Scoping Level Cover Assessment for Minto Closure Covers

Prepared for

Minto Explorations Ltd.

Prepared by

SRK Consulting (Canada) Inc.
1CM002.007
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Executive Summary

Minto Explorations Ltd. (Minto) is considering the use of covers as one of the remedial strategies for mine waste at their Minto Mine site in Yukon Territory, Canada. Mine waste at Minto site includes both waste rock and tailings (dry stack and in-pit tailings). At the end of Phase IV (the current phase of mining), there will be six distinct waste rock and overburden piles on site, and these will be expanded as future mine development takes place.

Geochemical characterization of the mine waste has confirmed that acid generation potential is low; however, neutral metal leaching will be a long-term concern. This scoping level cover assessment provides a comprehensive evaluation of appropriate cover design concepts that should be considered for the Minto site, taking into account site specific conditions and overall site wide closure objectives.

Mine waste covers are one remedial technology that can be used to manage drainage. Successful closure covers over mine waste facilities depend on many factors; however, two factors dominate decisions on what may be appropriate at any specific site, i.e., climatic conditions and locally available material (i.e., soils).

The evaluation demonstrates that the hydrologic and climatic regime at the Minto site is best suited to the use of water covers or infiltration reducing covers (i.e., barrier covers). In contrast, store-and-release and thermal covers are not likely to be successful. The available overburden soils at Minto are however not well suited for construction of low or very low infiltration barrier covers.

These soils are best used as isolation and vegetation supporting covers, and are expected to result in overall infiltration typically between 10 and 20% of mean annual precipitation. Periodic higher breakthrough events will occur. Soil amendments or use of synthetic products are therefore required to construct low to very low infiltration covers at the site. Conceptual designs of each of these different cover variants are proposed.

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1 Introduction

1.1 Background

Minto Explorations Ltd. (Minto) is considering the use of covers as a remedial strategy at their Minto Mine site in Yukon Territory, Canada. The general concepts of this plan are documented in Minto's current Decommissioning and Reclamation Plan (D&RP) (Minto 2011). A rigorous assessment of the proposed cover concepts taking into account site specific conditions has not been carried out and therefore the cover design concepts are not optimized. This work is intended to provide a rationale for how covers can best be utilized at Minto.

Mine waste at Minto includes both waste rock and tailings. At the end of Phase IV (the current phase of mining) there will be six distinct waste rock and overburden piles on site as illustrated on Figure 1, and these will be expanded as future mine development takes place.

Historic tailings deposition consisted of dry-stacked compacted filtered tailings. This deposition strategy was discontinued in October 2012, in favour of conventional low solids content (50 to 60% by mass) slurry tailings deposited sub-aqueously into Main Pit. Future tailings deposition will continue as hydraulically deposited tailings in Main and Area 2 Pits.

Geochemical characterization carried out on both waste rock and tailings confirms that, for the most part, the mine waste is not highly reactive, and has very low potential to generate acid; however, there is potential for neutral metal leaching (SRK 2013a). Mitigation strategies are therefore required to manage this leachate, including water treatment, waste relocation and waste encapsulation (i.e., closure covers).

1.2 Scope of Work

While it is understood that covers are one of many possible mitigation strategies that can be used to achieve site wide closure objectives, the scope of this study was to specifically determine what cover concepts are most likely to be successful at Minto, and how best to implement them. This was done by carefully evaluating site specific conditions that affect cover design, construction and ultimately long-term performance, including but not limited to design life, climate, material availability, waste characterization, seismicity, slope stability, erosion resistance, etc.

Once the cover concepts that are most likely to be successful at Minto were identified, appropriate cover functions were defined to specifically ensure overall site wide closure objectives would be met. Finally conceptual cover designs are presented that demonstrate actual implementation plans for all of the concepts.

1.3 Report Layout

Specific design elements that need to be considered in cover design are described in Section 2. Section 3 of this report describes the different cover types and whether they should be given consideration at Minto. Section 4 provides a generalized overview of the currently stated site wide closure objectives, complete with preliminary suggestions for cover functionality. Finally, different conceptual cover designs suitable for application at Minto, complete with expected performance criteria, are presented.

2 General Cover Design Elements

2.1 Cover Design Life

SRK does not believe that engineered soil covers can be expected to continue to perform in accordance with their original design intent for an infinite lifetime after construction (i.e., in perpetuity), especially if there is no monitoring and maintenance plan in effect. Therefore, it is appropriate to design soil covers and associated monitoring and maintenance plans with a finite lifespan in mind. The length of that time period should dictate to what standard the cover must be designed and constructed, and also what level of monitoring and maintenance would be required.

There are no specific guidelines or standards in Canada that specify a lifespan for covers, leaving the design decision to the discretion of the mine operator. Internationally, there are also no fixed criteria for cover lifespan; however, some mining companies explicitly adopt life spans of 100, 200 or even 500 year periods during which the cover is expected to perform in accordance with the original design intent (Rykaart *et al*. 2006).

The design life of a cover is complicated by the fact that some cover failure modes require inherently different approaches. For example, if Minto was to adopt a design life for the conceptual cover designs presented in this report of say 200 years, then it would be assumed that these covers would continue to perform the functions listed in Section 4 for this lifespan. However, portions of the cover design may have different design criteria, for example surface water conveyance channels may be designed to withstand 1:100 year storm events with an understanding that the necessary maintenance and repair would be carried out for the 200 year design life of the cover.

It would be premature for SRK to recommend a design life for the Minto covers in isolation of the overall closure design, as well as input from stakeholders. A risk assessment approach can be used during detailed design to evaluate the consequences of the different cover failure modes and what the optimal cover design life should be.

2.2 Site Climate

Site specific climate is one of the primary drivers that define what the most appropriate and sustainable cover may be for any given project area. The three dominating climatic parameters include the climatic water balance, air temperature, and radiation energy.

Site specific climate data is available with records from two onsite weather stations. Both stations have data from 2005 to 2011; however, the datasets are incomplete and generally too short to be useable or representative for a scoping level cover assessment. Regional climate data is available from the Pelly Ranch station, managed by Environment Canada. This station is located about 25 km north of Minto and has data dating back to 1955.

Based on the Pelly Ranch data, the mean annual total precipitation (MAP) for Minto is estimated to be about 335 mm. Roughly 50% of this precipitation falls as rain, with the remainder being the snow water equivalent of the annual snowpack. The maximum annual precipitation on record is 466 mm.

Monthly lake evaporation (aka potential evaporation) has been recorded at the Pelly Ranch station from 1965 to 2005 and the mean annual lake evaporation is 452 mm. Site specific data suggest that the mean annual evaporation is closer to 430 mm (Clearwater 2008) and 438 mm (Clearwater 2010). EBA (2010) applied an elevation correction to the Pelly Ranch data (1971-1990) to reduce the mean annual evaporation to 400 mm. SRK calculated the mean annual evaporation from first principles using the FAO method (FAO 1998) which computes to 410 mm evaporation per year. For the purpose of this study, the mean annual evaporation was selected based on the elevation correction presented by EBA (2010) to the Pelly Ranch evaporation data to yield a mean annual evaporation of 400 mm. The mean monthly climatic water balance based on this data is presented in Figure 2 and it demonstrates that between March and September, the climatic water balance is net negative, i.e., evaporation exceeds precipitation. This highly seasonal water balance deficit on a near neutral annual water balance makes it challenging to determine the most suitable cover type and a more in depth analysis of the climate is required.

Using the elevation corrected annual lake evaporation and precipitation data from Pelly Ranch from 1965 to 1995, the Thornthwaite and Mather (1955) Moisture Index was calculated to provide an indication of the site climate classification taking into consideration both water and temperature influences. This is presented in Figure 3 and confirms, generally, the site can be classified as Dry Subhumid; however, over the years the site spans both the Moist Subhumid and Semi-Arid climate zones.

The climatic water balance and climate classification are good indicators for what the most appropriate cover type would be at any given site and this is illustrated for Minto on Figure 4. This graph has been adapted from the Holdridge *et al.* (1971) life zone classification, as presented in the Global Acid Rock Drainage (GARD) Guide (INAP 2012). The data confirms that the site is best suited towards either water covers or infiltration controlling (i.e., barrier type) covers. Store-and-release and thermal covers on the other hand are not recommended for the site based on climatic conditions.

The mean monthly ambient air temperature for the site is also plotted on Figure 2. The annual average ambient air temperature is -4^{o}C. This leads to seasonal ground freezing, and site specific measurements suggest that the annual depth of frost penetration is less than 4 m. The site is also located in the discontinuous permafrost region of Canada and where permafrost is present, it is generally relative warm at about -1^{o}C.

Empirical methods were used to determine the annual depth of frost penetration at Minto, which amounts to between 2 and 3.5 m depending on soil porosity, water content and bulk density. Therefore, any low permeability barrier cover that could be damaged through freeze-thaw action would have to be constructed with a protection cover of at least 3 m.

Freezing temperatures also lead to a unique moisture distribution profile which is important when considering possible covers. During spring, significant surface runoff is present in the form of snowmelt; however, during this time the ground is still frozen and therefore water is less likely to infiltrate. When considering the climatic water balance illustrated in Figure 2, it appears that during spring (freshet) and early summer, when the most runoff is expected, the highest evaporation potential exists.

Figure 5 provides an overall climate wheel for the Minto site which summarizes key dates and timelines which will affect cover performance from both a hydrologic and physical perspective.

2.3 Potential Cover Materials

Locally available candidate cover soils consist of the overburden soils which can generally be classified as silty sands. Numerous geotechnical characterization programs have been carried out over the years including a dedicated cover soil characterization program in 2012 (SRK 2013b).

Three primary candidate cover soil sources have been identified as illustrated in Figure 1; (1) overburden stockpiled on the Main Waste Dump (MWD); (2) the Reclamation Overburden Dump (ROD); and (3) the Ice-Rich Reclamation Overburden Dump (IROD). Additional material is currently being developed from Area 2, Stage 2 Pit development and is being stockpiled on the Dry Stack Tailings Storage Facility and the Reclamation Overburden Dump. In total, it is estimated that there is about 2.8 Mt of these soils available for use as cover material.

Indicator property characterization testing has been completed on these soils (i.e., particle size distribution and Atterberg Limits) and the summarised results are presented in Figures 6 and 7. Their results demonstrate that there is minimal variability in the available material when considering its use a candidate cover source. Based on the overall grain size distribution envelope for all of the candidate cover soils (Figure 6), nine curves were initially selected to represent the possible range in cover performance (Figure 8).

Hydraulic testing (i.e., porosity, saturated hydraulic conductivity and Soil Water Characteristic Curves (SWCC)) was carried out on select samples and the results are summarized in Table 1 and Figure 9. Prior to the completion of the SWCC testing, six of the nine samples in Figure 8 were chosen and SWCCs were estimated using empirical methods. These resultant curves are illustrated in Figure 10. Comparisons of these estimated curves with the measured curves are presented in Figures 11 through 13. The final six calibrated SWCCs that were used in the cover analysis presented in this report are presented in Figure 14.

The MWD overburden material is sandy, lean clay (CL, in accordance with the Unified Soil Classification System). The porosity is estimated at about 36% and saturated hydraulic conductivity is about 1.38 x 10^{-7} m/sec. The air entry value is estimated to be between 23.1 and 71.9 kPa.

Materials from the ROD and IROD range from silty sands to clayey sands (SM-SC). Porosity is estimated at 29% to 31%, and saturated hydraulic conductivity ranges between 7.72 x 10^{-8} and 9.24 x 10^{-8} m/sec. The air entry value is estimated to range between 1.5 and 12.1 kPa.

Table 1: Hydraulic properties of overburden material from MWD, ROD, and IROD

Material Type	Porosity	Saturated Hydraulic Conducticity (m/s)	Field Capacity (VWC)	Wilting Point (VWC)	Storage Capacity (VWC)	Air Entry Value (kPa)
MWD1	36.0%	1.38 x 10^{-7}	0.339	0.223	0.116	71.9
MWD2	36.0%	1.38 x 10^{-7}	0.304	0.192	0.112	23.1
ROD2	31.0%	9.16 x 10^{-8}	0.260	0.160	0.100	12.1
ROD3	29.0%	7.72 x 10^{-8}	0.176	0.112	0.065	1.5
IROD1	31.0%	9.24 x 10^{-8}	0.243	0.127	0.116	4.8
IROD2	30.5%	8.79 x 10^{-8}	0.202	0.122	0.080	1.7

Three properties dominate the suitability of material as it relates to its use as a candidate cover material. First, for barrier covers intended to reduce infiltration, the saturated hydraulic conductivity is the most important. As a general rule of thumb, a soil should have a saturated hydraulic conductivity of at least 1 x 10^{-8} m/s (315 mm/year) to be considered an infiltration barrier.

Secondly, the property that dominates the suitability of a store-and-release type cover is how well graded it is, which translates into its moisture holding capacity (i.e., difference between its air entry value and residual suction). The moisture holding capacity is often simplified in terms of the Storage Capacity as listed in Table 1. This is calculated as the difference between the soil's Field Capacity and Wilting Point. Field Capacity correlates closely to the air entry value but is generally considered to be the volumetric moisture content of a soil at a soil suction of 33 kPa. Likewise, the Wilting Point correlates closely with the residual suction, but is generally considered to occur at a suction of about 1,500 kPa. The Field Capacity is the point where a soil starts to de-saturate, and the Wilting Point is the point where plants are no longer able to extract moisture from the soil pore space. Generally the greater the storage capacity of a soil, the greater the potential for being an efficient store-and-release cover, provided the climate is suitable.

Lastly, a soil cover must resist surface erosion and therefore silty soils, which are highly prone to erosion, are normally considered less desirable.

It can therefore be concluded that the available soils at Minto are not ideal store-and-release materials (although certainly workable) and are definitely not suitable for construction of low infiltration (barrier) covers. Construction of such covers will require intervention such as adding bentonite.

2.4 Waste Settlement

Mine waste settlement, specifically differential settlement can affect cover integrity. The waste rock dumps and dry-stack tailings at Minto are not expected to undergo significant settlement; however, the tailings in Main Pit will undergo settlement as a result of self-weight consolidation, as well as the surcharge from cover placement.

Consolidation testing has not been done on the Main Pit tailings; however, based on general experience with similar tailings it is conceivable that tailings consolidation, and associated cover settlement could be around 30 cm on the exposed beaches, and up to 1 m on the slimes regions near the central pond area (not accounting for entrained ice). Such settlement could affect cover integrity, and therefore the cover design should either compensate for potential settlement, or construction should only be done once settlement is complete.

Complete tailings settlement will require tailings dewatering, and even then it could take years or even decades. Therefore, it is recommended that the Main Pit tailings impoundment cover design be such that up to 1 m of settlement would still result in the cover performing as designed.

2.5 Seismicity

According to the 2010 National Building Code of Canada seismic hazard calculator, the corresponding peak ground acceleration (PGA) for the Minto site is 0.057 g for a 2% probability of exceeding in 50 years (1 in 2,500). This means that this site is not particularly seismically active.

Assuming the cover is constructed from a non-liquefiable material, seismic action will affect cover integrity in two ways:

First, a cover placed on steep side slopes not subject to liquefaction, would be subject to classic failure mechanisms such as increased pore water pressures induced by ground shaking. At the Minto site this failure mechanism would only apply to covers constructed on the waste rock pile and dry-stack tailings impoundment.

Second, a cover constructed on potentially liquefiable material such as the Main Pit tailings could cause surface manifestations of liquefaction in the cover in the form of cracks and boils.

The occurrence of such surface manifestations, assuming liquefiable tailings at depth, is a function of the thickness of the non-liquefiable cap (cover plus the unsaturated tailings layer). For a cap thickness greater than 3 m, case histories (Ishihara 1985, as reported by Ritchie (1999)) suggest that there will not be a surface manifestation for ground surface accelerations up to 0.2 g. Since this is an order of magnitude greater than the design earthquake this is not considered to be a concern.

2.6 Trafficability/Constructability

The construction of any cover over saturated tailings is challenging, due to the fact that construction equipment cannot travel over the surface that needs to be covered. This means that the cover has to be constructed in one of five possible ways:

1. Construction of the tailings cover is delayed until the tailings have had enough time to naturally dewater such that equipment can safely travel on it. The problem with this approach is that this process can take very long, i.e. many years, if ever.
2. The tailings are actively dewatered through installation of wick drains or other similar dewatering devices. This can be cost prohibitive, and still must address the issue of access onto the tailings for the installation of these dewatering devices.
3. A platform is developed from the perimeter of the saturated zone by dumping cover material and dozing it over the saturated tailings. This platform becomes the working base for the construction equipment as it advances. The problem with this method is the amount of cover material that is required is significantly greater due to the requirement for a trafficable surface, and often a tailings bow wave forms immediately ahead of the working face. This results in an uneven tailings surface which may add to the need for increased cover material.
4. Cover construction can sometimes be done with specially modified low ground pressure equipment. This still requires a de-saturated surface layer, and the equipment is highly specialized and expensive.
5. Construct the cover in winter, after the frost has penetrated to a depth sufficient to support construction equipment.

