Environment

Yukon Government,
Assessment and Abandoned Mines Branch

Mt. Nansen Alternatives Characterization

DRAFT – Missing Water Quality Results

Prepared by:

AECOM

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January 13, 2010

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Dear Mr. Patch:

Project No: 60119144 - 112359

Regarding: Mt. Nansen Alternatives Characterization Alternatives Characterisation

Sincerely,
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1. Introduction

This report is a summary of the work carried out by AECOM to characterise various alternatives for the closure of the Mt, Nansen mine site. The work has been carried out in close co-operation with Lorax, Altura, EDI and GEEC consultants, 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. This effort has entailed very close and enthusiastic co-operation and liaison with the consultants involved, Yukon Government Abandoned Mines staff, INAC/DIAND, and the members of and advisors to the Little Salmon and Carmacks First Nation (LSCFN).
The overall site layout is shown in Figure 1 Mt. Nansen Site Overview.

1.1 Scope of Work in 2009

The scope of work carried out during 2009 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; and
- Preparation of this draft report.

The current scope of work has been carried out under YG contract C00001327 .

1.2 Results of Gap Analysis

1.2.1 History and Synthesis of Alternatives

Taking 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 identified:

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.

1.2.2 Closure Objectives

The closure objectives presented in Appendix C of Options for Closure of Mt. Nansen Mine, Technical Review Version, July, 2008, were developed in consultation between Indian and Northern Affairs Canada, Yukon Government, Department of Fisheries and Oceans, LSCFN, and Environment Canada. They 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 concerns and objectives expressed by the consulted parties:

- 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 tables 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 characterisation program.

1.2.3 Summary of Gap Analysis

With a list of five main alternatives, options for each element of the site were identified, and available information reviewed, in order to arrive at an assessment of gaps in information that would preclude a balanced and objective comparison of alternatives, with the closure objectives as a frame or reference. The results of the gap analysis were summarized in the detailed tables in Appendix A.

This section summarises the results of the gap analysis, and the feedback and discussion from the related workshop held on March 23/24, 2009. 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.

We were reminded by LSCFN 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 one to proceed as soon as possible. The results of the gap analysis, per the tabled spreadsheet matrices, form a basis for the team to carry out detailed planning and integration of field, laboratory, design and impact assessment tasks. The gaps are described for each discipline later in this section.

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 characterisation of alternatives that are free of fatal flaws and are likely to result in tolerable residual risk.

There was general acceptance that options to leave the situation as it is, and to create new tailings storage facilities in Dome Creek, or elsewhere, 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 mine rock into the pit.

It was noted that the existing tailings storage facility, placed as an obstruction in Dome Creek, 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 effort combining engineering and environmental science was identified, to be initiated through a detailed work planning session that was held in Whitehorse in April 2009.

It was noted that certain areas of work have a very high priority, so as not to miss seasonal windows or cause delay because of time required to conduct them e.g., 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 noted 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 risk 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 that have been assessed. The next step was 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 preliminary 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.

The following description of gaps is divided into the principal disciplines of study, and, where appropriate, focusses on the alternatives 3 A and B, and 4 A and B, which were recommended for further work and evaluation.

Geochemistry

All alternatives

- conduct pit seepage modeling to determine leaching rates and loading to environment, which fits with ground and surface water disciplines and is common to both alternatives;
- assess pit lake water quality treatment options prior to dewatering and backfilling (bioremedation, active treatment, etc) – tie this in to work for water treatment engineer when characteristics of alternatives have been predicted [need to discuss when to schedule this work, which might involve some treatability testing];
- conduct leach test work on tailings/waste rock to evaluate short-term pit lake water quality after flooding [this would tie in with ongoing water quality sampling];
- conduct pit lake water quality modeling to determine leaching rates and loading to environment;
- conduct leaching test work of exposed tailings and nearby sand (cover) material [this is given a lower priority because it will not influence comparison of alternatives];
- develop water management plan and/or treatment plan and mitigation options for pond and seepage treatment [need to tie in with possible treatment investigation and assessment and schedule it];
- conduct waste rock monitoring and/or characterization to determine long-term leaching rates [refer also to Altura recommendations for further work];
- evaluate waste rock seepage rates and quality into open pit [combined task];
- water treatment, sludge management and storage optimization [see comments above regarding when and how to bring treatment into alternatives selection process]; and
- verification sampling and geochemical characterization of soils remaining following tailings/waste rock relocation; [this is two separate sites – existing tailings area if decommissioned and/or waste rock piles if partially or wholly relocated [tie in to recommendations and work by/for Altura; can be deferred as not likely to affect alternative comparison].

Alternative 3 – Upgrading TMF

- determine TMF water balance, pond size, and groundwater seepage rates [surface and ground water tasks];
- verify source(s) of seepage being collected in seepage collection pond (install nested monitoring wells) [ground water task];

- conduct detailed seepage monitoring test work, including in-situ measurements of sulphide, oxygen, redox [combined geochemical and ground water task];
- install piezometers along the seepage flow path from the tailings to the seepage pond and monitor water quality[combined geochemical and ground water tasks]; and
- conduct laboratory test work to determine capacity for dam (clay) materials and foundation soils to attenuate As and long-term leaching rates.

Alternative 4 – Decommissioning TMF

- conduct long-term leaching rate test work on tailings to simulate pit closure conditions;
- evaluate tailings relocation method (paste, thickened, underground backfill, etc) with respect to geochemical considerations;[link in with geotechnical/civil evaluation];
- geochemical characterization of contaminated organics, soils and groundwater under TMA and evaluate best management; and
- geochemical characterization of contaminated dam material and evaluate best management options.

Geotechnical

All Alternatives

- install stream gauges (at TMF) [a surface water task];
- characterize waste rock for construction purposes e.g., gradation, durability, etc. [work with Altura on this];
- further evaluation of metals mobility (geochemistry) in construction rock [overlap with Altura and geochemical work];
- survey waste rock volumes [review available information on quantities]; and
- determine available storage volumes relative to static water levels in open pit.

Alternative 3 [following apply entirely to existing TSF)

- test hole drilling program [combined hydrogeology, geochemical and geotechnical];
- install piezometers to measure groundwater levels for dam stability, and assess ground water flow and quality;
- install thermistor strings to measure ground temperatures;
- CPT testing to evaluate foundation soils/liquefaction potential;
- determine design flows for diversion channel and spillway [in conjunction with surface water program];
- review hydraulic capacity of interceptor ditch, diversion channel and emergency spillway;
- classify tailings dam following CDA Guidelines;
- evaluate need for seepage dyke [this is important as it may impact on the dam stabilization options e.g., toe berm];
- evaluate feasible alternative to improve foundation soils (liquefiable soils) beneath tailings dam;
- stability analysis of tailings dam to determine stabilization options [a preliminary assessment stabilization options; and
- deformation survey of existing pins.

Alternative 4

- design restored creek channel and dam breach geometry– lower priority for final detailed design;
- evaluate methods of relocating tailings; and
- evaluate dewatering and water treatment alternatives [link in to general involvement of water treatment advisor at appropriate time.

Surface Water

All Alternatives

- hydrology of Receiving Environment and internal mine site (baseline);
- measure year-round daily surface flow for Victoria Creek and Back Creek;
- conduct low flow analysis for receiving environment flows – Q5 or Q10;
- update hydrological analysis since work done in 2004 by NHC;
- install a hydrometric instrument at the site to allow direct measurement of pond lake evaporation [not essential to alternative selection but desirable for implementation/detailed design];
- measure year-round daily surface flows for Dome Creek (upstream of Victoria Creek) to help quantify the overall Dome Creek drainage basin water balance, and provide a quantitative check on assumptions of surface runoff coefficients and drainage areas;
- measure year-round daily surface flows for Pony Creek (at the highest point of flow);
- develop waste rock hydrology conceptual model;
- determine surficial drainage patterns to better delineate the extent of catchment runoff zones and quantify the effect of roads and ditches within the catchment area;
- conduct a site visit to determine and better refine the catchment drainage areas and patterns; and
- collect manual measurements of pond staff gauge readings periodically to validate level-logger data (tailings pond and pit pond).

Water Quality of Receiving Environment and Internal Mine Site (baseline)

- analyze statistics for water quality for all parameters of concern in receiving environment (Victoria Creek, Back Creek) and within internal mine site;
- evaluate existing treatment plant performance; and
- evaluate the background impacts on receiving environment of other mining in the area (placer mining).

Confirm Conceptual Model for Water Quality Impact Assessment

- confirm and document why water quality objectives for the protection of aquatic life apply to Victoria Creek and Back Creek (but not Pony Creek, Dome Creek and standing water in the Tailings pond and Pit pond);
- develop appropriate water quality objectives for the receiving environment (estimates) to shape decision making for waste and water management closure planning (i.e., do not use inappropriate water quality objectives for decision making);
- determine water quality objectives for end of pipe (lower than MMER and BYG licence limits to be protective of receiving environment (i.e., meet CCME/SSWQO);
- develop SSWQO for “problem contaminants” if required (and consider appropriate methodology for development of SSWQO in the Yukon context [advice from Leslie Gomm recommended]; and

- estimate receiving environment impact assessment for closure options and help redefine data gap needs based on key input parameters identified.

Water Balance Model

- use preliminary mine closure design details of alternatives for detailed water balance modelling and water quality source term estimation for each closure options;
- update water balance models for pit and tailings pond since 2004/2005 [overlap with groundwater task];
- integrate site wide water balance for internal mine water management and external receiving environment water quality modelling;
- estimate uncertainty and ranges for the parameters listed to be used within the water balance model; and
- determine longer-term climatic changes in hydrology parameters from climate warming [not essential to alternative comparison].

Alternative 3

- determine tailings pond seepage and rates of flow from the seepage pond;
- determine the amount of flow in the diversion ditch, both upstream and downstream of the tailings pond, to help quantify the amount of leakage that may be occurring from the ditch to the groundwater system or from the ditch, directly to the tailings impoundment as surface flow, and to determine if the stream within the ditch is losing or gaining water;
- continue the collection of water quality data for the different water quality source term components (tailings pond, seepage pond, Dome Creek, groundwater, tailings porewater, etc.) to help determine the interaction of the different components;
- utilize tailings pond pumping rate data since 2000 (if available) to better constrain the water balance model; and
- evaluate surface water runoff changes resulting from cover materials placed for longer-term closure on tailings.

Alternative 4

- estimate pit water balance to assess if tailings would remain submerged after mitigation measures applied to water sources flowing into the pit are achieved; and
- estimate risk of the Pony Creek adit filling and impact on surface water.

Ground Water

All Alternatives

- characterize the hydrology of Pony Creek (i.e., measure timing and magnitude of flows surface water task – see above];
- quantify groundwater inflow from Pony Creek to Brown-McDade pit;
- determine static water level within Brown-McDade pit;
- determine seasonal groundwater level fluctuations surrounding the pit;
- evaluate potential for management of the pit water balance (i.e., groundwater seepage in/out of pit, cover);
- evaluate the effect of existing exploration berms on groundwater recharge along the length of Pony Creek [this may not be important to alternative comparison, so low priority];
- confirm flow pathways leaving pit (i.e., identify receptors);

- determine potential for groundwater emanating from pit to impact receptors;
- determine seasonal variability in groundwater chemistry surrounding the pit;
- evaluate potential for groundwater flow around bulkhead in adit;[this is lower priority unless it becomes a part of a preferred alternative];
- determine bedrock permeability surrounding the pit to support travel time calculations;
- install long-term monitoring wells surrounding pit to verify groundwater flow and monitor groundwater chemistry [long-term monitoring wells will likely be required and may provide useful information during closure planning];
- characterize hydrology of Dome Creek above and below TMF (i.e., measure timing and magnitude of flows);
- confirm magnitude and quality of groundwater discharge to TMF and seepage collection pond;
- determine background groundwater quality in Dome Creek valley;
- determine magnitude and extent of groundwater contamination beneath existing tailings pond;
- evaluate metal attenuation along the groundwater flow pathway (i.e., across tailings dam) [somewhat less important if move all tailings];
- confirm groundwater flow pathways surrounding waste rock piles and identify potential receptors; and
- determine long-term seepage water quality from waste rock piles.

All of the recommended hydrogeological gaps that require further work are applicable to both alternatives 3 and 4.

1.3 Results of Planning Workshop

The following points were made during the planning session held on April 22/23, 2009, which focussed on the alternatives 3A and B, and 4A and B for closure of Mt Nansen mine site. The 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 characterize the selected alternatives.

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.

LSCFN noted that the elders recognise that it may not be practical to completely restore the pre-mining landscape. The 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 other consultants have completed baseline studies for a human health and environmental risk assessment, and have run a preliminary risk analysis. The main risk receptor pathways are water and airborne dust.

1.3.1 Mine Waste Rock Characterisation Planning

Altura Environmental Consulting (Altura), who were tasked with guiding the development of alternatives involving mine waste rock, gave a summary presentation of their work to April 2009, and its implications for alternative design and comparison. Their conclusions were:

1. No large scale net acidity issue occurring in waste rock pile, nor likely to occur (pockets of net acidity only), but zinc solubilization issues require consideration and management for decommissioning;
2. Due to favourable location, climate regime, and depth to groundwater, overall there is likely little migration of rock pile 'contact water' to receiving environment, but some low-volume seeps were noted, and to validate this conclusion additional monitoring, reconnaissance, basic water balance is recommended;
3. Rock excavated later in mine life most problematic in terms of localized areas of net acidity/metals. Northwest, South, and Lower Southwest Piles contain higher proportions of this Marginal material than other sector, but all piles are a mix of rock types/alteration/weathering. On-ground confirmation and screening required during any earthworks and relocation activities.

Table 6-1 of the recent report by Altura (March 2009) presents four classifications for mine rock and corresponding management objectives, which will be taken into account in developing the alternatives for the site as a whole.

Waste Rock Type	Waste Rock Management Strategy
Marginal Rock - Partially oxidized, elevated sulphide, soluble zinc ± acidity	Minimize contact with water
Low-Reactivity Rock - Partially oxidized, lower sulphide, little soluble zinc, no acidity	No special management (but careful segregation from Marginal rock if submerging)
Construction Rock - Competent, low zinc solubility and no net acidity potential	West Lower Pile coarse rock - potential candidate for construction / submergence (needs confirmatory testing)
Ore Stockpile Rock - Highly oxidized, net acidity/metals	Minimize contact with water Possible lime amelioration

Further recommendations from Altura were:

1. Re-establish climate monitoring (precip, snowpack);
2. Seep / lysimeter monitoring in 2009;
3. Additional geochemical testing of construction rock (possibly look further afield, depending on needs);
4. Pit wall sampling – limited information noted;
5. Update topographic base, source pre-mine topography; and
6. Simple rock pile water balance (incorporate into site balance).

A few additional points about waste rock were noted:

- in addition to the geochemical aspects, re-vegetation aspects and natural site weathering and morphological processes may influence reclamation planning;
- only two sectors of the rock piles were considered to be problematic and they account for approximately 20% of the total;
- seepage zones from the rock piles are limited in number, of low flow rate, and favourably located in terms of water management; and
- there is some concern that there may not be sufficient quantity of rock suitable for construction. Note that a desktop study of potential sources has been conducted, and will be ground-truthed in the summer of this year. Preliminary closure alternative designs need to take this limitation into account.

1.3.2 Environmental Monitoring Planning

EDI summarised the environmental monitoring work across the site. This includes both terrestrial and aquatic aspects. Fish have only been found in Back and Victoria Creeks. For Mt Nansen project, the receiving environment for fish should be Victoria Creek. There is no evidence of fish in Pony Creek, which does not flow on surface continuously. Dome Creek very likely is obstructed by a chute near its confluence. EDI contribute a strong understanding of site environmental conditions and will be contributing ongoing assistance in evaluating the alternatives and executing field programs in conjunction with ongoing environmental monitoring. Subsequent to the April planning session, Lyndsay Doetzel and Stephanie Whitehead visited the site to identify sites for flow monitoring at selected locations to be conducted in the coming spring and summer periods.

1.3.3 Geochemical Characterisation Planning

Lorax summarised recent work to assess best approaches to long-term containment and management of the tailings with respect to geochemistry and minimising adverse related impacts. The tailings are likely to be acid generating if not submerged permanently. From a geochemical perspective, the tailings, located where they are in the impoundment, are largely saturated and their behaviour is relatively well characterised. Other than physical risks, the chemistry in the current situation is well understood, except for the arsenic, and there exist three potential mechanism for the detected attenuation of it, as evident from monitoring downstream. Lorax proposed to evaluate these mechanisms in coming investigations during 2009.

By contrast, Lorax expressed concern that the uncertainties associated with moving the tailings to backfill the open pit were much less well defined, and potentially it would be difficult to manage and design containment measures to achieve desired conditions for effective chemical management. The key question of defining the pit water balance remained, as it was not clear as to whether or not it will be possible to ensure fully submerged and saturated conditions, which could be labelled as current best practice. Alternatively, could an effective drained containment be achieved, isolated from significant flow towards the regional ground water system?

Lorax proposed to conduct test simulation of the possible alternative storage conditions. The tests could take up to 50 weeks. It was a concern that no useable information from the tests would be available at the time that it is needed to influence comparison of the alternatives. If possible and available, such test data will be used. However, Lorax proposed to employ other experience and judgement to develop credible source terms that can be used to predict sitewide effects on water quality at down gradient points of concern.

For Alternative 3, leaving the tailings in the existing impoundment, previous testing by NRCan indicated that simulation of the mechanisms affecting arsenic transport cannot be completed within the timeframe available for comparing alternatives. Instead, seepage sampling and monitoring will be used to infer the mechanism currently attenuating arsenic through and beneath the dam structure.

1.3.4 Geotechnical Characterisation Planning

The existing tailings impounding dam would be assessed and classified, and a preliminary design for its stabilisation to meet Canadian standards for such a permanent structure prepared. This would include provision of a very robust system for intercepting and diverting surface flow for the long-term. Permafrost conditions would be further investigated as they affect stability and integrity, with the expectation that the existing permafrost is discontinuous, relatively warm and may degrade further with time. No major geotechnical problems were anticipated at the open pit. Gradual degradation of the pit walls would likely occur, if left exposed, but sudden catastrophic failure was considered very unlikely. AECOM would take responsibility for all preliminary engineering and costing of all aspects of the alternatives being considered for the site, including tailings impoundment stabilisation or decommissioning, mine rock pile closure or re-location to the pit, and all placement and transportation of rock or tailings into the pit.

1.3.5 Surface Water Characterisation Planning

The largest gap in information is flow measurement at site. A number of potential monitoring sites were identified for field reconnaissance by Stephanie Whitehead and Lyndsay Doetzel on April 29th, 2009. Site flow measurements would improve understanding of site hydrology, and add to the credibility of future impact assessments. This would be supplemented by the use of regional information to derive flow parameters for both impact prediction and engineering of permanent hydraulic structures. It was noted in particular that a suitable site for low flow measurement was needed.

