GRAPHITE ONE INC.

SNOW AVALANCHE HAZARD ASSESSMENT FOR THE GRAPHITE CREEK PROJECT

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June 14, 2024
Project No: 2386-001

Graphite One Inc.
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Attn: Kevin Torpy, Vice President, Operations
Re: Avalanche hazard assessment for the Graphite Creek Project.

Dear Mr. Torpy

Please find attached a report summarizing the results of an avalanche hazard assessment for the Graphite Creek Project, located on the Seward Peninsula near Nome, Alaska. Thank you for the opportunity to complete this work.

Sincerely,
Alpine Solutions Avalanche Services

per:

Cam Campbell, M.SC., P.L.Eng.
Senior Avalanche Specialist

Executive Summary

This report summarizes an assessment of snow avalanche hazard for the Graphite Creek Project in northwestern Alaska. The objective of the assessment is to provide an evaluation of avalanche hazard to proposed infrastructure and facilities, and an overview of mitigation options, to assist Graphite One Inc. (Graphite One) with feasibility level planning.

Avalanche paths were identified using desktop- and field-based methods supplemented with discussions with Graphite One's staff on site. Twenty-five separate avalanche paths were identified as having the potential to affect the Graphite Creek Project's proposed facilities, infrastructure, and access road locations. The types of avalanche paths include large open alpine bowls that funnel into channelled tracks, broad open slopes, and short roadside avalanche paths. Locations and extent of avalanche paths are illustrated on the maps provided in Appendix B.

The hazard affecting each element at risk was estimated in terms of avalanche magnitude and frequency and is summarized in Section 3. An overview of avalanche risk mitigation measures is provided in Section 4, which includes both short-term (i.e., generally active day-to-day) and long-term (i.e., generally policy based or engineering) measures.

Based on the findings of the assessment summarized in this report, Alpine Solutions recommends the following:

1. Avalanche risk mitigation should be considered for the proposed access road, facilities and infrastructure exposed to avalanche hazard. Mitigation may include short- or long-term measures, as described in Section 4, or a combination of these. A risk assessment and cost-benefit analysis are normally used to determine the optimal approach to mitigation.
2. For occupied structures or other high-risk elements that are near the edge of avalanche areas, an avalanche hazard zone map should be developed in order to optimize structure locations, and/or to locate safe/unsafe areas for where workers frequently congregate (e.g. parking area).
3. If structural mitigation is considered, further study should be undertaken to consider the nature of structural protection, which includes the geometry, the ability to absorb peak impact pressures, and the influence of various heights of previous snow on the ground for the design event.
4. Avalanche hazard should be reassessed during construction and operations as new avalanche terrain is created due to excavation, fill, and other artificial and natural alterations to the terrain.
5. The project area should continue to be monitored for signs of avalanche activity. If possible, records should follow observation guidelines and recording standards as per guidelines outlined in AAA (2022). This will assist with future studies and help to reduce uncertainty in avalanche hazard assessment and forecasting.
6. An assessment of slush flow hazard should be completed for the project facilities and infrastructure. Background information on the nature of slush flows can be found in Section 5.

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1 Introduction

1.1 General

This report summarizes an assessment of snow avalanche hazard for the Graphite One Inc. (Graphite One) Graphite Creek Project in northwestern Alaska (AK). The objective of the assessment is to provide an evaluation of avalanche hazard to proposed infrastructure and facilities, and an overview of mitigation options. Alpine Solutions understands that the results will be used to inform Graphite One with feasibility level planning.

This report includes the following:

1. An overview of physiography for the region including a description of the avalanche terrain, a snow climate analysis, and an overview of the avalanche hazard characteristics.
2. An avalanche hazard identification and analysis that includes avalanche path mapping, and magnitude and frequency estimates for 25 separate avalanche paths that have the potential to impact existing and proposed roads, infrastructure, and facilities.
3. An overview of avalanche risk mitigation measures that could be incorporated for this project.
4. Background information regarding characteristics of slush flows.
5. Recommendations based on the findings of the study.