Cover construction at Minto over the slimes zones of the Main Pit tailings impoundment will definitely be subject to trafficability challenges. Therefore, any cover design does need to mitigate these challenges, for example by doing winter construction to take advantage of a frozen tailings surface.

For the dry-stack tailings impoundment and the waste rock piles cover constructability should not be too much of a concern, provided that where possible the side slopes be kept flatter than 33% (3H:1V). Cover placement on steeper slopes becomes less efficient. Should geosynthetics be used, slopes may have to be flattened to as low as 20% (5H:1V).

2.7 Physical Exposure of Mine Waste

Physical exposure of mine waste is a human and terrestrial health and safety concern at mine sites (including Minto). Exposure pathways include direct physical contact, as well as indirect contact via dust and overland surface runoff. In order to mitigate this, any physical separation cover over the mine waste areas would suffice. There may however be other cover design criteria that could dominate such as infiltration control, and therefore a cover for the sole purpose of separation may not be appropriate at Minto.

2.8 Oxygen Reduction

As previously documented, geochemical characterization of the tailings and waste rock suggest that rapid oxidation is not a concern. Therefore construction of oxygen limiting/reducing covers at Minto is not warranted.

2.9 Infiltration Reduction

It has already been documented that the available cover materials are not good candidate materials to construct effective barrier covers, even if well compacted. Furthermore, in most cases, the saturated hydraulic conductivity of the mine waste is less than or equal to the available cover material, further negating the possible usefulness of constructing barrier covers with these candidate cover materials. Although data is not available it is estimated that the saturated hydraulic conductivity of the dry-stack tailings is about 1×10^{-7} m/sec (3,154 mm/year), and the Main Pit tailings (beach tailings) would be similar. The slimes would be at least an order of magnitude less (i.e., 1×10^{-8} m/sec or 315 mm/year). Data for the waste rock is not available but it is likely to be about 1×10^{-4} m/sec (3,153,600 mm/year).

Site specific water balance calculations suggest that about 30% (Clearwater 2010) of precipitation gets discharged as overland runoff at the Minto site. Very little overland runoff is however observed and, in reality, the bulk of this volume is actually shallow infiltration which emerges as stream flow downstream of the Minto site at the flow gauging station. Therefore it is not unreasonable to assume, in the absence of specific infiltration analysis, that although the available soils would allow for construction of store-and-release covers, they would likely not be able to consistently perform to a standard better than reducing infiltration to about 20% of mean annual precipitation.

As a result, in all likelihood, the only viable method to reduce infiltration further would be to make use of a synthetic cover, or alternately a bentonite-amended barrier layer.

2.10 Slope Stability

For the most part, the cover designs at Minto will be on relatively flat surfaces. The waste rock piles and dry-stack tailings impoundment have been designed with final slopes of either 2.5H:1V or 3H:1V which would support efficient cover construction, provided the slopes are not too long. Should geosynthetic covers be required, these slopes may be considered too steep.

2.11 Wind Erosion

The fines content of the candidate cover material suggest that, under prolonged dry periods, wind erosion could be a concern with respect to cover integrity. Appropriate mitigation strategies could include sacrificial increase of the cover thickness to compensate for material loss over time, or providing a physical barrier against wind erosion.

Wind erosion is a complex phenomenon and is a function of the soil properties, climate and the vegetation characteristics. Wind erosion simulation models can be used to evaluate what the potential soil loss would be; however, the lack of data precludes the use of such models at this time.

A number of physical wind erosion studies provide some useful indicative data to use as a first order estimate of wind erosion rates in this conceptual design. Forward *et al*. (2004) reported that the annual soil loss through wind erosion from agricultural land in Southern Australia ranges between 0.01 and 0.06 mm/year. Basher and Webb (1997) reported wind erosion rates in bare soil in New Zealand of 0.90 mm/year. Based on this data, a sacrificial increase in soil thickness for a 200 year cover design life would be between 3 and 180 mm. However, considering the uncertainty associated with these estimates, the difficulty in transposing the data to a site specific condition, combined with the risk of exposed mine waste, mitigation against wind erosion through sacrificial increase of the cover should be considered a potential optimization strategy at this time.

An alternative method of preventing wind erosion would be to construct a physical barrier (i.e., some form of armouring such as fine gravel) on the erosion susceptible soil cover. Since there is no readily available source of such a material at Minto, this mitigation measure is likely not viable.

Cover stabilization using vegetation is commonly acknowledged and is likely the preferred method of wind erosion stabilization for the site.

2.12 Overland Surface Runoff

The high silt content of the cover soils suggest that surface erosion will be a problem. Just as with wind erosion, overland surface water erosion rates are difficult to estimate, and can be managed by adding sacrificial cover material, or providing a suitable physical barrier. The thickness of a sacrificial cover layer cannot be estimated at this time; and further optimization in this area is recommended.

Similar to wind erosion, a definite method of ensuring that erosion protection is provided in the long-term would be to clad the erosion susceptible cover with erosion resistant soil or rip-rap. Since there is no readily available material of this nature at Minto (other than waste rock), this alternative is not recommended.

Vegetation is a proven erosion stabilization technique and is therefore the preferred mitigation strategy against overland surface runoff. To further reduce the risk of developing erosion gullies, appropriate landform engineering must be carried out to promote the development erosion resistant landforms.

It is important to remember that water shed by runoff has to be safely conveyed over the cover to its receiving environment. Therefore, the cover design must account for the volume, frequency and intensity of runoff that is anticipated and the seamless integrated designs of the cover and conveyance channel contact zones are integral to the overall success of the cover.

Naturally, more runoff implies that less water is available for infiltration. This presents potential opportunities that are of relevance in selecting a suitable cover design for the Minto site. Firstly, if a significant portion of the freshet season infiltration is shed as runoff, then the amount of infiltration that has to be accounted for in a store-and-release cover becomes less, and the likelihood of reaching a workable ratio of infiltration versus potential evaporation increases (although it may still not be enough), making this type of cover more viable.

2.13 Evapo-Concentration

Chemical constituents present in the mine waste pore water, specifically salts, can be transported up (“wicked”) towards the waste surface, and continue up through the cover soil due to capillarity associated with upward fluxes caused by evaporation. This problem, also termed evapo-concentration, is common in net negative climates where the predominant flux is upward. If evapo-concentration occurs, it leads to contamination of surface water, which would constitute as non-compliance with the site closure objectives. During the wet season, there would be a constant variability of the flux within the cover, but evapo-concentration is not likely to be a major concern. However, during prolonged dry periods, the predominant flux would be upwards, especially if the underlying waste has a high moisture content. As a result evapo-concentration is not expected to be much of a concern at Minto.

This can however be mitigated by making the cover thick enough that all the meteoric action occurs within the cover with no contribution from the underlying waste, or by including a physical barrier in the cover that prevents this pore water from migrating up through the cover. The most common physical barrier is a capillary break. Since evapo-concentration is not expected to be a concern at Minto, the cover design will not take this into consideration.

2.14 Root Uptake

Allowing vegetation to establish on the final Minto closure covers is probably the most sustainable long-term solution, notwithstanding the limited growing season. A vegetative cover offers benefits in terms of reducing meteoric infiltration through increased evapotranspiration, whilst also providing erosional stability from wind and surface runoff. Disadvantages of a vegetative cover include creation of preferential flow paths through root penetration, and potential contaminant uptake from the underlying waste by the plant root systems to the surficial plant biomass, which in turn could pose a terrestrial exposure risk.

Mitigation against root uptake could include limiting plant growth outright, or constructing a chemical or physical root barrier as part of the cover. Outright prevention of vegetation can only be done through active site management, since even if coarse rock is used as a cover, dust and seed will be transported to the cover over time through wind from neighbouring undisturbed land and, ultimately, some vegetation will establish. Since active site management is not acceptable, a chemical or physical root barrier should be included as part of the cover.

Chemical root barriers, although expensive, work well in cold climates and are likely to have a significant lifespan. A more common root barrier would be a physical barrier, consisting of a layer of gravel and cobbles filled with fines such as the candidate cover soils. The fines will prevent the layer acting as a capillary break. This root barrier should be at least 20 cm thick and should be above the barrier layer or, alternatively, below the store-and-release cover layer.

The root barrier will serve a secondary purpose of acting as a bio-intrusion layer preventing burrowing animals from penetrating the underlying waste. A root barrier needs to be constructed at Minto if low infiltration covers are required and active vegetation management is not being proposed.

2.15 Animal Activity

Minto is in a wilderness area and, therefore, after closure terrestrial animals are expected to move across the site. Burrowing activity by animals could compromise the cover, and to prevent such an occurrence, a gravelly layer can be designed into the cover. The likelihood of large scale damage due to animal burrowing action is very small and, therefore, such measures are not recommended at Minto.

2.16 Human Activity

Following closure, the site is likely to be infrequently used by seasonal hunters. Hunters typically use snowmobiles and all-terrain vehicles to get around and these machines can erode away the vegetation layer of a cover and subsequently result in damage to a geosynthetic liner. This can be mitigated by limiting access to the covered areas or, alternatively, adding in a coarse rock protection layer to the cover. The site is, however, sufficiently remote that concentrated access routes from these off-road vehicles are not expected and therefore no specific design elements will be included to protect against such damage.

3 Generalized Cover Types

3.1 Water Covers

Water covers involve permanently submerging mine waste. A water cover effectively shuts down oxygen ingress to the underlying waste, preventing oxidation. The water cover provides a constant hydraulic head that promotes seepage which may provide a pathway for mobilizing soluble oxidation products present in the waste. Therefore, water covers work best if oxidation of the waste is prevented from starting in the first place. If the waste has already undergone significant oxidation, exclusion of oxygen through a water cover to prevent further oxidation may not be warranted, or even desirable, given the inventory of oxidation products already present in the waste.

Water covers are best suited to net positive climatic water balance areas (i.e., annual precipitation exceeds evaporation), since that implies a surplus supply of water to the cover. Water covers are less favourable when permanent large engineered water retaining structures are required, such as dams that may be subject to long-term integrity concerns.

Based on the diffusion coefficient of oxygen through water, it is accepted that under ideal conditions only 30 cm of water cover would be sufficient to prevent oxidation. In reality, waste disposal facilities are typically large, and are subject to wind induced wave action, counter-current flows, seiching, lake/pond turnover (and lake/pond ice formation in cold climates) etc. These physical actions result in water turbulence, which in turn, may result in re-suspension of particles. Re-suspended particles may undergo oxidation rendering the water cover ineffective. Rules-of-thumb state that a 1 m thick water cover would mitigate against these concerns; however, a review of current practice shows that typical water cover depths are between 2 and 5 m thick.

As described in Section 2.2, the climate at Minto is conducive to the use of water covers. The mine waste at Minto is however not highly oxidizing and therefore maintaining a permanent water cover is not necessary for long-term geochemical stability. More importantly however is the fact that, with the exception of tailings deposited in Main Pit (and possible future pits), the mine waste rock and dry-stack tailings facility cannot readily be flooded unless large containment structures are constructed, and/or waste is relocated. For the tailings in Main Pit, a water cover could likely easily be engineered; but a perpetual water retaining dam would be required. Water covers were, therefore, not given further consideration at this time.

3.2 Saturated Soil Cover

Saturated soil covers are an alternative method of ensuring isolation of wastes from exposure to oxygen, but by eliminating the need for large stretches of open water, the issues associated with re-suspension are eliminated. The concept entails using a coarse (ideally gravelly) material with significant void space as the primary cover material and placing it in a perpetually saturated state. This saturated layer can be at surface or at depth, i.e., providing opportunity for an upper cover layer that may, for example, sustain vegetation. This type of cover works best if the climatic water balance is positive, and just as with the water cover, may be problematic if significant oxidation products are already present.

At Minto this type of cover may have merit for in-pit tailings although, given the fact that neutral metal leaching is a concern, the constant hydraulic head and subsequent risk of seepage may be problematic. Therefore this cover type was not explored further at this time.

3.3 Barrier Covers

3.3.1 Concept

Barrier covers (also known as water shedding or infiltration controlling covers) work on the principle of physically limiting and/or preventing meteoric infiltration and/or oxygen ingress. As described above, if the waste has been significantly oxidized, an oxygen barrier may be of limited benefit; however, a cover controlling infiltration may be of benefit.

Physical barriers can come in many different forms, including impermeable synthetic barriers such as high density polyethylene (HDPE) liners, low density polyethylene (LDPE) liners, bituminous liners, geosynthetic clay liners (GCL), or natural low permeability soil. A barrier cover can also be constructed by amending the surface layer of mine waste to achieve a low permeability layer. A brief summary of these different barrier cover types is provided below.

3.3.2 Natural Low Permeability Soil Cover

The effectiveness of a natural low permeability soil cover is determined by the following criteria:

- The cover should have a sufficiently low saturated hydraulic conductivity in order to restrict meteoric infiltration rates to the underlying waste;
- The cover should have a significantly lower saturated hydraulic conductivity than the underlying waste; and
- The cover should maintain a high degree of water saturation in order to limit the entry of atmospheric oxygen to the waste (a rule of thumb is at least 85% saturation).

A natural low permeability soil cover that is intended to act as both a water and oxygen reducing cover should adhere to all criteria above, whilst if the cover is only required to act as an infiltration barrier it needs to only adhere to the first and second criteria. If the intent of the cover is to act as only an oxygen barrier, it needs only to adhere to the third criterion.

Natural low permeability soil covers work best in net positive water balance climates which are not subject to freeze-thaw cycles. Under such conditions, there is sufficient moisture to keep the level of cover saturation high, and cover degradation due to frequent wetting and drying cycles (i.e., shrinkage and cracking) is limited. The annualized climatic water balance at Minto is largely net positive; however, three months of the year it is net negative, and more importantly, the site is subject to annual ground freezing. Therefore, if the barrier layer can be constructed below the annual depth of freezing, a barrier cover would likely work well at the site.

Generally, natural low permeability soil covers consist of clays and silts, with plasticity ranging from moderate to high. These materials are generally placed in a compacted state. Theoretically, a low permeability cover does not have a minimum thickness, i.e., the performance of a 1 m thick layer with a specific saturated hydraulic conductivity value would have exactly the same net effect as a geosynthetic clay liner (GCL) of the same saturated hydraulic conductivity given the same hydraulic gradient (i.e., unity). In practice, however, low permeability layer thickness is governed by constructability and allowance for desiccation cracking. Therefore, if the low permeability cover: (a) has limited desiccation cracking risk due to a well-graded texture and low plasticity, (b) is not subject to extreme wetting and drying cycles; (c) is below the depth of ground frost penetration; and, (d) is protected against surface runoff erosion, then the cover could be relatively thin, and constructability issues would be the primary concern (i.e., it is difficult to place a consistent thin compacted layer of low permeability soil over an undulating waste pile surface, and it is almost impossible to do so on soft saturated ground).

It is generally considered poor practice to allow vegetation to establish directly on a compacted low permeability layer because the design hydraulic conductivity and performance will be compromised. If a single-layer cover is adopted, using only the compacted low permeability cover material, then the thickness must be appropriately increased to allow at least a 60 cm thick layer of compacted low permeability soil that will not be penetrated by roots. As an added safeguard, consideration can be given to placing a root barrier. At Minto, use of a single layer at surface is not recommended due to ground freezing.

In order to get a general sense of what type of cover material would be required to perform as an effective natural low permeability soil cover at the Minto site, some general calculations can be carried out. Infiltration due to precipitation will be reduced if the hydraulic conductivity of the soil cover profile is less than the intensity of precipitation. For example, if the annual precipitation at Minto is about 335 mm, or 1.06×10^{-8} m/sec, water infiltration will be limited should the hydraulic conductivity of the cover be less than this value. Therefore, if it is intended to reduce infiltration through the cover to less than 20% of mean annual precipitation (i.e., less than 67 mm), the cover material should have a saturated hydraulic conductivity of at least 2.12×10^{-9} m/sec. From a water infiltration perspective, this a conservative assessment, since in reality the cover would not be completely saturated all the time, and based on unsaturated soil property theory, the hydraulic conductivity of an unsaturated soil profile is significantly less than in its saturated state. However, if the profile is significantly de-saturated to benefit from a low unsaturated hydraulic conductivity, the soil air entry value will be exceeded, and significant oxygen ingress will occur, i.e., the cover cannot be an oxygen barrier.

