Modeling Store and Release Covers at Three Northern Mining Properties Using SoilCover

Final Report

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Executive Summary

The long term management of tailings deposits that remain "on-site" after ore bodies have been economically depleted and milling operations have ceased, often represent the largest post operational political and financial risk facing mining companies. One major aspect, common to a complete tailings remedial plan,[1] is the placement of a physical barrier over the footprint of the tailings impoundment; these physical barriers, which are referred to as "caps" or "covers", are designed to protect human and ecological health by obtaining any or a combination of the following performance criteria:

(1) Protecting local water quality by preventing the flux of contaminated waters through the tailings and subsequently into the surrounding ground water (covers only mitigate vertical infiltration from meteoric waters and do not prevent the lateral movement of groundwater into the tailings);
(2) preventing the direct exposure of humans, wildlife and other ecological receptors to the tailings deposit;
(3) preventing wind and water erosion and subsequent downstream deposition of tailings material;

Covers designs can typically be classified into five distinct categories: vegetation only covers, waste rock covers, water covers, conventional covers and store and release covers; each cover design has associated benefits and drawbacks. In order to properly remediate a tailings deposit, each of the above mentioned cover designs must be evaluated within: (1) the context of statistically representative site specific meteorological conditions; (2) the local regulatory regime; (3) the available construction resources; and (4) the prevailing public opinion.

[1] Other parts of a tailings remedial plan may include: long term geotechnical inspections of dam integrity, public awareness campaigns, leachate treatment etc.; the overall plan is highly dependent upon the local regulatory regime, policies of the mining company and the local available resources.

The purpose of this document titled *"Modeling Store and Release Covers at Three Northern Mines using SoilCover"* was to model, based on site specific modeling data and local available resources, store and release covers at the Colomac, Con and Giant Mines. The data generated: (1) will allow a more informed decision to made by northern resource managers regarding the placement of covers on current and historical tailings deposits within the North Slave Geological Province, NWT[2] (Appendix A); and (2) will guide future store and release cover research by AEL. In addition, waste rock and vegetation only covers were modeled as a benchmark for comparison to store and release cover modeling results.

[2] The Slave Geological Province Contains the Con, Colomac and Giant Mines.

Modeling Results

Both the 0.25 and 0.50 m store and release covers with no and poor vegetation preformed well with respect to hydraulics. (0.50m = 9mm or 3% total precipitation and 0.25m = 7mm or 2% of total precipitation; net annual flux at the cover base/tailings interface). Furthermore, the poor vegetation scenarios had a net annual flux from the tailings into the cover material and did not percolate any water into the tailings during the freshet period (Figure 13) (0.25m = -3.77 mm and 0.50m = -7mm; net annual flux at the cover base/tailings interface). It should be noted that the no vegetation store and release covers will be prone to erosion and therefore could incur excessive maintenance costs and lead to long term failure of the cover.

The store and release covers experienced a net drying of the soil profile following freshet (Section 7.3). The 0.25 m store and release cover experienced plant stressing soil matric suctions throughout its entire profile for the modeling period following freshet; as a result the excellent vegetation scenario for store and release covers may be an invalid assumption unless some for of external irrigation is applied. Furthermore, the 0.25 m cover scenario experienced static soil moisture contents below plant stressing limits within the tailings material (4.5 m above water table) (Figure 14). Two plant growth scenarios could occur under these conditions: (1) either the plants will die or experience very limited growth due to moisture stress (roots remain within the low moisture zone of the 0.25 m cover); or (2) the plants will send their roots deeper into the tailings in search of more favorable moisture conditions. The latter scenario poses concern, as the plants transpirational stream may uptake soluble deleterious elements such as arsenic, into its above ground tissues. These above ground tissues could then be ingested by grazing wildlife, leading to possible negative health effects. The 0.50 m store and release cover experienced plant stressing soil matric suctions within the top 0.40 m of its profile (Figure 15). A static soil matric suction below the plant limiting value of 100 kPa was present from 0.40 to 0.50 m within the 0.50 m cover profile. Since favorable moisture conditions were present within the cover profile, plants may not have to extend their rooting system into the tailings material in search of a permanent water supply (may not extend past 0.50 m). Conversely, if the plants only extend their rooting system within the top 0.40 m of the cover profile then vegetation growth may be severely limited or the plant may die. (Section 7.3.5). Vegetation only covers with poor vegetation performed well hydraulically percolating 4% of total precipitation into the underlying water table (Section 7.4). However, The no cover with no vegetation scenario preformed poorly, transmitting approximately 23% of total precipitation into the water table (representative of no remediation of the tailings). As can be seen by comparing Figure 20 and Figure 21 the waste rock only cover scenarios preformed poorly compared to a store and release cover. The waste rock only covers (no vegetation and poor vegetation scenarios) rapidly transmitted water during the freshet period (approximately 27 % of total precipitation). Following freshet, the waste rock only covers had a flux from the tailings to the cover. Both waste rock only scenarios had a annual cumulative base flux of approximately 16% of total precipitation (from the cover into the tailings).

Based on the above discussed modeling results and other factors such as the lack of available cover construction materials within the NWT (Section 8.1.3) and the local political and regulatory regimes (Section 8.1.2), no clear solution currently exists for placing a cover at the Con, Colomac and Giant Mines. Vegetation only covers are the most economically attractive solution and they do limit the transmittal of water into the underlying tailings (Section 7.4). However, they could require long term site access restrictions to prevent direct and indirect exposure of ecological receptors to the tailings materials and they are also subject to much public scrutiny. Furthermore, an excellent vegetation coverage may be difficult to establish due to the semi-arid conditions of the NWT (Section 7.3). Moreover, if a vegetation only cover is to be placed, then all seeding should occur immediately following freshet in order to take advantage of the plant available soil moisture. Experimentation should also be undertaken to select a plant species which does not translocate elements into its above ground tissues; this plant species should also be drought tolerant and slightly halophytic (tolerant to salt).

Waste rock only covers can take advantage of on-site available construction materials (waste rock) for placement of a cover and they also protect against direct ecological exposure (Section 7.5). However, they transmit much water into the underlying tailings, which could lead to the contamination of the surrounding water table. Store and release covers sufficiently address all previously stated cover criteria, provided the cover is of a depth that provides adequate water storage to prevent the translocation of roots into the underlying tailings material. The seed placement and selection should be similar to the vegetation only cover recommendations. However, store and release covers require the placement of large quantities of soil, which is in short supply within the NWT. The future research by AEL will attempt to address the above discussed limitations with respect to placing a final tailings cover in the NWT. The overall goals of the research are to: (1) provide a blended cover material that will take advantage of on-site available construction materials, while limiting the need to open additional borrow/quarry sites (the material will have to be able to allow more infiltration than that of the fine grained giant soil modeled in order to promote the growth of vegetation) (Section 7.1); and (2) identify and propagate a suitable seed line for use in the NWT. Research Goals are discussed within Section 9.0 of this report.

Acknowledgments

I would like to acknowledge and personally thank the following persons for their support and technical advice during the writing and researching of this report: Dr. Fernando Junqueiro for taking time out of his busy schedule to provide guidance during laboratory analysis, modeling and analysis of results; Dr. Ward Wilson and Dr. Sheldon Duff (thesis supervisors) for their willingness to support my project and their wealth of technical guidance; Jaime Romano (Taiga Environmental Laboratories) and Justin Hazenburg (Aboriginal Engineering Ltd.) for collecting tailings samples; Mike Samuels and Ron Connell (Miramar Mining Ltd) for collecting tailings samples and providing access to the Con and Giant mines; Bob Johnson (Aboriginal Engineering Ltd) for providing the funding necessary to ship the tailings samples from Yellowknife to Vancouver; Bob Reid (Water Resources, Indian and Northern Affairs) for providing hydrological technical information and data from the Colomac and Giant mine weather stations; Jay Woosaree (Alberta Research Council) for providing plant species identification; and William H. Albright (Desert Research Institute), for providing information with respect to conventional covers and the Alternative Cover Assessment Program (United States Environmental Protection Agency).

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1.0 Introduction

The long term management of tailings deposits that remain "on-site" after ore bodies have been economically depleted and milling operations have ceased, often represent the largest post operational political and financial risk facing mining companies. (i.e., leaching of contaminants into the surrounding groundwater, direct exposure to the tailings by humans and/or wildlife, physical failure of dams etc.) In order to mitigate these risks, tailings impoundments must be properly abandoned and remediated. One major aspect, common to a complete tailings remedial plan is the placement of a physical barrier over the footprint of the tailings impoundment; these physical barriers, which are referred to as "caps" or "covers", are designed to protect human and ecological health by obtaining any or a combination of the following performance criteria:

(1) Protecting local water quality by preventing the flux of contaminated waters through the tailings and subsequently into the surrounding ground water (covers only mitigate vertical infiltration from meteoric waters and do not prevent the lateral movement of groundwater into the tailings);
(2) preventing the direct exposure of humans, wildlife and other ecological receptors to the tailings deposit; and
(3) preventing wind and water erosion and subsequent downstream deposition of tailings material[3].

Covers designs can typically be classified into five distinct categories: vegetation only covers, waste rock covers, water covers, conventional covers and store and release covers; the reader is referred to Section 3.1 of the Proposal for a detailed discussion pertaining to each of the previously discussed cover forms.

A common liability facing private companies, governmental agencies and public stakeholders within the Northwest Territories (NWT) is the need to properly remediate

[3] Covers can also be designed to prevent the emission of radon gas and the creation of acid mine drainage; these two factors are not within the scope of this thesis and are therefore not discussed.

the many abandoned and currently functioning tailings deposits. Each of the above discussed cover designs must be evaluated within: (1) the context of statistically representative site specific meteorological conditions; (2) the local regulatory regime; (3) the available construction resources; and (4) the prevailing public opinion. Examples of tailings deposits currently within the NWT that will need to receive future remediation are, but not limited to: (1) the Spruce Lake and Tailings Lake deposits present at the Colomac mine; (2) the Upper and Middle Pud tailings impoundments of the Con Mine; (3) the South, Central, North and Northwest tailings impoundments present at the Giant Mine; (4) the tailings deposits at the Discovery mine; and (5) the Long Lake Containment Facilities of the Ekati Diamond Mine

The purpose of this document titled *"Modeling Store and Release Covers at Three Northern Mines using SoilCover"* was to model, based on site specific modeling data and locally available construction materials, store and release covers at the Colomac, Con and Giant Mines. The data generated: (1) will allow a more informed decision to made by northern resource managers regarding the placement of covers on current and historical tailings deposits within the North Slave Geological Province, NWT (Appendix A); and (2) will guide future store and release cover research by AEL. In addition, waste rock and vegetation only covers were modeled as a benchmark for comparison to store and release modeling results.

The following sections of this report will: (1) review store and release cover principles; (2) describe the SoilCover software package; (3) provide an overview of the representative meteorological conditions; (4) detail the modeling inputs and design; (5) discuss the store and release cover modeling results and compare them to the waste rock and vegetation only covers; and (6) summarize the conclusions and future work.

2.0 A Review of Store and Release Cover Mechanisms

The following is a brief review of the principles of store and release covers; for a more detailed discussion, the reader is referred to the Proposal, Section 3.1.5 and Appendix 3.

Store and release covers, employ basic water balance principles; a soil layer holds incoming precipitation until it is removed by evapotranspiration[4]; if the soil layer has sufficient storage capacity, then no deep percolation of water into the underlying wastes will occur. Store and release covers also prevent direct physical exposure of ecological receptors to the tailings and the wind and water erosion and subsequent downstream transportation of the underlying tailings material.

[4] Evapotranspiration is the composed of both evaporation from the soil profile and transpiration from the plant cover.

3.0 SoilCover Model Description

The SoilCover[5] model was selected to characterize the hydraulics of store and release covers at the Giant Mine, NT. SoilCover is a finite element package that simultaneously solves the equations of mass, and energy transfer under transient conditions; Darcy's law models the flow of liquid water through a porous media; Fick's law models the exchange of water vapor between the soil and leaf atmosphere interface; and Fourier's law models the flow of conductive and latent heat within the soil profile. The soil covers are modeled as porous media in one dimension. Boundary conditions at the soil surface (daily mean precipitation and temperature) and soil base (soil suction or water content and temperature) are inputted for each of the specified run days. Initial conditions consist of temperature and soil suction or water content specified at both the surface and base of the soil layer for the first run day. Vegetation can also be incorporated into the model to predict the effects of transpiration. The SoilCover model assumes that all water that cannot infiltrate will runoff. Flat homogeneous surfaces such as a constructed tailings cover are best modeled with SoilCover. Verification of and key fundamental equations and theories for the SoilCover model are contained within the SoilCover users manual (accompanying CD) and (1) other projects which have been completed using Soil Cover and (2) projects which compare SoilCover output to the modeling output of other various hydrological algorithms are available within the following literature sources: (O'Kane , et. al 1997), (Scanlon, et. al 2002), (EDR-ER-279 2001), (G. Savci & A.L. Williamson 2002), (Ernest K. Yanful 2002), (Rykaart et. al 2001), (Wels et. al 2001), (Chammas et. al 2001), (Shurniak & Barboour 2003), (Chapter 4, Hydraulic Analysis and Design) and (Appendix B, Reclamation Cover Performance Modeling). All of the previously listed literature sources are contained within the accompanying CD.

[5] Developed for the Unsaturated Soils Group University of Saskatchewan by Geo-Analysis 2000 Ltd.,

4.0 Meteorological Overview

4.1 Selection of Median and Wet Years (Pocket Lake, Giant Mine)

Based on metrological data from the Pocket Lake, Giant Mine (Photograph 4), for the period between 1995 – 2003, the max or wet and median annual precipitation experienced at the Pocket Lake corresponds to 351.6 mm (2001) and 242.0 mm (1995), respectively. (Pocket Lake 1995 – 2003). Data was provided by Indian and Northern Affairs Canada (INAC) and is also representative of average conditions experienced at the Colomac and Discovery mines (North Slave Geological Province). Statistical data regarding the median and wet year selection and their respective data are presented in Appendix A. In addition, the raw data for the Pocket Lake meteorological station (1995 - 2003) is contained within the accompanying CD.

Data for the individual meteorological variables, (1) specific to the Pocket Lake and therefore the Giant Mine and (2) general to the Discovery and Colomac mines, are presented below for the period between May 1st and Oct. 15th [6] for the years 1995 (median precipitation year) and 2001 (wet precipitation year). In addition, the medians for years 1995 to 2003 are employed as a benchmark for comparison (Section 5.1 discusses the selection of the max and median years and Appendix A contains respective statistical data). Also discussed is the affect of meteoric variables on evapotranspiration a key variable affecting the hydrological performance of store and release covers.

4.2 Precipitation

Precipitation is an important factor that controls the rate of evapotranspiration. As soils begin to dry due to prolonged periods of sparse precipitation the energy required per unit water removed from the soil profile increases; this effect is a result of the increasing attractive forces between the water and soil as soil moisture decreases. Plants begin to

[6] Meteorological data was only presented for the period between May1st and Oct. 15th as this corresponds the selected modeling period.

experience difficulties supplying the energy required to uptake soil water at a soil matric suction of approximately 100 kPa (plant limiting moisture) and can no longer remove water at a soil matric suction of approximately 1500 kPa (permanent wilting point) (plants die once the soil matric suction surpasses the permanent wilting point). Plants respond to the stress of low available soil water by closing stomata which in turn decreases transpiration (photographs 1 through 3 display the stomata of various plant species). In addition, a dry soil leads to decreases in evaporation rates as more solar energy is required to remove water.

Proper consideration of precipitation should take into account two distinct meteoric sources: (1) snow water equivalent and (2) rainfall. Figure 1 presents monthly total rainfall data for the Pocket Lake meteorological station.

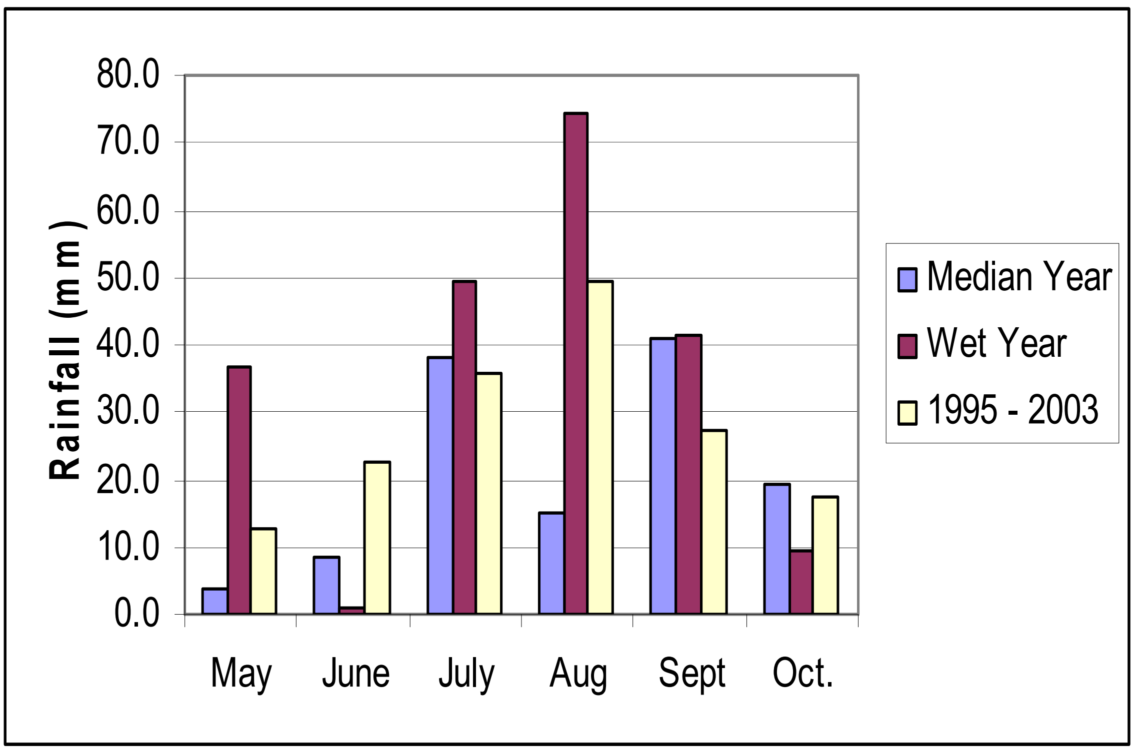

Figure 1 Pocket Lake Monthly Total Rainfall (May – Oct.)

