Yukon Government,
Assessment and Abandoned Mines Branch

Overview of Mt. Nansen Closure Alternatives Characterization

Prepared by:

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Project Number:

60119144 (112359)

Date:

May 2010

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May 31, 2010

Frank Patch
Senior Project Manager
Assessment and Abandon Mines Branch
Department of Energy Mines and Resources
Yukon Government
4114, 4th Ave, Room 2C
Whitehorse, Yukon Y1A 1H9

Dear Mr. Patch:

Project No: 60119144 - 112359
Regarding: Overview of Mt. Nansen Closure Alternatives Characterization – Version 2

We are pleased to submit the Version 2 of the Overview of Mt. Nansen Alternatives Characterization report. This is an updated version of the report that was issued on March 8, 2010. This report summarizes the work completed in 2009.

The intent of the report and the supporting technical memos is to provide enough information that the stakeholders can select the best option for tailings management at this site. Additional work during the summer of 2010 is recommended to reduce the uncertainty associated with the site water balance and tailings cover systems. A third and final version of this report, including any new data collected in 2010, is proposed to be issued in September 2010.

If you have any questions regarding the enclosed report, please do not hesitate to contact me at 604.412.3537.

Sincerely,
AECOM Canada Ltd.

Rob Dickin, M.Sc., P.Geo.
Project Manager
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RD:gc

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1. Introduction

This report is a summary of the work carried out by AECOM to characterize various alternatives for the closure of the abandoned Mt. Nansen mine site. The overall current site layout is shown in Figure 1.1 (back of report).

The goal of this assessment was not to select an option, but to characterize various closure alternatives for the closure option selection process which follows this work.

The general concepts of the closure alternatives under consideration were selected based on previous work carried out by the Yukon Government, Stakeholders (Yukon EMR 2008), AECOM and other consultants. The current study has developed a more detailed closure concept. Nine alternatives have been assessed in terms of geotechnical stability at closure. Of these nine alternatives, four alternatives have been assessed in terms of geochemistry and potential water quality impacts to the receiving environment. The alternatives assessment is concerned primarily with the tailings dam, the tailings mass, the waste rock piles and the open pit. Other mine related contaminants such as the Mill Complex area are not considered in detail in the alternatives analysis. It is assumed that the Mill Complex will require remediation that is common to all closure options under consideration.

The work has been carried out in close co-operation with Lorax Environmental Services (Lorax), Altura Environmental Consulting (Altura), Environmental Dynamics Incorporated (EDI and Gomm Environmental Engineering Consultants (GEEC), who have respectively led related programs, and/or provided advice, to characterize geochemistry across the site, characterize mine waste rock, characterize the site environment through ongoing monitoring, and advise on site water quantity and quality prediction. Each of these consulting companies, together with AECOM, and its former legacy companies UMA and Gartner Lee, have participated in various monitoring, investigation and evaluation programs of the component parts of the Mt. Nansen site over several previous years. The work conducted during 2009 has involved a concerted effort to bring past work together into a coherent basis for selection by the stakeholders of a preferred alternative means of closing the site.

Technical memorandum on the geotechnical, hydrogeological, geochemical and surface water aspects of these closure alternatives have been provided by the group of consultants listed above. The geochemical work was carried out by Lorax Environmental and Altura. The surface water quality work was carried out by AECOM, EDI and GEEC. The hydrogeological and geotechnical work was carried out solely by AECOM.. This effort has been coordinated with the Yukon Government Abandoned Mines staff, INAC/DIAND, and the members of and advisors to the Little Salmon and Carmacks First Nation (LSCFN).

1.1 Scope of Work in 2009/2010

The scope of work carried out during 2009/2010 to advance the overall process of selecting a preferred alternative for the closure of the Mt. Nansen mine site has involved the following steps:

- compilation of Information and Gap Analysis – completed at the end of Fiscal Year 2008 – March 2009;
- review of Gap Analysis and Planning Workshop conducted in April 2009;
- field investigations conducted between May and September 2009;
- analysis of data during October and November 2009;
- synthesis of Data;
- preparation of Draft Report (March 2010) for review, including the IPRP and LSCFN; and
- preparation of this report, incorporating comments received during the review process.

Descriptions of the field work conducted in 2009 are presented in the discipline specific chapters below (i.e., Hydrology, Hydrogeology, Geotechnical and Geochemical).

The scope of work completed by AECOM was carried out under YG contracts C00001327 and C00003403.

The characterisation will be subjected to a peer review to verify adequacy and feasibility of the work. It will review the risks and liabilities for each alternative, the degree to which closure objectives are achieved, and cost. Subsequently, an assessment of residual impacts for selected proposed/preferred alternatives will be prepared. The exact nature of this process has yet to be determined, but the current work plan for characterisation has sought to provide sufficient information on the conceptual design of alternatives and permit comparison of their residual impacts on the key receptors.

1.2 User Guide for the Supporting Documents

The main contribution of the work done on the closure alternatives assessment is found within the memorandums completed by discipline. A summary of these documents is provided in Table 1-1. These 25 memorandums are located on the AECOM SharePoint site.

Table 1-1. Summary of the Supporting Documents

Discipline/Consultant	Memorandum Title	Final Date
Geotechnical/AECOM	Placement Scenarios	14 Jan., 2010
Geotechnical/AECOM	Cover Options	14 Jan., 2010
Geotechnical/AECOM	Consolidation of Tailings	14 Jan., 2010
Geotechnical/AECOM	Tailings Transport Methods	14 Jan., 2010
Geotechnical/AECOM	Dam Classifications	14 Jan., 2010
Geotechnical/AECOM	Stability Analysis	14 Jan., 2010
Geotechnical/AECOM	Spillway	14 Jan., 2010
Geotechnical/AECOM	Diversion Channel	14 Jan., 2010
Geotechnical/AECOM	Pony Creek Diversion	14 Jan., 2010
Geotechnical/AECOM	Restoration of Valley	14 Jan., 2010
Geochemistry/Lorax	Derivation of Tailings and Pit Lake Source Terms	15 Nov., 2009
Geochemistry/Lorax	“Best Case” and “Lower Bound” Source Term Estimates	1 Feb., 2010
Geochemistry/Lorax	Derivation of Waste Rock Water Balance	14 Nov., 2009
Geochemistry/Lorax	Derivation of Brown McDade Waste Rock and Ore Source Terms	15 Nov., 2009
Geochemistry/Lorax & Altura	Pit Backfill – Waste Rock Management and Cover Sensitivity	20 Nov., 2009
Geochemistry/Altura	Waste Rock Pile Catchment Areas – Proposed Zones	4 Oct., 2009
Geochemistry/Altura	Summary of Studies Assessing Waste Rock Field Screening Potential	18 Dec., 2009
Geochemistry/Altura	Mine to Mill Haul Road – Summary of Rock Characterization Studies	22 Dec., 2009
Geochemistry/Altura	Brown McDade Waste Rock Characterization - Summary 2009 Program	31 Dec., 2009
Surface Water/AECOM	Mt. Nansen Hydrology Field Summary Report for 2009	4 Feb., 2010
Surface Water/AECOM	Mt. Nansen Baseline Water Quality Baseline Characterization	11 Feb., 2010
Surface Water/AECOM	Mt. Nansen Water Quality Model for the Alternatives Assessment	11 Feb., 2010
Surface Water/GEEC	Receiving Water Quality Assessment of Closure Options for Mt. Nansen	26 Feb., 2010
Hydrogeology/AECOM	Hydrogeological Conceptual Model	15 Dec., 2009
Hydrogeology/AECOM	Hydrogeological Field Investigation	3 Dec., 2009

Additionally, the following reports summarize work conducted by Lorax and Altura, respectively:

Lorax Environmental Services Limited (Lorax), 2009:

Mt. Nansen Geochemical Assessment in Support of Evaluating Closure Plan Options. Report prepared for Government of Yukon Assessment and Abandoned Mines Branch, Energy, Mines and Resources, November, 2009. 109pp.

Altura Environmental Consulting (Altura), 2009:

Brown McDade Waste Rock Pile, Mt. Nansen Mine Site, Yukon – Geochemical Characterization. Report prepared for Government of Yukon Assessment and Abandoned Mines Branch, Energy, Mines and Resources, March 2009, 237 pp.

Altura Environmental Consulting (Altura),2009:

Brown McDade Waste Rock Characterization, Mt. Nansen Mine Site, Yukon – Summary of 2009 Work Program. Report prepared for Government of Yukon Assessment and Abandoned Mines Branch, Energy, Mines and Resources, December 2009, 116 pp.

2. Background

2.1 Mt. Nansen Mine Closure Project Objectives

Long-Term Project Objectives

The following closure objectives were established by Yukon Government (GY), Government of Canada (Indian and Northern Affairs Canada (INAC), Environment Canada (EC) and Department of Fisheries and Oceans (DFO)), and Little Salmon Carmacks First Nation (LSCFN) (Yukon EMR “Options for Closure of Mt. Nansen Mine” (July 2008)).

1. **Protect Human Health and Safety**
    - Reduce and eliminate, where possible, risk to human health and safety. (INAC)
    - Protect human health and safety (GY)
    - People using the area will be safe from remaining mine hazards. (LSCFN)
    - Animals, plants and berries around the mine site are safe to harvest and will stay that way. (LSCFN)
    - Water at mine site and downstream will be as clean and safe as possible. (LSCFN)

2. **Protect the Environment Including Land, Air, Water, Fish and Wildlife**
    - Reduce and eliminate, where possible, risk to environmental health. (INAC)
    - Reduce the risk of current and future impacts from the Mt. Nansen mine on the aquatic resources and fish habitat to support healthy, productive fish populations in the Victoria/Nisling watershed. (DFO)
    - The valley of Dome Creek should be reclaimed to the extent practicable, to ensure physical stability and reduce the risk of transport of particulate matter to Victoria Creek. (DFO)
    - Adverse impacts of surface and groundwater from the site are reduced to the extent possible and otherwise do not alter the value of the receiving environment. (EC)
    - Reduce and mitigate current and future negative environmental impacts. (GY)
    - Protect ground water and surface water quality. (GY)
    - Ensure the protection of and restore to the extent possible, aquatic and terrestrial habitat. Reclamation conducive to natural regeneration where practical. (GY)

- People using the area will be safe from remaining mine hazards. (LSCFN)
- Animals, plants and berries around the mine site are safe to harvest and will stay that way. (LSCFN)
- Water at mine site and downstream will be as clean and safe as possible. (LSCFN)

3. Return Mine Site to an Acceptable State that Reflects Original Use where Possible

- Return mine site to an acceptable state that reflects original use where possible. (INAC)
- Return land to an acceptable state that doesn't inhibit future land use. (GY)
- Ensure the protection of and restore to the extent possible, aquatic and terrestrial habitat. Reclamation conducive to natural regeneration where practical. (GY)
- Water at mine site and downstream will be as clean and safe as possible. (LSCFN)
- The opportunity for traditional uses of the area will be restored and as close to before mining use as possible. (LSCFN)
- Animals, plants and berries around the mine site are safe to harvest and will stay that way. (LSCFN)

4. Maximize local, Yukon and First Nation benefits.

- To maximize the social and economic benefits that may accrue to First Nations, and northerners when carrying out activities. (INAC)
- Provide economic opportunities for Little Salmon Carmacks First Nation members, Carmacks area residents and Yukoners in general. (GY)
- Local people will be hired to help clean up at the mine. The economic development chapter of the LSCFN Final Agreement should be followed. (LSCFN)

5. Government Liability and Risk Management

- Reduce federal liability for this site in the long term. (INAC)
- Reduce long term site risk in a cost effective manner (INAC)
- Reduce long term risk in a cost effective manner. (GY)
- Design of reclamation to minimize to the extent possible, long-term treatment. (GY)

These closure objectives presented in Appendix C of Options for Closure of Mt. Nansen Mine, Technical Review July, 2008, were developed in consultation between Indian and Northern Affairs Canada, Yukon Government, Department of Fisheries and Oceans, LSCFN, and Environment Canada. They cover environmental, community, economic, and health and safety aspects and were presented under the following categories:

- protect human health and safety.
- protect the environment including land, air, water, fish and wildlife.
- return Mine Site to an acceptable state of use that reflects original use where possible.
- maximize local, Yukon and First Nation benefits.
- reduce government Liability and Risk.
- closure planning core values.
- related Community Concerns.

For the purposes of the gap analysis and to facilitate comparison of alternatives the following overall closure objectives were distilled from the expressed concerns and objectives:

- Is surface water protected, such that the risk to the environment and human health is reduced?
- Is groundwater protected such that risk is reduced?
- Is transmission of dust managed such that risk is reduced?
- Is useful aquatic habitat restored?
- Is useful terrestrial habitat restored?

- Is disturbed land returned to original use?
- Is passive closure maximised?
- Is long-term liability reduced?
- Is overall footprint of disturbance reduced?

These objectives have been kept in mind by the characterisation team during the current phase of work, and are considered in the information describing the alternatives presented in Appendix A, which were the result of the gap analyses used to develop the scope of work for the 2009/2010 characterisation program.

The geotechnical, hydrogeological, geochemical and surface water analysis provided in this report and the supporting technical memoranda can inform an assessment against some of these objectives, but do not fulfill the need for an assessment of alternatives against all of the stated objectives for Mt Nansen. The Government of Yukon, Government of Canada (INAC) and Little Salmon Carmacks First Nation are presently working on developing the appropriate process that will be used to assess and evaluate each of the proposed closure alternatives, based on all the stated closure objectives.

2.2 Results of Gap Analysis

The following section summarises the results of a gap analysis, and the feedback and discussion from the workshop held on March 23rd and 24th, 2009. The gap analysis considered the overall objectives established in the YG report, “Options for Closure of Mt. Nansen Mine, Technical Review Version”, July 2008. The following overall alternatives were considered:

1. Care and Maintenance for entire site – Status Quo.
2. Infill Pit with Waste Rock and Care and Maintenance of Tailings Management Area (TMA).
3. Upgrade TMA, with variations including partial or complete pit backfilling with mine rock.
4. Relocate all tailings to pit as backfill and decommission TMA, with options to partially or completely re-locate waste rock as pit backfill.
5. Decommission TMA and create new TMA, with options to partially or completely re-locate waste rock as pit backfill.

With this list of five main closure alternatives, disposal and remediation options for each element of the site were identified, (e.g., pit, waste rock, tailings, tailings dam, etc.) and available information was reviewed. Data gaps were identified that would preclude a balanced and objective comparison of alternatives, with the closure objectives as a frame of reference. The results of the gap analysis are summarized in Appendix A.

The following points were made during the workshop, which reviewed the alternatives for closure of the Mt. Nansen mine site. These points have served subsequently to guide detailed planning to fill the data gaps and to characterize selected alternatives:

- LSCFN reiterated to the team that the key objectives for mine site remediation are footprint reduction and a holistic approach to the full restoration of the land, to the extent practical, making reference in particular to re-vegetation of the pit area.
- It was noted that the mill site required investigation in 2009, although the results would not necessarily affect the process of investigating and characterizing the alternatives for reclamation of the pit, mine rock and tailings areas.
- Two main sets of alternatives were selected for further detailed investigation and analyses, in order to allow a rational and defensible selection process of a preferred option to proceed as soon as possible. The results of the

gap analysis (Appendix A) formed a basis for the team to carry out detailed planning and integration of field, laboratory, design and impact assessment tasks.

- Residual risks and uncertainty for each alternative assessment were identified as needing evaluation. Fatal flaws and unacceptable risks required identification and mitigation or resolution as the selection process occurs, as and when adequate information becomes available. In other words, some iterative discussions were needed to scope out work required for characterization of alternatives that are free of fatal flaws and are likely to result in tolerable residual risk.
- There was general acceptance that the options to leave the situation as it is (Alternative 1), or to create new tailings storage facilities in Dome Creek, or elsewhere, (Alternative 5), are unlikely to be acceptable, and that the team should focus on alternatives likely to be acceptable, namely: either to stabilize the existing tailings dam for the very long-term; or to move all tailings and related dam materials to the open pit. Variations on these two principal alternatives are the additional relocation of some or all of the waste rock into the pit.
- It was noted that the existing tailings storage facility, current located in the original Dome Creek drainage path, is not considered good practice for a permanent facility because of the requirement for permanent flood diversion. Work in 2009 on this alternative was therefore required to seek ways to achieve acceptable levels of long term risk.
- It was noted that options within the principal alternatives centre on whether full saturation and submergence of problematic materials such as tailings and mine rock can be achieved reliably. Investigations for 2009 were required to focus on this aspect, including improving knowledge about surface and ground water flow across the entire site, and practical ways to control these flows (diversions, cut-offs, cover layers).
- Alternatives considered for the open pit need to range from leaving a long-term pit lake, partially backfilling with waste rock, or backfilling with a combination of tailings, tailings dam material, and mine rock. Methods for de-constructing the existing tailings facility, transporting materials, and placing them optimally in the pit need to be considered in order to completely characterize that alternative.
- An integrated multi-disciplinary approach combining engineering and environmental science was identified to key to the investigation of closure alternatives. This approach was initiated through a detailed work planning session held in Whitehorse in April 2009.
- It was noted that certain areas of work have a very high priority, so as not to miss critical seasonal windows or cause delay because of time required to conduct them. This includes geochemical testing and hydrological monitoring. Monitoring and sampling of spring freshet was identified as a priority. Access onto the tailings for sampling before spring thaw occurs was also a priority.
- It was highlighted that the process of preparing alternatives for consideration would need to be undertaken with the full knowledge and awareness of the advisory committee. They were invited to attend and contribute to the planning and ongoing work. Regular communication to advise on activities and progress was required of the project team.
- It was noted that ultimately the decision to select an alternative will be influenced by both cost and consideration of long-term risk and liability. The challenge for 2009 was to characterize these factors adequately. The work to be conducted would be subjected to independent peer review.
- Short term risks associated with the existing tailings storage facility was questioned. This has been addressed in a report by AECOM, prepared in January 2009, which describes the types and levels of risk assessed. The next step is to assess alternative means of reducing risk and liability to acceptable levels for the long-term. This would include a formal dam safety evaluation, and a prediction of failure risk and consequences. All alternatives need to consider the need for ongoing monitoring, adaptive management and any active maintenance measures.
- It was clarified that the next phase of work would include conceptual designs for alternatives to a level which allows reliable comparison with other alternatives. Closure objectives have been developed by various interested parties. These can be refined and interpreted in the context of each alternative, so that they are relevant, in consultation with the advisory group. Closure design criteria will be developed, including for seismic, flood and other elements as appropriate.

2.3 Results of Planning Workshop

Appendix A contains a listing of the points made during the planning session held on April 22nd and 23rd, 2009. This workshop focussed on the four following alternatives for the closure of the Mt. Nansen mine site:

- 3A - Upgrade tailings dam, install cover (soil, water or sponge), no waste rock management;
- 3B - Upgrade tailings dam, install cover (soil, water or sponge), waste rock moved to pit;
- 4A - Tailings excavation and disposal in the Pit- wet or dry condition; and
- 4B - Tailings excavation and disposal in the Pit- wet or dry condition with waste rock.

The closure scenarios listed above are a refinement of original closure alternatives presented by GY (2008) and were refined as part of the Gap Analysis Workshop described above and in Appendix A.

The planning workshop facilitated detailed planning to fill the data gaps and carry out conceptual design and effects comparison of the selected alternatives. In other words, the purpose of this phase of work was to define work plans and studies aimed at characterizing the selected alternatives and previously identified data gaps.

LSCFN noted that the elders recognise that it may not be practical to completely restore the pre-mining landscape. In addition, LSCFN re-iterated their preference for tailings to be re-located to the open pit. They seek alternatives that will restore their traditional use of the site water ways. They seek robust defensible proposals.

It was noted that SENES Consultants Limited has completed a preliminary Human Health and Ecological Risk Assessment (HHERA) in 2009. The results of this work indicate that the main risk receptor pathways identified in the report are water and airborne dust.

Appendix A contains detailed points from the workshop organized as:

- Mine Waste rock Characterization Planning;
- Environmental Monitoring Planning;
- Geochemical Characterization Planning;
- Geotechnical Characterization Planning;
- Surface water Characterization Planning;
- Hydrogeological Characterization Planning; and
- Review of Alternatives and Work Required for Characterization.

3. Hydrological Characterization

3.1 2009 Hydrology Investigations

The hydrology field program was managed by AECOM with data collection conducted by Environmental Dynamics Inc. (EDI) in conjunction with their existing water quality monitoring program. Hydrological stations were installed at six locations with each station consisting of a datalogger, to continuously measured water depth and temperature, and a staff gauge. Figure 3-1 (back of report) shows the surface water sites. At each site a cross-section and benchmark were established and surveyed in conjunction with the corresponding velocity measurements.

Five sets of cross-sectional velocity measurements and water level measurements were made throughout the field season in an attempt to cover the range of hydrological conditions at the site. Dataloggers were downloaded by

AECOM staff working on the hydrogeology program in August. At this time the hydrometric station on Back Creek was relocated as the water levels had dropped below the datalogger sensor. Details of the field program are provided in a separate memorandum that is posted on the AECOM SharePoint site.

3.2 Stream Flow Characterization

Preliminary rating curves were generated for each hydrometric station installed in 2009. Given the amount of data the overall trends between water level and discharge were strong with R^2 values between 0.7 and 0.94. As the hydrological monitoring program was initiated after spring freshet, the Chezy-Manning[1] equation was used to estimate a flow at bankfull conditions. This was used in the preliminary rating curves to help remedy the trend towards overestimating flows at higher water levels. Bankfull stage estimates and the associated area and hydraulic radius were taken from the field surveys completed during the installation of the gauges and slopes estimated using field observations.

Using these preliminary rating curves, a hydrograph was generated for each site from the continuous stage data collected by the data loggers. The results are provided in a detailed memorandum and summarised in the following sections.

3.2.1 Upper Victoria Creek

Victoria Creek is the largest watercourse running through the site and, at the gauging site, appears to be groundwater fed due to open water year round at this particular location. The hydrograph developed for Victoria Creek shows high flows during freshet and lower flows throughout the rest of the year, with very little peaking during rain events. The logger in Victoria Creek was winterized and left in place to collect water level data over the winter. The preliminary rating curve for Victoria Creek shows a very strong correlation with an R^2 value of 0.94.

3.2.2 Back Creek

Back Creek is a smaller water course that flows into Victoria Creek just downstream of the Victoria Creek station. This creek was heavily influenced by placer mining during the summer of 2009, which is evidenced by the heavy sedimentation and the spike in flows observed in late June during releases at the placer mine.

Due to silt deposits around the datalogger, the station was moved in mid-July. Based on datalogger data after the logger was move, the flows in Back Creek do not appear to react strongly to rain events. For a period between mid June to when the logger was moved July 14th, the datalogger was completely buried in silt. The datalogger appears to be less accurate after being cleaned out and reset; however, it does provide a relatively good stage record when compared with the manual measurements. The preliminary rating curve for Back Creek shows an acceptable correlation with an R^2 value of 0.83. The rating curve appears to be under-estimating flows at the mid-level, as observed on both the hydrograph and the rating curve. This may be due to the change in channel shape from sedimentation during the placer mining activity.

3.2.3 Pony Creek

Pony Creek is a small creek affected by an access road crossing with a culvert and previously conducted earthworks at various points along the creek. The flow along the drainage conveying Pony Creek is suspected to influence the seepage into the north wall of the mine pit. Two dataloggers were placed at the site in to support the hydrogeological investigations as well as the water balance modelling.

The first logger was placed high in the drainage, upstream of the pit. The earthworks in this part of the drainage are older and not revegetated for the most part and have resulted in a series of berms, causing the stream to pool and meander in places. The second logger was placed downstream of the access road culvert, in order to correspond with the existing water quality sampling locations. The downstream site was also chosen as this stream does tend to go to very low flows or dry over the summer and the culvert was used to enable the measurement of flow during these low flow periods using a timed bucket test.

Due to the extremely low-flow conditions over the summer, collecting flow and level data at the downstream Pony Creek site was challenging and the levels and resulting flows estimated for the hydrograph do not exhibit te level of accuracy expected. The rating curve for the downstream site shows a strong correlation with an R^2 value of 0.92 while the upstream site had a limited amount of data with an acceptable correlation and an R^2 value of 0.70. While all other rating curves at this site have been completed with a logarithmic formula, the rating curve for the upstream site appears to exhibit a linear trend. It should be noted that data available for the upstream site was limited due to a later installation and the flow going dry at points throughout the summer.

