Closure Landform Design and Reclamation Landform Units for the Minto Mine

Prepared for

Minto Explorations Ltd.

Prepared by

SRK Consulting (Canada) Inc.
1CM002.031
May 2016

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Project No: 1CM002.031

File Name: RLU_SiteWideLandformDesign_1CM002-031_20160520_eh_im_dbm

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Site Description

The Minto Mine is a high-grade copper mine located in the Yukon, approximately 240 km north of Whitehorse. The mine site occupies the valley in the upper reaches of Minto Creek, a tributary on the west side of the Yukon River, about 9 km from the mouth. Operations are ongoing at this time (2016) and began in October 2007. Three pits have been completed to date: the Main Pit, the Area 118 Pit, and the Area 2 Stage 2 Pit.

Initially tailings were deposited in the Dry Stack Tailings Storage Facility (DSTSF) which was completed in 2012. Currently tailings and process water are managed in the Main Pit Tailings Facility (MPTF) and the Area 2 Pit Tailings Management Facility (A2PTMF). Various waste rock storage facilities exist across the site including the Main Waste Dump (MWD), Main Waste Dump Expansion (MWDE), the Main Pit Dump (MPD), the Southwest Waste Dump (SWD), the Area 118 Dump, and the Mill Valley Fill (MVF) currently undergoing the Stage 2 expansion.

1.2 Purpose of this Report

Some mine structures are complete (e.g. DSTSF) or are nearing completion (e.g. Main Waste Dump Expansion) and are in need of reclamation designs. In order to facilitate the reclamation of various structures across the site, Minto Explorations Ltd. (Minto) has retained SRK Consulting (Canada) Inc. (SRK) to prepare general landform design concepts specific to the Minto site, and to define Reclamation Land Units (RLUs) that will serve as the building blocks for establishing closure landforms across the site.

This report documents the work completed to develop site-specific landform design concepts and RLU designations for the Minto Mine.

1.3 Scope of Work

As part of the larger project scope, site reconnaissance was completed in 2014. Based on the information gleaned from the site visit, coupled with other relevant information such as closure cover soil availability and type, SRK has prepared general landform design concepts or “rules” specific to the overall Minto site. The purpose is to develop landform design concepts that will ensure geotechnical stability and landforms that have a natural appearance that fits with the surrounding landscape, and that drains surface water, while minimizing the potential for erosion. Reclamation Land Units (RLU) will also be developed for the site. Each RLU will have specific function(s) and will be used in future design stages as the guiding principles for establishing a closure landform.

This report documents the landform design concepts and RLUs and is the deliverable for this task. Some cost considerations are also provided, together with landform monitoring recommendations.

It is intended that this work will become the basis for all future site reclamation and development planning. This document should be considered a “live” document, as it is expected to be adjusted as progressive reclamation takes place and improvements are made based on lessons learned along the way.

1.4 About this Report

This Report is organised into seven sections, excluding the references section. Following the introduction (Section 1), relevant site background description is provided in Section 2. The technical analysis part of the report is comprised of three sections, with Section 3 presenting the soil erosion analysis completed, Section 4 providing the methodology and results of the conceptual landform design while Section 5 presents a description of the RLU designations. The erosion analysis and the landform design process are equally important in informing the RLU descriptions, which in turn will become an important part of final reclamation planning for Minto Mine. Section 6 discusses the RLU designations and their application to closure planning at Minto.

2 Site Background

The general conditions at the Minto Mine site are discussed in a number of public documents related to permitting, operation, expansion and closure of the mine (Access 2013, Access 2014, SRK 2014). This section of the report will therefore focus primarily on those topics which are of direct relevance.

2.1 Overburden

Overburden thickness across the site is closely correlated with geomorphological features. Near topographic highs, there is little to no overburden, with increasing overburden thickness down valley slopes. The thickest deposits are found in the valley bottoms and along the paleochannel, which is offset to the south from the Minto Creek valley bottom and identified on the south side of the Main Pit and north side of the DSTSF (SRK 2014).

Generally, ridge tops are dominated by sandy residual soils grading to weathered bedrock. Fine weathered products have been washed downslope, and have also been deposited by glacial, periglacial and aeolian processes, which has resulted in accumulations of finer sandy silts and clays within the valleys.

2.2 Permafrost

Minto Mine is located in a discontinuous permafrost region. In general, the south facing slopes are unfrozen, while north facing slopes and valley bottoms contain permafrost. Where permafrost is present it is generally warm, with temperatures close to -0.5ºC. The active layer is variable ranging from less than 1 m to about 3 m in thickness (SRK 2014). The general distribution of permafrost on the site is illustrated in Figure 1.

Ice content within the overburden ranges from non-visible to 30% excess ice, although ice lenses are common and massive ice up to 4 m thick occurs, particularly near the bedrock surface within the paleochannel. The depth of permafrost is variable, but in certain locations it is known to extend down to the base of the paleochannel.

2.3 Vegetation

Vegetation on site is dominated by mixed Willows and Trembling Aspen, with fire history (and related vegetative succession) exerting a very strong influence on the present distribution of plant species. Lodgepole Pine is a later successional species that will dominate mid and upper well drained slopes. White and Black Spruce seedlings are common in the undergrowth and will likely outgrow the pine and aspen communities, especially on northern aspects and along slope toes and valley bottoms. Small grassland areas exist along ridge-tops and steep south-facing slopes as these areas do not retain enough moisture to support tree growth. Much of the planned mine expansion is along ridgetops and mid-slopes, with vegetation in these areas being mostly comprised of willow, aspen, pine, and understory seedling growth. No rare or endangered plants were found during surveys of the planned impact areas (Access 2013).

It should be noted that vegetation trials were conducted at Minto until 2015. Vegetation test plots on the sloped face of the Main Waste Dump were being actively managed and assessed annually and findings from this trial program will be transferred to more progressive reclamation efforts at other areas of the site. As trial results become available, knowledge relating to growth media, seed mixes, vegetation establishment, and vegetative erosion control will evolve and reclamation land unit designations will be revised accordingly (Access 2014).

3 Erosion Analysis

Land impacted by mining is often characterized by steep slopes as illustrated in Figure 2. Waste rock dumps are usually constructed by end-dumping from slope crests such that the dump material lies at its natural angle of repose. Dump faces constructed in this manner often have a high erosion potential due to the uniformly steep and relatively long slopes. In cases where soil covers are required to achieve the long-term closure objectives, the slope of these dump faces needs to be reduced to allow the construction of a soil cover.

Even soil covers constructed on regraded slopes (typically much shallower than angle of repose) may exhibit excessive erosion that could, under certain conditions, compromise the overall performance. It is therefore important to identify if erosion could become a failure mechanism. This is typically done through erosion modelling, as described below.

3.1 Erosion Assessment Methodology

Various numerical methods are in use worldwide to determine soil loss on an inclined slope, most originating from agriculture and soil sciences. One of the most commonly used models in North America is the USLE model, short for Universal Soil Loss Equation, which was developed using runoff and soil loss data from over 10,000 plot years at 49 locations across the US in the 1950s (USDA 1978). The USLE was developed to predict the long term average annual rate of erosion on a sloped field and is based on a combination of rainfall pattern, soil type, topography, crop type, and management practices. One of the major limitations of this approach is that it assumes sheet erosion as the only erosional mechanism, whereas rill erosion is typically predominant for recently placed soil cover material on slopes.

Although rudimentary in its approach, the USLE method was chosen for its simplicity, as the intent here was to demonstrate relative sensitivity of slope erosion to the various environmental factors affecting the slope, rather than compute a highly accurate soil loss estimate. Using a rigorous erosion prediction method was necessary to compare the various slope configurations and identify the range in which each input parameter will exert a strong influence on performance.

The erosion assessment approach may be re-evaluated at a later stage (with consideration given to using a more sophisticated model), when specific slope designs will be completed for the distinct mine waste facilities.

An estimate of the potential erosion from slopes with a soil cover at gradients ranging from 2.5H:1V to 6H:1V was completed using the USLE. At the Minto site, conservation measures similar to those used in farm planning can be applied to evaluate closure options among landform designs, and were therefore considered in the erosion estimates.

The governing equation is presented below:

$$A = R * K * LS * C * P \qquad \text{[Eq. 1]}$$

Where;
R = rainfall and runoff factor (dimensionless)
K = soil erodibility factor (t/Ha)
LS = slope length and steepness factor (dimensionless)
C = crop/vegetation management factor (dimensionless)
P = support practice factor (dimensionless)

The slope length and steepness factor (LS) is calculated using the following equation:

$$LS = (0.065 + 0.0456S + 0.006541S^2)*(L/22.1)^X$$

Where:
S = slope steepness (%)
L = slope length (m)
X = 0.2 (S<1%), 0.3 (1≤S<3), 0.4 (3≤S<5), 0.5 (≥5)

3.2 USLE Parameter Selection

Table 1, at the end of this section, summarizes the parameters used in the USLE calculation. For the rainfall and runoff factor, it was decided to use a rainfall and runoff factor from an area in the United States of America with a similar mean annual precipitation (MAP). The Minto project has a MAP of approximately 350 mm. Areas in the mid-west US with comparable MAP have rainfall and runoff factors of 75 or less. It has been assumed that a value of 75 is appropriate for the Minto site.

For the soil erodibility factor, it was assumed that cover material will be sourced from the reclamation overburden dump (ROD) or from stripping related to the Phase V/VI pit development activities. On average, the ROD material has an average of 17% gravel, 46% sand, 27% silt, and 10% clay (SRK 2013). Removing the gravel proportion, this equates to normalized sand, silt, and clay percentages of 55, 33, and 12, respectively, which means the fine portion of the material falls into the Sandy Loam soil category and is on the fine end (Figure 3 (a)). Several sources provide soil erodibility factors for loam soils that fit this general soil type. A factor of 0.54 was chosen as the average between sandy loam (0.31) and loam (0.71) (Stone and Hilborn 2015). However, the factor was varied for different cover soil types as illustrated in Figure 3 (b).

Slope-length and slope steepness (gradient) were varied in the calculations to allow a comparison of the calculated erosion rates at different slope lengths and gradients. Slope lengths and gradients will vary on reclaimed landforms as they vary across the unimpacted areas of the site, so the analysis focused on slopes between 22° (2.5H:1V) and 9° (6H:1V) with lengths between 20 m and 200 m. Figures 3 (c) and (d) illustrate the change in calculated erosion values for this range of slope lengths and gradients.

The crop and vegetation factor is a reduction factor based on the type of erosion protection given by particular vegetation types, ranging from 0.01 for anti-erosion blankets and mats to 1.0 for no vegetation. For mine reclamation it is important to understand the relationship between erosion and different levels of vegetation establishment. Figure 3 (e) includes an analysis of erosion based on vegetation factors covering the entire available USLE model input range, from no vegetation to purpose-built anti-erosion mats. This range also includes trees, bushes, straw mulch, and grass.

The support practice factor is included to characterize the effect of particular cover surface treatment. A smooth surface will increase erosion as it allows surface water to move with maximum energy, while tracked surfaces provide natural kinetic energy reduction due to micro-scale step pools that help dissipate energy. The support practice factor for agricultural practices like cross-slope farming and contour farming (analogues for cross-slope tracking or ripping) ranges between 0.25 and 1.0. However, since mine reclamation does not typically involve annual re-work of surfaces, as is common with farm applications, it was assumed that no improvements will be maintained in the long term and the support practice factor has been set to 1.0 for all analyses.

Table 1: Parameters Selected in USLE Calculation

USLE Factor	Base Case	Variation
Rainfall and Runoff Factor – R (dimensionless)	75	N/A
Soil Erodibility Factor – K (t/ha)	0.54	0.07 to 0.74 for different soil types.
Slope Length and Steepness – LS (dimensionless)	18.83 (100 m slope length and 3:1 slope)	5.62 to 26.63 for slope lengths between 20 and 200 m and slopes from 2.5:1 to 6:1.
Crop/Vegetation Management Factor – C (dimensionless)	0.25 (no cover and no tillage)	0.005 to 0.25 for different vegetation/cover treatments from erosion blankets to trees to no cover. Tillage not considered in range.
Support Practice Factor – P (dimensionless)	1	N/A

3.3 USLE Analysis Results

A base case for erosion at the Minto site was defined in order to allow comparison of erosion rates for differing soil types, vegetation, and slope lengths and gradients. Erosion for the base case was calculated for a sandy loam on a slope 100 m long at 18° (3H:1V) with no vegetation or support management. The base case estimated an annual erosion of 270 tonnes/hectare, which is considered severe in terms of crop soil loss. Single parameter values were then varied in the equation from the base case in order to illustrate the influence of each parameter on the final landform performance. Comparative graphs of the erosion estimates are shown in Figure 3 (b) through (e).

The analysis showed that erosion can be minimized by reducing slope lengths and gradients, using sandy covers, and ensuring thorough revegetation. The relationship between the amount of erosion and slope length is clear and almost linear – as slope length increases, so does erosion. As slope gradient decreases, erosion decreases; however, the effect becomes less pronounced at slope gradients shallower than 11° (5H:1V). This is important to note as regrading large, steep slopes to long, flat ones can be costly. From this analysis, it appears that short slopes covered with sand and densely vegetated with an angle of 11° or less will yield the least erosion from final landforms at Minto. This analysis shows that flatter slopes lead to reduced erosion.

In practical terms, slope lengths can be reduced by grading landforms such that multiple micro-catchments are constructed within a single landform. If absolutely necessary, sub-horizontal benches that reduce the cumulative energy of surface water can be constructed in such a way that standing water is avoided but that flow along the landform is still slowed. Revegetation also plays a large role in minimizing erosion as shown in Figure 3 (e), so landforms should be revegetated with appropriate mixes as soon as possible after landform construction has been completed.