Leslie Gomm (GEEC) agreed to provide senior review and advice to the team on water management and impact prediction.

It was noted that seepage/leakage from the diversion channel around the tailings impoundment was expected to be significant and would be characterised.

Goldsim software was proposed to simulate flow through all elements of the site, with inputs from surface and groundwater flows, and chemical loadings from mine rock, tailings and other materials contacting flows. AECOM would manage and coordinate input from each discipline for the existing situation, and then for the alternatives as they were defined. A monthly simulation frequency was recommended. Water quality objectives would be reviewed in the context of these predictions. As a minimum, each alternative must achieve CCME in Victoria Creek. As preliminary designs emerged, source terms would be developed and the water quality predicted to provide a basis for alternative comparison.

1.3.6 Hydrogeological Characterisation Planning

Site groundwater conditions surrounding the open pit have been variously evaluated in the past few years, employing a limited number of drill holes, and through analysis of site observations and monitoring of the pit lake. The main uncertainties in understanding ground water flow into and out of the pit are the magnitude of flow between Pony Creek and the north end of the pit, and in the elevation and direction of flow beneath the pit. These may be influenced by variations in weathering and fracturing, particularly faulting which intersects the open pit. Upcoming investigations will attempt to reduce uncertainty and to characterise these aspects more clearly. At the existing tailings impoundment, the flow of seepage into, through and beneath needs improved definition. This would be investigated in conjunction with geotechnical and geochemical work.

1.3.7 Review of Alternatives and Work Required for Characterisation

As previously noted, the focus of ongoing characterisation of alternatives during 2009 has been on Alternative 3, leaving the tailings in their current location, and Alternative 4, moving the tailings to the open pit. For either alternative, varying amounts of waste rock could be considered for use in that alternative.

Pit backfilling alternatives were reviewed, and options to place tailings in either a dry or wet condition were judged to be worth further consideration. This needed to be influenced by the reliability of either diverting water away from the pit or of ensuring saturation up to a certain design objective elevation. Options for the excavation, transportation and placement of tailings needed to be assessed, including frozen, drained or slurried, with further options to amend their properties with additives. Selected waste rock can be used to provide both drainage beneath dry tailings or to ensure robust covers. The disposal of excavated dam materials needed to be included, together with the restoration of the valley floor and side slopes in Dome Creek. Overall, AECOM would take charge of the pit backfilling preliminary design, with input and support from the other disciplines.

Similarly, AECOM would take charge of preliminary designs for the amendment of the existing tailings facility to achieve long-term passive care objectives. This work was to include drilling investigations, classification of the dam structure according to Canadian standards, and analysis of the consequences of dam breaching and releasing its contents.

For all civil work, it would be necessary to establish the feasibility and credibility of the alternatives, and for an estimate of their costs to be developed that is sufficiently accurate to support selection/ranking. In other words, if uncertainty in an element of cost could later change the selection decision, then further investigation and/or analysis should be anticipated and carried out as part of the current mandate.

Following breakout sessions, the following points were noted by the discipline leads:

EDI (environmental monitoring):

- AECOM to provide information and monitoring requirements to EDI;
- EDI to post selected site photographs to the project sharepoint; and
- EDI to provide comments and evidence concerning presence/absence of fish in Dome and Pony creeks.

AECOM (hydrogeology):

- consider installing monitoring well down-gradient of waste rock piles;
- coordinate all dam investigations with geotechnical and geochemical leads; and
- in conjunction with geotechnical lead, consider practical ways to divert/control inflows from Pony Creek towards or away from the pit area.

Lorax (geochemistry):

- coordinate investigation and sampling at all sites with AECOM;
- consider monitoring groundwater flow and quality upstream of the tailings impoundment in conjunction with hydrogeological program;
- not necessary to obtain deep samples of tailings in the middle of the impoundment;
- provide interim source terms estimates, albeit conservative ones, for all components for use in prediction of impacts; and
- coordinate with geotechnical lead in devising potential options for pit backfilling with tailings in either wet or dry states.

AECOM (civil and geotechnical):

- coordinate dam site investigations with hydrogeological and geochemical leads;
- manage all conceptual designs for alternatives to ensure consistency of assumptions and engineering principles;
- collaborate with Lorax in particular to develop options for pit backfilling;
- coordinate with hydrogeology lead so that management of water within the backfill is compatible with the emerging understanding of the groundwater system around and beneath the pit;
- coordinate with surface water lead to develop hydraulic design criteria that are consistent and defensible; and
- manage preliminary design of backfilling alternatives, and their options, with input from Altura, Lorax and AECOM.

Altura (mine rock management):

- coordinate her program with Lorax, so that Lorax can surface water lead with appropriate source terms for impact prediction;
- provide input to conceptual design and costing, managed by AECOM's geotechnical lead for waste rock pile reclamation or re-location, consistent with site wide assumptions for all civil work; and
- assist with locating appropriate original topography so that estimates of waste rock quantity can be improved.

AECOM (surface water management):

- set up and manage the model to predict sitewide water flow and quality;
- coordinate with hydrologists to develop best understanding of site and develop credible flow parameters for engineering and impact prediction;
- coordinate with rest of team to collate and document all input assumptions; and
- liaise with Leslie Gomm, who will provide review and advice on water quality prediction and management planning.

2. Field Investigations

2.1 Hydrology Investigations

The hydrology field program was managed by AECOM while data collection was conducted by Environmental Dynamics Inc. (EDI) as part of their existing water quality monitoring program. Stations were installed at six locations with each station consisting of a datalogger that continuously measured water depth and temperature and a staff gauge. At each site a cross-section and benchmark were established and surveyed in conjunction with the corresponding velocity measurements.

The collection of field data was conducted by EDI staff, who collected five sets of velocity and water level measurements throughout the field season. 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.

2.2 Hydrogeological 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 1.

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). 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.

2.3 Geochemical Investigations

The YTG contracted Lorax Environmental Services Limited (Lorax) to conduct an investigation of waste materials at Mt. Nansen with the ultimate objective of developing scientifically defendable chemistry source term estimates for drainage from all geologic materials that will require storage at closure. In order to achieve the objectives of this investigation, representative tailings, waste rock and ore materials from the Mt. Nansen Mine site were collected during site visits conducted in April and July 2009. These samples were submitted for bulk characterization analyses in order to determine how well these materials represent the previously established range of concentrations. Additionally, a laboratory based (humidity cells) and field based (field weathering bins and saturated column experiments) kinetic programs were developed to help derive realistic chemistry source terms that would be expected from Mt. Nansen waste materials under different closure storage scenarios.

In order to achieve the objectives of this investigation, a field program was conducted during 2009. This program involved the collection of tailings, waste rock, and ore material for bulk geochemical characterization as well as the establishment of field-based experiments in order to obtain estimates on drainage chemistry from each of the waste materials under various storage conditions. The rationale used in sample selection, the methods used in the design of the field based experiments, and the analytical methods used have been documented in a separate report, posted to sharepoint, for each of the following materials:

- tailings;
- native substrate beneath tailings pond;
- waste rock; and
- low grade ore.

Both laboratory based (humidity cells – tailings only) and field based kinetic experiments (field weathering bin and saturated columns) were conducted as part of this investigation. The experimental design for both the laboratory and field based programs of this investigation included humidity cell tests on three types of tailings:

- clay;
- sandy silt; and
- silty clay.

Field bin tests were conducted on the following materials, to simulate anticipated conditions applicable to the alternatives under consideration:

- Waste rock – unsaturated;
- Waste rock with organics – saturated;

- Low grade ore, backfilled in to the south end of the open pit – unsaturated;
- Tailings with organic soil – saturated; and
- Sandy tailings – unsaturated.

Laboratory analyses on samples obtained from the various test programs included Acid base Accounting, Sulfur Speciation, Shake Flask Extraction, Solid-phase Elemental Analysis and Particle Size Distribution on solid phases, and a suite of water quality analyses.

Altura worked closely with other consultants including AECOM, Lorax Environmental Services Ltd., EDI Environmental Dynamics Inc., and Protore Geological Services in carrying out the following tasks:

1. routine monitoring of the two lysimeters L1 and L2 installed in fall 2008;
2. spring seepage surveys and a routine seep monitoring program through the spring and summer 2009 season;
3. install mini-piezometers at the two known rock pile seepage locations;
4. additional 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;
5. trenching in Southwest Upper pile to assess heterogeneity, field screening feasibility, and potential for use as general construction fill material;
6. pit wall sampling and geological mapping within pit and to north;
7. mineralogical investigations via x-ray diffraction;
8. confirm volumes of rock pile and haul road as required;
9. rock pile infiltration/water balance estimates based on monitoring, climatic inputs, and rock pile final geometry;
10. develop source terms for waste rock into site model; and
11. identify availability of any pre-mine topography.

Altura's field work is described in a separate technical memorandum.

2.4 Geotechnical Investigations

Geotechnical investigation were conducted at the existing tailings facility, integral with the hydrogeological investigations. Additional boreholes were completed to facilitate thermistor installation on the downstream face of the dam as part of the geotechnical program and are discussed in a separate memo. All cores were brought to surface within acrylic liners, cut open and logged for geologic properties including density, colour, grain size, moisture, plasticity and cohesiveness. All geologic materials were then classified according to the Unified Soil Classification System. After logging each borehole, photographs of each run were taken and representative samples of material were collected and placed in labelled polyethylene bags for later testing. Air rotary drilling technology combined with the ODEX casing system was used for all drilling downstream of the main dam crest and for all boreholes in the vicinity of the open pit. Standard penetration tests were conducted at regular intervals and split spoon samples were collected for later analysis.

Several soil samples were collected to provide an understanding of the physical properties of on site materials including the coarse and fine fractions of tailings and the dam foundation materials, during drilling in the vicinity of the TMA. Samples were tested for determination of grain size distributions, water contents, specific gravity, Atterberg limits and soil moisture characteristic curves, as appropriate.

3. Hydrological Characterization

3.1 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 program was started after freshet, the Chezy-Manning[1] equation was used to estimate a flow at bankfull. 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 dataloggers. The results are provided in a detailed memorandum and summarised as follows:

Locations of the gauging sites can be seen on Figure 2, titled Water Quality Sites.

3.1.1 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.

3.1.2 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.

3.1.3 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. After the logger was moved, 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 on the 14th of July, 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, seen on Figure 7, 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.

3.1.4 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 order to help the hydrogeology 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 conduct flow testing with 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 the 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.

3.1.5 Diversion Channel

The Diversion channel is a man made structure bringing water from the top of the Dome Creek drainage around the tailing pond and back into Dome Creek. A logger was placed in the Diversion Channel, downstream of the bridge crossing the channel as this is an area of interest for future engineering design with regard to the tailings pond. In addition to the water from Dome Creek, the Diversion Channel conveys water pumped out of the tailings pond as part of dam safety maintenance, runoff from approximately 2/3 of the area surrounding the tailings pond and is suspected to be losing flow to groundwater seepage upstream of the bridge. 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. All measurements conducted showed the channel to be losing flow as suspected.

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. A hydrograph was not developed for the Diversion Channel, given the inconsistency between the datalogger and manual stage measurements, for the reasons discussed above. 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.

3.2 Hydrological Characteristics Synthesis

A 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 Mount 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 Mount 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.

Flow records were 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 Mount 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.

3.3 Tailings Dam Seepage

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.

4. Hydrogeological Characterization

4.1 Background

This section summarizes the interpretation of information collected as part of the hydrogeological field investigations conducted at the Mt. Nansen mine site during the 2009 field season, and builds on previous hydrogeological investigations including work conducted by Gartner Lee (2006, 2007 and 2008) and others. The conceptual model described here supercedes previous hydrogeologic reports because it is based on a significant body of information collected during 2009 as part of hydrogeological, geochemical, geotechnical, surface water quality and hydrological field investigations.
Figure 3 shows the geology in the vicinity of the open pit. (titled Brown-McDade Pit Geology)

4.2 Key Assumptions

The key assumptions used for the hydrogeological interpretation were:

- permafrost is continuous on north-facing aspects and in native soils that are insulated by a layer of organics;
- groundwater flow is homogeneous and isotropic;
- the deep groundwater table is a subdued replica of surface topography;
- stunted vegetation is indicative of the presence of underlying permafrost;
- Dome Creek and Pony Creek represent flow divides in valley bottoms;
- deep groundwater catchments for Dome Creek and Pony Creek are separated by a no flow boundary located north of the Brown-McDade pit, running from northwest to southeast; and
- permafrost is impermeable.

Figure 4 shows the conceptual groundwater flow across the site area around and between the open pit and the tailings impoundment. Figures 5, 6 and 7 are cross-sections that illustrate the hydrogeological conditions respectively at the tailings dam, at the tailings dam seepage collection pond, and between the open pit and Dome Creek valley.

4.3 Stratigraphy

Based on the available information, the following three hydrostratigraphic units have been incorporated into the conceptual flow model:

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

4.3.1 Overburden Characteristics

Based on the results of all investigations conducted to date, overburden typically ranges in thickness from less than one metre on upland bedrock outcrops to in excess of 20 metres in the centre of the Dome Creek valley.

The predominant soil type within the study area is colluvial blanket sediments, which mantle bedrock throughout much of the study area and range from less than one metre to in excess of 50 metres thick in large landslides.

Colluvium and lacustrine sediments are up to approximately 20 metres thick along the ridge between Dome Creek and Pony Creek. Within the upper Dome Creek valley, complex alluvial sediments are confined to a relatively narrow, linear band along the axis of Dome Creek. At the headwaters, these alluvial complex sediments are overlain 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. A layer of glacial till overlies bedrock at the confluence of Dome Creek and Victoria Creek, which is in turn overlain by relict alluvial terrace sediments and recent alluvial fan deposits. A small meltwater channel is also present on the south-facing slopes of the Dome Creek valley, just west of the Brown-McDade pit.

Organic soil horizons were observed in several boreholes and test pit locations within the tailings management area.

During the July 2009 drilling program, the White River ash layer was observed beneath the surficial organic soil horizon in several boreholes, test pits and along road cuts within the Dome Creek valley.

4.3.2 Bedrock Characteristics

The bedrock geology of the Mount Nansen property consists of highly deformed Upper Paleozoic or older gneiss and schists that are intruded by Upper Triassic/Juassic granodiorite and syenite batholiths (BYG, 1994). Mid to late Cretaceous mafic to felsic stocks, dykes, volcanic flows and pyroclastic rocks have also intruded into the other rock types. In addition, a series of subparallel anastomosing veins occur in a 2.5 km wide belt that bear precious metals and extend the length of the property. The veins strike northwesterly and exhibit steep northeasterly to moderate southeasterly dips and crosscut all rock types.

Altered wall rocks and clay gouge are commonly found associated with the quartz veins and are reported to exist within the identified footwall fault.

4.4 Faulting

Multiple fault and shear zones occur within the vicinity of the open pit. Fault zones are commonly coarse granular host rock or sandy, with some clay content. The fault zones are strongly weathered and reportedly range from less than one metre to five metres in thickness. In some cases, the faults coalesce into zones consisting of multiple faults. The major hanging wall and footwall faults form a graben structure that trends northwest. These major faults are in turn crosscut by a second series of faults that trend north to northeast and are generally steeply dipping to the east or west.

4.5 Weathering

The study area was not glaciated during the last period of continental glaciation and as such, bedrock is deeply fractured and weathered, especially within the faulted and altered sequences. The deep (north) end of the Brown-McDade pit was minded to the depth of weathering.

4.6 Permafrost

Each of these units may be frozen or unfrozen, based on the presence or absence of permafrost. The area is classified as exhibiting discontinuous permafrost and drill refusal as a result of frozen ground was noted in numerous drill logs, particularly 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. A number of thermistors have been installed in the vicinity of the TMA, confirming the presence of permafrost within the north and south abutment of the main tailings dam and within the seepage dyke downstream of the seepage collection pond. Boreholes drilled north of the Brown-McDade open pit as part of the 2009 drilling program revealed permafrost in several. The presence of stunted vegetation within both the Pony Creek and Dome Creek catchments indicates that permafrost is relatively widespread in the study area. Permafrost is inferred to function as a no-flow zone (barrier) with respect to groundwater flow. Where permafrost is present, a zone of seasonally unfrozen ground overlying permafrost (active layer) develops during the summer and fall months.

4.7 Overburden Hydrogeology

This unit is the uppermost geologic unit and overlies shallow weathered bedrock in most places. It is generally comprised of a combination of glacial, aeolian and alluvial/colluvial deposits depending upon the location within the study area. Overburden is generally thin to non-existent on topographic (bedrock) highs and within the upper portions of the Dome Creek and Pony Creek catchments, but is greater than 20 metres thick in the lower reaches of the valleys.

The hydraulic conductivity of the overburden unit (where unfrozen) is anticipated to range from 10^{-4} m/s to 10^{-6} m/s. Given the texture of the predominant material within the catchment, porosity is anticipated to be approximately 30%. This unit is generally unsaturated within the upland areas of the study area and hosts a water table aquifer within the lower portions of the Pony Creek and Dome Creek valleys.

Within upland areas, permafrost defines the base of this unit throughout much of the study area. As such, the lateral and vertical extent of the aquifer overlying permafrost changes seasonally. During the frozen months (late fall, winter and early spring), the aquifer within the overburden unit does not transmit significant quantities of water. During the unfrozen months (late spring, summer and early fall), this unit progressively thaws from ground surface downward and forms a seasonal aquifer on top of permafrost. Within the lowland portions of the study area, this hydrostratigraphic unit is inferred to host moving groundwater year round as it receives groundwater discharge from the deeper regional groundwater flow system throughout much of the year which inhibits permafrost formation.

In the vicinity of the TMA, low permeability tailings and dam fill (primarily aeolian sand) have been deposited on top of native soil and bedrock. Due to their limited spatial and vertical extent, they are not discussed as a separate hydrostratigraphic units.

4.8 Shallow Weathered Bedrock Hydrogeology

Shallow weathered bedrock lies beneath overburden and above relatively unweathered competent bedrock throughout much of the study area. Where overburden is not present, this unit forms the uppermost hydrostratigraphic unit. It is derived from the underlying parent bedrock material that has been affected by a suite of weathering processes including faulting, frost-shattering, solution leaching and oxidation. The base of the weathered bedrock hydrostratigraphic unit is defined by the depth of weathering, which ranges from five metres at the north end of the pit to in excess of 70 metres at the south end of the pit. In the spatial context, this unit is inferred to be thicker in upland areas and thinner in lowland areas. The breccia pipe at the north end of the pit was mined from the pre-mining ground surface down to the full depth of weathering during mine operations.