3.2.4 Dome Creek

Dome Creek is relatively small, approximately 1 m wide at the gauge site located just below the mine access road. Immediately below the gauge site and above the access road, the channel is braided and meandering. The hydrograph developed for Dome creek shows the creek to be flashy in response to rain events. The preliminary rating curve developed for Dome Creek shows a linear relationship between stage and discharge, with a strong correlation and R^2 value of 0.98.

3.2.5 Dome Creek Diversion Channel

The diversion channel is a man made structure conveying Dome Creek around the tailings pond and back into Dome Creek downstream of the tailings dam and seepage pond. In addition to the water from Dome Creek, the diversion channel conveys runoff collected in an interceptor ditch on the west side of the tailings pond. Water from the tailings pond is intermittently pumped into the diversion channel downstream of the seepage dyke. The channel is not lined and therefore is suspected to be losing water along its path through infiltration, in particular where elevated above its natural bed elevation. A logger was placed in the diversion channel, downstream of the bridge crossing the channel. This location was selected as this is an area of interest for future engineering design with regard to the tailings pond. A second cross-section was established just below the inflow of Dome Creek (upstream of the datalogger) to measure discharge and compare with the flows recorded at the gauge site. Measurements confirmed that flow in the channel decreases in a downstream direction.

Due to the fine channel substrate upstream of the logger and dredging of the channel in early July, sedimentation occurred at the logger site, potentially changing the channel shape as well as the bed elevation. Again, sedimentation around the datalogger is suspected to have affected the readings. For these reasons, a hydrograph was not developed for the diversion channel, given the inconsistency between the datalogger and manual stage measurements. The preliminary rating curve developed for the diversion channel shows a strong correlation, despite the channel dredging, with the R^2 value of 0.86. Rating curves developed before and after the dredging activities, do not appear to change substantively. Given the apparently strong rating curve, a gauge could be re-established at this site, with a new datalogger, protected from sediment and used to generate future flow estimates.

3.3 Hydrological Characteristics Synthesis

A synthetic historical flow record was constructed from Jan. 1963 to Feb 2007 for select locations along Pony Creek, Back Creek, Dome Creek and Victoria Creek at Mt. Nansen, utilising available precipitation data from Environment Canada and Yukon Environment.

A representative runoff coefficient for the mine site was estimated by comparing known stream flow events in the region with the corresponding known precipitation event. A search for recorded Water Survey Canada (WSC) stream flow data and recorded Environment Canada precipitation data in closest proximity to the Mt. Nansen site yielded three WSC gauges and four Environment Canada gauges.

The steepness of the local terrain at the Mt. Nansen site is the predominant factor affecting the time of concentration and runoff coefficient. Reviewing documentation for Rational Method runoff coefficients in mountain environments indicated that runoff coefficients should range between 0.6 to 0.8 for Mountain Terrain (Slopes >10%) for events with a 2-10 year return period. Watershed slopes for the various sub-basins at the Mt. Nansen Mine Site were computed and found to be as high as 40%. This indicated that the runoff coefficient should be at the upper end of the suggested range.

Additional documentation for Rational Method runoff coefficients indicates that a factor of 0.1 be added to the runoff coefficient to account for snowmelt conditions. As such it was decided to use a runoff coefficient of 0.7 to compute the flows in the summer months and a runoff coefficient of 0.8 to compute the runoff in the spring snowmelt during the months of April and May.

To support the water balance modelling efforts, flow data was required for sites along Pony Creek, Back Creek, Dome Creek, and Victoria Creek. These were developed in Excel using the monthly historical precipitation data recorded at the Environment Canada Carmacks precipitation gauge. The recorded daily total rain, total snow, and total precipitation were summarized as a monthly time-series from August 1963 to February 2007 (the period of record in the Environment Canada database).

The rainfall precipitation data recorded at the Carmacks gauge was adjusted for the Mt. Nansen mine site using a regression formulae developed between coincident precipitation data recorded at both the Mt. Nansen site and the Carmacks site.

Snow water equivalents were estimated using information provided by Environment Canada, as described in the memo. In the 33 years of record, the average water content in the snow pack decreases on average by 82% in the month of April with the remaining 18% to decrease in May. This distribution was adopted to compute the additional water volume encountered during the spring melt in April and May.

3.4 Tailings Dam Seepage

Seepage water is collected in a pond immediately downstream of the tailings dam. The pond is lined with a geomembrane and thermosyphons were installed to maintain frozen ground conditions in response to seepage losses evident on the downstream side of the containment dyke.

The following observations about tailings dam seepage were presented in AECOM's 2008 Inspection Report (January 2009).

- Seepage water is collected year round in the pond and pumped over the dyke by the pumphouse. There are no means to regulate pond levels other than by pumping.
- Pumping rates ranging from 1.9 L/sec (30 USGPM) to 4.7 L/sec (75 USGPM) during periods of significant precipitation are used to maintain a fairly constant water level in the pond. It takes about two days worth of seepage to fill the pond if pumping is stopped (personal communication, H. Copeland).
- Seepage was observed entering the pond at two locations. The first is at the southwest corner of the pond where active seepage through the rock fill at the downstream edge of the stabilizing berm has caused iron staining of the rock. Seepage rates are estimated to be less than 4 L/min (<1 USGPM).
- The seepage water appears clear and the ground in the vicinity of the seepage is algae covered suggesting the flow at this location is nearly continuous throughout the year.
- The second location is at the northeast corner of the pond where flow is estimated to be in the order of 4 L/min (1 USGPM) at the toe of the north terrace slope . The seepage area is also covered in green algae.
- Subsequent examination of photos suggests that seepage may have been occurring in the past.
- We are not aware of any water chemistry results associated with the individual seeps.
- What appeared to be seepage was observed along the downstream toe of the seepage dyke, in particular along the southern half.

3.5 Summary of Hydrology Uncertainties

The period of surface water flow measurements at this site is limited to one year of data which presents some uncertainty in projecting the data into the future. Surface water flow monitoring is continuing in 2010 to reduce this uncertainty. There are also missing climatic records from the nearest Environment Canada climatic station at Carmacks for the period when the surface water flows were measured which also increases uncertainty in the surface water flow inputs into the water balance. Further discussion of hydrological uncertainty is included in the following chapters that describe the geotechnical conceptual design of dams and diversion structures as well as the water quantity and quality modelling.

4. Geotechnical/Civil Engineering Characterization

4.1 Current Condition

This section summarizes the evaluation of the existing tailings impoundment conducted by AECOM in 2008 (AECOM 2009), supplemented by the results of drilling and further monitoring of geotechnical instrumentation conducted in the summer of 2009. No significant changes in the overall condition of the tailings dam and associated works were observed in the summer of 2009 although detailed surveys were not carried out.

Overall, the tailings dam and seepage dyke are considered to be in reasonably good condition. There do not appear to be any significant deformations of either structure that would indicate active instabilities. Seepage water is collected at the toe of the rock fill in the seepage pond where it is pumped over the seepage dam having met discharge criteria. The seepage water appears clean although there is considerable sediment visible in the pond. Settlement of the south half of the tailings dam crest, as evidenced by surveys of monitoring pins and the centerline profile in 2008 remains visible but without additional surveys, additional ground movements (if any) cannot be quantified. The spillway is in good condition although the constriction from widening the road approaching the south side of the bridge remains.

The interceptor ditch and diversion channel are functioning although the banks upstream of the tailings dam spillway are typically over-steepened with active erosion and sloughing. It appears that excavation of sediment along flatter grades was undertaken after the 2008 inspection. The diversion channel downstream of the tailings dam spillway remains in good condition with only minor loss of bank armouring material in the downstream half of this portion of the channel.

4.2 2009 Subsurface Investigations

4.2.1 Drilling and Instrumentation Program

Geotechnical investigations were conducted at the existing tailings facility using air rotary drilling techniques combined with the ODEX casing system. Boreholes were completed to evaluate soil and groundwater conditions at key locations and to supplement data from previous investigations. Thermistor strings were installed in selected boreholes to measure ground temperatures. Standpipe piezometers were installed to facilitate groundwater level monitoring and sample collection. Standard penetration tests were conducted at regular intervals and split spoon samples were collected for further testing and classification. Approximate soil temperatures were measured at ground surface on split spoon samples using a digital temperature probe. All geologic materials were then classified according to the Unified Soil Classification System and photographs of each sample were taken. Results from the geotechnical program have been used in subsequent assessments of existing slope stability, seepage and the feasibility of dam upgrading alternatives. It is important to note that the monitoring data from geotechnical instrumentation installed by AECOM is limited to the short period of time during the field investigation in late July and August. Additional monitoring is required to determine long term trends and seasonal variations.

AECOM Test Hole GT09-01 was drilled adjacent to EBA TH 12861-03 where the depth of fill and the zero degree isotherm (permafrost contact) was undetermined. TH GT09-01 was advanced to a depth of 30 m and a thermistor string was installed. Monitoring well 09-23 was installed in an adjacent borehole. The depth of fill was confirmed to be at about 16 m below the crest, terminating at about elevation 1085.4 m. It appears that the organic layer was stripped before fill placement, an observation that is consistent with previous observations by EBA. Permafrost was encountered at a depth of 21.5 m below ground surface during drilling. Based on one monitoring event, permafrost is suspected to be at a depth of about 22 m (elevation 1,079.9 m) which corresponds well with the field observation. This information suggests the depth of thaw into the foundation soil below the dam at this location is approximately 5 m which is greater than observed at the closest adjacent borehole with a full depth thermistor string (EBA TH 12861-02). The elevation of the permafrost contact however, is similar between these two test holes (about elevation 1080 m). The groundwater level two days after installation of the monitoring well was at 12.5 m below the dam crest.

AECOM Test Hole GT-09-02 was drilled on the road to the stabilizing berm from the south abutment where significant settlement of the dam crest and downstream face has historically been observed (AECOM 2009). Previous remedial works have been carried out in this area to address seepage (Klohn-Crippen 1999). The depth of fill was determined to be about 4.3 m and permafrost, as evidenced by field observations and subsequent monitoring, was at a depth of about 5.5 m or elevation 1,084.9 m. It appears that the organic layer was stripped prior to fill placement. The depth of thaw is therefore estimated to be in the order of 1.2 m (assuming the permafrost was immediately below the organic layer before construction). Groundwater levels at this location are at about 4 m below grade (MW 09-22). Measured ground settlements are greater than would be expected from permafrost degradation over this depth of thaw. It is therefore possible that the settlement is related to internal erosion, an observation that warrants close monitoring during subsequent condition assessments. This potential can be addressed during dam upgrading through the installation of a filter that allows seepage to continue but retains fine grained soil particles that may be carried in the seepage water.

AECOM Test Hole GT-09-03 was drilled on the north terrace in the vicinity of EBA TH 12861-07 where progressive thawing of the permafrost is apparent (EBA 1999 and 2002). The zero degree isotherm in TH 12861-07 was believed to be below the lowest bead or greater than 9.4 m below grade. TH GT-09-03 was drilled to a depth of 19.9 m and a thermistor string for the full depth was installed. Frozen ground was logged at a depth of 16.5 m below ground surface. Short term thermistor monitoring indicates the permafrost is at about the same depth as the field observation, or at elevation 1,075.8 m. Even at and below this depth, the ground temperatures are only just below zero, at about -0.05℃. Based on a depth of fill of just over 1 m at this location, and an assumed depth to permafrost of 2 m before construction (Klohn 1995) the depth of thaw is now estimated to be in the order of 13.5 m. This observation confirms previous interpretations that the presence of the dam on the south facing slope has lead to lateral as well as vertical thawing at this location (EBA 1999). Seepage from the diversion ditch may be a contributing factor in the warmer ground temperatures.

AECOM Test Hole GT-09-04 was drilled to a depth of 16.2 m on the upstream edge of the seepage dyke crest in the vicinity of the former EBA TH 12861-10. A thermistor string was installed to the full depth of the hole and a piezometer was installed immediately adjacent (MW 09-20). Fill was encountered to a depth of 4 m and frozen ground was encountered at 2.8 m into the fill. Based on short term thermistor monitoring, frozen ground in late August was estimated to be within the fill at a depth of about 3.2 m, or at elevation 1,077.6 m. Additional monitoring is required to determine if this depth corresponds to permafrost at this location i.e., it could be the thawing front within the active layer. These readings suggest there may be a continuation of the decrease in thawed depth that extended to a depth of 4.8 m in 1998 and 4.2 m in 1999 (EBA 1999). The adjacent piezometer was dry.

AECOM Test Hole GT-09-05 was drilled to a depth of 19.8 m on the north terrace above the seepage pond in the vicinity of EBA TH 12861-09. There was no historical instrumentation data in this area and therefore a full depth thermistor string was installed. Monitoring wellMW 09-24 was installed in an adjacent borehole. Frozen ground was reported at a depth of 7.6 m when drilling TH 12861-09 in 1998. Frozen ground was encountered at a depth of 11.3 m during drilling of Test Hole GT 09-05. Thermistor monitoring confirms permafrost is located at about the same depth (approximately 12 m or elevation 1077.6 m). Similar to TH-GT-09-03, the permafrost is warm with minimum temperatures of -0.1℃. The groundwater level was at about 3 m or elevation 1,084.5 m the day after completing the well installation.

4.3 Mine Closure Alternatives

Closure alternatives described in this report are variations of previously defined “Alternative 3” and “Alternative 4”. Alternative 3 involves upgrading the existing tailings dam, while Alternative 4 involves decommissioning the tailings dam and associated works and relocating the tailings into the open pit. Inherent with both alternatives are geotechnical and civil engineering considerations necessary to maintain long term closure objectives in particular dam stability, water management and geochemical stability. A brief description of Alternatives 3 and 4 are provided below with reference to the appropriate Drawings in Appendix B1. Geotechnical considerations as they relate to these alternatives are discussed in subsequent report sections and in the Summary Table in Appendix B2.

4.3.1 Alternative 3 – Upgrade Tailings Dam and Associated Works

Alternative 3 requires that the tailings dam and associated works be upgraded to meet long term closure objectives. Variations of Alternative 3 are to leave the waste rock in place (3A) and to move the waste rock into the open pit in conjunction with tailings dam upgrading (3B). Three different covers were considered for the tailings in Alternative 3A; a soil cover (i), a water cover (ii) and a “sponge” cover (iii). These three cover options are relatively similar in that each involves some thickness of inert soil and/or water cover to prevent exposure of the tailings to oxygen. In summary, the variations on Alternative 3 are as follows:

- Alternative 3A (i) – Upgrade tailings dam and associated works and provide a saturated soil cover over tailings (Drawing B-01);
- Alternative 3A (ii) – Upgrade tailings dam and associated works and provide a water cover over tailings (Drawing B-02);
- Alternative 3A (iii) – Upgrade tailings dam and associated works and provide a sponge cover over tailings (Drawing B-04); and
- Alternative 3B – Waste Rock Deposition into the Pit in conjunction with upgrading the tailings dam and associated works with one of the tailings cover options (Drawing B-07).

4.3.2 Alternative 4 – Relocate Tailings to Open Pit and Decommission Tailings Dam

Alternative 4 involves relocating all of the tailings and contaminated soil beneath the tailings from the existing tailings management area (TMA) to the open pit. Variations of Alternative 4 include placing the tailings in the open pit under wet or dry (semi-saturated) scenarios and with or without the addition of waste rock as part of backfilling. Alternative 4A (i) involves storing the tailings in a saturated environment within the open pit with no inclusion of waste rock i.e., either a saturated soil cover, a water cover or a sponge cover. Alternative 4A (ii) and 4A (iii) involve placing the tailings above the water table on a layer of waste rock within the open pit with and without internal layers of waste rock to facilitate internal drainage and consolidation. Alternative 4B (i) and 4B (ii) are the same as Alternatives 4A (i) and 4A (ii) but with the addition of as much waste rock as possible to completely fill the open pit. All of the alternatives include decommissioning of the existing tailings dam and associated works and restoration of the Dome Creek valley at the TMA. In summary, the variations of Alternative 4 are as follows:

- Alternative 4A (i) – Tailings relocated to open pit with a wet cover (Drawing B-08);
- Alternative 4A (ii) – Tailings relocated to open pit and maintained in a dry (semi-saturated) state with intermediate waste rock layers (Drawing B-09);
- Alternative 4A (iii) – Tailings relocated to open pit and maintained in a dry (semi-saturated) state without intermediate waste rock layers (Drawing B-10);
- Alternative 4B (i) – Same as Alternative 4A (ii) but with as much waste rock as possible added to completely infill open pit (Drawing B-11); and
- Alternative 4B (ii) – Same as Alternative 4A (iii) but with as much waste rock as possible added to completely infill open pit (Drawing B-12).

4.4 Geotechnical Considerations

There are several geotechnical considerations associated with each of the mine closure alternatives under consideration. These considerations can be broadly characterized for each of Alternatives 3 and 4 as follows:

Alternative 3 – Upgrade Existing Tailings Dam and Associated Works

- Stability and upgrading of the existing tailings dam and associated works;
- Stability and sizing of water diversion structures associated with the existing TMA;
- Design and construction of a suitable cover; and
- Design and construction of water diversion structures and spillway to maintain desired water level in the tailings pond.

Alternative 4 – Relocate Tailings to Open Pit and Decommission Existing tailings Dam

- Transportation, placement and consolidation of tailings in the open pit;
- Design of internal waste rock layers and reservoir below the tailings;
- Design and construction of a tailings dam or waste rock plug at the south end of the open pit;
- Design of cover options for tailings in the open pit;
- Design and construction of water diversion structures and spillway to maintain desired water level;
- Decommissioning of the existing tailings dam; and
- Restoration of the Dome Creek valley within the TMA.

Technical memos addressing specific geotechnical considerations in the context of the various closure alternatives under consideration were prepared and included in the initial draft report submitted to the Yukon Government. While these memos are still appended, further discussion and elaboration is provided in the following sections of this report.

4.4.1 Existing Tailings Dam Classification (Alternative 3)

Upgrading the existing tailings dam in association with Alternative 3 requires the classification of the structure (dam) in accordance with the Canadian Dam Association's, (CDA) 2007 *Dam Safety Guidelines.* This classification system is based on the consequences of a failure which may include loss of life, injury, property and environmental damage. In general, the consequences of a failure of the tailings dam would involve the release of water cover (which could be contaminated) and the release of tailings. The severity of a failure (in terms of consequences) will therefore depend on the alternative under consideration. For example, the downstream impacts could be greater for the alternative where a failure of the dam resulted in the release of a large volume of water and liquefied tailings over a long run-out distance. In the event of a dry cover, the impacted area could be considerably less as a result of a shorter run-out associated with slumped tailings.

A Dam Safety review carried out by EBA Engineering in 2002 considered the existing facility to be a *high* to *very-high* consequence facility, upgraded from the design consequence ranking of *high.* It should be recognized that these classifications were based on the 1999 CDA Guidelines which had four classifications (ranging from very low to very high) compared with the 2007 Guidelines which have five classifications ranging from low to extreme. The intent of AECOM's review was to establish preliminary dam classifications for the proposed closure scenarios using the most recent (2007) CDA *Dam Safety Guidelines* and based on our assumptions regarding incremental losses resultant from a hypothetical failure of the existing tailings dam.

For the case of a soil cover in Alternative 3A (i), a failure of the dam would not result in the release of a significant volume of water and tailings run-out would be limited. In the case of an earthquake induced failure, the tailings may liquefy and flow a greater distance downstream. The potential for loss of life is remote and would only apply to persons temporarily in the vicinity of the dam. From a consequence perspective, the implications of loss of life can be considered "unspecified". In our opinion, significant environmental consequences are unlikely and restoration or compensation in kind would be possible. Based on these consequences, we are of the opinion that an appropriate preliminary classification of the structure would be *Significant*.

Alternatives 3A (ii) and 3A (iii) include a water cover of approximately 72,000 and 11,000 m^3 respectively. The potential loss of life is still considered unspecified, however, a release of tailings pond water could result in more significant environmental impacts. In this regard, we are of the opinion that alternatives that include a water cover should be assigned a *High* classification until such time as more detailed assessments of the potential incremental impacts of dam failure demonstrate a lower classification is justifiable. For example, it may be determined that a significant classification is justifiable based on the reduced volume of water for Alternative 3 (iii), in particular if the water quality is acceptable for direct discharge to the environment.

The dam classification has implications regarding design flows (spillway design), seismic loading factors for slope stability analysis and the frequency for dam safety reviews and maintenance and operations. In this regard, the suggested design flood and earthquake levels recommended in the 2007 CDA Guidelines for significant and high classification structures are summarized in Table 4-1.

Table 4-1. Suggested Design Flood and Earthquake Levels (CDA 2007)

Classification	Annual Exceedance Probability for Inflow Design Flood	Annual Probability of Exceedance for Earthquake Design Ground Motion
Significant	Between 1/100 and 1/1,000	1/1,000
High	1/3 between 1/1,000 and the Probable Maximum Flood (PMF)	1/2,500

In accordance with the CDA Guidelines, dam safety reviews should be conducted at 7 and 10 year intervals for *High* and *Significant* consequence dams respectively but in any case, the frequency should also consider the presence or change of external hazards, the results of surveillance and the demonstrated performance. Maintenance and emergency response programs must be carried out while the dam remains in service (CDA 2007). It should be recognized that ongoing monitoring and inspections as part of the assessment of closure alternatives at the Mount Nansen Mine has significantly fulfilled the objectives of a dam safety review, in particular the completion of slope stability analysis.

4.4.2 Dam Stability (Alternative 3)

4.4.2.1 Failure Modes

The four most likely failure modes of the tailings dam are considered to be overtopping, seepage leading to internal erosion (piping), slope instabilities and liquefaction from an earthquake. The age of the tailings dam and repair work done to address previous instabilities has an influence on the potential for the identified failure modes. In general, many of the unknown defects in the Mount Nansen tailings dam have been tested throughout its life and therefore, there is a greater level of confidence in achieving satisfactory performance. The exception would be operating strategies that create untested conditions, for example, increased tailings pond elevations. Each of the potential failure modes is discussed separately as follows:

Overtopping

Overtopping would most likely occur as a result of flooding and therefore can be considered more of an issue with respect to water balance (hydrology) than geotechnical considerations e.g., the spillway must be designed to safely pass the design flood. The exception would be dam crest settlement which could cause a reduction in freeboard and an increased likelihood of overtopping. In this event, the failure mechanism would most likely be a breach of the dam and release of impounded water. Settlement of the south abutment has been observed and was reported in AECOM’s 2009 report. It is possible that the settlement of the dam crest is a result of internal erosion and/or thawing of the permafrost foundation below the dam. *Continued monitoring of the crest is recommended to assess any ongoing settlement and determine the need to raise the dam to restore freeboard.*

Seepage and Internal Erosion (Piping)

The most common failure mechanism for this failure mode is retrogressive internal erosion which may occur over a period of many years. At Mount Nansen, water from the tailings pond and natural groundwater pass through the dam fill material and foundation soils. The seepage water either enters the seepage collection pond or enters into the regional surface or groundwater system downstream of the dam. Excessive seepage on the downstream face of the dam resulted in the construction of the stabilizing berm in July 1997 (GLL 2006). Seepage analysis by AECOM indicated a factor of safety of 3.5 exists against piping failure due to heave compared to a minimum value of 2.5 typically adopted. This theoretical determination however, does not agree with observations made previously with respect to evidence of piping conditions at the toe of the dam at the seepage pond which was attributed to possible thawing of frozen ground allowing for "roofing" and localized high gradients (EBA 2002). In this regard, the dam upgrading should incorporate a weighted filter layer at the downstream toe of the dam. The filter will extend into any buttressing required for the upgrading. While this filter is not intended to prevent seepage, it should be designed to prevent internal erosion and the development of quicking (heaving) conditions at the downstream to of the dam.

Seepage losses (flow) should continue to be monitored on a regular basis to identify any changes that might indicate a change in the overall condition or integrity of the dam and the impact these changes could potentially have on the upgrading alternatives under consideration.

Liquefaction

Previous investigations have shown that soils which were previously frozen (permafrost) and thawed have a reduced strength that makes them susceptible to liquefaction under seismic loading conditions. Under an earthquake loading, the soil may experience a loss of shear strength resulting in slope failure, overtopping (from settlement) or internal erosion (from conduits opening). In this regard, the dam upgrading must be designed to provide adequate factors of safety against failure during an earthquake and after an earthquake when the liquefiable soils are at their critical (residual) state.