As can be seen in Figure 1, July, August and September tend to be the wettest months, with August receiving the largest total monthly rainfall of 49.4 mm. May and Oct. are the driest months, receiving 12.8 and 17.4 mm total monthly rainfall, respectively (based on 1995-2003 averages).

Snow water equivalent results from the melting of the snow pack during freshet[7]. Freshet, in the Yellowknife area, generally begins on April 29th +/- 1 week and has a duration of approximately 2 weeks in length (1993 – 2003 mean value; Yellowknife A weather station) (Appendix A). Figure 2 displays the relative contribution of snow water equivalent to overall precipitation for the median and wet years based on Pocket Lake data.

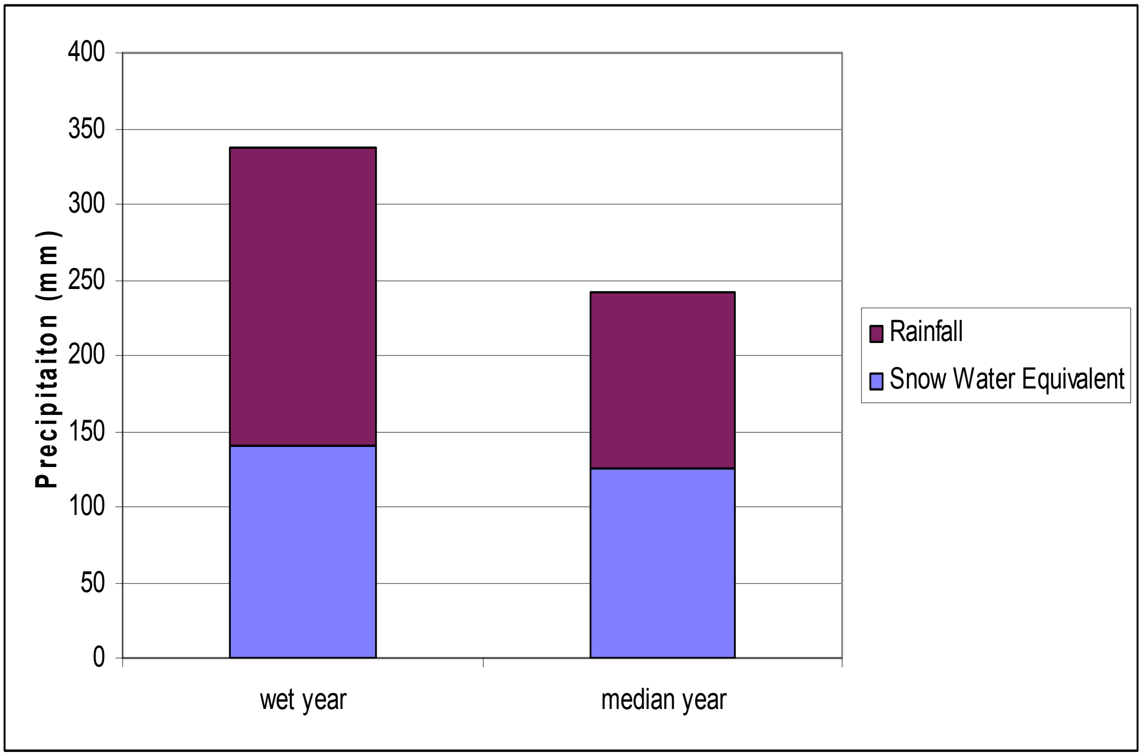

Figure 2 Relative Contribution of Snow Water Equivalent and Rainfall to Precipitation

As can be seen in Figure 2, snow water equivalent accounts for 52% and 42% of total precipitation for the median and wet years, respectively. The melting of the snow water equivalent has a major effect on the hydraulic performance of a store and release cover. The approximately 50% of precipitation contributed by snow water equivalent is

[7] Freshet is the period when the snow pack melts

experienced by the cover with a relatively short period of time (2 weeks), leading to a high demand on cover storage capacity.

4.5 Temperature

Temperature is an important variable as it influences the length of the plant growing season; longer periods above freezing lead to longer leaf area duration and hence, surface area available for transpiration. In addition, temperature affects the ability of the atmosphere to store water vapor; the higher the temperature of the atmosphere the more water vapor it can hold and therefore the greater the rate of evapotranspiration. Figure 3 presents Pocket Lake median daily temperatures.

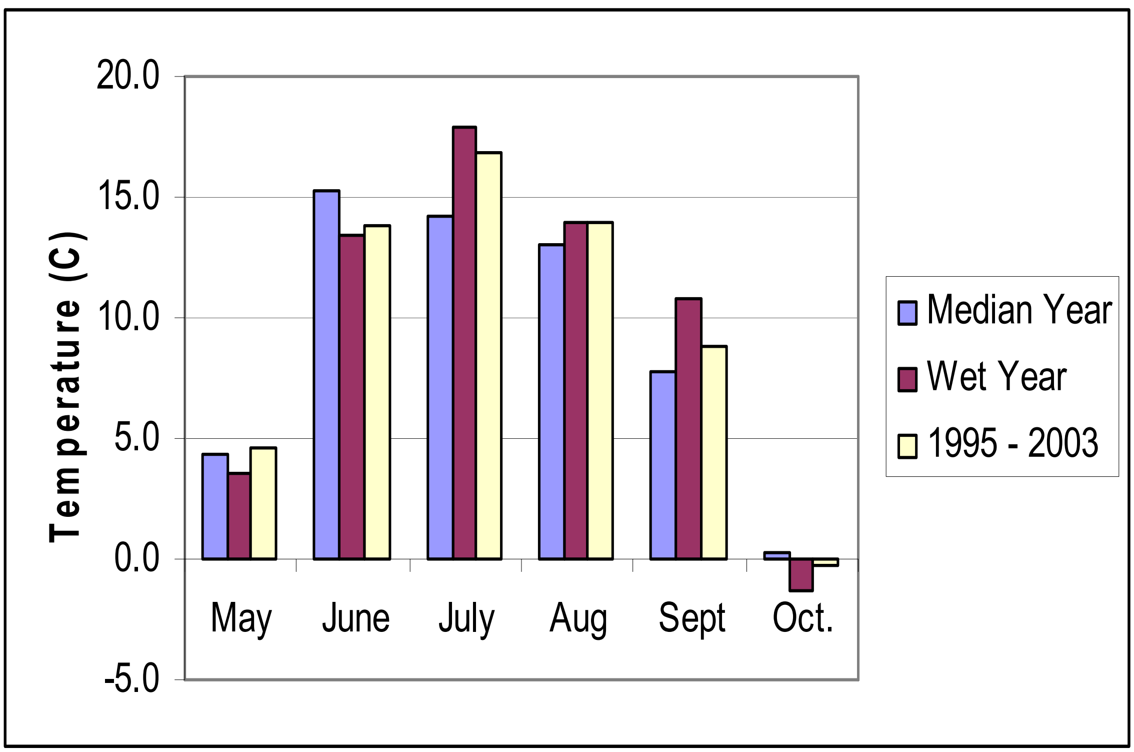

Figure 3 Pocket Lake Median Daily Temperature (May – Oct.)

As can be seen in Figure 3, temperatures are similar between the months of June, July and August with July having the highest median value of 16.9^0C. Temperatures are significantly lower during May with a median value of 4.7^{0}C and drop below 0^{0}C during Oct. (median of -0.3^{0}C) (1995-2003 mean value).

4.6 Net Radiation

Net radiation is essential for high levels of evapotranspiration as it provides the necessary energy to evaporate water from the soil and plant stomata into the surrounding atmosphere. In addition radiation also regulates the opening of stomata. As can be seen in Figure 4, Pocket Lake receives high median daily levels of net radiation between May and August due to the long hours of daily sunshine; this fact allows for large quantities of water to evapotranspirate in a relatively short time period (essential for the efficient: functioning of a store and release covers). Median net radiation drops significantly during Sept. and Oct. as the hours of daily sunshine begin to decrease (data for daily hours was multiplied by a factor of ten to allow a better visual representation).

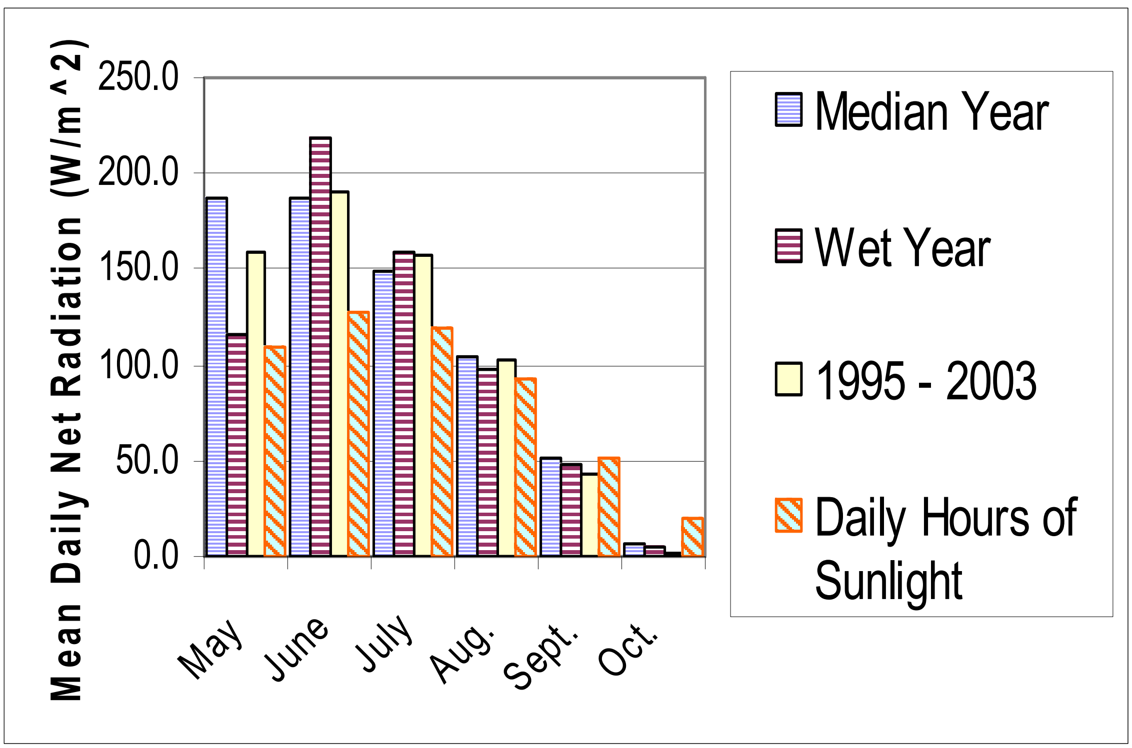

Figure 4 Pocket Lake Mean Daily Net Radiation (May - Oct.)

4.7 Wind Speed

Wind speed directly influences evapotranspiration rates through its affect on the moisture barrier layers between the leaf/atmosphere and the soil/atmosphere. High wind speeds lead to turbulent wind flow, which both: (1) decreases the width of the atmospheric boundary layer at the leaf/atmosphere interface; and (2) removes excess moisture from the bulk atmosphere surrounding the soil and leaf boundary layer. The result of these effects is a sustained high water vapor gradient and a decrease in the diffusional path length, which leads to a large potential for mass transfer of water to the atmosphere. Median wind speed at Pocket Lake remains relatively constant from May to August at approximately 7.5 km/h and then drops slightly during Sept and Oct., with respective values of 5.8 and 4.9 km/h.

4.8 Relative Humidity

A relative humidity gradient between the leaf/soil surface and the atmosphere provides the driving force for mass transfer of water; no mass transfer of water will take place without a relative humidity gradient between the boundary layer and the surrounding atmosphere Evapotranspiration approaches zero as the relative humidity of the atmosphere sounding the soil and leaf boundary layer approaches 100% (i.e., saturated with water). Furthermore, as temperature decreases the ability of the atmosphere to hold water vapor also decreases, resulting in an increase in relative humidity. Pocket Lake median daily relative humidity is similar for May, June and July with a median value of 59.2 % and increases from August to Oct. to a maximum median value of 87.5% in Oct.

5.0 Modeling Inputs

The following sub sections describe the modeling inputs; the SoilCover model requires the input of mean meteorological variables on a daily time step. Additional required model inputs include the following soil properties: soil-water characteristic curve (SWCC), porosity (%P), specific gravity (G_s), saturated permeability (k_{sat}) and coefficient of volume change (M_v). Descriptions of these variables are available within the SoilCover manual. In addition, the modeling run length, length of growing season, latitude, root depth, vegetation status (i.e., none, poor, good or excellent) and moisture limiting and wilting points are also required input.

5.1 Modeling Period

Each modeling run corresponded to the period between May 1st and Oct. 15th (166 days). This time period was selected as it spans the beginning of freshet to the beginning of freeze up (Appendix A).

5.2 Meteorological

The meteorological input variables for the SoilCover model were presented in the previous section of this report titled Meteorological Overview. Values for median daily precipitation, net radiation, temperature, relative humidity and wind speed were used as modeling inputs for the wet year respectively; the wet year was chosen as this represents the upper limit for cover performance and therefore a conservative modeling approach. The raw meteorological data for the Pocket Lake is provided within the attached CD.

5.3 Soil Properties

Three soils were chosen for modeling: (1) tailings from the beach adjacent to Dam 1 at the Colomac Mine (tailings); (2) a mean fine grained material from local borrow sources at the Giant Mine (giant); and (3) a waste rock material.

5.3.1 Giant Mine Mean Borrow Soil (Cover Material)

Data for the sample selected to represent a fine soil was obtained from the report prepared for the Giant Mine Remediation Project titled, "*Report on Giant Mine Borrow Investigation*" (Golder 2004). The mean for the grain size distribution curves from each of the individual borrow sites listed within the Golder report were calculated and then an overall mean was found across the entire set (Figure 5). This overall mean grain size distribution curve was selected to represent the giant fine grained soil and was used to model the store and release covers. As can be seen in Figure 6, the SWCC for the giant sample is gradually sloping and has an air entry value of approximately 10 kPa. The properties of the giant sample are typical of an unconsolidated fine soil.

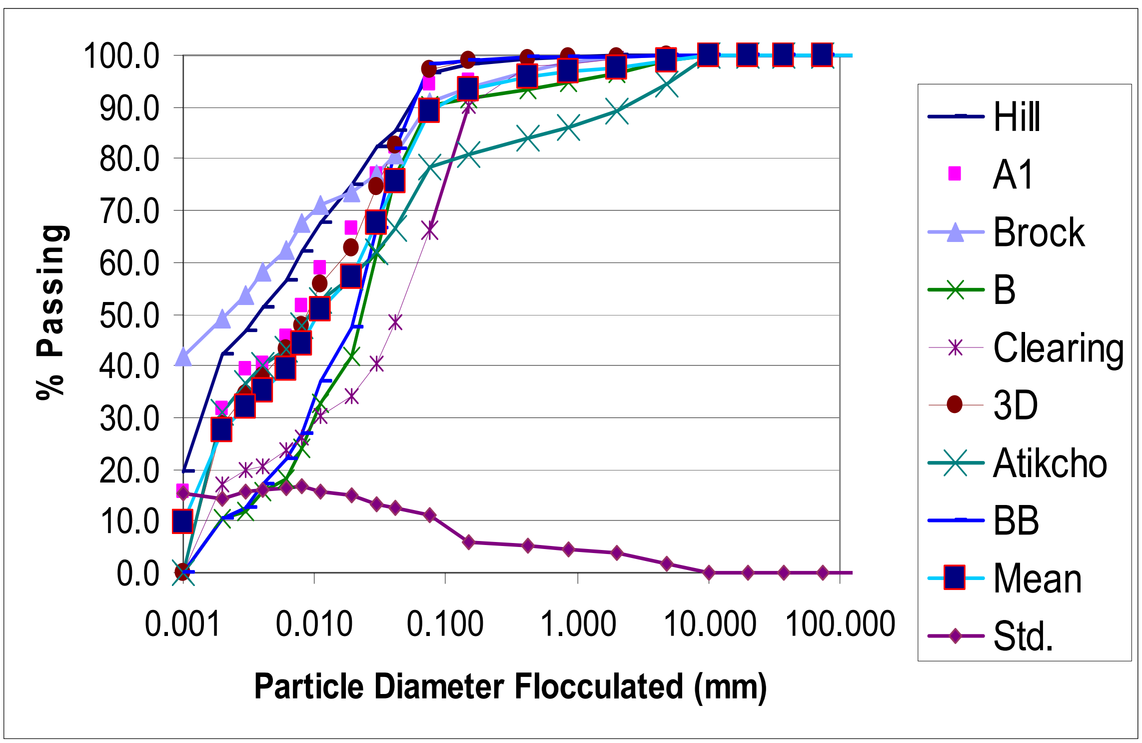

Figure 5 Giant Mine Mean Borrow Source Grain Size Distribution Curve (Cover Material)

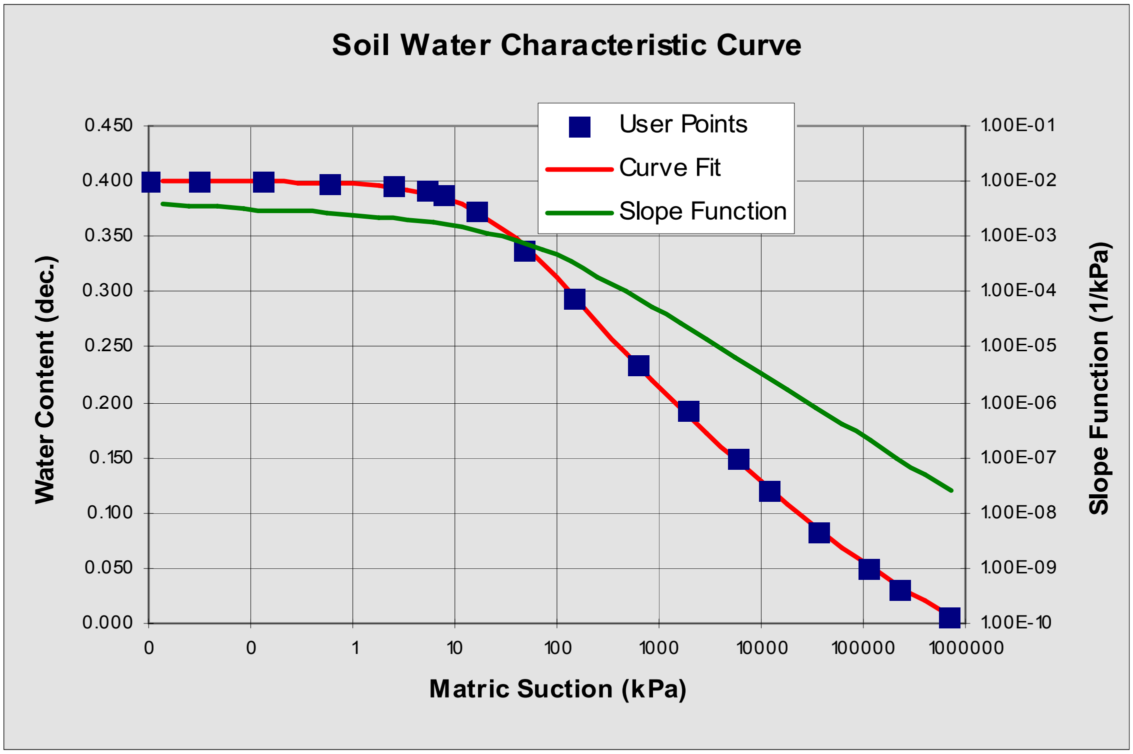

Figure 6 Giant Mine Mean Borrow Source SWCC

5.3.2 Colomac Mine Dam 1.0 Tailings (Tailings Material)

The soil selected to model tailings was obtained from the Colomac Site Remediation Plan, 2004, Supporting Document K, titled *"Borrow Source Assessment"* (SRK 2003) As can be seen in Figure 7, the sample was well sorted and coarse grained; approximately 90% of the samples mass is composed of sand sized particles and the remaining 10% is silt or smaller. The steep slope of the SWCC curve (Figure 8) and the K_{sat} (1.0E-05 cm/s) (Table 1) are compatible with that of a coarse grained and poorly sorted material. The air entry value for the Dam 1 sample is approximately 10 kPa.