The physical properties of the shallow bedrock unit are anticipated to be relatively similar throughout the study area. This hydrostratigraphic unit was largely unsaturated or frozen at all boreholes drilled north of the pit. The bulk hydraulic conductivity of the weathered bedrock mass underlying the open pit is about 1×10^{-6} m/s. Based on field observations (structure, jointing, hardness, etc.) and the understanding that bedrock is highly weathered due to a lack of recent glaciations, it is inferred that the porosity of weathered bedrock is on the order of 10%. Most of this unit is unsaturated within the upland portions of the Dome and Pony Creek catchments, but may be saturated at depth or beneath surface water courses such as Pony Creek. This unit primarily functions as a conduit for vertical groundwater recharge from surface to the regional water table, but may host the regional water table where the depth of weathering is extensive (i.e., around topographic highs). Shallow locally perched flow systems may also be present on top of lower hydraulic conductivity horizons or permafrost within the larger, otherwise unsaturated hydrostratigraphic unit.

4.9 Bedrock Hydrogeology

This competent bedrock is the deepest hydrostratigraphic unit within the hydrogeological conceptual model. It underlies the weathered bedrock unit over the majority of the study area and consists of relatively competent bedrock. Within the upland portions of the study area, this hydrostratigraphic 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.

4.10 Pit Lake Hydrogeology

The pit lake within the Brown-McDade open pit is underlain by relatively competent bedrock as the majority of the weathered bedrock was removed as ore and waste rock during mining. The rate of water level decline in the pit lake during frozen winter months suggests that the bulk hydraulic conductivity of the relatively competent bedrock mass underlying the open pit is approximately 1×10^{-7} m/s. 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. Structural discontinuities within the competent bedrock unit, including those shown on Figure 1, appear to be more permeable than the surrounding competent bedrock. The porosity of massive, competent bedrock is assumed to be on the order of 1%, while the porosity of weathered materials within zones of structural weakness are inferred to be 10%, and similar to the overlying hydrostratigraphic unit. This unit is not anticipated to be heavily impacted by permafrost and is inferred to be largely unfrozen.

5. Geochemical Characterization

5.1 Assumptions

Previous work, and characterisation conducted during 2009, by Lorax and Altura is documented in detailed in various reports and memoranda posted to Sharepoint. The work conducted by Altura has been integrated by Lorax to provide overall source term characterisation, as summarised in the following sections. The detailed parametric recommendations are provided on Sharepoint in respective memoranda, and also in the documentation provided for water quality simulation.

In general, the task was carried out using the following methods:

- Parameter Screening - porewater quality and groundwater quality within and underlying the tailings impoundment screened against CCME freshwater aquatic life guidelines. Parameters that exceeded the CCME guideline in multiple wells 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 screened.
- For consistency, water quality parameters that were screened from pit lake water quality or for the development of waste rock source terms were also selected for source term designation.
- Source terms were derived from total concentrations measured from surface water quality samples, and dissolved concentrations measured in groundwater quality samples.
- Surface water quality from the tailings pond and tailings seepage collection pond were collected by EDI. The data were evaluated to assess the stability of the tailings mass, and to derive source terms for Scenario 3.
- Groundwater quality and water table elevations from the Lorax monitoring wells and select AECOM monitoring wells (MW09-08, MW09-21, MW09-22, MW09-23) were used to identify groundwater flowpaths and to elucidate mechanisms that may be occurring within the dam to control the mobility of key parameters. This information was utilized in the derivation of source terms for all closure scenarios.
- For closure options 3 and 4a two sets of source terms were developed. The “Best Estimate” is a best estimate based on professional judgment and a statistical evaluation of existing data (i.e.: seepage collection pond). The “Worst Case” is a reasonably conservative upper bound, also based on professional judgment and a statistical evaluation of existing data.

5.2 Saturated Tailings Source Term (Alternative3)

- Surface water quality data suggest that flow from the seepage pond and the diversion channel comprises the primary contributions of loading to Upper Dome Creek. Plots of sulphate and As water quality data from D1 (upstream of the tailings mass), tailings pond, tailings seepage collection pond, and Upper Dome Creek (downstream of the tailings) suggest that Upper Dome Creek waters are typically more dilute than each of the identified contributors. Thus, water quality from the seepage collection pond and the headwaters of Dome Creek (Dome Creek Station D1) represent the dominant contributions of constituent loading from the tailings impoundment.
- Contributions from other sources (e.g., deeper or more concentrated groundwater sources) to Dome Creek have not been measured to date.
- Tailings source terms for Scenario 3 are based on observed water quality data from the seepage collection pond, and these data are used for tailings source terms due to the long, year-round historical record.
- Tailings source terms are assumed to be constant with time.

- For the reasons listed above, tailings source terms for Option 3 correspond to total flow estimates currently measured for the entire seepage collection pond. In the event these flows change, tailings source terms may need to be revised.
- "Best Estimate" tailings source terms were derived under the assumption that geochemical equilibrium has been maintained over the past two years. Source terms were estimated by averaging the concentration of each parameter in the seepage collection pond over the time interval from November 2007 to present.
- "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 is 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 scenario.
- Water quality data from MW09-08 suggests that tailings-impacted groundwater may be bypassing the seepage collection pond. Surface water quality demonstrates that this bypass flow does not have a measurable impact on Dome Creek. However, dam upgrades may change seepage flow paths. While unlikely, it is possible that groundwater quality may evolve to concentrations similar to those observed at well MW09-8.
- Exceptions to approaches described above include:
  - Copper: Cu was added during processing and is a finite source. Cu concentrations have depleted significantly in the past five years. Therefore, only the past five years of data was considered for determination of the Worst Case scenario.
  - Nitrate: nitrate has been increasing steadily in the seepage pond. Therefore, only the past two years of data was averaged to attain a Best Estimate source term. The Worst Case source term was approached in two different ways. The first was to take the general approach and record consistent spikes in the seepage pond data. The second was to calculate the concentration of nitrate if nitrite and ammonia oxidized to nitrate. The values obtained using the two different approaches were consistent.
  - Nitrite: similarly, the Worst Case source term for nitrite was determined by calculating the sum of the nitrogen species.
  - Total Cyanide: Total cyanide was not analyzed in seepage pond water samples after November 2007. Therefore, data from January 1999 to November 2007 was used in the calculation of total cyanide source terms.
  - Sulphate: similar to copper, concentrations of sulphate are decreasing over time, albeit more steadily than copper. Only the past three years of seepage, pond data was utilized in the calculations of source terms for sulphate.

5.3 In-Pit Saturated Tailings Source Term (Alternative 4a - wet)

- The methods used to derive tailings source terms under closure Alternative 4A-wet are different than under closure Alternative 3. Under closure Alternative 4a it is assumed that the water quality data attained from the groundwater wells in and below the tailings represent seepage water quality that may emanate from the tailings in the pit. The presence of removal processes similar to those occurring between the tailings impoundment and the seepage collection pond, and dilution from other sources (as is observed in the seepage collection pond), are not accounted for under this scenario. There is little evidence to suggest these processes will occur in the pit.
- Data from the tailings bins is interpreted to represent flushing of the tailings porewater with distilled water and natural precipitation. The tailings bins have not yet come to equilibrium; therefore the data derived thus far is not used in the derivation of source terms. It is recommended that the bin sampling program continue to validate source term predictions.

- Upon relocation, native, organic-rich sediments will be combined with tailings into the open pit. Saturated conditions and the presence of organic matter will likely lead to the persistence or more advanced development of suboxia within tailings impounded in the pit. Certain elements, such as As, Fe, and Mn may become mobilized under suboxic conditions.
- "Best Estimate" scenario assumes currently observed suboxic conditions persist within the tailings mass. Mild suboxia is characterized as having depleted nitrate, slightly elevated Mn and Fe, and low sulfide (the presence of sulfide indicates the development of reducing conditions). Monitoring wells MP09-12 and MW09-04 show elevated Mn (~3.5 mg/L), depleted nitrate (<0.05 mg/L), and low sulfide (<47 µg/L) concentrations. These wells are considered to be suitable proxies. 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. Iron concentrations are 5-10 mg/L, Mn is 20-25 mg/L, nitrate is <0.3 mg/L and sulfide is <20 µg/L. MW09-02 was used a proxy for "Worst Case" concentrations that may occur within the pit, in the long term.

5.4 In-Pit Dry Tailings Source Term (Alternative 4a - dry)

The methods used to derive tailings source terms under closure Alternative 4A make the following assumptions:

- Tails will be disposed of in a manner that allows them to freely drain, become exposed to oxygen, and oxidize;
- Static data suggest that the Mt Nansen tailings will produce acidic drainage.
- Kinetic laboratory and field bins have been established for Mt Nansen tailings to evaluate their potential to produce acidic drainage;
- Results are too preliminary to determine. Tests are ongoing;
- Lab kinetic testing program suggest that the tails are becoming acidic…. Data remain inconclusive (too early to tell);
- Mt. Nansen tailings have similar geology and geochemical characteristics to Arctic Gold and Silver Tailings:
    - arctic tailings are exposed to oxygen and have produced acidic drainage; and
    - seepage water quality from the Arctic tailings are used as a proxy for dry Mt. Nansen tailings.

5.5 Waste Rock and Low Grade Ore

Altura issued a number of technical memorandums summarizing key aspects of the 2009 program for specific input into the Mount Nansen Closure Alternatives Assessment, as described in the following sections. The reader is referred to these memos for more complete information.

5.5.1 Waste Rock Pile Catchment Areas – Proposed Zones

Issued October 4, 2009 (Altura, 2009b), this memorandum proposes the major infiltration 'catchment' areas of the Brown McDade waste rock pile for input into the rock pile water balance. The work was based on seepage survey and test pit information, as well as pre-mining topographical information.

The summary gives a best estimate of the pre-mining topographical divide between Pony and Dome Creek drainages, and concludes that in most areas of the waste rock piles, the majority of infiltration reports to a deeper system and not to the toe of the rock pile as surface flow. A key exception to this is a portion of the west area of the rock pile where frozen ground conditions were encountered both in the rock pile and in the undisturbed vegetation down slope of the pile. In this area, the frozen ground appears to act as an infiltration barrier, allowing for seepage to manifest itself at or near surface rather than infiltrating downwards as in most other areas of the rock pile. The three main infiltration zones and associated characteristics are given in Table 5.1.

Table 5-1. Infiltration Zones, Brown McDade Waste Rock Pile (excerpt from Altura 2009b)

Waste Rock Infiltration Zone	Description	Infiltration Reports To	Estimated Area (m^2)	Estimated Volume of Waste Rock in Contact with Infiltrating Water (m^3)
A – Permafrost – Underlain Zone	Majority of West Lower pile, and part of West Mid pile. Underlying permafrost acts as infiltration barrier, and seepage migrates along this interface in rock pile, reporting as seeps / pondings in vegetated area downgradient of LW pile toe. This seepage then percolates at shallow depth along the permafrost interface through vegetation, to a tributary just above monitoring station DESS-01. Estimated 2.5 m thickness of waste rock above permafrost interface	Shallow seepage zone in vegetation below Lower West Pile, and ultimately to station DESS-01.	26,425	66,062
B – Non-Permafrost Zone, Dome Catchment	Majority of NW pile, entirety of old Ore Stockpile area, South, Southwest piles. Portions of West Mid and West Lower piles, divided into the following sub-zones: NW Pile (12,750 m^2; 7 m average thickness) Mid-Sector (21,325 m^2 at 0.4 m average thickness; 725 m^2 low grade ore stockpile at 3 m average thickness) South and Southwest Pile 38,225 m^2 at 5m average thickness)	Groundwater recharge	73,025	291,080
C - Non-Permafrost Zone, Pony Catchment	Eastern Lobe of NW pile, entirety of East pile: NW Pile (7,025 m^2; 8 m average thickness) East Pile (5,800 m^2; 4 m average thickness)	Groundwater recharge	12,825	79,400
Total			**112,275**	**436,542**

5.5.2 Testing in Waste Rock Pile Area

Altura's 2009 investigations in the waste rock pile area consisted of geochemical investigations by way of additional test pits in the West Lower and West Mid piles to follow up on anomalous levels of metals in seep LW Seep-01, additional sampling of free dump piles of coarse material on the West Lower pile, and test pits in the area just west of the pit where an old ore stockpile area was located during mine operation. Trenching in Southwest Upper pile was conducted to assess heterogeneity, field screening feasibility, and potential for use of waste rock as general construction fill material. Finally, several samples from the 2008 assessment were submitted for identification of neutralizing minerals in waste rock.

5.5.2.1 West Lower and West Mid Pile Test Pits

Monitoring of seep LW Seep-01 during 2009 returned elevated concentrations of zinc, cadmium and copper from the LW Seep-01 site (in the order of 20 mg/L Zn, 0.15 mg/L Cd, and 0.2 mg/L Cu). In an effort to identify any specific source material causing these high concentrations, eight additional test pits (TP22 to TP29) were completed in the West Lower and West Mid pile area during 2009, with a total of ten samples submitted for various static analyses. Sample descriptions and results are provided in Appendices A.5 and A.6. Only two of nine samples assessed for field paste pH returned values below 6.5, and both these samples in turn yielded the only elevated shake flask zinc values from this area (5.3 and 141 mg/kg Zn from TP 29 and TP26 respectively). The TP26 sample was taken from a 0.2 m wide pyritic horizon cutting across the test pit, and its result represents the highest zinc leaching value out of all 56 shake flask tests conducted in both the waste rock pile and ore backfill areas. The site is located approximately 40 m upgradient from seep LW Seep-01, thus could be contributing to the elevated zinc in the downgradient seepage.

Another important finding of the test pits in this area is the occurrence of frozen ground conditions within portions of the West Lower and West Mid waste rock piles – 1.6 to 2.0 m below the platform in the West Lower pile, and in the order of 3.5 m below the platform for the West Mid pile. As summarized in Altura (2009b), it is considered that the underlying frozen layer of waste rock acts as an infiltration barrier. Infiltrating water follows this interface down-gradient to where the water can be seen at or just below the surface of the moss at the toe of the Lower West pile, which during 2009 was monitored at site LW Seep-01.

5.5.2.2 Free Dump Pile Sampling, West Lower Pile

One additional site on the West Lower coarse rock free-dump piles was sampled in 2009 to supplement the three sites sampled in 2008. The intent of this sampling is to characterize the feasibility of material use for construction purposes. Both coarse and fine fractions were analysed for acid base accounting, multi-element analysis, and shake flask extractions, with results given in Appendix A.7. While traces of pyrite were visible on about a quarter of the fragments examined, laboratory results for both the fine and coarse fractions returned only 0.01% sulphide, paste pH in the order of 7.0, a low NP of around 5 kg $CaCO_3$/t, and favourable NP:AP ratios of greater than 10. Shake flask results, performed only on the fine fraction, yielded less than 0.1 mg/kg Zn and no other metals of note. Results considering all four West Lower sites sampled are overall favourable with respect to the use of this material for construction purposes, however it is cautioned that pockets of sulphidic material do occur within the material stacked on the West Lower platform. In addition, the four sites sampled contain a wide range of metal concentrations (51 to 2,989 ppm As and 274 to 1,349 ppm Zn), and thus metals may be solubilised under various pH and redox conditions. As such this material is likely unsuitable for applications such as waterway protection or subdrains. If used for a specific construction purpose, the material should be carefully field-screened and sulphide-bearing, low paste pH, or highly altered and bleached material not utilized.

5.5.2.3 Old Ore Stockpile Area

Topography based on 1998 aerial photography (six to eight months before mine closure) shows the presence of stockpiled material in the central part of the Brown McDade waste rock pile area, immediately west of the pit. Given the presence of rust- stained patches throughout this area, five test pits (OS-01 to OS-05) were completed to test the material underlying this sector. Excavations and sample packaging and shipment were carried out under the supervision of Altura, with sampling and pit descriptions completed by Lorax (2009).

Results, given in Appendices A.5 and A.6, indicate the presence of a shallow veneer of residual ore (e.g., 1 to 5 ppm Au with 198 to 5,197 ppm As), and with it, varying levels of sulphide. Two of the seven samples indicated paste pH in the 6.0 range, and one sample from OS-01 returned a paste pH of 4.29. Shake flask leachable metals were low with the exception of the OS-01 sample, which returned 64.5 mg/kg Zn along with 1.5 mg/kg Cd, 4.6 mg/kg Cu, and 0.07 mg/kg As.

5.5.2.4 Trenching in Southwest Upper Pile

A 13-metre long by two metre wide by 1.6 metre deep trench was cut through a section of the Southwest Mid Pile in order to visually assess larger scale spatial variability of waste rock in the pile. Along the 13 metre stretch three main zones were identified: 1) a blocky intrusive material with minor fines (approximately 3 m in length and the full trench depth), 2) a rust-weathering and clayey zone (approximately 8 m at surface tapering to 1 m at bottom of trench), and 3) dark brown fines with small cobble-sized fragments (2 m in length and the full trench depth). This variability is consistent with that observed in the smaller test pits and profile trenches completed in other areas of the waste rock pile, and it demonstrates that the material can show substantial variation in particle size and weathering over the space of a few metres. As indicated in Altura (2009c), if this material is used for construction purposes other than general fill, some form of field screening assessment would likely be required along a similar spacing.

5.5.2.5 Identification of Neutralizing Minerals

Eight samples from the 2008 waste rock characterization program were selected in August 2009 for mineralogy assessment via x-ray diffraction (XRD). The purpose of this sampling was to gain a better understanding of potential neutralizing minerals available in various geochemical categories of waste rock. The 2008 waste rock database was analysed and four 'Neutralizing Potential Categories' were designated:

- Category 1: Moderate to High C-NP and Relatively Low NP
- Category 2: Moderate to High C-NP and Equivalent or Higher NP
- Category 3: Lower C-NP
- Category 4: Very Low C-NP and NP

A discussion of results and original laboratory reports are included in Appendix A.9 of Altura December 2009c. In general, quartz is by far the dominant gangue mineral with much higher peak intensities than the other minerals. Muscovite ($(KAl_2(Si_3Al)O_{10}(OH,F)_2$) was also reported in all samples, but with varying peak intensity levels. Carbonate minerals included ankerite ($Ca(Fe^{+2},Mg)(CO_3)_2$) and calcite ($CaCO_3$)were detected only in the samples in the two higher NP and C-NP categories.

5.5.3 Summary of Studies Assessing Waste Rock Field Screening Potential

Issued December 18, 2009 (Altura, 2009c), this memorandum summarizes the feasibility and expected performance of using field-determined measurements and observations to segregate Brown McDade waste rock and remnant ore into geochemically favourable or unfavourable material.

The assessment concluded that test results indicate that identification of Low-Reactivity material is possible by using the two key criteria of: i) no visible sulphides under hand lens, and ii) paste pH ≥ 6.5, coupled with avoidance of areas of obvious mineralization such as ore stockpile areas and zones of intense bleaching and alteration (to minimize the potential for elevated arsenic and other related trace elements). Altura considers that this segregated material would have very low potential for ARD, as well as presenting low solubility of metals, and subject to confirmatory testing could be suitable for use as exposed structural fill and certain erosion protection applications. Depending on the needs for definition of rock types during closure, there is potential for other criteria to be developed as required.