Current soil characterization data suggest that the saturated hydraulic conductivities of the available candidate cover materials range from 1.99×10^{-7} to 1.12×10^{-7} m/sec (6,275 to 3,532 mm/year), which is clearly not suitable for use as a barrier cover. Experience has shown that in practice, it is not realistic to expect natural soil barrier covers to have saturated hydraulic conductivities of less than 10^{-7} m/sec (about 3,154 mm/year), even though laboratory tests would often suggest otherwise. This is especially true if the barrier layer is located within the soil active zone (i.e., it is within the zone of cyclic wetting and drying, or freezing and thawing). Furthermore, Wilson *et al*. (2003) demonstrate that world wide experience with natural soil barrier covers, especially in seasonally wet/dry climates almost always yield greater than expected or predicted infiltration numbers. Given the site climatic conditions, SRK would not recommend the use of natural soil barrier covers at Minto using the locally available soils.

3.3.3 Synthetic Cover (HDPE, LDPE, Bituminous Liner)

Low permeability soils, if available, are almost always more economical than synthetic products; however, when natural soils are not readily available, or if the environmental risk is high, synthetic products such as capping materials can be appropriate. HDPE, LDPE, and bituminous liners are essentially impermeable; however, due to manufacturing and installation errors, even under the best quality control procedures, small pin holes can develop in the liner, such that generally for design purposes these liners are assumed to have saturated hydraulic conductivity values in the order of 10^{-15} m/sec (0.00003 mm/year). The difference between HDPE, LDPE, and bituminous products is generally the chemical resistance and workability of the material, with HDPE and bituminous liners being more robust products.

Synthetic liners must be installed according to manufacturer installation procedures that call for seaming of joints between liner sections, as well as placing the liner on an appropriately prepared surface. An appropriately prepared surface implies a clean, stable, smooth surface with limited undulations and few surface protrusions. If the waste surface is sufficiently coarse, the liner may be damaged, and an appropriate bedding material consisting of either a layer of clean sand or a non-woven geotextile are required.

Finally, the liner would have to be covered with a suitable cover depending on the final adopted land use. Again, if the cover soil contains a significant coarse fraction, then a protective sand or geotextile layer must first be placed over the liner.

An HDPE, LDPE, or bituminous liner would effectively eliminate oxygen and water ingress and provide a reclamation alternative with the least risk of impacting the environment in the long-term. Synthetic liners do, however, have a finite lifetime (manufacturer’s guarantee is normally limited to about 20 to 40 years), and there is a possibility that the closure plan would have to allow for complete liner replacement every 100 to 200 years. Finally, synthetic liners cannot be constructed on steep slopes, with the general rule of thumb being slopes flatter than 3H:1V for short slopes, and as flat as 5H:1V for longer slopes. If low infiltration covers are required at Minto, these types of covers should be considered.

3.3.4 Synthetic Cover (Geosynthetic Clay Liner)

A GCL consists of a thin layer (generally less than 1 cm thick) of bentonite clay sandwiched between two non-woven geotextile layers. Under ideal conditions, a GCL is generally assumed to have a hydraulic conductivity of approximately 10^{-11} m/sec (0.3 mm/year); however, in practice a value of 10^{-9} m/sec (31.5 mm/year) is often adopted for design calculations. GCLs are considered to be less susceptible to installation damage than HDPE, LDPE, or bituminous liners; however, they must be installed according to manufacturer’s installation procedures. Since GCLs are generally used with liquid containment in mind, and the use of a GCL as a cover (infiltration barrier) is somewhat different, the sub-grade specification can be relaxed. Depending on the surface preparation, it is conceivable that the GCL may be placed directly onto the mine waste and similarly the protective cover could be placed directly onto the GCL. The built-in geotextile, if appropriately specified, may provide sufficient protection.

A cover which includes a GCL may prove to be an extremely effective infiltration and oxygen barrier, provided the bentonite can remain hydrated and confined at all times. At the Minto site, this hydration should not be a problem during the wet season, but during the dry season, the bentonite may de-hydrate if the protective layer does not have sufficient moisture retaining capability. In addition, if the GCL is subject to freeze-thaw cycles, the physical integrity of the liner may be impacted. A GCL can be penetrated by roots, and therefore, as with a natural low permeability soil cover, it is desirable to ensure the vegetative substrate is thick enough to ensure roots do not reach the GCL, or alternatively, introduce a root barrier into the cover design.

It is also important to carefully consider the calcium content of meteoric water that will permeate through the GCL. As water passes through the GCL, calcium will cause ion exchange with sodium in the bentonite, which leads to permanent aggregation of the GCL. This results in an increased hydraulic conductivity, and subsequently increased infiltration rates (Lin and Benson 2000).

GCL covers are worth considering at Minto if low infiltration covers are required.

3.3.5 Bentonite Amended Mine Waste/Cover Soils

It is possible to reduce the surface hydraulic conductivity of the mine waste or a candidate cover material by mixing in bentonite clay and compacting the mixed layer, thereby creating an in-situ low permeability layer. This type of amendment is often done as a more cost effective solution than a synthetic cover to reduce surface permeability due to the fact that limited importing of soils and/or synthetic products is required. The hydraulic conductivity is reduced by mixing in bentonite clay which has a high affinity for moisture and hydrates to more than twice its volume, thereby taking up void space in the host material, which would otherwise have a high hydraulic conductivity. Naturally the same restrictions apply to bentonite amended soils with respect to possible aggregation of the bentonite as a result of ion exchange as has been previously discussed for GCLs.

There are two primary methods to mix the bentonite and host soil (or mine waste): (a) off-site mixing using a pug mill, and (b) in-situ mixing. Off-site mixing requires stockpiles of host material and bentonite, which is fed into a pug mill, and the mixed product is trucked to the deposition location for application and compaction. This method allows for excellent control over the mix, including moisture control which is important to ensure proper hydration of the bentonite (the mix is normally placed at above optimum moisture content). In-situ mixing requires the upper layer of the location to be ripped before spreading the bentonite at the desired application rate.
The bentonite is then mixed into the host soil using agricultural equipment. This method allows for less control over application rate and moisture, and therefore requires more bentonite product. However, if the host material is not pre-stockpiled then this method is usually more cost-effective.

The thickness of the bentonite amended layer will be site specific; however, a realistic thickness for use as a low permeability cover would be between 15 cm and 30 cm thick, with an application rate of 4 to 6% bentonite by weight (of the host soil). The bentonite-amended layer will perform as an effective low permeability layer, reducing infiltration and oxygen ingress as long as the bentonite remains hydrated. Should the layer be allowed to dry out, the volume change will result in cracks, which will increase the hydraulic conductivity. Bentonite does however have self-healing characteristics which will help cracks to reseal if the bentonite becomes re-hydrated. Normally, to minimize chances of drying of the bentonite amended layer, it would be overlain with 50 cm of compacted, but non-modified material that would remain at high saturation due to the low permeability of the bentonite amended layer. Should vegetation be a requirement, a suitably designed vegetation substrate layer would have to be placed on the amended and compacted layers, to limit root penetration of the amended layer. Bentonite amended covers would be a worthwhile alternative to consider at Minto should low infiltration covers be required.

3.4 Store-and-Release Cover

An alternative method of reducing infiltration is to make use of the inherent soil moisture storage capacity of the soil. Meteoric infiltration is not prevented as with a barrier cover, but rather promoted, such that the moisture is stored in the cover soil. This moisture is returned to the atmosphere via evapotranspiration before is has the opportunity to drain through the cover and enter the underlying waste. These covers are referred to as “store-and-release” covers (also called “water retention” or “alternative” covers), and work most effectively in dominantly net negative climates, i.e., the potential evaporation greatly exceeds the mean annual precipitation (typically at least two or three times greater).

As discussed in Section 2.2, the site climate is not particularly well suited towards use of store-and-release covers; however, during the summer months, they certainly can be effective provided that the wet (frozen) season precipitation is shed as runoff, such that the amount of infiltration for which storage would have to be created, would be manageable. It may also be beneficial to provide a barrier layer beneath the store-and-release layer to prevent breakthrough during the prolonged wet season.

Ideal store-and-release cover soils are well-graded soils that have sufficient fines to allow capillarity to be high whilst not compromising too much on the material porosity. Store-and-release covers are less susceptible to site preparation and quality control since compaction of the soil cover is generally not required (or in fact not recommended) and the cover is of sufficient thickness to mask minor undulations on the waste surface. Settlement of the waste will also not affect the cover as much. Direct re-vegetation of the store-and-release cover is generally undertaken, unless the soil has a nutrient deficiency. The successful establishment of vegetation on a store-and-release cover is crucial towards its success, since the enhanced evapotranspiration will ensure long-term cover performance.

Notwithstanding the reservations about the applicability of using store-and-release covers at Minto, we can use the estimated hydraulic properties of the available cover soils at Minto, and use empirical methods (Chen 1999) to estimate the likely range of store-and-release cover thicknesses that would be required at Minto. Assuming 20% mean annual precipitation as the infiltration target, the store-and-release layer thickness would have to be between 384 and 740 mm. This increases to between 676 and 1,225 mm if the infiltration target was lowered to 2%. It is important to note that due to the relatively low air entry value of these soils, their capillarity is limited and, therefore, increasing the thickness of the store-and-release layer provides very little added benefit. Although the available storage space is increased, the moisture cannot be moved upward more than about 1 m at most, but more importantly, there is not enough radiating energy available to extract the excess moisture.

At Minto, considering the available soils and climate, an infiltration target of about 20% on average for a store-and-release type cover is probably as good as would be consistently attainable. Under specific conditions this cover is likely to yield much better performance; however, significant breakthrough events will frequently occur.

3.5 Reactive Cover

Reactive covers normally refer to covers that include chemically active components. Broadly speaking, two types of such reactive covers are referred to: (1) covers where the reaction leads to consumption of oxygen, and (2) covers where the reaction leads to formation of low permeability layers and/or barriers to oxygen diffusion.

Oxygen consuming covers can be either organic or inorganic. Organic covers, for example wood waste over an acid generating tailings impoundment have been shown to have good success, however the main complication with these kinds of covers is that they are not sustainable. The organic cover loses its ability to consume oxygen over time, and as a result become ineffective. Organic oxygen consuming covers can be in the form of materials that have high neutralizing potential, and as a result, balance out the overall seepage waste load as a result of the buffering capacity.

The concept of deliberately placing reactive materials to create low-permeability covers rests on the principal that two layers are placed in contact, each one being a reagent. Where these layers contact each other, the reactants will meet and combine to form a precipitate that fills the pores.

Although in theory reactive covers show potential, to date they have not been used in full scale mine closure applications. Some long-term and medium scale pilot scale covers have been constructed; however, the principle of using reactive covers as final closure covers has not been adopted by the industry to date.

There does not appear to be any potential cover materials that would make for good reactive cover construction at the Minto site, and therefore this type of cover was not given further consideration in this evaluation.

3.6 Capillary Break Cover

A capillary break cover can be used to limit infiltration and to prevent contaminants from a waste deposit from being wicked up into the cover soil. It works by placing a fine grained soil over a coarse soil (typically a gravely soil containing little or no fines). The upper fine soil can come close to saturation, before it allows flow to pass through the underlying gravel. Generally, if a capillary break is used to limit infiltration, it can be used to reduce the thickness of an overlying store-and-release cover layer.

A capillary break may also be useful to maintain a high degree of saturation in a cover such that it would act as an oxygen barrier. Therefore, a capillary barrier may be constructed under a low permeability cover layer to ensure that the degree of saturation remains high, and limit oxygen ingress.

Capillary barriers also work in the reverse, i.e., if there is an upward flux through the cover due to evaporative action through which contaminants in the waste body may be wicked to the surface, the capillary break will prevent this from happening. Such wicking could result in surface water contamination in runoff from the cover, and it could also lead to metal uptake of vegetation established on the cover. Wicking is generally more of a concern in a net negative climate, where the upward flux often dominates. This may only be a concern during the three dry months at Minto.

Assuming the capillary barrier has been correctly designed with the appropriate hydraulic properties (it must have a residual suction which is lower than the air entry value of the overlying fine soil), a capillary break layer has no minimum thickness. In reality, the rule of thumb is to design these layers at least 30 cm thick. Depending on the difference between the gradations of the capillary break and the overlying fine soil, a filter media or geotextile may be required at the upper and lower interfaces.

In many cases, the waste material to be covered is sufficiently coarse that, if a low permeability cover is applied, the gradation difference is sufficiently large enough that the waste itself would act as a capillary break. Capillary break covers are quite complex to design and construct, but are best used to either keep an upper or lower layer at a higher degree of saturation, or to specifically prevent upwards wicking. Neither of these conditions appears to be specifically required at Minto and therefore this cover variant was not considered further at this time.

3.7 Frozen/Thermal Cover

In cold regions, mine waste may freeze, or measures can be implemented to promote freezing. This effectively eliminates any risk of contamination from these wastes. Covers can therefore be designed to preserve the frozen waste mass. This concept, generally, only works in areas where cold continuous permafrost is already present and the covers are normally very thick (i.e., in excess of 2 m).

Minto is located in the discontinuous permafrost region of Canada and the permafrost present is relatively warm (i.e., about -1^{o}C near surface). Considering climate change predictions which are forecasting warming trends, design of a frozen cover at Minto is not considered a viable option.

4 Conceptual Cover Designs

4.1 Site Wide Closure Objectives

In accordance with the D&RP (Minto 2011), the site wide closure objectives are as follows:

- Have a closure planning process that seeks input from the Selkirk First Nations, understands the input received, and incorporates the input into closure planning decisions;
- Protect the health of people pursuing traditional activities including hunting, fishing, trapping, camping, and collection of plants for food, medicinal or cultural purposes;
- Protect people from safety risks when they are pursuing traditional activities including hunting, fishing, trapping, camping and collection of plants for food, medicinal or cultural purposes;
- Protect the environment (including land, air, water, plants, animals fish and other environmental components and their interrelationships) from long-term effects caused by the mine activities and facilities;
- Return the mine site and affected areas to a state similar to surrounding lands so that people can pursue traditional activities the same as they did before mining, including hunting, fishing, trapping, camping, and the collection of plants for food, medicinal or cultural purposes;
- Protect the environment from long-term effects caused by post-closure access to the mine area;
- Protect the environment from effects of earthquakes, floods, climate change, and other natural events on related mine structures;
- Have effective management and control structures in place during operation, closure and post-closure to provide;
  - Adequate financial resources to carry out all closure activities including plan implementation and long-term activities;
  - Adequate flexibility during closure and post-closure to allow adaptation of activities in order to address unexpected performance and events; and
  - Consideration of the Company’s long-term desire to “walk away” from the site under conditions acceptable to Selkirk First Nations and with adequate resources provided to address long-term requirements.
- Minimize long-term activities by ensuring long-term chemical and physical stability of mining components and disturbed areas;

- Confirm the effectiveness of closure measures by monitoring the site after closure;
- Undertake mine planning incorporating progressive reclamation;
- Provide short and long-term slope stabilization and erosion control on linear and non-linear disturbances;
- Ensure the long-term chemical stability of residual mining components and minimize their effects on water quality draining the property;
- Ensure the long-term physical stability of key structures such as the waste dumps and the diversion and drainage ditches; and
- Work towards a passive closure scenario for most or all mine components.

4.2 Possible Cover Functions

Covers are one of many possible mitigation strategies that can be used to achieve site wide closure objectives. Other two common strategies include waste relocation and water treatment. If conditions are such that covers are a suitable mitigation strategy, then the specific function that the cover needs to perform in order to meet the closure objective must be explicitly stated. The following cover functions are recommended for Minto based on the current understanding of site conditions:

- Reduce infiltration to a specific target that would ensure site wide water quality objectives can be met;
- Isolate the mine waste to avoid direct contact by human or other terrestrial animals; and
- Provide a stable landform that is aesthetically pleasing.

4.3 Cover Design Criteria

The cover functions in Section 4.2 above could be considered ambiguous if they are considered in isolation and therefore these functions needs to be explicitly defined in terms of measurable design criteria. A set of example design criteria is provided in Table 4.1.