4.4.3 Slope Stability

The stability of the existing tailings dam was assessed to determine the factor of safety (FS) against slope instabilities for both existing conditions and seismic loading conditions in accordance with the 2007 Canadian Dam Association (CDA) Dam Safety Guidelines. The analysis evaluated the sensitivity of the dam to seismic loads and groundwater levels and formed the basis for determining potential upgrading alternatives to conform to accepted practice for design of closure of such structures. Numerical modeling was done with Geo-Studio 2007, (Geo-Slope Int. Ltd.) using the Slope/W and Seep/W modules. The loading cases analyzed and required factors of safety are summarized in Table 4-2.

Table 4-2. Loading Cases for Slope Stability Analysis (CDA 2007)

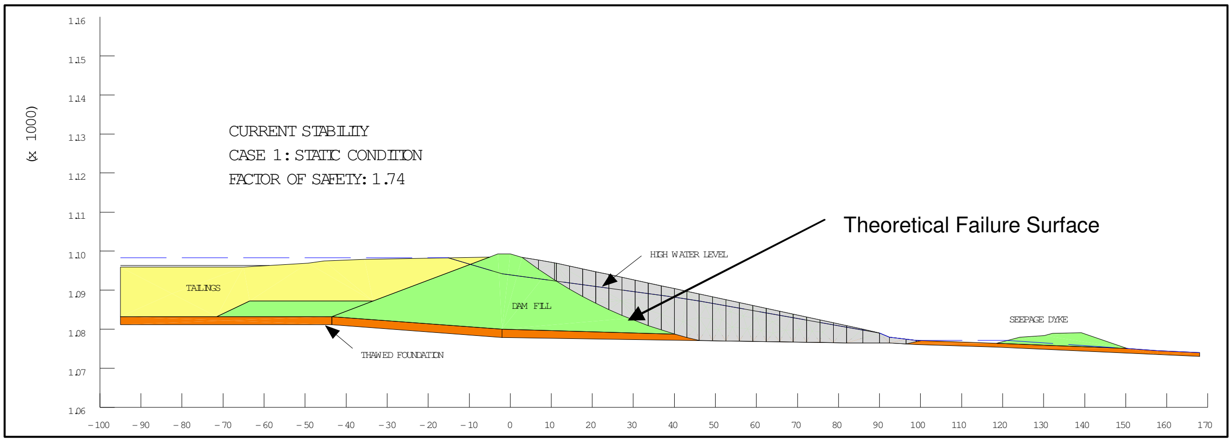
Case	Loading Condition	Peak Ground Acceleration (annual probability of exceedance)	Dam Classification	Minimum Factor of Safety (note 1) Against Slope Instability
1 - Static	Steady state seepage	NA	NA	1.5
2 – Pseudo-static	Earthquake	0.27 (1/10,000)	Extreme	1.0
2a – Pseudo-static	Earthquake	0.11 (1/2,500)	High	1.1 (note 2)
3 - Static	Post-Earthquake	NA	NA	1.2

Note 1: The Factor of Safety is defined as the ratio of the resisting forces to the driving forces.
Note 2: 2007 CDA Guidelines allow a minimum FS of 1.0 for this loading case.

Section for Analysis

A typical stratigraphic profile was developed using the depth to permafrost and the thickness of the thawed foundation zone based on borehole and monitoring data from previous geotechnical investigations and information obtained in AECOM's 2009 investigation. The cross section chosen for the slope stability analysis (Section A) is shown in plan view on Drawing B-02. A typical output from the slope stability model showing the cross section is illustrated on Figure 4-1. The results of the stability analysis for the three loading cases for existing and upgraded dam configurations are summarized on Drawings B-05 and B-06.

Figure 4-1. Cross Section for Slope Stability Analysis



Piezometric Levels

Piezometric (groundwater) levels were based on historical monitoring and represent a range from low to high to bracket possible levels and evaluate the sensitivity of slope stability to piezometric conditions. The low piezometric level is consistent with that observed through monitoring during 2008 when pond levels were drawn down. This level is also considered approximate to what would be expected during normal operating conditions for an upgraded dam where the edge of the water is maintained at least 50 m from the dam crest (as per the original design). The high piezometric level represents the highest levels recorded historically and which would be associated with high pond levels (as occurred during operation of the tailings facility) or high infiltration events. Because of the history of seepage through the dam, it is considered prudent to evaluate upgrading alternatives using the high piezometric levels.

Soil Properties

The engineering properties of the soil units were adopted from the EBA Dam Safety Assessment (2002) in which we are in concurrence. These values are based on engineering judgement and the results if in situ testing. Based on the results of previous cone penetrometer and standard penetration testing, thawed foundation soils beneath the dam were considered to be liquefiable. Residual soil strengths were assigned for the soil units after a severe earthquake event in accordance with recommendations in the 2007 CDA guidelines which cross-reference the methodology outlined in the Canadian Foundation manual (CFM 2007). In this case, the critical soil strengths are input into the stability model as residual cohesive strengths. The material properties assumed for the analysis are summarized in Table 4-3.

Table 4-3. Summary of Soil Properties

Soil Unit	Unit Weight γ(kN/m^3)	Friction Angle ϕ deg	Cohesion c' (kPa)
Tailings	18.6	28	0
Tailings (Post Earthquake)	18.6	0	9
Compacted Dam Fill	19.5	34	0
Native Foundation Soil (thawed)	19	28	0
Native Foundation Soil (Post Earthquake)	19	0	14.4
Rock Fill	21	45	0

Seismic Conditions

A detailed probabilistic seismic hazard assessment was not considered necessary to carry out preliminary assessments of slope stability. Rather, the current seismic hazard model and set of hazard maps developed by the Geological Survey of Canada for the 2005 Edition of the National Building Code of Canada were used to estimate peak ground accelerations (PGA) for the mine site. Peak (horizontal) ground accelerations of 0.11 and 0.27 g representing predicted return periods of 1/2,500 and 1/10,000 respectively were considered. The selection of the appropriate PGA depends in part on the final dam classification. The higher value (PGA=0.27g) would be consistent with an *Extreme* classification while the lower value (0.11) would apply to a *High* classification based on the 2007 CDA Guidelines. Both values have been used in the analysis in order to bracket the range of factors of safety under earthquake loading recognizing that more detailed seismic analysis would be required for detailed design. For conceptual design purposes and in consideration that a classification of extreme is considered unlikely, we have established a target of 1.0 for a PGA of 0.27 and 1.1 for a PGA of 0.11.

4.4.3.1 Existing Stability

The existing factor of safety for the loading cases was calculated with the results summarized in Table 4-4. The tailings dam has an adequate factor of safety (>1.5) under both low and high piezometric levels. Under seismic (pseudo-static) loading conditions, the factors of safety for an extreme earthquake event (1/10,000), the factors of safety are 0.72 and 0.93 for low and high piezometric levels respectively, both of which fall below the minimum FS of 1.1. For a 1/2,500 return period, which is consistent with a *High* dam classification, the factors of safety are 1.12 and 1.45 for high and low piezometric levels respectively, values which exceed the minimum FS of 1.1 (note: CDA allows a minimum FS of 1.0 for this loading case). The calculated factors of safety for post-earthquake loading conditions are 0.56 and 0.63 for high and low piezometric levels respectively. These values fall well short of the minimum FS of 1.2 and for this reason, represent the basis for which dam upgrading alternatives were evaluated.

Table 4-4. Factors of Safety for Existing Stability

Case	Loading Condition	Minimum Factor of Safety	Calculated Factor of Safety	
			Low Piezometric Level	High Piezometric Level
1 - Static	Steady state seepage	1.50	2.23	1.74
2 – Pseudo-static (PGA=0.27)	Earthquake	1.0	0.93	0.72
2a – Pseudo-static (PGA=0.11)	Earthquake	1.10	1.45	1.12
3 – Static	Post-Earthquake	1.20	0.63	0.56

The impact of additional permafrost thawing beneath the dam was evaluated for Cases 1, 2 and 3 to help understand the importance of this variable in dam stability and provide some guidance as to appropriate upgrading scenarios e.g., determine how the depth of thaw affects the relative improvement from ground improvement techniques. The results of this sensitivity analysis are summarized in Table 4-5 for analysis where the permafrost elevation below the dam was dropped by an additional 2 m. In all cases, the high piezometric level was assumed. The relatively small reductions in the calculated factors of safety indicate that the stability of the dam is more sensitive to the presence of the thawed layer e.g., Case 3, rather than its thickness. The scenario of a potential increased depth of thaw will require further evaluation during detailed design.

Table 4-5. Factors of Safety for Existing Stability With Increased Depth of Thaw

Case	Loading Condition	Minimum Factor of Safety	Calculated Factor of Safety	
			Existing Depth to Permafrost	Increased Depth of Thaw
1 – Static	Steady state seepage	1.50	1.74	1.66
2a – Pseudo-static (PGA=0.11)	Earthquake	1.10	1.12	1.08
3 – Static	Post-Earthquake	1.20	0.56	.49

4.4.3.2 Dam Upgrading

A number of dam upgrading alternatives were evaluated with the objective of meeting or exceeding the minimum factors of safety for all loading cases considered. The alternatives all involve altering the downstream geometry of the dam by slope flattening and/or construction of a toe berm (buttress). These measures are effective in improving the stability for static and pseudo-static loading conditions but are largely ineffective in improving the factor of safety for post earthquake conditions where the layer of liquefiable soil layer does not behave as a frictional material. In this case, the soil strength does not increase with higher overburden pressure. The problem is exacerbated by a gradually sloping permafrost surface that mirrors the sloping valley floor downstream of the dam. These conditions make it impractical to provide the resistance to sliding necessary to achieve the desired level of improvement with respect to global dam stability for the post-earthquake loading condition.

Ground improvement techniques were therefore considered to provide the necessary resistance to slope movements under post-earthquake conditions. A variety of techniques were looked at but they all fall into the general category of replacing a portion of the thawed (liquefiable) soil with higher strength material, a technique referred to in this report as a shear key. In this regard, a shear key could theoretically consist of frozen foundation soil or high strength granular soil in a thawed state. Any theoretical failure (slip) surface must then pass through the shear key whereby the factor of safety increases. Enough material must be placed above the shear key to prevent a failure surface from exiting above (rather than passing through) it. The material above the shear key could consist of waste rock or other suitable granular material. A fundamental requirement of the shear key is that it be keyed into frozen soil and that the permafrost be protected against thawing to guard against the slip surface running below the bottom of the key.

Final design of the stabilization measures will require a thermal analysis to evaluate the necessary means to maintain frozen ground or prevent degradation of the permafrost beneath the shear key. In this regard, the toe berm or buttress will act as an insulating layer and if sufficiently thick, may provide some freeze-back of the thawed layer. The results of the thermistor monitoring at the seepage dyke are also encouraging in that it appears that ground freezing through the use of thermosyphons could be considered to provide thermal stability or possibly freeze-back in the vicinity of the shear key. Additional measures such as insulating layers of organic material e.g., sawdust or woodchips within the toe buttress could also be considered. Although a detailed thermal analysis is beyond the scope of this study, we are of the opinion that measures can be taken to prevent degradation of the permafrost even with the inclusion of the latest global warming predictions.

Compacted granular material for a shear key could be placed into either a trench or large diameter casing drilled into the permafrost. The selection will depend in part, on the location of the shear key and the depth of installation. For the purposes of evaluating the feasibility of the concept, we have assumed that the key would be located immediately downstream of the seepage pond where the depth to permafrost is in the order of 2 m in Test Hole 14618-04 (EBA 2008). Test pits excavated farther downstream in 2001 show that the permafrost within the valley bottom remains at a depth of about 1.5 m e.g., 14618-TP01. It may be possible to shift the location of the shear key closer to the dam but the depth to permafrost beneath the seepage pond is likely to be greater than that measured just downstream of the seepage dyke. The width of the shear key and fill thickness above the key was varied until a combination that raised the FS to 1.2 was achieved. For the shear key positioned immediately downstream of the seepage dyke, the required width is about 15 m assuming complete thawing of existing freeze-back beneath the existing seepage dyke. The piezometric level across the dam was left high knowing that it has very little influence on this loading case.

The results of the analysis are provided in Table 4-6. In satisfying the minimum factors of safety for post-earthquake conditions, the factors of safety for the other two loading cases (static and pseudo static) are raised well above the minimum values. This is primarily because the buttress increases overburden pressures and hence shear strength along theoretical failure surfaces passing through the thawed layer. Stability analysis along a section to the south of section A, orientated towards the south abutment, indicates the toe berm should extend to higher ground on the south valley slope as shown on Drawing B-02. This requirement is a consequence of liquefiable soils evident in the vicinity of the south abutment (EBA 2002). Similar (liquefiable) conditions do not appear towards the north terrace and a similar elevated berm on the north side of the valley does not appear necessary.

Table 4-6. Factors of Safety for Upgraded Dam

Case	Loading Condition	Minimum Factor of Safety	Calculated Factor of Safety		
			Toe Berm With Shear Key (high piezometric level)	**Toe Berm With Frozen Foundation (high piezometric level)**	**Toe Berm With Frozen Foundation (low piezometric level)**
1 – Static	Steady state seepage	1.50	2.62	2.88	3.43
2 – Pseudo-static (PGA=0.27)	Earthquake	1.0	1.01	1.03	1.25
2a – Pseudo-static (PGA=0.11)	Earthquake	1.10	1.60	1.72	2.11
3 - Static	Post-Earthquake	1.20	1.26	1.25	1.29

An integral part of the construction will be the installation of instrumentation to measure ground temperatures after construction. Should ground temperatures unexpectedly rise causing increased thawing of the permafrost at the shear key location, a contingency plan should be in place to implement remedial works. These works would likely consist of either extending the shear key to a greater depth (likely using drilled rock columns) or reconstructing a shear key immediately downstream to the necessary depth. If not part of the original design, it may also be possible to retrofit the completed stabilization works with thermosyphons to freeze-back the soil.

The conceptual design assumes that the seepage pond will no longer be required since the water currently meets discharge criteria. Should the criteria become more restrictive or if the water quality deteriorates, it may be necessary to construct a new seepage collection pond downstream of the toe berm. Costs for a replacement seepage pond were not included in capital cost estimates. The crest of the tailings dam may need to be raised by up to 1 m where it has settled to accommodate the freeboard requirements for closure Alternatives 3(ii) and 3(iii). It is not expected that this additional load will have any significant consequence on the overall stability or the feasibility of upgrading measures.

4.4.4 Spillway Upgrading (Alternative 3)

4.4.4.1 Hydraulic Analysis

Peak flow rate and volume estimates were computed for the tailings pond to evaluate the necessary spillway upgrading. The assumed 6 hour storm duration peak flow rate for the 1000-year (0.1% event), 10,000-year (0.01% event), Probable Maximum Flood (PMF), and Inflow Design Flood (IDF) have been estimated as 4.0 m^3/s, 4.8 m^3/s, 12.5 m^3/s, and 6.8 m^3/s, respectively. The assumed 6 hour storm duration volumes for the 1,000-year, 10,000-year PMF, and IDF have been estimated as 89,000 m^3, 107,000 m^3, 281,500 m^3, and 153,000 m^3, respectively. Spillway widths of 5, 7 and 10 m were analyzed for the tailings pond based on the estimated peak flow rates and volumes for the above noted events. The maximum water level rise in the tailings pond has been assumed as 1 m.

Based on a high classification and in accordance with the Canadian Dam Association 2007 guidelines, the IDF should be estimated as 1/3 between the 1,000-year event and the PMF. The catchment area draining to the site has been estimated in a previous AECOM hydrologic analysis as 3.3 km^2. The Tailings Pond catchment area is based on the combined Dome Creek catchment areas for the diversion ditch north of the pond and the interceptor ditch south of the Pond. The precipitation records from the Environment Canada meteorological gauging station at Carmacks, Yukon were used to estimate the peak flow rate and volume for the 1,000-year, 10,000-year, IDF, and PMF events. The recorded rainfall records at the Carmacks gauge have been adjusted to estimate the rainfall depth at the Mt. Nansen mine site based on a regression analysis performed in the previous AECOM hydrological analysis.

The 1000-year and 10,000-year rainfall intensities have been extrapolated from the Intensity-Duration-Frequency curves (IDF curve) at the Carmacks gauge provided by Environment Canada. The Environment Canada estimated 2, 5, 10, 25, 50, and 100 year rainfall intensities were plotted to obtain regression equations for various storm durations. The regression equations were used to approximate the 1,000-year and 10,000-year rainfall intensities for various storm durations. CDA discourages the extrapolation of flood statistics beyond the 1,000-year event. The 10,000-year has been provided for the sake of analysis.

The Probable Maximum Precipitation (PMP) was used to develop the PMF. The PMP was computed using the maximum annual 24 hour rainfall records adjusted from Carmacks gauge. The summer PMP event has been estimated using the Hershfield statistical analysis ("Manual for Estimation of Probable Maximum Precipitation" – WMO No. 332). The general frequency equation is:

$$X_m = X_n + K_m S_n$$

Where:

X_m = rainfall for maximum observed rainfall
X_n = mean of a series of n annual maxima
S_n = standard deviation of a series of n annual maxima
K_m = common statistical variable that varies with X_n for different rainfall durations

The calculated annual mean, standard deviation and the selected Km for the adjusted Carmacks precipitation series as well as the area adjusted PMP estimate using the Hershfield statistical method are summarized in Table 4-7.

Table 4-7. Summer PMP Estimate for Adjusted Environment Canada Carmacks Records

X_n	S_n	K_m	Fixed Observation Adjustment	Area Adjustment	Area Adjusted PMP (mm)
18.0	6.0	19	1.13	1	149

The 1,000-year, 10,000-year, and PMF peak flow and volume estimates have been computed using the classic Rational Method. The estimated peak flow based on the Rational Method is computed using a runoff coefficient, rainfall intensity, and catchment area. The runoff coefficient has been approximated as 0.7 for the Mt. Nansen site, based on the previous AECOM hydrological analysis. The peak flow and volume estimates for the 1,000-year and 10,000-year events for various storm durations are provided in Table 4-8.

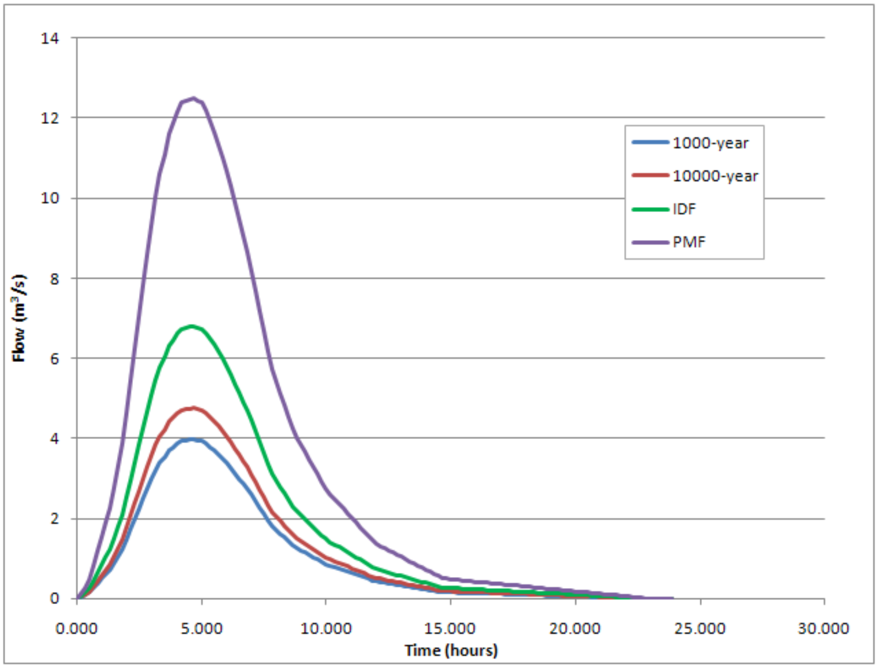
Table 4-8. Peak Flow and Volume Estimates for 1000-year and 10000-year Events

Duration	1000-year Event		10000-year Event	
	Peak Flow (m^3/s)	Volume (m^3)	Peak Flow (m^3/s)	Volume (m^3)
5 min	151.3	45,500	179.2	54,000
10 min	83.1	50,000	98.9	59,500
15 min	58.7	53,000	69.9	63,000
30 min	32.4	58,500	38.8	70,000
1 hr	18.0	65,000	21.5	77,500
2 hr	10.0	72,000	12.0	86,500
6 hr	4.0	89,000	4.8	107,000
12 hr	2.2	96,000	2.7	115,000
24 hr	1.2	108,000	1.5	128,500

A 6 hour storm duration has been assumed for this analysis. The computed 24 hour storm duration peak flow and volume estimates for the PMF event are 3.9 m^3/s and 338,000 m^3. The 6 hour storm duration PMF estimate has been computed by approximating the ratio of 6 hour to 24 hour calculated for the 1,000-year and 10,000-year events. The 6-hr/24-hr peak flow ratio is 3.2. The 6-hr/24-hr volume ratio is 1.25. The estimated 6 hour storm duration PMF peak flow and volume estimates are 12.5 m^3/s and 281,500 m^3.

The IDF is computed as 1/3 between the 1000-year event and the PMF. The peak flow and volume have therefore both been computed as 1/3 between the two events. The IDF peak flow and volume estimates are 6.8 m^3/s and 153,000 m^3. Hydrographs were developed for the 1000-year, 10000-year, IDF, and PMF events based on the computed peak flow rates and volume. A hydrograph was developed for each event using a dimensionless hydrograph approach. The 1,000-year, 10,000-year, IDF, and PMF event hydrographs are shown in Figure 4-2.

Figure 4-2. 1000-year, 10000-year, IDF and PMF Event Hydrographs



The 1000-year, 10000-year, IDF, and PMF hydrographs were routed through the modelled tailings pond. A HEC-HMS model of the tailings pond was developed in the previous AECOM hydrologic analysis. A stage-storage curve was not available at the time the model was developed. A stage-storage curve was developed for the tailings pond assuming the pond has a 7 ha cylindrical storage area (i.e., area at the water cover elevation is the same at the dyke top: 7 ha). Spillway widths of 5 m, 7 m, and 10 m were analyzed for the 1000-year, 10000-year, IDF, and PMF events. The Tailings Pond spillway modelling results are shown in Table 4-9.

Table 4-9. Tailings Pond Spillway Peak Outflow and Maximum Water Level Rise

Event	Spillway Width (m)	Peak Inflow (m^3/s)	Inflow Volume (m^3)	Peak Spillway Outflow (m^3/s)	Maximum Water Level Rise (m)
1,000-year	5	4.0	89,000	2.8	0.5
1,000-year	7	4.0	89,000	3.1	0.4
1,000-year	10	4.0	89,000	3.4	0.3
10,000-year	5	4.8	107,000	3.5	0.6
10,000-year	7	4.8	107,000	3.8	0.5
10,000-year	10	4.8	107,000	4.1	0.4
IDF	5	6.8	153,000	5.2	0.7
IDF	7	6.8	153,000	5.6	0.6
IDF	10	6.8	153,000	6.0	0.5
PMF	5	12.5	281,500	10.3	1.1
PMF	7	12.5	281,500	11.0	0.9
PMF	10	12.5	281,500	11.5	0.8

For the purposes of conceptual design, we have selected a 5 m wide spillway as being required to pass the IDF. Assuming that a minimum of 0.5 m of remaining freeboard would be required at this flow, the spillway channel would have to be at least 1.2 m below the tailings dam crest, or at about elevation 1,098.5 m. The spillway elevation will in turn be dependent on the final cover design. For example, a spillway elevation of 1,098.5 is suitable for either the soil cover in Alternative 3A (i) as it would retain a small amount of water in drainage swales in the cover or the sponge cover in Alternative 3A (iii). If a 1 m water cover is considered (Alternative 3A (ii)) however, it may be necessary to raise the spillway elevation to about elevation 1098.9 m. To maintain the desired remaining freeboard during the IDF, the dam crest would have to be either raised to elevation 1100.1 m (a raise of about 0.4 m) or alternatively, a wider spillway channel could be considered to almost eliminate the requirement for a dam raise. In any case, there is sufficient room on the north terrace at the existing spillway location to provide for the necessary spillway channel geometry although some modification to the existing road alignment may be required. Consideration will have to be given during detailed design to side slopes and channel armouring compatible with the anticipated velocities at peak flows. A conceptual cross section through the spillway channel is shown on Drawing B-03 (Appendix B). Depending on the ultimate water management plan and associated flows over the spillway, a concrete spillway (overflow) structure may be more suitable.

4.4.5 Diversion Channel Upgrading (Alternative 3)

The necessary upgrades to the diversion channel will depend in part on the selected alternative for the tailings pond cover, in particular the requirement to divert flow into the tailings pond to maintain a water cover or saturated soil cover. A conservative peak design flow of 10 m^3/sec was previously chosen for a conceptual channel design upstream of the emergency spillway (AECOM, 2009). While at less than 7 m^3/sec, the IDF is less than this assumed value, the results from our previous assessment of channel upgrading are considered representative for conceptual design purposes. The peak design flow was based on the following assumptions (AECOM 2009).