It should be recognized that due to the heterogeneous nature of the waste rock stored in the Brown McDade piles, segregation of a Low-Reactivity material would likely require field assessments every few metres as excavation proceeds. This may result in a manpower-intensive process that while perhaps suitable for isolating smaller amounts of good quality materials, may not be justifiable for an across-the-board relocation of the rock pile.

5.5.4 Seepage and Ponding Surveys

5.5.4.1 Seepage Surveys

Reconnaissance for seeps in spring 2009 was completed both on and around the rock pile perimeter, as well as several hundred metres downgradient in the Dome Creek valley, where an old powerline/waterline road cuts across the slope. In addition, Lorax sampled a seep located in the mid-levels of the pile in late April 2009; however, this seepage ponds on the West Mid Pile platform prior to infiltrating to waste rock and/or evaporating.

As noted in Altura Environmental Consulting (2009a), two seepage areas were observed in the late 2008 field season: i) NW Seep-01, a low-flow seepage from the toe of the east side of the NW Pile, and ii) LW Seep-01, at the toe of the Lower West pile. No additional seep areas from the waste rock pile were identified in the 2009 surveys. However, the surveys did identify that the Lower West seep area is comprised of a wide belt of small pondings and flows in and over vegetation, including the main LW Seep-01 point. This entire vegetated area was noted to be underlain by permafrost within 30cm of surface, and its vegetation cover of thick sphagnum moss / black spruce / labrador tea can be seen as a distinct zone in the satellite photograph. On May 14, seepage at LW Seep-01 was observed to daylight on the face of the Lower West pile approximately 2 m above the toe, however by May 22 all seepages were confined to the immediate toe area and in the mossy area downgradient.

Seepage and water accumulations in the Lower West seepage zone consistently returned high levels of conductivity (in the 1,500 to 2,000 µS/cm range) and pH in the slightly acidic to neutral range. Water quality monitoring over the coarse of the 2009 field season returned elevated concentrations of zinc, cadmium and copper from the LW Seep-01 site (in the order of 20 mg/L Zn, 0.15 mg/L Cd, and 0.2 mg/L Cu). Flow rates were difficult to ascertain, but were estimated to peak at 0.4 L/s during May and markedly decrease from June throughout the remainder of the summer and fall. A shallow mini-piezometer to facilitate sampling was installed at the LW Seep-01 site on July 8, penetrating just 40 cm below the top of vegetation with the intent of intercepting seepage above the permafrost layer. At the time of installation, the static water level was 20 cm below the top of vegetation.

Downslope in Dome Creek valley, a broad moist area was encountered downgradient from the Lower West seepage area and it appears that the rock pile seepage converges into a single tributary approximately 250m from the waste rock pile toe. Results from DESS-01 indicate a strong Zn signature in the order of 3 to 4 mg/L, with estimated flows up to 1 L/s in late May and gradually diminishing over the summer.

Site NW Seep-01 at the eastern toe of the Northwest Pile produced only minor amounts of seepage during the 2009 monitoring season (in the order of 1 mL/min or 0.00002 L/s). Concentrations of Zn were slightly elevated in the order of 0.1 mg/L, with Cd tending to be in the 0.002 mg/L range.

5.5.4.2 Ponding Surveys

Reconnaissance to identify areas of water ponding on the rock pile was conducted in May, and seven sites were identified. Field measurements indicated circum-neutral waters with conductivity typically less than 1,000 µS/cm. In contrast, many ponded areas in vegetation below the Lower West pile had markedly higher conductivity with pH neutral to slightly acidic.

5.5.5 Pit Area Investigations

Altura's investigations in the pit area consisted of overseeing the geological mapping of pit wall and Pony Creek area to north, sampling along several benches of the pit wall for static test work, mineralogical investigations of precipitate, and test excavation and sampling of ore backfilled into the south end of the pit.

5.5.5.1 Geological Mapping

Altura contracted Protore Geological Services (Robert Stroshein, P.Geo.) to update the pit wall geological map and to provide additional geological interpretation of the Pony Creek area to north. Protore provided a summary memorandum (Stroshein, 2009) and sketch map which were both forwarded to AECOM. The map was then digitized by AECOM and is included in the AECOM hydrogeological assessment. In general, the updated work highlighted the recognition of weak to moderately metamorphosed units within the pit area, as well as the presence of a small plug of marbleized carbonate unit at the north end of the pit. While the mapping confirmed previous interpretations that the most prominently defined faulting trends northwest, it also identified an east-dipping fault on the hangingwall side of the pit which along with the previously identified footwall fault, contains the deposit as a zone of alteration and structural weakness within a graben like structure. At the north end of the pit, a quartzite unit in the lower benches is relatively impervious and Stroshein's interpretation is that seasonal seepage into the pit daylights just above this horizon.

5.5.5.2 Sampling

Sampling along several benches of the pit wall was conducted in late July, with a total of 14 samples submitted for static testing. In most cases, samples were composites over intervals of several tens of metres in order to obtain average-condition values. Data is given in Appendix A.4, and results were forwarded to Lorax to assist in their defining source terms for the open pit water quality model. Overall, the lower footwall area of the pit returned elevated shake flask metal loadings (7.8 to 1113 mg/kg Zn), accompanied by slightly acidic to acidic paste pH. This is considered largely attributable to a veneer of residual ore (mainly sulphidic) exposed along the footwall in the lowest bench. Metal loading was less than 1 mg/kg for samples elsewhere in the pit. Almost all samples showed relatively low NP:AP with only three of the 14 samples returning values ≥ 3.0, and the occurrence of sulphides were noted in some areas of the upper pit, indicating the non-uniformity of surface oxidation depth.

5.5.5.3 Mineralogy – Precipitate Analysis

Samples of secondary mineral products were taken from site PWE-07 on the lower east pit wall of the pit on July 30. The purpose of this sampling was to identify the mineral products in order to gain a better understanding of soluble products and of potential solubility constraints of the rock exposed in the pit. In this area, secondary minerals form a distinct white-green zone on a small talus fan of highly weathered and sulphidic material. While smaller formations of similar-looking products are seen in some other areas of the pit, it should be noted that the area sampled represented an anomalously thick and concentrated accumulation of these products.

Samples were submitted to the Queen's University Department of Geological Sciences and Geological Engineering for x-ray diffraction analysis. Of most interest was the identification of both the white-green and more darker green products; as such two separate samples were submitted PWE-07a (pale white-green precipitate crust on rock fragments) and PWE-07b (green precipitate crust on rock fragments). Detailed results and a summary memo are given in Appendix A.8. In general the mineralogy indicates a dominance of magnesium and iron sulphate minerals forming in the precipitate.

5.5.5.4 Ore Backfill Sampling

Ten test pits in the order of 1.5 metres deep (OB01 to OB10) were completed in the ore material backfilled into the south end of the Brown McDade pit. This material is stockpiled ore from the upper platform of the mill site near the crusher feeder, and was relocated back to the pit in the fall of 2008. Stroshein (pers. communication, 2008) believes this material originates from an ore zone discovered in the south end of the pit late in the mine's life. A total of nine samples were submitted for various static analyses. Data is given in Appendices A.5 and A.6, and results were forwarded to Lorax to assist in their defining source terms for the open pit water quality model. Lorax also took bulk samples from pits OB09 and OB10 for use in their test bin program.

Site personnel indicate that a veneer of organics from the original base of the stockpile was spread over the backfilled area at the end of the ore relocation project, and likewise, some of the test pits did not intercept ore-like material. Nonetheless, static test results from several excavations particularly in the upper elevations of the backfill (e.g., OB04 and OB07 through OB10) do confirm that much of this material is of ore grade and with a tendency for elevated values of sulphide, gold, arsenic and shake flask zinc loading.

5.5.6 Mine to Mill Haul Road – Summary of Rock Characterization Studies

Issued December 22, 2009 (Altura, 2009d), this memorandum summarizes geochemical and general physical characteristics of the 'Mine to Mill Haul Road'as they apply to use in closure activities, and estimated volume potentially available for use during closure. The study concludes that:

- Largely owing to its more uniform composition, the road bed material from the main haul road stretch (sites HR08 through HR22) shows more potential as a low-reactivity construction material than most waste rock pile material. Nonetheless, as indicated by one very high shake flask zinc concentration of over 30 mg/L, field verification using paste pH and assessment of sulphide presence is imperative prior to its use in closure construction. This may be some room for additional refinement of the field criteria for the haul road material, possibly allowing for trace amounts of visible sulphides in the material.
- Preliminary estimates indicate that in the order of 14,000 m^3 of road bed fill is potentially available.

Compared to the HR08 to HR22 road bed fill, the berm material exhibits much more mixing with less desirable highly altered and sulphidic material, and is not considered a good candidate for use as a low-reactivity construction material. The roadbed fill from HR08 towards the mill tends to be mixed with altered and possibly low grade ore and is also not recommended.Removal of the fines from excavated material would likely produce an improved product, however additional analyses would be necessary to confirm this. Several archived samples from 2009 are available for this work.

6. Geotechnical Characterization

This section summarizes the previous evaluation of the existing tailings impoundment conducted by AECOM, supplemented by the results of drilling and further monitoring conducted in 2009. The geotechnical inspections were carried out in 2008, as documented in detail in AECOM, January 2009, and key points of the assessment are summarised as follows:

6.1 Tailings Dam and Pond

Overall, the tailings dam was deemed to be in relatively good condition. Piles of tailings sand were pushed up at either end of the beach adjacent to the dam in the winter of 2008 during additional investigations of the tailings by the Government of Yukon. The crest is about 5 to 7 m wide with downstream side slopes estimated to be in the order of 3.5 H:1V.

The upstream slope from the crest to the tailings beach is about 2.5H:1V and about 1.2 m high. Vegetation is sparse consisting of occasional saplings and there are no signs of rodent burrowing. An erosion gully meanders through the tailings beach from the seepage pond discharge structure to the tailings pond, although this is of no consequence to the stability of the dam. The dam crest above the sand fill consists mainly of coarse gravel and small cobbles. The crest elevation is generally level until the mid point where fill has been added over the seepage pond return lines. The crest south of the line crossing is visibly lower than the north section.

Seepage Pond Discharge

A stabilizing berm was constructed in 1997 to address stability and seepage (piping) concerns associated with higher than expected pond levels. It was reported that seepage was daylighting as high as elevation 1083 m on the downstream face of the dam. The berm was constructed along the toe of the southern half of the tailings dam to about elevation 1088 m. The top of the berm now serves as an access road from the south abutment to the seepage pond pumphouse.

Movement monitoring pins were installed in 1999 along the edge of the crest (11 pins) and downstream slope (16 pins) south of the north terrace to measure vertical and horizontal displacements (deformation) of the earth fill dam. Following the baseline survey in 1999, the pins were subsequently surveyed again in 2000 and 2001.

Data from the 2001 deformation survey indicated cumulative crest settlements ranging from 8 to 61 mm occurred with the most significant in the vicinity of the south abutment.

Over the same period, cumulative settlements on the downstream face of the dam ranged from 10 to 40 mm. No measurable cumulative horizontal displacements were measured on the dam crest. Cumulative displacements ranging from 6 to 64 mm were measured on the downstream face, generally in an easterly of south-easterly direction.

Additional 2008 surveys were completed using global positioning system (GPS) surveys. A centerline profile of the tailings dam and seepage dyke was also surveyed by YES in 2008. Cumulative displacements up to the most recent (2008) survey have been determined by summing the displacements from 1999 to 2001 and from 2001 to 2008.

There are a number of sources of error, including systematic errors, equipment, etc., that must be considered when interpreting the deformation survey results. Any or a combination of these errors can affect the accuracy of the survey. With this in mind, it is difficult to conclusively determine the magnitude of deformations with the limited data set to date. In some cases, the reversal in movement direction is likely attributable to survey error rather than actual ground displacement. The data is meaningful however in identifying deformation trends e.g., areas of settlement or relatively large displacements. Incorporating data from future surveys will allow more meaningful interpretation of the results.

Overall, AECOM concluded that there is no clear indication that significant horizontal deformations of the dam have occurred since monitoring began. Consistent with EBA's observations in 2002 however, settlement of the southern portion of the dam crest appears to be continuing with up to 265 mm of cumulative settlement. The cause of continued settlement is undetermined but could be related to internal erosion associated with seepage and/or permafrost degradation. Deformations along the downstream toe of the stabilizing berm coincide with visible settlement and spreading at this location. It is likely however, that these deformations are a result of lateral spreading of loosely placed fill material used to repair an erosion channel on the downstream side of the south abutment.

6.2 Seepage Dyke and Pond

The seepage dyke is in good condition with no evidence of settlement or instabilities. The dyke is about 3.5 to 4 m high with upstream and downstream slopes of about 3H:1V that are well armoured with coarse gravel and cobble sized material. There is no engineered spillway and if the pond level were to rise to the dyke crest, water would spill over the north end of the dyke, based on a 2008 centerline profile survey.

No measurable flow was observed but the ground at the toe is very soft and wet with lush vegetation. A short distance downstream, water begins to collect in a meandering stream along what appears to be the original Dome Creek alignment. There is no visible seepage along the downstream toe of the northern half of the dyke where seepage pond water is pumped over the dyke into the discharge sump.

6.3 Interceptor Ditch and Diversion Channel

The interceptor ditch collects surface water beginning at its south (upstream) end, where a small creek enters the ditch. The grade on the channel is about 0.5% as shown on the profile (2008 survey). Along the upper reaches, the ditch meanders through a sand bedding and bank material with little to no armouring. The channel bottom width and bank heights are about 3 and 1.5 m respectively. Vegetation is relatively well established along both banks although sloughing of the sand into the channel still occurs. Farther downstream, the bank heights gradually increase to about 2 m as does the amount of larger rock along both banks. Vegetation is sparse on the east bank.

Iron Staining Main Tailings Dam

Seepage Dyke

A secondary ditch branches out from the main interceptor ditch at Station 0+280. Water enters the south end of the secondary ditch via a creek channel to the west. The secondary ditch cuts through the edge of a former sand borrow area to its west. The channel is up to 6 m wide and almost flat with active erosion along the toe of both banks about 1 m above the bottom. There is no armouring along the banks which are primarily fine grained sand. A considerable amount of sediment in downstream stretches appears to originate from erosion of bank material along the secondary ditch.

The interceptor ditch becomes very narrow with over-steepened un-armoured banks between the secondary ditch outlet and the confluence with the Dome Creek Diversion channel. The diversion channel widens out considerably at the bend to the east where it traverses the wide Dome Creek valley.

The diversion channel downstream of the confluence with Dome Creek is flanked on the south side by the road and the natural valley bottom and valley slope on the north side. The road is about 2 m above the channel bottom, where a significant thickness of fine grained sediment is continually being deposited (at the observed flows). The channel slopes at about 0.5 percent. Sediment in the channel bottom has been excavated in the past with the castings windrowed along the south edge of the road. Sediment excavation is an ongoing maintenance item and it is our understanding that it is required at least annually. The road bank is over-steepened at about 1H:1V and shows signs of slumping and undercutting. The channel cuts through the east Dome Creek valley slope as it heads to the east. The bank material is mainly sand with sparse vegetation. The channel narrows as it approaches the access road bridge although the slopes are flatter, at about 2H:1V.

Excavated Soil

The channel upstream and downstream of the bridge is narrow (1 to 2 m) with steep banks made up of sandy gravel. There is little armouring on the north bank along this relatively flat stretch before the confluence with the spillway. Armouring on the south bank is more extensive consisting of coarse gravel and small cobbles. The natural bank consists mainly of fine grained sand.

The bank at the bridge crossing has over-steepened sideslopes of about 1H:1V. The diversion channel steepens considerably just downstream of the confluence with the tailings pond spillway. This section is heavily armoured and contains 13 drop structures constructed with large boulders. There are no signs of bank erosion and the drop structures are in good condition.

(Flow is contained within the armoured section and although not significantly restricted by the boulders; at the flow rates observed, water tends to flow around (rather than over) individual boulders. It is likely however, that more evident steps in the hydraulic profile would occur at higher flows.

The armouring on the upper portion of the channel banks appears to have been pulled back downstream of about Station 0+920. Geotextile can be seen along both the north and south banks and the channel would be susceptible to erosion above the armouring at higher flow depths). Iron staining is also evident along the entire stretch of the diversion channel that has been lined with rock.

The downstream end of the diversion channel widens out to about 25 m at the confluence with Dome Creek and channel flow becomes divided at the end of the road on the south side of the diversion channel. The channel is well armoured between the last drop structure (DS # 13) and the creek channel.

6.3.1.1 Spillway

The tailings pond spillway is in good condition although it does not appear to have been recently operational. The spillway entrance is formed by waste rock and gravel banks in the northeast corner of the tailings pond. Beyond the limits of the pond, the spillway channel has been cut into the north terrace and is flanked by the access road on the north side. The bend in the access road at the south bridge abutment has been widened into the spillway channel creating a constriction.

A survey of the channel indicates that the high point of the spillway is just upstream of the road crossing at elevation 1,098.5 m. Sideslopes are in the order of 2H:1V with the exception of steeper slopes where the road fill encroaches.

The material lining the spillway bed consists of coarse gravel. Coarser rock fill has been used to armour the banks. The channel bedding material downstream of the road crossing consists of sand; however, it is possible that the sand has been deposited over the coarser bedding material. Vegetation consisting of saplings, shrubs and grasses are becoming established in the spillway, in particular in the section between the inlet and road crossing.

6.4 Summary

Overall, the tailings dam and seepage dyke at the time of the 2008 inspection were 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 at the toe of the rock fill at the edge of the seepage pond appears clean, but it is important to recognize that this condition could worsen with increased water elevations in the tailings pond. Internal erosion of the earth fill dam associated with the toe seepage cannot be ruled out. Settlement of the south half of the tailings dam crest, as evidenced by surveys of monitoring pins and the centerline profile is of some concern and the cause should be investigated further, in particular to determine if it is associated with the observed toe seepage.

Consideration should be given to restoring the design crest elevation in this area. The emergency spillway is in good condition although the constriction from widening the road approaching the south side of the bridge should be removed to restore full design hydraulic capacity.

The interceptor ditch and diversion channel are functioning although the banks upstream of the emergency spillway are typically over-steepened with active erosion and sloughing. Blockages associated with failures of the channel banks could lead to breaching of the adjacent road that separates the channels from the tailings pond. Excavation of sediment along flatter grades will continue to be required on an on-going basis until channel stabilization measures are undertaken. The diversion channel downstream of the emergency spillway is in good condition although some additional bank armouring and repairs to the drop structures should be considered in the downstream half of this portion of the channel.

