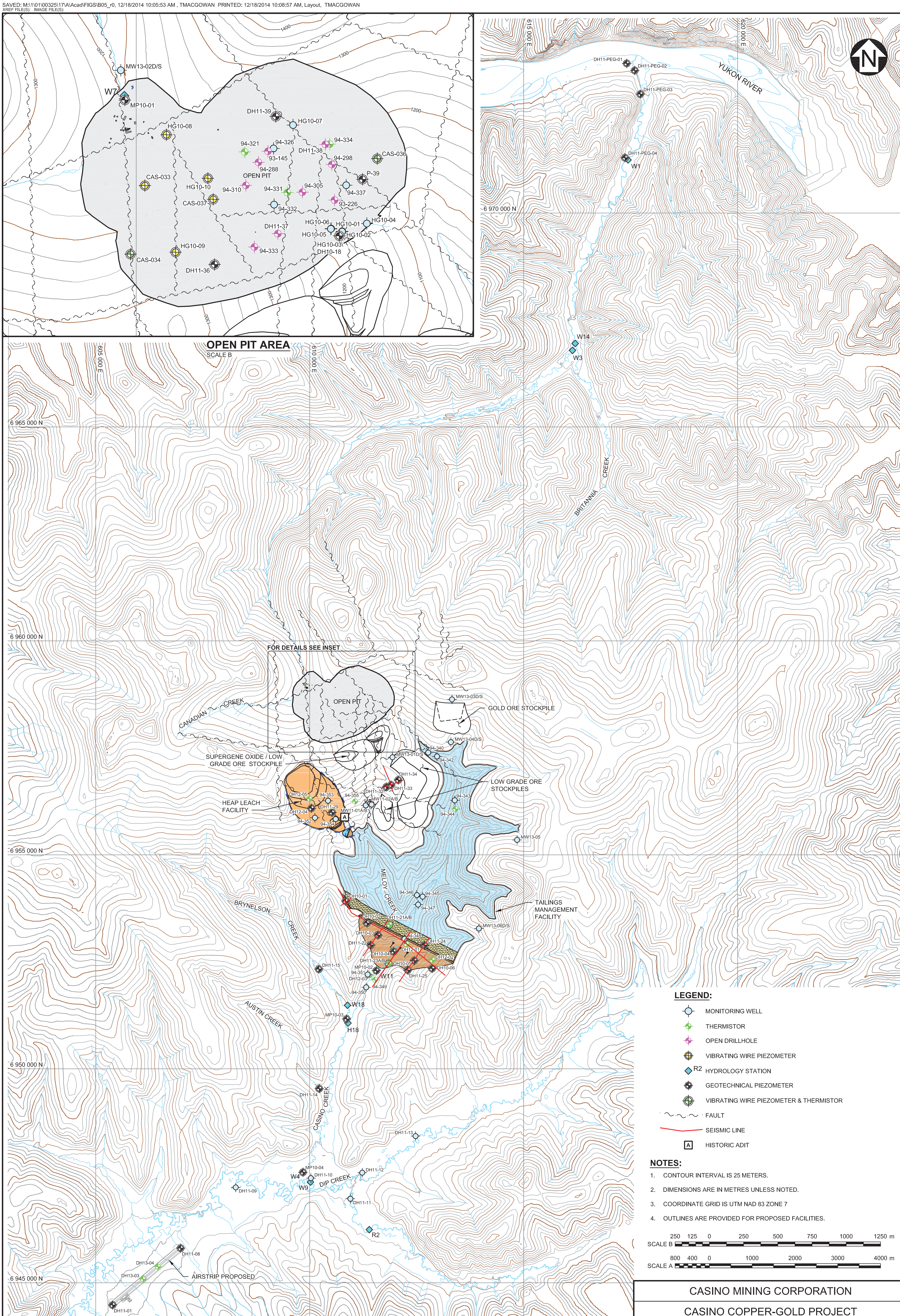

LEGEND:

- MONITORING WELL
- THERMISTOR
- OPEN DRILLHOLE
- VIBRATING WIRE PIEZOMETER
- R2 HYDROLOGY STATION
- GEOTECHNICAL PIEZOMETER
- VIBRATING WIRE PIEZOMETER & THERMISTOR
- FAULT
- SEISMIC LINE
- A HISTORIC ADIT

NOTES:

1. CONTOUR INTERVAL IS 25 METERS.
2. DIMENSIONS ARE IN METRES UNLESS NOTED.
3. COORDINATE GRID IS UTM NAD 83 ZONE 7
4. OUTLINES ARE PROVIDED FOR PROPOSED FACILITIES.