- minimum grade of 0.5% in the diversion channel upstream of emergency spillway;
- maximum flow depth of 1 m;
- minimum freeboard depth of 1 m; and
- flow channel base width of 3 m; and side slopes of 3H:1V.

The resulting channel velocity for the design section under peak flow is about 3 m/s which would erode both the channel bottom and sideslopes in an unprotected channel. Channel erosion protection is therefore a requirement and could be accomplished using properly sized granular material, possibly in combination with permanent synthetic reinforcement mats. Widening the diversion channel to the design geometry will require partial excavation of the adjacent access road (Drawing B-03). In this circumstance, the access road can be shifted towards the tailings pond. The road should be a minimum of 6 m wide with downstream sideslopes of 3H:1V. The road top should be graded away from the tailings pond and topped with traffic gravel. Exposed soil on both banks above the necessary armouring for channel flows should be revegetated.

The diversion channel downstream of the emergency spillway appears to be closer to the design cross section of the upstream stretch and it should therefore be possible to maintain a flow depth of approximately 1 m or less. Based on the observations from our inspection, additional armouring and upgrading of some of the drop structures should be considered, in particular downstream of Drop Structure 6. *A more detailed hydraulic analysis is recommended to determine if the drop structures are sufficient to achieve velocities in the steeper channel section that are acceptable for the size and thickness of bedding and bank armouring material.* In lieu of this information, an allowance has been carried in our cost estimate for upgrading this section of the diversion channel. An allowance has also been carried to upgrade or replace the existing timber bridge.

4.4.6 Interceptor Ditch Upgrading

The interceptor ditch on the west side of the tailings pond was originally excavated to intercept runoff before it entered into the tailings pond. The water from the ditch is conveyed to the north where it enters the Dome Creek diversion channel as shown on Drawing B-01(Appendix B). Maintenance of the channel has been problematic since it was constructed and we are of the opinion that it is no longer a necessary feature for closure alternatives under consideration. The only exception might be an alternative that is intended to only capture enough water to maintain cover saturation with no discharge from the pond over the spillway (although this may not be possible). The final decision as to the requirement for the interceptor ditch will depend on the outcome of the detailed design of the water management system and cover. For the purposes of this report, we have assumed that the ditch will be backfilled and the perimeter road will be extended as shown on the section on Drawing B-03 (Appendix B).

4.4.7 Water Diversion from Dome Creek (Alternative 3)

Depending on the selected alternative, the diversion of some, or possibly all of the flow in Dome Creek into the tailings pond may be required. For the purposes of this report, we have described these scenarios as either primary or secondary diversion channels depending on the relative percentage of flow diversion. The elevation of the water cover for Alternative 3A (ii) is 1098.9 m, which is the highest water level for the three alternative covers under consideration. In comparison, the elevation of the channel bottom of the diversion ditch at the confluence with Dome Creek is about elevation 1,100 m, rendering it possible to divert water from the diversion channel into the tailings pond in this vicinity for any of the alternative cover designs.

Without any diversion of water from Dome Creek into the tailings pond, it is anticipated that the pond will eventually fill, in particular if the interceptor ditch on the west end is filled and runoff from the area west of the TMA is allowed to enter the pond. Diverting water from the creek could be considered to maintain a constant water level and/or allow for replenishment with clean water, an operating strategy that may be preferred for the water cover alternative. In this case, the entire creek flow could be diverted through the tailings pond since the spillway is designed for the IDF (Drawing B-02). The attenuation in the pond will also help reduce the peak flow over the spillway for short duration but high flow events. It may still be desirable to divert a portion creek flow through the tailings pond for the soil and sponge cover alternatives although it will be important to determine if infiltration from the channel bottom into the tailings is compatible with the cover design and objectives for the overall geochemical stability of the tailings.

If the entire creek flow is diverted into the pond, the spillway will be in service year round with the exception of freeze-up in the winter. Although this strategy eliminates the need for the diversion channel on the north edge of the pond during normal operation, it would be advisable to upgrade the diversion channel and have it remain as an emergency spillway in the event of a blockage of the spillway on the tailings dam, or if repairs to the spillway are required. An overflow weir could be constructed to spill water into the diversion channel should water in the tailings pond reach a critical elevation. A decision can be made during detailed design once a more detailed water balance has been completed. In any case, it appears that sufficient water can be routed into the pond to satisfy all of the cover alternatives under consideration.

4.4.8 Water Diversion from Pony Creek (Alternative 4)

Depending on the alternative selection, diversion of water from Pony Creek into the open pit pond may be required. In order to achieve this, a side hill diversion channel would be required as shown on Drawing B-08. Given the intermittent flow in the creek, it is anticipated that water would be re-routed entirely through the open pit and back into the creek via a spillway on the north end of the pit. A weir structure could accomplish this and would have the advantage of redirecting flow in the natural creek channel should water quality objectives not be met in the pond or if maintenance of the cover over the tailings is required. It may be possible to incorporate bedrock in the overflow spillway, depending on the necessary elevation. Additional hydrological data is required to further evaluate the feasibility of this water management strategy.

A Pony Creek diversion channel and spillway channel would each have to cross the mine site access road at the north end of the open pit. Crossing options would include bridges, fords or culverts. A bridge crossing would be the most expensive option, and is likely not necessary considering the small volumes anticipated in the diverted flows. A culvert would be less expensive than a bridge, and would still provide an all-weather, dry crossing. The culvert would require ongoing maintenance and may be susceptible to plugging or constriction due to ice or debris. A ford crossing is the most economical option and requires the least maintenance, but would not provide all weather/all vehicle access. Some maintenance may be required depending on usage. Diverting water through a pipe or culvert would alleviate some of the challenges of building and maintaining a channel on a slope, but introduces other long term maintenance challenges of its own such as plugging or constriction with ice or debris, more difficulty inspecting and more costly and complex control structures

4.4.9 Cover Design (Alternatives 3 and 4)

The objectives of a cover system would be to i) control fugitive dust, ii) inhibit the ingress of oxygen (and hence oxidation) by maintaining saturated conditions within the cover, iii) limit the infiltration of water into the tailings and iv) provide a medium for the establishment of vegetation. Clearly, these objectives are very different in their intent as well as the methods of design and construction. Until such time as a preferred closure alternative has been selected, cover systems have only been considered in concept with recognition to existing hydrology and readily available construction materials. In this regard, a terrain mapping and materials search was carried out by EBA Engineering to locate suitable borrow sources of fine grained material potentially suitable for capping tailings or waste rock (EBA 2009). The results of this study indicated a high probability of locating such material within 30 km of the mine site and a moderate to low probability of locating such material within 5 km of the mine site. The predominant soil types in the immediate vicinity of the mine consist of poorly graded glaciofluvial sand and gravel.

4.4.9.1 Fugitive Dust Control

Dust could be controlled by placing a layer of suitable clean soil suitable for vegetative growth. Mulch could be added to the cover surface to temporarily stabilize the soil before vegetation has become established and a hummocky terrain could be created to minimize erosion during heavy runoff. Granular deposits in the immediate vicinity of the mine could be utilized for a cover intended to control dust, however, these materials alone may not satisfy the deign intent for saturation or infiltration.

4.4.9.2 Soil Cover

Soil covers are often utilized to minimize oxidation of tailings and surface water contamination. A soil cover prevents water infiltration from entering into direct contact with the tailings and consequently reducing the generation of contaminated runoff. Essentially, a blanket of saturated soil (tension saturated zone) is created within the cover which limits oxygen diffusion into the tailings. The soil cover therefore provides a water cover without the need for a surface pond. One advantage of this approach is that it is possible to establish vegetation on the top of the cover. The most significant disadvantage of soil covers is the continued oxidation of the tailings due to residual concentration of oxygen in the voids of the cover. Another disadvantage of soil covers (as observed in other cover systems as well) is the potential negative impact on groundwater quality if the tailings release contamination under anaerobic condition (e.g., arsenic). A soil cover has a higher risk in terms of maintaining a saturated condition in dry periods.

For Mt. Nansen, it may be desirable to maintain the tailings saturated while at the same time limiting net infiltration into the tailings. This can be accomplished by either providing a low-permeability cover where water is stored near the surface and released as runoff or allowing water to infiltrate the cover where it can be subsequently released by evapotranspiration. The latter approach is referred to as a moisture store-and – release cover system. Either scenario is more easily achieved in the existing tailings pond where water can be routed from Dome Creek if there is insufficient precipitation and run-on from surrounding terrain. In this regard, the elevation of the tailings pond spillway would be set at the same elevation as the top of the soil cover or at about elevation 1,098.75 m. The cover should contain an optimum percentage of fines to retain some moisture under dry conditions and it may therefore be necessary to amend the locally available sands with finer grained soil. Amending the soil or incorporating a geosynthetic liner will be a requirement if a low-permeability barrier is required. Maintaining saturation of a soil cover at the open pit for Alternative 4 (wet) would be more challenging as it may be difficult to replenish sufficient water should the losses from evapotranspiration exceed infiltration aMt.s.

The soil cover for Alternative 4 (dry) would be maintained in a semi-saturated condition and hence infiltration through the cover would be minimized. Otherwise, any infiltration through the cover will report initially to the tailings layer and later to the waste rock reservoir at the bottom of the pit. The cover would be at least 1 m thick over the relocated tailings and surface water runoff would be directed to the north and south or laterally to ditches along the east and west perimeters of the pit. In assessing the surface water management integral to the dry alternative, we have considered the quality of the waste rock along the west edge of the pit to minimize the potential for contamination due to contact with potentially acid generating waste rock.

4.4.9.3 Water Cover

A 1 m thick water cover is considered to be an efficient method for reducing oxidation of tailings. In terms of dam safety, the water cover could impose a more stringent classification and seepage volumes at the downstream toe may increase marginally compared to other cover scenarios e.g., soil cover. A 0.15 m thick sand diffusion layer should be placed to minimize direct contact with the tailings. Even with this layer however, , potential contamination of the water cover must be considered, in particular if the water remains stagnant (zero discharge). To prevent discharge of potentially contaminated water over the spillway, the water management plan should consider site specific hydrology, precipitation, seepage and evaporation to maintain the desired inflow and outflow. There is a higher risk of not being able to maintain a water cover in dry years if water diversion is not implemented.

The water management plan could consider routing flow in Dome Creek (Alternative 3) or Pony Creek (Alternative 4) into the pond to provide dilution. In this case, the spillway would be used to discharge water and control the pond elevation. A thicker soil cover could be considered above the tailings to provide additional diffusion or protection from weathering. This strategy would be relatively easy in the open pit (Alternative 4) but may not possible at the existing tailings pond (Alternative 3) without raising the dam by about the same aMt. as the additional cover. The operating pond level in this scenario could be beyond any previous experience and the consequential impacts on seepage and stability would be uncertain.

4.4.9.4 Sponge Cover

A sponge cover requires the placement of a 0.5 m thick soil cover over the tailings and maintenance of a water cover approximately 0.15 m above the soil cover to maintain the soil cover in a saturated condition. This technique potentially allows for the development a wetland habitat on the cover. The sponge cover is considered a lower risk in terms maintaining saturated conditions since in dry years where the water cover cannot be maintained since soil would still cover the tailings. Since water is impounded, a spillway is required and would be set at 0.15 m above the top of the soil cover, or at about elevation 1,098.4 m at the tailings pond. Dam classification would likely be similar to the water cover scenario. Of significance is the potential that locally available fine sand may be suitable without amendments. The water that will potentially flow through the spillway is expected to be suitable for direct discharge if a base flow is maintained through the pond.

4.4.10 Tailings Relocation (Alternative 4)

Alternative 4 requires the relocation of approximately 300,000 m^3 of tailings and contaminated soil from the TMA to the Brown Mc-Dade Open Pit under various infill and cover scenarios. The Alternatives range from minimal to maximum utilization of waste rock. It will likely be a requirement to provide a more effective seal at the Pony Creek adit to reduce this potential pathway for groundwater seepage. Seepage losses from the pit will be governed by the hydraulic gradient associated with the elevation of the final cover and the permeability of the tailings and the host rock.

4.4.10.1 Transportation of Tailings

Tailings are commonly relocated using i) mechanical, ii) hydraulic and iii) dredging methods. The selection of the preferred method depends on tailings characteristics, climatic factors, distance and relief from tailings source, to name a few. The mechanical removal of tailings, namely by excavator and truck to a contained disposal site, has been shown to be successful for tailings deposits which are not submerged or are above the water table. For below water table deposits, mechanical removal may require dewatering (sump and pump) systems with water treatment.

Hydraulic removal utilizes high pressure sprays (water cannons) to liquefy the tailings deposit. Tailings are washed to sumps where slurry pumps and pipelines transport the tailings to the final destination (likely the open pit). Careful consideration of tailings gradation is a key consideration as it influences the ability to maintain a slurry during transport. In addition, the process is limited to summer operations, thereby limiting the time to remove and remediate the tailings area. The difference in elevation between the tailings pond and the open pit (approximately 105 m) and the distance (approximately 1 km) present significant challenges for this method.

Approximately 300,000 m^3 of water would be required to slurry the tailings to allow hydraulic relocation to the open pit. Considering an average porosity of the tailings of 0.6 and saturated condition, it is estimated that the tailings contain approximately 180,000 m^3 of water in the pores. An additional 120,000 m^3 of water would therefore be required for the process, a portion of which would eventually end up in the open pit. Water for the slurry process would have to be stored in the tailings pond or in a different location prior to relocation of tailings and recycling of process water should be considered. Potential environmental impacts associated with this method include spills along the pipe line system.

Dredging has also been successfully used for relocating tailings. Key factors which influence the operation are the challenges of managing the volume of tailings, minimizing the water cover to achieve dredge flotation and maintaining sufficient freeboard in the tailings area to avoid unplanned release. Other forms of removal in this class are dumping the mechanically excavated tailings into a sump and transporting them as a slurry to the open pit, if economically justified.

In consideration of the general site conditions and tailings characteristics within the conceptual scope of this study, it was concluded that tailings relocation by mechanical removal was the preferred option; final selection should be based on a more detailed review of applicable case histories. Based on discussions with experienced Contractors, the tailings could be excavated during the winter in layers (2 to 3 m thick) to allow the surface of the tailings to freeze to allow machinery access to the tailings pond. The use of conveyors to move the tailings was also discussed as a potential transportation means. With sufficient equipment and working 24 hours per day, it may be possible to relocate to the open pit in one season based on moving up to 10,000 m^3 of tailings/day. If work is carried out over more than one season, a plan to operate the tailings dam in the interim (summer) must be developed. Water treatment would be an anticipated requirement, either at the open pit, or water could be pumped to the mill site for treatment. In this regard, leaving one or more of the existing buildings at the mill site intact could provide a suitable location for water treatment facilities.

4.4.10.2 Consolidation Settlement of Relocated Tailings

Saturated Environment

In a wet condition (Alternative 4A-i) the tailings are not expected to consolidate as effective stresses will remain similar to their current condition (submerged) in the tailings pond. Some consolidation may occur however based on the transportation method chosen for the relocation of tailings to the open pit, due to load (cover) and/or due to potential fluctuations of the water table within the tailings layer (if any). Potential consolidation will be an important consideration in establishing spillway control. For example, it may be necessary to provide the ability to lower the spillway elevation if maintaining a constant water depth is desired after consolidation takes place.

Dry (semi-saturated Environment)

Consolidation and resulting settlement is expected to occur due to an increase in effective stress since the water table will be confined to the underlying waste rock. The time required for consolidation settlement to occur depends on the length of either vertical or horizontal drainage paths; the shorter the drainage path, the more rapidly the tailings will consolidate. Geotechnical properties of the tailings were determined based on laboratory testing results and published information. If the tailings are placed in one continuous layer (up to 25 m thick), the estimated time to reach 90% consolidation (end of primary consolidation) is estimated to be in the order of 20 years (Alternative 4A-iii). If intermediate horizontal layers of permeable waste rock are placed in the tailings mass (Alternative 4A-ii), the estimated time to reach 90% consolidation is about one year. In either scenario, the anticipated total vertical settlement from consolidation is expected to be in the order of 0.8 to 1.5 m. This settlement will not be uniform across the tailings surface due to differences in density, the presence of frozen material and the varying thickness. It should be recognized that considerably more settlement could occur if the tailings are placed in a frozen state with large void spaces and it may also take considerably longer for thaw induced settlement to occur. The soil cover design should consider the uneven settlement of the tailings with time and final regrading of the cover may have to be delayed by several years. Consolidation of the tailings will be an important consideration in establishing spillway control.

As the tailings consolidate, the contaminated porewater will report to the underlying waste rock reservoir. The volume of water released will be directly related to the volume change of the tailings mass. Depending on the assumed compression index for the tailings (0.08 vs 0.15), preliminary calculations indicate that this volume is in the order of 3,000 to 21,000 m^3. The final volume of water reporting to the waste rock reservoir will be a combination of the water expelled during consolidation and that which will drain by gravity from the tailings (in excess of that via consolidation). This volume will depend on the matric suction of the tailings (the force that binds water in the tailings matrix), the presence of capillary breaks e.g., sandy tailings, etc. In no case however, can the total volume of water be greater than the volume in the pore spaces at the time of placement. Without the addition of additional water e.g., to slurry the tailings, this is estimated to be about 180,000 m^3 based on a porosity of 0.6. A more realistic estimate of maximum seepage water from the tailings (assuming no additional flux) is 50,000 to 100,000 m^3.

4.4.11 Tailings Dam at Open Pit (Alternative 4A-i)

A dam at the south end of the open pit will be required to contain the tailings and water cover (Drawing B-08) for Alternative 4(i). The dam is shown on Drawing B-08 at the high point in the ramp into the pit, and although it could possibly be moved to the south (closer to the road), the height of the dam is expected to be in the order of 8 to 10 m. A liner would likely be required to minimize seepage losses through the dam since these losses would report as surface water at the south end of the pit. The liner would likely need to be extended into the bedrock foundation to minimize the potential for underflow. A significant uncertainty at this time is the volume of seepage losses that can be expected around the wetted perimeter of the pond, into fractured bedrock, and the possible requirement for seepage control measures in this regard.

The dam would be founded on bedrock and as such, the concerns that exist with respect to liquefiable soils at the existing tailings dam do not exist. The dam would still require design and construction following the 2007 Canadian Dam Association Guidelines, including the spillway which would be designed for the IDF associated with a high classification (to be confirmed during detailed design). The dam would be constructed using locally available materials, primarily inert waste rock and/or granular borrow materials. The same requirements for routine inspections, dam safety reviews and maintenance as exist for the existing tailings dam would apply to a tailings dam constructed to contain tailings at the open pit. In terms of risk, there would be very little difference between the existing and a new structure given that the consequences of a failure would be similar. It may be possible to demonstrate that the potential volume of tailings released in a failure would be less because of the natural bedrock barrier at elevation 1195 m but this would have to be quantified during detailed design.

4.4.12 Co-Disposal of Tailings and Waste Rock in Open Pit

Alternatives 4A (ii), 4A (iii), 4B (i) and 4B (ii) all require that the tailings be placed above the water table on a layer of waste rock placed into the open pit to an elevation of 1190 m. We have estimated that approximately 44,000 m^3 of waste rock is required for the base layer which will contain coarse fractions of rock which acts as a reservoir. In this scenario, it will be necessary to seal the Pony Creek Adit as it is possibly submerged once water levels in the pit stabilize. Any water (flux) from the tailings will report to the waste rock reservoir where its release will be governed by the regional groundwater flow in the surrounding rock. A trench would be excavated between the two existing ponds in the open pit to allow for a pumping well to be installed in the lowest section of the pit at a later date should future pumping and treating be required.

Alternative 4A (ii) incorporates sloping intermediate layers of permeable waste rock within the tailings (Drawing B-09). These layers are connected to a waste rock chimney drain at the north end of the pit which is hydraulically connected to the waste rock reservoir. The intent of these layers is to accelerate the time to achieve primary consolidation, provide more overall stability of the waste material and provide an opportunity for disposal of waste rock. A waste rock plug is required at the south end of the pit for containment. It is anticipated that a liner will be required on the inside face of the plug to prevent seepage to the south. A clean soil cover would be placed and the backfill above the tailings and waste rock plug sloped to towards Pony Creek and Dome Creek catchments respectively.

This plug would be designed with an adequate factor of safety for all loading cases to prevent the potential for flow slides from the contained tailings. In this storage environment the tailings will be draining and gradually becoming more stable. In this regard, it may be possible to move away from classifying the plug as a dam. However, for the purposes of this study, we have assumed that until such time as this reclassification can be made and is accepted by the Regulators, the waste rock plug should be considered to be a dam with all associated requirements for dam safety reviews, surveillance monitoring, etc.

Alternative 4A (iii) does not incorporate intermediate layers of waste rock and therefore can be configured differently within the open pit as shown on Drawing B-10. A clean soil cover would be placed and the backfill above the tailings and waste rock plug sloped to towards Pony Creek and Dome Creek catchments respectively. Alternative 4B (i) and 4B (ii) as shown on Drawings B-11 and B-12 respectively are variations of 4A (ii) and 4A (iii) but additional waste rock is added to completely fill the open pit. Surface drainage would be to the south and north off of the final cover of clean soil.

The gradation of the waste rock used for the base reservoir and the intermediate layers will be determined during detailed design. Preliminary inspections of the waste rock piles indicates a wide range of gradations are available although processing is likely required. It will be important to consider the appropriate filter layers at the interface between the waste rock layers and fine grained tailings. If a natural filter layer is uneconomical to produce, geotextiles could be considered.

4.4.13 Valley Restoration

Once the tailings are removed from the existing TMA, it is expected that a series of staged and sequenced engineering, environmental and botanical solutions will be required to restore the affected tailings management area back to a natural setting. Some of these considerations will require a multi-disciplinary approach to the challenges of at least:

i. Removal and deposition of fill soils to original natural ground and groundwater conditions.
ii. Replacement with natural imported vegetative soil cover(s) with appropriate contouring and drainage improvement.
iii. Revegetation using native plant species and selected fertilizers.

At this stage of the study of closure options, and in consideration of the complexity of technical issues and related costs at this remote location, this report has only identified these requirements. Further study will be required by appropriate expertise to define and design these measures, before more accurate cost estimates can be prepared. It is likely that locally available sands and gravel can be used for site restoration. It may also be possible to utilize existing dam material for regrading, depending on the levels of residual contamination.

4.5 Areas of Uncertainty and Risk

4.5.1 Areas of Uncertainty

There are several areas of uncertainty with respect to geotechnical considerations associated with the closure alternatives under consideration. These uncertainties are summarized as follows and also in the Summary Table in Appendix B2:

4.5.1.1 Existing Tailings Dam

- Potential long term thermal conditions, including the potential consequences of global warming.
- Downstream consequences associated with a hypothetical dam failure (and hence dam classification).
- Potential for thawing of permafrost may require design changes to improve stabilizing/insulating measures.
- The consequence of additional permafrost thaw on the north terrace on stability and seepage.
- The extent of tailings run-out or consequences of a dam failure (dam break analysis has not been completed).
- Frequency and cost for routine or unexpected maintenance.
- Seepage rates and water quality trends in the seepage pond.
- Potential ongoing settlement of the south abutment.

4.5.1.2 Cover Systems

- The effectiveness of the cover including the ability of coarse grained tailings to maintain saturation.
- The requirement for cover amendments or inclusion of geosynthetic materials.
- Water management plans associated with cover designs.
- The need for additional freeboard.
- The ability to divert water from Pony Creek to maintain saturated tailings (water cover) in the open pit.
- The impact on performance of the cover due to frozen water.
- Time and magnitude of consolidation settlement of relocated tailings (dependent on transportation and placement methods).
- Consequences of differential settlement with respect to cover integrity, surface drainage and spillway design.
- Surface water quality (as runoff) from open pit.
- Dilution of pond water and treatment requirements.
- Frequency and cost for routine or unexpected maintenance.

4.5.1.3 Water Diversion Structures

- Water management plan based on selected cover design and determination of acceptable risks associated with routing creek flows through tailings ponds.
- Frequency and cost for routine or unexpected maintenance uncertain.
- Regulatory approval requirements.

4.5.1.4 New Tailings Dam

- Foundation and abutment conditions at dam location.
- Downstream consequences associated with a hypothetical dam failure (and hence dam classification).
- Seepage from tailings pond water into surrounding bedrock.
- Need for grouting or other measures to seal fractured rock.