4 Landform Design

4.1 Methodology

4.1.1 Landform Design Concepts

Landform design which adheres to the principles of fluvial geomorphology aims to emulate the characteristics of mature, natural landforms with fully developed and self-healing drainage systems. Such landforms are capable of adapting to geomorphological changes without accelerated erosion or unacceptable environmental impacts (Sawatsky and Beckstead 1995; Toy and Chuse 2005). Characteristics of landforms designed using these principles include:

- Slopes in equilibrium with local rainfall and soil conditions;
- Considerable variability in topographic relief;
- Well-defined watersheds with easily recognizable watercourses set in incised swales;
- Overland flow path lengths that do not violate thresholds that can be determined from local natural terrain;
- Watershed areas that do not exceed a threshold defined by the slope of their watercourses;
- Drainage systems patterned after natural streams in the surrounding area;
- Erosion rates comparable to those of the natural environment;
- Convex crests of increasing steepness transitioning to concave slope profiles that begin steep and become shallower along the flow path; and
- Drainage systems that are able to evolve and are “self-healing”.

Landforms designed using geomorphological principles have been shown to experience reduced erosion and improved hydrologic response to large storm events, as peak runoff rates and total runoff from these landforms have been shown to be lower than for traditionally engineered designs (Snyder 2013). Geomorphic landform designs have also been shown to have improved long term slope stability as there is often reduced migration of fine particles towards slope toes. This can improve slope stability by reducing the likelihood of slope toes becoming saturated (Russell 2012). The complex topography of geomorphic landforms has also been shown to increase flora diversity, which can lead to decreased erosion, improved slope stability, and better closure outcomes (Bugosh and Epp 2014). Figure 4 illustrates some of the landform design concepts described above.

4.1.2 Design Objectives

Closure landform design at the Minto Mine has the following objectives:

- Ensure the geotechnical stability of final landforms against surficial failures;
- Ensure the hydrotechnical stability of final landforms;

- Create conditions for the natural succession of vegetation on final landforms;
- Employ a combination of design slopes and vegetation to assist in maximizing erosional stability; and
- Develop criteria to assist with performance monitoring and maintenance of future reclaimed structures at the Minto Mine.

4.1.3 Landform Design Approach

In order to design landforms that meet the closure objectives, a methodology should be established that allows for investigation of natural landforms, site conditions, and possible techniques for incorporating natural landform features into final mine closure landforms. The following methodology is proposed:

- Observe natural landforms that are preferably mature and stable and note common features of these landforms, such as soil cover and moisture, slope length, profile, aspect and gradient, and vegetation cover;
- Look at site layouts and decide the course of action to create closure landforms that best emulate natural, stable landforms;
- Develop specific landform resloping designs that emulate natural landforms or the pre-mining landscape as much as practical;
- Evaluate options to create micro-landforms within larger landforms should it not be practical to emulate the natural landscape for large landforms; and
- Develop a progressive reclamation monitoring plan in order to monitor the performance of the designed landforms.

The above methodology was developed based on the principles of geomorphic landform design and was followed in the design of the SWD regrading and progressive reclamation plan. It should be considered in all future reclamation designs at the Minto site in order to be consistent with the principles of geomorphic landform design.

4.2 Results of Site-Specific Landform Analysis

4.2.1 Site Reconnaissance

Two SRK engineers travelled to the Minto Mine site for three days in late May 2014 to observe the natural geomorphological features in the general area of the mine as well as the immediate vicinity of the various waste dumps and other facilities. The current shape of the SWD, MWD, and DSTF were also observed and relevant features noted. Specifically, on built landforms, engineers looked for geotechnical stability indicators, erosional features, vegetation, slope angles and aspects, particle sizes and type, water conveyance structures, and areas with ponded water. In general, it was noted that:

- Most built landforms appeared geotechnically stable, even when apparently over steepened slopes are visible, at or exceeding theoretical angles of repose. There were a number of small surficial skin failures evident on some of the finer grained waste rock dump slopes;
- Erosion was very visible on most built landforms, and ranged from sheet erosion to considerable progressive rill and gully erosion. Most of the progressive rill and gulley erosion appeared to be associated with long continuous runoff surfaces, or areas where water was allowed to concentrate. Interestingly, some of the flatter regraded slopes appeared to show more demonstrated evidence of erosion;
- Physical composition of the different waste and overburden materials are highly variable, ranging from well-graded to poorly graded compositions with particle sizes ranging from boulders to silt. There was however no clear evidence of substantial self-armoring of erosion gulley's in any of these materials. Many of the finer grained materials do exhibit measurable evidence of erosional deposition at the slope toes; and
- Some areas are revegetating naturally, but by far the predominant reason for natural revegetation appears to be in areas where organic rich overburden soils are stockpiled; Areas where active revegetation has been done on organic poor overburden soils, vegetation succession appears to be poor.

In natural undisturbed landscapes in the vicinity of the site, engineers noted slope profiles and aspects, vegetation type, the presence or absence of standing water, erosional features, and channel profiles, cross-sections, and armouring material. These aspects of the surrounding natural landforms were observed and the information gathered will be used to inform the design of landforms that mimic the local natural geomorphic features. In general, it was noted during the site visit that natural landforms tended to have relatively shallow slopes with limited evidence of erosion. There was however clear evidence of well-developed gulley's parallel to most slopes suggesting that sheet flow is occurring with localized concentration. For the most part all slopes supported healthy vegetation, including many of the south southeast and south southwest facing slopes which are steeper than 3H:1V.

4.2.2 Landform Desktop Study

Catchment Areas

To complement the field observations, an investigation into the natural landforms in the general area of the Minto Mine was performed using GIS techniques. The investigation began with a review of the undisturbed catchment areas and the associated flow routing for each catchment area on site. It will be important to attempt to emulate these catchments in the reclamation designs for site landforms so as to ensure landforms are in equilibrium with landscape-wide flow patterns.

Groundwater flow in the Minto area is topographically driven and is generally towards Minto Creek, with recharge occurring at higher elevations and discharge occurring in valley bottoms. Reclaimed landforms at the Minto Mine should strive to maintain these flow directions in order to be hydrotechnically and erosionally stable. Catchment areas for the Minto Mine site are shown in Figure 5.

Slope Aspect

Slope directions, also known as slope aspects, were analyzed across the Minto Mine site and are pictured in Figure 6. In general, the mine lies in an area with east-west trending low mountain ranges that have significant variability in slope aspects across the site due to the curvilinear natural ridgelines that cause the slope aspects to vary along each slope.

The natural variability in slope aspect across the site is strongly correlated with vegetation type, which will be discussed further in sections below. The introduction of similar variability in slope aspect to reclaimed landforms at the Minto site wherever practical may lead to a wider variety of vegetation that is successfully established, and may ultimately lead to a more natural landscape over the long term post-closure.

Slope Gradient

From Figures 7 through 11, it can be seen that the majority of slopes in undisturbed areas are typically shallower than 18° (3H:1V), whereas slopes in mine-impacted areas are typically closer to 27° (2H:1V) for waste dumps or significantly steeper in the open pits. Figure 2 shows that areas close to natural ridgelines are often between 8° (7H:1V) and 14° (4H:1V), but away from the ridgelines the natural slopes become shallower than 6° (10H:1V). This is known as a concave slope profile, in which the slope is steeper at higher elevations and shallower at lower elevations, as shown in Figure 4. The analysis shows the significant variability in the natural slope angles.

Landform Patterns

Landform analysis found a correlation between elevation and surficial geology and a weaker (but still useful) correlation between slope aspect and vegetation type respectively.

The correlation between elevation and surficial geology is caused by the fact that certain soil types are stable only at certain slope angles, and as can be seen from Figure 2 and Figures 7 through 11, slope angles are also correlated with elevation in that slopes closer to crests and higher in elevation tend to be steeper than those farther from slope crests at lower elevations. At higher elevations and steeper slope angles, surficial geology tends to be either bedrock outcrop or a thin colluvial soil cover. At lower elevations and flatter slope angles, thicker sequences of glacial, periglacial, aeolian, and fluvial deposits are present, as pictured in Figure 12.

The correlation between slope aspect and dominant vegetation type is a function of the amount of sunlight experienced at different slope aspects, but is complicated by the recent fire history and subsequent vegetative succession. In general, southern aspects experience significantly more sunlight than northern aspects, which leads to decreased soil moisture contents, earlier snow melts, increased soil temperature and increased photosynthesis. These items combine to favour significantly different dominant species depending on the slope aspect, as can be seen in Figure 13. The present distribution of vegetation does not reflect the climax species mix at all locations due to the succession following various fires that have occurred at different times, and this likely is a factor in the weaker correlation between current vegetation and aspect.

5 Reclamation Land Units

The development of appropriate reclamation land units (RLUs) for the Minto Mine will facilitate achievement of the following outcomes:

- Geotechnical stability of reclaimed slopes;
- Minimal surface erosion by water and wind;
- Maintenance of acceptable long term water quality objectives, especially with respect to suspended solids; and
- Creation of conditions that will allow for re-colonization by native plant species, for basic ecological functions, and for use by local wildlife populations.

5.1 RLU Delineation

Delineation of reclamation land units is often based on end land use, initial and final surface configuration, and likely vegetation patterns (Bowman and Baker 1998). It is useful therefore to understand the land and vegetation patterns and existing biogeoclimatic zones defined within the given project area. Maps can be a valuable tool for achieving this. Biogeoclimatic zones are generally defined by superposition of the terrestrial ecozones and ecoregions, ecoclimatic regions, and the bioclimatic zones of a specific target area. The Minto Mine area is characterised as part of the Yukon Plateau ecoregion within the Boreal Cordillera ecozone (Figure 14), while from an ecoclimatic perspective, the mine area is part of the Northern Cordilleran High Boreal region (Figure 15).

Detailed biogeoclimatic zonation is not readily available for the Minto Mine area; however, extrapolation of biogeoclimatic zones onto the Minto site can be roughly performed based on the bioclimate zones determined for West Central Yukon (Figure 16) corroborated with the ecoclimatic description provided above.

Based on the above considerations, the vast majority of the Minto site falls within the Boreal High (BOH) biogeoclimatic zone, with some higher elevation areas possibly falling within the Subalpine (SUB) zone and some lower elevation areas falling within the Boreal Low (BOL) zone. In general, the BOH zone occurs at middle to upper elevations, is usually forested by black or white spruce, and is characterized by short, cool, and moist summers with long, cold winters. The SUB zone occurs at higher elevations on steep slopes and rocky highlands above the BOH and is sparsely forested or non-forested. The BOL zone occurs below the BOH zone at lower elevations along major river valleys and is usually forested by spruce and aspen with moderate understories. Vegetation is similar to the BOL zone but the warmer climate often results in much larger trees (McKenna *et al*. 2010).

5.1.1 End Land-use Designations

In the absence of published biogeoclimatic zones for the Minto site, reclamation land unit delineation was primarily based on End land-use designations. End land-use designations were defined by analyzing the native vegetation mapping data available for the Minto area as follows:

- Rocky Slope: Defined as slopes having little vegetation, coarse, thin soil veneers, and slopes steeper than 50% (27°, or 2H:1V). Roughly 6% of land in the Minto area falls into this category;
- Wetland: Defined as having flat slopes (<1%), thick vegetation, and standing water with organic soil. Less than 1% of land in the Minto area falls into this category;
- Forested: Defined as areas having primary vegetation types of Trembling Aspen, White Spruce, Black Spruce, Lodgepole Pine, or Alaskan Birch. Approximately 59% of land in the Minto area falls into this category; and
- Deciduous Shrubland: Defined as areas having primary vegetation types of Willow, Alder, or Scrub Birch. Approximately 35% of land in the Minto area falls into this category.

5.1.2 Slope Aspect

RLUs were then divided based on slope aspect category. Slope aspects can be categorized in a number of ways (France 2007; Gelbard and Harrison 2003); for the Minto site warm slopes were defined as having an aspect between 135º and 270º, cool slopes were defined as having aspects between 330º and 90º, and remaining aspects were defined as neutral. A schematic of this distribution is presented in Figure 17.

Flat slopes (defined as having a slope gradient less than 3°) were considered as a separate slope aspect category (Figure 18). Although in some cases aspect of these flat slopes may be directionally consistent with the cool slope, in practical terms these are warm slopes as direct solar radiation is received for most of the day.

5.1.3 Elevation, Slope Gradient, and Biogeoclimatic Zones

Four categories were defined based on the likely biogeoclimatic zones and the range in both slope gradient and elevation in the Minto area. These categories were formed based on the vegetation that the landscape in the Minto area will likely be able to support, and are as follows:

- BOL – Low elevations and flat slopes;
- BOH – Low to middle elevations and shallow to moderate slopes ranging from 1 to 25%;
- BOH – middle to high elevations and moderate to steep slopes ranging from 25-50%; and
- SUB – high elevations and steep slopes over 50%.

5.2 RLU Categories

Table 2 displays the RLUs for the Minto Mine site. It should be noted that these RLUs are conceptual only and have not yet been applied to specific areas of the site.

Table 2: Reclamation Land Units for the Minto Site

End Land-Use	Biogeoclimatic Zone	BOL	BOH	BOH	SUB
	Elevation	**Low**	**Low-Mid.**	**Mid.-High**	**High**
	Slope	**Flat (<1%)**	**Shallow-Mod. (1-25%)**	**Mod.-Steep (25-50%)**	**Steep (>50%)**
	Slope Aspect				
Forested	Cool and Neutral	-	FLm_{CN}	-	-
	Warm	-	FLm_{W}	FMh_{W}	-
Deciduous Shrubland	Cool and Neutral	-	SLm_{CN}	SMh_{CN}	-
	Warm	-	-	SMh_{W}	SH_{W}
Wetland	All	WL*	-	-	-
Rocky Slope	All	-	-	-	RH

* The first letter of each RLU denotes the end land-use category. The second and third (for some) letters denote the elevation category (i.e. L for low, Lm for low to middle). The subscript letters stand for slope aspect.

Figures 18 and 19 display the slope aspect and angle categories overlain by vegetation types that were used to define the RLUs for the Minto site. Figure 20 is a combination of slope aspect and angle in relation to vegetation. Mining-impacted areas where the slope differs significantly from the surrounding landscape, shown in black, will likely require significant resloping.