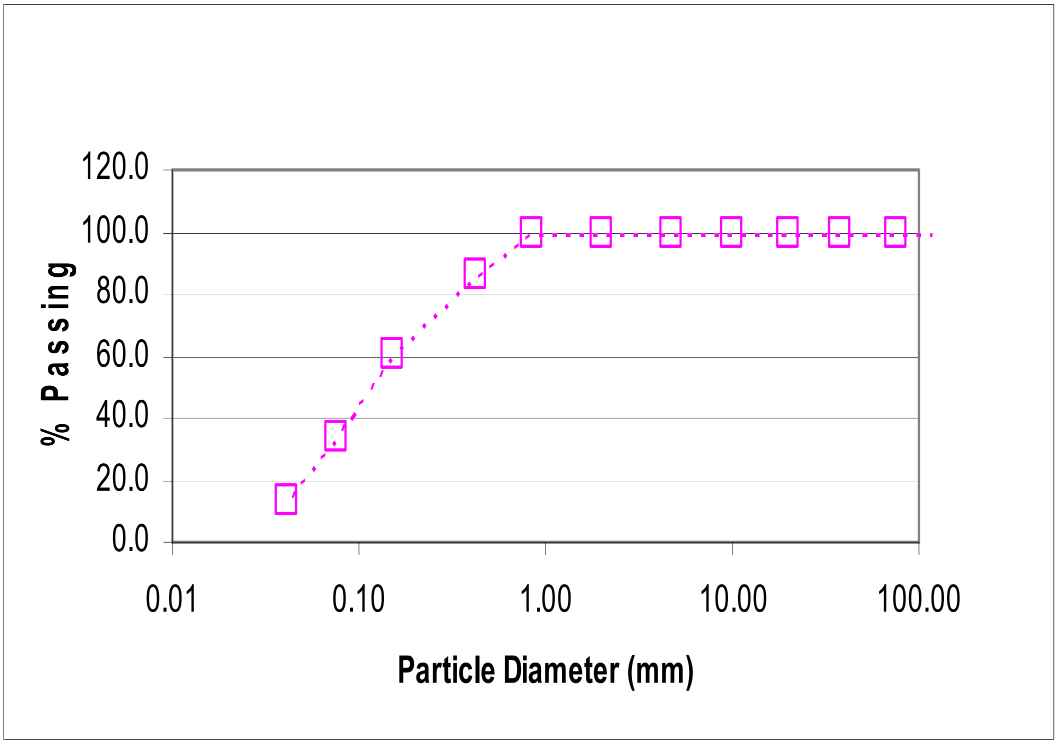

Figure 7 Colomac Mine Dam 1.0 Tailings Grain Size Distribution Curve (Tailings Material)

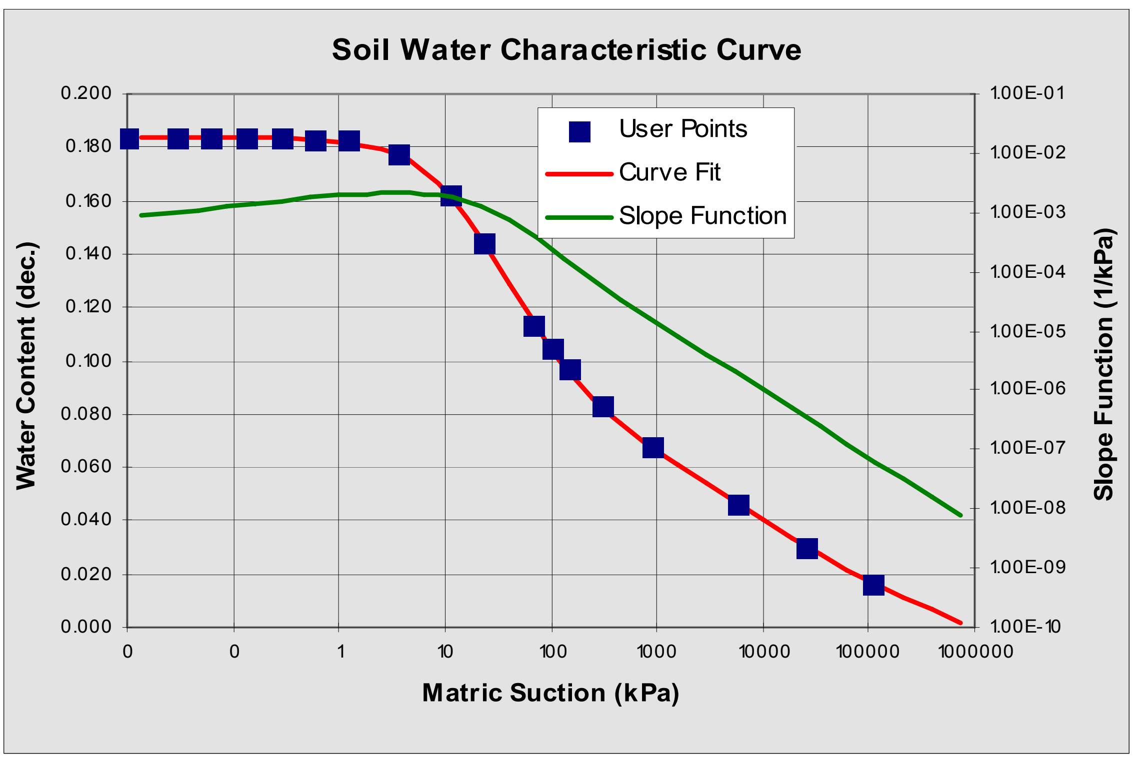

Figure 8 Colomac Dam 1.0 Tailings SWCC

5.3.3 Waste Rock (Cover Material)

The soil selected to model a waste rock cover was chosen on a conservative assumption that some fines such as clay or silt would be present along with the coarser material. In addition, an upper particle size of gravel was set as a ceiling limit. These criteria were chosen to allow the modeling results from the waste rock sample material to represent an upper limit on the performance that could be expected for a cover constructed entirely of waste rock. A waste rock cover was modeled to provide an alternative cover to which a store and release cover could be compared. A sample fitting the above mentioned criteria was found in the literature within the report titled "*Predicting the soil-water characteristics of mine soils.*" (Danziger, D. & Weiskopf, R. 1999). As can be seen in Figure 5, 42% of the samples mass is composed of gravel sized particles; 31% is sand; and the remaining 27% is silt or finer. The SWCC for the waste rock sample, presented in figure 10, has a fairly gradual slope and an air entry value of approximately 10 kPa. The air entry value coupled with K_{sat} (1.0E-04 cm/s) (Table 1) and the SWCC slope suggests that the fine grained material influences the hydraulic behavior of the waste rock material.

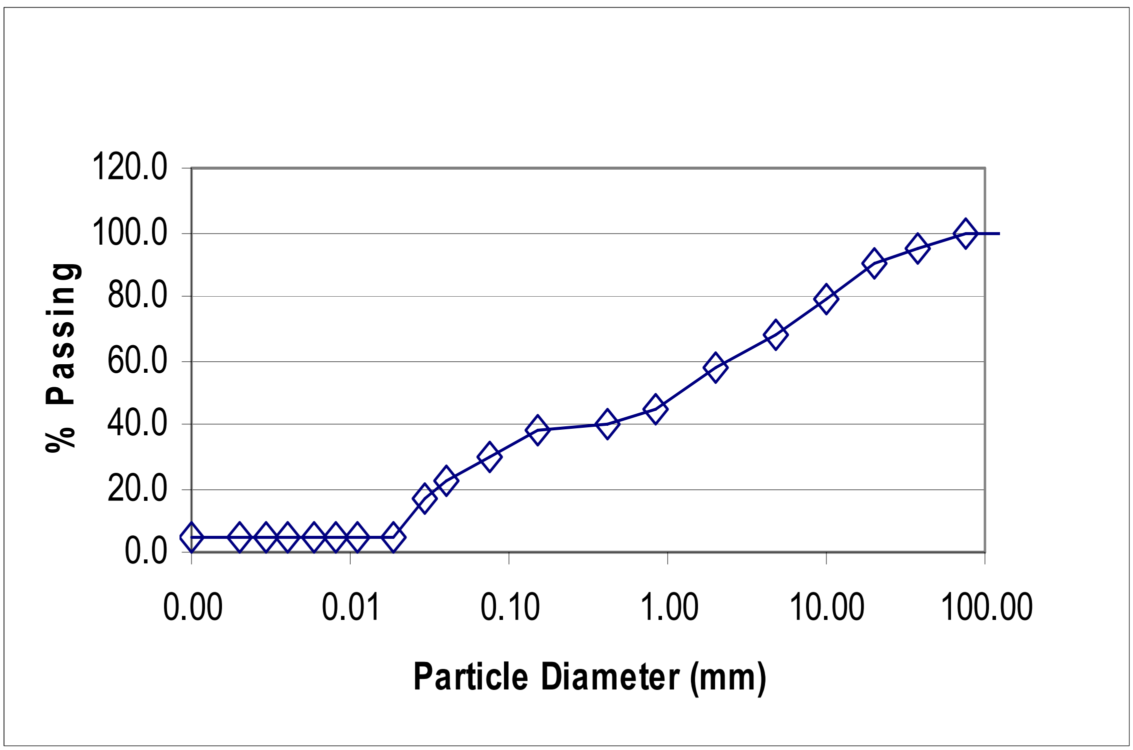

Figure 9 Waste Rock Grain Size Distribution Curve

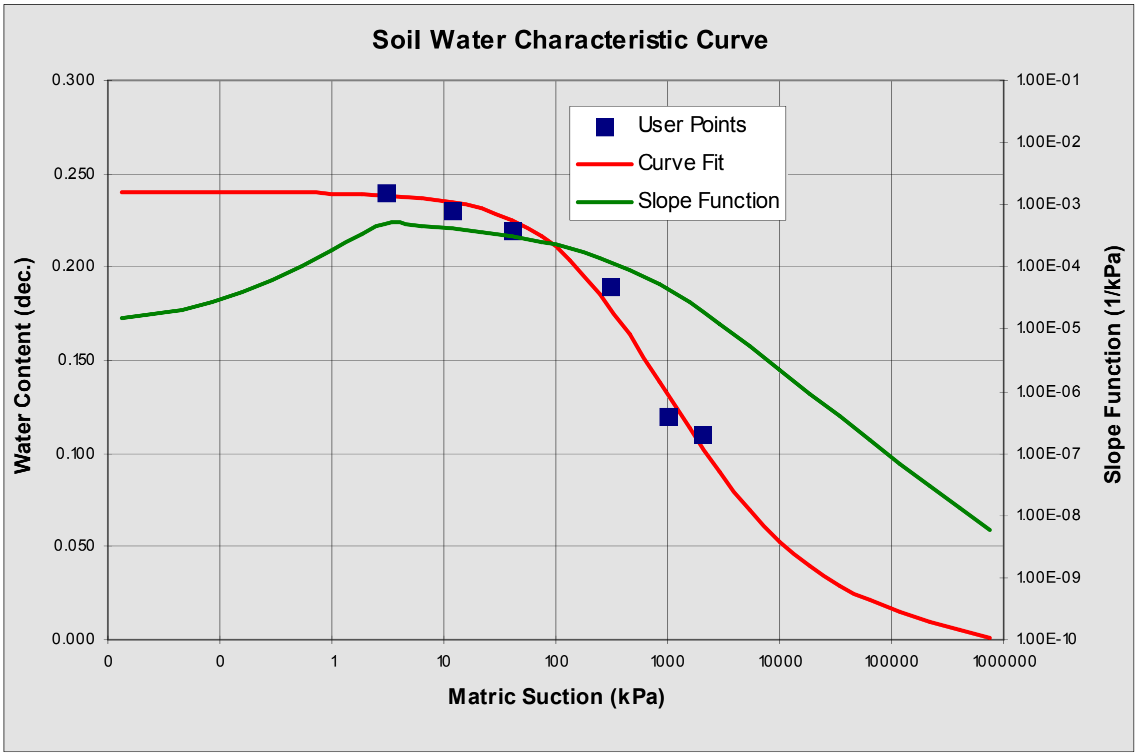

Figure 10 Waste Rock SWCC

The following Table 2 presents the G_s, K_{sat}, M_v and %P of the above mentioned three soils.

Table 1 K_{sat}, M_v, G_s and %P for the Waste Rock, Tailings and Giant Soils

Soil	K_{sat} (cm/s)	G_s	%P	M_v (1/kPa)
Waste Rock	1.0E-04	2.8	0.35	1.35E-05
Tailings	1.0E-05	2.8	0.35	1.30E-05
Giant	5.8E-06	2.8	0.40	2.4E-05

5.3.4 SWCC Generation

Data from the grain size distributions presented above for each of the selected soils, along with two mass properties were inputted into the SoilVision[8] software, which employed a pedotransfer[9] function to estimate the corresponding SWCC data points; these points were subsequently used by the SoilCover program to fit a SWCC curve using the method developed by Fredlund and Xing (1994). (SoilCover 2000).

5.4 Vegetation

The selection of slender wheatgrass (*Agropyron trachycaulum)*, the vegetation used in modeling, was based on vegetation surveys of the Discovery, Con and Giant Mines conducted by staff from Aboriginal Engineering Ltd. (AEL) and Jay Woosaree, Project Leader, Native Plants Program of the Alberta Research Council (ARC). Slender wheatgrass was noted as growing throughout both impacted and non-impacted areas of the above mentioned three mine sites. Slender wheat grass grows as an erect, tufted bunchgrass ranging in height from 2 to 2-1/2 feet and has an average rooting depth of 45 cm. This rooting depth was adjusted to 30 cm to reflect a conservative estimation for modeling purposes. A document detailing additional properties of slender wheatgrass in contained within the accompanying CD.

The average growing season for the Yellowknife area ranges between 120 to 140 days (3rd Edition, 1957, Atlas of Canada) (Appendix A); 122 days was selected as the growing season, as this value corresponded to the beginning of May and the end of August

5.5 Boundary Conditions

For each day of all modeling runs, the soil base boundary condition was set to both: (1) 0 kPa matric suction at a depth of 5m[10]; and (2) a temperature of 0.5^{0}C. These conditions correspond to a water table of 5m at a temperature slightly above freezing. The upper

[8] Soil Vision Systems
[9] A document describing the
[10] A depth of 5m for the water table was based on the piezometer data contained within the accompanying CD.

boundary condition for each day of all modeling runs was set to its corresponding Pocket Lake daily precipitation value (wet year). Initial conditions consisted of the following: (1) a top soil layer temperature and matric suction of 0.75 ^{0}C and 10 kPa (air entry value), respectively; and (2) a soil base temperature and matric suction of 0.5^{0}C and 0 kPa (saturated soil), respectively. Each modeling scenario was initially run for 5 years; year 1 received the above mentioned initial conditions. The matric soil suction profile at the end of the first year was then entered as the initial conditions for year 2. These steps were repeated for the five year modeling period and were undertaken to minimize the error associated with estimating the initial conditions, as no field data was available.