4.5.1.5 Diversion Channels

- Conditions along side-hill channel from Pony Creek to open pit.
- Requirement for crossings of entrance and spillway channels from Pony Creek to open pit.
- Frequency and cost for routine or unexpected maintenance.

4.5.1.6 Existing Tailings Management Area

- Environmental impacts in existing TMA once tailings have been relocated.

4.5.2 Risk

Risk can generally be defined as a chance of loss and can be measured as the product of the probability of an event and its consequence. For the purposes of this study, which primarily addressed scenarios for closure of the Mt. Nansen project, a limited risk ranking of geotechnical considerations associated with mine closure was conducted. A comprehensive risk analysis at this stage is considered premature and not consistent with the assessment of closure options (present scope). Nevertheless, some identification of risk is warranted to make informed decisions and reflect a degree of confidence. Risk has been addressed as relative uncertainties regarding an acceptable degree of performance to achieve design objectives. In this regard, the classification of risk for each discipline within this preliminary risk assessment has been selected as low, medium and high. Justification for these rankings is provided in the Summary Table in Appendix B-2. Residual risks have been identified which are those that remain once the alternative under consideration has been implemented e.g., the waste rock piles may remain in place. The risks associated with the closure alternatives are summarized in Table 4-10.

Table 4-10. Summary of Geotechnical Risks

Alternative	Geotech Risk Ranking	Identified Risks	Residual Risks
Alternative 3A (i) – Remediate tailings dam and associated works and provide a soil cover over tailings.	Low	• Soil Cover drying out and tailings oxidize • Dam Failure • Seepage water volume and quality may change; might require a future collection pond and treatment	• Waste rock piles remain • Pit walls and lake pose potential risk to public safety
Alternative 3A (ii) – Remediate tailings dam and associated works and provide a water cover over tailings.	Medium	• Spillway Failure • Dam Failure • Seepage water volume and quality may change; might require a future collection pond and treatment	• Waste rock piles remain • Pit walls and lake pose potential risk to public safety
Alternative 3A (iii) – Remediate tailings dam and associated works and provide a sponge cover over tailings	Low to Medium	• Spillway failure • Dam failure • Seepage water volume and quality may change; might require a future collection pond and treatment	• Waste rock piles remain • Pit walls and lake pose potential risk to public safety
Alternative 3B – Waste Rock Deposition into the Pit (in conjunction with remediation of the tailings dam and associated works with one of the tailings cover options)	3B (i) = Low 3B (ii) = Medium 3 B (iii) = Low to medium	• Risks are primarily geochemical	• Minimal waste rock piles remain • Soil contamination below existing waste rock piles •
Alternative 4A (i) – Tailings relocated to open pit with a water cover	Low to medium	• Dam failure • Spillway failure	• Waste rock piles remain • Pit walls and lake pose potential risk to public safety • Potential for legacy contamination of soil and water at existing TMA
Alternative 4A (ii) – Tailings relocated to open pit and maintained in a dry (semi-saturated) state with internal waste rock drains	Low	• Plug at south end of pit may be considered a dam • Risks are primarily geochemical	• Some waste rock piles remain • Pit walls and lake pose potential risk to public safety • Potential for contamination of soil and water at existing TMA
Alternative 4A (iii) – Tailings relocated to open pit and maintained in a dry (semi-saturated) state without internal waste rock drains	Medium	• Long term performance issues with cover due to differential settlement • Risks are primarily geochemical	• Waste rock piles remain • Pit walls and lake pose potential risk to public safety • Potential for contamination of soil and water at existing TMA
Alternative 4B (i) – Same as Alternative 4A (ii) but with waste rock added to completely infill open pit	Low	• Poor surface water chemistry (runoff from pit) • Risks are primarily geochemical	• Potential for contamination of soil and water at existing TMA
Alternative 4B (ii) – Same as Alternative 4A (iii) but with waste rock added to completely infill open pit	Medium	• Poor surface water chemistry (runoff from pit) • Risks are primarily geochemical	• Potential for contamination of soil and water at existing TMA

4.6 Summary of Costs

4.6.1 Capital Construction Costs

The estimated capital costs for the various closure alternatives are summarized in Table 4-11. These costs include a 30 % contingency but do not carry any allowance for additional filed investigations, instrumentation monitoring, design engineering, routine inspections, operation or maintenance.

Table 4-11. Capital Cost Estimates

Alternative	Cover Type	Cover Details	Tailings	Pit	Waste Rock	Capital Cost Estimate
3A *i*	Soil	• 1 m thick soil cover on tailings	Stabilize tailings dam with toe berm	No change	Little change	$12,000,000
3A *ii*	Water	• 1 m thick water cover • Divert water from Dome Creek	Stabilize tailings dam with toe berm	No change	Little change	$9,000,000
3A *iii*	Sponge	• 0.5 m thick soil cover on top of tailings • 0.15 m thick water cover on top of cover	Stabilize tailings dam with toe berm	No change	Little change	$11,000,000
3B *i*	Soil	• 1 m thick soil cover on tailings	Stabilize tailings dam with toe berm	Filled with waste rock	Relocate 500,000 m^3	Tailings Dam $12,000,000 Waste Rock $7,000,00 Total $19,000,000
3B *ii*	Water	• 1 m thick water cover • Divert water from Dome Creek	Stabilize tailings dam with toe berm	Filled with waste rock	Relocate 500,000 m^3	Tailing Dam $9,000,000 Waste Rock $7,000,000 Total $16,000,000
3B *iii*	Sponge	• 0.5 m thick soil cover on top of tailings • 0.15 m thick water cover on top of cover	Stabilize tailings dam with toe berm	Filled with waste rock	Relocate 500,000 m^3	Tailing Dam $11,000,000 Waste Rock $7,000,000 Total $18,000,000
4A *i*	Water	• 1 m thick water cover • Divert water from Pony Creek	Relocate 300,000 m^3 to pit	Partially filled with tailings	No change	$14,000,000
4A *ii*	Soil	• 1 m thick soil cover	Relocate 300,000 m^3 to pit	Partially filled with tailings and waste rock	• Waste rock layers in tailings • Waste rock reservoir beneath tailings	$16,000,000
4A *iii*	Soil	• 1 m thick soil cover	Relocate 300,000 m^3 to pit	Partially filled with tailings and waste rock	• Waste rock reservoir beneath tailings	$14,000,000
4B *i*	Soil	• 1 m thick soil cover	Relocate 300,000 m^3 to pit	Completely filled with tailings and waste rock	• Waste rock layers in tailings • Waste rock reservoir beneath tailings • All remaining air space filled with waste rock	Same as 4A(ii)$ 16,000,000 + Waste Rock $2,000,000 Total $18,000,000
4B *ii*	Soil	• 1 m thick soil cover	Place tailings in pit without waste rock layers	Completely filled with tailings and waste rock	• Waste rock reservoir beneath tailings • All remaining air space filled with waste rock	Same as 4A(ii)$ 14,000,000 + Waste Rock $2,000,000 Total $16,000,000

4.6.2 Inspection and Maintenance

The requirement for inspection and maintenance is dependent on the alternative under consideration. For example, alternatives where the tailings remain in place will require long term monitoring and maintenance of completed works. Alternatives where the tailings are relocated may have similar albeit reduced inspection and maintenance requirements. For example, the water cover in Alternative 4A (i) requires a diversion channel, diversion structures, spillway and a dam. In terms of inspection and maintenance, there would be very little difference between this alternative and Alternative 3A (ii) (water cover in existing tailings pond). The alternative with the lowest anticipated inspection and maintenance costs would be dry storage of tailings with a waste rock plug, in particular if the tailings properties (drained) and design of the plug will allow movement away from classifying this structure (plug) as a dam.

For preliminary comparison of alternatives, we recommend that an annual allowance of $500,000 be carried for each of the first five years after construction is complete for inspection and maintenance (total $2.5 million). This would be sufficient for monitoring and inspection at least twice a year and any necessary major repairs to the completed works. If good performance of the structures is confirmed after the first five years, it is anticipated that the frequency of inspections and requirement for maintenance could be significantly reduced. For long term budgeting, an annual allowance of $100,000 is recommended which should be sufficient to also include maintenance and replacement of instrumentation if required. It may eventually be possible to reduce these annual allowances further for scenarios where water management is not a critical component e.g., Alternative 4A – Dry, in particular if the waste rock plug is not considered to be a dam.

5. Hydrogeological Characterization

5.1 2009 Hydrogeological Field Investigations

Hydrogeological field investigations were conducted at the abandoned Mt. Nansen mine during the summer and fall of 2009. The purpose of this task was to collect field data to help refine the hydrogeological conceptual model and support water balance development. The key objectives of the investigations were to:

- document drilling observations and survey all wells on site;
- develop and sample groundwater wells in July and September;
- conduct hydraulic conductivity testing of tailings, soil and bedrock;
- characterize groundwater seepage emanating from the north face of the pit; and
- determine the physical properties of the tailings.

The field methods for each of the tasks are described in the memorandum provided December 3, 2009, and summarized below:

An extensive drilling program was conducted between July 7th and July 21st, 2009, using a drill rig with air rotary, mud rotary and direct push drilling capabilities. It was also equipped with a split spoon sampling device and an automatic SPT hammer for geotechnical testing purposes. The same drill rig was utilized for the hydrogeological (AECOM), geotechnical (AECOM) and geochemical (Lorax) investigations. A total of 21 new monitoring wells were installed as part of the combined hydrogeological, geotechnical and geochemical investigations within and surrounding the tailings management area (TMA), north of the Brown-McDade open pit and downslope of the mill building.

Drilling was completed without injecting water whenever possible. Screen lengths and target installation depths were selected in conjunction with Lorax staff to ensure the geochemical and hydraulic information provided by each well was optimal. Whenever possible, the use of a sand filter pack was avoided and wells were allowed to naturally develop. To help identify the nature of interactions between groundwater and surface water, 14 mini-piezometers were installed within the Dome Creek and Pony Creek drainages and within the TMA.

The location of all groundwater monitoring wells and mini-piezometers installed during the July 2009 field investigation are shown on Figure 5-1 (back of report) along with the conceptual groundwater flow interpretation.

Following completion of the drilling program, all boreholes, monitoring wells and other points of interest were surveyed using a differential GPS. Prior to groundwater sample collection, each monitoring well was developed to improve the hydraulic connection between the well and the aquifer and remove drill cuttings from the borehole.

Following well development, groundwater samples were collected for wells surrounding the mill, on the downstream face of the tailings facility and in the vicinity of the open pit. The majority of groundwater sampling within the TMA was conducted by Lorax staff. Static groundwater levels were collected prior to sample collection in both July and September 2009.

Two sets of groundwater samples were collected, in July 2009 and September 2009. Field parameters including pH, conductivity and temperature were recorded prior to collecting each sample. Groundwater samples collected as part of the hydrogeological investigation were analyzed for pH, conductivity, total dissolved solids, hardness, ammonia, nitrate, nitrite, dissolved anions, cyanide species, total organic carbon and dissolved metals. In addition to the above analyses, LEPH, HEPH and polycyclic aromatic hydrocarbons were analyzed in samples collected from wells downslope of the mill building as part of a preliminary contaminant investigation targeted at identifying whether any large scale fuel or cyanide spills were impacting groundwater on site.

During installation of groundwater monitors downslope of the mill building, soil samples were collected from the continuous soil cores brought to surface during direct push drilling for the purposes of hydrocarbon and metals analysis.

In order to understand the permeability of the various overburden and bedrock units found on site, rising and falling head slug tests were conducted in selected wells, resulting in a pair of slug tests for each well consisting of one falling head test and one rising head test. All slug test data was analyzed for an unconfined aquifer.

During the field programs, an attempt was made to characterize the volume and quality of seepage entering the north end of the pit through one of the abandoned cross-cut drifts. During the July inspection, the drift remained largely full of ice from the previous winter, but evidence of slow melting was observed in the form of small runoff channels in the surface of the ice. Occasional drips of water were also falling from the ceiling at the time of the site visit. During the September site visit, ice was still present in the drift, with only occasional dripping from the drift ceiling which formed a small puddle on the drift floor. Unfortunately no direct measurements of flow into the pit could be made as a result of the ice blockage (July) and general lack of concentrated flow (both July and September). The presence of numerous north trending faults and the long-term weathering of bedrock has likely resulted in inflows to the pit that take place largely below ground surface and are thus, immeasurable. However, the presence of a large block of ice in the drift, dripping water from the drift ceiling and the presence of a large icing which forms on top of the resistant quartize beds above the drift every fall and early winter indicates an input of groundwater to the pit. The geologic structure north of the pit is well described by R. Strohshein in a memo dated August 21, 2009 (Appendix D of Hydrogeology Conceptual Model technical Memorandum dated Dec. 15, 2009). The input of groundwater to the pit is most likely the result of flow through the shallow active zone and along northerly trending faults that are exposed in the pit walls and are inferred to extend beneath the Pony Creek channel which provides a source of recharge to the shallow groundwater system.

5.2 Hydrostratigraphic Units

The hydrogeological conceptual model described here supercedes previous hydrogeologic reports (Gartner Lee 2006, 2007 and 2008) because it incorporates a significant body of new information collected during 2009 as part of hydrogeological, geochemical, geotechnical, surface water quality and hydrological field investigations. A detailed description of the 2009 hydrogeological investigation and the updated hydrogeological conceptual model can be found in AECOM (2010b). A map and cross-section depicting inferred deep groundwater flow pathways is provided in Figures 5-1 and 5-2, respectively.

Based on the available surficial and bedrock geology information, the groundwater flow system consists of the following three hydrostratigraphic units:

- overburden;
- shallow weathered bedrock; and
- competent bedrock.

Each of the hydrostratigraphic units may be frozen or unfrozen depending on the presence or absence of permafrost.

Overburden is the uppermost geologic unit and overlies shallow weathered bedrock throughout most of the study area. It is comprised of a combination of glacial, aeolian and alluvial/colluvial deposits. Overburden is generally thin to non-existent on topographic highs and up to 20 metres thick in the lower reaches of the Dome Creek and Pony Creek valleys. Within the Upper Dome Creek valley, complex alluvial sediments are confined to a relatively narrow, linear band along the axis of Dome Creek and are overlain in places by blanket bog sediments less than one metre thick. Near the tailings management area (TMA), the alluvial sediments are overlain by a silty fine to medium aeolian sand that is up to 15 metres thick. This soil was used for borrow material during construction of the tailings dam. Overburden is anticipated to exhibit hydraulic conductivities ranging from 1×10^{-4} m/s to 1×10^{-6} m/s and porosity values on the order of 30%.

The shallow weathered bedrock unit underlies unconsolidated sediments (overburden) throughout much of the study area and is the product of a suite of weathering processes including faulting, frost-shattering, solution leaching and oxidation. The study area was not glaciated during the last period of continental glaciation and as such, bedrock is highly fractured and weathered near surface, especially within the faulted and altered sequences surrounding the open pit. The deep (north) end of the Brown-McDade pit was minded to the depth of weathering.The base of the weathered bedrock unit is defined by the depth of weathering and ranges from five metres north of the Brown-McDade pit, to in excess of 70 metres at the south end of the pit. The shallow bedrock is anticipated to exhibit a hydraulic conductivity on the order of 1×10^{-6} m/s and a porosity of 10%.

Competent bedrock forms the deepest hydrostratigraphic unit, underlying shallow weathered bedrock throughout much of the study area. Within upland areas, this unit hosts the regional groundwater table. Complex geologic structure within the suite of rock types has resulted in numerous fault sets that cross each other at various angles within the study area. These faults, together with other joint sets and geologic contacts, form the dominant pathways for groundwater flow within competent bedrock. The hydraulic conductivity of the competent bedrock unit is inferred to range over approximately one order of magnitude from 1×10^{-6} m/s to 1×10^{-7} m/s based on the available data, with a porosity of approximately 1%. At the local scale, geologic structure will likely influence groundwater flow pathways and hydraulic gradients. However, for the purposes of this regional assessment of groundwater flow, it is assumed that groundwater flow is homogeneous and isotropic.

The study area exhibits discontinuous permafrost. Permafrost is particularly noted at locations with north facing aspects and within the upper reaches of Dome Creek. Permafrost was also encountered in several boreholes drilled within the TMA, north of the Brown-McDade open pit, within the north and south abutment of the main tailings dam and within the seepage dyke downstream of the seepage collection pond. The presence of stunted vegetation within both the Pony Creek and Dome Creek catchments indicates that permafrost is relatively widespread in the study area. During warmer weather, a shallow groundwater flow system is present within the active zone on top of permafrost and a deeper flow system is present year round within the deep regional bedrock aquifer.

5.3 Shallow Groundwater Flow

The shallow groundwater flow system is hosted entirely within the active zone and within the overburden and shallow weathered bedrock hydrostratigraphic units. Shallow groundwater flow occurs seasonally and largely depends on the thickness and extent of the active layer. During winter months, much of the overburden and shallow weathered bedrock units are frozen and groundwater flow ceases. Prior to completely freezing, groundwater flow within this unit continues to discharge along road cuts and into the north end of the pit to form an icing. Groundwater flow divides within the shallow system are inferred to conform to surface drainage divides.

5.4 Regional Groundwater Flow

Figure 5-1 shows the conceptual groundwater flow across the site area around and between the open pit and the tailings impoundment. The regional water table is inferred to reside within the weathered and competent bedrock units in the upland areas, and within alluvium and organic materials within the lower Dome Creek and Pony Creek valleys, where the shallow and deep groundwater flow systems connect, and groundwater discharges to surface. Pumping data from the seepage collection pond indicates that the Dome Creek valley bottom aquifer discharges groundwater to Dome Creek year round. Pony Creek drains a much smaller catchment with relatively thin overburden overlying bedrock. Mini-piezometers installed in the upper reaches of Pony Creek suggest a losing stream located above the regional water table, while lower in the valley, groundwater discharges to the stream from the weathered bedrock and alluvial sediments underlying the stream channel. Based on groundwater elevations measured during September 2009, the regional groundwater flow divide between the Dome Creek and Pony Creek catchments is located north of the Brown-McDade pit and seepage leaving the pit is inferred to travel south toward the Dome Creek valley.

5.5 Groundwater Flow Surrounding the Brown-McDade Open Pit

Groundwater flow in the area surrounding the Brown-McDade open pit is complex. Based on field observations, there is very little groundwater discharge to the pit above the elevation of the pit lake, with two exceptions: 1) above the resistant quartzite bedrock unit at the north end of the pit, and; 2) from the easternmost exploration drift at the north end of the pit. The highly fractured and faulted zone surrounding the pit is inferred to provide a preferential pathway for groundwater flow from Pony Creek toward the open pit. The open pit is located high on a ridge and the position of the groundwater flow divide between Dome Creek and Pony Creek catchments is anticipated to move on a seasonal basis in response to changes in infiltration. The majority of shallow groundwater flow between Pony Creek and the pit occurs within the shallow weathered bedrock unit during late spring (May and June) and late fall (October, November and December) and icings are known to form above the quartzite beds at the north end of the pit (~1,195 m ASL). The groundwater travel time from Pony Creek to the open pit was estimated to be 105 days (3.5 months).

Based on the historical record of pit lake fluctuations and measured groundwater levels, the pit lake is inferred to be an expression of the regional water table. Because groundwater levels frequently fluctuate on the order of several metres in low porosity fractured bedrock systems, the water table is inferred to detach from the pit lake during winter months creating a tension saturated zone below the pit during the winter and spring months. The long-term record of pit lake fluctuations reveals a relatively constant net groundwater discharge rate of 0.2 L/s during the winter months. Water discharging from the pit lake flows downgradient toward the Dome Creek valley, with travel times estimated to be on the order of 23 years.

5.6 Groundwater Flow Surrounding the Tailings Management Area

The groundwater flow system surrounding the tailings management area consists of a shallow flow system within the active layer on top of permafrost and a deeper flow system underlying permafrost. These two systems interact in areas where permafrost is not present such as south facing slopes and in the lower regions of the Dome Creek valley.

The shallow aquifer underlying the tailings management area (TMA) receives groundwater contributions primarily from the valley bottom aquifer upstream of the TMA and the south facing slopes of the Dome Creek catchment. A portion of the groundwater reporting to the valley bottom aquifer upwells into the diversion channel and is conveyed downstream around the TMA.

Groundwater level measurements in nested wells installed in the TMA indicate strong downward vertical gradients. The relatively permeable materials beneath the tailings are inferred to function as a drain beneath the TMA and transmit groundwater downvalley along a primarily horizontal flow pathway. The overlying tailings are inferred to be tension saturated to saturated with dominant vertical drainage. Near the upstream face of the tailings dam, where the underlying dam fill is relatively permeable, the tailings pond is perched above the underlying groundwater flow system. Tailings pore water and water in the tailings pond is anticipated to slowly infiltrate through the tailings and enter the underlying aquifer. It then flow downgradient through the remnant organic horizon and tailing dam fill and reports to the seepage collection pond.

Based on investigations conducted during July 2009, permafrost has aggraded into the seepage dyke above the level of the seepage pond and is inferred to behave as an impermeable barrier to groundwater flowing along the axis of the Dome Creek valley. A significant aMt. of groundwater is inferred to flow through the uppermost unfrozen zone in the aeolian sand deposit located north of the seepage collection pond in its current configuration. A portion of the groundwater flowing through the aeolian sand is inferred to report to the seepage collection pond, with the remainder reporting to Dome Creek downstream of the seepage dyke.

5.7 Summary of Potential Hydrogeological Risks and Uncertainty

The hydrogeological conceptual model is based on the interpretation of data collected up to and including 2009. While it provides a starting point for the assessment of closure alternatives, some uncertainty remains surrounding the depth and extent of permafrost within the study area, the influence of seasonality on the position of the shallow and deep groundwater divides between the Dome Creek and Pony Creek catchments, seasonal fluctuations in groundwater elevations across the entire site and the degree of attenuation of metals offered by the natural groundwater environment. Additional uncertainties also exist in the context of the identified closure options. These uncertainties are discussed below:

For options that involve upgrading the existing tailings facility in the Dome Creek valley (Option 3), groundwater flow directions are fairly well understood and controlled, although the thickness and continuity of permafrost beneath the tailings facility is not fully understood and has potential implications on groundwater flow pathways. These options involve maintaining the tailings in a saturated state and could result in higher groundwater gradients and greater contaminant flux through the tailings mass (and dam). With the installation of a toe berm at the base of the dam, the seepage collection pond will be removed and there will not be an opportunity to collect and treat groundwater discharged through the tailings dam, although the seepage pond could be relocated and reconstructed if required. The attenuation of contaminants by the organic soil horizon underlying the tailings facility is not fully understood and there is some uncertainty around whether this attenuation mechanism offers a permanent solution and will continue to mitigate contaminant loadings to Dome Creek, or if it is temporary and attenuation capacity will eventually be exhausted, resulting in contaminant discharge to Dome Creek.

If waste rock is relocated to the open pit, there remains some uncertainty with respect to the position of the groundwater flow divide north of the pit due to the presence of discontinuous permafrost and sparse groundwater level information between the open pit and Pony Creek. In addition, the potential for attenuation of any contaminants that are released from the pit as groundwater seepage has not been investigated or quantified and inhibits the direct comparison of options.

For options that involve relocating the tailings to the open pit (Option 4 - wet or dry storage scenarios), the tailings will be located within a relatively small footprint and for some configurations underlain by waste rock. Should short or long term treatment of seepage from the overlying tailings be required, a groundwater extraction well could be installed to collect tailings seepage. The wet in-pit storage option will require diversion of clean surface water into the pit to maintain saturation of the tailings. Maintaining the water table near ground surface would result in an increased hydraulic gradient and increased flux through the tailings mass to the water table. Because the surrounding bedrock is more permeable than the tailings, it may prove to be challenging to ensure infiltration of water into the tailings mass to maintain saturation. While preliminary estimates of groundwater recharge to the water table have been made using conservative assumptions, additional 1-D or 2-D modelling would improve the understanding of the magnitude of seepage delivered to the water table for all closure and cover scenarios. For all in-pit storage options, a better understanding of seasonal fluctuations in groundwater levels and the extent of permafrost is required. This information together with additional climate data and pit lake level fluctuations will help improve the pit lake water balance. Once infilled, it is expected that pit water levels will rise three times higher for each pit recharge event because the tailings (and/or water rock) will occupy more than two thirds of the pit volume.

The degree of attenuation of metals offered by the natural groundwater environment remains uncertain. This could have important implications on estimated contaminant loading rates observed in Dome Creek as a result of groundwater travelling southward from the Brown-McDade open pit.