Table 2. Proposed Minto mine cover design criteria

Component	**Criteria**
Design Life	100 years (while it is recognized that the cover will remain in place for a longer period, design performance will be measured against this criteria)
Oxygen Reduction	Not required
Infiltration Reduction	Isolating Cover: no more than the uncovered waste; Low Infiltration Cover: no more than 10% of mean annual precipitation with no significant breakthrough events, and; Very Low Infiltration Cover: no more than 2% of mean annual precipitation with no breakthrough events
Waste Settlement	Waste Rock Piles and Dry-Stack tailings: no criteria; Main Pit Tailings: up to 30 cm on beach areas and up to 100 cm on slimes areas (cover is not expected to perform without maintenance and repair when subject to these settlements)
Seismicity	1 in 2,500 year recurrence interval (10% probability of exceeding in 50 years)
Trafficability	Concern for the Main Pit tailings area only. Mixing zone acceptable; but minimum cover design thickness to be measured from above the mixing zone
Physical Exposure	As far as practicable keep mine waste covered. In no areas may more than 1 m^2 of mine waste be exposed as a contiguous area for the life of the structure
Slope Stability	Overall factor of safety of at least 1.3 under static conditions and 1.1 under seismic loading
Wind Erosion	No visible dust up to and including wind speeds with a recurrence interval of 1:10 years, for any given duration. In no areas may overall cover thickness be less than 75% of original design thickness for the life of the structure
Overland Surface Runoff	Capable of withstanding 1:100 year, 24 hour duration storm during peak freshet with no damage. In no areas may overall cover thickness be less than 75% of original design thickness for the life of the structure
Evapo-Concentration	Not required
Root-Uptake	Not required
Vegetation	Self-sustaining vegetation cover endemic to the region within 20 years after cover construction (foreign species and fertilizers during early years acceptable if it supports the final objective)
Land Use	General wilderness area. Large terrestrial animals, birds and aquatic life will be present. Humans will travel through the area infrequently (mostly hunters and trappers). Specific measures to preclude damage to the covers due to human and/or animal use not required
Landform	Promote use of landforms consistent with the current landscape. Provide for variability on cover thicknesses and landscaping to promote establishment of microclimates and variability

4.4 Conceptual Designs

4.4.1 Isolating Cover

Figure 15 illustrates a conceptual isolating cover for the Minto site. The bottom trafficking layer of run-of-mine waste rock is only required for the Main Pit tailings. For beach areas, the trafficking layer thickness of about 0.5 m is probably sufficient, but in the slimes areas, this layer may have to be up to 1 m thick. It is recommended that these trafficking layers be constructed during the winter season when the tailings surface is frozen as the added strength will facilitate in minimizing the mixing zone which would reduce the total volume of material required. Note that tailings may migrate through the trafficking layer as traffic passes over the cover and therefore placement of this layer alone does not constitute an isolating layer.

The isolating layer will be a minimum 0.5 m thick compacted layer of local overburden soil. No specific measures need to be taken to specifically preclude compacting through trafficking across the covered surface; however, to the extent practical, to facilitate vegetation establishment, care must be taken to prevent excessive vehicle compaction. The soil cover will then be re-vegetated.

Detailed numerical analysis has not been carried out; however it is SRK's opinion based on the material characterization and site climate that this cover would consistently result in infiltration values of between 10 and 20% of mean annual precipitation. Significant breakthrough events can, however, occur based on large individual rainfall events. The cover will be susceptible to surface erosion and, therefore, it would be of paramount importance to establish stabilizing vegetation soon after cover placement. Where surface runoff concentrates, dedicated surface water conveyance channels will have to be constructed.

The performance of this cover will not be affected by freeze-thaw and wetting/drying cycles and is not significantly affected by waste settlement. Some maintenance in the form of regrading will be required if significant differential settlement is experienced to ensure that water is not trapped in ponds on the covered surface.

4.4.2 Low Infiltration Cover

A conceptual low infiltration cover for the Minto site is presented in Figure 16. The locally available soils are not suited to constructing low infiltration covers and therefore soil amendment will be required. Although no specific testing has been carried out, it is expected that a 4% bentonite mix with the locally available soils will yield an appropriate infiltration barrier to ensure infiltration remains consistently below 10% of mean annual precipitation. The amended layer should be about 0.3 m thick, be compacted and covered with a 0.5 m loosely compacted isolating layer as described in Section 4.4.1.

The trafficking layer requirements are also consistent with those described in Section 4.4.1.

The infiltration performance of this cover will be affected by freeze/thaw and wetting/drying cycles; however the self-healing properties of the bentonite should compensate against total failure. It is, however, conceivable that small breakthrough events could occur unless the upper isolating cover is increased in thickness to about 3 m to ensure the amended barrier layer is below the annual frost penetration depth.

The cover performance is sensitive to waste settlement, as large displacements of the bentonite amended layer may result in significant discontinuities in the layer which would increase infiltration. Frequent inspections of the cover will have to be undertaken over the Main Pit tailings and where large depressions are observed, the bentonite amended layer must be exposed and possibly in-filled to compensate for potential loss of performance.

On the dry-stack and possibly the Main Pit beach areas, consideration can be given to amending the upper tailings surface with bentonite as opposed to the dedicated 0.3 m thick imported overburden layer.

Appropriate trade-off studies will have to be carried out to determine the most cost effective method of mixing the amended layer.

4.4.3 Very Low Infiltration Cover

Suitable natural soils to construct a very low infiltration cover at Minto are not available and, therefore, a geosynthetic liner is recommended if this level of cover performance is required. An appropriate trade-off study will have to be carried out to determine the most economical geosynthetic product; however, for the purpose of this study, a 60 mil textured HDPE liner has been assumed. The overall conceptual cover design is illustrated in Figure 17. As described before, the trafficking layer only applies to the Main Pit tailings impoundment.

A levelling and protective layer of compacted tailings (borrowed from Main Pit beach tailings or the dry-stack tailings impoundment) at least 10 cm thick must be placed between the mine waste and the liner. Note this is not required on the dry-stack, but will be required on the Main Pit tailings since the trafficking layer will be the surface on which the liner is placed.

A similar protection layer must be placed over the liner prior to constructing the overliner soil cover. Given the relatively benign geochemical composition of the tailings, it is recommended that this layer be tailings. Should focussed characterization prove this is unacceptable, suitable clean sand would have to be imported, or alternaticely a robust (e.g., 16 oz) non-woven geotextile can be substituted.

The overliner soil cover should consist of a 0.3 m thick compacted layer (at least 98% Standard Proctor) of local overburden soils, overlain by a 0.5 m thick, loosely compacted layer similar to that recommended for the isolating cover. The lower compacted layer serves to better anchor the liner, and to provide a root barrier to resist deep penetration which may damage the liner.

Although detailed numerical analysis has not been carried out, the liner, if installed with due care, will ensure infiltration to less than 2% of mean annual precipitation with no chance of breakthrough events due to extreme events. The upper isolating cover will be susceptible to surface erosion and would require the same treatment as described in Section 4.4.1.

The infiltration performance of this cover will not be affected by freeze/thaw and wetting/drying cycles; however the compacted layer will become less dense overtime, thereby reducing its functionality as described. A complete loss of functionality over the design life of the cover is, however, not expected.

The liner performance is very sensitive to waste settlement, and may tear or rupture under severe conditions. Frequent inspections of the cover will have to be undertaken over the Main Pit tailings impoundment in the first 5 to 20 years following cover construction. If trampolining (i.e., unsupported liner) is observed, the liner would have to be exposed, and remedial works initiated.

5 Conclusions

The hydrologic and climatic regime at the Minto site is best suited to the use of water covers or infiltration reducing covers (i.e., barrier covers). Store-and-release and thermal covers are not likely to be successful. The available overburden soils at Minto are not well suited for construction of low or very low infiltration covers.

These soils can however be used as effective isolation and vegetation supporting covers, and are expected to result in overall infiltration of between 10 and 20% of mean annual precipitation, typically. Periodic higher breakthrough events will, however, occur. Soil amendments or use of synthetic products would be required to construct low to very low infiltration covers at the site. Conceptual designs of each of these different cover variants have been proposed.

This report ***"Scoping Level Cover Assessment for Minto Closure Covers"*** has been prepared by:

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6 References

Basher, L.R., Webb, T.H. (1997). Wind erosion rates on terraces in the Mackenzie Basin. Journal of the Royal Society of New Zealand 27: 499-512.

Chen, C. (1999). Meteorological Conditions for Design of Monolithic Alternative Earthen Final Covers (AEFCs). Master of Science thesis submitted to the Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

Clearwater Consultants Ltd. (2008). Minto Copper Project – Water Balanace Model. Memorandum CCL-MC3 by Peter S. McCreath to Dan Cornett, Access Consulting Group, File 087.01, March 28.

Clearwater Consultants Ltd. (2010). Minto Copper Project – Surface Water Hydrology Conditions – FINAL. Memorandum CCL-MC6 by Peter S. McCreath to Randall Thompson, General Manager Minto Mine, File 087.04, August 12.

EBA Engineering Consultants Ltd. (2010). Minto Mine 2010 Climate Baseline Report. Report prepared for Minto Explorations Ltd., Project W14101068.025, August 2010.

FAO (1998). Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56. ISBN 92-5-104219-5.

Forward, G., Payne, R., Bright, M. (2004). The Estimated Cost of Wind Erosion in South Australia’s Agricultural Lands. Source unknown, 6 pp.

Holdridge L.R., Grenke, W.C., Hatheway, W.H., Liang, T, Tosi, J.A. (1971). Forest Environments in Tropical Life Zones. Pergamon Press, Oxford.

INAP (2012). Global Acid Rock Draingae (GARD) Guide. http://www.gardguide.com., May.

Ritchie, D.G. (1999). Discussion of Sesimic Design Considerations for Soil Covers on Tailings. Proceedings of the Sudbury ’99, Mining and Environment II, Volume 1. Sudbury, Ontario, Canada, September 13-17, pp. 49-58.

Lin, L.C., Benson, C.H. (2000). Effect of wet-dry cycling of swelling and hydraulic conductivity of GCLs. J. Geotech. Geoenviron. Engrg., 130(12), 1236 – 1249.

Minto Explorations Ltd. 2011. Decommissioning and Reclamation Plan, Minto Mine, Yukon Territory. Revision 3.2, prepared June 2011.

Rykaart, M., Hockley, D., Noel, M., Paul, M. (2006). Findings of international review of soil covers design and construction practices for mine waste closure. International Conference on Acid Rock Drainage (ICARD). St. Louis MO.

SRK Consulting (2013a). Minto Mine Phase V/VI Expansion: ML/ARD Assessment and Inputs to Water Quality Predictions. Report prepared for Minto Explorations Ltd. July 2013.

SRK Consulting (2013b). Overburden Characterization Factual Data Report. Report prepared for Minto Explorations Ltd. To be completed Summer 2013.

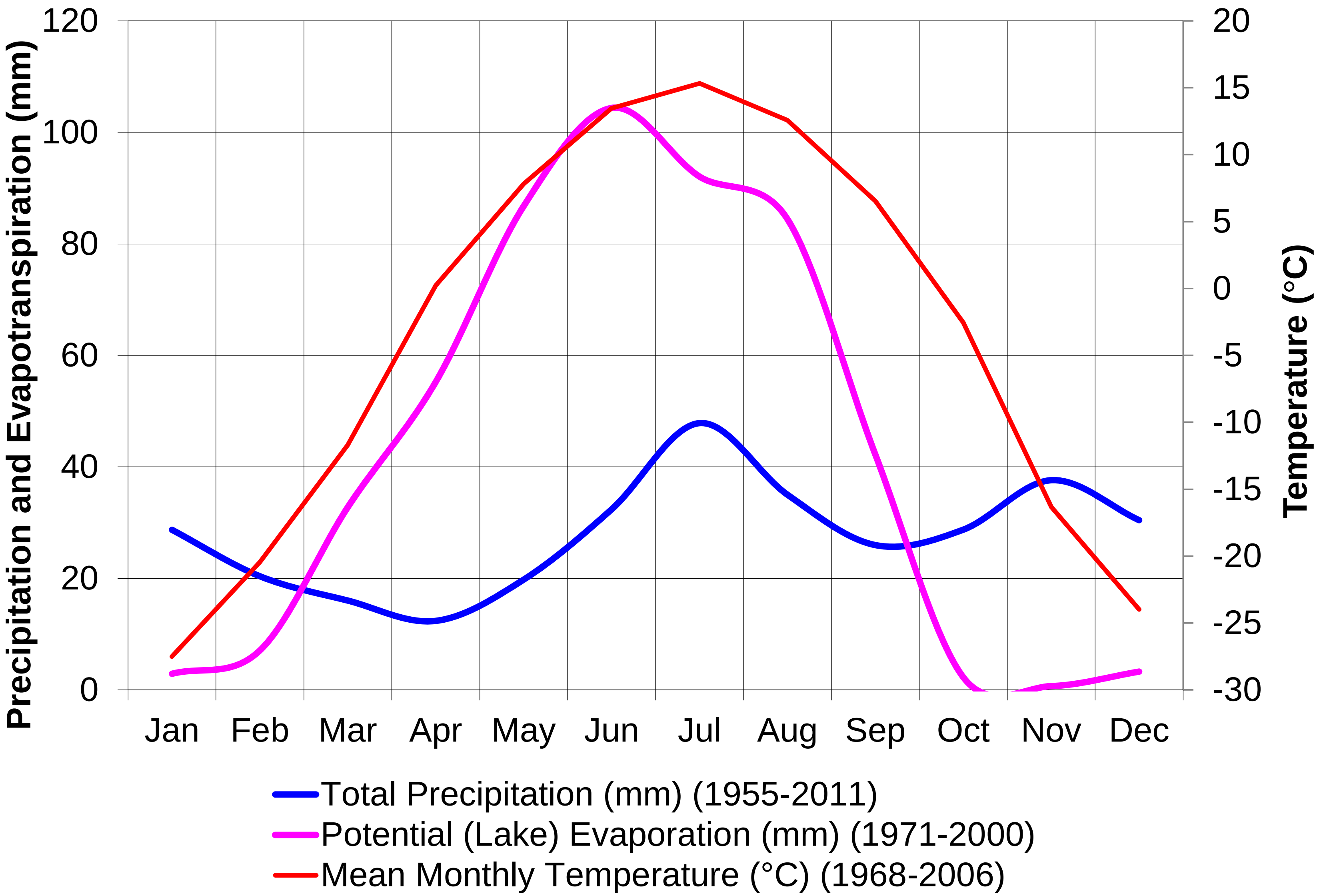
Thornthwaite, C.W., Mather, J.R. (1955). The Water Balance. Publications in Climatology VIII(1): 1-104, Drexel Institute of Climatology, Centerton, NJ.

Wilson, G.W., Williams, D.J., Rykaart, E.M. (2003). The Integrity of Cover Systems – An Update. The AusIMM Bulletin. Journal of the Australasian Institute if Mining and Metallurgy, No. 6, November/December, pp. 63-69.