7. Surface Water Quality Characterization

7.1 Previous Work

Analysis of the Mt. Nansen mine site surface water quality data (December 2007 to October 2009) has revealed the following information:

- parameters that had the most exceedence of CCME guidelines throughout the study area include: Nitrite-N and the following total metals: aluminum, arsenic, cadmium, copper, iron, lead and zinc;
- parameters that had the most exceedances of EQS throughout the study area include: TDS and total iron;
- the tailings pond water quality exceeded CCME guidelines for total metals: arsenic, cadmium, copper, iron, lead, silver and zinc;
- seepage pond water is similar to the water in the tailings pond except with higher concentrations of ammonia;
- the Brown-McDade pit exceeded of CCME and EQS for following total metals: aluminum, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc;
- Pony Creek, downstream of the Brown-McDade pit is more impacted than the upstream site, either from seepage from the Brown-McDade pit or from the waste rock in the creek;
- Dome Creek is being impacted from the Mt. Nansen mine and the Dome @ Road site contains elevated concentrations of sulphate, ammonia and total arsenic;
- Back Creek exceeded CCME guidelines for total cadmium and total iron in 100% of the samples;
- Impacts on Back Creek may be from either Pony Creek or from the active placer mining, although analysis indicates it may be more influenced by the placer mining;
- Vic @ Rd exceeded CCME guidelines for the following total metals: aluminum, arsenic, cadmium, copper, iron, lead and zinc, with total cadmium exceeding CCME and EQS the most;
- impacts on Victoria Creek seem to be influenced both from Dome Creek and Back Creek, where inputs from Dome Creek likely originate from the Mt. Nansen mine and inputs from Back Creek are likely from the placer mining; and
- seasonal variability was identified for the surface water quality results, indicating that data should be split into two data sets (turbid and clear water) for water quality modeling.

7.2 Work in Goldsim for Base Line

8. Overall Synthesis and Characterization of Alternatives 3 and 4

8.1 Geotechnical

The following sections summarise various geotechnical assessments contributing to characterisation of alternatives to remediate the existing tailings dam (Alternative set 3), or to decommission it and place tailings as backfill into the open pit (Alternative set 4).
These alternatives and options within these alternatives are illustrated in plan and profiles on a set of 9 figures, as follows:

1. Alternative 3A(i) – Soil Cover;
2. Alternative 3A(ii) – Water Cover;
3. Alternative 3A(iii) – Sponge Cover;
4. Alternative 3B – Waste Rock Deposition;
5. Alternative 4A(i) – Tailings Deposition - Wet Condition;
6. Alternative 4A(ii) – Tailings Deposition with Waste Rock Drains - Dry Condition;

7. Alternative 4A(iii) – Waste Rock and Tailings Deposition - Dry Condition;
8. Alternative 4B(i) – Maximize Tailings and Waste Rock with Drains - Dry Condition;
9. Alternative 4B(ii) – Maximize Tailings and Waste Rock without Drains - Dry Condition;

8.1.1 Dam Classification – Existing Tailings Impoundment

Dam classification was conducted for the evaluation of closure alternatives under consideration for the Mt. Nansen tailings facility. Alternative 3 scenarios, where the tailings remain in place, require dam classification to determine the necessary dam upgrading. The tailings dam classification has implications regarding design flows (spillway design), design factors of safety, dam safety reviews and maintenance and operations. The classification of the dam depends on the consequences of failure and therefore on the type of cover under consideration e.g., water vs. soil. Alternative 4 also involves construction of structures to retain tailings solids, and in some cases ponded water. These situations are also considered in this memorandum.

The following sections discuss the information and results obtained by dam classification:

- If saturated tailings are placed in the Brown-McDade pit, with a wet cover (Alternative 4a(i)) the required retaining structure should be designed as a dam according to the CDA Guidelines.
- The plug structures of partially dewatered disposal scenarios (Alternative 4A (ii), 4A(iii), 4B(i) and 4B(ii)) in the Brown-McDade pit) would fall outside of the definition of a dam as they are not required to “retain” solids that would be highly mobile if unsupported. It is expected that as a result of co-disposal with mine rock that the tailings would not be highly mobile.
- The run-out of liquefied tailings following a catastrophic dam failure has not been considered. Further analysis would help define the potential impacts of dam failure.

The following conclusions have been arrived at through dam classification:

- Stability modeling of the existing dam has identified the post-earthquake scenario as the critical case (with liquefied tailings and thawed foundation material). The input parameters in this model are not dependant on the dam classification, and therefore the major stabilization measures would not change with changes in dam classification.
- The spillway and diversion channel design flows are dependent on the dam classification.
- Any modifications to the existing dam will trigger a new dam safety review.
- If tailings are relocated to the Brown McDade open pit and maintained in a wet condition, the retaining structure to be constructed at the south section of the pit would have to be designed as a dam differently than other alternatives where the tailings are co-disposed with mine rock or are otherwise partially dewatered, and thus are not in highly mobile condition (Alternatives 4A (ii), 4A(iii), 4B(i) and 4B(ii)).

8.1.2 Dam Stability

The stability of the existing tailings dam was assessed, as a basis for determining potential remediation options to conform to accepted practice for design of closure of such structures. If the tailings are left in place, (Alternative 3) the existing dam will require upgrading to satisfy the requirements of the Canadian Dam Association (CDA) Dam Safety Guidelines.

The key objectives of the stability assessment of the existing tailings dam were to:

- develop a representative dam cross-section and geotechnical parameters;

- assess the current stability under three scenarios established by the Canadian Dam Association (CDA) Guidelines:
  - Case 1: Static loading;
  - Case 2a: Pseudo-static seismic loading - 0.27g (Extreme, 1/10000);
  - Case 2b: Pseudo-static seismic loading - 0.11g (High, 1/2500); and
  - Case 3: Post earthquake conditions, accounting for liquefaction.
- consider the sensitivity of the dam to porewater pressures and seismic loads; and
- determine potential remediation alternatives which satisfy CDA criteria for all scenarios.

The following key results were obtained from assessing the stability of the tailings dam:

- the stability of a cross section south of the centerline of the dam has been considered;
- the foundation soils were also found to be liquefiable in this area and therefore a toe berm should be incorporated to provide toe stability toward the south abutment;
- the foundation soils in the area of the north terrace are not considered to be liquefiable;
- the tailings dam is currently “stable” under static loading, but cannot satisfy the seismic and post seismic stability criteria;
- the required factor of safety for the post earthquake scenario can only be achieved with freeze-back of the foundation soil into a toe berm, construction of a shear key, or through some method of ground improvement that would increase the density of unfrozen soils;
- the “high” piezometric line based on monitoring well observations is conservative, and has little impact on the critical case;
- sensitivity analysis shows that the porewater pressures do not significantly impact the stability in Case 3, because the foundation material is assigned only cohesive strength;
- the wet versus dry cover scenarios do not affect the stability analysis significantly as the piezometric elevations would be essentially the same during wet periods (ie. after snow melt);
- the CDA guidelines do not differentiate between the various dam classifications when considering post-earthquake stability;
- the crest of the dam may need to be raised slightly (<1 m) to accommodate the freeboard requirements for closure Alternatives 3(ii) and 3(iii). It is expected that this additional load would have minimal impact on the stability, but should be considered in the final design;
- a keyed in toe-berm would satisfy all cases, but potential for additional thawing beneath a shear key would limit its effectiveness;
- a seepage cut-off wall will not provide significant improvements to the dam stability (for Case 3) because the stability is limited by the undrained, residual shear strength of the thawed foundation material;
- a toe berm with either a shear key, freeze-back or some form of ground improvement will satisfy all stability cases. The toe berm will be approximately 9 m high, and will extend 8 m downslope of the toe of the existing seepage dyke;
- additional future permafrost degradation may increase groundwater flows in the thawed foundation zone and possibly in the dam fill itself. Filter design should accommodate potential future increases in flow;
- both the shear key and thermosiphon solutions at the base of the toe berm achieve similar results at similar costs. Both solutions are susceptible to climate changes. Thermosiphons become less effective as temperatures increase;
- a shear key must key into a stable (i.e., frozen) layer, and if the permafrost would degrade below the depth of the key, the shear key would become ineffective;
- the stability analysis has not considered all permafrost degradation scenarios. Additional degrading of the permafrost reduces the stability of the dam in the post-earthquake scenario. The FOS decreases at a rate of approximately 0.06 per meter of degradation, assuming that the shear key still extends into the permafrost;

- preliminary analysis indicates that the current toe berm and shear key configuration could maintain the required FOS if the thawed zone increases to 4 m thick, as long as the shear key extends into frozen ground at depth (or if the thermosiphons can maintain frozen conditions beneath the berm). There would be some additional associated costs. The current permafrost depth is approximately 1.5-2 m below the native ground surface, and this would allow for 2 m of additional degradation;
- if permafrost would degrade to below 4 m then other solutions should be considered;
- we do not know the liquefaction potential of the currently frozen soils;
- we do not know the depth of bedrock (it is at least 10 m below base of seepage dyke);
- we have not determined probabilities or estimated timeframes for future permafrost degradation;
- with our current understanding of soil and environmental conditions, it would not be practical to stabilize the dam in a way that would ensure the required factors of safety under all potential future ground conditions;

Table 8-1. Summary of Stability Modeling Results

	Case 1	Case 2		Case 3
	Static Condition	Pseudo-Static (0.27 g)	Pseudo-Static (0.11 g)	Residual Strength
Design Factor of Safety*	1.5	1.1	1.1	1.2
Existing	1.74	0.72	1.12	0.56
Toe Berm with key	2.62	1.01	1.60	1.26
Toe Berm with Frozen Foundation (high water level)	2.88	1.03	1.72	1.25
Toe Berm with Frozen Foundation, (low water level)	3.43	1.25	2.11	1.29

**Canadian Dam Association: Dam Safety Guidelines 2007.*

8.1.3 Spillway Requirements

Potential alterations and upgrades to the Mt. Nansen tailings dam spillway have been considered for the Alternative 3 which assumes remediation of the existing tailings impounding facility for the long-term. The existing spillway has two sections. Upslope of Station 0+770, as shown on Figure 1, the spillway discharges excess flows from the main surface impoundment atop the tailings. At Station 0+770 the spillway merges with the diversion channel that conveys catchment flows around the north side of the tailings impoundment. The combined flows are conveyed around the main dam structure to a point in Dome Creek some 150 m downstream of the toe of the seepage collection pond. The portion of the diversion channel upslope of Station 0+770 is discussed in a separate memorandum addressing the interceptor ditch and diversion channel.

Alternative three calls for the remediation and upgrading of the existing tailings facility, including the diversion ditch and spillway; the spillway design will be somewhat different for each closure scenario. Alternative 4 scenarios involve the relocation of the tailings to the pit and restoration of the present tailings management area, requiring the tailings dam to be breached and removed.

The following discusses requirements for a permanent spillway for the Alternative 3 scenario of remediating the impoundment as a long-term solution:

- The 1:1000 year flow in the diversion channel where it reports back to Dome Creek at the downstream side of the dam is 18 m^3/s without attenuation.
- If in a worst case scenario all Dome creek valley flows were to discharge into the tailings area, the 1:1000 yr flow through the spillway is estimated to be 5 m^3/s, after taking into account attenuation by flood routing within the tailings impoundment area.

- The spillway is currently designed and used as an emergency spillway.
- Water accumulations behind the dam have been controlled by pumping ponded water over the dam, rather than letting the spillway control water levels.
- Alternative 3 closure scenarios require the spillway to control water levels for a water cover or the flow of water across a soil cover in order to maintain saturation of the underlying tailings
- If the surface water quality of the pond water is below the acceptable standard, then excess cover water may need to be intercepted and treated before being released into Dome Creek. This will probably be necessary for the Alternative 3(ii) water cover scenario.

The following conclusions and recommendations arise from review of spillway requirement for Alternative 3:

- The spillway upstream of Station 0+770 should be designed to handle $5m^3/s$.
- Additional analysis may be required based on refined water balance.
- a spillway weir with a 5m wide base would handle flows of 5 m^3/s with a depth of 0.7 m;
- the spillway downstream of Station 0+770 should be designed to hand 18 m^3/s; and
- the spillway should be armoured to prevent erosion.

8.1.4 Assessment of Pit Backfilling Alternative 3 Using Mine Rock

Alternative 3B, comprises the placement of the entire waste rock pile into the open pit, while the tailings remain within the existing impoundment. Approximately 500,000 m^3 of waste rock is used to backfill the open pit. The main tailings dam will be upgraded and tailings will be maintained in place. It will be preferable to select relatively coarse free-draining non acid generating or metals leaching waste rock for placement in the lower part of the pit up to the highest expected long term ground water level. The remainder of the waste rock would be placed above the long term water table.

8.1.5 Assessment of Pit Backfilling Alternative 4 Using Tailings and Mine Rock

Alternatives 4A and 4B respectively include the relocation of the tailings from the tailings pond to Brown Mc-Dade Open Pit, without and with the re-location of the entire external rock pile. The alternatives for pit disposal of tailings and waste rock were based on two concepts: either maintain the tailings saturated, or keep the tailings in a partially dewatered relatively dry condition in the pit. Three options for Alternative 4A were compared:

4A-i

- This alternative assesses the placement of tailings in the open pit in a wet condition.
- Tailings will be placed at the bottom of the open pit to about elevation 1,207.5 m.
- A 150 mm thick diffusion layer will be placed on the surface of the tailings to prevent contaminant migration to the water cover. A water cover (1.0 m above tailings) will be maintained to abut elevation 1,208.5 m, preventing oxidation of the tailings.
- Water will be diverted from Pony Creek through a side hill channel. A stop log weir will be installed in Pony Creek to allow the diversion of enough water to maintain the tailings saturated in the pit. A spillway will be constructed to allow excess water to be discharged back to Pony Creek (downstream of the stop log weir).
- A dam will be built at about section 0+680 (called invert elevation of the pit).
- The former tailings management area will be remediated.
- The waste rock piles are not relocated from their current location (approximately 500,000 m^3).
- Active care and maintenance of the water diversion and cover system will be required.

4A-ii

- This alternative assesses the placement of tailings and some waste rock in the pit in a partially dewatered relatively dry condition.
- A ditch will be excavated at the bottom of the open pit to connect upper pond to lower pond.
- A waste rock drain will be placed at the bottom of the open pit to about elevation 1,190 m. Approximately 44,000 m^3 of waste rock are required for the waste rock base drain. Seasonal fluctuations of the water table in the pit are expected to occur within the waste rock drain to prevent contact with the tailings. This is being verified as part of water balance simulations described elsewhere.
- Future consideration will be required in the design of the drain to preclude migration of tailings material into the drain.
- Approximately 300,000 m^3 of tailings will be relocated from the tailings pond to the open pit.
- Layers of waste rock will be placed each 5 m in the tailings to accelerate consolidation, and enhance trafficability for backfill placement (approximately 45,000m^3 of waste rock required).
- A waste rock embankment will be constructed at the south end of the pit to contain the inter-layered tailings and waste rock (approximately 40,500m^3 of waste rock).
- A well will be installed, if water balance simulations indicate that it is likely to be required, at approximately station 0+410, in order to allow extraction of water out of the waste rock drain and preclude flooding of the Pony Creek adit or flooding of overlying tailings.
- A geomembrane liner will be placed along the interface between the tailings and waste rock embankment to reduce seepage.
- A 1.0 m thick soil cover will be placed on the tailings surface to reduce infiltration through the tailings layer. The cover will be designed to drain surface water (precipitation and snow melt) off the cover.
- The former tailings management area will be remediated.
- Approximately 356,000 m^3 of waste rock will remain in their current location.

4A-iii

- This alternative assesses the placement of partially de-watered tailings as backfill, with a waste rock drainage zone in the pit in a dry condition.
- A waste rock drain will be placed at the bottom of the open pit to about elevation 1,190 m. Seasonal fluctuations of the water table in the pit is expected to occur within the waste rock drain. Approximately 44,000 m^3 of waste rock are required for the waste rock reservoir.
- Approximately 300,000 m^3 of tailings will be relocated from the existing tailings pond to the northern section of the open pit.
- No dam or waste rock plug is required for this alternative.
- A sump well will be installed at about station 0+410 (if required).
- The former tailings management area will be remediated.
- Approximately 556,000 m^3 of waste rock will remain in their current location.

Options for the sub-set of Alternative 4 wherein all mine waste rock is placed into the open pit were compared as follows:

4B-i

- This alternative assesses the placement of tailings in the pit (dry condition) with layers of waste rock to accelerate consolidation, overlying a waste rock reservoir to elevation 1,190 m. This alternative is similar to Alternative 4A-ii. Additional waste rock will be placed in the pit to backfill the open pit. This alternative is shown in Figure 9.

- A total of 300,000 m^3 of tailings and contaminated soil and approximately 334,000 m^3 of waste rock will be placed in the pit according to this alternative.
- The former tailings management area, and the entire mine rock footprint will be remediated.
- Approximately 152,500 m^3 of waste rock will remain in their current location.

4B-ii

- This alternative is similar than Alternative 4A-iii and assesses the relocation of 300,000 m^3 of tailings and contaminated soil from the tailings pond to the open pit. Additional waste rock will be placed in the pit to backfill the top of the tailings layer and along the south end area of the pit. Approximately 44,000 m^3 of waste rock is required to build the waste rock reservoir to elevation 1,190 m and 300,000 m^3 of waste rock is necessary to backfill the pit.
- The former tailings management area, and the entire mine rock footprint will be remediated.
- Approximately 156,000 m^3 of waste rock will remain in their current location.

8.1.6 Tailings Transport and Handling

Alternative 4 identifies the option of the relocation of approximately 300,000 m^3 of tailings and contaminated soil from the tailings pond to Brown Mc-Dade Open Pit. Potential practical methods were assessed for achieving this goal efficiently and in an environmentally acceptable manner. Current practice in Canada and the influences of climate and material behaviour on constructability (winter and summer conditions) were considered.

The following options were considered and compared in this evaluation:

- **Hauling Tailings:** Discussions were held with Hazco Environmental Services, the contractor responsible for the relocation of 450,000 m^3 of tailings from a temporary stockpile area to the final storage area of the former Kam Kotia Mine Site, 35 km northwest of Timmins, Ontario. According to Hazco Experience in Kam Kotia, winter conditions would be required to access the tailings pond and relocate the tailings in a semi-frozen condition to the open pit. Hazco suggested excavating the tailings 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 300,000 m^3 of tailings can be relocated to the open pit in one season, with crew working 24 hours a day, seven days a week, relocating up to 10,000 m^3 of tailings/day. As the relocation of tailings takes place in a semi-frozen condition according to Hazco experience, potential spills of pore water from the tailings is minimized. Eventual spills would be remediated by relocating the contaminated material to the open pit during final site cleanup.

- **Slurry Tailings**: Literature suggests that available slurry pumping systems are capable of transporting in excess of 300 tonnes of slurried tailings per hour with 250 mm diameter pipes. This might equate to in excess of 5,000 cubic metres per day. The specific energy consumption of current systems is approximately 0.13 KW.h/tonne/km for 250 mm diameter pipes. Approximately 1 m^3 of water would be required to slurry 1 ton of solid tailings. Approximately 300,000 m^3 of water would be required to slurry the tailings to allow hydraulic relocation to the open pit.