6.0 Modeling Design

A factorial design was selected to create a distribution of modeling input combinations. Coverer depth (0.25 and 0.50 m) and vegetation coverage (none, poor, excellent) were selected as the varied input variables. All other modeling parameters remained constant. Table 2 displays the combinations of input variables used for modeling store and release covers (table generated with the jump in statistical software)

Table 2 Factorial Design

Trial	Combination	Cover Depth	LAI
1	31	0.25m	Poor
2	32	0.25m	Excellent
3	12	0.50m	Excellent
4	13	0.50m	None
5	11	0.50m	Poor
6	33	0.25m	None

Cover depth and vegetation coverage were selected based on economical and environmental considerations. The upper limit of 0.50 m for cover thickness is based on the limited available fine grained borrow sources at the Giant Mine. According to Golder, there is currently 710, 000 m^3 of silt to silty clay borrow soils available on-site at the Giant mine (Golder 2004). Furthermore, the available fine grained borrow materials within the Yellowknife area have been mostly removed during previous construction activities. The footprint of the Giant Mine tailings deposit is 94.9 hectares or 940,900 m^2 (Photographs 6 and 7). Distributing 0.50 m evenly across the tailings footprint would require the use of 474, 500 m^3 of fine grained soils, leaving 235,500 m^3 of fine grained soils for use in other reclamation activities at the Giant Mine (dams, liner base material etc.). In addition, waste rock only and vegetation only covers were modeled as benchmark for comparison of store and release cover modeling results.

Table 4 presents the economical and environmental considerations with respect to vegetation coverage and cover thickness and Figure 12 presents a cross section profile of the cover model.

Table 3 Input Variable Selection (Economic and Environmental Factors)

Response Variable	Economical Considerations	Environmental Considerations
Increasing LAI (vegetation coverage)	Additional labor, seeds and amendments	Positive: lower erosion, healthier ecosystem
Increasing cover thickness	Additional Borrow soils and labor to place	Negative: additional environmental disturbances due to borrowing

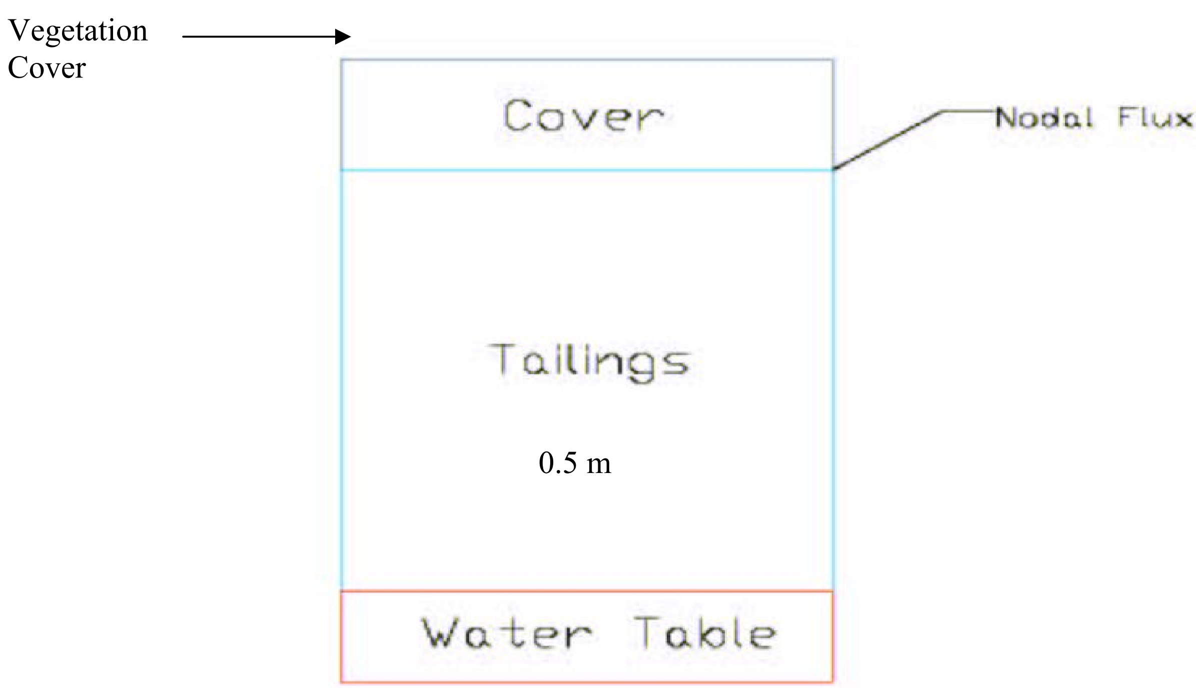

Figure 11 Cover Cross Section

7.0 Modeling Results

7.1 Water Balance

The overall water balance for a tailings cover can be stated as follows:

Precipitation – Surface Runoff – Percolation – Evapotranspiration = Soil Storage (eq.1)

Table 4, presented below, tabulates the above stated water balance variables for the 0.50 and 0.25 m store and release covers with poor and excellent vegetation.

Table 4 Water Balance (Store and Release)

Cover Depth (m)	Veg. Cov.	AT* (mm)	AE** (mm)	AET*** (mm)	Runoff (mm)	Base Flux (mm)	Soil Storage (mm)	Precip. (mm)
0.25	poor	40.5	120.0	160.5	223.3	3.80	-36.0	351.6
0.25	ex.	115.0	80.8	195.8	195.0	0.26	-40.1	351.6
0.50	poor	42.0	120.0	162.0	224.9	6.06	-41.3	351.6
0.50	ex.	118.0	81.0	199.0	195.0	6.10	-48.5	351.6

*AT= Actual Transpiration
**AE = Actual Evaporation
***AET = Actual Evapotranspiration

As can be seen in Table 4, the 0.25m and 0.50 m cover depths had similar values for water balance variables between the poor and excellent vegetation scenarios. Runoff had a major influence on the hydraulics of the store and release covers, shedding 63% of total annual precipitation for the poor vegetation scenarios for both the 0.25 and 0.50 m cover depths and shedding 55% of total precipitation for the excellent vegetation scenarios for both the 0.25 and 0.50 m cover depths. Figure 12 displays cumulative cover runoff versus modeling day.

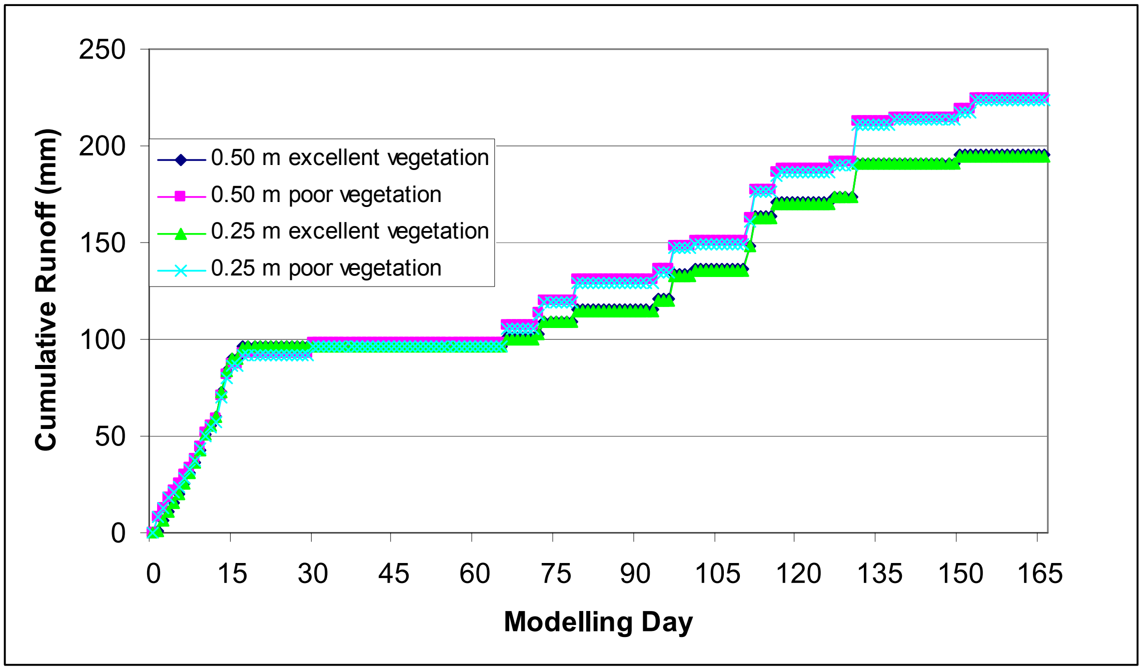

Figure 12 Cumulative Runoff Versus Modeling Day

As can be seen in Figure 12, the overall trends are similar for all modeling scenarios; runoff is most pronounced during freshet and following individual rain events. This is due to the saturation of the cover soil during these time periods; saturated soils will shed addition precipitation. Runoff during freshet accounts for approximately 28% of total runoff for all modeling scenarios.

In addition, all cover scenarios experienced an net drying trend with a mean of 41.5 mm of water being removed from the soil profile (std. = 5.2 n=4). Evapotranspiration increased slightly between the poor and excellent vegetation scenarios, increasing by approximately 35 mm from the poor to excellent vegetation for both the 0.25 and 0.50 m cover depths (transpiration increased and evaporation decreased between poor and excellent vegetation by approximately 75 mm and 40 mm, respectively, for both the 0.25 and 0.50 m covers).

7.2 Flux at the Store and Release Cover and Tailings Interface

Figure 13 presents the annual cumulative flux at the store and release cover and tailings interface for the factorial design modeling inputs.

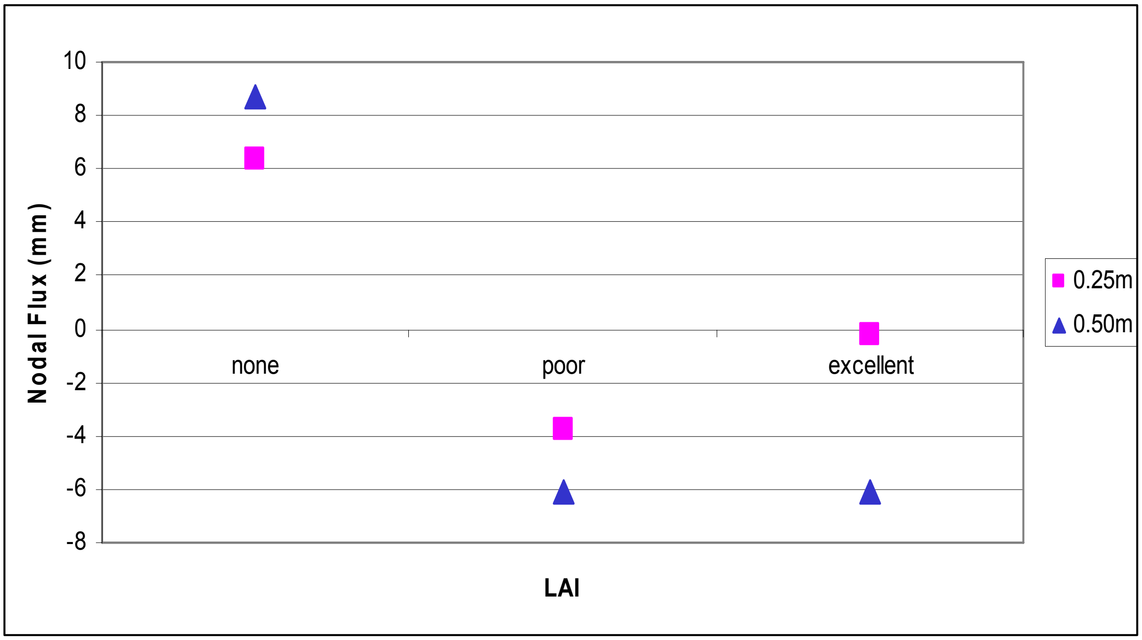

Figure 13 Store and Release Cover and Tailings Interface Annual Cumulative Flux

As can be seen in Figure 13, the annual cumulative flux decreases from the no vegetation to the poor vegetation scenarios for the both the 0.25 and 0.50 cover depths. The annual cumulative flux for the no vegetation scenarios were from the cover into the tailings (0.50m = 9mm or 3% total precipitation and 0.25m = 7mm or 2% of total precipitation). The annual cumulative flux for the poor vegetation scenarios were from the tailings into the cover (0.25m = -3.77 mm and 0.50m = -7mm). An unexpected data trend occurred when the vegetation coverage was adjusted from poor to excellent; the flux at the cover/tailings interface either remained constant (0.50 m) or increased (0.25m, -3.7 mm to 0.25 mm). The flux was expected to further decrease, as the increase in vegetation should have removed more water from the soil profile via additional transpiration. This unexpected trend can be explained by the effects of the drying soil profile (post freshet) on plant transpiration, which is further discussed within the following section.

7.2.1 Anomalous Data Trend (Annual Cumulative Flux, Poor to Excellent Vegetation)

When the vegetation coverage of a store and release cover increases, the amount of solar energy reaching the soil profile decreases, leading to lower soil evaporation rates; this decrease in evaporation is generally compensated for by a corresponding large increase in transpiration. In addition, a dense vegetation coverage also tends to trap more water at the surface of the cover, leading to higher infiltration of meteoric water. As stated previously, when the vegetation coverage was increased the net annual evaporation decreased by approximately 40 mm and the net annual transpiration increased by approximately 75mm, leading to a 35 mm net annual increase in water removal from the cover profile. This increase was offset by the decrease in net annual runoff between the poor and excellent vegetation scenarios (approximately 30 mm). The overall result of the change from poor to excellent vegetation coverage scenarios was no net decrease in cover base flux. If the plant transpiration was not limited by the effects of the drying cover profile (Section 7.3), the increase in transpiration would most likely have more than offset the decrease in runoff, leading to an overall decrease in net annual cover base flux. The excellent vegetation assumption does not seem to be valid for the climatic condition present at Pocket Lake[11].

7.3 Effects of Cover Soil Drying Trend on Cover Vegetation

The soil suction values predicted by the SoilCover model (post freshet) could have a negative impact on the health of the cover vegetation.

[11] This effect could be offset through irrigation; treated mine drainage could be used to supply the necessary additional moisture to promote the growth of an excellent vegetation coverage.

7.3.1 0.25 m Cover Depth (Soil Matric Suction)

As can be seen in Figure 14, the cover was initially dry (approximately 11,000 kPa at the soil surface and 1000 kPa at the cover base). The cover then quickly became saturated during the freshet period, with corresponding soil suctions below the plant limiting moisture value of 100 kPa. Following freshet, the cover quickly dried at the soil/atmosphere interface, becoming essentially void of water for the duration of the modeling period (with the exception of periods of rainfall when the surface rapidly wets and then rapidly dries again). The drying effect became less pronounced with cover depth. Soil moisture reached the wilting point (1500 kPa) at a depth of 0.10 m below the cover surface at approximately day 37 and remained above the wilting point for the remainder of the modeling period. Soil suction remained just below the plant wilting point for the entire modeling period at the cover base (5.0 m). A static soil moisture of approximately 80 kPa was experienced at a depth of 4.5 m above the water table or 0.25 m below the 25 cm cover base. Atmospheric influence extended throughout the entire cover profile.

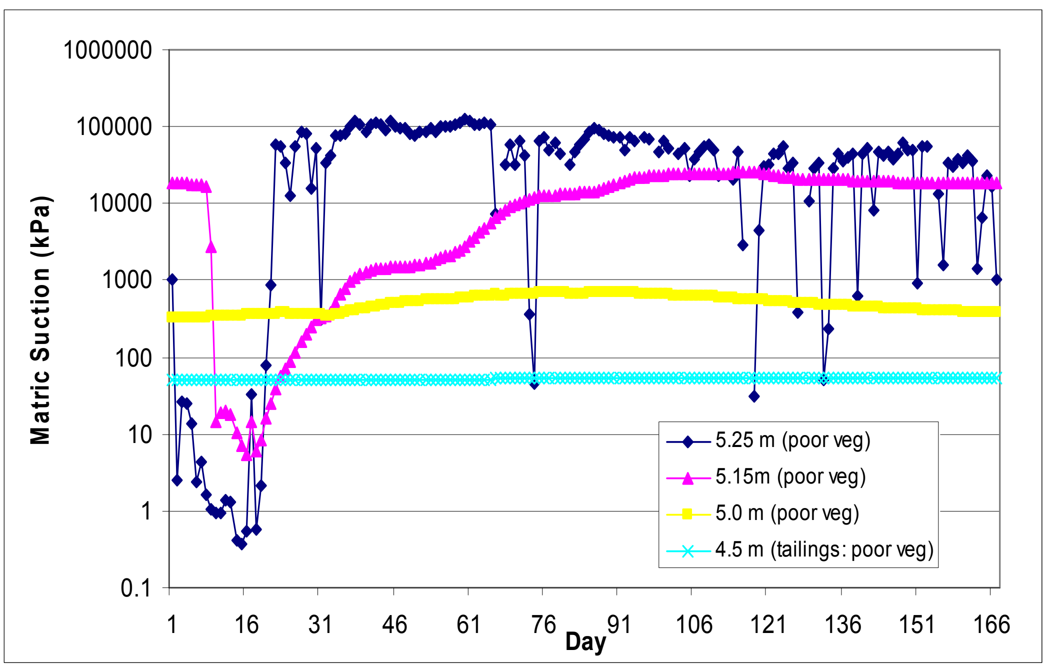

Figure 14 Soil Matric Suction Versus Modeling Day (0.25 m Cover Depth and Poor Vegetation)

7.3.2 0.50 m Cover Depth (Soil Matric Suction)

As can be seen in Figures 15, the 0.50 m cover had similar matric suction trends as the 0.25 m cover; initially the 0.50 m cover was dry (approximately 3000 kPa at the soil surface and 90 kPa at the cover base). Following freshet, the surface dried less rapidly than that of the 0.25 m cover. Nonetheless, the 0.50 m cover surface was very sensitive to rainfall events and remained extremely dry for the period following freshet. The plant wilting point was reached at approximately day 38 at a depth of 0.10 m below the surface. The static moisture content occurred at a depth of 0.40 m below the cover surface, remaining at approximately 90 kPa. Overall, atmospheric effects seemed to be limited to the top 0.40 m of the cover profile.