6 Discussion

6.1 Use of Site Specific Reclamation Land Units

In natural catchments, slope gradients develop over time as a function of prevailing substrate and hydrologic conditions. The type and amount of vegetation established on slopes depends heavily on the soil moisture availability of those slopes, which greatly depends on substrate, slope gradient, and slope aspect. Slopes on reclaimed landforms at the Minto Mine will likely experience less erosion and greater vegetation establishment if they are graded similarly to the surrounding natural slopes.

RLUs and landform design concepts have been defined for the Minto site based on site-specific features and the current mine plan. As progressive reclamation activities proceed according to the principles described in this document, it is expected that there will need to be opportunities for refinements to the design concepts, RLUs, and monitoring processes based on lessons learned during progressive reclamation and monitoring of performance indicators. As such, this should be considered a “live document”.

The RLUs defined in this document are conceptual and still need to be applied to specific landforms on the Minto site. It is important to work within the framework of the RLU categories from the beginning of progressive reclamation until final closure of specific landforms so that performance may be monitored accordingly and costs can be tracked to inform future closure planning. Progressive reclamation activities have already begun at the Southwest Waste Dump and RLUs are required there. The Main Waste Dump and the Dry Stack Tailings Facility will require RLU designations as soon as both facilities are complete or nearing completion, with initial progressive reclamation underway and final reclamation activities expected to begin in the near future.

The approach outlined in this report provides a basis for developing closure landform designs for each of the specific waste storage facilities at Minto Mine.

6.2 Reclamation Costing Considerations

While the RLUs were delineated based on various physical aspects of the site, they were also delineated in order to provide a framework for closure and reclamation costing. Specific land treatments can be developed for each RLU as part of the closure design detailing the amount of effort necessary to both reslope and revegetate mine-impacted landforms. Average costs may then be calculated to apply those treatments to each RLU, thus creating a unit cost basis for waste facilities and disturbed land reclamation.

For example, areas needing significant resloping will be more expensive to reclaim than those needing little or no resloping. As well, it is reasonable to assume that more effort will be necessary to revegetate cool and neutral forested slopes than warm slopes covered with shrub, so separate RLUs were defined accordingly. As progressive reclamation takes place within a specific RLU, actual completion costs can be recorded and projected for future reclamation activities.

6.3 Landform Monitoring

Monitoring should occur within the framework of the defined RLUs such that landform performance is measured for each RLU. Monitoring should begin while progressive reclamation takes place so that RLU assignments may be adjusted based on performance as reclamation proceeds.

Monitoring should include the following actions:

- Erosion monitoring – set up erosion monitoring stations on each RLU after reclamation activities have taken place to estimate the annual erosion from constructed closure landforms and compare to both degree of revegetation and to erosion estimated during design for performance indicators;
- Water quality monitoring – monitor water quality from closure landforms for each RLU, specifically for suspended solids along with any other pertinent quality indicators, depending on the landform; and
- Vegetation surveys – periodic surveys of vegetation establishment on each RLU to ensure reclamation goals with respect to vegetation type and density are being met.

This report, Closure Landform Design and Reclamation Landform Units for the Minto Mine, was prepared by

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Practice Leader

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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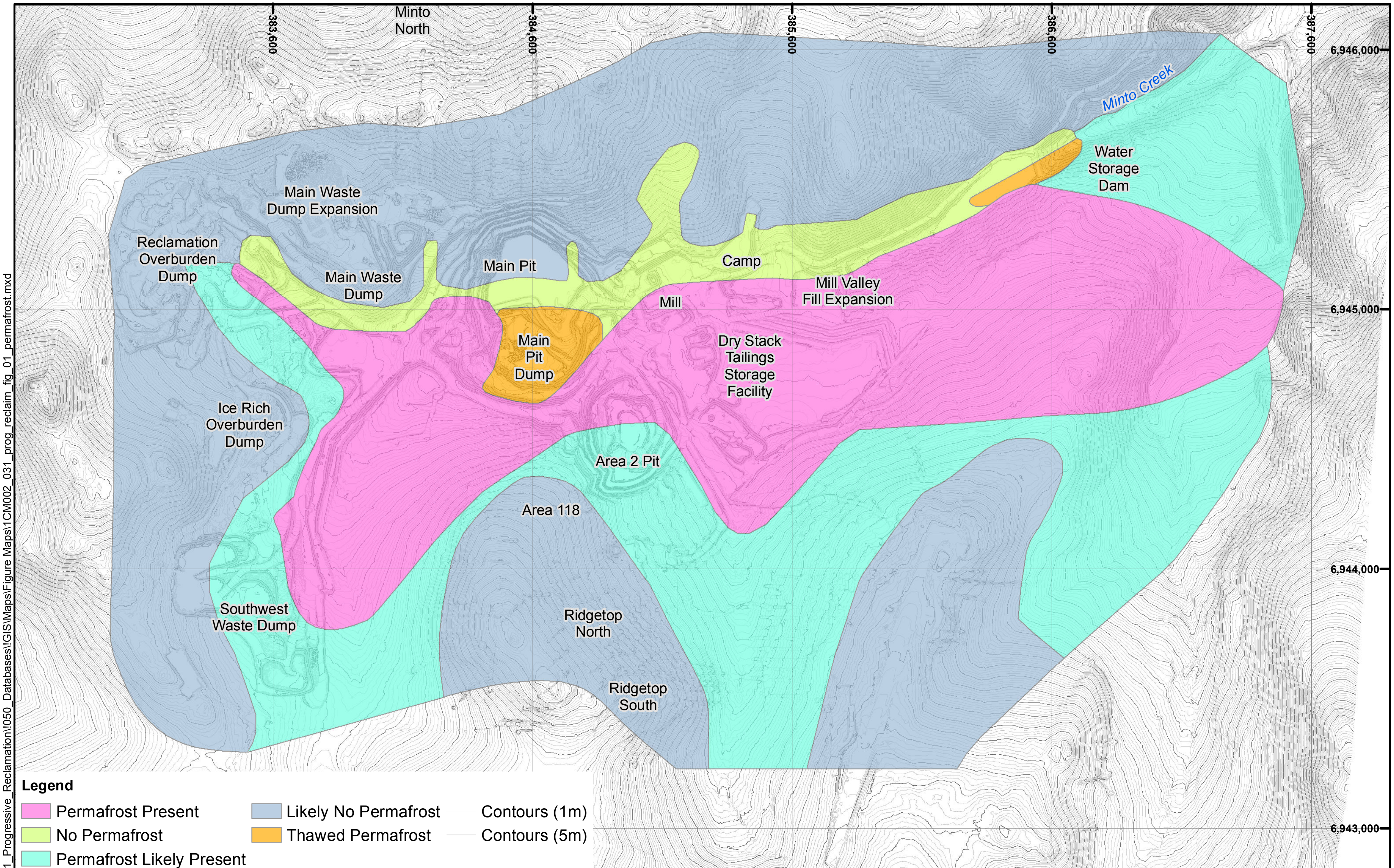
Figures



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Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_01_permafrost

Minto Mine

Closure Landform Design and RLUs

Permafrost Extent Across Site

Date:	Approved:	Figure:
April 2016	EKH	1

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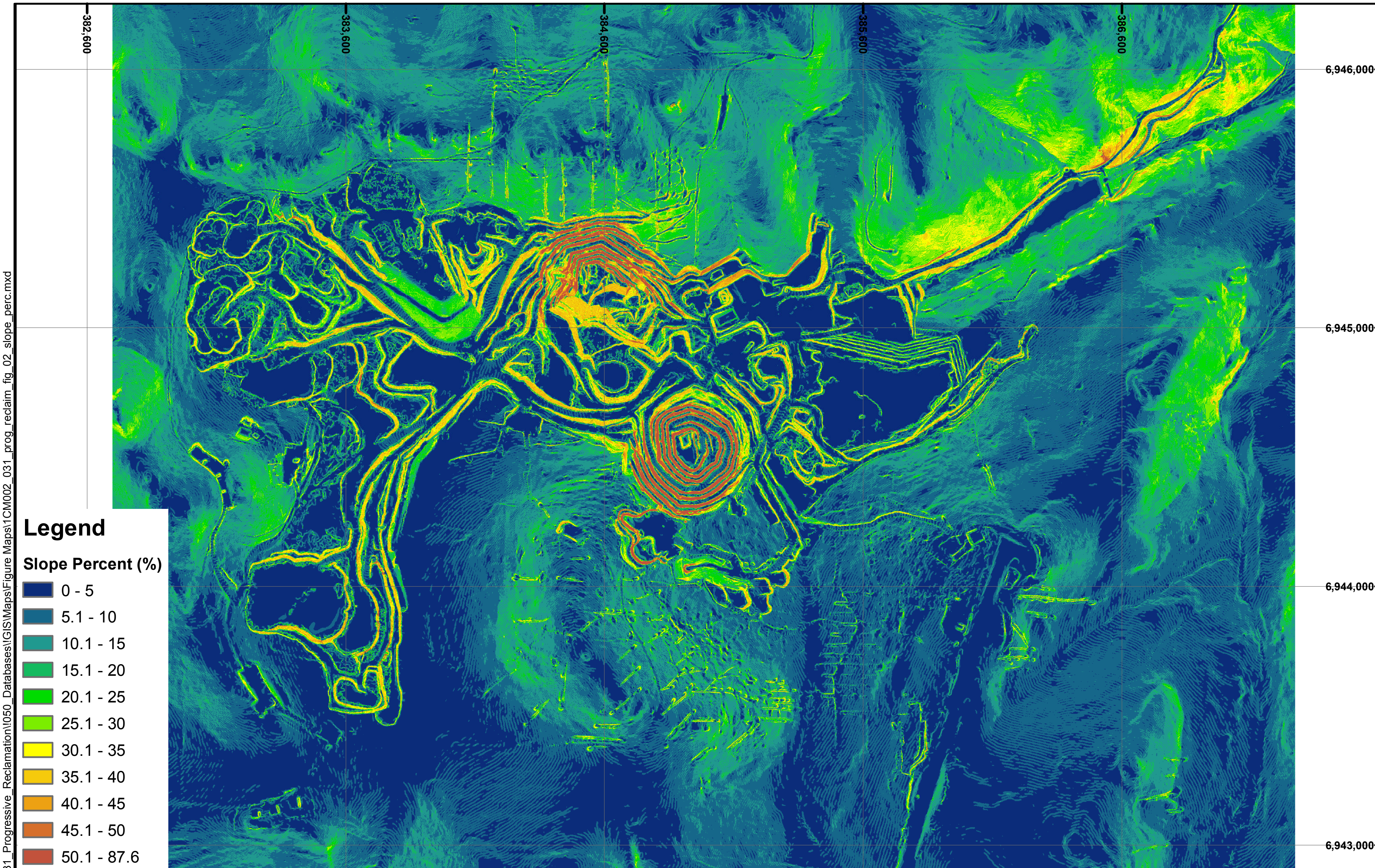

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		Closure Landform Design and RLUs
		Slope Gradients
Job No: 1CM002.031 Filename: 1CM002_031_prog_reclaim_fig_02_slope_perc	Minto Mine	Date: April 2016 / Approved: EKH / Figure: 2

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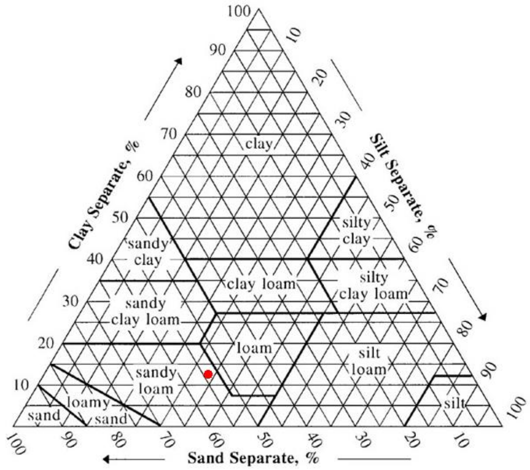
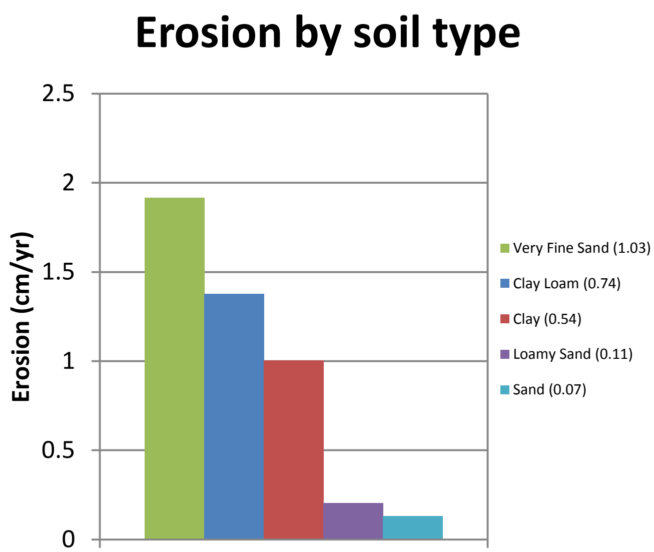
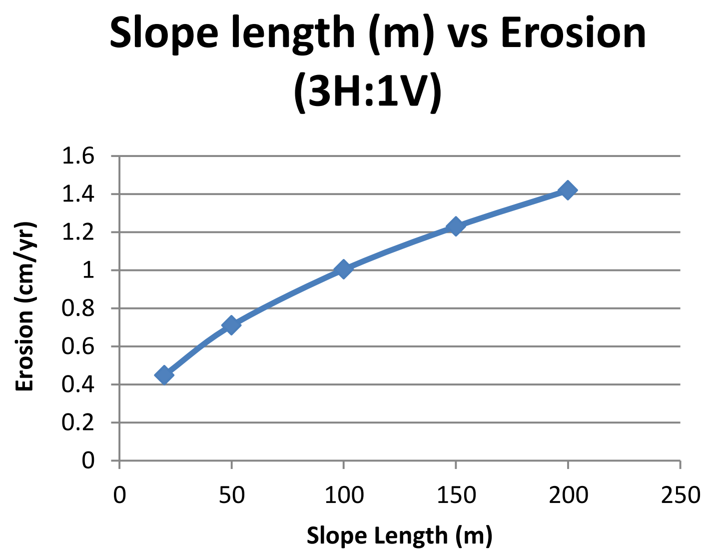