For Option 4A – Wet, it is uncertain what effect elevated water levels within the pit will have on the location of the groundwater flow divide between Dome Creek and Pony Creek. If the divide shifts southward, seepage from the tailings mass could report to Pony Creek. Additional investigation is required to confirm the aMt. of water required to maintain saturation of the tailings mass and the aMt. of water available within the pit catchment and the Pony Creek catchment for potential diversion into the pit. The integrity and water tightness of the bulkhead within the Pony Creek adit also needs to be confirmed.

For Option 4A – Dry, seepage through the tailings mass would likely be minimized through the installation of a low permeability cover system to restrict infiltration, although, based on geochemical source terms, it is anticipated that the quality of any seepage emanating from the drained tailings would be worse than those from saturated tailings. The tailings located near mill building would also need to be moved to the pit as part of this optionin order to achieve groundwater (and surface water) quality improvements within the upper Dome Creek catchment. Some uncertainty surrounds the ability to construct a low permeability cover that will maintain its integrity over time as the tailings consolidate. Increased permeability of the cover could result in increased seepage with poor water quality reporting to the water table underlying the open pit, potentially requiring interception and water treatment. The elevation of the water table underlying the open pit also needs to be confirmed in relation to the tailings mass for this option in order to predict long term performance.

6. Geochemical Characterization

6.1 2009 Geochemical Scope of Work

The Government of Yukon (GY) contracted Lorax Environmental Services Limited (Lorax) to conduct a geochemical assessment of mine waste materials at Mt. Nansen. The ultimate objective of this assessment was to develop scientifically defendable chemistry source term estimates for drainage emanating from mine features at closure, namely the open pit, tailings facility, and waste rock dumps. Note that the mill area was not included within the scope of this assessment. Additionally, Lorax was asked to participate in key workshops, including the data gap analysis and planning workshops. Lorax also contributed toward the evaluation, refinement, and conceptual design of closure alternative scenarios considered in this assessment. Lastly, in an effort to integrate geochemical drivers in the evaluation of closure alternatives, Lorax provided guidance on the development of conceptual water balances and surface water model, as described in Section 8.

This 2009 geochemical investigation builds on previous studies by Kwong (2002), Jambor (2005), and Lorax (2008, 2009a).

6.2 Summary of Closure Options Included in the Geochemical Assessment

Closure alternatives for the site were initially presented by GY (2008). Two closure alternatives were selected for more detailed evaluation and include upgrading of the tailings dam (Scenario 3) and relocation of tailings to the open pit (Scenario 4). Variations of these options include leaving waste rock in its current location (variation “A”) or relocation of waste rock to the open (variation “B”). The closure options considered in this assessment include the following:

- Scenario 3A – upgrade tailings dam to maintain permanently saturated tailings within the pre-existing impoundment;
- Scenario 3B – same as Scenario 3A combined with relocation of waste rock into the open pit;
- Scenario 4A wet – tailings relocated into bottom of pit and maintained under permanent saturation; and
- Scenario 4A dry – tailings relocated into upper pit and maintained under dry conditions (hydraulically isolated).

This investigation focused on the geochemical evaluation of how mine features would behave in the long–term when exposed to the conditions posed by the closure options listed above. In essence, the evaluation focused on the behaviour of tailings and/or waste rock in both saturated and unsaturated (dry) conditions.

It is important to note that the mill area was not included in this evaluation. It was previously determined that the mill area would be remediated at closure and was not a critical component of the closure options evaluation.

6.3 Geochemical Field Investigations and Experimental Design

Field programs and geochemical characterization programs are describe below. These include tailings and waste rock characterization programs, lab kinetic testing of tailings, mine waste field bin studies, and groundwater monitoring well installation and sampling program.

6.3.1 Field Programs

Three field programs were conducted in 2009 and are described in detail in a separate report title: Mt. Nansen Geochemical Assessment in Support of Evaluating Closure Plan Options (Lorax 2009b). The first field program was conducted in April and focused on the collection of tailings in an effort to initiate a lab-kinetic program. The second, more extensive program was conducted in July and included the installation of experimental mine waste field bins and groundwater monitoring wells in the tailings area. The last field program focused on the collection of groundwater samples and maintenance of mine waste field bins and waste rock lysimeters

The July field program was done in collaboration with other consultants and was coordinated to overlap with their programs (e.g., Lorax's geochemistry and mine waste characterization programs; AECOM's hydrogeology program; Altura's waste rock characterization program; and EDI's water quality sampling program). Tailings, waste rock, ore, native sand, and organic material were collected from excavated trenches and drill logs for bulk geochemical characterization. The majority of samples were collected for static geochemical testwork including total metals, Acid Base Accounting (ABA), and Shakeflask extraction (SFE) analyses. These tests were conducted to assess elemental enrichment, quantity of water-soluble metals, and the potential for mine waste to leach metals and/or to generate acid mine drainage (AMD). Tailings, organics, waste rock, and ore were used to establish lab and field-based experiments in order to obtain estimates on drainage chemistry from each of the waste materials under various storage conditions. A detailed description of sample collection methods, sample locations, and experimental design is included in Lorax (2009b).

A drilling program was conducted at the tailings area in collaboration with AECOM and included the collection of core samples by sonic drilling methods (Geotech Drilling) and Pionjar geoprobe drilling methods (Rocky Mountain Soil Sampling). Groundwater monitoring wells were installed within the tailings, below the impoundment in native substrate, and within the tailings dam. Well locations targeted different lithological contacts between the tailings, native substrate, and dam material (Figure 5.1). Groundwater samples were collected in July and again in September. The sampling methods, parameter list, analytical methods, and analytical results are included in Lorax (2009b).

6.3.2 Lab Kinetic Program

Tailings were collected from trenches in the impoundment area and were composited into three sample sets for humidity cell experiments: clay, sandy silt, and silty-clay tailings (e.g., the three predominant tailings grain sizes). A total of six humidity cells were initiated for this program: three are standard humidity cell designs, and three have undergone processes to remove the carbonate neutralization potential (NP) to accelerate the weathering and oxidation process. The fundamental purpose of the kinetic program is to assess the variation in leachate chemistry and reactivity for the relatively fine and coarse tailings under oxidizing conditions (e.g., upon exposure to oxygen).

The "accelerated" humidity cells will be used to evaluate non-carbonate NP and its capacity to buffer acid production from the oxidizing tailings. Toward this end, the three sample sets were split and subjected to sulphuric acid leach to remove carbonate minerals and secondary sulphate products prior to commencing the kinetic experiments. Carbonate extraction was conducted to accelerate the kinetic program due to the tight timeline for this study. The removal of carbonate minerals from the tailings samples promotes the development of acid conditions and provides the opportunity to observe leaching behaviour under decreased pH conditions. In addition, leaching of the carbonate minerals provides an opportunity to assess the ability of non-carbonate minerals to neutralize acidity generated from sulfide oxidation. Processing of the tails for the humidity cells began in May with the humidity cell tests going on line in July, 2009. Cells are sampled every week for sulphate and pH, and every second week for leacheate chemistry (e.g., cations).

6.3.3 Field Kinetic Bin Program

Five field bin tests were established at site in July 2009 to simulate anticipated field conditions applicable to the alternatives under consideration. The five bins represent two types of field-based experiments: unsaturated weathering bins, designed to mimic storage conditions in a subaerial, unsaturated environment for tailings, waste rock and ore; and saturated field columns which were designed to investigate the effect of saturated conditions on drainage expected from saturated waste rock and tailings. The five field bins were constructed as follows:

- *Unsaturated (exposed) waste rock* – chemistry represents seepage from waste rock remaining in its current location or in the pit and above the water table;
- *Saturated waste rock with organics* – chemistry represents seepage from waste rock in the pit and below the water table; inclusion of organics assumes that excavation of the waste rock will entrain some of the underlying organic layer;
- *Unsaturated low grade ore* – chemistry represents seepage from exposed low grade ore in its current location (e.g., above the water table);
- *Saturated tailings with organic soil* – chemistry represents seepage through tailings in the pit and below the water table; inclusion of organics assumes that excavation of the tailings will entrain some of the underlying organic layer;
- *Unsaturated sandy tailings* – chemistry represents seepage through exposed, unsaturated tailings, as in scenario 4A dry or in the event that a water table cannot be maintained in Scenario 3 and 4A wet (e.g., in the event of prolonged drought).

6.3.4 Waste Rock Characterization

The characterization of waste rock was a collaboration between Altura and Lorax with the majority of the field work and site characterization being conducted by Altura, as described in a separate report titled: Geochemical Characterization Brown McDade Waste Rock Pile, Mt. Nansen Mine Site, Yukon (Altura 2009) and in technical memoranda listed in Table 1-1. Additional characterization work was conducted by Lorax as described above. The main objective of the waste rock characterization program was to derive conservative drainage chemistry estimates from waste rock located within the Brown McDade stockpile. Altura worked closely with other consultants including AECOM, Lorax, EDI Environmental Dynamics Inc., and Protore Geological Services in carrying out the following tasks:

- installation of lysimeters and mini-piezometers in waste rock pile seepage locations;
- routine monitoring of lysimeters and seeps through spring and summer 2009;
- geochemical sampling along haul road, main rock pile, ore backfill in pit, coarse rock piles, and the base of the old ore stockpile area to the west of the pit;
- trenching in Southwest Upper pile to assess heterogeneity, field screening feasibility, and potential for use as general construction fill material;
- pit wall sampling and geological mapping;
- mineralogical investigations via x-ray diffraction; and
- assessment of waste rock volumes.

Lorax collaborated with Altura on the collection of additional materials for characterization and for the design of field-bin studies, as described above. Data from these studies was collated and assessed as part of the derivation of source terms (Lorax 2009b).

6.4 Summary of the Geochemical Results

Results acquired from the bulk chemistry, ABA, and SFE tests of the tailings, native, and organic materials, humidity and field bin results, groundwater chemistry, and waste rock characterization were integrated to provide chemistry source terms for each of the closure scenarios. A summary of results is provided below. More detailed discussion of the results can be found in Lorax (2009b).

6.4.1 Tailings Static Test Results

ABA analyses reveal that the majority of the tailings are likely to generate acid mine drainage (AMD) (Kwong, 2002 and Lorax, 2009b). Bulk chemistry results indicate a tailings enrichment of Ag, As, Cd, Cu, Pb, Sb, and Zn and that a significant portion of these elements are associated with the water soluble component (as indicated by the SFE tests). Arsenic concentrations in tailings do not display a correlation to any element or ratio of elements suggesting that As is associated with multiple mineral hosts (Jambor, 2005). Iron, As, Pb, Zn, and S are elevated in the native materials but in lower concentrations than are observed in the tailings. Copper, Zn, As, Cd, S, and Fe are all more elevated in the organic native substrate compared to other native substrate. These elements are all effectively removed from groundwater via sulfide precipitation under reducing conditions (Huerta-Diaz *et al*., 1998; Benner *et al*. 1999; Nordstrom 2000). The prevalence of these elements in the organic layer suggests that the organic layer promotes sulfide precipitation, and hence attenuation. An integrated discussion of this mechanism as it applies to attenuation of As and other metals at Mt. Nansen is included in Lorax (2009b).

6.4.2 Lab Kinetic Test Results

The lab-based humidity cells are sampled every week for pH and sulfate and every second week for cations. At the time of writing of this report up to 10 samples were collected and analyzed from the Mt. Nansen tailings humidity cell testing program. The pH values for the standard humidity cells remain between 7.2 and 7.9 for the first ten cycles of the humidity cell experiments. Sulfate production remained relatively constant for the standard humidity cells and is mainly attributed to the dissolution of water soluble sulfate minerals and not sulphide oxidation processes. The results from the standard humidity cells were considered preliminary and were not applicable toward the development of source terms at the time of reporting.

Humidity cells with carbonate-NP removal demonstrated active sulphide oxidation processes. A rapid decease in pH from greater than 7 to less than 5 was observed with a slow but steady increase in sulfate production rates. Given that secondary sulfate phases were intentionally removed from these samples during the weak acid leach, sulfate production in these samples is most likely reflective of primary sulfide oxidation. Metal cation concentrations from these cells also show a greater increase relative to the standard humidity cells. At the time of reporting, sulphide oxidation and metal release rates had not yet stabilized and were considered too preliminary for this assessment. While results are preliminary, they do indicate that the fine-grained tailings are reactive and susceptible to oxidation processes.

The kinetic program is on-going and is scheduled to continue through 2010 or until sulphide oxidation and metal release rates stabilize.

6.4.3 Field Bin Test Results

Three samples were collected from the field bins prior to the write-up of this report. The results are considered preliminary and are discussed in detail in Lorax (2009b). Field bin data was primarily used in the derivation of waste rock and ore source terms, as described in the Lorax memo Derivation of Brown McDade Waste Rock and Ore Source Terms (Lorax 2009e).

Field bin sampling is scheduled to resume in May 2010.

6.4.4 Tailings Groundwater Sampling Results

Groundwater wells screened over the tailings, native substrate, organic layer, and around the seepage pond were sampled in July and September 2009. Groundwater quality from these locations is representative of three distinct water quality groupings: tailings porewater, attenuated porewater, and dilution.

The wells screened within the tailings mass monitor tailings porewater signature(s) and are consistent with previously collected tailings porewater (Lorax 2008). Groundwater from these wells represents undiluted tailings seepage. Undiluted tailings seepage is representative of seepage that will likely originate from the tailings under scenario 4A (tailings stored in the pit under saturated conditions).

Groundwater from wells screened in the native substrate and the organic layer underlying the tailings is representative of metal attenuation mechanisms, namely sulphide precipitation, that are currently occurring within and under the tailings mass. The sulphide precipitation mechanism observed underlying the tailings mass is driven by elevated dissolved organic carbon (DOC) concentrations in the organic layer. The soil substrate below and upgradient of the tailings mass also contains dense concentrations of organic matter and is assumed to provide an infinite source of dissolved organic carbon to groundwater flowing beneath the impoundment. It is assumed that the source of DOC driving sulphide precipitation is infinite. Sulphide precipitation is not likely to occur if the tailings are moved to the pit as there is not be an underlying organic layer, nor is there an infinite source of groundwater rich in DOC flowing through the pit.

The wells screened around the seepage pond and water quality from the seepage pond itself define tailings water that has been attenuated by sulphide processes and then diluted by groundwater entering the seepage area via the north and south slopes. Again, this situation is unique to scenario 3A. Dilution and attenuation of the magnitude observed in the tailings impoundment is not likely to occur in seepage water exiting the pit. Dilution of tailings porewater will be dictated by the pit water balance and the groundwater flowpath from the pit to the receiving environment (e.g., Dome Creek).

The concentrations of most parameters varied considerably over the scale of the impoundment, as shown in Table 6-1. The observed variability is attributable to a number of factors, including varied redox conditions throughout the impoundment which influences the mobility of many metals, and variable flow rates, notably, minimal flow in discrete clay-rich areas of the impoundment. The variability of chemistry in the wells screened over the native substrate underlying the tailings may also reflect variable influence from the overlying tailings.

Table 6-1. Mt. Nansen Tailings Groundwater and Seepage Water Quality

	pH	Ammonia (as N)	Nitrate (as N)	Nitrite (as N)	Sulfate (SO4)	Sulfide (μg/L)	Cyanide, WAD	Cyanide, Total	Cyanate (CNO)	Thiocyanate (SCN)	Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Zinc (Zn)
Tailings Wells																	
Max	10.09	15.5	0.401	0.375	1750	46.89	0.964	2.96	5.9	5.56	24.9	0.00894	0.732	9.46	0.00404	23.7	0.462
Median (50th percentile)	8.06	2.94	0.05	0.02	1450	18.2	0.0281	0.361	n/a	2.89	7.56	0.000546	0.00243	0.381	0.0005	4.94	0.0451
Min	7.37	0.47	0.026	0.0019	59.9	11.25	0.005	0.005	0.5	0.68	0.274	0.00017	0.0005	0.03	0.0005	0.26	0.005
Native Substrate Wells																	
Max	9.2	14.4	7.15	1.14	1700	145.11	0.0335	0.298	5.1	35	6.58	0.000458	0.0152	66.4	0.00255	6.16	0.0307
Median (50th percentile)	7.9	10.15	0.05	0.01	355	58.19	0.01665	0.0669	1.17	3.13	2.205	0.000173	0.00164	4.146	0.00064	1.42	0.0084
Min	6.79	1.6	0.005	0.001	5	20.81	0.005	0.005	0.5	1	0.0923	0.000085	0.0005	0.118	0.0005	0.555	0.005
Wells in Dam																	
Max	n/a	14.4	7.15	1.14	1700	172.05	0.107	0.419	6.9	5.86	3.29	0.000196	0.005	19	0.0025	7.66	0.0104
Median (50th percentile)	n/a	9.49	1.44	0.058	879	66.01	0.0305	0.0729	2.65	1.1	0.0329	0.000184	0.0036	3.86	0.0005	3.9	0.005
Min	n/a	6.3	0.1	0.02	126	20.81	0.005	0.0165	1.6	1	0.00599	0.000085	0.0005	0.118	0.00025	0.555	0.005
Seepage Pond area																	
Max	7.33	8.17	15.2	0.119	634	476.27	0.0171	0.0542	3.42	5.8	0.284	0.0028	0.0324	40.7	0.0025	9.04	0.0354
Median (50th percentile)	6.91	3.52	3.95	0.0182	191.8	32.055	0.005	0.016	0.87	1.365	0.00244	0.00227	0.0085	0.188	0.0025	3.785	0.0114
Min	6.87	0.032	0.025	0.005	14.9	24.29	0.005	0.005	1.6	0.5	0.00105	0.000085	0.0005	0.03	0.0025	0.0115	0.005

6.4.5 Waste Rock Characterization

Waste rock was characterized by Altura (2009) and Lorax (2009b) using ABA, solid phase bulk chemistry, shakeflask extractions, and water sample chemistry from field bins, lysimeters and natural seeps. Previous work conducted by Altura (2009) suggests that the waste rock has a low potential to generate ARD. Netural mine drainage has been observed to contain elevated metals, most notably As, Cd, Cu, Mn, and Zn. Bulk chemistry analyses indicate enrichment in Ag, As, Cd, Cu, Pb, Sb, and Zn in waste rock and ore. A significant portion of the Cd, Cu, and Mn are associated with the water soluble component in waste rock, as well as Ag, As, and Sb in the ore. Field bin leachate, lysimeter leachate, and natural seeps from waste rock revealed leaching of significant aMt.s of sulphate, As, Cd, Cu, Mn, and Zn.

A waste rock water balance was also developed for the water quality model. The water balance was a collaborative effort between Lorax and Altura. The water balance is a function of precipitation and waste rock catchment areas. The water balance and its derivation are summarized in the following memoranda:

- Memo - Rock Pile Catchment Areas – Proposed Zones (Altura 2009a); and
- Memo - Derivation of Waste Rock Water Balance (Lorax 2009c).

In addition to the waste rock water balance, recommendations for waste rock management were also provided by Lorax and Altura, which included selection of waste rock for backfill into the open pit and sensitivity analysis of a cover design for scenario 4A-dry. These recommendations in the following memorandum were intended to provide guidance to closure design and water quality modeling:

- Memo - Pit Backfill – Recommendations on Waste Rock Management and Pit Cover Sensitivity Analysis (Lorax and Altura 2009).

6.5 Chemical Source Terms Generated for Water Quality Modelling

Development of source terms for mine features is summarized below. A more detailed discussion is provided in the following report and technical memoranda:

- Mt. Nansen Geochemical Assessment in Support of Evaluating Closure Plan Options (Lorax 2009b);
- Memo - Derivation of Brown McDade Waste Rock and Ore Source Terms (Lorax 2009e);
- Memo - Derivation of Tailings and Pit Lake Source Terms (Lorax 2009d); and
- Memo - “Best Case” and “Lower Bound” Source Term Estimates (Lorax 2010).

6.5.1 Parameter Screening

Chemistry source terms were developed for previously determined closure scenarios for waste rock (both subaerial/unsaturated and backfilled/saturated), subaerial unsaturated ore, saturated tailings in the tailings impoundment and in the pit, and tailings stored dry within the pit. The chemical constituents included in the modeling were selected by screening tailings porewater, tailings groundwater, and waste rock seepage quality against CCME freshwater aquatic life guidelines. Parameters that exceeded the CCME guideline were screened for use as source terms. Constituents related to screened parameters were also included. For example, WAD cyanide exceeded guidelines; thus all cyanide and nitrogen species were included. These source terms were used as input to the receiving environment water quality model to evaluate the Mt. Nansen closure options.

6.5.2 Source Term Derivation

For all source term types a best-case, best-estimate, and worst-case concentration was developed. A best-case estimate is defined as the best case for water quality concentrations in the short or long-term that may be reasonably achieved. Best-estimate concentrations are intended to provide a conservative best-estimate of the drainage chemistry expected from each mine feature. Worst-case concentrations represent the highest concentrations reported or predicted from any measured source used in this evaluation.

A lower-bound estimate is provided for tailings backfilled into the pit only (Options 4-wet and 4-dry). The “Lower Bound” is defined as the lowest concentration that might be reasonably achieved for tailings placed in the pit with the application of to-be-determined engineering and design changes that have not been explicitly identified for the existing closure plans. The rationale for the selection of lower-bound source terms is to identify whether or not the pit is a feasible candidate for storage of tailings at closure. The lower-bound estimate was provided for use in the water quality model for screening purposes only and the results associated with these estimates should be viewed with caution (Lorax 2010).

Main assumptions for the derivation of source terms are provided below:

- waste rock assumed to be non-acid generating;
- tailings in Scenario 3 and 4A-wet are assumed to remain saturated and non-acid generating; and
- tailings in Scenario 4A-dry are assumed to be acid generating.

Limited data were available to estimate long-term leachate chemistry for Scenario 4A-dry. Lab and field kinetic data were too preliminary at the time of reporting to provide a reasonable estimate of tailings behaviour under dry conditions. Tailings from the Arctic Gold and Silver Mine exhibit similar geochemistry to the Mt Nansen tailings and are a reasonable analog (Lorax, 2009b). Leachate from the Arctic tailings is acidic. Limited seepage water quality is available from the Arctic site. As a result, the “best estimate” and “worst case” tailings source terms are the same for the tailings in Scenario 4A-dry.

The chemistry source terms developed for the Mt. Nansen site are summarized in Table 6-2. Source terms were provided for waste rock, ore, and tailings under the closure scenarios being evaluated, as described above. Where mine waste is relocated to the open pit, the source term is defined for the mine feature (open pit) versus the mine waste it contains. For example, Scenario 3B includes source terms for mine waste rock relocated to the open pit. For this scenario, the source term for waste rock can be found under the open pit column. The same approach has been taken where tailings are placed in the open pit (Scenario 4).