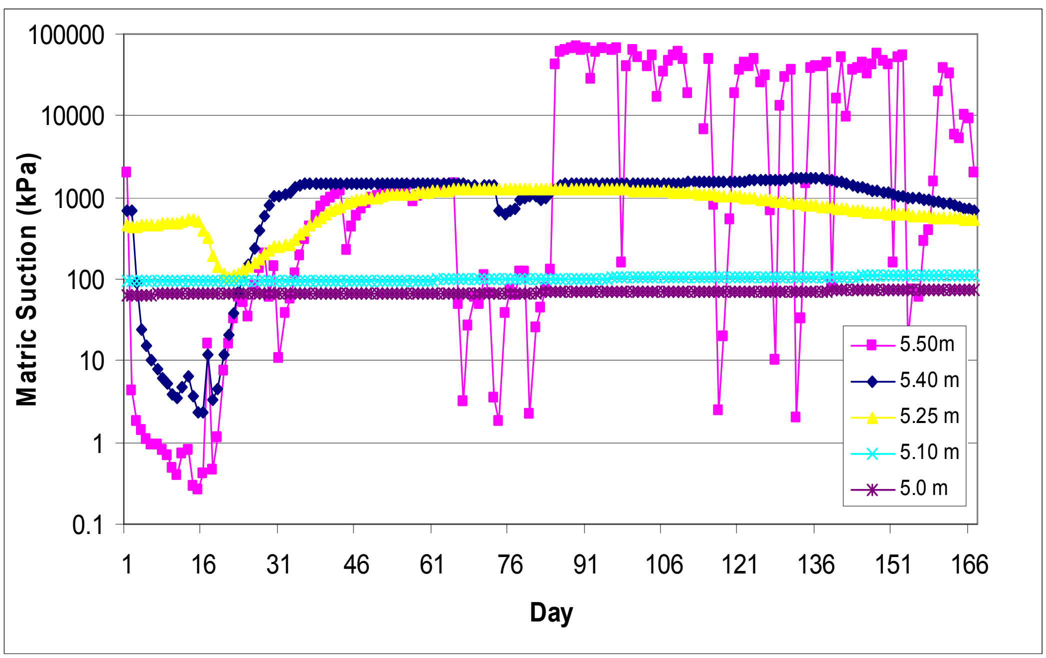

Figure 15 Soil Matric Suction Versus Modeling Day (0.5 m Cover Depth and Poor Vegetation)

Photographs

7.3.3 Negative Effects on Cover Vegetation

The 0.25 m store and release cover experienced plant stressing soil matric suctions throughout its entire profile for the modeling period following freshet. Furthermore, the 0.25 m cover scenario experienced static soil moisture contents below plant stressing limits within the tailings material (4.5 m above water table). Two plant growth scenarios could occur under these conditions: (1) either the plants will die or experience very limited growth due to moisture stress (roots remain within the low moisture zone of the 0.25 m cover); or (2) the plants will send their roots deeper into the tailings in search of more favorable moisture conditions. The latter scenario poses concern, as the plants transpirational stream may uptake soluble deleterious elements such as arsenic, into its above ground tissues. These above ground tissues could then be ingested by grazing wildlife, leading to possible negative health effects.

The 0.50 m store and release cover experienced plant stressing soil matric suctions within the top 0.40 m of its profile. A static soil matric suction below the plant limiting value of 100 kPa was present from 0.40 to 0.50 m within the 0.50 m cover profile. Since favorable moisture conditions were present within the cover profile, plants may not have to extend their rooting system into the tailings material in search of a permanent water supply (will not extend past 0.50 m). Conversely, if the plants only extend their rooting system within the top 0.40 m of the cover profile then vegetation growth may be severely limited or the plant may die.

7.3.4 Root Uptake

Figure 16 displays the effects of the post freshet soil drying trend on root flux (uptake of water by roots) for the 0.25 m cover depth with poor vegetation. Root flux is high during the freshet period when soil water is readily available. Following freshet, root uptake quickly drops to zero at the surface of the cover and ceases at approximately day 47 at a depth of 0.10 m from the cover surface. Root uptake is present at the base of the cover for the entire modeling period, suggesting that sufficient water is available for vegetation growth at the base of the 0.25 m cover. Once again, this may lead to plants extending their roots into the tailings in search of a constant water supply.

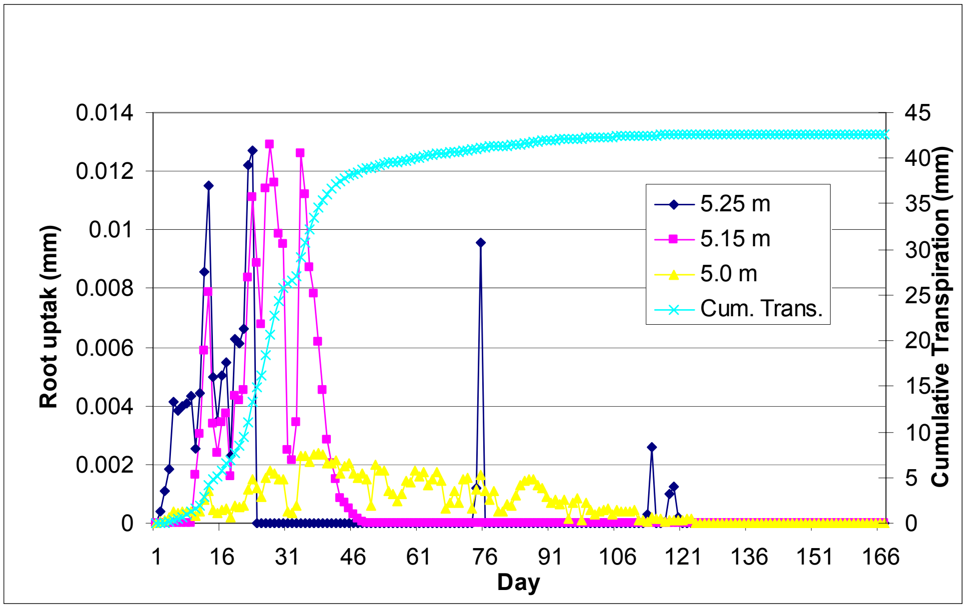

Figure 16 Root Flux Versus Modeling Day (0.25 m Cover with Poor Vegetation)

As can be seen in Figure 17, trends were similar for the 0.50 m cover depth with poor vegetation. However, the constant annual root flux began at the mid point of the cover depth, suggesting that plants may not have to extend their roots into the tailings in search of a constant supply of water.

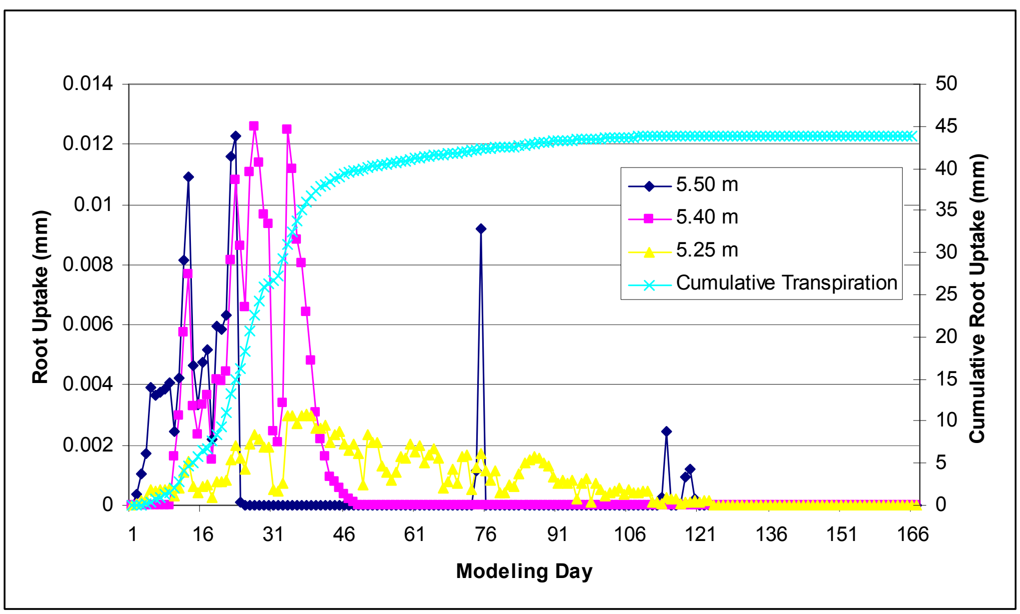

Figure 17 Root Uptake Versus Modeling Day (0.50 m Cover Poor Vegetation)

7.3.5 Potential Versus Actual Evapotranspiration

As can be seen in Figure 18, the actual evapotranspiration was limited to approximately 25% of the potential evapotranspiration. Potential Evapotranspiration is calculated based solely on the climate of the area being modeled and does not account for limiting factors such as soil moisture content. This data, further supports the limiting effects that the post freshet drying soil trend had on transpiration as evaporation.

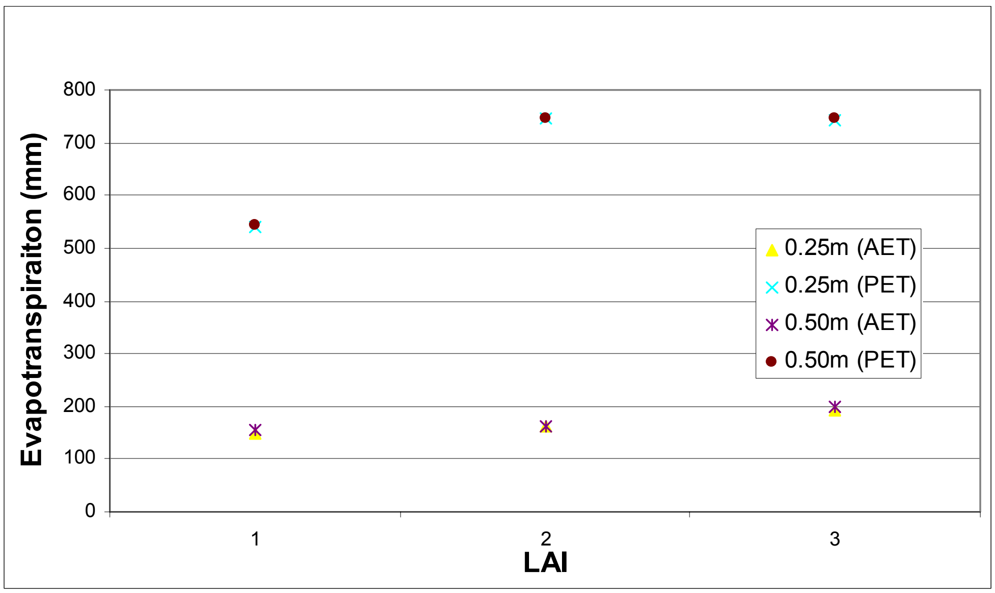

Figure 18 Potential Versus Actual Transpiration

7.4 A Comparison of Store and Release Covers to Vegetation Only Covers

As can be seen in Figure 19, the flux at the tailings/water table interface was similar for both the no cover, 0.25 and 0.50 m cover depths with poor vegetation. (approximately 3% of total precipitation). The no cover with no vegetation scenario preformed poorly, transmitting approximately 23% of total precipitation into the water table. Both the 0.25 and 0.50 m covers with no vegetation preformed well, transmitting approximately 4% of total precipitation into the underlying water table. These results suggest that: (1) a fine grained cover with no vegetation will satisfy the hydraulic requirements for a tailings cover[12]; and (2) a poor vegetation coverage, on a soil such as that used for modeling the tailings, will have a strong effect on the transmittal of water through a soil profile (within the context of the climate of the NWT).

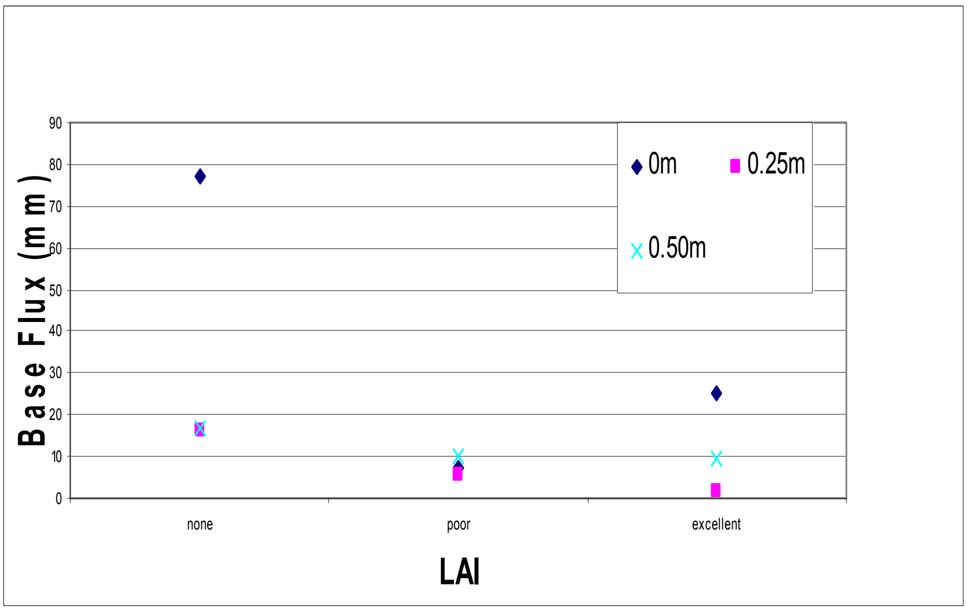

Figure 19 Annual Cumulative Flux at the Tailings and Water Table Interface (Store and Release Cover)

7.5 A Comparison of Store and Release Covers to Waste Rock Only Covers

A 0.25 m waste rock only cover was also modeled in order to provide a bench mark for comparison of store and release cover modeling results; both poor and no vegetation scenarios were modeled. As can be seen by comparing Figure 20 and Figure 21 the waste rock only cover scenarios preformed poorly compared to a store and release cover. The waste rock only covers (no vegetation and poor vegetation scenarios) rapidly transmitted water during the freshet period (approximately 27 % of total precipitation).

[12] However, a no vegetation cover scenario will be subject to much wind and water erosion, leading to high maintenance costs and possible long term failure of the cover system.

Following freshet, the waste rock only covers had a flux from the tailings to the cover. Both waste rock only scenarios had a annual cumulative base flux of approximately 16% of total precipitation (from the cover into the tailings). The change from no vegetation to poor vegetation for the waste rock only covers had little effect on the base flux. This can be explained by the porosity of the cover material. A waste rock only cover has a high fraction of coarse particles, which rapidly transmit water through their profile; plants cannot transpire quickly enough to remove the water before it passes through the cover profile.

The 0.25 m no vegetation store and release cover scenario also rapidly transmitted water through its profile during the freshet period (approximately 5% of total precipitation). However it preformed much better hydraulically than the 0.25 m waste rock no vegetation cover (5% versus 27% of total precipitation, respectively). The 0.25 m store and release cover with poor vegetation did not transmit any water through its profile during the modeling period (annual cumulative flux of approximately 3mm from the tailings into the cover material). This result displays the importance of having a cover material which can store water long enough to allow the plant coverage to transpire the water.

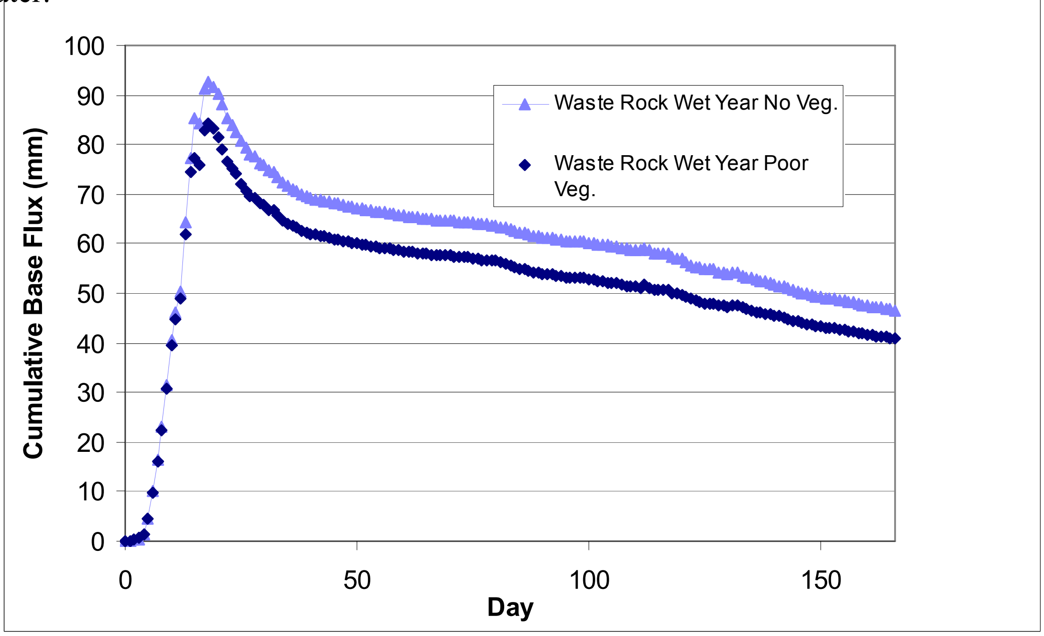

Figure 20 Cumulative Flux at the Cover and Tailings Interface (0.25 m Waste Rock Cover)

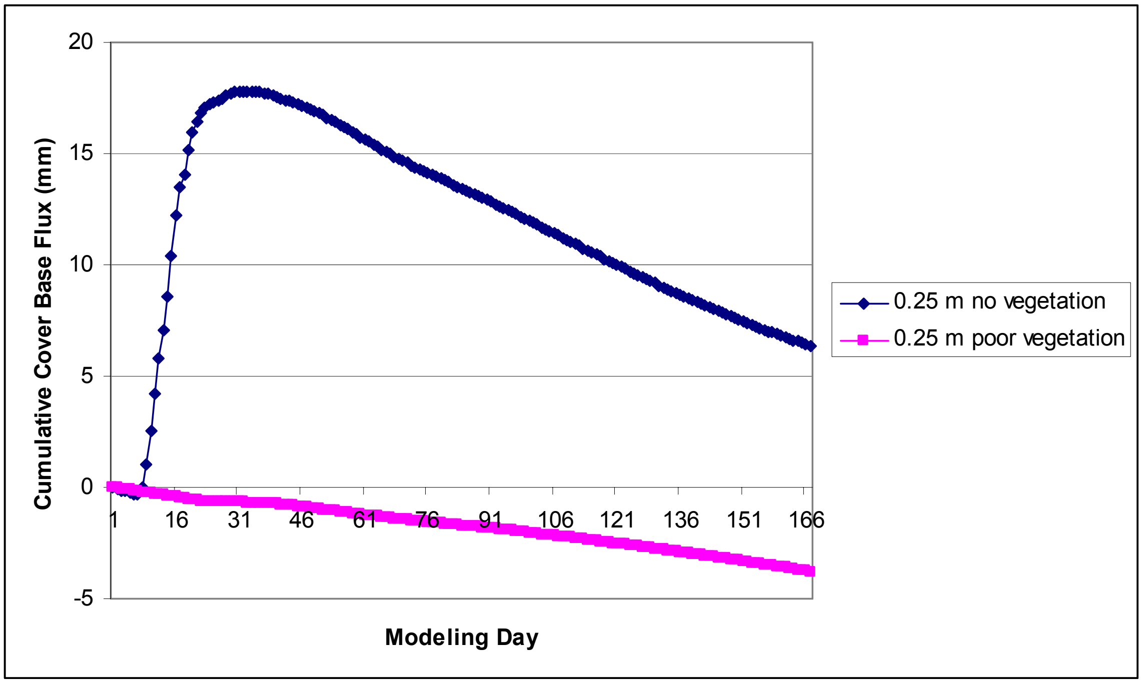

Figure 21 Cumulative Base Flux at the Cover and Tailings Interface (0.25 m Store and Release Cover)

8.0 Conclusions

8.1 Cover Selection

When selecting an appropriate cover for tailings deposit within the NWT the following variables must be considered: (1) the hydraulics (with respect to statistically representative site specific climatic conditions); (2) the ability of the cover to prevent the erosion of the tailings material; (3) the ability of the cover to prevent direct and indirect exposure of ecological receptors to the tailings; (4) the local political and regulatory regime; and (5) the locally available construction materials.