Average particle size distribution of soil in the ROD falls into the Sandy Loam category (USDA classification)

(a)



(b)



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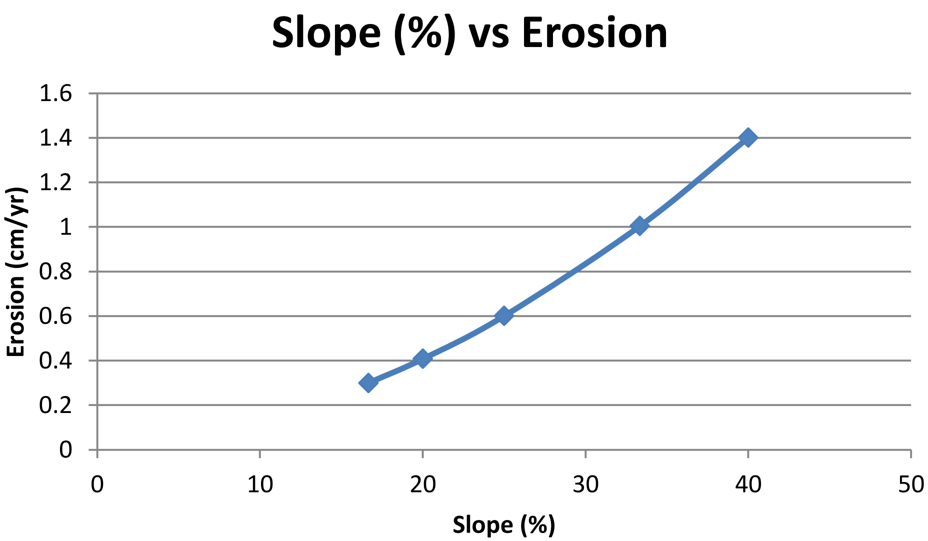

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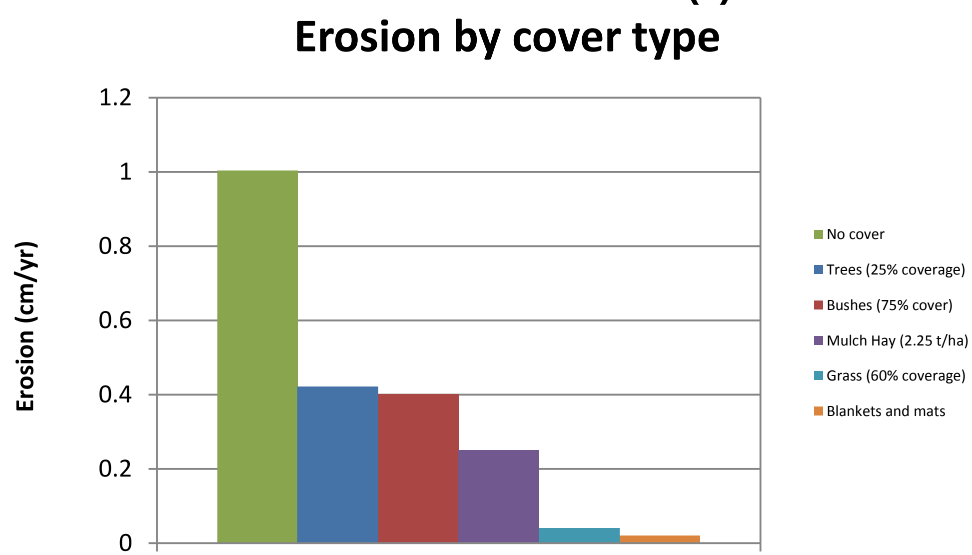

(e)

Note: Erosion modeling using USLE assumes uniform soil loss arising from sheet erosion – it does not address local gully erosion, and the results presented here are comparative rather than absolute. Density of soil was assumed to be 1.9 t/m^3 in calculations.

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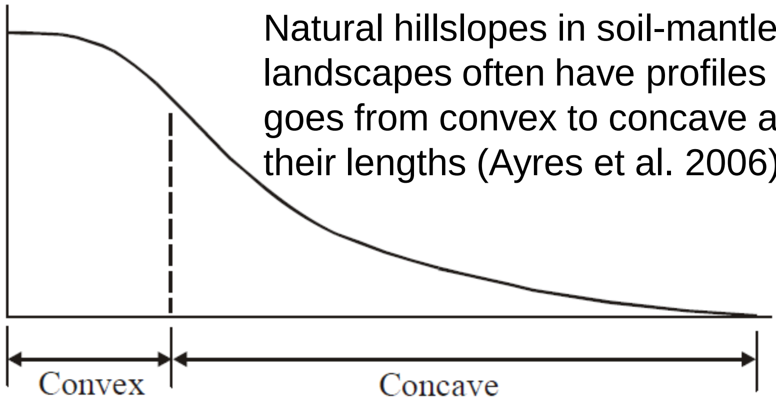
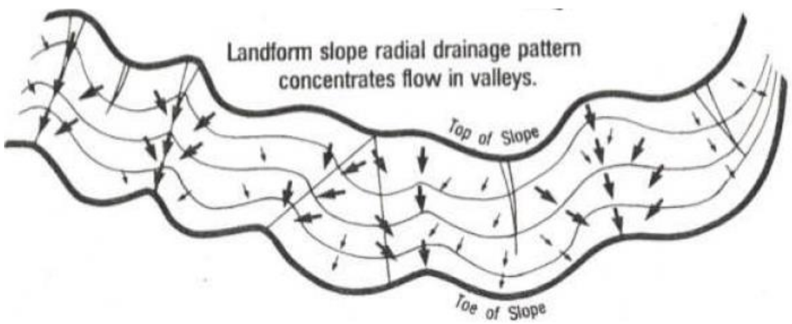
		Erosion Analysis
Job No: 1CM002.031 Filename: Fig03_ErosionAnalysis_rev02.pptx	Minto Mine	Date: April 2016 / Approved: EKH / Figure: **3**



Natural hillslopes in soil-mantled landscapes often have profiles that goes from convex to concave along their lengths (Ayres et al. 2006).



Landform-designed slopes have a radial drainage pattern that concentrate flow in valleys (Michael et al. 2010).

Landform-designed slopes are broken up into smaller drainage areas in order to limit the maximum overland flow path and resulting erosion (Schor and Gray 2013).

Sources

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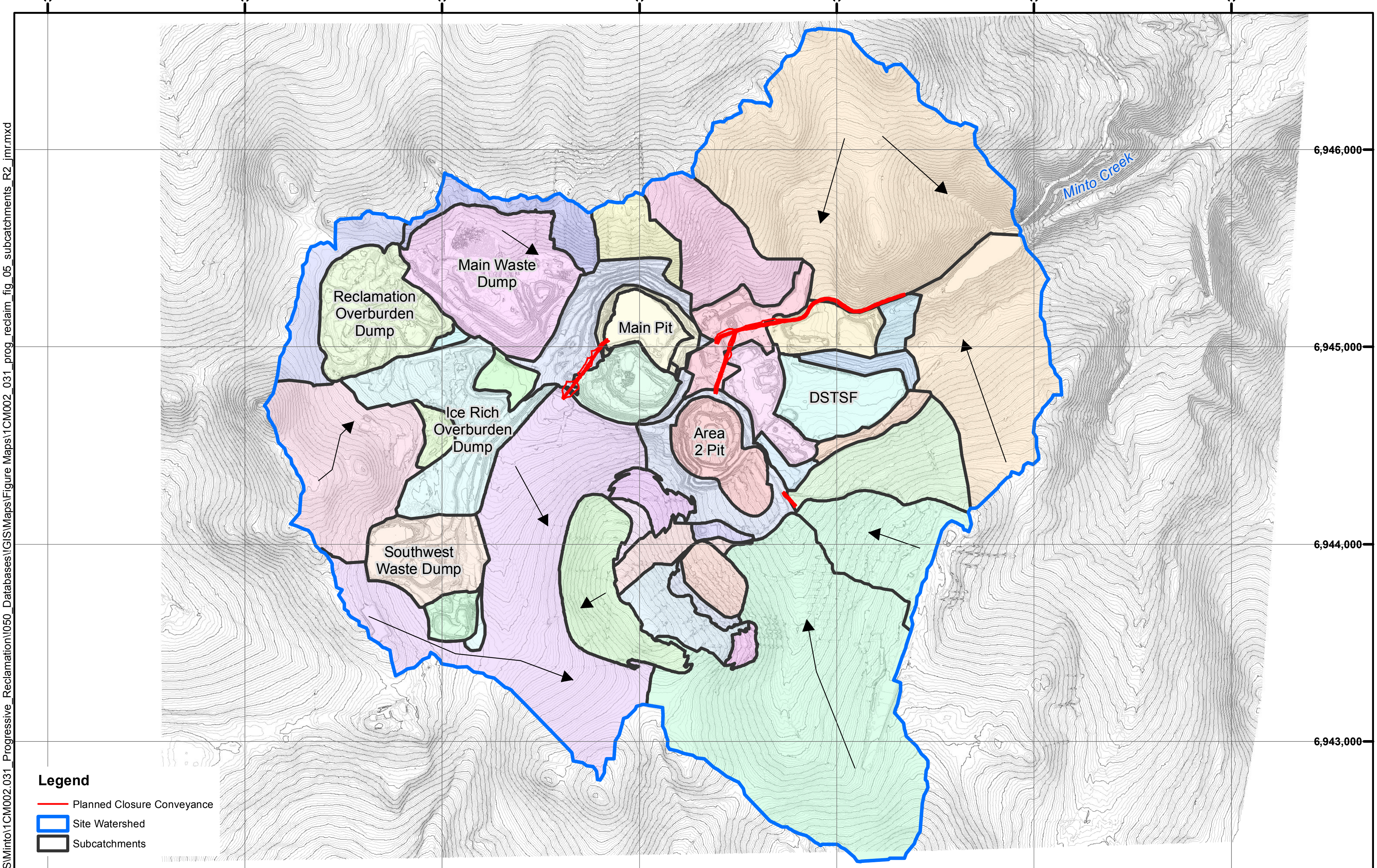

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Closure Landform Design and RLUs

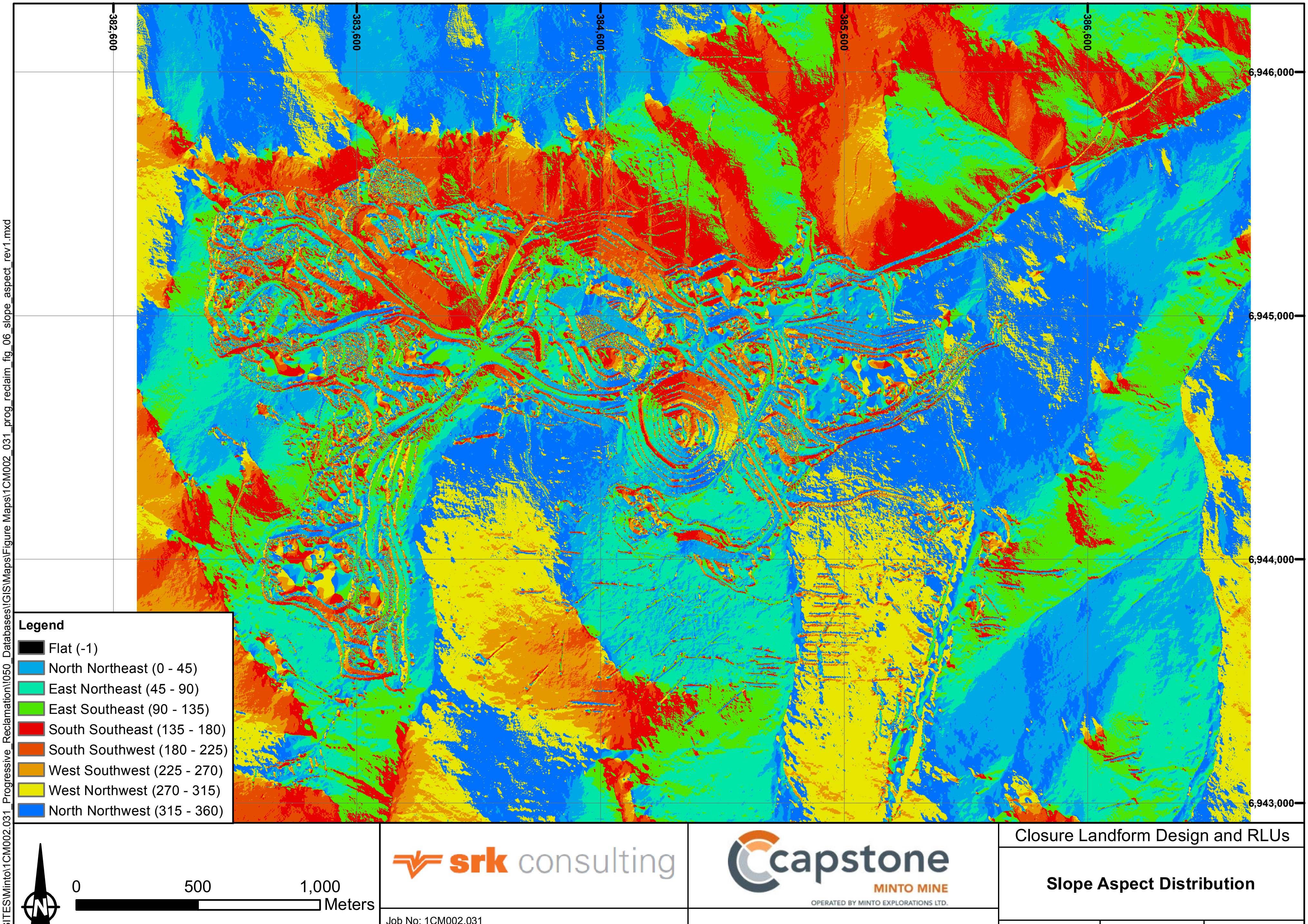
Sub-Catchment Areas

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_05_subcatchments_R2_jmr

Minto Mine

Date:	Approved:	Figure:
April 2016	EKH	5



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Closure Landform Design and RLUs