- The hauling method used in Kam Kotia is considered applicable for relocating the tailings from the tailings pond to the open pit in Mount Nansen. An experienced contractor has suggested this method rather than slurring the tailings, as discussed in the following section. The environmental impacts that would be initially involved in relocating the tailings to the open pit by hauling the tailings would be the potential contamination of the road to the open pit. A final clean up would be required to remove any contamination in the road.

- The difference in elevation between the tailings pond and the open pit (approximately 105 m) and the distance (approximately 1 km) are major factors that have to be considered as disadvantages of the slurry method. Another disadvantage of the slurry tailings method is the need to use approximately 300,000 m^3 of water to slurry the tailings. Considering an average porosity of the tailings of 0.6 and saturation condition, it is estimated that the tailings contain approximately 180,000 m^3 of water in the pores. Additional 120,000 m^3 of water would be required for the slurrying process. Water would have to be stored in the tailings pond or in a different location prior to relocation of tailings. Recycling water should be considered. Environmental impacts associated with this method for relocating tailings are typically: contamination of a large volume of water to slurry the tailings (which require later treatment); and spills in the pipe line system.

8.1.7 Tailings Consolidation – Pit Backfilling

Alternative 4 suggests a number of options for the relocation of tailings from the tailings pond to Brown Mc-Dade Open Pit. Alternatives 4A-ii and 4A-iii suggest the disposal of tailings in the Open Pit in a relatively dry condition, where the overall water table would be located within an underlying waste rock drainage zone, facilitating porewater to flow downward towards the waste rock layer. Consolidation and resulting settlement is expected to occur in the tailings at an accelerated rate if co-disposal with waste rock is considered, as compared to the alternative where saturated tailings are placed as a single mass. The consolidation time and settlement of tailings was estimated to:

- Determine settlement of the tailings after their relocation from the current tailings pond to the Brown Mc-Dade Open Pit.
- Determine the time for 90% of consolidation to occur (t_{90}).
- Investigate the benefit of horizontal drainage layers to reduce t_{90}.

The following results were calculated:

- t_{90} was calculated to be les^s than 1 year for Alternative 4A-ii (Dry).
- t_{90} was calculated to be equal 21 years for Alternative 4A (iii – Dry)
- By consolidation theory, the increase in effective stresses will generate a settlement of the tailings layer of approximately 0.8 to 1.5 m.

The following sections discuss the information and results obtained:

- Up to 1.5 m of consolidation settlement of the tailings is expected to occur from deposition in the open pit. The final cover design should account for this settlement by constructing it to a higher elevation e.g., over-build by 2 m.
- The rate of consolidation settlement can be significantly increased by incorporating drainage layers within the tailings. The rate of settlement should be considered in the final selection and timing for the construction of a soil cover.
- Uneven settlement is expected to take place due to differences in thickness of the tailings layer, which can affect the performance of the cover. Maintenance may be required to maintain the integrity of the cover, in particular shortly after construction when settlement is taking place.
- In a wet condition (Alternative 4A i) the tailings are not expected to consolidate, because effective stresses will remain similar to their current condition (submerged) in the tailings pond. Some consolidation may occur, depending on the transport 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).

8.1.8 Cover Concepts

8.1.8.1 Alternative 3 (tailings management area with tailings in their current location)

Alternative 3 comprises the stabilization of the main tailings dam with a toe berm, and the provision of an in situ cover of the tailings. Alternative 4 comprises the relocation the tailings to Brown Mc-Dade Open Pit in either a wet or partially de-watered or dryer condition, which also requires the placement of a cover over the tailings. Several options within these main alternatives have been defined as:

- Alternative 3A-i - the placement of a soil cover;
- Alternative 3A-ii - the placement of a water cover; and
- Alternative 3A-iii - the placement of a sponge cover.

The following sections describe the cover alternatives for the tailings impoundment for Alternative 3:

- Soil Cover:
  - Soil Covers are one of the most utilized techniques employed around the world to minimize oxidation of tailings and surface water contamination. A soil cover prevents water infiltration due to precipitation from entering into direct contact with the tailings and consequently reduces the generation of contaminated runoff. The advantage of this approach over other technologies is that it is possible to establish vegetation on the top of the cover. The most significant disadvantage of dry covers is the continued oxidation of the tailings due to residual concentration of oxygen in the voids of the cover. Another disadvantage of dry covers (as observed in other cover systems as well) is the inefficiency regarding groundwater quality if the tailings release contamination under anaerobic condition (e.g., arsenic).
  - The practice in several mine sites in Canada and around the world suggests the placement of a 1.0 m thick soil cover over tailings. Simulations using Vadose/W were completed by AECOM in 2008 to determined the optimum thickness and composition of a soil cover system for a Tailings Management Area in northern Manitoba to be 1.0 m of silty sand till (AECOM, 2008). It was also concluded however, that upward movement of water from the tailings as a result of root suction could potentially have several negative effects, the most prominent being the wilting and/or dying of the vegetation, and the potential contamination of the cover material.
  - For Mt. Nansen, it would be desirable to maintain the tailings in a saturated condition and only allow fluctuations of the water table to occur within the soil cover to minimize oxidation.
  - The elevation of the spillway should be set at the same elevation as the top of the soil cover.
  - The cover should contain an optimum percentage of fines to retain some moisture under dry conditions. A review of available borrow materials suggests that amendments to the local sandy materials would be required to satisfy this grading requirement (EBA, 2009).
  - Soil cover will require drainage swales to allow drainage of surface water off the cover.
  - This option allows vegetation to be established on the cover.

- Water Cover
  - Water cover is considered to be one of the most effective methods for reducing oxidation of tailings. The practice in Canada and around the world recommends the placement of a 1.0 m thick water cover over tailings to minimize oxidation by oxygen A 1.0 m thick water cover has shown to be efficient in reducing the concentration of dissolved oxygen in the tailings.
  - The placement of a water cover over the tailings (in-situ) at Mount Nansen will potentially involve the contamination of the water cover due to the direct contact with tailings. If a high flow event results in discharge of surface water through the spillway, there is some risk that the water quality will exceed acceptable levels.
  - A more stringent dam classification is required due to the impoundment of a large volume of (potentially contaminated) water in the tailings pond. Levelling of the tailings will be required and the required

freeboard with respect to the existing dam crest elevation likely needs to be increased, resulting in a small dam raise. This dam raise however is not enough to alter the stability assessment results.
  - There is a potential for an increased rate of seepage through the main dam due to the increase of the pond operating level. Concerns associated with increased seepage rates include the potential for internal erosion e.g., piping failure or downstream slope instabilities.
  - There is a need to maintain a water cover all year round, which requires a water management system.
  - To prevent discharge of potentially contaminated water through the spillway either the water balance of the tailings pond must achieve a consistent net negative balance of the inflow of surface water, precipitation, seepage and evaporation, or , the potential contamination of the water cover needs to be diluted by increasing the flow through the pond to meet discharge criteria. If this is not possible, water treatment prior to discharge to the environment is will likely be required for an indefinite period of time.
  - A water cover precludes the possibility of establishing vegetation over the tailings.

- Sponge Cover (Soil + Water)
  - A sponge cover is considered to be an effective techniques for reducing the oxidation of tailings. This method involves 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 saturated and maintain flow through the tailings management area. Also, this method would likely improve the potential for growth of vegetation on the top of the saturated cover.
  - In dry years where the water cover cannot be maintained over the cover and tailings, a partially saturated soil cover would still cover the tailings.
  - The emergency spillway would have to be set at 0.15 m above the top of the soil cover to allow a 0.15 m water cover on top of the soil cover.
  - The soil cover will prevent contamination of surface water in pond allowing direct discharge over the spillway.
  - The thin water cover may allow for less stringent dam classification although factors such as seepage and stability should also be considered..
  - The soil cover may not require amendments (local fine sand soil may be suitable for cover).
  - The water that will potentially flow through the spillway is expected to be suitable for direct discharge if a minimum flow is maintained through the pond (surface water).
  - There are some examples of successful application of sponge covers in Canada and around the world where sponge (or saturated) covers were successfully implemented to remediate mine tailings.

8.1.8.2 Alternative 3 Cover Concepts Review

- The soil cover over the tailings in Alternatives 3(i) and (iii) should prevent contamination of surface water and water flowing over the spillway is not expected to require treatment.
- Moderate amounts of water flow over the tailings area are encouraged to flush the surface water and maintain saturation for Alternatives 3(i) and (iii), therefore the interceptor ditch will be backfilled allowing surface runoff from the west slope to cross over the tailings area before draining via the spillway.
  - The spillway would be required to handle all flows directed over the tailings area.
  - The tailings area will attenuate surface flows.
- The water cover, in Alternative 3(ii), is expected to become contaminated, and therefore any outflows will require management, and possible treatment.
  - Maintaining the water cover while minimizing spilling of excess cover water will minimize treatment costs.
- Water cover is considered an efficient option for covering the tailings at the tailings management area. An advantage of this option for covering the tailings at Mount Nansen is the potential for water raise in the tailings pond to the desirable elevation under current conditions. It would not require additional water capture structures.

The disadvantages of this option are the high risks associated to the potential poor water quality in case of discharge through the spillway (may require treatment) and higher consequences associated with a failure scenario (and thus a more stringent dam classification).

- A soil cover is also considered an efficient option for covering the tailings at Mount Nansen. A soil cover would be efficient in preventing contamination of surface water that would flow through the pond and in maintaining the fluctuations of the water table in the cover, which would prevent continuous oxidation of the tailings. The disadvantage of this cover system is the requirement to upgrade and maintain the interceptor ditch and concerns regarding erosion in the cover with time.
- A sponge cover is considered by many authors the most appropriate cover system because the cover maintain the tailings saturated (water cover) and prevents surface water to be in contact with tailings (contamination). The most significant advantages of this cover system for Mount Nansen are the potential for surface water flow through the pond (no need for an interceptor ditch), dry conditions (if no water in the pond, a soil cover would still protect the tailings) and potential for surface water to be discharged through the spillway without the need for treatment.

8.1.8.3 Alternative 4 (relocate the tailings to the open pit and cover with soil).

Alternative 4 includes the placement of a soil cover over the tailings after their relocation to the open pit for all scenarios considered in this study:

- Alternative 4A-i - the placement of a sponge cover over saturated tailings;
- Alternative 4A-ii - the placement of a soil cover over co-disposed tailings and waste rock; and
- Alternative 4A-iii - the placement of a soil cover over tailings that have been partially drained and consolidated.

The designation A or B, respectively signifies that waste rock is left in its existing location, or it is placed in the pit.

The following section describes the cover options for the tailings for Alternative 4:

- Soil Cover:
  - Alternative 4 suggests the placement of the tailings in the open pit under different scenarios (4A-i, 4A-ii, 4A-iii, 4B-i and 4B-ii). For all these scenarios, it is suggested the placement of a 1.0 m thick soil cover on top of the tailings.
  - For dry scenarios (4A-ii, 4A-iii, 4B-i and 4B-ii), the cover will consist in placing a 1.0 m thick soil cover to protect the tailings and to promote runoff of surface water off the cover to maintain a dry condition in the tailings. The seepage will be collected and diverted off the cover through a ditch that will be built along the interface between soil cover and pit wall. 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.
  - For scenario 4A-i, the 1.0 m thick soil cover will be placed on top of the tailings to protect the tailings against erosion due to high flow events and to maintain the fluctuations of the water table in the pit in the soil cover. The water table will be maintained in the cover by diverting enough water from Pony Creek into the pit in order to maintain the tailings in a saturated condition.

Alternative 4 Cover Concepts Review

A relatively simple soil or rock cover is required to cover the tailings and waste rock placed under relatively dry conditions, as is the case for Alternatives 4A ii and iii, and 4B i and ii. In these situations, the key objectives are to achieve physical stability and minimise infiltration. By contrast, Alternative 4A i requires permanent saturation of the surface of the impounded tailings by means of a permanent water cover. In this case, the design concerns are the ability to maintain a water cover over the long-term, and the prevention of diffusion of contaminants from the saturated tailings into the flowing water cover.

Soil, water and sponge covers are the most common and effective alternatives for covering tailings in Canada and are believed to be applicable for covering the tailings at Mount Nansen. The cover scenarios presented in this memorandum suggest maintenance of saturation in the tailings to minimize oxidation of the tailings. Alternative 4A-i seeks to meet this geochemical objective. The key issue for this option to be successful is the ability to ensure a long term water cover through diversion of part of Pony Creek into the impoundment, preferably as a passive situation. The site water balance simulation is being used to provide an assessment of the feasibility of this approach.

Alternative 4A-ii accepts that through partial de-watering of the tailings, as they are co-disposed with layers of waste rock, some oxidation will occur. It is intended that the flow of water coming in contact with oxidised unsaturated tailings be minimised by placement of a cover with a low permeability. As noted in a separate memorandum, layers of co-disposed waste rock are expected to accelerate consolidation drainage from the tailings, promoting stability and reducing long term settlement of the completed backfill surface. This in turn will promote the relatively rapid achievement of an effective surface cover that reduces infiltration and net flux of contaminated water reporting to the base drain.

Alternative 4A-iii assumes that the tailings can in some manner be de-watered to the point where they can be placed as unsaturated fill material to form a stable mass, upon which a cover layer can be placed. The alternative set 4B, place additional waste rock atop the same concepts described for set 4A. The concepts demonstrate that all of the mine rock could be accommodated within the open pit footprint.

8.1.9 Water Diversions in Dome Creek

The potential alterations and upgrades to the Dome Creek diversion channel and interceptor ditch were assessed. The interceptor ditch collects runoff along the South-East side of the tailings pond before joining the diversion channel at the North-East corner of the tailings area. The Dome Creek diversion channel collects water from Dome Creek, and the interceptor ditch, and carries this water along the North edge of the present tailings management area. The diversion channel merges with the emergency spillway at station 0+770.

Alternative 3 scenarios call for the remediation and upgrading of the existing tailings facility, including the diversion and interceptor ditches. Alternative 3 scenarios are illustrated in Figures 1 to 3.

Alternative 4 scenarios involve the relocation of the tailings to the pit, and restoration of the present tailings management area. The interceptor ditch and diversion channel will then be unnecessary, and will be filled in and re-vegetated as part of the larger valley restoration works.

The diversion channel downslope of Station 0+770 is addressed separately as part of the spillway.

The following key results were obtained from assessing the diversion channel at the existing tailings dam:

- Current flow conditions along the channels are causing erosion and additional armouring is required.
- The 1:1000yr peak flow is 18m^3/s in the diversion channel at the tailings dam, assuming all flows upstream of the tailings dam are passing through the diversion channel.
- The diversion channel will need to be widened to accommodate design flows.
- The relatively low grade and therefore flow velocities along the diversion channel and interceptor ditch (compared to the natural creeks) result in these channels being depositional areas for sediment. Armouring will

reduce the amount of erosion along the channel slopes, but will not eliminate the deposition of sediment introduced by runoff or already suspended in Dome Creek's flows.

- Regular cleaning of the channel bottom will be required, regardless of channel design.
- The interceptor ditch should be widened for Alternative 3(ii) to accommodate increased design flows.
- The bridge over the diversion channel is necessary, and will need to be replaced if the channel geometry is modified.
- Widening of the channels will require the road to be shifted towards the tailings area as shown in Illustrations (a) and (c).
- The diversion channel will require ongoing regular maintenance to remove accumulated sediment;

8.1.10 Water Diversions in Pony Creek

The feasibility of the diversion of Pony Creek into the Brown McDade mine pit was assessed for Alternative 4A(i) which requires a water cover to be maintained over the tailings re-located into the Brown-McDade pit. Pony Creek is the only nearby natural water source available to maintain the cover. A diversion structure would divert some of the creek flow to the pit, allowing excess flows to continue along the existing creek alignment. An inflow channel and spillway are required to maintain the water cover and manage flows. A cross-slope channel, formed by cut and fill would tie into the pit near the North-West corner. A spillway at the North-East corner of the pit would direct excess water back into Pony Creek, or a spillway at the south end of the pit would direct water into Dome Creek.

The following points discuss the feasibility and implications of partial diversion of Pony Creek to maintain a water cover or saturated soil cover atop backfilled tailings within the open pit:

- A Pony Creek Diversion would have to cross the existing access road at least twice. Crossing options would include bridges, fords or culverts.
- A bridge crossing would be the most expensive option, and is not necessary considering the diverted flows, and the closure status of the project.
- A culvert would be less expensive than a bridge, and would still provide an all-weather, dry crossing. The culvert would need some 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 difficult to inspect; and
    - More costly and complex control structures.
- Water diverted into the Brown-McDade pit can either:
    - Spill over or around the impounding embankment at the south end of the Brown-McDade pit. These flows would join Dome Creek in the vicinity of the existing tailings impoundment. An appropriate channel with drop structures would be required:
        - Any potentially contaminated water would be kept out of Pony Creek. In this scenario, Dome Creek would flow through the existing TMA, and would require monitoring for contaminants.
        - Water would be diverted from the Pony Creek catchment basin into Dome Creek (which may require additional regulatory approval).
        - The tailings cover water would be refreshed because flow would be across the entire length of the pit.
- Alternatively, water spilling from the cover area can be returned to Pony Creek via a new channel exiting the pit at the North-East corner of the pit:
        - Tailings cover water would be added to Pony Creek, adding a potential source of pollution.

- The tailings cover water will not be naturally flushed because flow into and out of the tailings pond would be at the North end of the pit. This would allow higher concentrations of contaminants to build up in the stagnant water in the south portion of the pond. Some of this potentially contaminated water would flow out during rainfall or snowmelt events.

8.1.11 Valley Restoration

Alternative 4 involves the relocation of approximately 300,000 m^3 of tailings and contaminated soil from the tailings pond to Brown Mc-Dade Open Pit. The required activities to restore the Valley and Dome Creek after the relocation of the tailings to Brown Mc-Dade Open Pit (as part of the Alternative 4) were identified:

- complete relocation of tailings from the tailings pond to Brown Mc-Dade Open Pit;
- breach and removal of the tailings dam, using all uncontaminated fill to cover the tailings impoundment after removal of the tailings and any underlying contaminated soils. Any contaminated dam fill would also be conveyed to the open pit for backfilling;
- identify and remove contaminated soil below the tailings pond and in the dam fill and relocate to open pit;
- after relocating the tailings and contaminated soil to the open pit, cover the former tailings management area with local soil;
- fill the existing interceptor channel with local soil;
- fill the existing diversion channel with local soil;
- restore the flow (Dome Creek) through the Valley which may require an erosion control system of the new channel/creek; and
- promote vegetation of the cover.