Figures

Note: Drawing as supplied by Minto Explorations Ltd. (subsidiary of Capstone Mining Corp.)

srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment
		General Site Layout
Job No: 1CM002.007 Filename: Figure 1_1CM002.007_Gen Layout_Rev01.pptx	Minto Mine	Date: July 2013 / Approved: EMR / Figure: **1**



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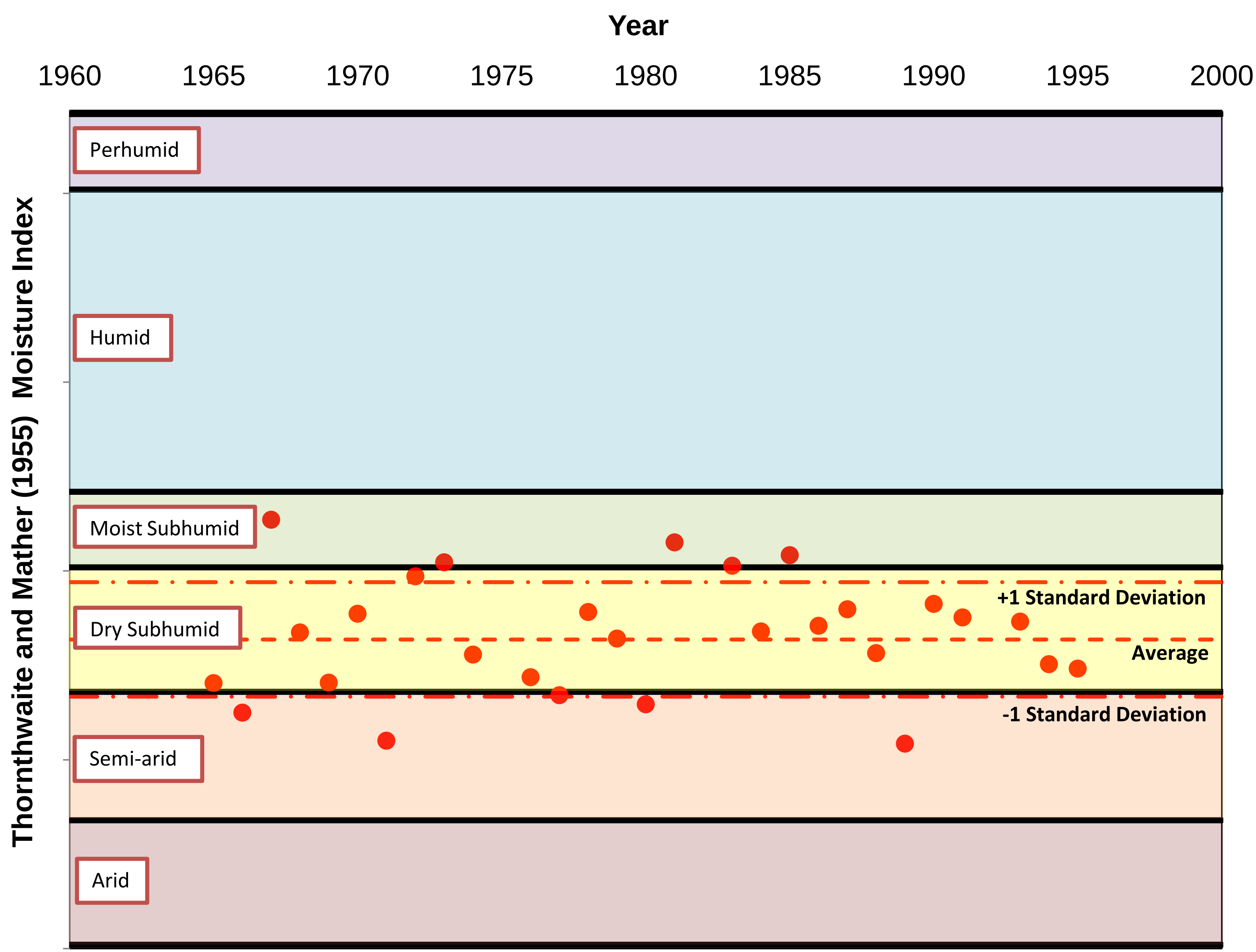
srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment
		Climatic Water Balance
Job No: 1CM002.007 Filename: Figure 2-14_1CM002.007_Rev05.pptx	Minto Mine	Date: July 2013 · Approved: EMR · Figure: **2**



srk consulting | CAPSTONE MINING CORP. MINTO MINE | Scoping Level Cover Assessment

Thornthwaite & Mather (1995) Moisture Index

Job No: 1CM002.007

Filename: Figure 2-14_1CM002.007_Rev05.pptx

Minto Mine

Date: July 2013 | Approved: EMR | Figure: 3

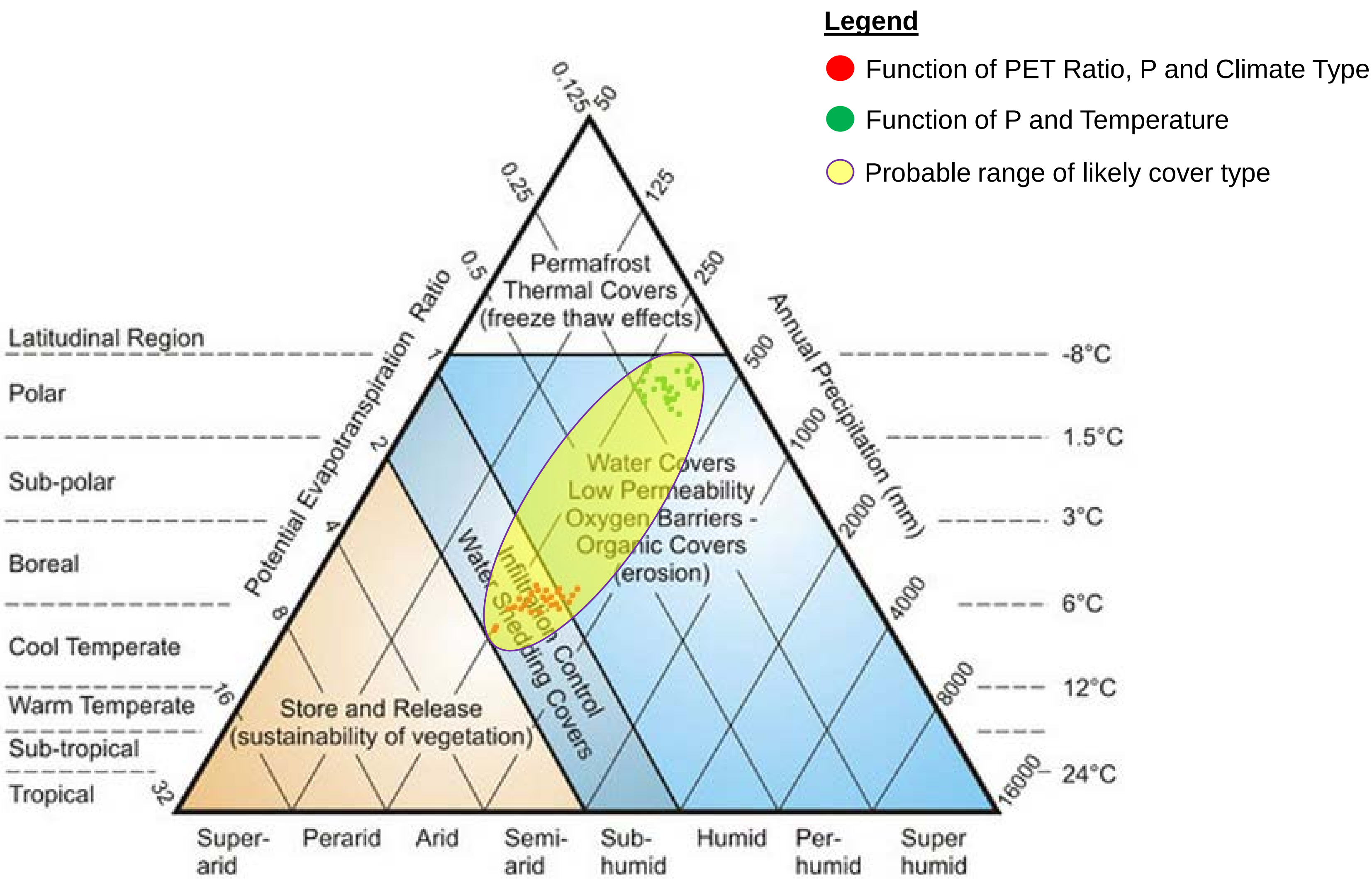
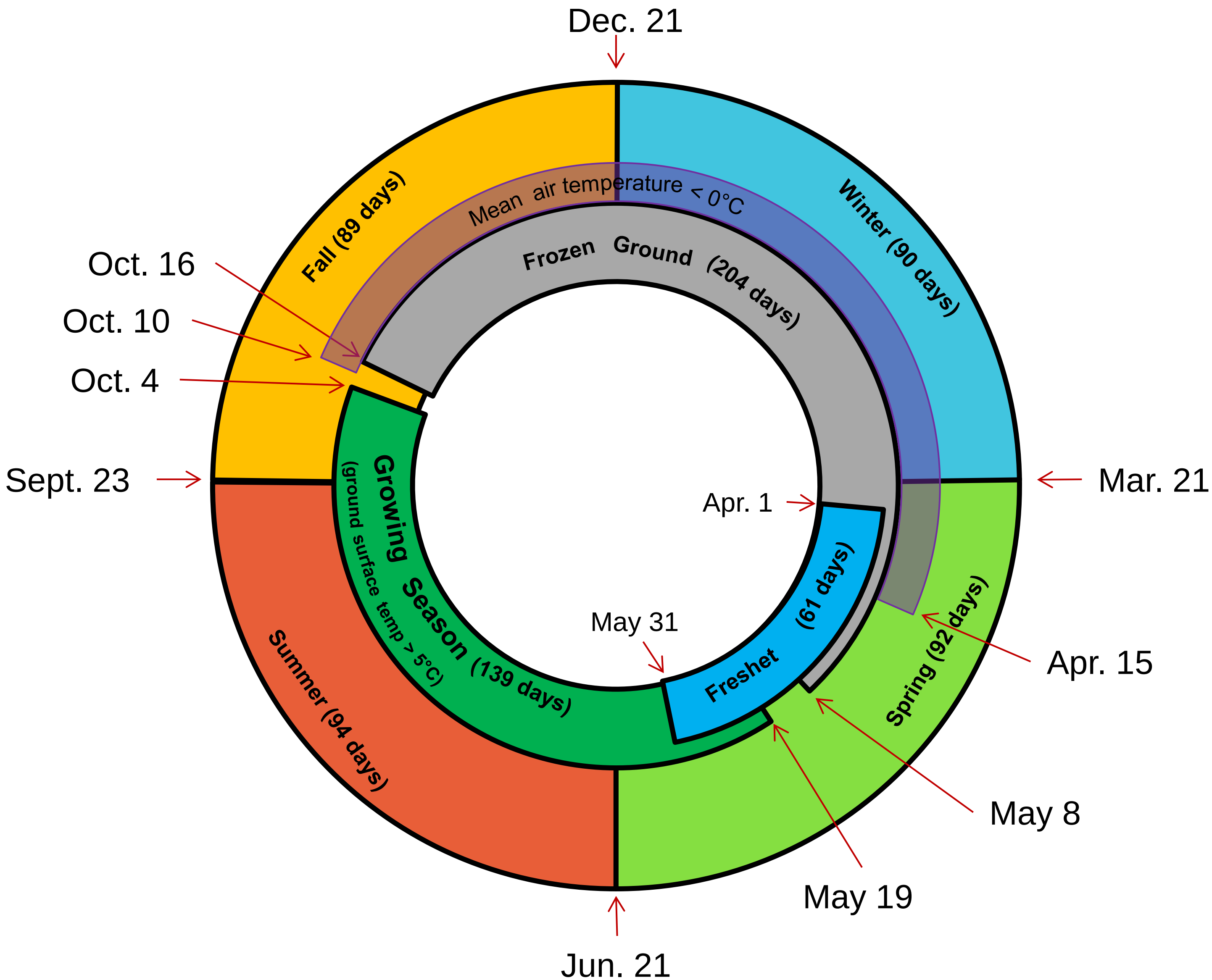


Chart obtained from:
Chapter 6 - GARDGuide. 2013. *Chapter 6 - GARDGuide*. [ONLINE] Available at: http://www.gardguide.com/index.php/Chapter_6. [Accessed 04 April 2013]. (Wickland and Wilson, 2006)

srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment
		Typical Cover Types
Job No: 1CM002.007 Filename: Figure 2-14_1CM002.007_Rev05.pptx	Minto Mine	Date: July 2013 · Approved: EMR · Figure: 4



srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment
		Climate Wheel
Job No: 1CM002.007 Filename: Figure 2-14_1CM002.007_Rev05.pptx	Minto Mine	Date: July 2013 · Approved: EMR · Figure: 5

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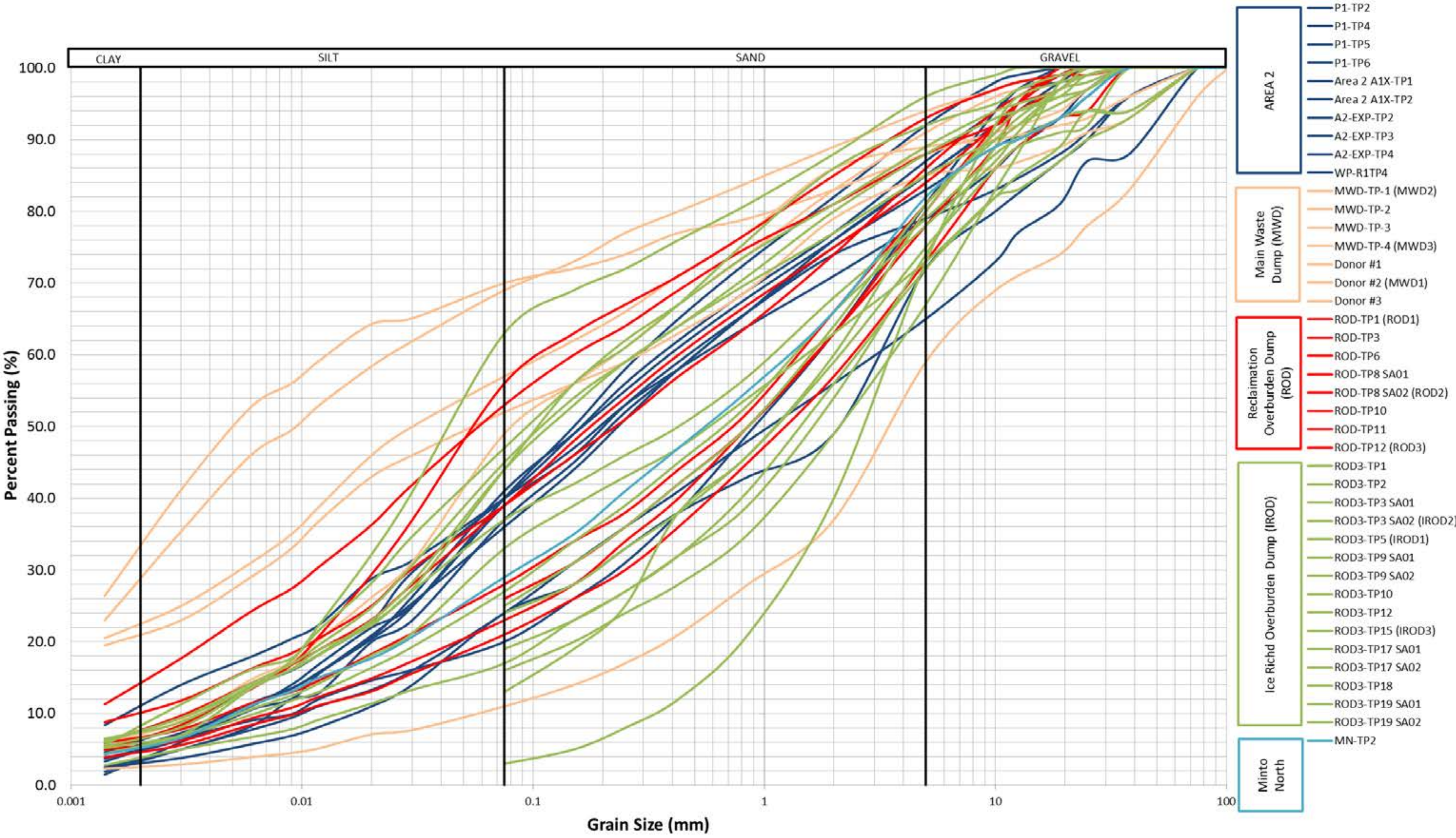