Slope Aspect Distribution

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_06_slope_aspect_rev1

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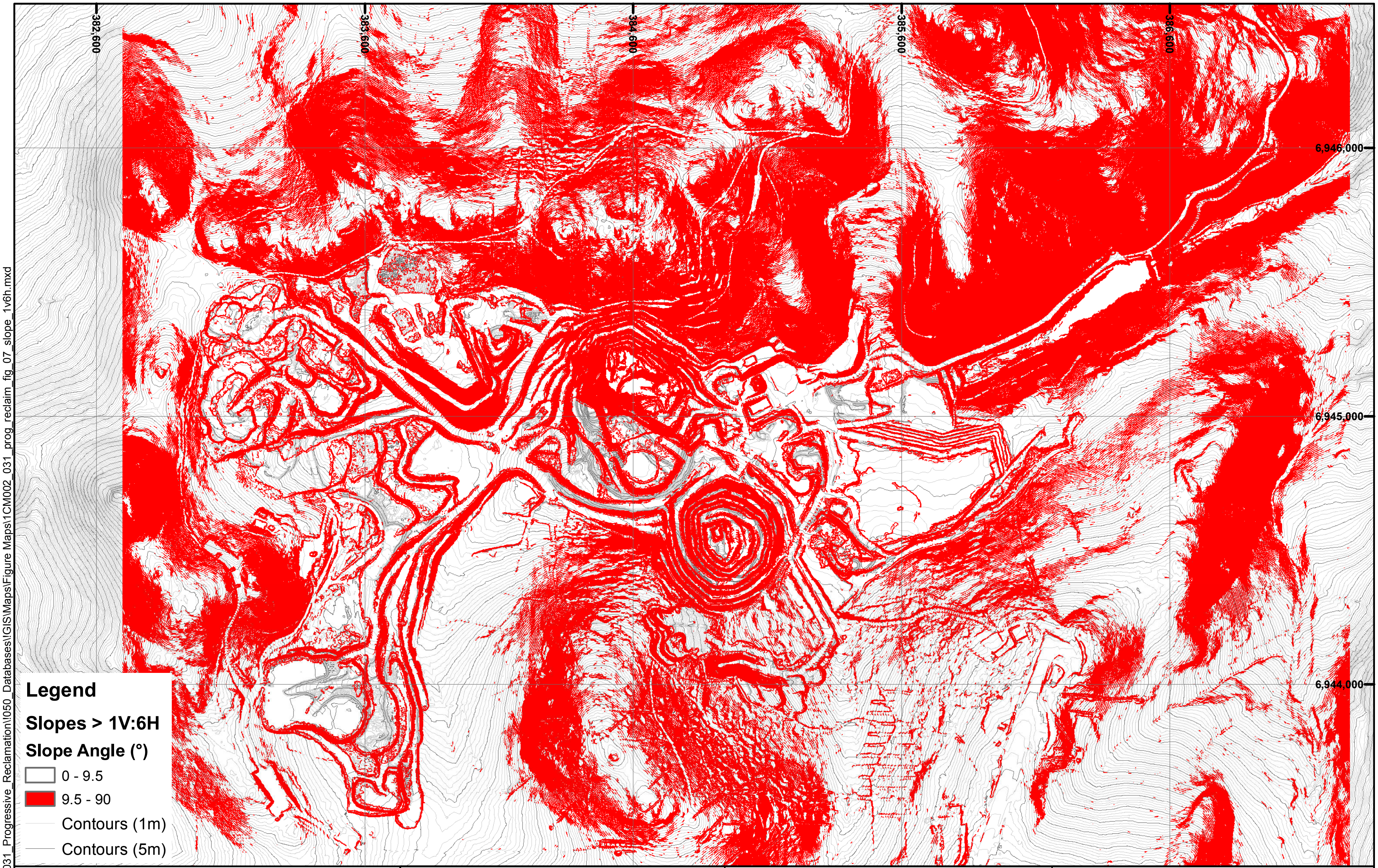

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Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_07_slope_1v6h

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Closure Landform Design and RLUs

Distribution of Slopes Steeper than 6H:1V

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April 2016	EKH	7

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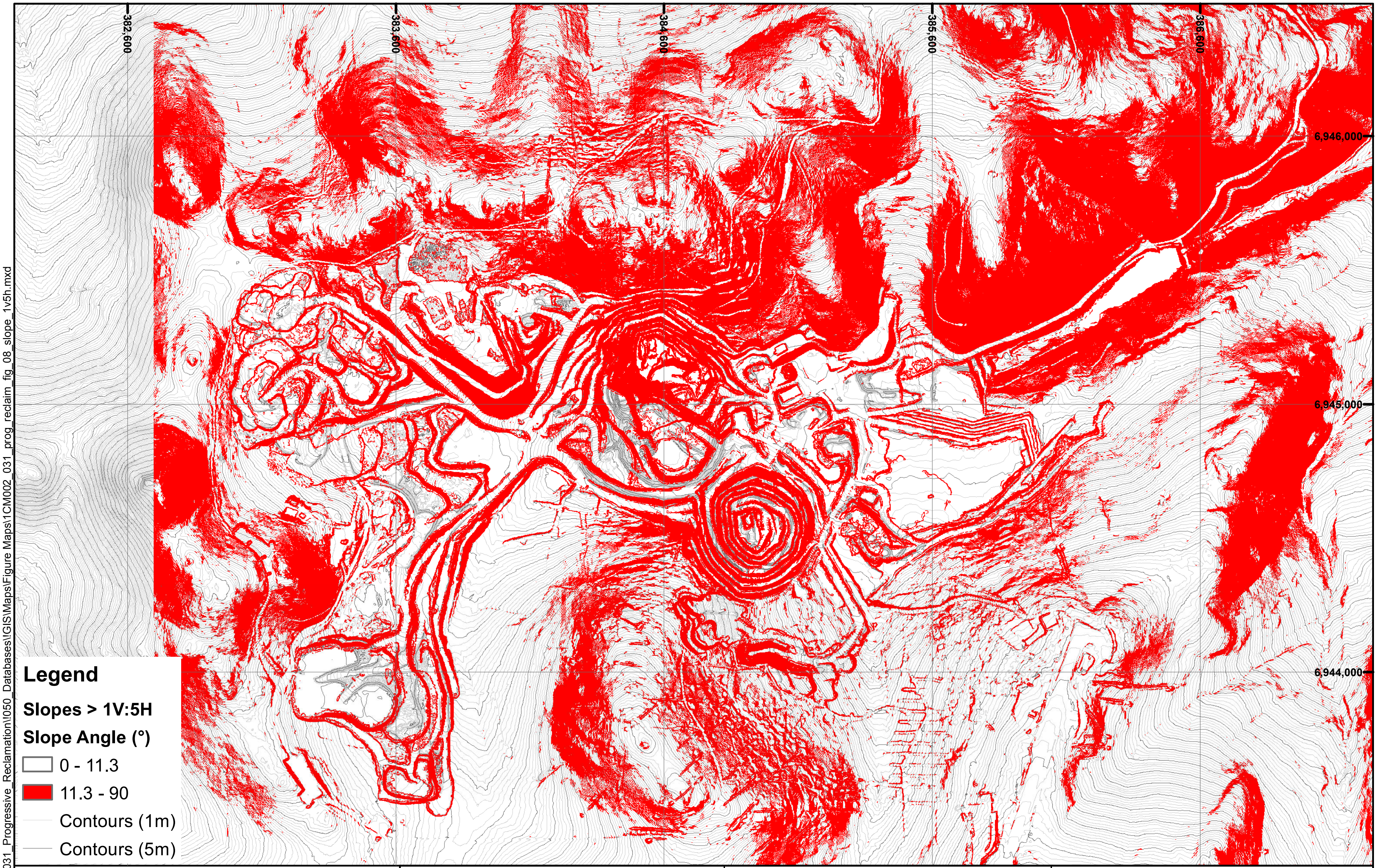

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Closure Landform Design and RLUs

Distribution of Slopes Steeper than 5H:1V

Job No: 1CM002.031

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Minto Mine

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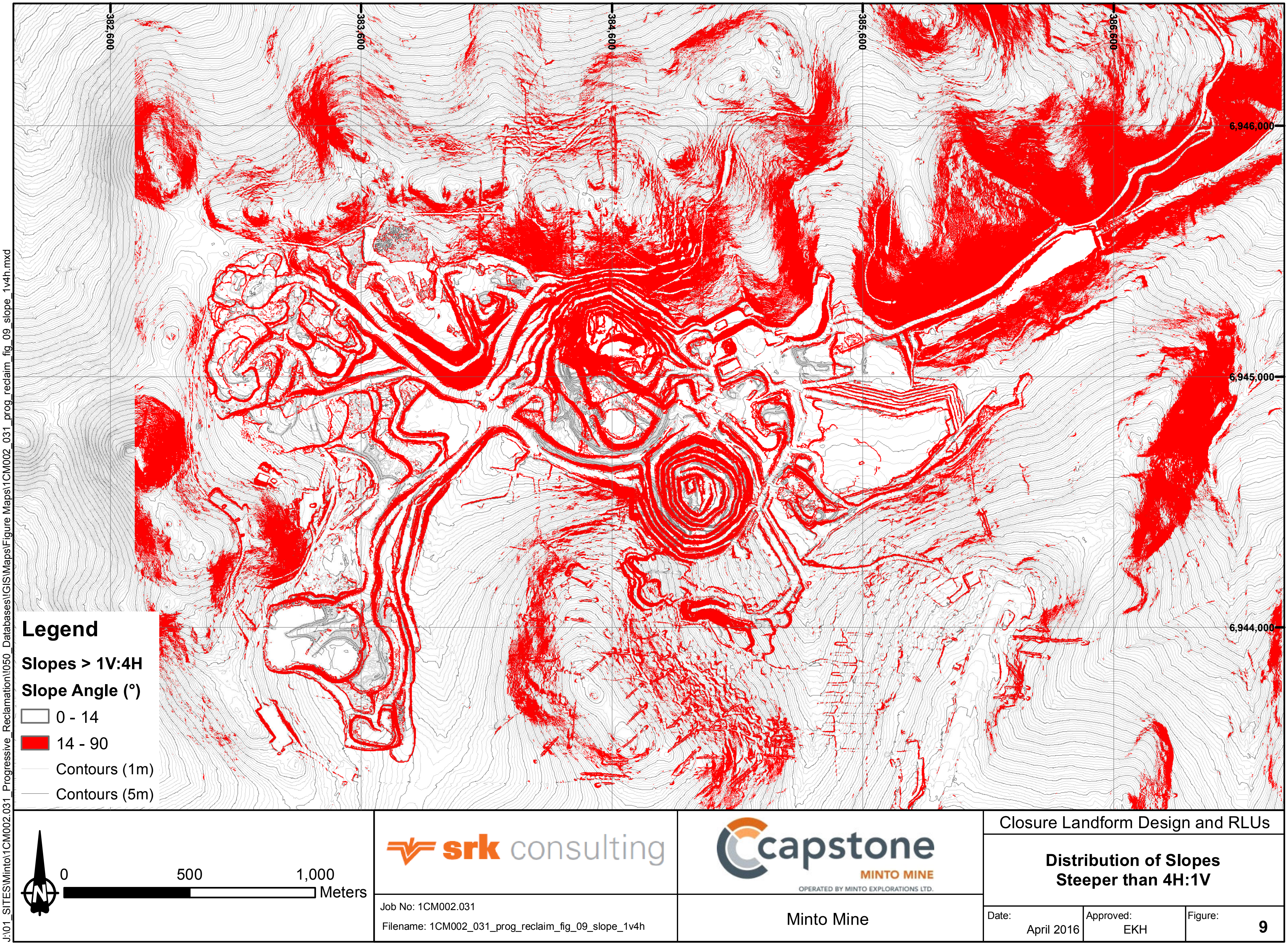
April 2016	EKH	8



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Closure Landform Design and RLUs

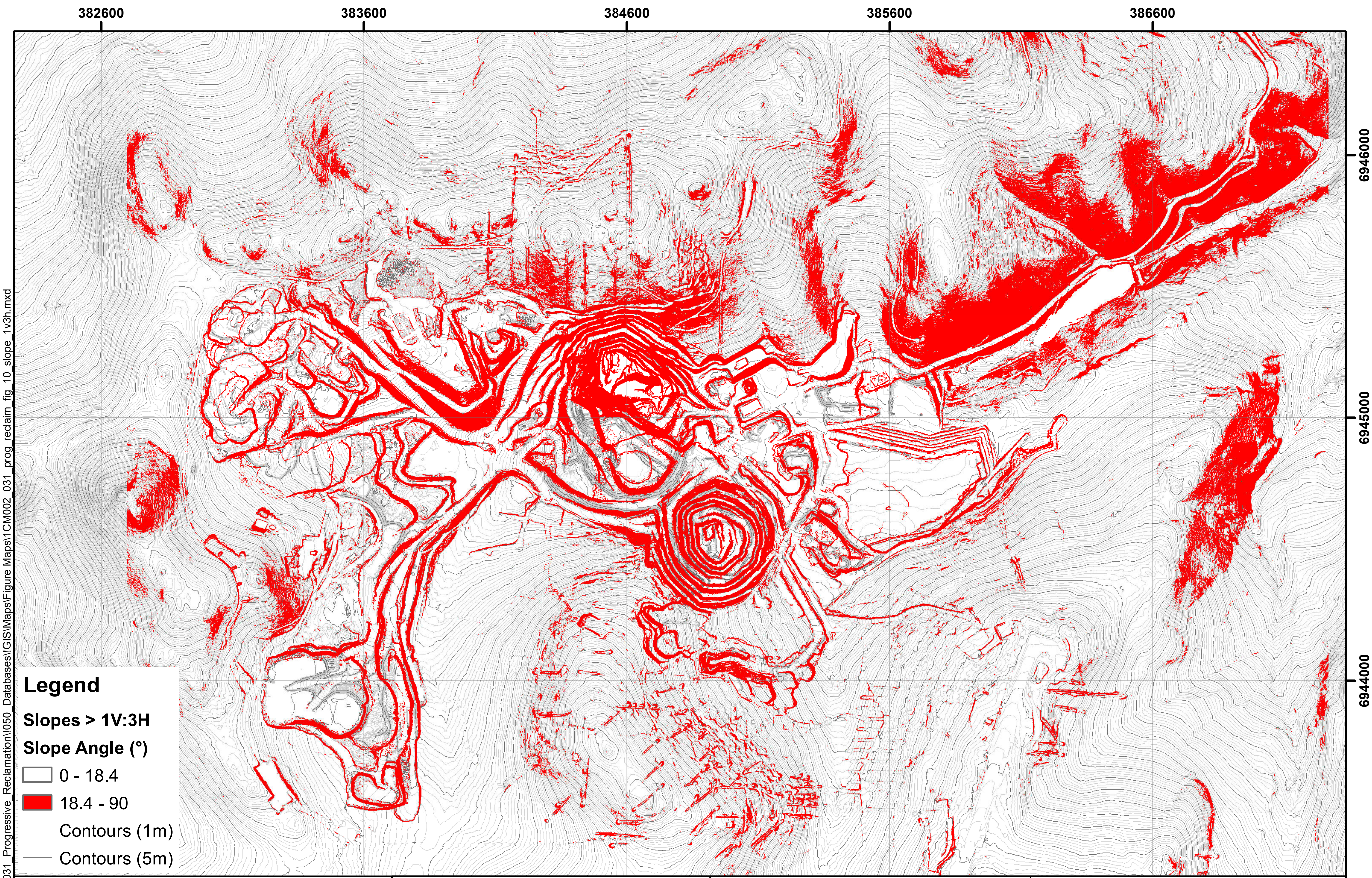
Distribution of Slopes Steeper than 4H:1V