Appended to this report are:

1. Background information on avalanches.
2. Avalanche path maps for the project site and proposed access road.

1.2 Location

The Graphite Creek Project is on the Seward Peninsula approximately 60 km north of Nome, Alaska in the Kigluaik Mountains on the southern shores of Imuruk Basin (Figure 1-1). The proposed access road travels from the Kougarok Road/Nome-Taylor Highway through Mosquito Pass where it follows the Cobblestone River to the mine site.

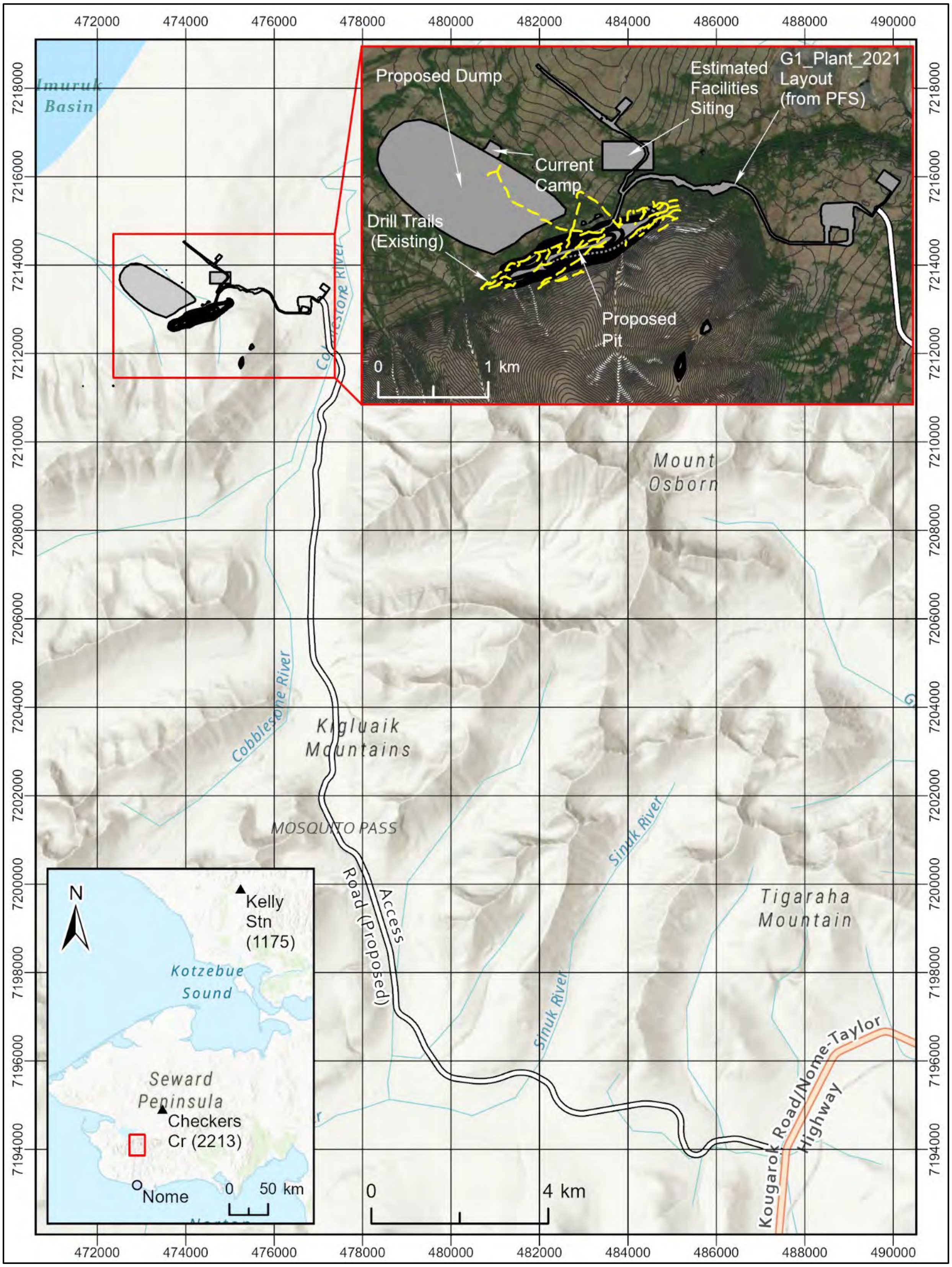

Figure 1-1: Overview map of the Graphite Creek Project showing the proposed access road (main map), current and proposed facilities and infrastructure locations (top-right inset map), and locations of weather stations used for the snow supply analysis (bottom-left inset map).