SCALE B: 250 125 0 250 500 750 1000 1250 m

SCALE A: 800 400 0 1000 2000 3000 4000 m

CASINO MINING CORPORATION

CASINO COPPER-GOLD PROJECT

Hydrogeological Instrumentation Locations

Knight Piésold CONSULTING

P/A NO.	REF NO.
VA101-325/17	1

Figure B.6.4-8 REV 0

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	CHK'D	APP'D
0	18DEC'14	ISSUED WITH REPORT	KTD	TAM	CAS	KJB

B.6.5 SURFICIAL GEOLOGY AND TERRAIN MAPPING METHODS AND MAPS

B.6.5.1.1 R2-93

R2-93. A reference to the legend used in the baseline terrain maps as well as a simpler interpretation (label) of the units, especially those with multiple capital letters and integers.

The terrain unit integers are an adaptation to Howes and Kenk (1997). The Terrain Classification System for British Columbia (Howes and Kenk, 1997) is a terrain mapping standard issued by the Government of British Columbia, Ministry of Environment (MOE). A field card of codes is issued by the MOE to assist map users in reading terrain labels, and is reproduced below for ease of use (the original can be sourced from https://www.for.gov.bc.ca/hts/risc/pubs/teecolo/terclass/fieldcar.htm#anchor510868).

Table B.6.5-1 Terrain Classification System for British Columbia Codes and Descriptions

TEXTURE			
Symbol	**Name**	**Size (mm)**	**Other Characteristics**
a	blocks	>256	angular particles
b	boulders	>256	rounded & subrounded particles
k	cobble	64-256	rounded & subrounded particles
p	pebbles	Feb-64	rounded & subrounded particles
s	sand	2-.062	
z	silt	.062-.002	
c	clay	<.002	
d	mixed fragments	>2	mix of rounded and angular particles
g	gravel	>2	mix of boulders, cobbles and pebbles
x	angular fragments	>2	mix of rubble and blocks
r	rubble	2-256	angular particles
m	mud	<.062	mix of clay and silt
y	shells	-	shells or shell fragments
e	fibric		well-preserved fibre; (40%) identified after rubbing
u	mesic		intermediate decomposition between fibric and mesic
h	humic		decomposed organic material; (10%) identified after rubbing

SURFICIAL MATERIALS			
Symbol	**Name**	**(Assumed Status of Formative Process)**	**Description**
A	anthropogenic	(A)	Man-made or man-modified material
C	colluvial	(A)	Products of mass wastage
D	weathered rock	(A)	In situ bedrock

E	eolian	(I)	Materials deposited by wind action
F	fluvial	(I)	River deposits
F^{G}	glaciofluvial	(I)	Fluvial materials deposited by meltwater streams
I	ice	(A)	Permanent snow, glaciers and icefields
L	lacustrine	(I)	Lake sediments; includes littoral deposits
L^{G}	glaciolacustrine	(I)	Sediments deposited in glacial lakes
M	morainal	(I)	Material deposited directly by glaciers
O	organic	(A)	Accumulation/decay of vegetative matter
R	bedrock	(-)	Outcrops/rocks covered by less then 10 cm
U	undifferentiated	(-)	Layered sequence; three materials or more
V	volcanic	(I)	Unconsolidated pyroclastic sediments
W	marine	(I)	Marine sediments; incudes littoral deposits
W^{G}	glaciomarine	(I)	Sediments of glacial origin deposited in a marine environment

QUALIFIERS

Symbol	**Name**	**Description**
G	glacial	Used to qualify surficial material where there is evidence that glacier ice affected the mode of deposition of material
A	active	Used to qualify surficial material and geomorphological
I	inactive	processes with regard to their current state of activity

SURFACE EXPRESSION

Symbol	**Name**	**Description**
a	moderate slope	Unidirectional surface; 16 to 26°.
b	blanket	A mantle of unconsolidated materials; >1m thick.
c	cone	A cone or sector of a cone; >15°.
d	depression	A sharply demarked hollow.
f	fan	A sector of a cone ; up to 15°.
h	hummocky	Hillocks and hollows, irregular plan; 15 to 35°.
j	gentle slope	Unidirectional surface; 4 to 15°.
k	moderately steep	Unidirectional surface; 27 to 35°.
m	rolling	Elongate hillocks; parallel in plan; 3 to 15°.
p	plain	Unidirectional surface; 0 to 3°.
r	ridged	Elongate hillocks; parallel in plan; 15 to 35°.
s	steep	Steep slopes; >35°.
t	terraced	Step-like topography.
u	undulating	Hillocks and hollows; irregular in plan; 0 to 15°.
v	veneer	Mantle of unconsolidated material; 10cm to 1m thick.