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_09_slope_1v4h

Minto Mine

Date:	Approved:	Figure:
April 2016	EKH	9



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Closure Landform Design and RLUs

Distribution of Slopes Steeper than 3H:1V

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_10_slope_1v3h

Minto Mine

Date: April 2016

Approved: EKH

Figure: 10

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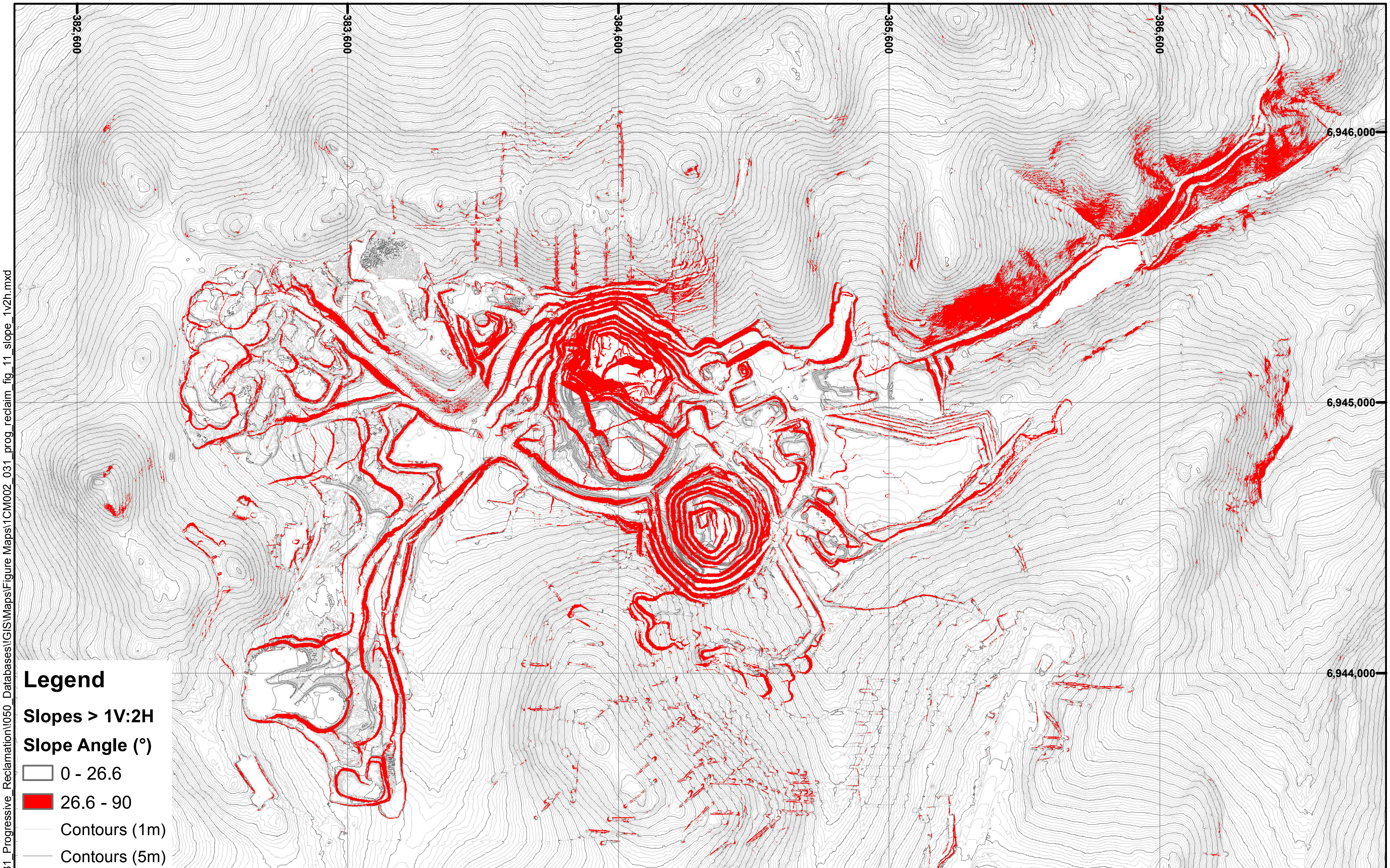

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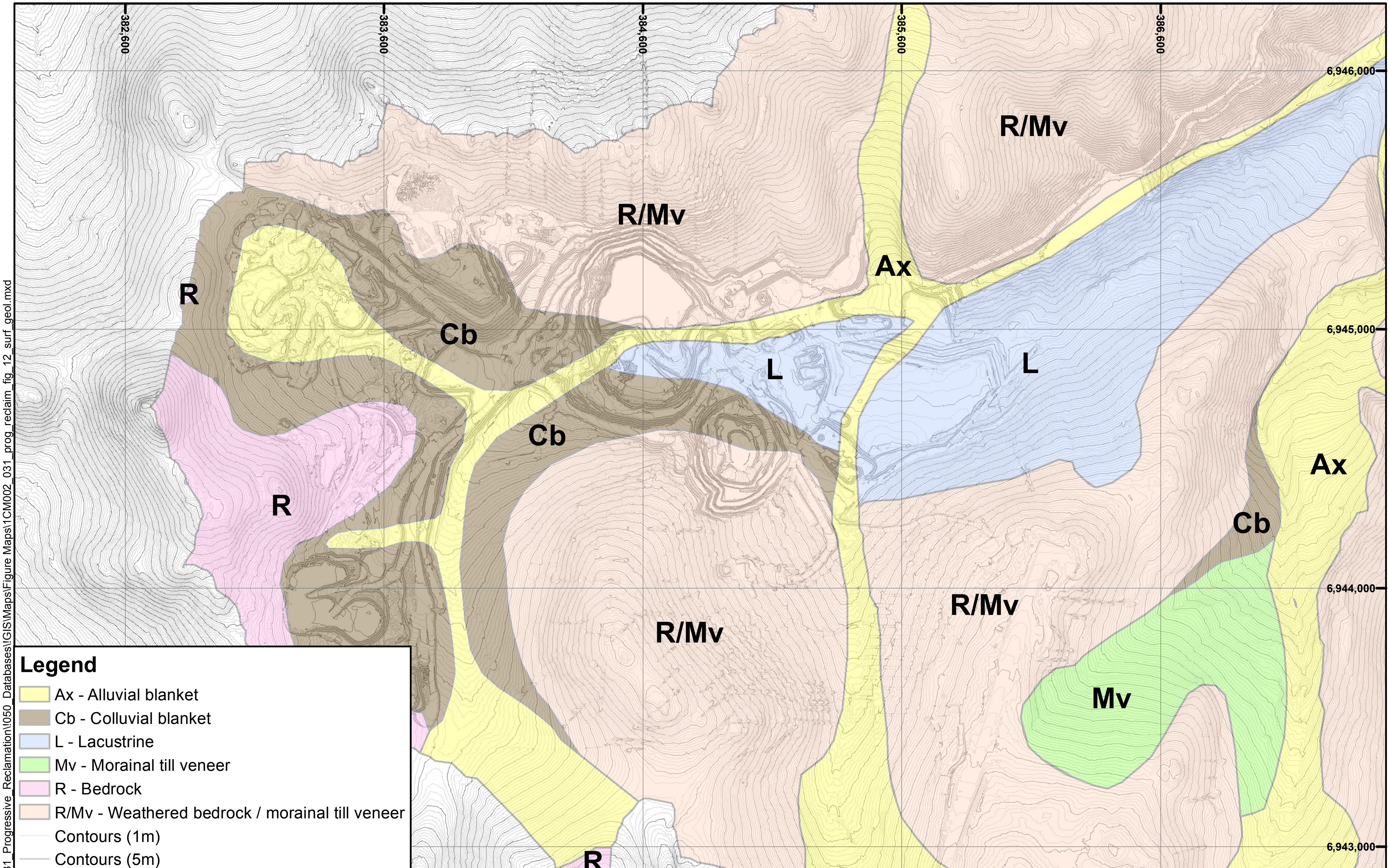
Closure Landform Design and RLUs

Distribution of Slopes Steeper than 2H:1V

Job No: 1CM002.031
Filename: 1CM002_031_prog_reclaim_fig_11_slope_1v2h

Minto Mine

Date:	Approved:	Figure:
April 2016	EKH	11



Source: SRK Consulting (US) Inc. (2014). Surficial Geology Map - Minto Creek Watershed

0 500 1,000 Meters

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Closure Landform Design and RLUs

Surficial Geology Map

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_12_surf_geol

Minto Mine

Date:	Approved:	Figure:
April 2016	EKH	12

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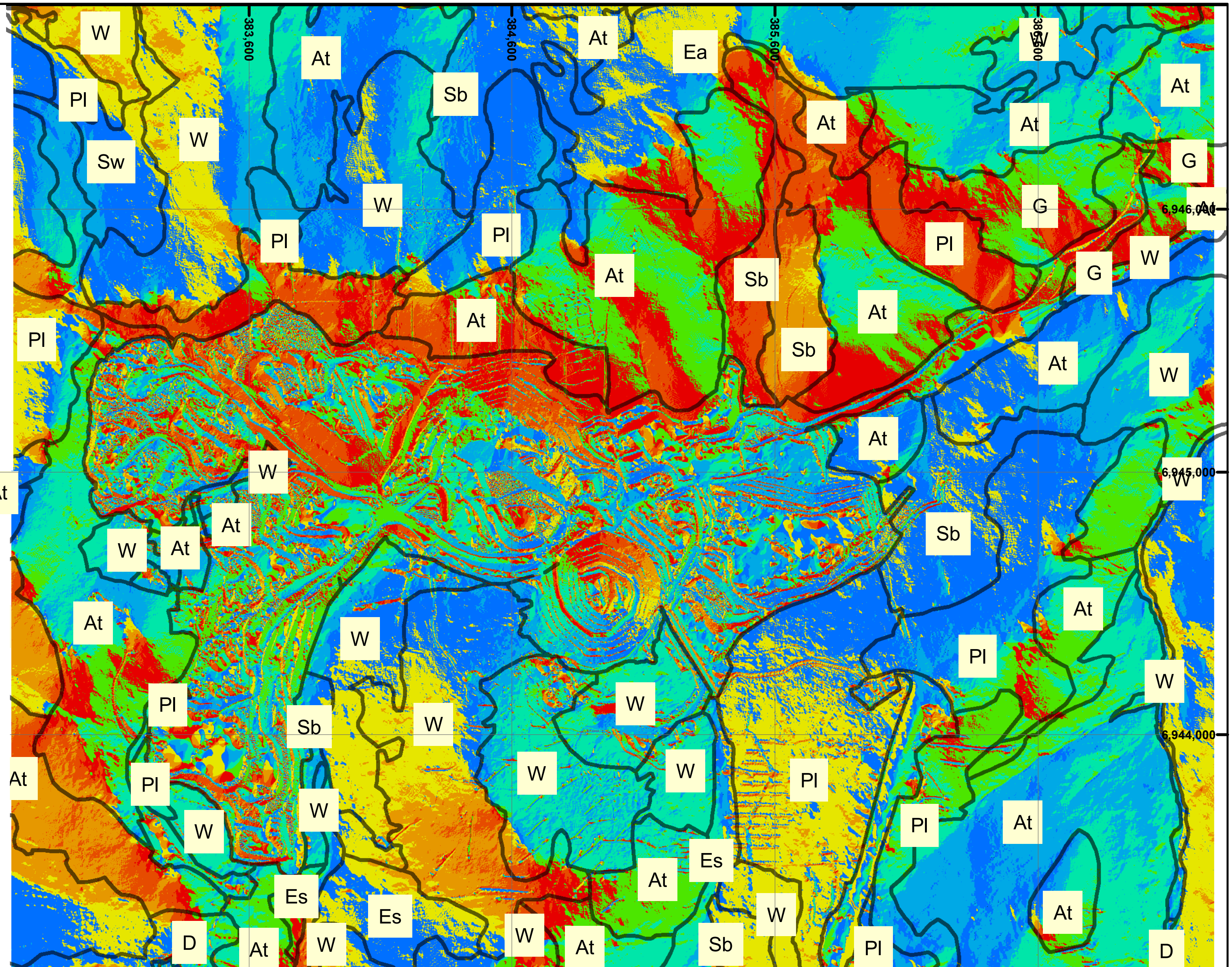