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MINTO MINE

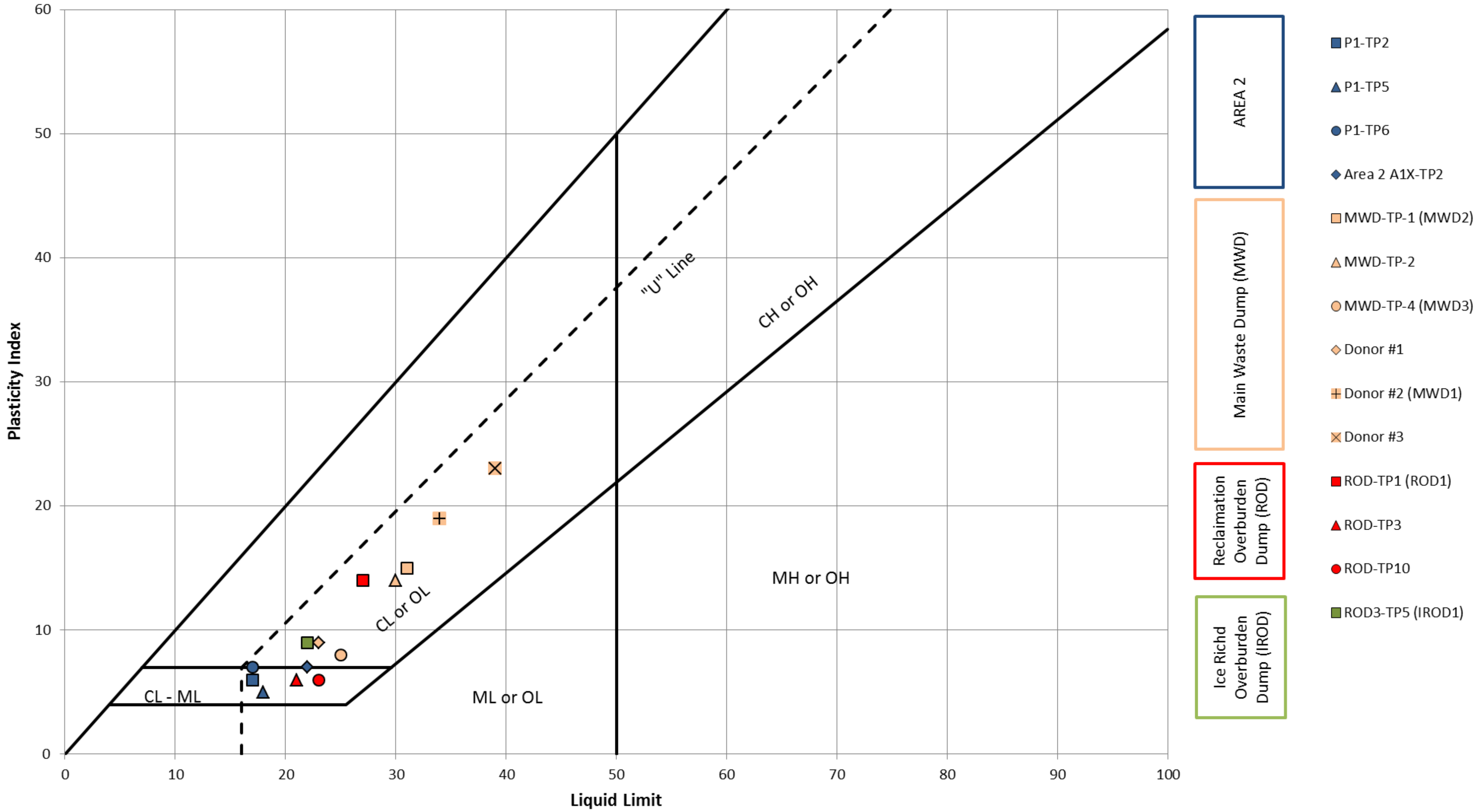
Scoping Level Cover Assessment

Grain Size Distribution Curves for All Candidate Cover Materials

Job No: 1CM002.007
Filename: Figure 2-14_1CM002.007_Rev05.pptx

Minto Mine

Date: July 2013
Approved: EMR
Figure: 6



srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment **Atterberg Limits for All Candidate Cover Materials**
Job No: 1CM002.007 Filename: Figure 2-14_1CM002.007_Rev05.pptx	Minto Mine	Date: July 2013 | Approved: EMR | Figure: 7

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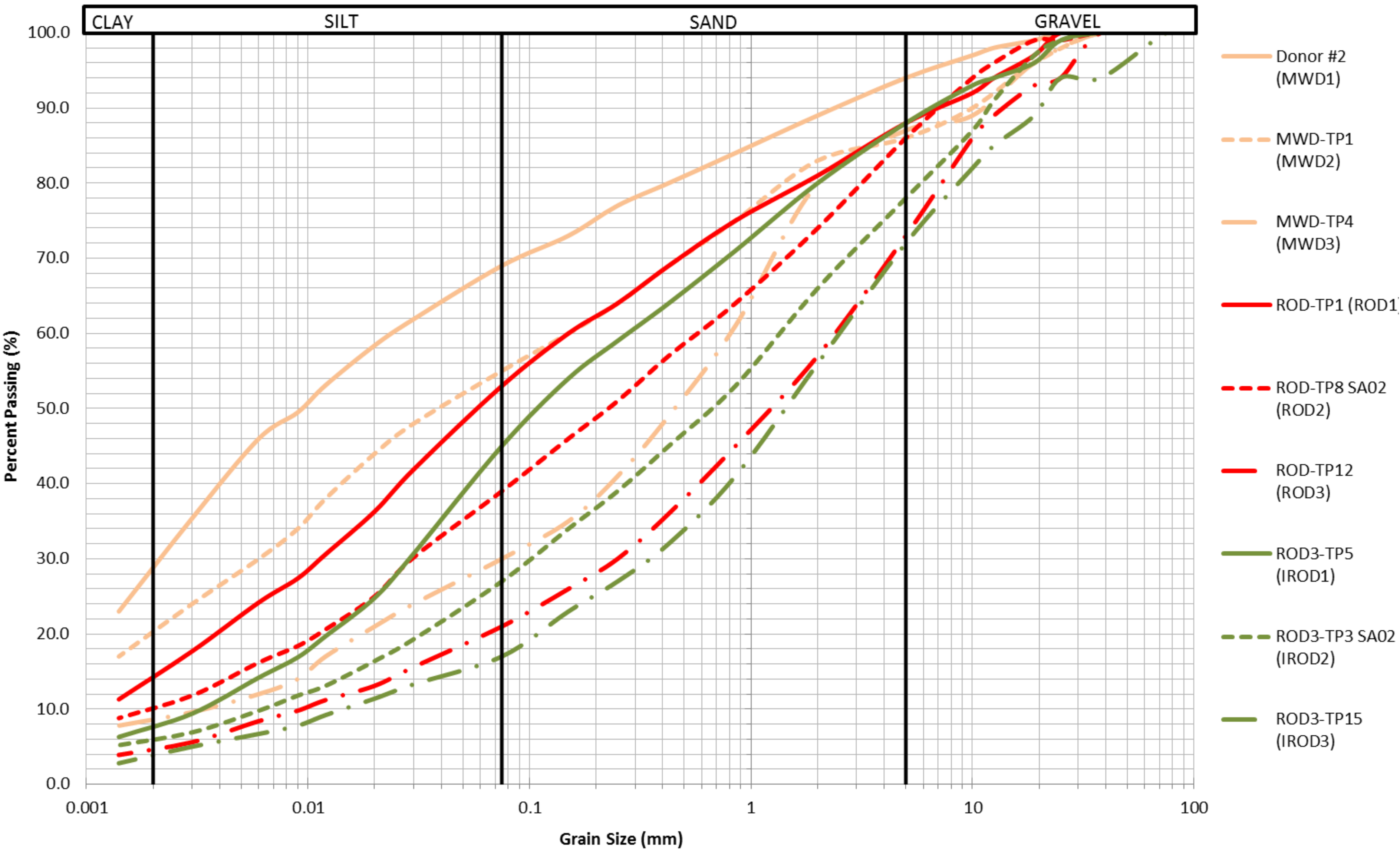

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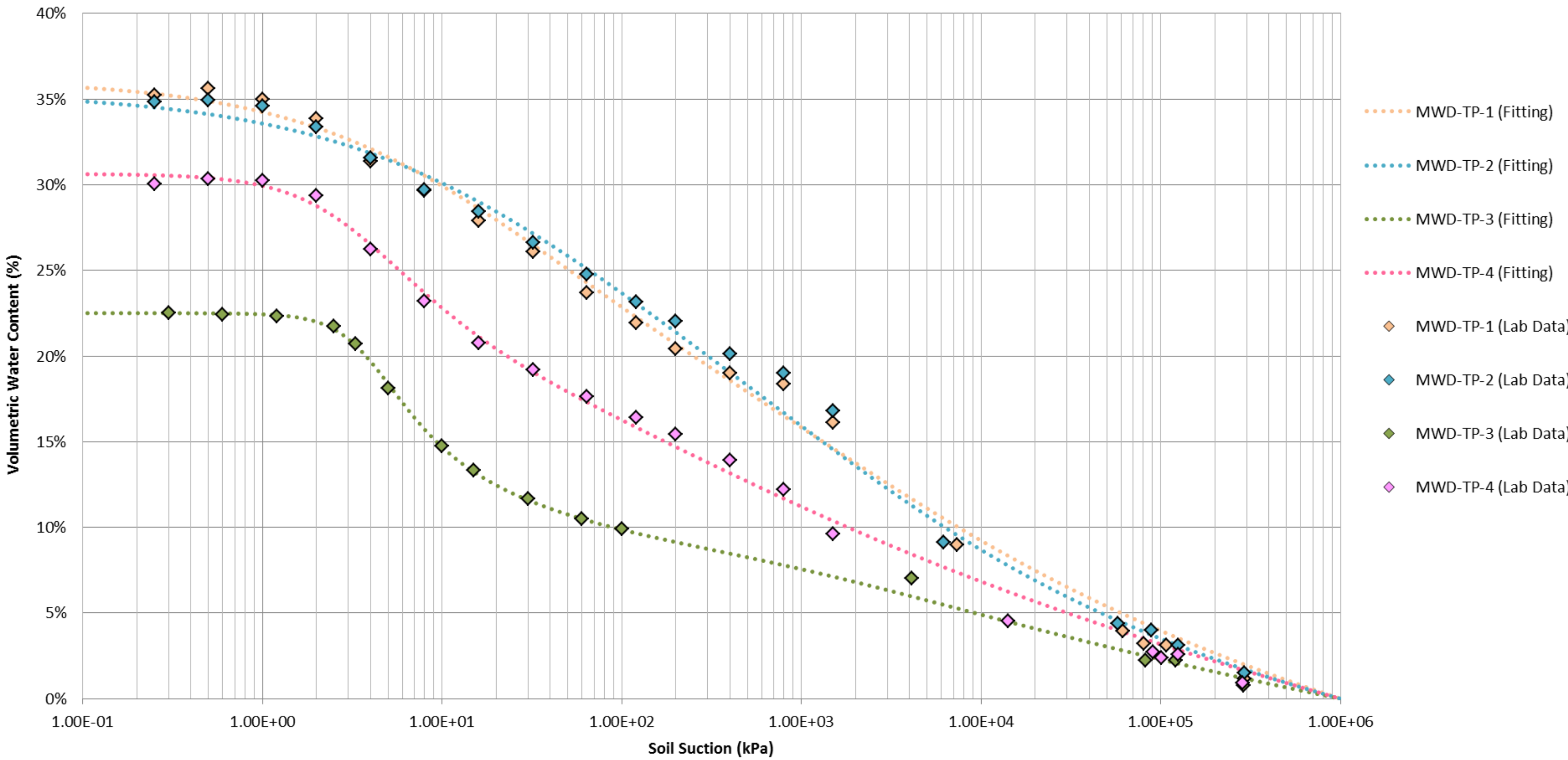
		Representative Cover Materials
Job No: 1CM002.007 Filename: Figure 2-14_1CM002.007_Rev05.pptx	Minto Mine	Date: July 2013 / Approved: EMR / Figure: **8**



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MINTO MINE

Scoping Level Cover Assessment

Measured Soil Water Characteristic Curves

Job No: 1CM002.007

Filename: Figure 2-14_1CM002.007_Rev05.pptx

Minto Mine

Date: July 2013 | Approved: EMR | Figure: 9

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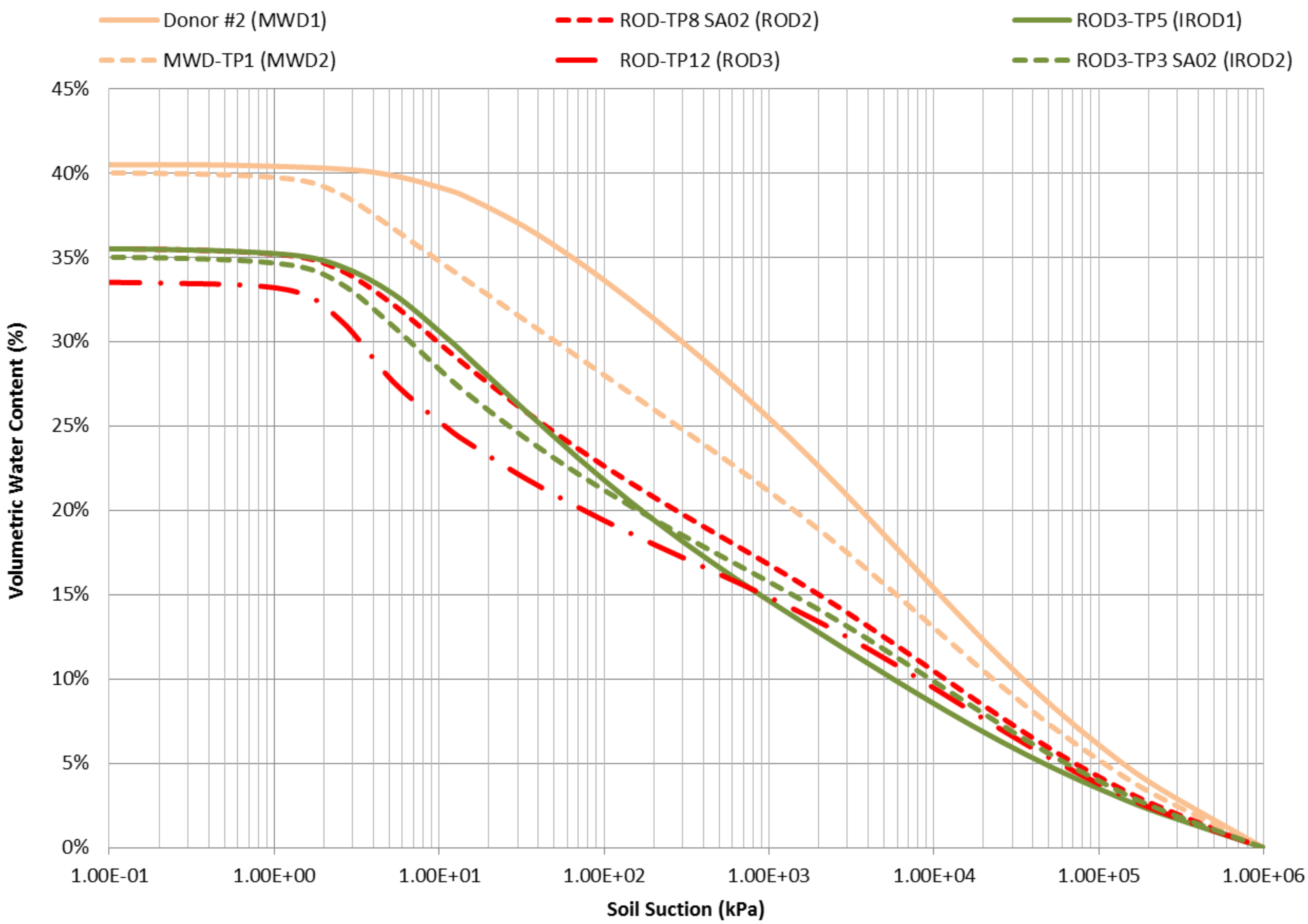

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Scoping Level Cover Assessment