w	mantle of variable thickness		Suficial material of variable thickness; (0 to about 3 m).
x	thin veneer		Similar to veneer; (2-20 cm thick).
GEOMORPHOLOGICAL PROCESSES			
Symbol	**Name**	**(Assumed Process Status)**	**Description**
A	avalanches	(A)	Terrain modified by snow avalanches
B	braiding	(A)	Diverging/converging channels; unvegetated bars
C	cryoturbation	(A)	Sediment modified by frost heaving and churning
D	deflation	(A)	Removal of sand and silt by wind action
E	channeled	(I)	Channel formation by glacial meltwater
F	slow mass movement	(A)	Slow down-slope movement of masses of cohesive or non-cohesive material and/or bedrock
H	kettled	(I)	Depressions due to the melting of buried glacier ice
I	irregular channel	(A)	A single, clearly defined main channel displaying irregular turns and bends
J	Anastomosing channel	(A)	A channel zone where channels diverge and converge around vegetated islands
K	karst	(A)	Processes associated with the solution of carbonates
L	surface seepage	(A)	Abundant surface seepage
M	meandering channels	(A)	Channels characterized by regular patterns of bends with uniformed amplitude and wave length
N	nivation	(A)	Erosion beneath and along the margin of snow patches
P	piping	(A)	Subterranean erosion by flowing water
R	rapid mass movement	(A)	Rapid downslope movement of dry, moist or saturated debris
S	solifluction	(A)	Slow downslope movement of saturated overburden across a frozen or otherwise impermeable substrate
U	inundation	(A)	Seasonally under water due to high watertable
V	gully erosion	(A)	Parallel/subparallel ravines due to erosion by various processes
W	washing	(A)	Removal of fines by waves and running water
X	permafrost	(A)	Processes controlled by the presence of permafrost
Z	periglacial processes	(A)	Solifluction, cryoturbation and nivation processes occurring within a single unit

B.6.5.1.2 R2-94

R2-94. A Hazard Map and associated methodology that:

a. Predicts the type, nature, frequency and magnitude of all hazards in the study area.

b. Where the study area is bound by moderate to steep slopes please modify the terrain map and the terrain stability map to include upslope areas (to the height of land). Note: In the case of the

road, this only need apply to the side of the valley that supports the road.
c. Where the study area is bound by moderate to steep slopes please increase the detail of the mapping to capture areas commonly associated with hazards such as gullies but not currently mapped.
d. From the map above, if appropriate, identify specific risks to the project.
e. From the map above, if appropriate, identify specific risks to the environment from the project.
f. Based on the risk identified in response to the questions above, please provide general options and considerations for engineering design to mitigate the identified risks.

Terrain mapping and terrain stability mapping was conducted to predict the potential for landslides, snow avalanches and permafrost disturbances, and the results are provided in Appendices 6B, 6D and 6E and summarized in Section 20.3.2. The overall potential effects of terrain instability, in particular permafrost degradation, on the Project is not considered significant. Even though the overall likelihood of occurrence has been determined to be HIGH and is likely to occur over the life of the Project, the consequence of the most likely event is considered to be LOW because Project components, activities and critical services are not anticipated to be interrupted for more than 24 hours with the implementation of proposed mitigation measures. However, given the uncertainty in predicting the extent to which permafrost degradation will occur, CMC has adopted design based mitigation measures for potentially sensitive structures and will establish and monitoring and response measures prior to the construction of the Project, which include:

- During construction, permafrost zones and potentially unstable foundation materials within the proposed footprint of sensitive structures will be removed to encourage thawing and drainage and to ensure stability before placement of foundations or embankments.
- Sensitive structures will be monitored for their performance throughout life of the Project through regular inspections to identify areas of potential instability. Mitigative measures will be carried out to decrease the likelihood of failure.
- A program can be established to monitor permafrost conditions adjacent to cleared areas within the Project footprint after the construction phase. This program can monitor for downslope movement and soil moisture in sufficient frequency to assess the effects conditions that may affect terrain stability.

Site selections for potentially sensitive structures including the HLF, TMF embankments and stockpiles were based on engineering assessments that considered geotechnical conditions informed by completing geotechnical investigations and stability analysis for the proposed locations of the embankments and foundations.