Legend

Leading Species

Slope Aspect

- Flat (-1)
- North Northeast (0 - 45)
- East Northeast (45 - 90)
- East Southeast (90 - 135)
- South Southeast (135 - 180)
- South Southwest (180 - 225)
- West Southwest (225 - 270)
- West Northwest (270 - 315)
- North Northwest (315 - 360)

Vegetation Species

At - Trembling Aspen
D - Alder
Ea - Alaskan Birch
Es - Scrub Birch
G - Graminoids
Pl - Lodgepole Pine
Sb - Black Spruce
Sw - White Spruce
W - Willow

N

0 500 1,000 Meters

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Job No: 1CM002.031
Filename: 1CM002_031_prog_reclaim_fig_13_slope_and_veg

Minto Mine

Closure Landform Design and RLUs

Slope Aspect and Vegetation Categories

Date:	Approved:	Figure:
April 2016	EKH	13

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Source: Smith, C.A.S., Meikle, J.C., Roots, C.F. (2004). *Ecoregions of the Yukon Territory: Biophysical Properties of Yukon Landscapes*. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313 p. Retrieved from: http://www.env.gov.yk.ca/animals-habitat/documents/ecoregions_of_yukon_reduced.pdf

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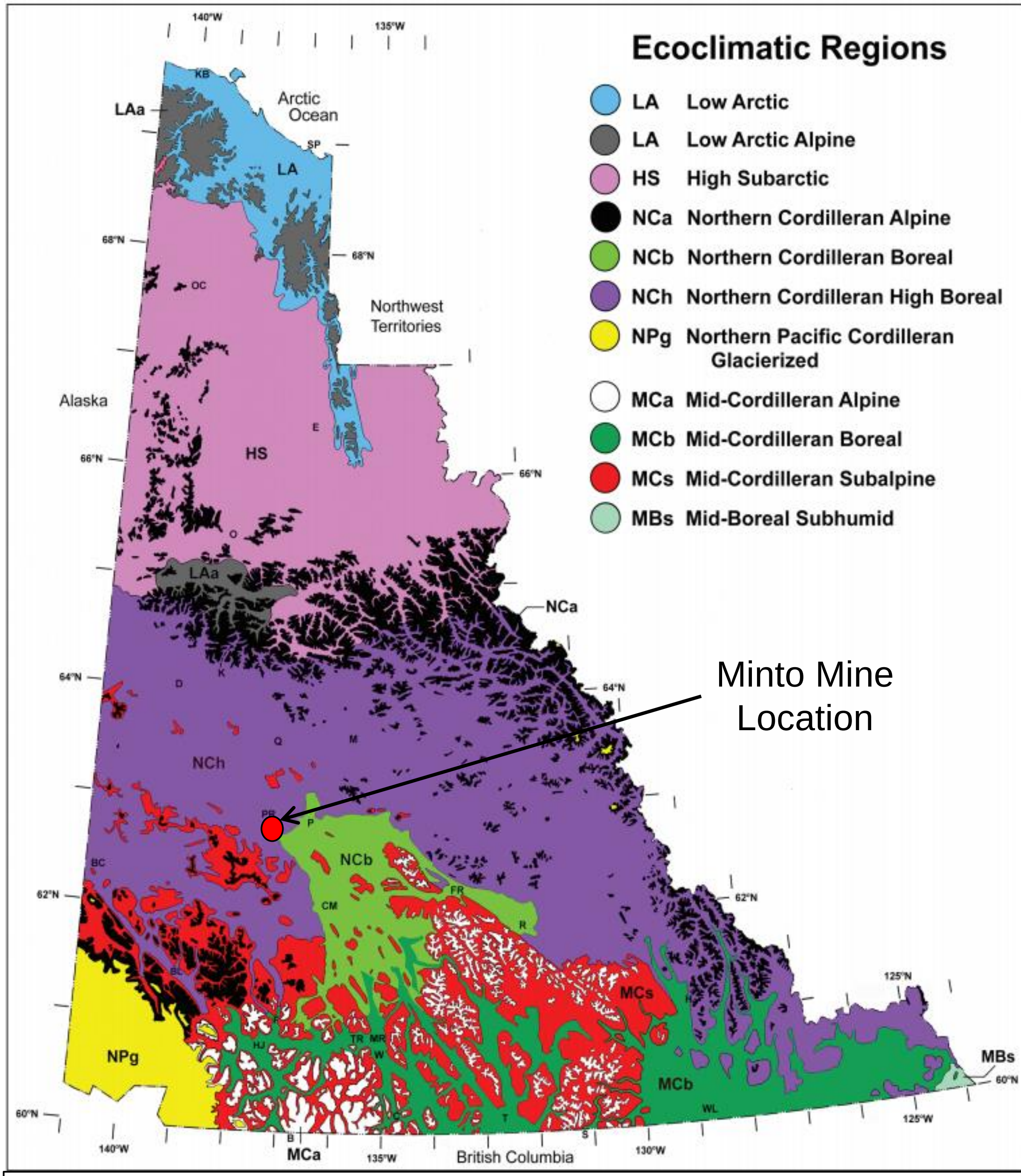
		Terrestrial Ecozones of the Yukon		
Job No: 1CM002.031	Minto Mine	Date: April 2016	Approved: EKH	Figure: **14**
Filename: Fig14_TerrestrialEcozones_rev02.pptx				



Letters other than ecoclimatic regions indicate the location of selected settlements and meteorological station locations: B – Blanchard River; BC – Beaver Creek; BL – Burwash Landing; C – Carcross; CM – Carmacks; D – Dawson City; E – Eagle Plains; F – Otter Falls; FR – Faro; H–Hour Lake; HJ – Haines Junction; K – Klondike; KB – Komakuk Beach; M – Mayo; MR – Mayo Road; O – Ogilvie River; OC – Old Crow; P – Pelly Crossing; PR – Pelly Ranch; Q – McQueston; R – Ross River; S – Swift River; SP – Shingle Point; T – Teslin; TR – Takhini Ranch; W – Whitehorse; and WL – Watson Lake.

Source: W.L. Strong (2013) Ecoclimatic Zonation of Yukon (Canada) and Ecoclinal Variation in Vegetation

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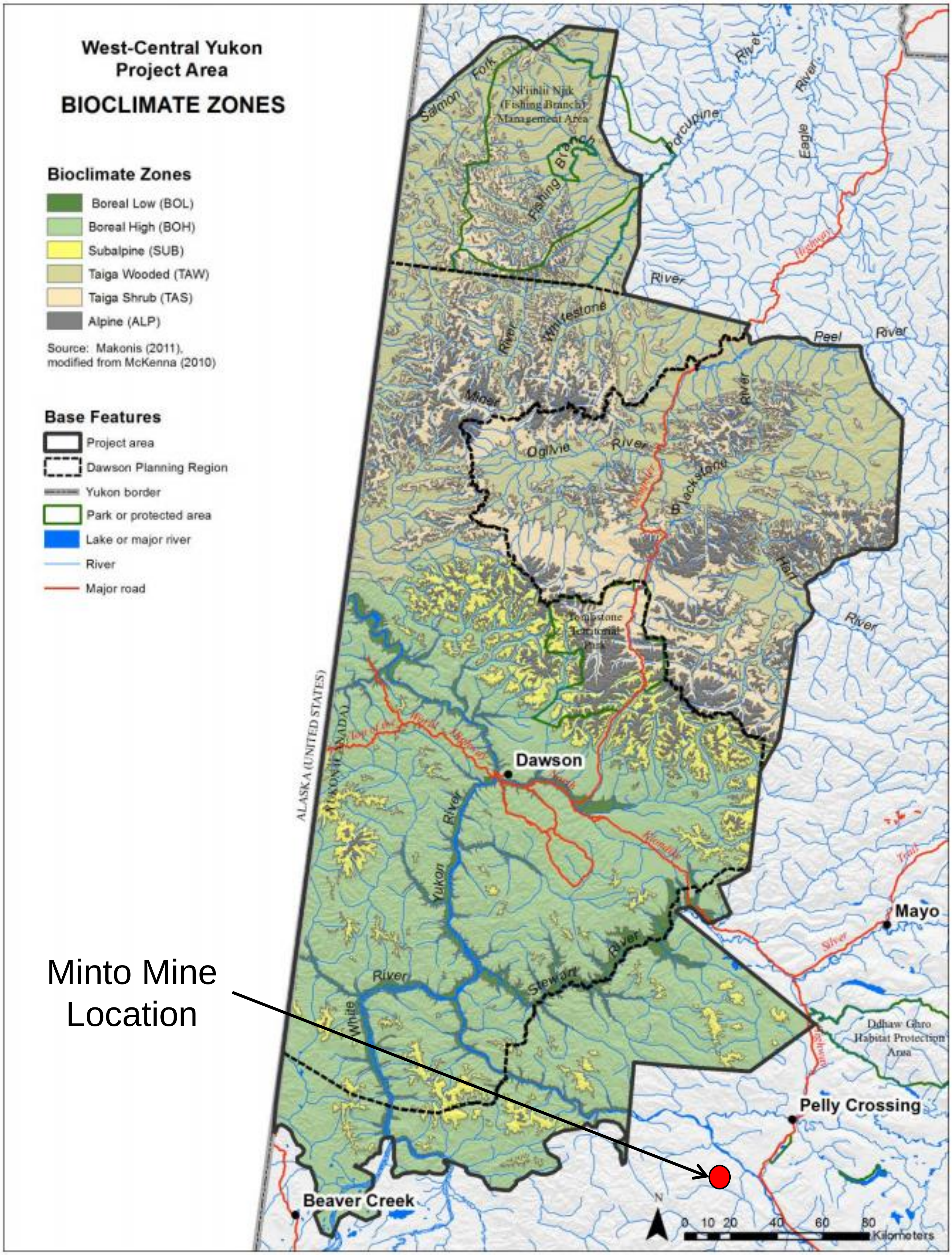
Job No: 1CM002.031 Filename: Fig15_EcoclimaticZones_rev02.pptx	Minto Mine	Date: April 2016	Approved: EKH	Figure: **15**



Source: Makonis Consulting Ltd. (2012) Regional Ecosystems of West-Central Yukon

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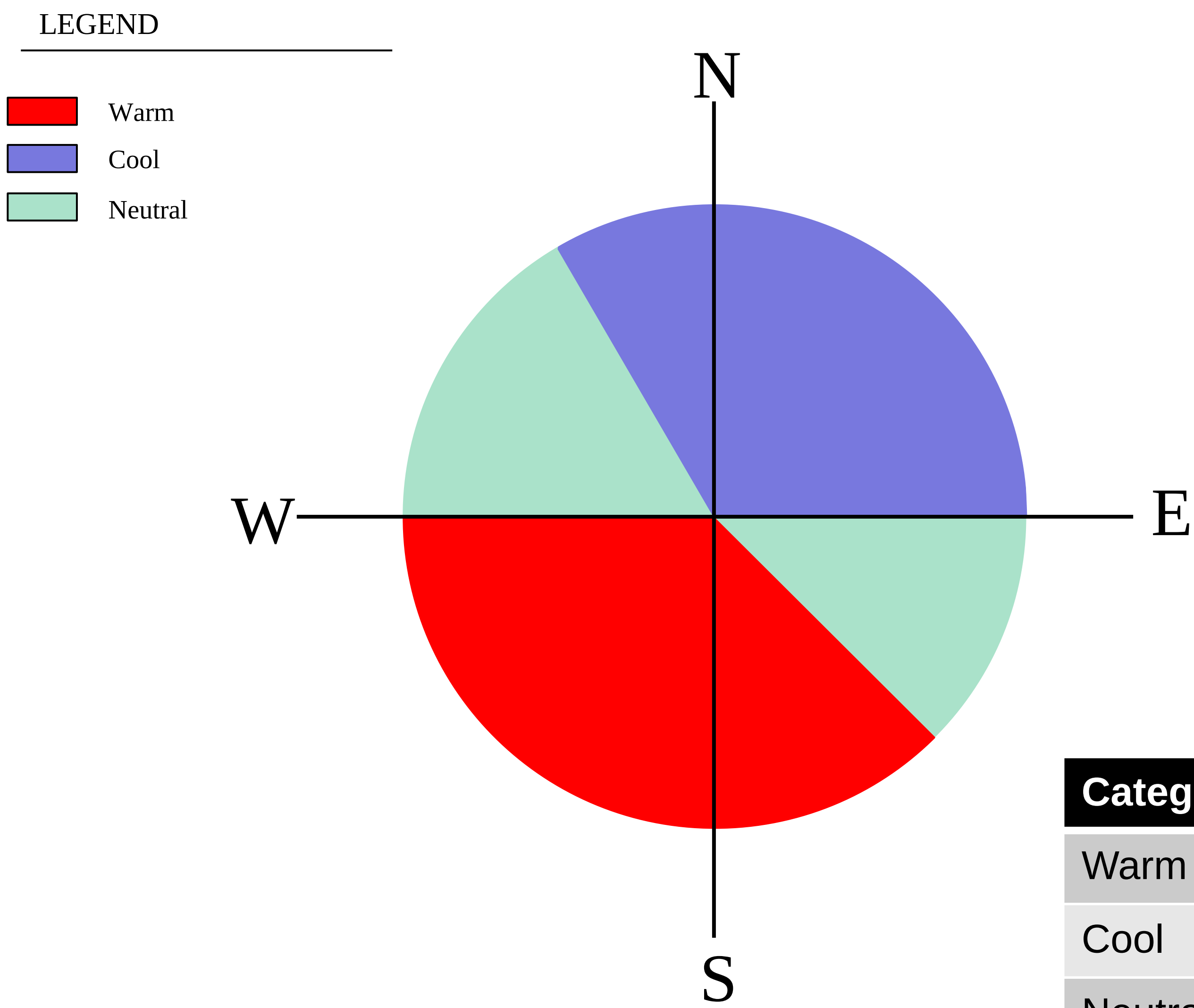
Job No: 1CM002.031 Filename: Fig16_BiogeoclimaticZones_rev02.pptx	Minto Mine	Date: April 2016 / Approved: EKH / Figure: **16**



Category	Azimuth Range (º)
Warm	135 – 270
Cool	330 – 90
Neutral	90 – 135, 270 – 330