Estimated Soil Water Characteristic Curves

Job No: 1CM002.007
Filename: Figure 2-14_1CM002.007_Rev05.pptx

Minto Mine

Date:	Approved:	Figure:
July 2013	EMR	10

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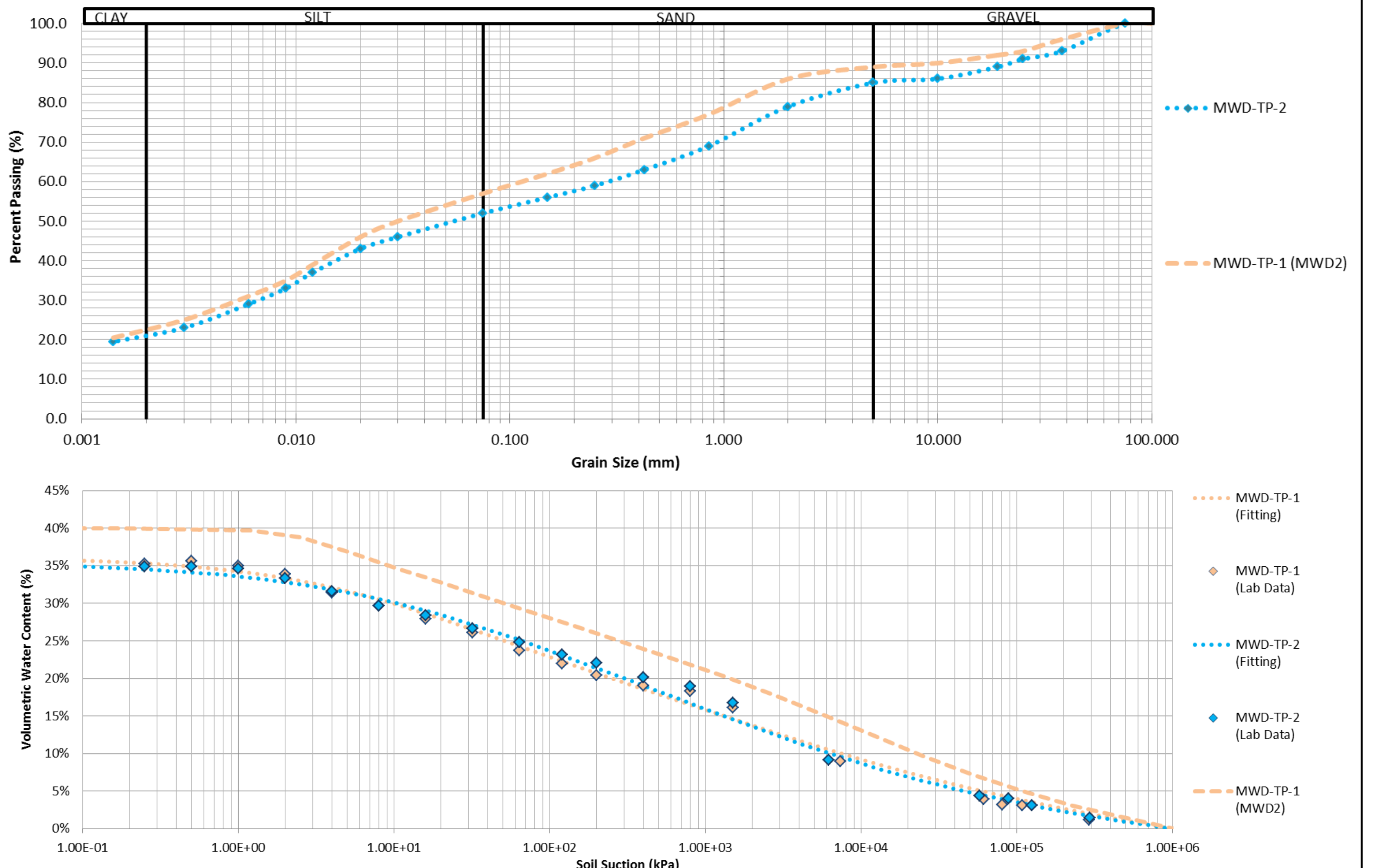

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Scoping Level Cover Assessment

Comparison of Measured and Estimated SWCC's (MWD Material)

Job No: 1CM002.007	Minto Mine	Date: July 2013	Approved: EMR	Figure: 11
Filename: Figure 2-14_1CM002.007_Rev05.pptx				

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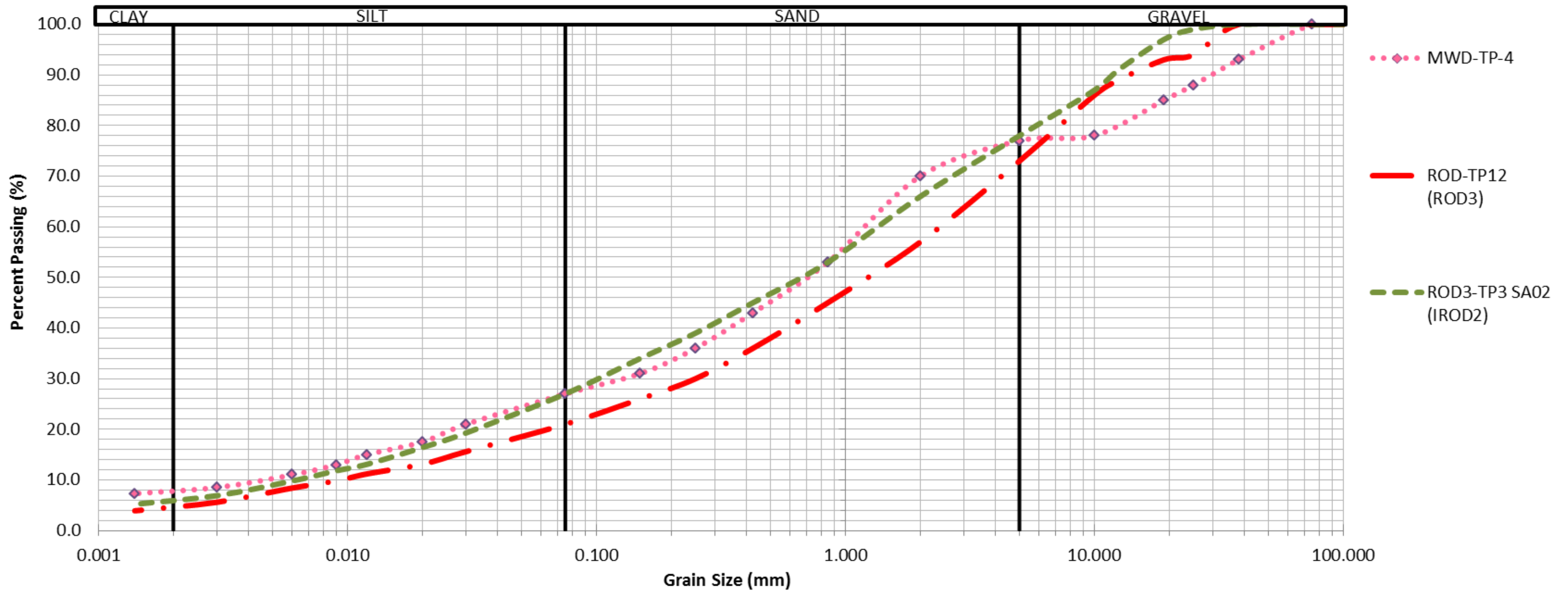

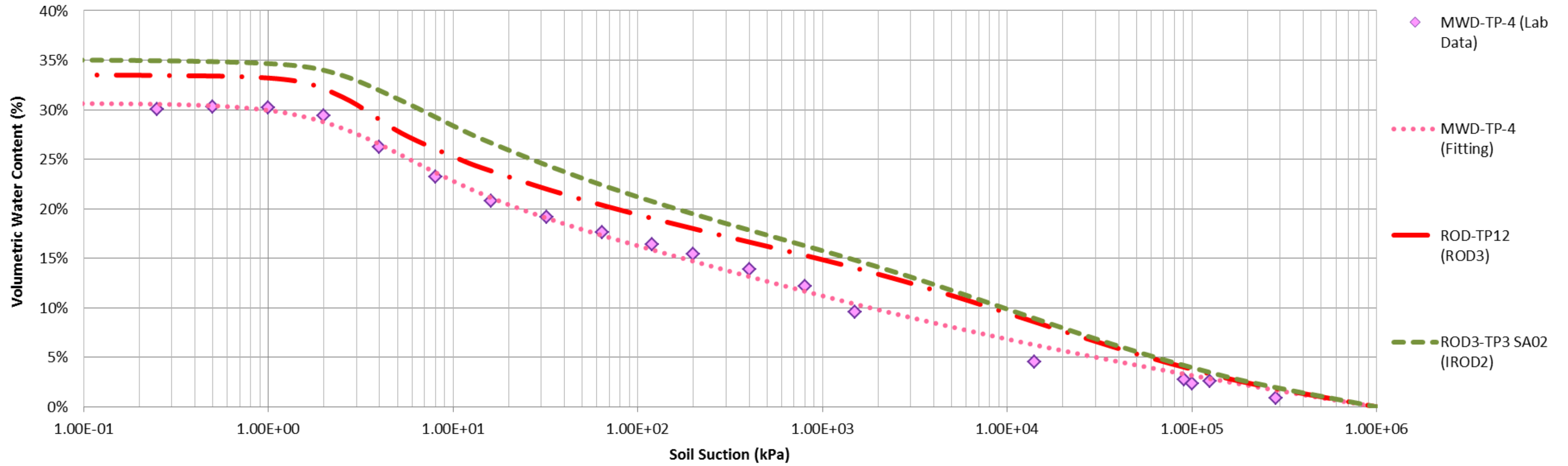

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MINTO MINE

Scoping Level Cover Assessment

Comparison of Measured and Estimated SWCC's (ROD & IROD Material)

Job No: 1CM002.007
Filename: Figure 2-14_1CM002.007_Rev05.pptx

Minto Mine

Date: July 2013
Approved: EMR
Figure: 12

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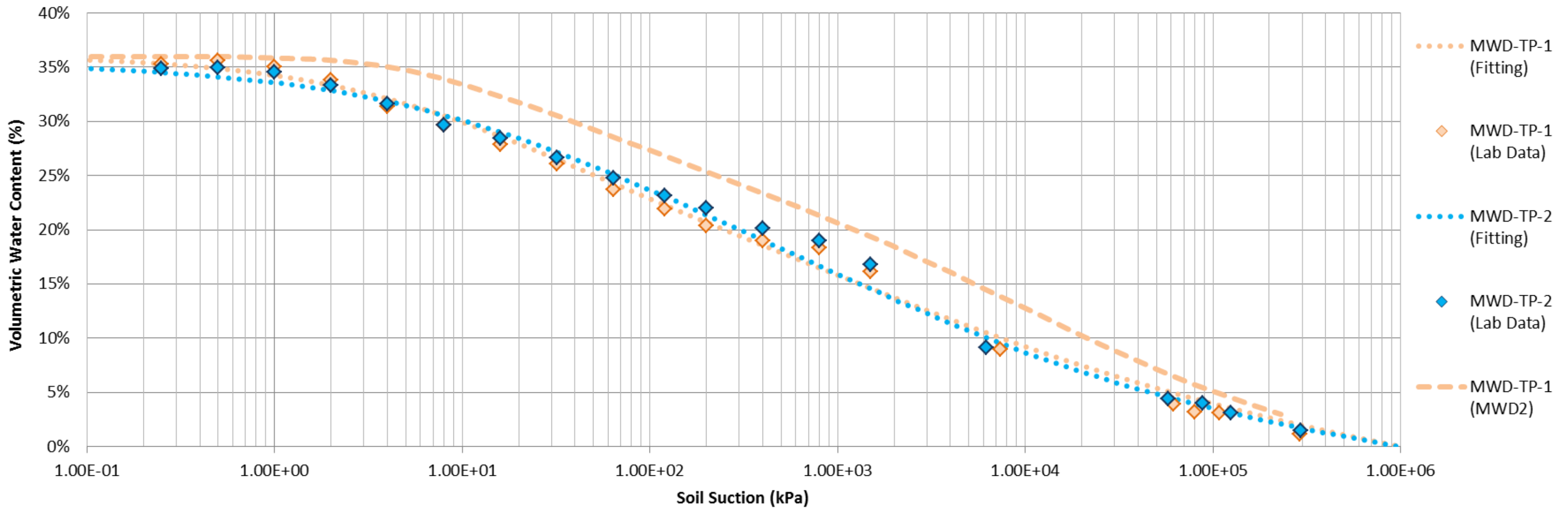

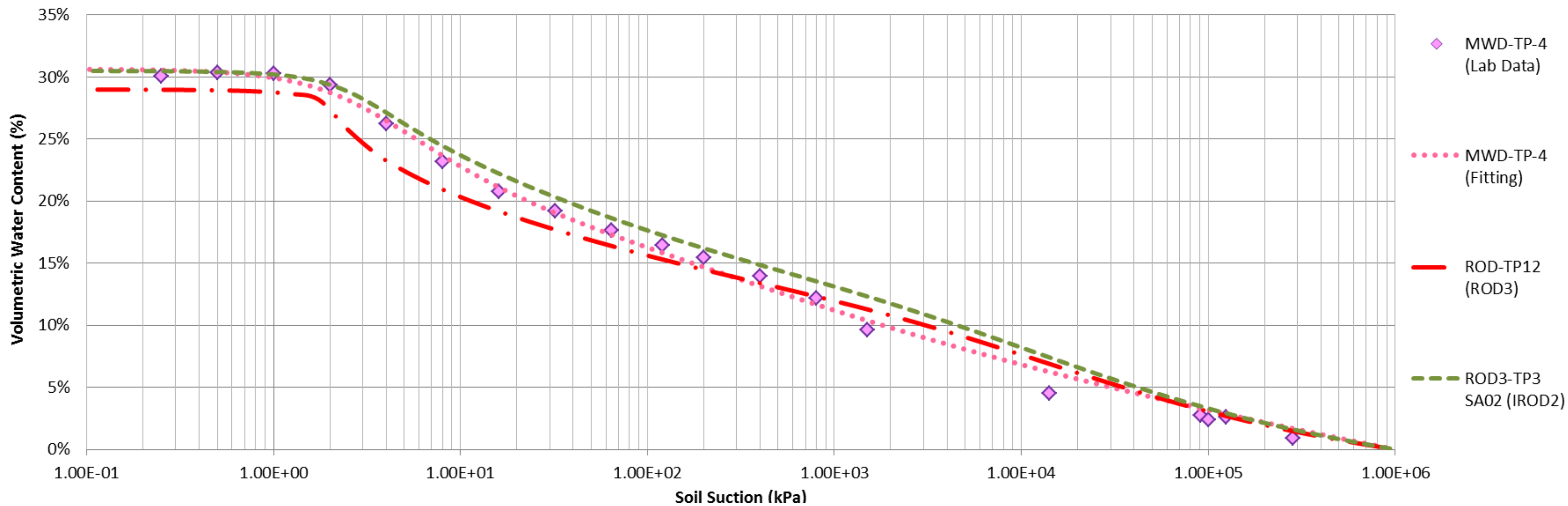

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CAPSTONE MINING CORP. MINTO MINE

Scoping Level Cover Assessment

Calibrated SWCC Estimates Compared to Measured Data

Job No: 1CM002.007	Minto Mine	Date: July 2013	Approved: EMR	Figure: 13
Filename: Figure 2-14_1CM002.007_Rev05.pptx				

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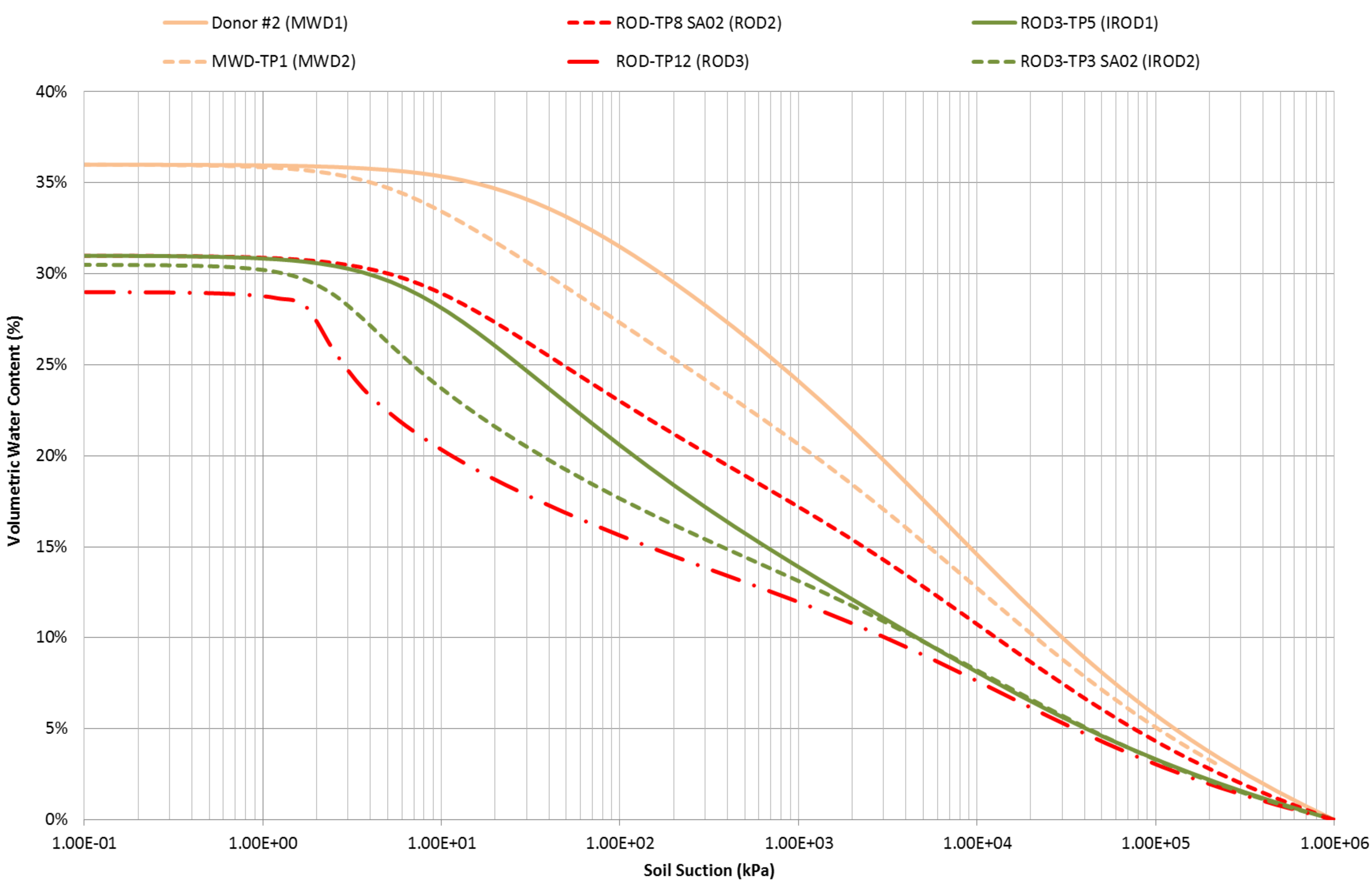