Along the road route, minor slope instability and erosion of embankments can be monitored and mitigated quickly to prevent sediment delivery to watercourses. Project components, activities and critical services are not likely to be interrupted. In an unlikely worst-case scenario, differential settlement of air strip embankments, road embankments and bridge foundations may occur. Complete shutdown of Project components, activities and critical services may occur for more than one week.

In consideration of the above, the responses to requests a. through f. are provided below.

a. A terrain hazards assessment was carried out for the Casino mine site, Freegold Road Extension, and the Casino Airstrip (Appendices 6B, 6D and 6E). The terrain hazards assessment incorporated terrain mapping, terrain stability mapping and a preliminary assessment of potentially hazardous permafrost-related features. The potential likelihoods for landslides, snow avalanches and permafrost disturbances are described below.

   Likelihood of Occurrence

Terrain stability mapping was undertaken in 2012 to analyse the terrain stability in relation to the proposed locations of the Project components and activities. Terrain stability refers to the likelihood of a landslide initiating in a terrain polygon following construction activities and timber harvesting and was evaluated based on the slope angle, the slope aspect, the surficial geology, the permafrost conditions and the presence of gullied terrain. Three terrain stability classes were used for the terrain mapping study:

- Stable – Identified as terrain with a 'negligible' to 'low' likelihood of landslide initiation following road construction
- Potentially Unstable – Expected to contain areas with a 'moderate' likelihood of landslide initiation following road construction
- Unstable – Expected to contain areas where there is a 'high' likelihood of landslide initiation following road construction.

Terrain stability maps were produced for the Casino mine site, Freegold Road Extension and Casino Airstrip and Airstrip Access Road, to show areas of stable, potentially unstable and unstable terrain (Appendix 6B, 6D). The areas of potentially unstable and unstable terrain are based on the inferred presence of ice-rich soils. Table B.6.5-2 summarizes the potential likelihoods of occurrences of terrain instability based on the terrain stability mapping exercise for the Project.

Table B.6.5-2 Potential Likelihoods of Occurrences of Terrain Instability

Locations	Stable Terrain (%)	Potentially Unstable Terrain (%)	Unstable Terrain (%)	Occurrence Type	Likelihood
Mine Site	86.5	13	0.5	Landslides and avalanches	Negligible
				Permafrost degredation	High
Airstrip and Airstrip Access Road	95	5	0	Landslides and avalanches	Negligible
				Permafrost degredation	High
Freegold Road Extension	88	9	3	Landslides and avalanches	Low
				Permafrost degredation	High

Casino Mine Site

The terrain stability mapping indicates that approximately 13% of the Casino mine site is considered to be 'potentially unstable' terrain and approximately 0.5% is considered to be 'unstable' terrain (Appendix 6D). The terrain stability mapping identified areas of potentially unstable terrain and unstable terrain at the TMF location. Additional areas of potentially unstable terrain were also identified at the temporary stockpile sites and the HLF. Field studies did not observe any recent debris slides, debris flows or rockfalls within the Casino mine site. A possible solifluction lobe was identified in the footprint area of the proposed location of the Open Pit and discussed in further detail in the terrain hazards assessment report (Appendix 6B).

Snow avalanches and landslides generally occur on terrain with slope angles of approximately 27 to 40 degrees. The predominant slope angle classes within the Casino mine site are gentle slopes (of 4 to 15 degrees) and moderately inclined slopes (of 16 to 26 degrees). Therefore, the likelihood of avalanches and landslides were thought to be negligible.

The Casino mine site is located within a zone of widespread discontinuous permafrost and there is regional evidence of permafrost degradation as well as visually observed evidence (Appendix 6B). Permafrost is 'most prevalent on north-facing slopes and in valley bottoms where thick fine-grained slope toe complexes (interbedded loess, colluvium and peat) and alluvial sediments have accumulated' (Bond and Lipovsky, 2011). Terrain mapping work at the Casino mine site confirmed that permafrost is present close to ground surface within the majority of summits and ridgelines. Pingos were also identified through field observations in the northeast part of the Casino mine site.

Casino Airstrip and Airstrip Access Road

The terrain stability mapping indicates approximately 5% of the proposed Airstrip and Airstrip Access Road alignment to be 'potentially unstable' terrain (Appendix 6B). The existing variable ground conditions along the Casino Airstrip alignment can result in an increased likelihood of differential settlement of the proposed embankment if not mitigated. The terrain hazards study identified local evidence of permafrost degradation in the area of the proposed Casino Airstrip and Airstrip Access Road. It was believed that the extent of permafrost degradation has been exacerbated, by anthropogenic effects, in particular the construction of access tracks and winter roads.