Interpretation of Source Term Results and Conclusions

- Scenario 3A – Pit Lake: "Best Estimate" source terms were obtained by first, determining the layer which consistently contained the highest concentration of each parameter of interest. The source term was then calculated by averaging the concentration of the parameter within the most concentrated layer since December 2005 (since pit dewatering practices ended). "Worst Case" source terms were determined based on consistent spikes in the pit lake water quality data and were assumed to be a consequence of geochemical processes that may dominate in the future. There were some exceptions to the general approach which are outlined in Lorax (2009d). The range between the "Best Estimate" and "Worst Case" source terms for pit lake water quality is relatively low. The limited range reflects a higher degree of certainty attributed to the availability of a four year water quality database and the apparent stabilization of most of the parameters of concern.
- Scenario 3A – Saturated Tailings As Is: "Best Estimate" tailings source terms were derived by averaging the concentration of each parameter in the seepage collection pond over the time interval from November 2007 to present, assuming geochemical equilibrium has been maintained within the impoundment over the past two years. "Worst Case" terms were developed using two approaches: 1) infrequent yet consistent spikes observed in seepage pond data since January 1999 represent mechanisms that may dominate in the long term; and 2) groundwater quality from well MW09-08 as a proxy for deeper groundwater that may report to Dome Creek following tailings dam upgrades and backfilling of the seepage pond. To assure conservatism is accounted for in all the source terms, the highest value determined under each approach, for each parameter, was selected to represent the source terms for the "Worst Case". Source terms for saturated tailings located within the current impoundment exhibit a higher range between the "Best Estimate" and "Worst Case" estimates compared to the In Pit options (Scenario 4). The difference between As, Cd, Zn, sulfate, cyanide species, and nitrite under the two scenarios is approximately an order of magnitude. The broad range reflects a high degree of geochemical and hydrogeological variability within the tailings mass itself (as shown in Table 6-1).
- Scenario 4A wet – Saturated Tailings In Pit: "Best Estimate" term assumes the currently observed suboxic conditions persist within the tailings mass. Monitoring wells MP09-12 and MW09-04 are considered to be suitable proxies for suboxic conditions that will likely persist within tailings relocated to the pit. For each parameter, the most conservative value from the two wells was selected such that the source term presented as "Best Estimate" represents a composite water of these two mildly suboxic wells. "Worst Case" estimates are derived under the assumption that strongly suboxic conditions develop within the tailings in the long-term. Groundwater well MW09-02 best demonstrates strongly suboxic conditions within the tailings mass and therefore was used a proxy for "Worst Case" concentrations that may occur within the pit, in the long term. The difference between the Best Estimate and Worst Case source terms under closure option 4A-wet is small compared to the estimates for option 3. This range reflects a more conservative approach to attaining "Best Estimate" source terms, rather than being a product of certainty.
- Option 4A dry – Tailings In Pit: "Best Estimate" and "Worst Case" source term estimates are identical due to data limitations. Site-specific kinetic data are not yet available. Data from an analog site, Arctic Silver and Gold Tailings, are limited to one sample of complete seepage water chemistry. The "Best Case" estimate assumes the tailings do not develop acidic conditions and is the same as the "Best Case" estimate for Scenario 4A-wet.
- Waste Rock: source terms were primarily derived from waste rock drainage data from field bin experiments, constructed lysimeters, and natural seeps:
  - "Best Estimate" values were typically obtained from average or median values calculated from waste rock leachate data;
  - "Worst Case" source terms were derived as the highest concentration obtained from any waste rock drainage data set; and
  - Saturated waste rock source terms were derived from the saturated field bin data. "Worst Case" estimates were screened against seep data, as described above.
- Ore: a relatively small volume of low-grade ore has been backfilled into the upper portion of the open pit and will remain above the water table. Source term estimates for ore are based on leachate water quality from the ore field bin and waste rock seepage data. The method for source term derivation is the similar to that of waste rock, as described in Lorax (2009e).

Table 6-2. Summary of Mt. Nansen Long-term Waste Rock, Ore, and Tailings Drainage Chemistry Estimates

Parameter	Best Estimate				Worst Case				Best Case				Lower Bound
	Tailings Impoundment	Open Pit	Waste Rock Pile	Ore	Tailings Impoundment	Open Pit	Waste Rock Pile	Ore	Tailings Impoundment	Open Pit	Waste Rock Pile	Ore	Pit
Option 3A Tailings Dam Upgrade - Waste Rock As Is													
Ca	260	400	374	417	300	500	463	462	227	392	371	358	*n/a*
Mg	35	140	188	274	40	240	488	350	31	150	93	229	
As	0.04	0.05	0.007	0.023	0.3	0.25	0.03	0.032	0.04	0.007	0.007	0.02	
Cd	0.0009	0.012	0.041	0.108	0.007	0.04	0.184	0.201	0.0009	0.012	0.003	0.07	
Cu	0.009	0.05	0.039	0.022	0.09	0.12	0.223	0.036	0.008	0.04	0.009	0.02	
Fe	12	1	0.01	0.03	40	8.5	0.06	0.03	12	0.19	0.01	0.01	
Mn	8	4	1.79	64.9	11	10	28.6	97.4	8	4	0.11	45	
Zn	0.02	2.5	1.23	8.39	0.2	3.5	26.2	31.2	0.02	2.4	0.13	8.3	
Sulfate	800	1350	1530	2410	3200	2050	2940	2940	600	1310	1220	1930	
Ammonia	6.5	0.4	0.03	0.024	12.5	0.5	0.12	0.12	6	0.22	0.025	0.01	
CN (Tot)	0.07	*n/a*	*n/a*	*n/a*	0.6	*n/a*	*n/a*	*n/a*	0.07	*n/a*	*n/a*	*n/a*	
WAD CN	0.03	*n/a*	*n/a*	*n/a*	8	*n/a*	*n/a*	*n/a*	0.03	*n/a*	*n/a*	*n/a*	
Cyanate	2	*n/a*	*n/a*	*n/a*	30	*n/a*	*n/a*	*n/a*	1	*n/a*	*n/a*	*n/a*	
Nitrate	3	2	2.21	0.5	10	5	9.96	9.96	3	0.76	0.44	0.25	
Nitrite	0.3	0.2	0.085	0.083	10.5	5	0.36	0.36	0.3	0.14	0.01	0.01	
Option 3B Tailings Dam Upgrade - Waste Rock In Pit													
Ca	260	518	*n/a*	417	300	558	*n/a*	462	227	371	*n/a*	358	*n/a*
Mg	35	226		274	40	253		350	31	93		229	
As	0.04	0.016		0.023	0.3	0.04		0.032	0.04	0.0066		0.02	
Cd	0.0009	0.041		0.108	0.007	0.184		0.201	0.0009	0.0028		0.07	
Cu	0.009	0.039		0.022	0.09	0.223		0.036	0.008	0.009		0.02	
Fe	12	1.8		0.03	40	5.28		0.03	12	0.01		0.01	
Mn	8	91.3		64.9	11	134		97.4	8	0.11		45	
Zn	0.02	3.48		8.39	0.2	26.2		31.2	0.02	0.13		8.3	
Sulfate	800	2040		2410	3200	2940		2940	600	1220		1930	
Ammonia	6.5	0.978		0.024	12.5	1.29		0.12	6	0.025		0.01	
CN (Tot)	0.07	*n/a*		*n/a*	0.6	*n/a*		*n/a*	0.07	*n/a*		*n/a*	
WAD CN	0.03	*n/a*		*n/a*	8	*n/a*		*n/a*	0.03	*n/a*		*n/a*	
Cyanate	2	*n/a*		*n/a*	30	*n/a*		*n/a*	1	*n/a*		*n/a*	
Nitrate	3	2.21		0.5	10	9.96		9.96	3	0.44		0.25	
Nitrite	0.3	0.18		0.083	10.5	0.36		0.36	0.3	0.01		0.01	
Option 4A - Wet (Satd) Tails In Pit - Waste Rock As Is													
Ca	*n/a*	490	374	417	*n/a*	510	463	462	*n/a*	190	371	358	394
Mg		65	188	274		55	488	350		52	93	229	53
As		9.5	0.007	0.023		15	0.03	0.032		3.5	0.007	0.02	0.061
Cd		0.006	0.0412	0.108		0.0003	0.184	0.201		0.0004	0.003	0.07	0.001
Cu		0.003	0.039	0.022		0.001	0.223	0.036		0.001	0.009	0.02	0.014
Fe		1	0.01	0.03		10	0.06	0.03		0.015	0.01	0.01	18
Mn		5	1.79	64.9		25	28.6	97.4		3.6	0.11	45	12
Zn		0.05	1.23	8.39		0.5	26.2	31.2		0.005	0.13	8.3	0.030
Sulfate		1750	1530	2410		1750	2940	2940		1430	1220	1930	1212
Ammonia		15	0.03	0.024		16	0.12	0.12		2.0	0.025	0.01	9.85
CN (Tot)		0.9	*n/a*	*n/a*		1	*n/a*	*n/a*		0.4	*n/a*	*n/a*	0.11
WAD CN		0.3	*n/a*	*n/a*		0.4	*n/a*	*n/a*		0.005	*n/a*	*n/a*	0.045
Cyanate		6	*n/a*	*n/a*		5	*n/a*	*n/a*		0.5	*n/a*	*n/a*	3.0
Nitrate		0.05	2.21	0.5		0.25	9.96	9.96		0.05	0.44	0.25	4.5
Nitrite		0.1	0.085	0.083		0.05	0.36	0.36		0.01	0.01	0.01	0.45
Option 4A - Dry (Unsatd) Tails In Pit - Waste Rock As Is													
Ca	*n/a*	250	374	417	*n/a*	250	463	462	*n/a*	490	371	358	394
Mg		60	188	274		60	488	350		65	93	229	53
As		28.4	0.007	0.023		28.4	0.007	0.032		9.5	0.007	0.02	0.061
Cd		0.184	0.041	0.108		0.184	0.041	0.201		0.006	0.0028	0.07	0.0010
Cu		1.4	0.039	0.022		1.4	0.039	0.036		0.003	0.009	0.02	0.014
Fe		574	0.01	0.03		574	0.01	0.03		1	0.01	0.01	18
Mn		28.6	1.79	64.9		28.6	1.79	97.4		5	0.11	45	12
Zn		26.2	1.23	8.39		26.2	1.23	31.2		0.05	0.13	8.3	0.030
Sulfate		2500	1530	2410		2500	1530	2940		1750	1220	1930	1212
Ammonia		6.5	0.03	0.024		6.5	0.3	0.12		15	0.025	0.01	9.85
CN (Tot)		0.07	*n/a*	*n/a*		0.07	*n/a*	*n/a*		0.9	*n/a*	*n/a*	0.11
WAD CN		0.03	*n/a*	*n/a*		0.03	*n/a*	*n/a*		0.3	*n/a*	*n/a*	0.045
Cyanate		2	*n/a*	*n/a*		2	*n/a*	*n/a*		6	*n/a*	*n/a*	3.0
Nitrate		3	2.21	0.5		3	2.21	9.96		0.05	0.44	0.25	4.5
Nitrite		0.3	0.085	0.083		0.3	0.085	0.36		0.1	0.01	0.01	0.45

6.6 Summary of Potential Geochemical Risks and Areas of Uncertainty

Geochemical risks and uncertainty for the Mt. Nansen abandoned mine site are provided below. Included are risks and uncertainty associated with the current condition, as well as those posed by proposed closure scenarios.

The primary geochemical risk at the Mt. Nansen site is the tailings mass itself. In the current impoundment, the long-term, geochemical stability of arsenic within the tailings mass is the primary risk. The tailings also pose a significant residual risk to develop acid mine drainage (AMD). The risk of AMD is negated as long as the tailings remain saturated and are not exposed to oxygen. Since deposition the majority of the tailings have remained saturated and have not developed acidic drainage.

The risk of AMD occurring increases with the likelihood of the tailings becoming unsaturated and being exposed to oxygen. Dam upgrades will improve the current condition and will be done in a manner that maintains saturated conditions in the tailings. Preliminary water balances have suggested that this is feasible; however sensitivity to long-term drought has not been evaluated. All closure variations proposed for Scenario 3 present low-risk for AMD. The risk of AMD increases for all closure scenarios where tailings are relocated into the open pit (Scenario 4) and is highest for Scenario 4A-dry, which proposes to store the tailings dry. The management approach for Scenario 4A-dry is not to prevent AMD, but to contain AMD with hydraulic isolation. This approach relies on an ability to limit the aMt. of water contacting the tailings, principally as infiltration. The performance and design of a cover system for the pit has not been conducted for this assessment. Furthermore, the long-term performance of a water barrier cover has not been demonstrated, particularly in the north. As a result, the risk of AMD evolving in the long-term is highest for Scenario 4A-dry.

Metal hosting phases in the tailings solids are not stable under acidic conditions. Under AMD conditions, the release of cations (e.g., arsenic and metals) from the tailings solids into tailings porewater will increase exponentially relative to the current condition. The magnitude of metal release under acidic conditions is highly uncertain given the lack of data at the time of writing (e.g., preliminary kinetic data). As a result, source terms estimates for closure scenario 4A-dry have the greatest uncertainty. More data from the Arctic Silver and Gold mine site, the AMD geochemical analogues to Mt. Nansen, and further humidity cell and field bin sampling will help to assess likely drainage chemistry.

Risk of large-scale acid rock drainage from the Brown McDade waste rock pile is low (Altura, 2009). While acidic waste rock seepage has not been observed to date, waste rock and ore are designated as potentially acid generating. ARD remains uncertain in the long-term (i.e., 100 + years). As a result, best management practices should be taken to limit infiltration of water and minimize the flushing of soluble metals/oxidation products from these materials. While water saturation and placement below the water table in the pit may also be a reasonable method to prevent the further oxidation of sulfides present in the waste materials, the low sulfide content and the extensive aMt. of pre-existing oxidation products in these materials suggests that wet storage may act to mobilize metals more than inhibit their release by sulphide oxidation. This is particularly true for arsenic and zinc.

In the event waste rock is relocated to the open pit, the drainage chemistry from saturated waste rock with entrained organics also has significant uncertainty due to a lack of data. The waste rock on site is already highly weathered and contains a large aMt. of oxidized and water-soluble minerals. Under saturated and suboxic conditions, it possible that metals associated with the oxidized and soluble products will be released, however the rate of release is unknown. Seepage data from the field bin that contains saturated waste rock and organics should help to elucidate likely drainage chemistry.

Significant uncertainty remains in the closure water balances for the tailings impoundment and the open pit, in particular the water balance for the open pit in the event it is backfilled with waste rock and/or tailings. An integrated water balance should be developed for each closure scenario that takes into account mine waste materials (e.g., waste rock and/or tailings), their influence on the water balance, cover materials, and geochemical constraints and or performance criteria. Based on the results water balance the design of the pre-existing closure scenarios should be refined or revised. Source term estimates will then be refined accordingly and should result in more defendable and comparable water quality estimates for the closure scenarios.

A more detailed description of risks for each closure scenario as it relates to geochemistry is presented in Table 6-3. Also described in the table are key geochemical aspects, key advantages, key disadvantages, and geochemical uncertainty. A thorough description of the closure scenarios and their variations is presented in Section 4.3 Mine Closure Alternatives and in Appendix B.

6.6.1 Recommendations

Recommendations are listed below and have been provided to address the uncertainty listed above:

- Develop an integrated water balance for the tailings disposal facilities for each closure scenario;
- Develop performance criteria for the tailings cover system, which will be used as a guidance criteria for engineering design:
  - Key to integrate cover design with water balance;
- Conduct more refined flow analysis of the tailings management facility;
- Continue mine waste monitoring program, which includes:
  - Field bin leachate sampling (sample on a monthly basis through 2010);
  - Waste rock seep and lysimeter sampling (sample when flows or water is present through 2010); and
  - One round of groundwater sampling from wells within and around the tailings management facility.
- Characterize the mill area, which should include the following:
  - Characterize the static geochemistry of mine waste around the mill (e.g., ABA and metals analysis of ore, waste rock and tailings);
  - Quantify volumes and tonnages of mine waste material; and
  - Conduct flow and water quality analyses of seeps and Dome Creek in an effort to identify which portions of the mill area are the major contributors to water quality degradation in Dome Creek.
- Maintain lab-based kinetic program. Kinetic cells should be maintained until sulphide oxidation and metal release rates have stabilized; and
- Conduct a more thorough evaluation of the Arctic Gold and Silver tailings, which are used as an analog for AMD from Mt Nansen tailings, either through the review of data or through a site characterization (seep survey).

These recommendations have been provided as a basis for refining the uncertainty associated with closure Scenarios 3 and 4. These recommendations should be considered when developing scope of work and plans for future characterization studies of the Mt. Nansen Mine.

Table 6-3. Table of Uncertainties - Geochemistry

7. Surface Water Model – Quality and Quantity

7.1 Introduction to the Site Water Quantity and Quality

The Mt. Nansen site is shown in relation to the receiving environment and the water quality stations monitored in Figure 3-1. The Upper Dome Creek monitoring site is downstream of the tailings facility, just downstream of where the tailings seepage water enters Dome Creek. Upstream of the tailings facility there are two water quality monitoring locations, DX and D1. The mill complex is situated in between these two stations. Upper Dome Creek is a key station for predicting loads to the receiving waters. Flow at Upper Dome Creek is a combination of flow through the diversion channel and pumped flow through a pipe that is continuously discharges from the tailings dam seepage collection pond to Upper Dome Creek. A description of the conceptual model of the current site (status quo) is provided (Figure 6).

At Mt. Nansen site, the main sources of contaminant loading in no particular order are the following:

- tails seepage from the tailings impoundment (pumped via the seepage pond);
- pit seepage;
- waste rock seepage (and ore seepage); and
- mill complex seepage.

Tails Seepage

The loading from the tailings facility is primarily via saturated groundwater flow beneath the tailings into the seepage pond. The seepage pond is pumped into Upper Dome Creek. A small component of the loading originates from the perched tailings pond that exists on the surface of the tails. The tailings pond water balance was not substantially revised from the past work completed in 2005 (GLL 2006). An update to the hydrogeological conceptual model of the tailings pond was completed as a part of AECOM's work on the Mt. Nansen Closure Alternative Analysis (AECOM 2009b).

Pit Seepage

The hydrogeological study concluded that all seepage from the pit currently enters the Dome Creek drainage as opposed to the Pony Creek Drainage. The hydrogeology study also concluded that the pit seepage enters Dome Creek by the time it reaches the Upper Dome Creek monitoring station. It should be noted that there is no surface water flowing out from the open pit. The pit water balance was revised from previous work completed in 2004 (GLL 2004) and further detail is provided in AECOM (2010a).

Waste Rock Seepage

Waste rock seepage is described in Lorax Environmental (2009a) and Altura Environmental Consulting (2009). The conceptual model for the water balance (Figure 7.1) depicts the three waste rock areas: area “A” reports to Dome Creek via shallow groundwater seepage; area “B” reports to Dome Creek via deep groundwater seepage; and finally areas “C” reports to Pony Creek via shallow groundwater seepage. Waste rock from area “C” represents the only source of contaminants to Pony Creek. However, there is an adit that travels from the open pit to Pony Creek. Although this adit is plugged, further work would be required to consider it sealed to water flow should the level of the pit rise above the elevation of the adit. The Pony Creek side of the adit is lower than the pit side of the adit, creating a possible pathway for contaminants should the pit level rise higher than the adit elevation.

Mill Complex

One component of the site that was not included within this scope of work is the mill complex and associated up stream sources of contaminants (a haul road composed of waste rock, older Huestis tailings, and the mill site area). It was not included within the scope of the work as the source loading from this area is common to all the closure alternatives being considered.

7.2 Overview

This section summarizes the assumptions within the water quality model developed for the Mt. Nansen mine closure alternatives analysis. The model was developed in GoldSim, a Monte Carlo simulator designed for water balance and water quality modelling at mine sites. A more detailed description of the model is provided in AECOM (2010a).

To explain the existing pit level fluctuation data, a monthly water balance model was developed in GoldSim. This model represents the period from 2001 to 2009. The calibrated model was used to develop a longer-term water balance model for the pit. This longer-term model includes site-wide water quantity including stream flows, pit water levels and tailings pond flows. Finally, a water quality model was developed to represent the impacts of the four closure alternatives considered in the assessment.

The water quality model was then used to predict the water quality at various locations in the Dome Creek and Victoria Creek watersheds for each of the four closure alternatives. The water quality model was run using a monthly time step. This time-step was consistent with the available input data and helps to understand seasonal variations in the predicted water quality. Furthermore, the water quality model assumes average long-term conditions for the assessment of the closure alternatives, without variation in annual precipitation from year to year. The results from the water balance model are summarized in this section. These results assist in understanding the current status quo at the site and the predicted changes with time for the closure alternatives.

7.3 Water Balance Model – Status Quo

7.3.1 Pit Water Balance Calibration

As part of this project, the 2004 pit water balance was updated (GLL 2004). The work completed included calibrating the model to a longer, multi-year data set of pit water level observations. Figure 7-2 shows the match obtained between the simulated and real data. The assumptions incorporated into the simulated data are described in AECOM (2010a).

A longer-term predictive model of the pit level was also developed to represent closure conditions. A correlation between precipitation site data and Carmack station precipitation data was completed. This information was used for generating stream flows and for running the 44 year water balance model using historical precipitation to predict the long-term variation in pit levels.

A “variable seepage assumption” is incorporated into the 9-year calibrated model of actual pit water fluctuations and the longer term (44 year) monthly water balance model of the pit. If this assumption was not employed, the pit would tend to fill up and eventually overflow. One underlying assumption of the alternatives assessment is that the pit will reach equilibrium with time. Other assumptions incorporated into the longer-term closure model of the pit can be found in AECOM (2010a).

7.3.2 Regional Hydrology

AECOM hydrologists summarized the regional hydrological analysis completed to estimate stream flows (AECOM 2010a, Appendix A). This work utilized regional precipitation data and runoff coefficients derived from local topography and soils. This work forms the basis for the stream flow approach utilized in the historical precipitation water balance model (44 years). Site-specific hydrology data was collected in 2009 (AECOM 2010c); however precipitation data was not available for a sufficiently long overlapping period. As a result, stream flow in the model is generated from regional stations, and is not linked to the field data collected in 2009. It should be noted that prior to 2009, hydrology data was not collected at this site.

7.3.3 Precipitation in Water Quality Model

A simple water quality model was developed to assess the closure alternatives. This model used a simple approach for precipitation. A mean annual precipitation (MAP) was calculated from the 44 year historical monthly record. From this monthly 44-year data set, an average monthly distribution was generated.

7.3.4 Waste Rock Water Balance Conceptual Model

A conservative water balance was derived for the Mt Nansen waste rock and ore stockpiles for the water quality modeling. This water balance was used to calculate loadings of constituents to receiving water bodies. Details of the water balance and relevant calculations are included in Lorax (2009c).

The pre-mining topographical divide between Pony and Dome Creek drainages is estimated (Altura 2009). This was used to estimate the portion of waste rock seepage that reports to Pony Creek and Dome Creek.

The waste rock water balance as incorporated into the water quality model includes a number of assumptions:

- there is no surface runoff from the piles (i.e., only seepage and evaporation);
- there is less seepage into the waste rock pile during snowmelt (55%) than during the rainfall season (85%) as a result of the flat surface for snow sublimation;
- there are two separate mechanisms for seepage, 1) a shallow seepage with a two month period for lag and 2) a deep groundwater seepage (yearly moving average); and
- there is no runoff or seepage into the pit catchment from waste rock.

Further details of the assumptions of the waste rock water balance can be found in the Lorax (2009c).

7.4 Water Quality Model – Baseline Status Quo

A large aMt. of baseline water quality data was collected over the past ten years at the Mt. Nansen site by EDI. This data was compiled in a baseline water quality report (AECOM 2010d). The three-year median (2007-2009) value from the baseline report was used in the model and key parameter values are summarized in Table 7-1. The baseline study of all existing water quality at site (AECOM 2010d) indicates that the mill site source term is a significant source of contaminants at site. This can clearly be seen by reviewing the change between Dx and D1 for all four parameters of interest. In addition, Back Creek, upstream of the majority of loadings to Victoria Creek from the Mt. Nansen site, has been impacted by placer mining. The median water quality in Back Creek is poorer than Victoria Creek for the parameters of interest.

Table 7-1. Summary of Baseline Data for Key Modeling Points in the Receiving Environment (mg/L)

Parameter	Dome Creek, Dx	Dome Creek, D1	Upper Dome	Upper Victoria	Back Creek	Victoria @ Rd
Sulphate	168	416	425	15	58	30
Total Arsenic	0.0057	0.015	0.0145	0.0004	0.0069	0.0016
Total Cadmium	0.00004	0.00223	0.00022	0.00002	0.00015	0.00003
Total Zinc	0.009	0.509	0.019	0.007	0.012	0.007

The source term water quality is summarized in Table 7-2 as provided by Lorax Environmental (2009d and 2009e) for the status quo condition. The source term from the tailings is not tailings pore water, which is very poor water quality, but is the water quality pumped from the seepage pond into Upper Dome Creek. A long-term data set of the pumped seepage pond water supports this conclusion.

Table 7-2. Source Term Water Quality Parameters – Under Present Conditions (mg/L)

Parameter	Tails (aver. 3-year seepage pond water quality)	Pit Lake	Waste Rock Source Terms
SO_4	680	1,350	1,530
As	0.04	0.05	0.007
Cd	0.0009	0.012	0.041
Zn	0.02	2.5	1.23

7.5 Assumptions - Water Quality Model Closure Alternatives

In order to understand the assumptions in more detail, a description of the conceptual model of the four closure alternatives is provided in a series of figures (AECOM 2010a). The main assumptions of these four closure alternatives used in the water quality model are listed in detail in AECOM (2010a).

7.5.1 Tailings Seepage – Closure Alternative 3A and Alternative 3B

In general, the alternatives 3A and 3B where the tailing are left in place, have greater certainty in terms of predicting loads to the receiving environment than alternatives where the tailings are moved into the pit (4A_wet and 4A_dry). This is because of the long-term water quality data set of the seepage from the tailings source term in status quo conditions. In alternative 4 the conditions on site for tailings storage would change significantly and it has been assumed that the water quality of tailings seepage would deteriorate significantly once the tailings are placed in the pit. This assumption is based on potentially changing redox conditions with tailings placed in the pit in saturated conditions and a lack of significant attenuation along the flowpath In the case of dry tailings storage, the assumed deterioration in water quality of seepage is based on the potential for the tailings to be oxidized and produce acid rock drainage and metal leaching. Since we do not have the benefit of long-term monitoring with the tailings in the pit under saturated or dry conditions, alternative 3 is clearly well characterized in comparison with alternative 4. Further information is provided in Lorax Environmental (2009d).