8.1.1 Hydraulics and Performance Data

The following table summarizes the hydraulics and the other important performance data for the previously discussed store and release, vegetation and waste rock covers.

Table 5 Hydraulics and Performance Data for Store and Release, Vegetation and Waste Rock Covers

Cover Type	Cover Depth (m)	Vegetation Coverage	Annual Cum. Percolation (hydraulics)	Prevent wind and water erosion of tailings	Prevent direct exposure to tailings
Vegetation	0	none	High (23% total precipitation)	No	No
		poor	Low <1% Total Precip.	limited to areas of veg. coverage	Dependent on land use and type of vegetation
		excellent	Low	Yes	Dependent on land use and type of vegetation
Store and Release	0.25	none	Low (7mm)	Yes (may fail in long term)	Yes (may fail in long term)
		poor	Low (water removed from tailings)	Yes	Dependent on rooting regime
		excellent	Low	Yes	Dependent on rooting regime
Store and Release	0.5	none	Low (9mm)	Yes (may fail in long term)	Yes(may fail in long term)
		poor	Low (water removed from tailings)	Yes	Dependent on rooting regime
		excellent	Low	Yes	Dependent on rooting regime
Waste Rock	0.25	None	High (16% total precipitation)	Yes	Yes
	0.25	poor	High (16% tot. prec.)	Yes	Yes

As can be seen in table 5, the no cover no vegetation and the no vegetation and poor vegetation waste rock scenarios preformed poorly with respect to hydraulics. All store and release cover scenarios and the poor and excellent vegetation only covers preformed well with respect to hydraulics (excellent vegetation assumption not valid under NWT climate unless external irrigation applied). All store and release and waste rock covers scenarios and the no cover excellent vegetation scenario will prevent erosion of the underlying tailings material[13]. Tailings erosion protection for the no cover poor vegetation scenario is limited to areas that are vegetated and the no cover no vegetation will not protect against tailings erosion (reflective of an non-remediated tailings deposit). Direct exposure to the tailings is prevented by all store and release and waste rock scenarios. However, if the roots penetrate into the tailings material, then the plants may translocate elements into their above ground tissues via their transpiration streams, indirectly exposing ecological receptors (most probable for the 0.25 m store and release cover due to the static soil moisture with the tailings). Direct tailings exposure protection for the no cover poor and excellent vegetation scenarios is dependent upon the future land use; vegetation could prevent exposure during activities such as light walking, but use of all terrain vehicles etc. will most likely directly expose the tailings. Some form of site access restriction could address this problem (such as fencing and access deterrents such as strategically placed boulders or berms) The no cover no vegetation scenario will directly expose receptors to the tailings.

8.1.2 Political and Regulatory Considerations

In addition to the above discussed performance criteria, the local political and regulatory regimes must be considered when selecting a cover for the Con, Colomac and Giant Mine tailings deposits. The vegetation only cover scenario is a particularly sensitive issue in the north as many public stakeholders are concerned that revegetation of the tailings will lead to the exposure of wildlife via uptake of elements into above ground plant tissues[14].

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[13] Excellent vegetation scenario not likely unless irrigation is applied
[14] The uptake of elements by plants could actually be beneficial. Plants could remove the elements and then be harvested. Over time, the tailings elemental concentrations within the root zone of the plants would

This opinion could possibly eliminate this option for the three mines under investigation ,even if the risk of plant elemental uptake is proven to be minimal (these public stakeholders have much political power). The availability and toxicity of the final form of the element within the plant tissue must be taken into consideration (i.e., many plants methylate arsenic, leading to a less toxic and biologically available form of the metal). The laboratory test most often used for elemental analysis (i.e., total metals by ICP MS) does not provide information with respect to the form that element has taken within the plant tissues. In addition, many plants have developed strategies to prevent metals from being taken up by the roots. If a vegetation only cover is to selected, a risk based approach along with restricted land use and a public awareness campaign may have to be undertaken.

The regulatory regime that has to be dealt with when designing a final cover for tailings deposits in the north is complex and not clearly defined.[15] Mines that are undergoing final abandonment and restoration must prepare and submit an abandonment and restoration document, which contains, as a portion of the document, a plan for abandoning tailings deposits (requirement of water license). This plan is then subject to review by a Mackenzie Valley Land and Water Board (MVLWB) working group (Mackenzie Valley Resource Management Act). This board is composed of many interested stakeholders including the city of Yellowknife, local aboriginal band representatives, federal government members etc. If the working group does not approve of the remedial plan, then any environmental bonds can be seized and an alternative plan can be implemented. In addition, the Government of the Northwest Territories (GNWT), Resources and Wildlife and Economic Development (RWED) (NWT Environmental Protection Act) must be consulted and approve of the remedial plan and federal agencies such as the Department of Fisheries and Oceans (DOF) (Fisheries Act) influence any final decision.

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decrease, leading to a store and release cover scenario without the use of additional resources. This would require long term site access restrictions.

[15] No specific regulations exist in the NWT with respect to the placement of a final tailings cover. Devolution of the NWT and aboriginal land claims further complicate the process.

8.1.3 Available Construction Materials

A factor that strongly limits the placement of tailings covers within the NWT is the availability of construction materials. The construction of a final cover for a tailings deposit requires the use of large quantities of borrow (soil) and/or quarry (rock) materials. Such materials are in short supply within the NWT. Historical glacier advance and retreat has stripped much of the soils from the area. The deposits of materials that are available are generally not developed (i.e., road access and clearing), as many of the mines are in remote locations. The development of a borrow or quarry at these remote locations will require significant economical investment and could have a large additional environmental impact on pristine areas (large amounts of fine grained deposits are present at the base of bodies of water, which will have to be drained). Finally, borrow and/or quarry sites that have been developed within the Yellowknife area have been mostly exhausted. One method of addressing this situation, which has been formally proposed for the Colomac Mine, is to place on-site available waste rock over the tailings footprint. This practice is economically attractive and does not require additional borrow sources. However it does not protect the surrounding water table from contamination, as much meteoric water is transmitted into the underlying tailings material. Unfortunately, there is no simple solution to the lack of available cover construction materials within the NWT.

8.1.4 Selected Cover Scenario

No clear solution currently exists for placing a cover at the Con, Colomac and Giant Mines. Vegetation only covers are the most economically attractive solution and they do limit the transmittal of water into the underlying tailings. However, they could require long term site access restrictions to prevent direct and indirect exposure of ecological receptors to the tailings materials and they are also subject to much public scrutiny. Furthermore, an excellent vegetation coverage may be difficult to establish due to the semi-arid conditions of the NWT. Moreover, if a vegetation only cover is to be placed, then all seeding should occur immediately following freshet in order to take advantage of the available soil moisture. Experimentation should also be undertaken to select a plant species which does not translocate elements into its above ground tissues. This plant species should also be drought tolerant and slightly halophytic (tolerant to salt)[16]. Waste rock only covers can take advantage of on-site available construction materials (waste rock) for placement of a cover and they also protect against ecological exposure. However, they transmit much water into the underlying tailings, which could possibly contaminate the surrounding water table. Store and release covers sufficiently address all cover criteria, provided the cover is of a depth that provides adequate water storage to prevent the translocation of roots into the underlying tailings material. The seed placement and selection should be similar to the vegetation only cover recommendations. However, store and release covers require the placement of large quantities of soil, which is in short supply within the NWT. The future research that AEL has proposed will attempt to address the above discussed limitations with respect to placing a final tailings cover in the NWT. Research Goals are discussed in the following section.

[16] Semi-arid conditions tend to concentrate salts within the soil profile

9.0 Future Work

Future work proposed by AEL will focus on addressing the limitations of placing a cover within the NWT. The overall goals of research are to: (1) provided a blended cover material that will take advantage of on-site available construction materials, while limiting the need to open additional borrow/quarry sites (the material will have to be able to allow more infiltration than that of the fine grained giant soil modeled in order to promote the growth of vegetation); and (2) identify and propagate a suitable seed line for use in the NWT. AEL plans to model covers based on blended materials composed of on-site materials and available borrow soils. On-site materials could consist of: (1) road construction materials; (2) materials from unnecessary dams; (3) stockpiled waste rock and unused soils etc. Care will have to be taken to ensure that these materials have not been contaminated and are not acid generating. These materials will then be blended with available borrow soils in predetermined amounts and subject to grain size analysis. The generated grain size distributions will subsequently be entered into the SoilVison software to generate a SWCC. The SWCC will then be used, along with site specific climatic factors, to model the performance of the various blended materials using SoilCover. If a blended material is identified that provides economical and environmental benefits, then AEL would like to pursue the verification of the material performance using lysmeters at the specific mine in question. AEL would also like to solicit the involvement of the University of British Columbia Co-Mix Laboratory and the Alternative Cover Assessment Program to aid in technical and field activities.

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List of Abbreviations and Acronyms

AEL	Aboriginal Engineering Ltd.
ARC	Alberta Research Council
UBC	University of British Columbia
SWCC	Soil Water Characteristic Curve
K_{sat}	Saturated Hydraulic Conductivity
%P	Porosity
M_v	Coefficient of Volume Change
INAC	Indian and Northern Affairs Canada
NWT	Northwest Territories
Giant	Mean Fine Grained Soil Used for Modeling the Cover
Tailings	Tailings Taken from Dam 1.0 at the Colomac Mine used to Model the Tailings
Proposal	Refers to the Proposal Document titled *"Modeling Store and Release Covers at Three Northern Mines Using SoilCover 2000, Thesis Proposal"*
AET	Actual Evapotranspiration
AE	Actual Evaporation
AT	Actual Transpiration
MVLWB	Mackenzie Valley Land and Water Board
GNWT	Government of Northwest Territories
RWED	Resource, Wildlife and Economic Development
DOF	Department of Fisheries and Oceans