Freegold Road Extension

The terrain stability mapping indicates approximately 9% of the proposed Freegold Road Extension alignment to be within 'potentially unstable' terrain and approximately 3% within 'unstable' terrain (Appendix 6B). Along the Freegold Road Extension, the road sections considered least susceptible to instability are generally those in areas of bedrock exposure. The road sections considered most susceptible to landslides are those in areas of ice-rich, north-facing colluvial slopes, where permafrost degradation can result in slope instability. Gullied terrain is particularly susceptible to landslides because there tends to be concentrations of both surface and subsurface water.

Snow avalanches generally occur on terrain with slope angles of approximately 27 to 40 degrees. The predominant slope angle classes within the area are gentle slopes (of 6 to 26% or 4° to 15°) and moderate slopes (of 27% to 49%, or 16° to 26°). Overall, a significant proportion of the annual precipitation falls as snow, and the proposed Freegold Road Extension route will pass through some areas of moderately steep terrain that could be susceptible to snow avalanches.

The proposed Freegold Road Extension alignment will traverse extensive areas of permafrost terrain, a significant proportion of which was interpreted in the terrain hazard study to have a shallow (within approximately 1 m of the ground surface) permafrost table and ice-rich soils.

b. The Terrain Hazards Assessment conducted for the proposed access road and airstrip corridors comprised an approximately 1.5 to 2.5 km-wide corridor, corresponding approximately to the extent of the project LiDAR Survey. The scope of work included Air Photo Interpretation (API), analysing slope angle maps, undertaking field proofing and developing terrain hazards maps for the site. The mapping included terrain mapping based on the Terrain Classification System for British Columbia (Howes and Kenk, 1997), terrain stability mapping, delineation of past landslides and identification of potentially hazardous permafrost features.

The API was undertaken by inspecting 1:20,000 scale colour air photos, taken in September 2009, with a stereoscope. Slope angle maps of the terrain in the vicinity of the road alignments were prepared from the 5 m LiDAR contours using the ArcView Geographic Information System (GIS) software package with the '3d-Analyst' extension. The slope angle classes used correspond with those in the Terrain Classification System for British Columbia (Howes and Kenk, 1997). Terrain stability mapping was undertaken by integrating the terrain mapping with the slope angle maps and the corresponding slope aspect.

Terrain mapping was undertaken based on the Terrain Classification System for British Columbia, as detailed in Howes and Kenk (1997). The maps were developed from the API with the aid of the slope angle maps. The terrain units were identified based upon the morphology, the presence and nature of soil or rock exposures, as well as vegetation associations. The terrain mapping was refined, based on the findings of the field truthing. The mapping was conducted to TSIL 'D', requiring between 1% and 20% of the terrain polygons to be field truthed.

SNC-Lavalin has seemingly interpreted the borders of the mapping on sheets 6 through 17 in Appendix 6B as a "buffer"; however, in fact the border is simply the limit of the 1:20,000 scale colour air photos available for the Project. In areas where landslides were identified in the areas upslope from the Local Study Area (LSA) boundary, the LSA for terrain mapping was extended up to the top of the catchment. CMC considers the mapping provided in Appendix 6B and 7D appropriate for environmental assessment and comparable to other terrain and terrain stability mapping conducted for other mine projects (e.g., Kitsault Project – Avanti, 2011, KSM Project - Seabridge Gold, 2013). As the main hazard identified by the mapping is due to degradation of permafrost, and not landslides or avalanches, no further studies were necessary to predict the potential impacts of terrain hazards on the Project (Section 20.3.2) or to define mitigation measures.

c. Terrain and terrain stability mapping is provided in Appendices 6B and 6D. The primary objective of the terrain stability mapping was to analyse the terrain stability in relation to the proposed development. Terrain stability refers to the likelihood of a landslide initiating in a terrain polygon following road construction activities and timber harvesting. Terrain stability class criteria were developed for the Study Area. Terrain stability was evaluated based on the slope angle, the slope aspect, the surficial geology, the permafrost conditions and the presence of gullied terrain.