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Closure Landform Design and RLUs

Slope Aspect Category Limits Schematic

Job No: 1CM002.031

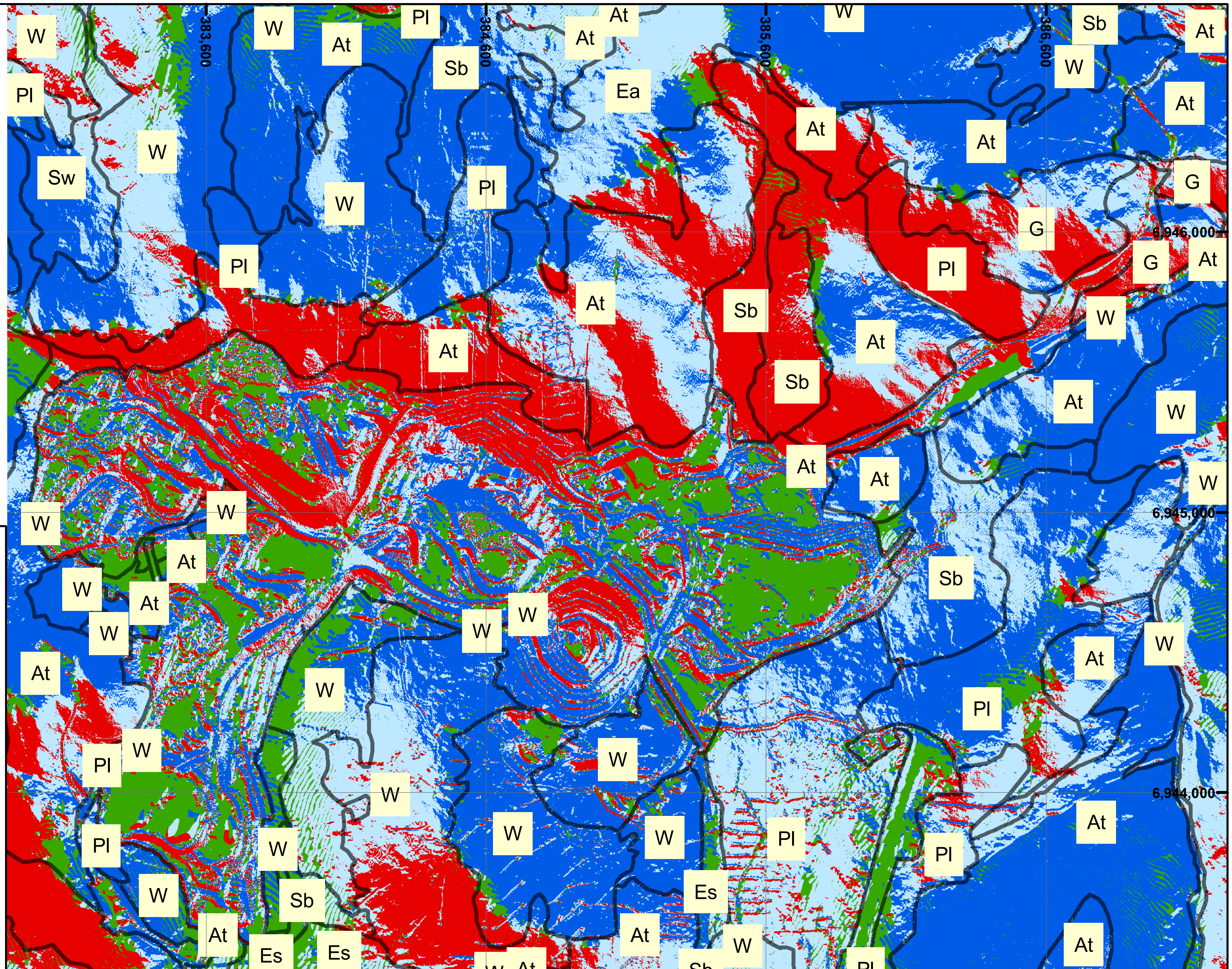
Filename: Fig17_SlopeAspectSchematic.pptx

Minto Mine

Date: April 2016

Approved: IM

Figure: **17**



Legend

Primary Species-Vegetation

Aspect

- Flat - All Aspects
- Sloped - Warm
- Sloped - Cool
- Sloped - Neutral

Vegetation Species

At - Trembling Aspen
D - Alder
Ea - Alaskan Birch
Es - Scrub Birch
G - Graminoids
Pl - Lodgepole Pine
Sb - Black Spruce
Sw - White Spruce
W - Willow

0 500 1,000 Meters

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Closure Landform Design and RLUs

Vegetation Categories and Slope Aspect

Job No: 1CM002.031

Filename: 1CM002_031_prog_reclaim_fig_18a_slope_angle_veg

Minto Mine

Date:	Approved:	Figure:
April 2016	EKH	18

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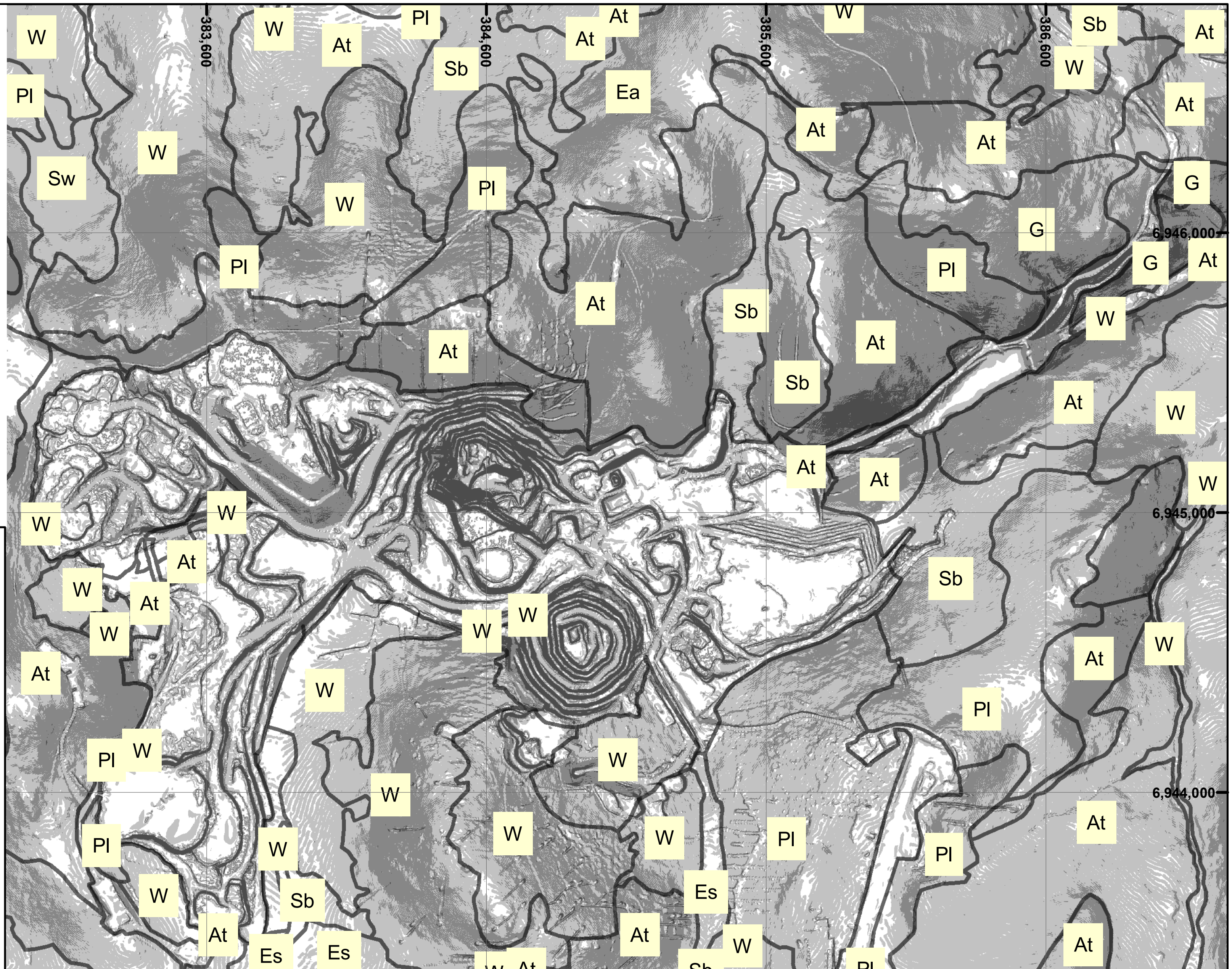

Legend

Primary Species-Vegetation

Slope (degree)

- Flat (0° to 3°)
- 6H : 1V (3° to 10°)
- 4H : 1V (10° to 14°)
- 2H : 1V (14° to 27°)

Vegetation Species

At - Trembling Aspen
D - Alder
Ea - Alaskan Birch
Es - Scrub Birch
G - Graminoids
Pl - Lodgepole Pine
Sb - Black Spruce
Sw - White Spruce
W - Willow

0 500 1,000 Meters

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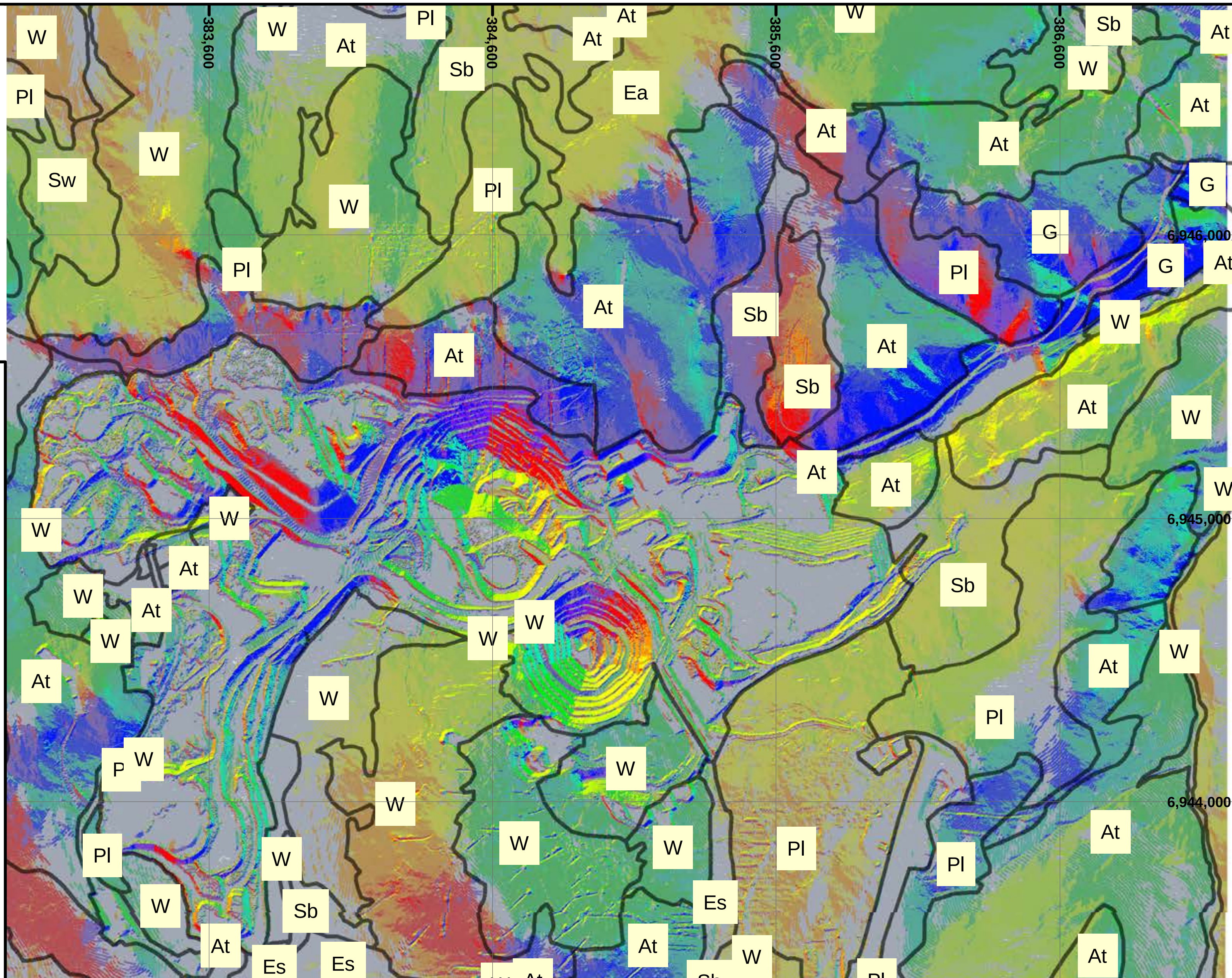
Job No: 1CM002.031
Filename: 1CM002_031_prog_reclaim_fig_18b_slope_angle_veg

Minto Mine

Closure Landform Design and RLUs

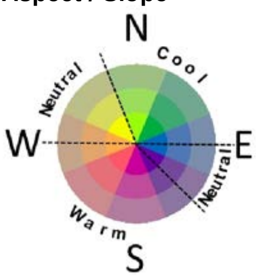
Vegetation Categories and Slope Angle Categories

Date:	Approved:	Figure:
April 2016	EKH	19



Legend

Aspect / Slope



Color Map
Inner Ring - Steep Slopes
Middle Ring - Moderate Slopes
Outer Ring - Shallow Slopes

Vegetation Species
At - Trembling Aspen
D - Alder
Ea - Alaskan Birch
Es - Scrub Birch
G - Graminoids
Pl - Lodgepole Pine
Sb - Black Spruce
Sw - White Spruce
W - Willow

0 500 1,000 Meters

srk consulting

capstone MINTO MINE
OPERATED BY MINTO EXPLORATIONS LTD.

Job No: 1CM002.031
Filename: 1CM002_031_prog_reclaim_fig_19_slope_angle_veg

Minto Mine

Site-Wide RLU Designation

Slope Aspect, Angle, and Vegetation Categories

Date:	Approved:	Figure:
Nov 2015	JBK	20

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