The requirements for valley restoration were assessed as follows:

- the Valley restoration involves practical challenges in removing the tailings and any potential remaining contamination from the foundation soil below the tailings and dam fill. These challenges include management of water quality during excavation of tailings, dam fill and natural soils, many of which are likely to be loose and wet. The option to conduct such operations during winter when less free water is present and which may enhance trafficability has been considered;
- there is limited data regarding the extent of the contamination in the foundation soil (which would have to be excavated and relocated to the open pit);
- the new creek through the restored valley is likely to require an erosion control system (armouring) to prevent migration of fine grained soil from the cover and exposure of soils with potential remaining contamination (if relocation to remaining contaminated soil to the pit is not possible);
- the side slopes of the impoundment area will require stabilisation through re-contouring and placement of a stable cover to control erosion and result in a stable long-term landform; and
- the restoration of the valley will require monitoring of water quality, vegetation cover, erosion, etc.

8.2 Groundwater

8.2.1 Groundwater Flow Systems

Two groundwater flow systems are present within the study area. During warmer weather, a shallow flow system is present within the active zone on top of permafrost (where present), and a second flow system is present year-round within the deep regional bedrock aquifer. These two systems interact with each other through unfrozen windows in permafrost (taliks). Groundwater flow is discussed below in the context of the groundwater flow pathway, from recharge through to discharge. 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.

8.2.2 Shallow Groundwater Flow

The shallow groundwater flow system is hosted entirely within the active zone 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 frozen months, much of the overburden and shallow weathered bedrock units freeze, and the source of recharge reporting to this aquifer is dramatically reduced or eliminated. Groundwater flow within this unit is assumed to cease when the ground has frozen from surface down to permafrost each winter and begins flowing again in the late spring or early summer following snowmelt.

After the air temperature has dropped below freezing in the fall, but before the aquifer has frozen down to permafrost, groundwater continues to discharge from the shallow groundwater flow system along road cuts and into the pit forming icings. Within the Brown-McDade open pit, a large icing forms at the north end of the pit, extending from the uppermost bench down to the surface of the pit lake over the course of the early winter months. The icing forms just above the resistant quartzite bedrock at the north end of the pit and melts completely over the course of the spring and summer, with discharge reporting to the pit lake.

Throughout the remainder of the upper Dome Creek and Pony Creek catchments, shallow groundwater is anticipated to flow from topographic highs toward topographic lows within the active layer, and eventually discharge to Pony Creek and Dome Creek in the valley bottoms. Where permafrost is not present, groundwater will migrate vertically downward to the deeper regional flow system.

Groundwater flow divides within the shallow system are inferred to conform to surface drainage divides. In the vicinity of the open pit, shallow groundwater flow is influenced by the presence of waste rock piles and permafrost. Aggradation of permafrost into the waste rock piles was confirmed during the 2009 field investigation.

8.2.3 Regional Groundwater Flow

The regional groundwater table is inferred to reside within the weathered and competent bedrock units in the upland areas, and within alluvium and organic materials along the lower flanks of the Dome Creek and Pony Creek valley, where groundwater discharges to surface. Permafrost has been observed in the unconsolidated sediments within and downslope of the waste rock piles and TMA; however, the substantial variation in the density of vegetation on the south-facing slopes of the Dome Creek valley indicates that permafrost is not continuous within the Dome Creek or Pony Creek valleys. It is assumed that shallow and deep groundwater flow systems will only receive recharge from surface through the unfrozen windows in a landscape that is otherwise underlain by permafrost. Deeper in the Dome Creek and Pony Creek valleys, the shallow and deep groundwater flow systems connect, and groundwater discharges to surface. Where thick organic sediments are present, permafrost has been preserved, and the shallow and deep groundwater systems appear to be isolated from one another. Within the Dome Creek valley bottom, particularly near the TMA and in the lower reaches of Dome Creek, the valley bottom aquifer is inferred to discharge to Dome Creek year round. This is supported by pumping records from the seepage collection pond that indicate relatively stable pumping rates throughout the year at an approximate rate of 5 L/s.

Pony Creek drains a much smaller catchment. Surficial unconsolidated deposits are not extensive within the upper portion of the Pony Creek channel (i.e., above 1,160 m ASL). Numerous exploration trenches in the Pony Creek catchment confirm that overburden is relatively thin and bedrock is a short distance below the creek bed. Mini-piezometers installed in the upper reaches of Pony Creek indicate downward hydraulic gradients on all measurement dates, suggesting a losing stream located above the regional water table. Within the lower reaches of Pony Creek an upward groundwater gradient was observed, indicating groundwater discharge to the stream from the weathered bedrock and alluvial sediments underlying the stream channel. Permafrost was not encountered during installation of any mini-piezometers in the Pony Creek stream channel.

8.2.4 Pit Water

Groundwater flow in the area surrounding the Brown-McDade open pit is quite complex and its interaction with the regional groundwater flow system merits further discussion. Based on field observations, there is very little groundwater discharge to the pit above the elevation of the pit lake. However, groundwater discharge to the pit lake has been observed in two locations: 1) above the resistant quartite bedrock; and, 2) from the easternmost exploration drift at the north end of the pit.

The highly fractured and faulted (more permeable) zone surrounding the Brown-McDade 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 divide is expected to move slightly on a seasonal basis. The majority of the flow from Pony Creek to the pit will occur within the shallow fractured bedrock unit. This groundwater flow pathway is evident during late fall and early winter months, when a large icing forms on the pit wall at the north end of the pit, discharging to surface slightly above the resistant quartzite beds at approximately 1,195 m ASL. Based on field observations, this groundwater flow pathway is active during two periods of time in the year. During the months of May and June, discharge from the shallow weathered bedrock zone has been observed following the development of the active layer and in response to snowmelt and freshet in Pony Creek. Groundwater discharge from the shallow weathered bedrock unit to the north end of the pit has also been observed during the months of October, November and December following September and October rainfall, but prior to full freeze back of the active layer. For the remaining months of the year, this groundwater flow pathway is assumed to be frozen or unsaturated. Based on well yields during drilling north of the pit and measured groundwater gradients, the magnitude of groundwater flows through this shallow flow system were estimated to be 1,051 m^3 each year. The groundwater travel time from Pony Creek to the open pit was estimated to be 105 days or 3.5 months, based on known groundwater elevations and hydraulic conductivity values inferred from drilling observations.

At the north end of the pit, the remnants of two exploration drifts remain as short (<5 metre) tunnels into bedrock, approximately two metres above the current pit lake elevation (~1,184.1 mASL). All field observations to date indicate that the westernmost drift remains dry year round. Groundwater input to the pit from the easternmost drift at the north end of the pit has only been observed during the late summer and early fall months. During the remainder of the year, the drift is full of ice. Groundwater is observed to drip from the spine of the drift to the floor and seep downward through the floor into bedrock. Based on geological mapping and measured groundwater elevations, this drift is located within highly faulted bedrock and intercepts the water table. From Pony Creek, water infiltrates into shallow weathered bedrock and continues to flow downgradient, eventually entering geologic structure that is inferred to provide a preferential pathway to the pit. The water then discharges to the pit lake. Water eventually flows out of the pit at the southern end, flowing downgradient toward the Dome Creek valley. Groundwater travel times between the pit lake and the diversion ditch in the Dome Creek valley were estimated to be on the order of 23 years, but could range quite significantly (i.e., 2.3 – 230 years) depending on the hydraulic conductivity of the bedrock unit or structure in which the groundwater is flowing.

Measured pit lake elevations indicate that although the elevation of the pit lake fluctuates over time, it has not risen above ~1,184.5 m ASL over the period of record (~8 years). As such, the pit lake is inferred to be a surficial expression of the regional water table, but the water table may drop during the winter months, causing it to detach from the pit lake, forming a tension saturated zone beneath a portion of the pit. Groundwater elevations frequently fluctuate on the order of several metres in low porosity, low permeability bedrock settings.

During the winter months, the flows in the headwater section of Pony Creek are dramatically reduced and this narrow (<1 m), shallow (<0.5 m) creek eventually freezes to bottom. The ground surface throughout the study area also freezes and eliminates the input of spatially distributed recharge to the groundwater system for the winter months. During the winter, the water table is expected to drop several metres, resulting in steeper vertical groundwater gradients beneath the open pit. A long-term record of pit lake elevations reveals a relatively constant groundwater discharge rate of 0.2 L/s during the winter months. As a result of the decline in the regional water table and ongoing seepage out of the pit, the groundwater table may drop far enough below the open pit to become detached from the pit lake, forming a semi-perched system maintained by low permeability bedrock beneath the open pit.

8.2.5 Tailings Groundwater

The tailings management area is underlain by a thin veneer of organics, which is in turn underlain by a combination of silty aeolian sand and alluvial sediments associated with the Dome Creek stream channel. Permafrost was encountered in every borehole drilled within the TMA just below the base of tailings. Above permafrost, the unfrozen native organics and alluvial/aeolian sediments host the shallow groundwater flow system. Beneath permafrost, the deeper groundwater flow system is inferred to report to deeper parts of the Dome Creek valley.

The shallow aquifer underlying the 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. Run-off from the south and snowmelt within the TMA catchment raises the level of water in the tailings pond each spring.

Low permeability sand to clay size tailings were deposited on top of native materials during mine operations. Groundwater level measurements in nested wells installed in the TMA indicate strong downward vertical groundwater gradients. The relatively permeable materials beneath the tailings are inferred to function as a drain beneath the TMA and to transmit groundwater down the valley 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 porewater and water in the tailings pond is anticipated to slowly infiltrate through the tailings and enter the underlying aquifer. It then flows down gradient through the remnant organics and tailings 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 shallow groundwater flowing along the axis of the Dome Creek valley. A significant amount of groundwater is inferred to flow through the uppermost unfrozen portions of the aeolian sand deposit located north of the seepage collection pond. The native sand strata on the north flank of the tailings dam is inferred to be relatively permeable and is partially recharged by losses from the diversion channel. 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.

Groundwater flow into the seepage pond is inferred to be comprised of two components primarily: 1) seepage through the dam, and 2) groundwater flow from the diversion channel through the aeolian sand deposit. The north facing slopes located south of the seepage collection pond are inferred to be frozen and host a thin active layer. As such, they are not anticipated to contribute a significant amount of groundwater to the seepage collection pond. Water collected in the seepage collection pond is pumped over the seepage dyke and into Dome Creek above its confluence with the diversion channel. Long-term seepage pond discharge measurements indicate that the combined inputs to the seepage collection pond are on the order of 5 L/s.

The relative contributions of the two groundwater sources to the seepage collection pond were estimated and the results are provided under separate cover (AECOM, 2009).

8.2.6 Uncertainty in Hydrogeological Characterisation

Upon conclusion of the 2009 field investigation and a desktop assessment of the information collected to date, the following uncertainty remains:

The spatial extent and thickness of permafrost across the study area is unknown. Permafrost beneath the tailings facility has the potential to degrade over time as a result of the overlying body of water. This could have important implications on the degree of connection between the shallow and deep aquifers and on groundwater flow pathways. A.Kent note - if ground temperature rises, thaw occurs, cross-sectional area of flow beneath the tailings dam increases, seepage flow increases, dilution of seepage from overlying tailings increases, and downstream concentration of contaminants derived from tailings decreases – CHECK THAT GOLDSIM SIMULATES THIS IN THE SAME WAY; also note that deeper groundwater flow is probably not relevant to comparing alternatives; also note that permafrost is likely only 5 to 10 m thick.

The position of the shallow and deep groundwater divides between the Dome Creek and Pony Creek catchments have been assumed. The complex geologic structure, proximity to Pony Creek and the presence of permafrost in the area could cause the position of these divides to migrate seasonally with the development of an active layer and recharge from Pony Creek. The behaviour of the deep groundwater system is not yet well understood as a result of a limited number of boreholes and sparse water level data. A.Kent note - that this is more likely to occur for alternative 4A-wet, such that seepage towards Pony Creek from the pit backfill might occur.

Although two groundwater monitoring events were conducted during the summer of 2009, seasonal fluctuations in groundwater elevations, groundwater quality, permafrost and groundwater flow directions are not yet well understood. A.Kent note - only two months of data have been obtained so far – this information will be useful later for the EIS

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 from the Brown-McDade open pit. A.Kent note - Travel times could vary in range of 3 to 300 years, with “expected” around 20 to 30 years. There seems to be opinion that some significant attenuation is likely to occur between the pit and the Dome Creek discharge zone.

8.3 Geochemical

8.3.1 Tailings and Pit Lake Source Terms

8.3.1.1 General

- Source terms provided are intended to serve as long-term concentrations:
  - short-term degradation in water quality following remediation measures may occur and will be mitigated by water treatment.
- Source terms are constant concentrations that do not vary over time**:**
  - this assumption is made in an effort to maintain consistency between the various terms; and
  - insufficient data exist to develop variable or seasonal terms for the various closure options under consideration.

8.3.1.2 Pit Lake (Alternative 3a)

- The pit lake is assumed to be stable and current geochemical conditions present in the pit will persist into the future. Altura reported overall low metal solubility in the pit wall and pit floor samples, but do observe elevated extractable As and Zn. Also, the backfilled ore at the south end of the pit shows elevated Zn loading and low NP:AP values. Until recently the pit lake has been actively managed (e.g., dewatering and fertilization). Monitoring of the pit lake should continue into the future to validate source term predictions.

8.3.1.3 Tailings Located Within the Impoundment (Alternative 3)

- At present, the tailings mass is stable, i.e., flow rates and loadings have stabilized, and all geochemical mechanisms occurring currently within the impoundment will persist in the long term.
- The majority of loadings from the tailings impoundment reports to the seepage collection pond.
- Arsenic and other parameters are reductively attenuated along the flowpath from the tailings pond to the seepage collection pond. This mechanism is presumed to be infinite.
- The seepage collection pond is stable and current geochemical conditions existing along the flowpath from the tailings to the seepage pond will persist in the long term (Best Estimate).
- At present, the water bypassing the seepage collection pond does not enter Dome Creek or Victoria Creek.
- Dam upgrades and backfilling of the seepage collection pond may alter the groundwater flowpath. Currently, As is removed along this flowpath and before seepage discharges to the seepage collection pond. If the flowpath is altered groundwater quality represented by well MW09-08 (e.g., elevated arsenic) may report to Dome Creek (Worst Case scenario).

8.3.1.4 Saturated Tailings Located Within the Pit (Alternative 4a – wet)

- The tailings in the pit are homogeneous and evenly mixed with organic matter.
- Under the Best Estimate scenario mild suboxia will dominate in the pit.
- Under the Worst Case scenario strongly suboxic conditions will develop throughout the tailings mass.

8.3.1.5 Unsaturated Tailings Located Within the Pit (Alternative 4a – dry)

- The tailings are readily exposed to oxygen, oxidize, and become acidic;
- Acidic drainage from the tailings persists and dominates seepage quality emanating from the backfilled pit.
- Acid generation and metal leaching from the tailings is analogous to measured seepage from the Arctic Gold and Silver Tailings.

8.3.1.6 Key Results

Table 8-2 provides the chemistry source terms developed for the Mt. Nansen pit lake and tailings. For each scenario, best-case and worst-case values have been developed in an effort to capture uncertainty inherent in the establishment of one single chemistry source term. A summary of the methods and interpretation of results is provided herein. For a complete description of the methodology used to derive these source terms, refer to Lorax (2009).

Table 8-2. Mt. Nansen Long-term Pit Lake and Tailings Seepage Water Quality Estimates

Parameter	Pit Lake (3A)		Tailings As Is (3A and 3B)		Tailings (4a-Wet) Satd Storage In Pit		Tailings (4a-Dry) Dry Storage In Pit
	Best Estimate	Worst-case	Best Estimate	Worst-case	Best Estimate	Worst-case	Analog Estimate
As	0.05	0.25	0.04	0.3	9.5	15	28.4
Cd	0.012	0.04	0.0009	0.007	0.006	0.0003	0.184
Cu	0.05	0.12	0.009	0.09	0.003	0.001	1.4
Fe	1	8.5	12	40	1	10	574
Mn	4	10	8	11	5	25	28.6
Zn	2.5	3.5	0.02	0.2	0.05	0.5	26.2
Sulfate	1350	2050	800	3200	1750	1750	2500
Ammonia	0.4	0.5	6.5	12.5	15	16	6.5
CN (Tot)	*n/a*	*n/a*	0.07	0.6	0.9	1	0.6
WAD CN	*n/a*	*n/a*	0.03	8	0.3	0.4	8
Cyanate	*n/a*	*n/a*	2	30	6	5	30
Nitrate	2	5	3	10	0.05	0.25	10
Nitrite	0.2	5	0.3	10.5	0.1	0.05	10.5

The following sections discuss the results obtained:

- 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.
- The source terms for the tailings located within the current impoundment (Tailings Alternative 3) exhibit a higher range between the “Best Estimate” and “Worst Case” scenarios. 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.
- The difference between the Best Estimate and Worst Case source terms under closure Alternative 4A-wet is small compared to the estimates for Alternative 3. This range reflects a more conservative approach to attaining “Best Estimate” source terms, rather than being a product of certainty. Rather than direct measurements of the stability of the tailings under this scenario, inferences and a number of assumptions need to be made. As a result, these conservative assumptions were carried forward in the derivation of source terms for the backfilled pit.
- Only one estimate is provided for Alternative 4A-dry. 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. Data limitations prevent the development of a “Best Estimate” and “Worst Case” source terms for this closure option.
- Source terms for Alternative 4A-dry are based on Arctic seepage water quality and are screened against “Worst Case” waste rock data. The higher value is carried forward for the source term. Parameters that screened out from the waste rock source term include cadmium, manganese, and zinc, which are readily soluble under acidic conditions.
- Cyanide terms and associated degradation products (e.g., cyanate, ammonia, nitrate) for Alternative 4A-dry are based on “Worst Case” tailings estimates for Alternative 4A-wet.

8.3.2 Waste Rock Source Terms

Source terms for waste rock have been developed for two general conditions:

- “As is” in a sub-aerial or unsaturated condition; and
- Saturated backfill.

Detailed discussion is presented in Lorax draft technical memorandum (January 2010), as posted onto Sharepoint. The following section presents key recommended source terms as both "Best Estimates" and "Worst Case" ones.

8.3.2.1 As Is Unsaturated Waste Rock Characterisation

While all sources of data are considered in this evaluation, it should be noted that the natural seeps, which have not been disturbed by construction or human activity and have potentially been active for up to ten years, are used as general benchmarks against which all source term estimations have been qualitatively evaluated.

Best Estimates

The first step in developing the best estimates for Mt. Nansen waste rock was to determine the median concentrations of each element in three separate scenarios, including:

1. Each sample site separately (*i.e* median values for each of Lysimeter 1, Lysimeter 2, NW Seep 01, LW Seep 01 and Waste Rock Field Bin 1). In this scenario, the (a) median and (b) average values for each of the five sample sites was then calculated in order to arrive at a number best estimating the central tendency (both weighted and unweighted) of the median values of each of these sample sites;
2. All sample sites together (i.e., median values for the entire data set from all five sample sites together); and
3. Natural Seeps only.