   The dominant terrain instability hazard for the Project is permafrost degradation because landslides and snow avalanches are less likely to occur. The baseline rate of permafrost degradation and the extent to which permafrost degradation is anticipated to be affected by anthropogenic processes (including construction activities) is difficult to predict (Appendix 6B). CMC considers the mapping provided in Appendix 6B and 7D appropriate for environmental assessment and comparable to other terrain and terrain stability mapping conducted for other mine projects (e.g., Kitsault Project – Avanti, 2011, KSM Project - Seabridge Gold, 2013). As the main hazard identified by the mapping is due to degradation of permafrost, and not landslides or avalanches, no further studies were necessary to predict the potential impacts of terrain hazards on the Project (Section 20.3.2) or to define mitigation measures.

d. Risks to the Project from terrain instability were provided in Section 20.3.2 of the Project Proposal, and are supported by Appendices 6B and 6D.

e. Risks to the environment from the Project are defined in Section 6 of the Project Proposal, supported by Appendix 6A.

f. Following the terrain mapping and terrain hazard assessments conducted for the mine site and access roads and airstrip, engineering considerations to be incorporated into detailed design are described below.

   Access Road

   - In areas where the alignments traverse areas of known or suspected ice-rich soils, permafrost degradation effects can be mitigated by constructing the road/air strip on an embankment of non frost susceptible fill.

- The natural vegetation cover of sphagnum moss should be kept in place, wherever possible, to provide the maximum protection to the thermal regime. Winter construction is preferred in these areas.
- For summer construction, woven geotextile may need to be laid over thaw unstable ground, prior to placement of the fill.
- To mitigate sedimentation and erosion in areas of silty and organic soils (e.g., colluvial aprons and organic swamps on the flood plains of major watercourses), such soils should be left in place, wherever possible, with the surface cover of sphagnum moss intact and the road constructed on an embankment of non-frost susceptible fill.
- Develop robust erosion and sediment control plans in any areas where soils are to be disturbed.
- At Big Creek (15+800), the presence of a thick cover of colluvium on steep slopes in this area may have implications for the design of the proposed cut slopes and cut slope stabilization measures may need to be implemented in the detailed design.
- Natural slopes at 62+500 appear to be susceptible to ongoing instability due to river bank erosion, excavation of the colluvial veneer may be required at a point approximately 20 m above the elevation of the creek where the slope angle tapers off slightly and continues down slope to the proposed alignment. A stable road prism could then be developed in bedrock.
- Detailed design should include terrain stability assessments at 15+800 and 62+500, where there is the possibility of encroachment into the riparian zone.
- In areas where solifuction is particularly prevalent (e.g., moderate, north-facing colluvial slopes), the road should be constructed on an embankment that effectively buttresses the natural slope.
- Where the access road alignment traverses a solufuction lobe in, the alignment may need to be re-routed slightly.
- Minimize cut slopes to mitigate the risk of permafrost degradation.
- Detailed drainage design for the road should consider the shallow permafrost table in the north-facing colluvial mid-slopes and the colluvial aprons.

Airstrip

- Complete additional boreholes along the airstrip alignment as part of the detailed design to further investigate the extent of ice-rich soils and to facilitate the installation of thermistors.
- Incorporate additional measures into the detailed design of the airstrip to manage expected surface and shallow subsurface water flows and limit long-term thaw and/or creep settlements and displacements associated with the presence of ice-rich soils and massive ground ice (e.g., flattening or buttressing the side slopes of the embankment).
- Implement drainage measures to prevent water ‘ponding’ at the upslope toe of the embankment.
- Monitor the performance throughout the design-life of the airstrip against to-be-determined performance criteria.

Mine Site

- The surface water management strategies implemented should prevent water accumulating in the natural terrain adjacent to the proposed facilities in areas of known or suspected ice-rich soils. Ditching at the toe of embankments should be avoided in areas of known or suspected ice-rich soils.
- Detailed design of the Heap Leach Facility and the Supergene Oxide Ore Stockpile should account for natural seasonal sub-surface seepage flows within the active layer and seasonal surface flows.
- Ice-rich portions of the colluvial apron deposits within the proposed footprint area of the tailings embankment will need to be removed prior to the construction of the embankment, and replaced with non-frost susceptible fill.
- Additional site investigation is required in order to enhance the understanding of the ground conditions at the proposed embankment site and to facilitate a reasonably accurate estimate of the volume of unsuitable material needing to be removed, spoiled and replaced.
- In areas mapped “potentially unstable” and “unstable”, the natural vegetation cover should be kept in place to provide the maximum protection to the thermal regime. For summer construction, a woven geotextile may need to be laid over thaw unstable ground, prior to placement of fill. In areas where vegetation needs to be removed, winter construction is recommended for the initial lifts.