Appendix A Statistical Data Employed to Define a Representative Modeling Period

Figure 22 North Slave Geological Province

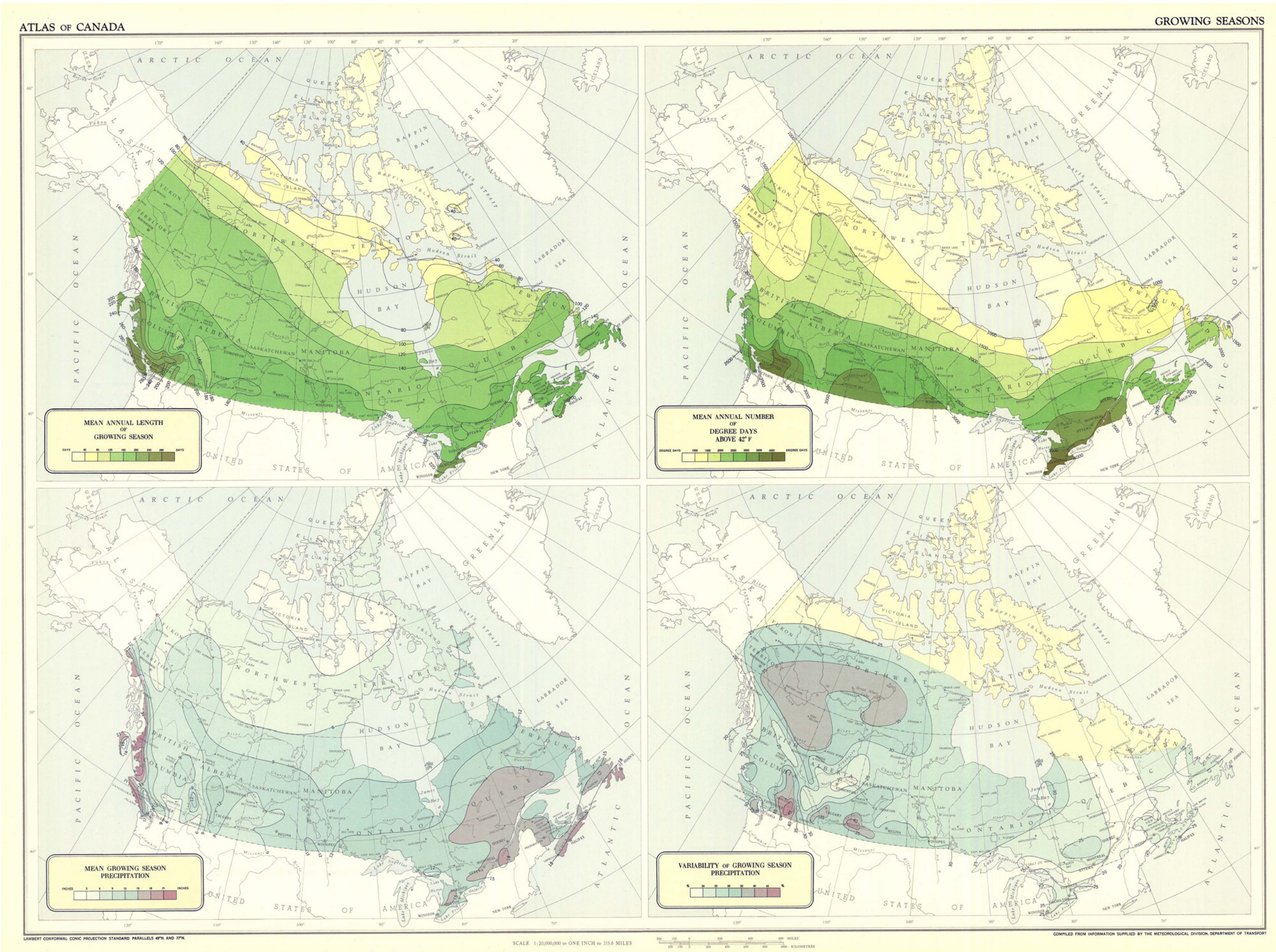


Figure 23 Mean Annual Growing Season

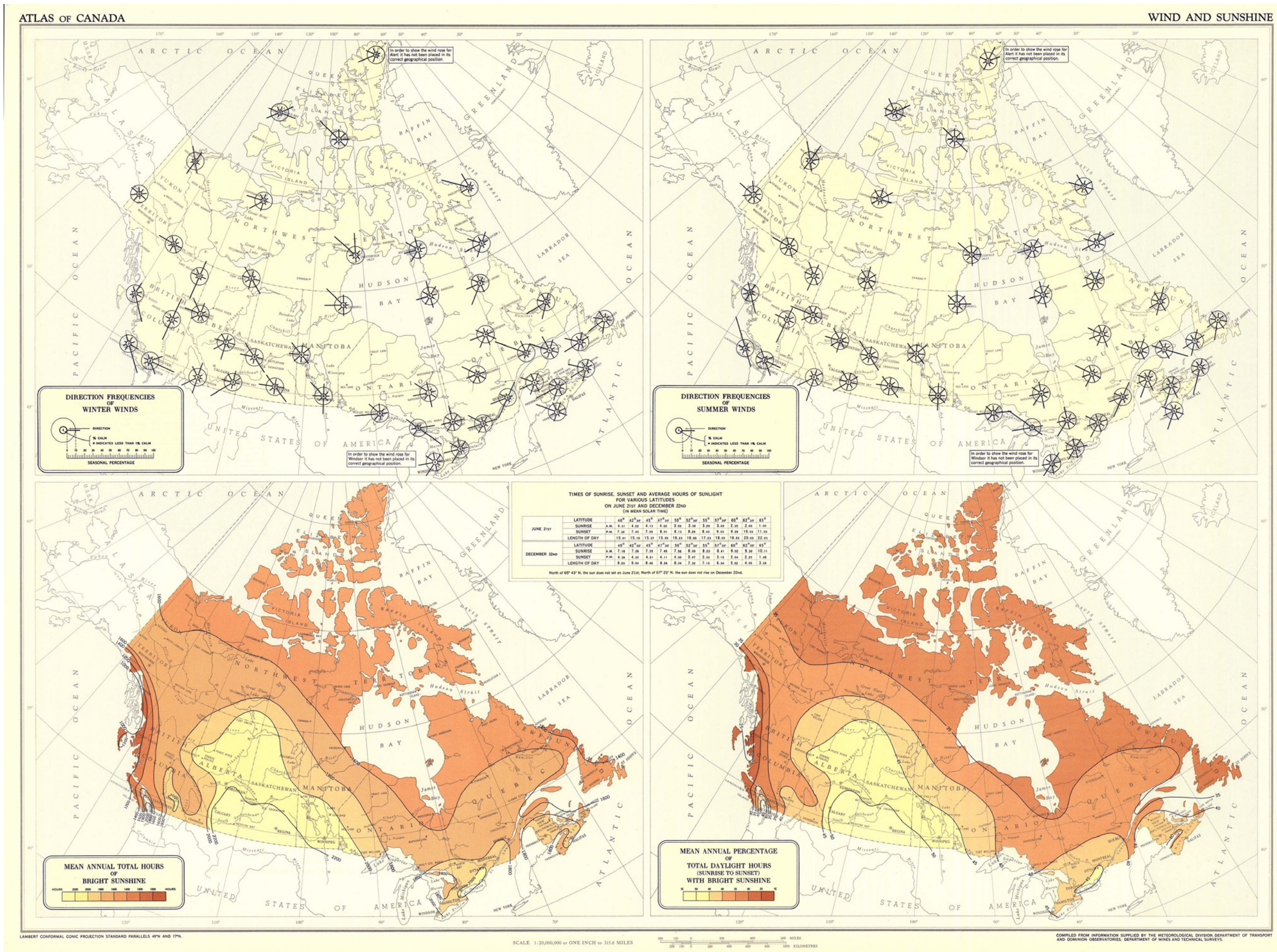


Figure 24 Sunshine Map

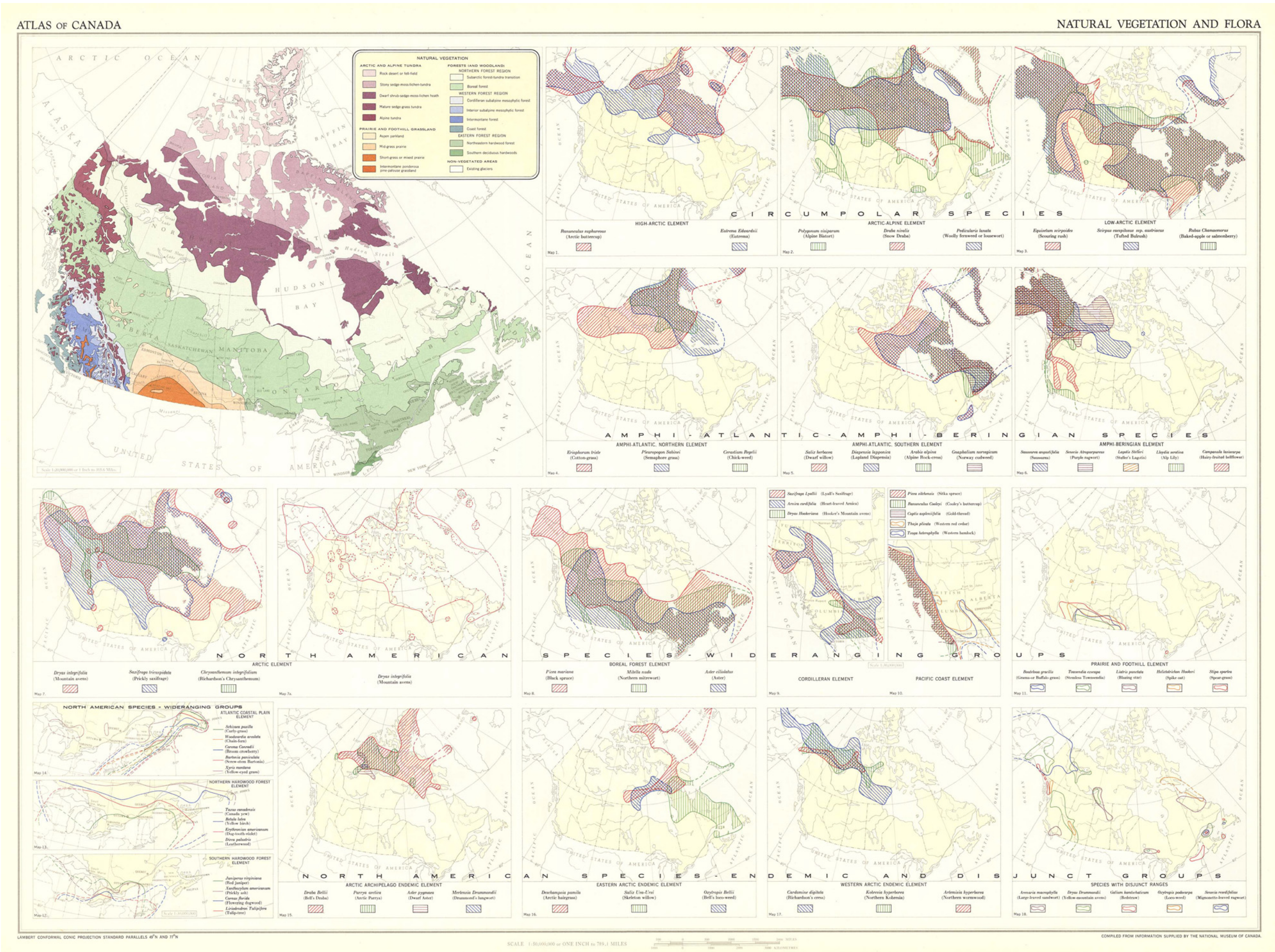


Figure 25 Vegetation Map

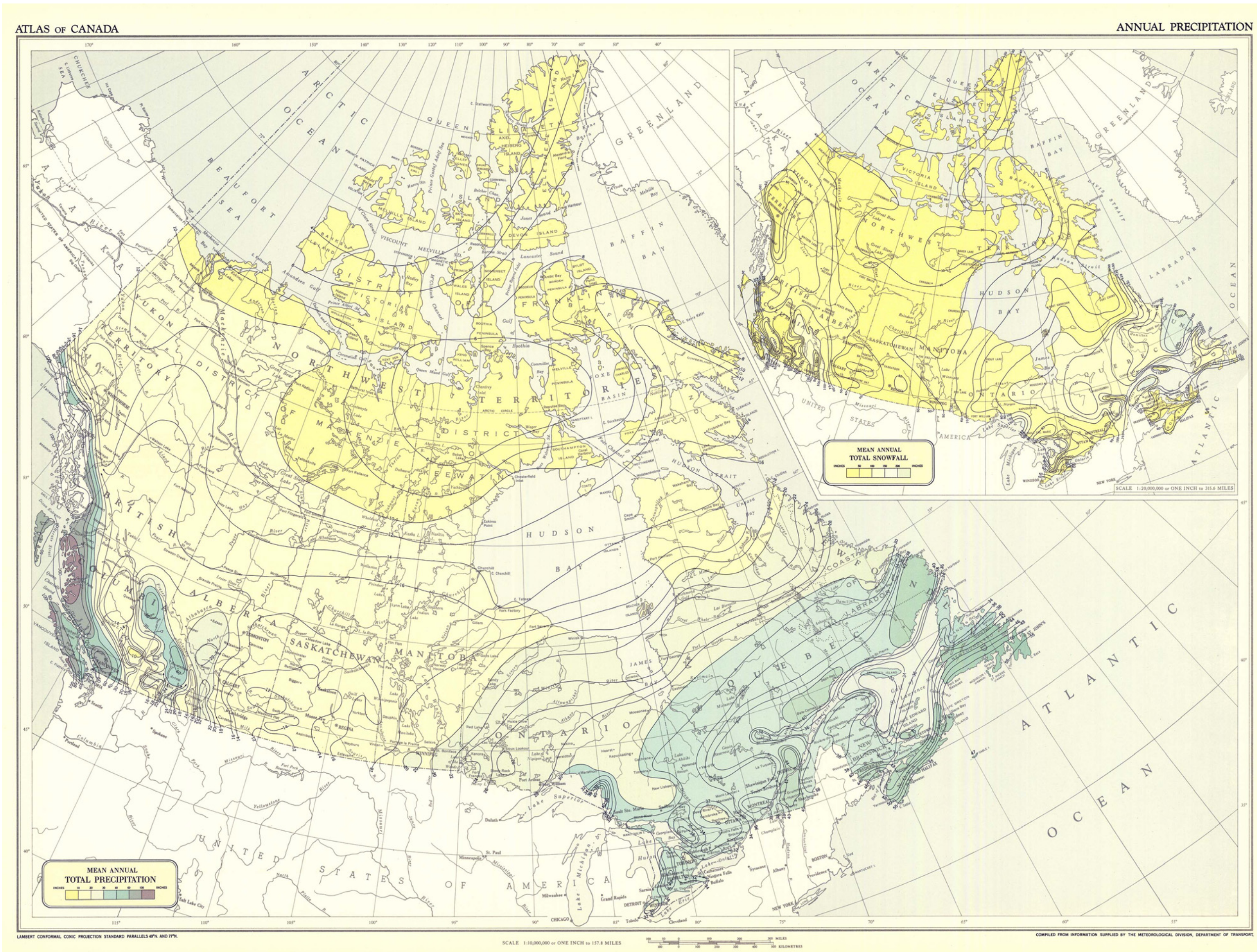


Figure 26 Frost Map

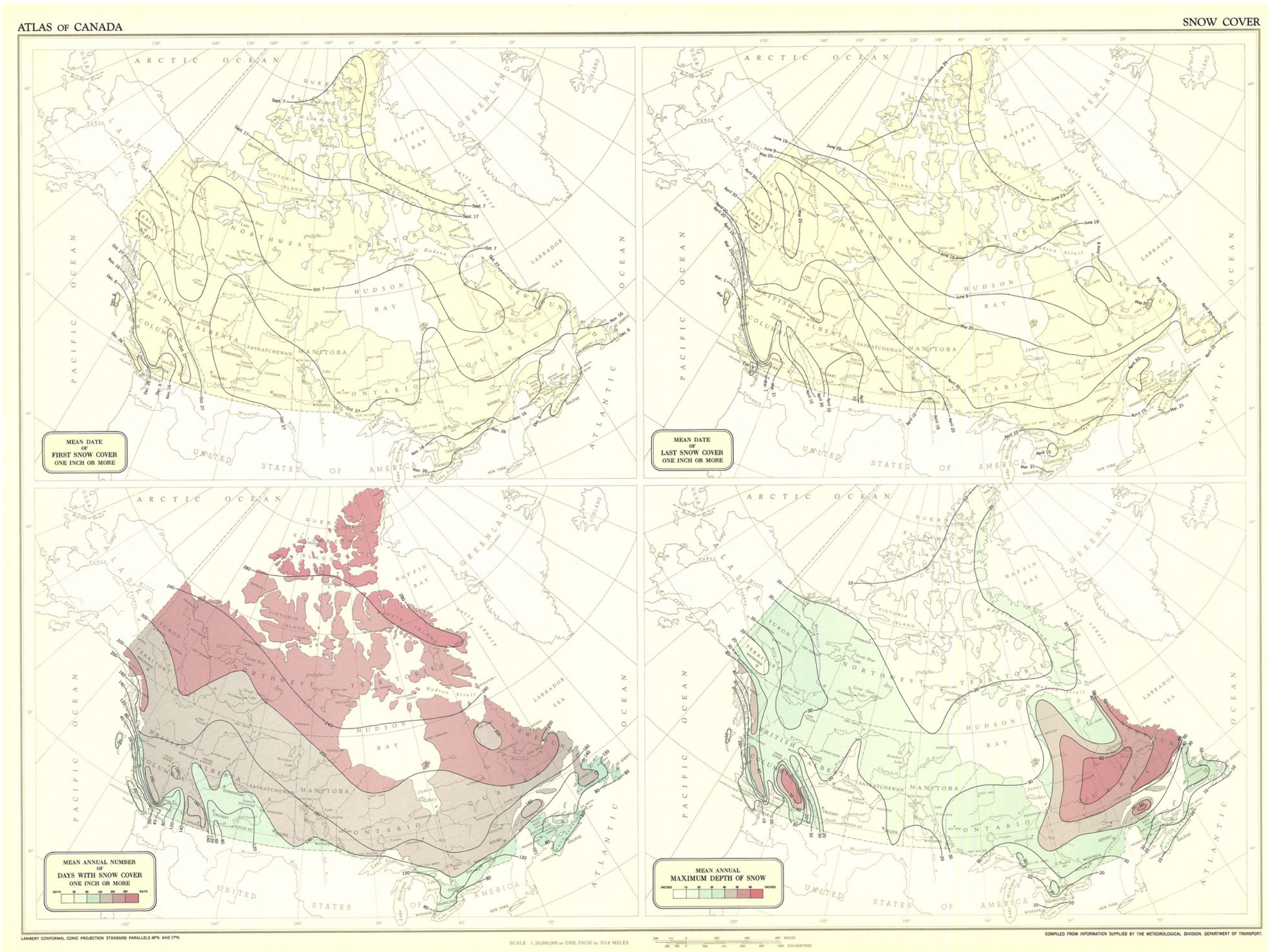


Figure 27 Snow Cover Map

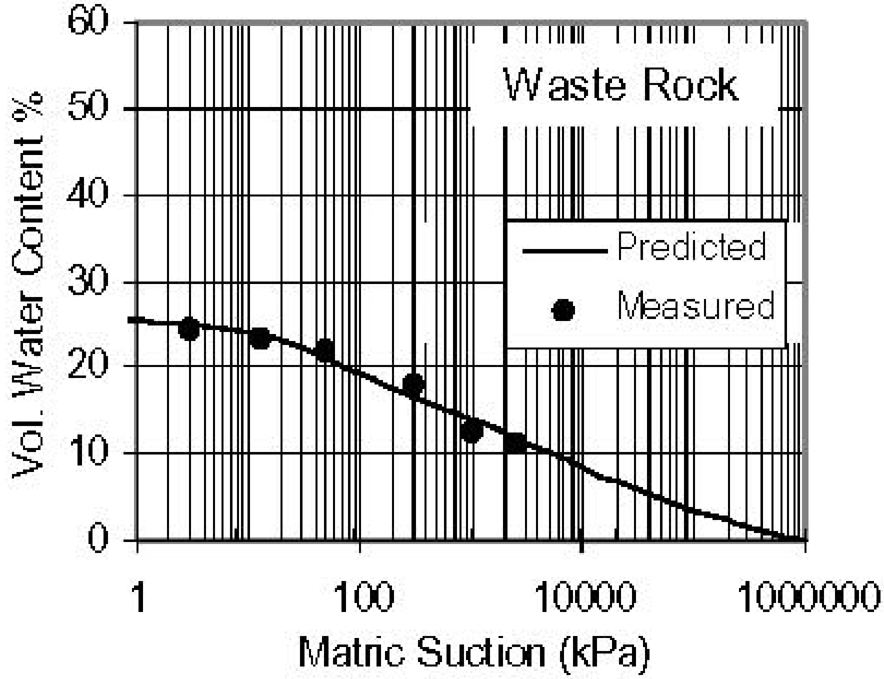


Figure 28 Waste Rock SWCC

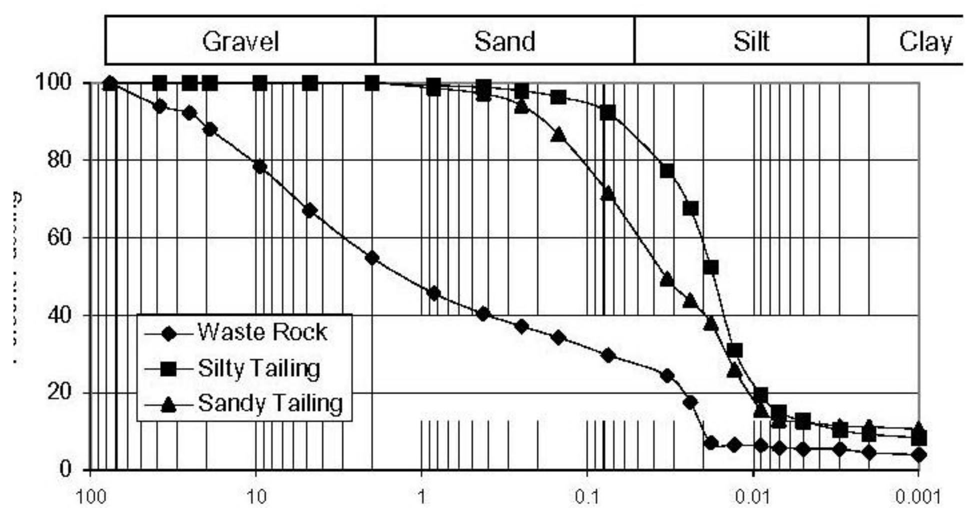


Figure 29 Waste Rock Grain Size Distribution

Selection of modeling period and duration of freshet

Table 6 Statistical Data for the First Day of Freezing and Snowfall

	Daily Temp < 0			Snow Fall
	MaxT <0	MinT< 0	Mn. T< 0	earliest day
mean	Oct-09	Sep-26	Oct-04	Oct-05
stdev	11	7	8	10
earliest	Sep-25	Sep-16	Sep-24	Sep-26
latest	Oct-28	Oct-07	Oct-26	Oct-27

Selection of Max or Wet and Median Annual Precipitation (Pocket Lake)

Table 7 Total Annual Precipitation Statistical Data (Pocket Lake)

Quantiles			Moments	
100.0%	maximum	351.6	Mean	247.6
75.0%	quartile	281.5	Std Dev	55.1
50.0%	median	242.0	Std Err Mean	18.3
25.0%	quartile	205.3	upper 95% Mean	290.0
0.0%	minimum	177.4	lower 95% Mean	205.2