The data from these calculations are presented in Table 8-3. It should be noted that, to remain conservative, all concentrations that were reported to be below detection were set at the limit of detection for all statistical calculations.

Table 8-3. Median Concentrations Calculated for Scenarios 1 to 3 (as above). All values Reported as mg/L.

Scenario	**1a**	**1b**	**2**	**3**
Sulphate	**1530**	1460	1290	1220
$Arsenic_{Total}$	0.00295	0.00475	0.0056	0.0066
Cadmium	0.018145	0.0412	0.00295	0.00277
Copper	0.0055	0.0394	0.005	0.009
Iron	0.01	0.014	0.01	0.01
Manganese	1.79	5.49029	0.0613	0.1137
Zinc	1.2305	5.5409	0.142	0.1305
Calcium	374	355	371	371
Magnesium	188	186	108	93.2
Nitrate-N	0.71	2.212	0.32	0.435
Nitrite-N	0.055	0.085	0.01	0.01
Ammonia-N	0.025	0.02985	0.025	0.025

Next, the median concentrations for each scenario were compared to each other as well as the full waste rock leachate data set in order to select the most appropriate "best estimate" value for "As Is" waste rock. Source term development for each of the ten parameters being considered in this evaluation are discussed in detail in the Technical Memorandum, and recommended values are shown in highlight in the above table.

Worst Case

In order to develop a robust set of source terms, not only is it important to determine the most reasonable best-estimate of drainage expected from the Mt. Nansen waste rock pile, but also it is important to conduct sensitivity testing on the receiving environment water quality model by considering potential worst-case concentrations that may be expected from waste rock at Mt. Nansen. In the current evaluation, the worst case source terms from “As Is” waste rock have been developed by considering the maximum concentrations obtained from any of the five sources of drainage data obtained from Mt. Nansen waste rock over the 2009 season. Additionally, the full SFE data set was also considered when developing worst case waste rock source terms for the “As Is” scenario. Besides As, which had higher reported concentrations from the historic SFE data set, all other worst case source term estimates were assigned as the maximum concentrations obtained from all sources of leachate data at Mt. Nansen. Table 8-4 provides a summary of the best-estimate and worst case “As Is” Mt. Nansen waste rock source terms.

Table 8-4. Mt. Nansen “As Is” Waste Rock Source Term Estimates. All Concentrations are Reported in mg/L

	Best-Estimate	Worst-Case
Sulphate	1530	2940
Arsenic	0.0066	0.030
Cadmium	0.0412	0.184
Copper	0.0394	0.223
Iron	0.01	0.06
Manganese	1.79	28.6
Zinc	1.23	26.2
Calcium	374	463
Magnesium	188	488
Nitrate-N	2.21	9.96
Nitrite-N	0.085	0.36
Ammonia-N	0.3	0.12

8.3.2.2 Waste Rock – “Saturated/Backfill”

Three water samples were collected from the Mt. Nansen saturated waste rock field column experiment on July 23, August 5, and August 19 of 2009 (Table 8-5). This table provides select data for the parameters of concern that are being considered for source term development at Mt. Nansen together with summary statistics.

Table 8-5. Saturated Waste Rock Field Column Data and Summary Statistics. All Values Reported as mg/L

	23/07/2009	05/08/2009	19/08/2009	Median	Mean	Maximum
Sulfate	1890	2040	2140	2040	2023	2140
Arsenic	0.0017	0.0397	0.007	0.007	0.016	0.040
Cadmium	0.0521	0.015	<0.00085	0.015	0.023	0.052
Copper	0.0028	0.0165	<0.0050	0.0050	0.0081	0.0165
Iron	<0.030	0.08	5.28	0.08	1.80	5.28
Manganese	29.4	91.3	134	91.3	84.9	134
Zinc	7.89	1.96	0.576	1.96	3.48	7.89
Calcium	496	499	558	491	518	558
Magnesium	151	253	226	226	210	253
Nitrate-N	<0.50	0.58	<0.50	<0.50	0.53	0.58
Nitrite-N	<0.10	0.34	<0.10	0.10	0.18	0.34
Ammonia-N	0.354	0.978	1.29	0.978	0.874	1.29

Care should be taken when interpreting these data, due to the fact that only three samples have been collected and results, at this point, are considered preliminary. Further monitoring should be conducted to determine the evolution of this system and to better evaluate and constrain the redox influenced drainage values. Nonetheless, the trends observed in the data provide insight into the current behaviour of saturated waste rock and the chemistry that may be expected from these materials at Mt. Nansen.

The data demonstrate that there are four distinct behaviours observed in the parameters of concern being considered. Specifically, elements are seen to exhibit:

a) a consistent increase from one sample to the next (SO_4, NH_3, Fe, Mn, and Ca);
b) a consistent decrease from one sample to the next (Cd and Zn);
c) a net increase from first to last sample (As, Cu, Mg); or
d) no net change (NO_3 and NO_2).

The consistent increase in ammonia, iron, and manganese suggests that the Eh of porewater within the saturated waste rock is decreasing, causing a resultant increase in these redox sensitive species. As well, the associated decrease in Cd and Zn may additionally be a reflection of the reducing conditions being established in this bin resulting in removal of these elements from solution. Although not as pronounced an increase, the conclusion that reducing conditions are being established within the saturated waste rock field bin is bolstered by the net increase observed in dissolved arsenic, which is also a redox sensitive species.

Therefore, with these general trends and preliminary conclusions about the behaviour of waste rock under saturated conditions, source terms have been developed (Table 8-6). Note that all trace metal concentrations presented are dissolved. The best estimate values have been determined based on the higher of the median or mean concentrations. Worst case concentrations, on the other hand, were developed by comparing the maximum concentrations obtained from saturated field column leachate samples, with the worst case concentrations developed for the “As Is” scenario, whichever value was higher was conservatively selected as the worst case concentration for backfilled/saturated waste rock.

Due to the fact that equilibrium conditions have not yet been established in the saturated waste rock field column experiment at Mt. Nansen, it is important to note that, for some elements, the concentrations reported potentially underestimate the long term concentrations that may be expected. For example, concentrations of SO_4, NH_3, Fe, As, and Mn, may increase as reducing conditions are more fully established in the saturated column experiment. On the other hand, elements such as Cd and Zn, which are indicated to be decreasing in response to the establishment of reducing conditions, may be overestimated in Table 8-6. Therefore, further monitoring of the Mt. Nansen saturated waste rock field column experiment is recommended in order to provide better constraints on the saturated/backfilled waste rock source terms.

Table 8-6. Mt. Nansen Saturated/Backfilled Waste Rock Source Term Estimates. All Concentrations are Reported in mg/L

	Best-Estimate	Worst-Case
Sulfate	2040	2940
Arsenic	0.016	0.040
Cadmium	0.023	0.184
Copper	0.0081	0.223
Iron	1.80	5.28
Manganese	91.3	134
Zinc	3.48	26.2
Calcium	518	558
Magnesium	226	253
Nitrate-N	0.53	9.96
Nitrite-N	0.18	0.36
Ammonia-N	0.978	1.29

8.3.3 Low Grade Ore Source Terms

Three water samples were collected from the Mt. Nansen saturated field column experiment on July 23, August 6, and August 20 of 2009 (Table 8-7). This table provides select data for the parameters of concern that are being considered for source term development at Mt. Nansen together with summary statitsics. As discussed previously, these data demonstrate a generally decreasing trend in concentrations for all parameters of concern for the Mt. Nansen project. However, care should be taken when interpreting these data, due to the fact that only three samples have been collected and results, at this point, are considered preliminary. Further monitoring should be conducted to determine the evolution of this system and to better evaluate and constrain ore drainage values. Nonetheless, the trends observed in the data presented in Table 8-7 provide insight into the current behaviour of backfilled Mt. Nansen ore material and the chemistry that may be expected from these materials.

Given the current level of uncertainty in drainage from ore materials at Mt. Nansen, the best estimate values for ore source terms were chosen to represent the greatest amount of spread between the best-estimate and worst case values. Depending on which is farthest from the maximum value, best estimate ore source terms were obtained from either the median or mean concentrations listed in Table 8-7 and are summarized in Table 8-8. Conversely, worst case values were taken as the maximum values listed in Table 8-7.

Table 8-7. Mt. Nansen Ore Field Weathering Bin Data and Summary Statistics. All Values Reported as mg/L

Parameter	23-Jul-09	06-Aug-09	20-Aug-09	Median	Mean	Maximum
Sulfate	2680	2620	1930	2620	2410	2680
Arsenic	0.0173	0.0321	0.0227	0.0227	0.0240	0.0321
Cadmium	0.201	0.108	0.0702	0.108	0.1264	0.201
Copper	0.0364	0.0216	0.0159	0.0216	0.0246	0.0364
Iron	<0.03	<0.03	<0.03	0.03	0.03	0.03
Manganese	97.4	64.9	45	64.9	69.1	97.4
Zinc	31.2	8.39	8.28	8.39	16.0	31.2
Calcium	462	432	358	432	417	462
Magnesium	139	334	350	334	274	350
Nitrate-N	<0.5	0.85	<0.25	0.5	0.533	0.85
Nitrite-N	<0.1	<0.1	<0.05	0.1	0.083	0.1
Ammonia-N	0.0147	0.093	0.0242	0.0242	0.0440	0.093

Table 8-8. Mt. Nansen Ore Source Term Estimates. All Values Reported as mg/L.

Parameter	Best-Estimate	Worst Case
Sulfate	2410	2940
Arsenic	0.0227	0.0321
Cadmium	0.108	0.201
Copper	0.0216	0.0364
Iron	0.03	0.03
Manganese	64.9	97.4
Zinc	8.39	31.2
Calcium	417	462
Magnesium	274	350
Nitrate-N	0.5	9.96
Nitrite-N	0.083	0.36
Ammonia-N	0.0242	0.12

8.4 Surface Water

- Water quality – work in Goldsim for each alternative

Discuss uncertainty
Synthesis using matrix developed for gap analysis

9. Conclusions and Recommendations

Key results summarizing findings that affect characterisation of alternatives, discussing uncertainty.

9.1 Recommendations for Dam Classification

- The classification for any proposed alternative should be reviewed in the final design stage. An appropriate program for maintenance, monitoring, emergency preparedness and dam safety reviews should established at that time.
- Specialists in the fields of environmental and cultural values should be consulted prior to a final recommendation, to assess the potential incremental impacts of dam failure.
- From a dam safety perspective, the partially de-watered tailings backfill disposal scenarios are the only potential "walk away" solutions. Dam safety reviews should be conducted at seven and ten year intervals for *high* and *significant* consequence dams respectively, and maintenance and emergency response programs must be carried out while the dam remains in service (CDA, 2007).
- Moving the tailings to the Brown-McDade pit with a water cover will require the design and construction of another tailings dam. There is little reduction in failure consequence, compared to remediating the existing dam (Alternative 4A(i) vs. Alternative 3A).

9.2 Recommendations Relating to Dam Spillways

The following recommendations are based on the results of the spillway evaluation:

- The adequacy of the armouring and drop structure designs should be assessed more closely, and upgraded where necessary.
- The capacity of the spillway should be upgraded to 18 m^3/s or as required by future analysis. The cross section shown in Illustration (a) show typical cross section.
- Additional hydraulic analysis should be carried out once the design flows have been finalized to:
  - optimize the cross section;
  - assess the adequacy of the drop structures; and
  - assess the adequacy of the armouring.
- Some maintenance is required on the spillway and drop structures to ensure the armouring is in place and effective.
- Alternative 3 (i):
  - The spillway elevation will be set to approximately 1,098.5 m, approximately 0.25 m below the typical soil cover elevation. This will retain a small amount of water in the drainage swales. The spillway will serve to drain all inflows into the tailings area the current capacity of the spillway, upstream Station 0+770 may be sufficient, considering the limited tributary area.

- Alternative 3 (ii):
  - The spillway invert will be set to 1,098.9 m, coinciding with the elevation of the water cover over the tailings. The spillway design capacity could conservatively be set to 10 m^3/s, even though the diversion channel will continue to carry a significant portion of the flood flows.
- Alternative 3 (iii):
  - The spillway invert will be set to 1,098.4,with the same design capacity as for Alternative 3(ii).
- Alternative 4 (all scenarios):
  - The spillway will be removed along with the dam.

9.3 Recommendations for Dam Stability

The following recommendations are based on the results of the task, and their interpretation:

- Assuming that suitable rock fill material is available in the waste rock piles, keying in the toe berm with a wedge of rock fill in a trench excavated down to the main mass of permafrost would be the most economical stabilization alternative.
- Temperature monitoring of the permafrost below a shear key will be required to warn of permafrost deterioration (which can affect the stability of the dam).
- Thermosiphons are an alternative to a shear key. They would maintain and aggrade permafrost beneath the toe berm.
- The existing seepage pond will be filled in with any toe-berm stabilization option. A replacement may be required based on seepage and geo-chemical quality.
- A granular filter should be included as part of a toe berm. Although seepage models do not demonstrate piping potential, observations reported by previous studies indicate that it is occurring, which according to EBA (2002) may be due to thawing of frozen ground allowing for "roofing" and localized high gradients. (EBA, 2002). The filter layer should be extended beneath the toe berm as well if piping potential is identified in the foundation material.
- The toe berm should incorporate a drainage layer at the base. The drainage layer should be at least 1m thick, consisting of compacted rock fill. The drainage layer should be built of geochemically inert material. The existing seepage dyke will be partially breached, and backfilled with compacted rock fill to accommodate drainage.
- The stability analysis should be revisited once a final cover option design has been chosen. The water cover scenario, 3A(i) may require the crest to be raised about 300 mm.
- Regular dam safety assessments (as required by the Canadian Dam Association Guidelines) will monitor the ongoing stability of the dam. Should climate changes degrade existing permafrost or reduce the effectiveness of the thermosiphons, then the potential impacts to dam stability would be identified at that time. This places the burden of ensuring long term safety on future reviewers.

9.4 Recommendations for Diversion at Existing Tailings Dam

The following recommendations are based on the results of the task, and their interpretation:

- The design flows and channel geometries should be reviewed at the final design stage.
- Alternative 3 (ii):
  - The capacity of the diversion channel should be upgraded to $18m^3/s$ or as determined by future hydrological analysis. Illustration (a), is a typical cross section:
    - The access road will be shifted southward; and
    - The bridge will be replaced.

  - The interceptor ditch should be armoured, and slopes flattened to 3H:1V to slow slope degradation, and reduce sediment load. Illustration (b), shows typical armouring requirements.
- Alternatives 3 (i) and (iii):
  - The capacity of the diversion channel should be upgraded to $18m^3/s$ or as determined by future hydrological analysis. Illustration (a), is a typical cross section:
    - The access road will be shifted southward; and
    - The bridge will be replaced.
  - The interceptor ditch will be backfilled and re-graded to match the existing topography. Runoff from the West and South sides of the tailings impoundment area will flow over the tailings, helping to maintain saturation.
- Alternative 4 (all scenarios).

The interceptor ditch and diversion channel will be decommissioned.

9.5 Recommendations for Tailings Backfilling

- Hauling tailings is the preferred option for an experienced contractor for relocating the tailings from the tailings pond to the open pit. The slurry method has potential but involves water management requirements to store water for the process and treatment of the water after the completion of the relocation of the tailings to the open pit. The contamination of a large volume of water necessary for slurring the tailings is also a disadvantage of this method for relocating the tailings to the open pit:
  - drainage layers should be considered in the design as an effective alternative to reduce the time of consolidation (t_{90}).;
  - drainage layers will have the added advantage of facilitating construction by enhancing access and trafficability during the backfilling operation;
  - the soil cover design should consider the uneven settlement of the tailings with time to maintain dry condition in the tailings layer; and
  - provision of multiple drainage layers also has the potential to accelerate consolidation settlement, so that a stable closure cover can be constructed more quickly after the completion of backfilling.

9.6 Recommendations for Pony Creek Diversion

The following recommendations are based on the results of the task, and their interpretation:

- Spilling water back into Pony Creek minimizes environmental disturbance, but may result in higher contaminant levels in the stagnant tailings pond water. Spilling water out of the south end of the Brown McDade pit would flush the water cover, but would require a more complex channel, to connect to Dome Creek.
- The most economical road crossing option, with the least onerous maintenance requirements, would be to implement shallow fords across the diversion channel.
- Diverting water via a cross-slope diversion channel is preferable to a buried conduit because it is easier to construct and is expect to require less maintenance.
- Spillway structures into Pony Creek or Dome Creek would need to satisfy dam spillway requirements established by the CDA Guidelines regarding capacity, and would be subject to ongoing regular assessments.
- Diverting Pony Creek to maintain a water cover is not a desirable option because:
  - Diverting Pony Creek would be an additional environmental impact (vs. leaving the tailings in their current location, or placing them in the pit with a dry cover). If possible, it would be desirable to leave Pony Creek relatively untouched.

- Diversion structures, spillways and tailings dams require ongoing maintenance and are not walk-away solutions.
- The cover water will potentially introduce additional contaminants into Pony Creek or Dome Creek, depending on the choice of spillway options.

9.7 Recommendations Regarding Geochemical Development of Pit Lake and Tailings Rock Source Terms

- Alternative 3a – pit lake source terms - Monitoring of the pit lake should continue into the future to validate source term predictions.
- Alternative 3 – Tailings Source Term – The tailings appear stable in the tailings impoundment. Dam upgrading may alter flowpaths out of the tailings and As removal mechanisms may change. Dome Creek and groundwater flowing through the dam should be monitored during and following dam upgrades.
    - Tailings source terms for Alternative 3 are based on observed water quality from the seepage collection pond (long-term monthly record). Tailings source terms for Option 3 correspond to total flow estimates currently measured for the entire seepage collection pond. In the event these flows change for the upgraded dam, tailings source terms may need to be revised based on the seepage collection pond water balance derived by AECOM and Lorax.
- Alternative 4a (wet) – Tailings Source Term – Derived source terms for wet tailings are based on groundwater data from the tailings impoundment. The tailings + organics field bin will provide valuable data in evaluating metal loadings under suboxic conditions. The field bin sampling program should continue and the source terms should be re-evaluated as field bin data becomes available.
- Alternative 4a (dry) – Tailings Source Term - Derived source terms for dry tailings are based on limited seepage water quality from an analog site. Additional seepage water quality should be sourced from the Arctic Tailings site in order to develop a range of source term estimates in the short-term (e.g., best and worst-case estimates).
    - In the long-term, site-specific kinetic monitoring (e.g., lab and field kinetic experiments) should be continued in an effort to develop site-specific data upon which to derive or validate source term estimates.

10. References

Drawings

Appendix A

Gap Analysis Results

AECOM

Appendix B

Hydrogeology

Appendix C

Geotechnical

Appendix D

Geochemistry

Appendix E

Water Quality

Appendix F

Costing