A Terrain Stability Assessment will be conducted during the detailed design phase, and will include:

- Confirmation of the design cut slope angles and the scope of any necessary mitigation measures.
- For those areas identified in the terrain stability mapping as “potentially unstable” and/or close to areas of “unstable” terrain, analysis of the landslide risks and, where necessary, recommendation of measures to mitigate risk.
- Determination of the extent of the necessary landslide mitigation and erosion and sediment control measures required between 86+000 and 95+000 including shallow soil sampling holes to better understand sub-surface conditions ahead of construction.
- Overview of possible snow avalanche hazards along the alignments by a snow avalanche specialist.

B.6.6 TERRAIN HAZARDS ASSESSMENT

B.6.6.1.1 R2-95

R2-95. Additional details in relation to terrain hazards assessment including:
a. Table 1, Table 2, Figure 1, and Figure 2 referenced to in the Fluvial Geomorphology report.
b. More detail on river ice buildup, ice jams, and thermokarst processes in relation to the proposed Freegold Road extension, Airstrip Access Road.
c. Watershed characteristics (watershed area, watershed length, relief, and melton ratio) for each road crossing of a side channel feeding into the main valley and provide comment on dominant depositional process at each crossing.
d. A correlation of lateral migration rate descriptors to an actual measured rate of migration (i.e. low = 0 to 0.1 m/year).

a. Table 1, Table 2, Figure 1 and Figure 2 referenced in the Fluvial Geomorphology report (Appendix 6E) are provided in Appendix B.6A.

b. River ice buildup, ice jams and thermokarst processes are incorporated into the detailed field investigations and topographic site surveys required for detailed road engineering. The fluvial geomorphological hazards described in the Fluvial Geomorphology report (Appendix 6E) correspond to possible risks that are considered as part of detailed road and crossing design.

c. Detailed field investigations and topographic site surveys will be conducted for all bridge crossings, and will include watershed area details. For comparison, detailed field investigations for the 27 major bridge crossings along the Freegold Road and extension were conducted in 2011, and the resulting hydro-technical analysis was used to prepare the conceptual bridge designs provided in Appendix 4B. Bridge lengths and minimum deck elevations are determined from hydro-technical analysis, environmental requirements, geotechnical information and road/stream alignment. The hydro-technical analysis for each crossing consisted of two phases: a hydrologic analysis to estimate the design flow that each crossing structure must accommodate during the 1:100 year return event; and a hydraulic analysis to predict the water surface elevation and water velocity for the design flow, detailed below.

Hydrologic Analysis

In order to estimate the design flow for each crossing, a regional flood frequency analysis was performed using information from the Water Survey of Canada (WSC) and Yukon Environment – Water Resources Branch. In order to confirm the results, flows were then estimated using the procedures outlined in the Design Flood Estimating Guidelines for the Yukon Territory (Janowicz, 1989).

Watershed Delineation and GIS Analysis

Watershed delineation and GIS analysis was based on the National Topographic Series (NTS) 1:50,000 scale digital maps. The digital elevation models (DEM) used to generate contours and delineate watershed boundaries were the 30 m resolution DEM dataset generated and distributed by Environment Yukon – Geomatics. Geographic information system (GIS) was used to delineate the upstream watershed boundary for each crossing and calculate the resulting watershed area. Other physiographic parameters such as average overland slope, maximum, minimum and average elevation, and the longest flow path were also obtained. Similar analysis was performed for the WSC and Yukon Environment stream gauge locations in the area.

Hydraulic Analysis

Detailed site surveys were conducted at each crossing location and digital terrain models were developed from the site surveys. This information, along with the estimated flows at each crossing, formed the basis for the hydraulic analysis. The hydraulic analysis was then completed using in-house software to confirm water surface elevation and water velocity through the proposed structures hydraulic opening. A freeboard allowance ranging from 0.6 m to 1.0 m was provided at each crossing based on the typical potential for bedload and debris movement.

d. The descriptors used to describe meander migration in the Fluvial Geomorphology report (Appendix 6E) (e.g., modest, substantial, low) are qualitative descriptors and provide relative descriptions, and not actual measured rates of migrations. As the fluvial hazards assessment was conducted entirely from desktop information sources (e.g., 1949, 1989 and 2009 air photos), a quantitative rate of lateral migration is not possible to calculate. More detailed analysis, with field inspections, will be carried out as part of the detailed design studies for the proposed roads and crossings, as described above for part c. Please note also that the assessment took account of the channel avulsion hazard as well the meander migration rate and it can be misleading to focus attention on the meander migration rate.

B.6.6.1.2 R2-96

R2-96. A soil erosion potential analysis for the LSA that includes the component of thermal erosion where permafrost is identified as being present.