Under status quo conditions, the seepage rate from the tailings areas is assumed to be constant at 5 L/s. In the past the seepage pond pump rates has varied from about 40 to 80 USGPM (or 2.5 to 5 L/s). Justification of the constant seepage rate for the closure modelling is provided in AECOM (2010a).

7.5.2 Discussion of Assumptions for Alternative 4A_wet

Estimates of the pit seepage rate for option 4A_wet are based on bounding the problem. The range used in the water quality model is 2-4 L/s, about an order of magnitude above the current pit seepage rate. In this alternative, the surface of the tailings is about 25 m higher than the current pit lake water elevation. The final assumption for the elevation of the water cover is that the tailings stay at least in tension saturation, (i.e., with water table staying within 10 m from the surface of the tailings).

For the lower bound, the assumption is that the hydraulic conductivity of both the pit bedrock and the fine portion of the tailings act to limit seepage out of the pit (AECOM 2010b). For the upper bound, two approaches were considered:

6. **The hydraulic conductivity of the tailings themselves; and**
7. **The available water sources for keeping the tailings saturated.**

Further justification is provided in AECOM (2010a).

7.5.3 Discussion of Assumptions for Alternative 4A_dry

The pit seepage rate for alternative 4A_dry was varied in order to test the range of infiltration expected (5% to 25% infiltration). The conceptual model is that surface water dominates the pit water balance at present. It is expected that by placing a cover of materials over the pit and keeping the water table low, the pit seepage rate will decrease considerable. If the sensitivity analysis results show that at 5% infiltration the alternative 4A_dry is favourable, then further work should be undertaken to reduce uncertainty of the pit seepage rate for this closure alternative.

7.5.4 Summary of Source Term Assumptions

A summary of the “best estimate” source terms is presented in Table 7-3 for four of the key contaminants of concern (COC). Table 7-3 is provided as a brief summary; further detailed information can be found in Lorax (2009d) and Lorax (2009e). It can been seen from Table 7-3 that arsenic is a problematic COC for tailings in the pit in either a saturated or dry state. Zinc and Cadmium are also problematic for dry tailings in the pit. This is primarily associated with the underlying assumption is that the tails will go acid over time in this alternative.

Table 7-3. Source Terms for Key Constituents (Best Estimates)

Parameter	Tails as is 3A/3B	Tails in pit 4A_wet	Tails in pit 4A_dry	Pit lake as is 3A	Open pit with WR 3B	WR as is 3a, 4A_wet/dry
SO_4	680	1,750	2,500	1,350	2,040	1,530
As	0.04	9.5	28.4	0.05	0.016	0.007
Cd	0.0009	0.006	0.184	0.012	0.041	0.041
Zn	0.02	0.05	26.2	2.5	3.48	1.23

Worst case estimates are not considered appreciably different from the best estimates from the point of view of water quality modelling and were not carried forward into the modeling. The best estimate and worst case source terms are provided in Lorax Environmental (2009d). The best case source terms are provided in Lorax Environmental (2010). Results of modelling the best estimate and, best case source terms (and the lower bound for alternative 4) are presented in GEEC (2010).

7.5.5 Water Quality Model Loadings – Status Quo

Predicted contaminant loadings to the stream locations modelled are the main feature of the water quality model. The loads in the model were all combined as a total load to Upper Dome Creek for the status-quo period (i.e., present conditions). If the model is accurate, then the total load to Upper Dome Creek divided by the flow at Upper Dome (i.e., the calculated water quality) should be roughly equal to the observed water quality at Upper Dome Creek. This section highlights loadings to the streams while the next section describes the pseudo-calibration of calculated vs. observed water quality.

The water quality model loadings are presented in Figure 7.3 for the Upper Dome Creek Site. The best estimate load from each source is compared as a function of time. It is clear that the load is the highest for the D1 load in the spring melt when flow is highest. Seasonal variation is seen for the D1 loadings (from the upstream site) and the waste rock seepage while the pit seepage and the tails loads are assumed to remain constant throughout the year. This pattern of loadings matches our assumptions as the waste rock seepage is linked back to monthly precipitation, the tailings contribute a constant load throughout the year via the continuously pumped seepage pond and the pit seepage is deep groundwater flow that is expected to continue year round.

The relative contribution of the loads varies for arsenic, cadmium and zinc.. Sulphate is expected to be conservative and is provided as a reference. Other than background, the main source of arsenic impacting Upper Dome Creek is the tailings with little contribution from the pit or waste rock. In contrast, the highest cadmium load to Upper Dome Creek is waste rock with little contribution from the tails or the pit. In the case of zinc, the highest load to Upper Dome Creek is from the waste rock and this is closely followed by the pit seepage with little contribution from the tails.

In the model and loadings presented (Figure 7.3) the load from D1 has been altered for Cd and Zn because the D1 concentration is much higher than the concentrations at Upper Dome Creek for Cd and Zn. Contaminate removal processes occurring along the stream channel may explain why the concentrations at Upper Dome Creek are much lower than the concentrations at D1 for Cd and Zn. In the case of Cd and Zn, the background load is the DX load. In the case of modelling the status quo conditions, this is justified by the calibration to existing conditions at D1 as discussed further in the next section.

7.5.6 Water Quality Model Calibration - Upper Dome Creek

The modelled and observed concentrations of sulphate, arsenic, cadmium and zinc are shown in Figure 7-4. In addition, the flow in Upper Dome Creek is shown with sulphate for reference. The seasonal variations in water quality are similar for each parameter as concentration is controlled by the quantity of stream flow. During spring melt, concentrations are lowest and during winter low-flows concentrations are highest. While this seasonal signature is evident in the monthly water quality calculated in the model, background concentrations used as model inputs are assumed to be constant with time (3-year median concentration).

While a rough calibration was achieved for Upper Dome Creek water quality during present conditions, a detailed calibration was not attempted as it is outside the scope of the closure comparison. The modelling presented in Figure 7-4 show that the observed and simulated water quality are generally similar. The largest discrepancy between modelled and observed water quality is for cadmium and zinc (see AECOM 2010a for further discussion). Overall the match between the observed and modeled water quality in Upper Dome Creek is considered adequate for the purposes of the closure comparison.

7.6 Pit Water Balance – Long Term Results

A pit water balance was constructed for the open pit as it currently exists. The following summarizes the key findings related to the long term Pit Water Balance. One objective of this component of the project was to consider if the pit water elevation will increase significantly overtime. Although some uncertainty still exists, for the purposes of this comparison study, it has been concluded that the pit reaches equilibrium around the current water elevation. This conclusion is based on a number of assumptions from the pit calibration model.

Note that a pit water balance was not derived for closure scenarios where the pit was backfilled with waste rock or tailings. The assumptions regarding pit seepage do not take into account effects of pit backfill.

The volume of water in the pit is relatively small, and thus it is difficult to distinguish the groundwater inputs from the surface water inputs. The groundwater inputs are small in comparison to the overall inputs to the pit.

The assumptions used to predict the long-term water level in the pit for the status quo (and Alternative 3A) are described below.

- pit seepage increases as the pit level rises because of increased surface area for seepage;
- pit seepage increases as the pit level rises because of higher permeability zones encountered in the upper portion of the pit; and
- the pit surface runoff assumptions are derived from calibration of the observed pit levels.

These assumptions are incorporated into the longer term (44 year) monthly water balance model of the pit. With this set of model assumptions, the pit does not reach a level higher than the Pony Creek Adit.

7.7 Summary Results from the Surface Water Quality Modelling Investigation

The Goldsim model developed by AECOM was used to support the assessment of the proposed closure alternatives for the Mt. Nansen site (AECOM 2010a). The results of the model in the receiving environment, specifically water quality and load in Upper Dome Creek and Victoria Creek, were used to compare the overall performance of the four main closure alternatives with respect to protection of the downstream aquatic environment (GEEC 2010).

As with all predictive models there are uncertainties related to the various inputs and assumptions that are the basis of the models. Some of these uncertainties are general in nature and apply to all the modeled alternatives such as monthly flow values, mean annual precipitation and background or upstream water quality. Others are unique to specific closure options such as source concentrations and source flow rates. Where there is more understanding on the performance of a component of an option, there is less uncertainty associated with the resulting predictions. For the 3A and 3B alternatives, (leaving the tailings in place), there was a substantial aMt. of historical data available to develop the tailings source terms and overall both these alternatives are relatively well defined with respect to the flow and source concentrations from the tailings.

For both the tailing relocation alternatives (4A Wet and 4A Dry) limited data are available to assess the geochemistry and water balance for the open pit in the event it is backfilled. As a result, a higher degree of uncertainty is associated with the estimates of source loading concentrations from the pit and the estimated seepage rate from the pit compared to Scenario 3A.

To evaluate the uncertainty associated with the various closure alternatives a sensitivity analysis was carried out. To facilitate this analysis, the following three scenarios were run using the Goldsim model:

1. **Best Estimate**
   Best estimate source terms for waste rock, ore, tailings, and pit and best estimate waste rock water balance. The "best estimate" is an estimate based on professional judgment and a statistical evaluation of existing data (i.e., seepage collection pond).

2. **Best Case**
   Best case source terms for waste rock, ore, tailings, and pit and best case waste rock water balance. The "best case" source terms are defined as the best case for water quality concentrations in the short or long-term that may be reasonably achieved.

3. **Lower Bound**
   The "lower bound" is defined as the lowest concentration that might be reasonably achieved for tailings placed in the pit. Achieving these concentrations includes engineering and design changes that have not been explicitly identified in the existing closure plans. If water quality modeling results are favourable using the lower bound source terms, then additional work will be required to identify how and at what cost the "lower bound" estimates may be achieved

For all these scenarios the pit seepage rates for the two pit backfill alternatives were modeled stochastically using a range of estimated pit seepage rates instead of a single seepage rate. For option 4A Dry, the pit seepage rate is assumed to range from 0.05 L/s to 0.16 L/s with a triangular distribution with a mean of 0.1 L/s. For option 4a Wet, the pit seepages is assume to range from 2 L/s to 4 L/s with a uniform distribution.

The results of the comparison of the four alternatives for the three modeled scenarios are summarized in Table 7-4. For each parameter and scenario the option that provides the best overall performance as measured by water quality in the receiving environment is highlighted.

Table 7-4. Summary of Comparison of Proposed Closure Alternatives

Parameter	Scenario		
	1.Best Estimate	2.Best Case	3.Lower Bound
Arsenic	3a/3b	3a/3b	4a Dry
Cadmium	3b	4a Dry	4a Dry
Zinc	4 Wet	4a Dry	4a Dry

To put this comparison into context it is important to consider the uncertainty associated with each of the proposed alternatives. This model uncertainty is primarily based on the range of predicted source loading concentrations. For alternatives where there is experience with the performance of a component of an option, there is less uncertainty associated with the resulting predictions particularly Alternatives 3A. For both the taialings in pit backfill alternatives, there is a significant aMt. of uncertainty in the predicted results. The lower bound values used in Scenario 3 provide an indication of what sort of performance may be achievable with significantly more engineering and design change that have not been explicitly identified in the existing closure plans. These may include chemical amendments that may be added to the tailings, reactive organic layers placed beneath the tailings, an engineered cover over the tailings, or any combination of these that might optimize the performance of the tailings and minimize the release of constituents from the pit.

Figure 7-5 and Figure 7-6 graphically illustrate the range of variability, and therefore uncertainty, in the predicted water quality for each parameter in Upper Dome Creek and Victoria Creek associated with Option 4A Dry and 4A

Wet. Further engineering design and test work to refine these alternatives would be required to reduce the range of water quality variability for these options.

7.8 Water Quality Model Summary of Potential Risk and Uncertainty

The water quality model developed to support the assessment of the various closure alternatives integrates the inputs and assumptions from the various key disciplines that are described previously in this report. As such, many of the uncertainties associated with the model, specifically the assumptions and inputs, have already been discussed in the previous sections. There are however, specific issues and uncertainties related to the pit water balance model and the surface water quality model.

For each of the closure alternatives, a relatively simplistic approach was taken for the water balance. For the various options for the tailings remaining in the valley, the same assumptions are assumed for all the cover options (soil, water, sponge) which result in the same water quality loading to the receiving environment for each of the cover options. In reality, each cover option will change the hydraulic characteristics in the tailings area and would result in different fluxes of load to the receiving environment.

For the in-pit options, further work needs to be done to define the assumed seepage rates out of the pit for both the wet and dry options, which take into considerations the characteristics of the tailings themselves and the specific hydraulic conditions in the pit for each option. The pit water balance has only been done for existing conditions. This needs to be updated for the various pit closure alternatives to adequately characterize how the water balance will change when backfilled with tailings and/or waste rock. Presently, for the assessment of the two in-pit options from a water balance perspective is based on modifying the pit seepage rates for each of the options. For either in-pit alternative, it will be imperative to have a good understanding of the ultimate water level in the pit.

For each closure alternative, both valley and in-pit, the modeling has been based primarily on the extension of the status quo model. Given that each closure alternative will result in changes to the local water balance in either the pit or the tailings facility, a more integrated approach should be taken for the modeling of each of the closure alternatives. To adequately assess the downstream water quality implications of the various closure alternatives, an integrated water balance/water quality model will be developed that incorporates the specific components of each option and the impacts of those options of the water balance. For each closure option, the revised model will provide for a more detailed assessment of the implications of the option on the local water balance, downstream water quality and possible water management needs. For example, for water cover options, is there enough water to maintain the required cover, what is the water quality of the cover, will it required treatment if discharged?

8. Summary and Discussion

The preferred tailings and waste rock management options will be determined by the Stakeholders not the technical consulting team and therefore no recommendations on a preferred option are provided.

The purpose of this chapter of the report is to integrate the discipline specific technical information presented in the previous chapters and in the supporting memoranda into a brief summary that outlines the key advantages, disadvantages of the four main closure options and to highlight any areas of uncertainty. The key areas of geochemical uncertainty are summarized in Table 6.3. The key areas of geotechnical uncertainty are provided in Appendix B-2.

This chapter specifically focuses on tailings management because the tailings management alternative selection is the most critical decision to be resolved before detailed design can proceed. Waste rock management is also considered in some of the options evaluated as part of this work but the amount of waste rock managed varies from option to option, and is somewhat dependent on the tailings management option selected.

This summary considers the four main tailings disposal options:

- 3A- wet – Upgrade tailings dam, install cover (soil, water or sponge), no waste rock management;
- 3B- wet – Same as 3A but with waste rock deposition in pit;
- 4A- wet – Tailings excavation and disposal in the Pit- wet condition; with or without waste rock drains; and
- 4A-dry – Maximize tailings and waste rock in the Pit with a soil cover- dry condition; with or without waste rock drains.

Many of the advantages, disadvantages and uncertainties relate to cover design and water balance issues. The technical team recommends further investigation, assessment and conceptual design of these aspects to allow a better inform the preferred closure option selection process.

8.1 3A- Wet: Upgrade Tailings Dam, Install Cover (soil, water or sponge), no waste rock management

This option maintains tailings in current location, water can be discharged without treatment, and maintains the tailings in a saturated state. Of all the options considered, this is the option with the least amount of geochemical uncertainty. However, there remains some uncertainty regarding how long the current attenuation of arsenic concentrations in the organic layer below the dam will be effective in reducing arsenic concentrations and allowing discharge to the receiving environment without treatment.

A soil cover over saturated tailings is judged to represent the least risk from water quality perspective for this option. A soil cover negates concerns related to wetland development and enhanced arsenic mobility due to reductive dissolution. Soil cover also limits the water elevation behind the dam and therefore is the least risk cover option from a dam stability and groundwater flow perspective. The soil cover also reduces evaporative losses and provides extra protection from oxidation during drought conditions. A sponge cover could represent degradation in surface water quality and a minor increase in groundwater flow and dam stability risk compared to a soil cover. A water cover has the greatest risk of poor water quality discharge to surface water, increased groundwater seepage under the dam and somewhat higher risk from a stability perspective.. Further work on water balance and cover system options is required to select the best cover system for achieving geochemical, geotechnical, surface water and groundwater goals.

From a geotechnical perspective this option requires upgrading of the existing dam. The foundation soils are potentially liquefiable and long term thermal conditions are not well understood, including the potential consequences of global warming. More frequent monitoring of existing instrumentation, thermal modeling, allowances for global warming and potential for thawing of permafrost will need to be addressed in detailed design. The dam will require routine dam inspection and maintenance and represents a long term liability, but these are requirements for all of the alternatives considered where the tailings are maintained in a saturated state, which is the paramount geochemical consideration.

A water management plan needs to be developed based on selected cover design and determination of acceptable risks associated with routing creek flows through tailings ponds. Hydrology requirements need to be further refined for detailed design including dam spillways and the Dome Creek Diversion structure.

While there remains some uncertainty regarding the water budget, Dome Creek flows are larger and more consistent than the smaller ephemeral Pony Creek flows, therefore the risk of not having enough water to maintain tailing saturation is less for the existing tailings facility(3A) than it is for the in pit options (4A).

The groundwater flow system in the vicinity of the existing tailings facility is relatively well understood and predictable relative to pit disposal options. The deep groundwater flow system below the permafrost has not been investigated. However, based on our understanding of: groundwater flow rates; groundwater discharge conditions along Dome Creek, there does not appear to be a large load of contaminants moving through the deep groundwater flow system to Dome Creek. This is supported by water quality in Dome Creek at the road (which likely receives deep groundwater discharge) which is similar or better than at Upper Dome Creek immediately downstream of the tailings facility.

8.2 3B-Wet: Same as 3A but with Waste Rock Deposition in Pit

The advantages, disadvantages and uncertainties for 3B tailings management are identical to 3A.

The disposal of waste rock in the pit does not create any significant geotechnical issues other than an increase in costs. The pit will need to be pumped dry prior to placement which will require short term water treatment.

From a geochemical perspective placement of waste rock into the pit lake may remobilize otherwise stable constituents, promoting enhanced leaching of metals (e.g., arsenic, zinc and cadmium). While ARD is considered a minor risk, portions of the waste rock are rated as potentially acid generating.

From a groundwater and surface water perspective, placement of waste rock in the pit will increase the likelihood that a large precipitation event or spring runoff will cause pit water levels to rise rapidly and cause contaminated pit water to move laterally in the adit or upper fractured bedrock. If this occurs then there may be a requirement for pumping from the pit and water treatment. It is expected that these seasonal water level rises will be temporary for this option and that the water level in the pit will eventually return to the static water level condition.

8.3 4A- wet: Tailings Excavation and Disposal in the Pit- Wet Condition; with or without Waste Rock Drains

This option assumes that the water balance is favourable for maintaining tailings saturation, but further hydrology and cover studies are required to confirm that the Pony Creek drainage will provide sufficient water to keep the tailings saturated year round including drought years.

From a geotechnical perspective, this option would still require a dam to contain the tailings. The dam will require routine dam inspection and maintenance and represent a long term liability. The foundation conditions for this new dam will be bedrock and are expected to be better than the existing dam. However, the dam foundation conditions for this option have not been investigated so there is associated uncertainty. The inclusion of waste rock drains would: facilitate future water collection if required; consolidation of the tailings; and reduce potential long term settlement damage to a soil or sponge cover.

From a geochemical perspective a key advantage of this option is that the tailings are kept in a saturated condition over the long-term, thus preventing acid rock drainage, similar to options 3A and 3B. However, remobilization of arsenic, cyanide and metals may occur from relocation of the tailings. While considered a minor risk, waste rock is rated as potentially acid generating and this represents a minor disadvantage if waste rock is used in internal drain construction.

From a geochemical and water quality perspective a soil cover, which enables the tailings to remain saturated, would be preferable for this option because it would reduce concerns for any potential discharge of surface water with poor water quality. A soil cover would also negates concerns related to wetland development and enhanced arsenic mobility due to reductive dissolution. Similarly a soil cover would minimize evaporative losses and provide extra protection from oxidation during drought.

From a groundwater perspective the raising of water levels in the pit by 25m constitutes a risk of lateral movement of contaminated groundwater via either the adit or the upper, more permeable fractured bedrock..

8.4 4A- Dry: Unsaturated Tailings in the Pit with a Soil Cover; Maximize Waste Rock Use as Drains

From a geotechnical perspective, the risks associated with the waste rock plug and dry tailings are considered to be less than a wet cover which requires a tailings dam. In the dry storage environment, the tailings will gradually become more stable and it may be possible to move away from classifying the plug as a dam. However, we have assumed that until such time as this reclassification can be made and is accepted by the Regulators, the waste rock plug should be considered to be a dam with all associated long term requirements for dam safety reviews, surveillance monitoring, etc.

However, from a geochemical perspective, there are no key advantages posed by this option. Lorax considers this option to be contrary to best management practices for preventing acid mine drainage. Under this option, tailings are exposed to oxygen and acid mine drainage conditions are predicted to evolve in the long-term with release of elevated arsenic and heavy metal concentrations. The addition of waste rock layers, while geotechnically beneficial for consolidation of the tailings, may increase exposure to oxygen and accelerate site acid mine drainage. Furthermore placement of waste rock into the pit lake may remobilize otherwise stable constituents, promoting enhanced leaching of metals including arsenic, zinc and cadmium.

Some water treatment would be required during to pump down the pit prior to placement of tailings and waste rock. If oxidation of unsaturated tailings does results in acid mine drainage then there is a potential requirement for long term seepage collection and treatment.

8.5 Additional Integration Steps

Further work to assess the advantages, disadvantages, risks and uncertainties associated with the eleven options considered by the geotechnical and geochemical assessment is required. The objective will be to reduce the number of option variations that are subjected to more detailed work to better define the alternative-specific water balance, geotechnical risk, geochemical risk and water quality modelling. Any closure options that are considered to not be feasible would be identified.

The first step would be a technical workshop on tailings cover systems (and drainage layers) in order to determine the preferred cover option for the three main tailings options: 3 Wet (existing tailings facility), 4 Wet (saturated tailings management in the pit) and 4 Dry (unsaturated tailings storage in the pit). This will result in a reduced number of closure options being carried forward. The workshop should also examine the geotechnical, geochemical and water balance issues and uncertainties associated with the various tailings management options. Potential waste rock management methods for each option should also be better defined.

Agreement on key conceptual design issues for the limited number of closure options carried forward will permit more focused, option-specific water balance definition, water quality modelling and engineering analysis to support the final selection of the preferred closure option by the stakeholders. The reduced number of closure options will also focus any further collection of field data and laboratory testing.

The mill area is also known to be a source of contaminants to the receiving environment and is common to all closure alternatives being assessed. It is our understanding that the Yukon Government has retained Altura to better assess and delineating the potential sources of contamination present in the Mill area.

The geotechnical, hydrogeological, geochemical and surface water analysis provided in this report and the supporting technical memoranda can inform an assessment against some of the Mt. Nansen Mine Closure Project Objectives closure objectives were established by Yukon Government (GY), Government of Canada (Indian and Northern Affairs Canada (INAC), Environment Canada (EC) and Department of Fisheries and Oceans (DFO)), and Little Salmon Carmacks First Nation (LSCFN). (Yukon EMR “Options for Closure of Mt. Nansen Mine” (July 2008)). However, the scope of AECOM’s work does not address all of the stated objectives for Mt. Nansen. Issues such as future land use and visual aesthetics, which are beyond the scope of this report. The Government of Yukon, Government of Canada (INAC) and Little Salmon Carmacks First Nation are presently working on developing the appropriate process that will be used to assess and evaluate each of the proposed closure alternatives, based on all the stated closure objectives. A systematic assessment of the relative impact of each alternative against each objective would be a solid foundation for selecting a preferred alternative. Such an assessment would make best use of a range of data, including field / model-based data (such as those presented in this report), subjective assessment / expert judgement and community feedback. This assessment could consider the Environment Canada alternatives assessment guidelines for projects that use fish-bearing water bodies for tailings impoundment areas.

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Figures

Appendix A

Gap Analysis Results

Appendix B

Geotechnical/ Civil Engineering Drawings

- B-1 Geotechnical/Civil Engineering Drawings
- B-2 Summary of Geotechnical Considerations for Mine Closure Alternatives
- B-3 Borehole logs
- B-4 Thermistor Data

B-1 Geotechnical/Civil Engineering Drawings

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Appendix C

CD of the Key Technical Memorandum from the AECOM SharePoint Site