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Job No: 1CM002.007	Minto Mine	**Calibrated Soil Water Characteristic Curves**
Filename: Figure 2-14_1CM002.007_Rev05.pptx		Date: July 2013 / Approved: EMR / Figure: **14**

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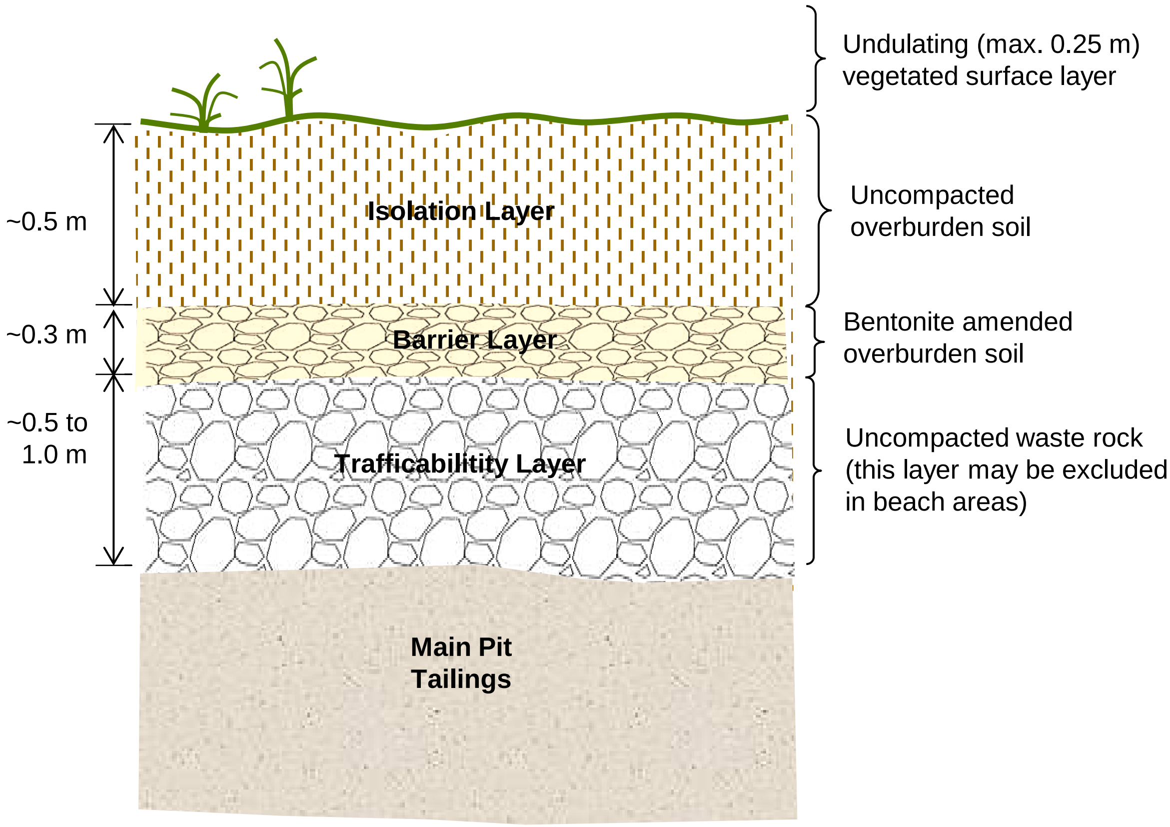

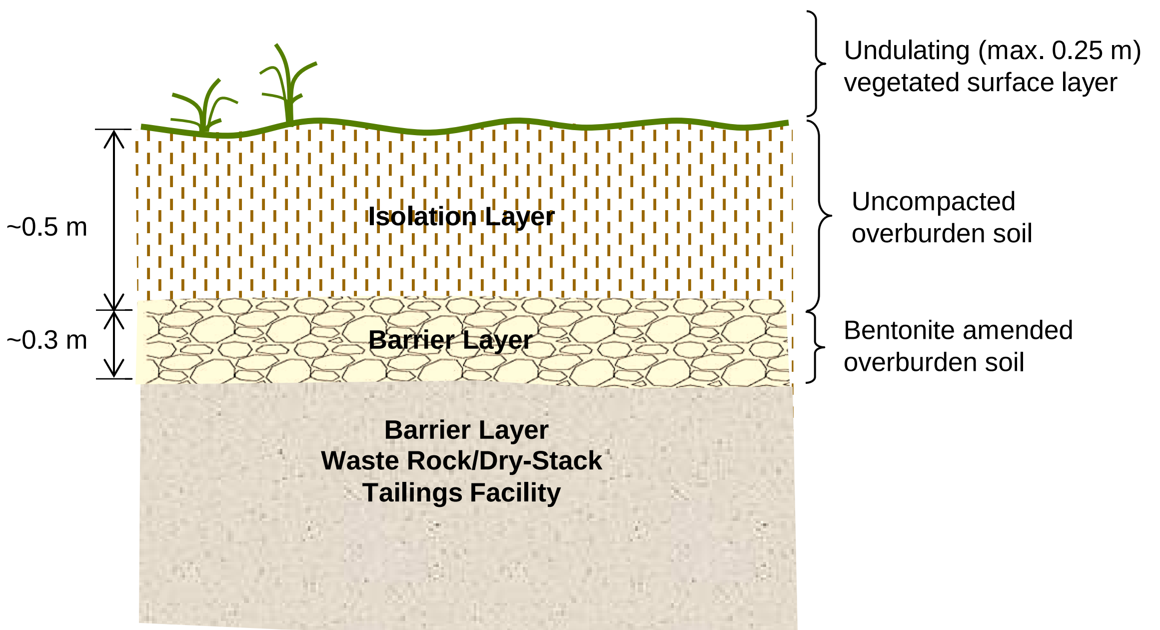

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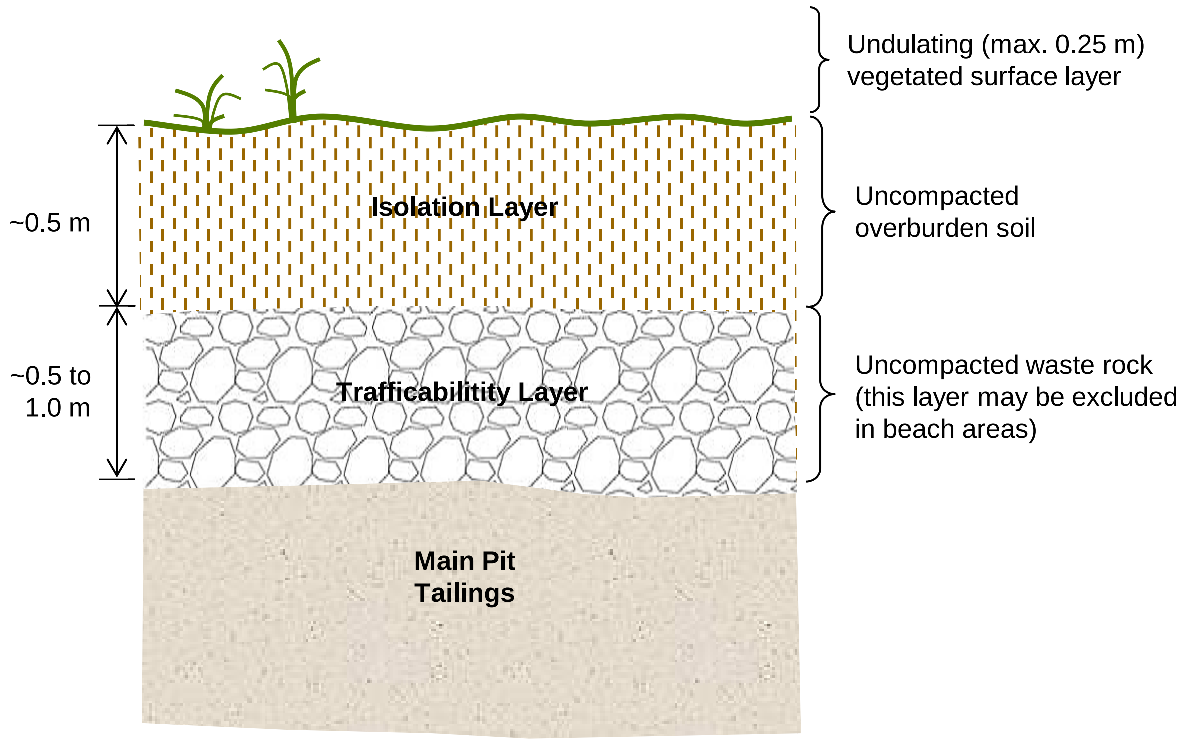
Conceptual Low Infiltration Cover

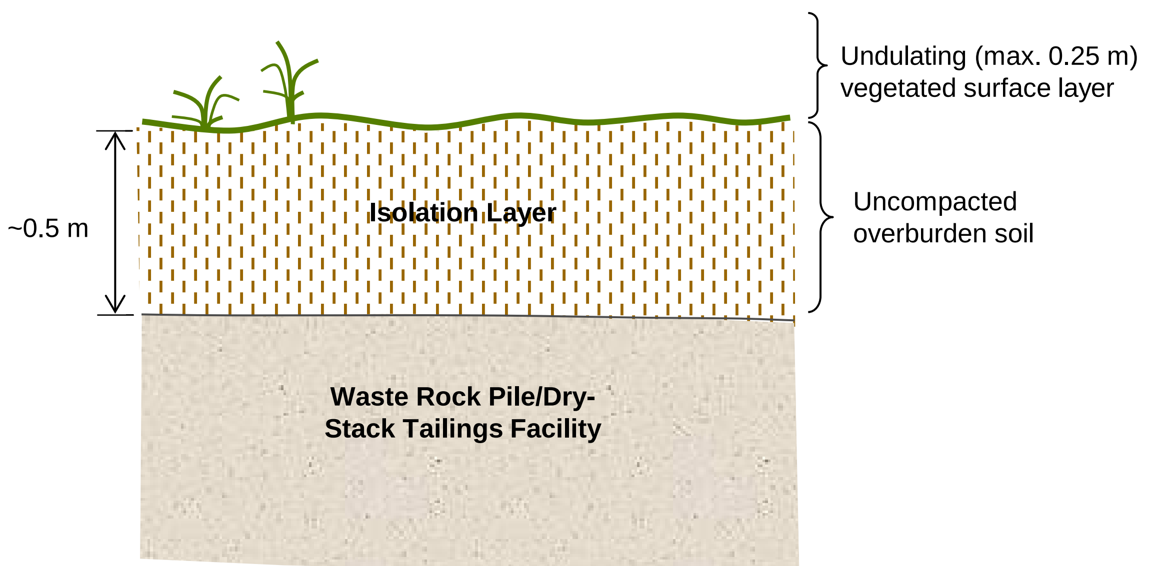
Job No: 1CM002.007

Filename: Figure 15-17_1CM002.0007_Conceptual Covers

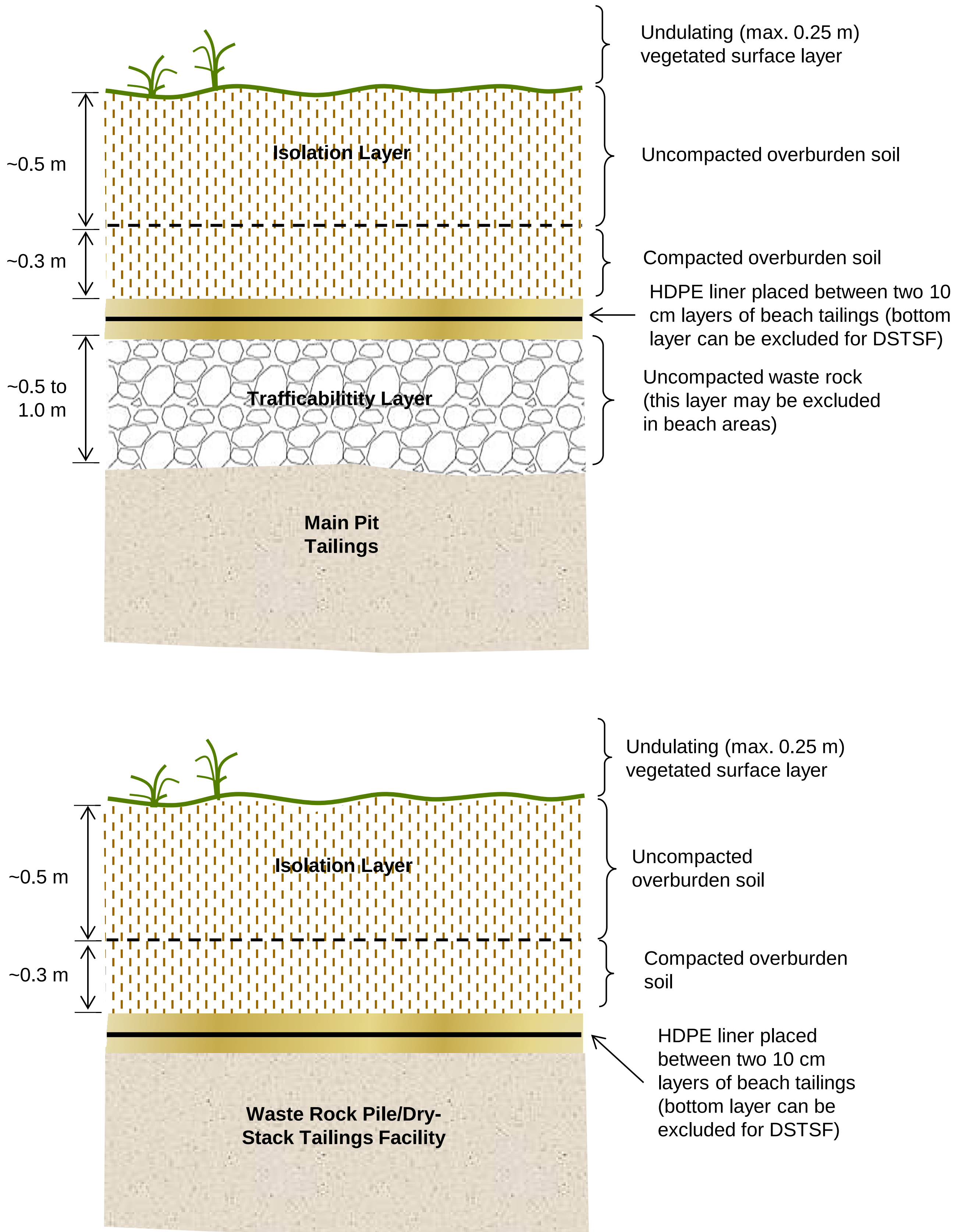
Minto Mine

Date: July 2013 | Approved: EMR | Figure: 16





srk consulting	CAPSTONE MINING CORP. MINTO MINE	Scoping Level Cover Assessment **Conceptual Isolation Cover**
Job No: 1CM002.007 Filename: Figure 15-17_1CM002.0007_Conceptual Covers	Minto Mine	Date: July 2013 · Approved: EMR · Figure: **15**



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CAPSTONE MINING CORP. MINTO MINE

Scoping Level Cover Assessment

Conceptual Very Low Infiltration Cover

Job No: 1CM002.007

Filename: Figure 15-17_1CM002.0007_Conceptual Covers

Minto Mine

Date: July 2013

Approved: EMR

Figure: 17