Modeling Input

Table 8 Wet Year Modeling Input

Radiation	Temperature	Rainfall	Rel Humidity	Windspeed	Rain+snow
1.99584	-3.273	0	0.6427	7.2504	9.37
4.2768	1.018	0	0.6274	5.6628	9.37
5.90112	3.401	0	0.723	8.1504	9.37
13.392	5.089	0	0.6853	8.6112	9.37
11.94912	2.142	0	0.72	9.3024	9.37
11.65536	0.621	0	0.739	9.9612	9.37
9.288	0.129	0	0.6136	6.0372	9.37
8.44128	1.735	0	0.5479	6.8832	9.37
4.84704	1.526	0.7	0.786	5.8392	10.07
9.27936	2.696	2.1	0.847	7.5636	11.47
16.2432	4.38	0	0.718	6.9444	9.37
18.80928	6.149	0	0.5871	6.2496	9.37
5.55552	6.542	6.6	0.719	9.2052	15.97
5.98752	3.278	5	0.963	7.7652	14.37
7.98336	4.153	0.2	0.883	5.0112	9.57
7.54272	4.541	0	0.838	8.3628	0
3.42144	0.83	9	0.947	8.3232	9
10.63584	-0.183	3.1	0.914	7.8372	3.1
8.76096	-1.865	0.4	0.799	8.5536	0.4
8.6832	-0.758	0.1	0.754	8.046	0.1
16.70112	1.52	0	0.6513	5.8284	0
21.27168	3.5	0	0.58	3.6	0
12.86496	8.3	0.6	0.65	7.2	0.6
10.96416	8.7	1.2	0.86	4.68	1.2
17.74656	8.7	0	0.68	6.84	0
20.85696	8.1	0	0.54	4.68	0
15.8544	8.2	0	0.49	10.44	0
12.82176	11.7	1.7	0.63	10.08	1.7
14.48064	13.6	0	0.67	6.12	0
3.83616	4.7	5.8	0.87	11.52	5.8
4.1904	3.6	0	0.87	5.4	0
6.57504	6.9	0.1	0.84	4.32	0.1
21.91104	14.9	0	0.61	7.92	0
20.736	17.5	0	0.57	7.92	0
19.24992	16.1	0	0.63	9	0
20.6064	18.6	0	0.52	5.76	0
19.93248	19.9	0	0.44	5.76	0
20.11392	21.3	0	0.44	4.68	0
18.85248	14.7	0	0.6	11.88	0
19.47456	13.4	0	0.5	10.08	0
19.90656	14.6	0	0.47	9.36	0
16.14816	13.5	0	0.46	6.84	0

18.54144	14.2	0.8	0.52	9.36	0.8
19.94112	14.1	0	0.41	7.92	0
18.71424	12	0	0.53	7.2	0
16.632	11.4	0	0.54	7.56	0
19.68192	12.1	0	0.56	6.84	0
16.03584	13.1	0	0.58	7.56	0
5.28768	10.9	0	0.67	4.68	0
20.51136	15.1	0	0.55	11.52	0
20.51136	14.9	0	0.63	7.56	0
20.304	16.2	0	0.55	6.12	0
10.99008	11	0	0.61	11.52	0
10.95552	6.3	0	0.5	8.28	0
7.82784	9.1	0	0.52	3.6	0
10.77408	10.8	0.1	0.54	4.32	0.1
16.33824	12.2	0	0.5	5.4	0
15.62112	13.3	0	0.51	4.68	0
19.90656	13.8	0	0.44	7.56	0
17.8416	11.7	0	0.42	7.92	0
18.99936	12.8	0	0.48	11.52	0
13.54752	15.8	0	0.53	6.12	0
17.69472	12.4	0	0.49	7.56	0
19.64736	15.1	0	0.5	8.28	0
13.9104	17.5	3.3	0.55	11.88	3.3
5.832	13.5	10.8	0.88	11.52	10.8
9.27936	13.6	0.4	0.83	7.56	0.4
15.2064	12.5	0	0.71	6.84	0
8.80416	14	0.7	0.82	5.4	0.7
19.9584	15.3	0	0.74	7.92	0
19.02528	18.1	1.1	0.68	10.08	1.1
6.03072	15.9	9	0.82	5.4	9
14.3424	15.5	10.3	0.72	11.52	10.3
19.04256	18.1	0	0.58	10.8	0
12.4416	19.8	0	0.61	5.4	0
7.45632	18.5	0.5	0.69	10.8	0.5
13.90176	19	0	0.71	6.12	0
4.57056	19.4	0.2	0.79	3.24	0.2
5.1408	18.6	12.2	0.93	6.12	12.2
8.64864	17.7	0	0.9	9.72	0
6.85152	16.5	0	0.77	7.92	0
13.54752	15.4	0	0.76	6.12	0
17.7552	15	0	0.68	10.08	0
17.496	18.2	0	0.61	10.44	0
17.56512	20.8	0	0.54	8.64	0
17.39232	21.7	0	0.53	8.28	0
16.61472	20.6	0	0.63	8.64	0
16.13088	19.4	0	0.61	8.28	0
11.94048	19.1	0	0.68	6.12	0
9.86688	19.6	0	0.69	3.6	0

11.18016	18.6	1.1	0.67	5.04	1.1
9.72864	15.1	0.2	0.63	5.4	0.2
13.32288	14.5	0	0.66	6.84	0
1.80576	14.3	6.4	0.82	3.96	6.4
11.47392	14.7	0	0.66	4.68	0
15.60384	14.7	0	0.67	4.68	0
0.48384	13.9	13.6	0.84	7.2	13.6
12.58848	16.8	0.4	0.79	7.56	0.4
8.18208	13	0	0.67	6.12	0
4.18176	13.2	0	0.72	6.84	0
8.5968	14.4	4.9	0.8	4.68	4.9
10.03104	12	0.4	0.73	6.48	0.4
13.31424	11.6	0	0.73	7.2	0
7.49088	14.2	1.2	0.81	7.2	1.2
12.85632	16.4	0.7	0.79	5.76	0.7
10.79136	15.3	0	0.8	8.28	0
10.27296	17.8	0	0.73	7.56	0
12.58848	15.8	0	0.72	7.56	0
11.7936	19.9	0	0.71	11.52	0
0.864	12	0.5	0.83	12.96	0.5
2.3328	9.3	13.4	0.8	12.6	13.4
1.0368	7.8	16.1	0.97	11.88	16.1
9.2016	8.9	0	0.73	11.16	0
8.09568	9.1	0	0.73	6.12	0
7.53408	12.5	2.4	0.76	7.2	2.4
3.12768	11.6	9.7	0.99	8.64	9.7
4.78656	11.7	4.1	0.94	6.48	4.1
6.18624	11.3	0	0.86	6.48	0
7.9056	12.3	0.2	0.91	5.04	0.2
7.22304	14.2	0.1	0.92	3.24	0.1
10.48896	13.4	0	0.78	5.4	0
10.18656	15	0	0.81	7.92	0
9.70272	17.7	0	0.7	5.4	0
4.89024	15.8	0.8	0.79	5.4	0.8
6.81696	13.7	0	0.86	7.2	0
3.78432	11.6	1.9	0.86	6.48	1.9
3.30912	11.2	5.3	0.96	4.68	5.3
8.77824	11.9	0	0.88	5.04	0
3.9312	10.8	0.1	0.91	4.32	0.1
7.2144	11	0	0.84	5.76	0
0.95904	10.5	21.9	0.97	6.12	21.9
0.44064	10	1.1	0.86	11.88	1.1
4.12992	8.7	0	0.73	7.92	0
6.10848	8	0	0.8	3.6	0
6.73056	8.4	0.1	0.84	9	0.1
5.26176	12.6	0	0.76	14.4	0
5.99616	13	0	0.74	7.2	0
2.97216	11.2	3.8	0.83	4.68	3.8

5.08896	10.6	0	0.77	6.84	0
5.5728	9.6	0	0.72	5.4	0
1.93536	5.6	1.1	0.74	7.56	1.1
2.21184	3.4	0	0.74	6.12	0
2.01312	4.3	0	0.79	5.4	0
1.9872	3.9	0	0.73	5.76	0
1.45152	6.3	0	0.8	7.92	0
5.75424	12	0	0.78	11.16	0
3.55104	10.7	0	0.6	12.6	0
4.43232	10.9	0	0.73	7.2	0
5.04576	14.5	0	0.75	4.68	0
0	11.5	5.4	0.84	15.48	5.4
4.104	9.1	0	0.65	15.48	0
2.78208	5.1	0	0.67	5.76	0
0.18144	4.6	6.3	0.85	5.04	6.3
1.06272	4.8	0	0.95	4.68	0
0.31968	5.4	0.6	0.9	4.68	0.6
0.93312	0.8	0	0.73	7.92	0
0	-2.1	0	0.77	3.96	0
1.18368	-0.4	0	0.76	6.84	0
2.376	6.5	0	0.81	13.32	0
0.68256	7.6	0	0.72	12.96	0
0.98496	2.4	0	0.79	4.68	0
1.23552	2.2	0.7	0.92	2.88	0.7
0.648	2.3	0.1	0.97	3.96	0.1
1.32192	4.3	0	0.91	3.6	0
0.58752	2.8	0	0.96	2.88	0
0.48384	0.9	0.5	0.99	3.96	0.5

Selection of Freezup Date

Table 9 Freezup Statistical Data

	Temp < 0 daily max temp < 0	daily min temp < 0	daily avg temp < 0	Snow falls earliest day
avg day	Oct-09	Sep-26	Oct-04	Oct-05
stdev (+/- days)	11	7	8	10
earliest day	Sep-25	Sep-16	Sep-24	Sep-26
latest day	Oct-28	Oct-07	Oct-26	Oct-27

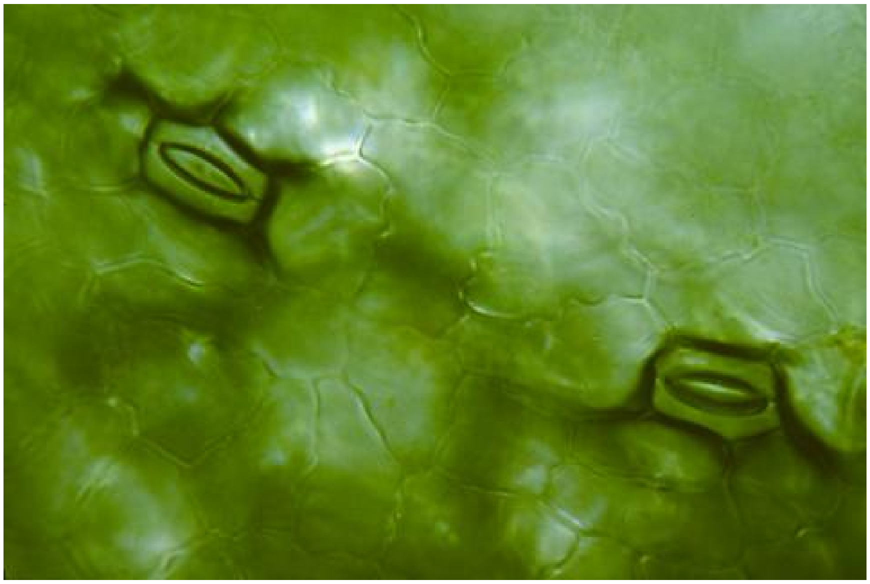
Selection of Sunlight Hours

Month	Hours sunshine / day Avg.
May	10.9
June	12.7
July	11.9
Aug	9.2
Sep	5.2
Oct	2.0

*Climate normals 1971-2000

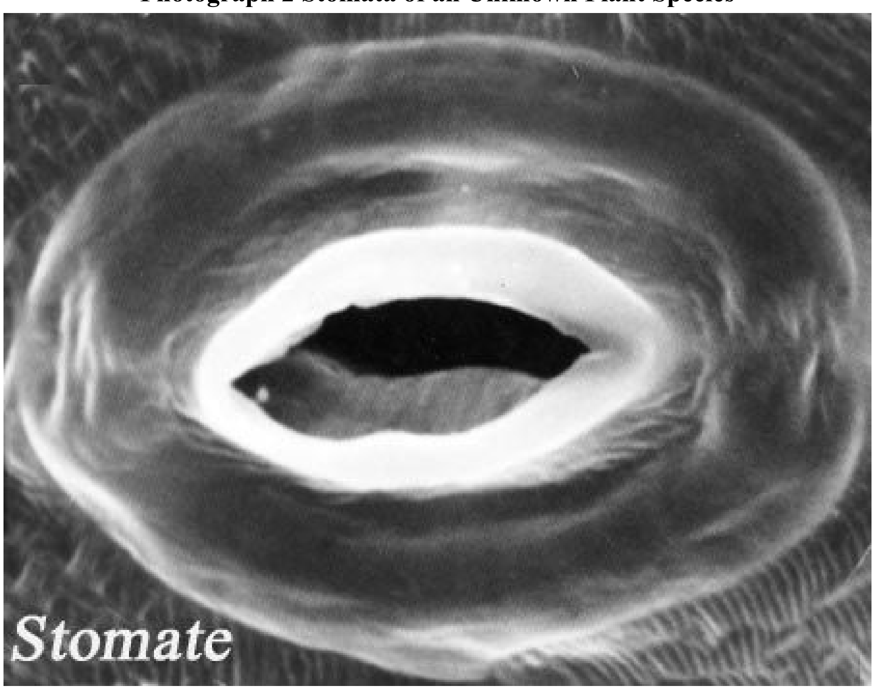
Appendix B Photographs

Photograph 1 Stomata Present on the Leaf of Lema Minor



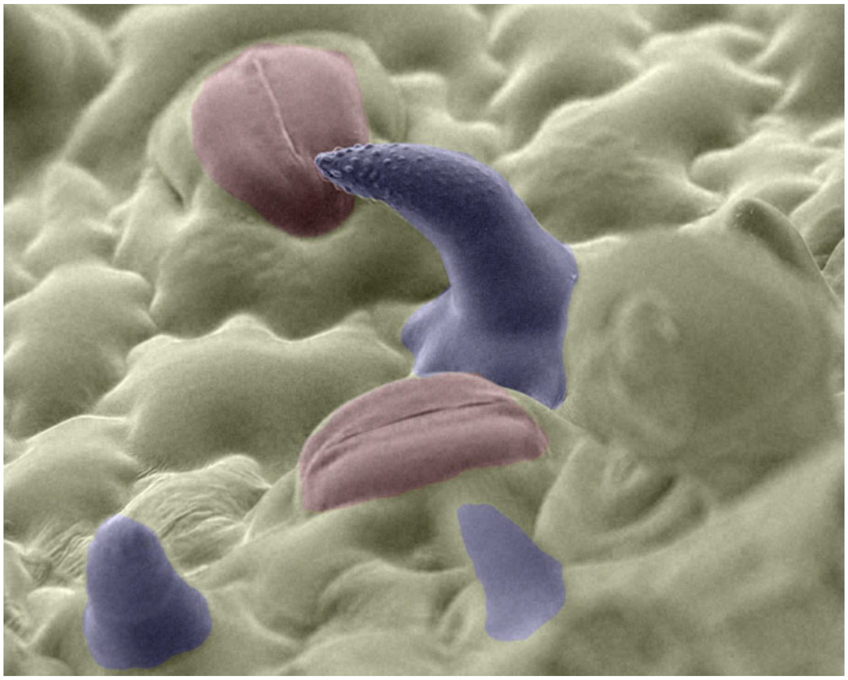
Source:
http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemna-01.htm <accessed on March 7, 2005

Photograph 2 Stomata of an Unknown Plant Species



Source: http://www.petitmusee.org/pages/stomate_jpg.htm <accessed on March 7, 2005
Unknown Plant Species

Photograph 3 Electron Scanning Photograph of the Stomata of Coleu sp.



Source: http://www.vcbio.science.ru.nl/eng/fesem/applets/surface/ <accessed on March 7, 2005

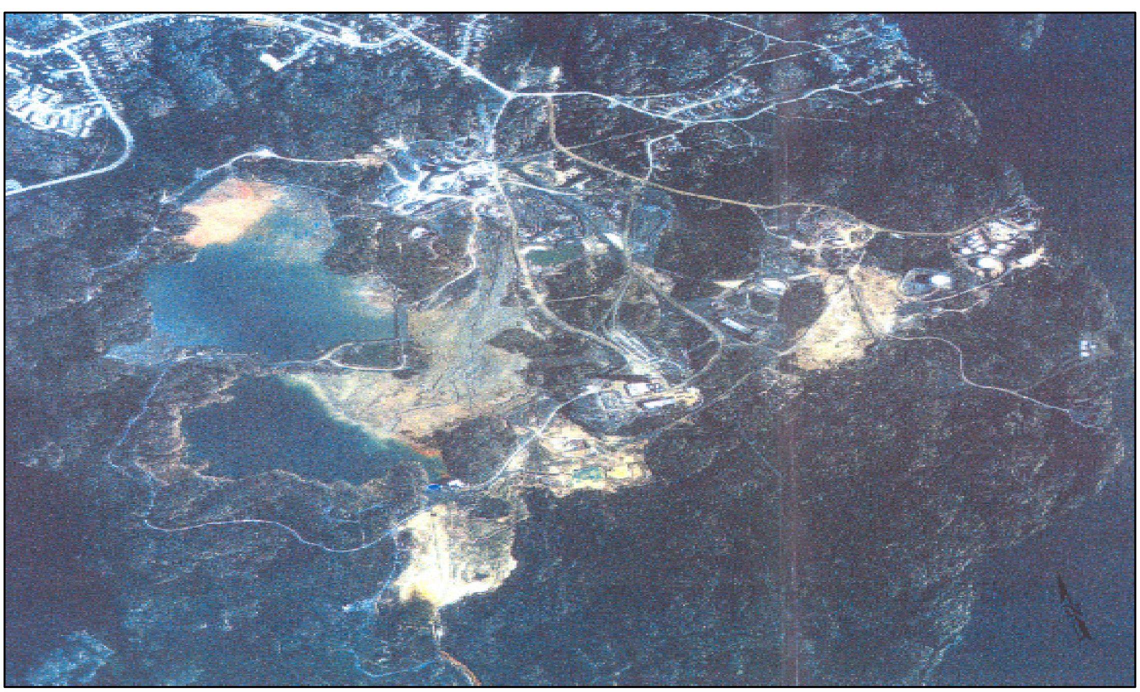
Photograph 4 Pocket Lake Weather Station

Photograph 5 Slender Wheat Grass Growing at the Giant Mine

Photograph 6 North, Central and South Tailings Deposits at the Giant Mine

Photograph 7 Northwest Tailings Deposit at the Giant Mine

Photograph 8 Upper and Middle Pud Tailings Deposits at the Con Mine



Photograph 9 Dust Generated from Dry Tailings at the Northwest Tailings Pond, Giant Mine (Mid August)

Photograph 10 Dust From Dry Tailings at the South Tailings Pond, Giant Mine (Mid July)

Photograph 11 A Poor Vegetation Coverage Developing on Historical Tailings