Soil erosion potential analysis has not been conducted separately, however, conclusions can be made from the terrain hazards assessment provided in Appendices 6B and 6D. The terrain mapping highlighted the widespread occurrence of silty and organic soils. These soils, which predominantly comprise colluvial apron and loess deposits, tend to be ice-rich and are expected to be especially prone to erosion and instability upon disturbance. A thaw flow was observed at the site of the proposed Tailings Embankment, where an access track had been formed on a colluvial apron with a natural slope angle of less than 25%.

The terrain stability mapping highlighted significant areas of ‘potentially unstable’ terrain and local areas of ‘unstable’ terrain at the site of the proposed Tailings Management Facility, related to the interpreted presence of silt-rich and ice-rich soils. Similarly, areas of ‘potentially unstable’ terrain were identified, locally, at the sites of the proposed Stockpiles, Heap Leach Facility and Open Pit. The surficial soils at the sites of the proposed Tailings Embankment and Open Pit are expected to be especially prone to erosion and instability upon disturbance.

Extensive and deep ice-rich colluvial apron deposits with bodies of massive ground ice have been identified at the site of the proposed Tailings Embankment that will need to be excavated in order to limit differential settlement of the embankment and mitigate the possibility of piping within the embankment foundations. A thick deposit of silt and ice-rich re-worked loess was identified in the north part of the footprint of the proposed Open Pit. The conventional strategy of cutting slopes at shallower angles requires a large area of land disruption in such terrain and has been found to result in increased erosion. The preferred management technique for dealing with mine cuts in ice-rich soils is to allow natural degradation of the permafrost slopes and slumping of the cuts to aid in reclamation. In areas where ice-rich soils at the site need to be excavated, robust sediment and erosion control plans will be developed.

Mitigations to be incorporated into detailed design and construction of the mine components and access road as they relate to permafrost include:

Access Road

- In areas where the alignments traverse areas of known or suspected ice-rich soils, permafrost degradation effects can be mitigated by constructing the road/air strip on an embankment of non frost susceptible fill.
- The natural vegetation cover of sphagnum moss should be kept in place, wherever possible, to provide the maximum protection to the thermal regime. Winter construction is preferred in these areas.
- For summer construction, woven geotextile may need to be laid over thaw unstable ground, prior to placement of the fill.
- To mitigate sedimentation and erosion in areas of silty and organic soils (e.g., colluvial aprons and organic swamps on the flood plains of major watercourses), such soils should be left in place, wherever possible, with the surface cover of sphagnum moss intact and the road constructed on an embankment of non-frost susceptible fill.
- Develop robust erosion and sediment control plans in any areas where soils are to be disturbed.
- In areas where solifuction is particularly prevalent (e.g., moderate, north-facing colluvial slopes), the road should be constructed on an embankment that effectively buttresses the natural slope.

- Where the access road alignment traverses a solufuction lobe in, the alignment may need to be re-routed slightly upslope or downslope.
- Minimize cut slopes to mitigate the risk of permafrost degradation.
- Detailed drainage design for the road should consider the shallow permafrost table in the north-facing colluvial mid-slopes and the colluvial aprons.

Airstrip

- Complete additional boreholes along the airstrip alignment as part of the detailed design to further investigate the extent of ice-rich soils and to facilitate the installation of thermistors.
- Incorporate additional measures into the detailed design of the airstrip to management expected surface and shallow subsurface water flows and limit long-term thaw and/or creep settlements and displacements associated with the presence of ice-rich soils and massive ground ice (e.g., flattening or buttressing the side slopes of the embankment).
- Implement drainage measures to prevent water ‘ponding’ at the upslope toe of the embankment.
- Monitor the performance throughout the design-life of the airstrip against to-be-determined performance criteria.

Mine Site

- The surface water management strategies implemented should prevent water accumulating in the natural terrain adjacent to the proposed facilities in areas of known or suspected ice-rich soils. Ditching at the toe of embankments should be avoided in areas of known or suspected ice-rich soils.
- Ice-rich portions of the colluvial apron deposits within the proposed footprint area of the tailings embankment will need to be removed prior to the construction of the embankment, and replaced with non-frost susceptible fill.
- Additional site investigation is required in order to enhance the understanding of the ground conditions at the proposed embankment site and to facilitate a reasonably accurate estimate of the volume of unsuitable material needing to be removed, spoiled and replaced.
- In areas mapped “potentially unstable” and “unstable”, the natural vegetation cover should be kept in place to provide the maximum protection to the thermal regime. For summer construction, a woven geotextile may need to be laid over thaw unstable ground, prior to placement of fill. In areas where vegetation needs to be removed, winter construction is recommended for the initial lifts.