1.3 Work Scope

The work has been conducted in accordance with Alpine Solutions' proposal dated February 7, 2024. The assessment involved both desktop analysis and field investigations and included avalanche terrain and hazard identification followed by hazard analysis and evaluation. Typical avalanche mitigation options are provided for all project facilities and infrastructure exposed to avalanche hazard that exceeds thresholds for mitigation provided in CAA (2016).

The assessment was completed for all facilities and infrastructure associated with the Graphite Creek Project illustrated in Figure 1-1, including:

- The proposed access road from the Kougarok Road/Nome-Taylor Highway to the mine site.
- All areas within the "G1_Plant_2021" layout from the Prefeasibility Study (PFS).
- The proposed pit and dump footprints.
- Estimated facilities siting footprint.
- Existing drill trails.
- Existing camp location.

Proposed facility and infrastructure locations were provided by Graphite One in both Esri ArcGIS Packaged Project File, Shapefile, and Geodatabase formats. This included "Avalanche RFP.ppkx" Packaged Project File that contained the following spatial data features:

- "Access Road CL (Proposed)" – linework for the proposed access road alignment.
- "Draill Trails – Existing" – linework for the existing drill trails.
- "Camp_Fence" – Polygon of the current camp boundaries.
- "G1_Plant_2021" – Layout from the PFS.

This also included:

- "FS_Perlim_Layout_02May24.gdb" - geodatabase with the proposed pit and dump layouts as well as the estimated facilities siting footprint.
- "G1_Access_Shapefiles.zip" – compressed folder containing shapefiles of the proposed access road alignment with crossing structure locations as well as materials sites (i.e., quarries and borrows).

Additional spatial data provided by Graphite One and used in this study include one-metre resolution LiDAR digital elevation data acquired in 2022. This was supplemented with freely available seven-meter resolution data from the United States Geological Survey (USGS) in areas outside of the extent of the 2022 LiDAR survey.

Furthermore, the following report was provided by Graphite One and referenced in this study:

- David Hamre and Associates, LLC. 2023. *Graphite One Winter Trail Avalanche Safety Assessment*. Prepared by: Aleph Johnston-Bloom and Andrew Schauer. Dated: March 25, 2023.

In lieu of equivalent US guidelines, Canadian Avalanche Association guidelines (CAA, 2016) were used in conjunction with methods described in Jamieson et al. (2018), which are internationally recognized references for avalanche hazard and risk assessment. These guidelines have also been used when completing avalanche hazard assessments for other mines in the US, as well as Department of Transportation projects that Alpine Solutions has worked on.

1.4 Uncertainty and Limitations

Snow avalanches are an erratic phenomenon. As such, characteristics such as runout extent and potential impact pressures cannot be precisely determined, especially without long-term records of avalanche occurrences in the area. There is further uncertainty due to a lack of vegetative indicators (e.g. trim lines in forest) because the project site is entirely in alpine terrain with no tree cover. Furthermore, estimating future avalanche characteristics based on historical data is becoming more uncertain with a changing climate. Uncertainty associated with avalanche hazard assessment has been accounted for by confidence weighting of results from different methods. In addition, for mitigation planning, it may be appropriate to incorporate a factor of safety for design of infrastructure or protection measures.

The following limitations apply to this study:

- The scope of this assessment is limited exclusively to snow[1] avalanches. Slush flows (i.e., containing mostly liquid water), landslides, and other geohazards are not considered in this study.
- Although there are many avalanche paths within the vicinity of the project, only avalanche paths that have the potential to affect the proposed roads, facilities, and infrastructure with Size D2 or larger (Table A-1) avalanches were included in the study.
- Only the existing terrain configuration was assessed, and no considerations were made for the modification of terrain due to mine development or geotechnical event. Any artificial or natural alteration of the landscape due to excavation, fill, landslide, etc. may change the nature of the avalanche hazard, necessitating a re-assessment for the area affected.

2 Physiography

2.1 Avalanche Terrain Overview

The proposed access road travels north through Mosquito Pass (Figure 2-1) and follows the Cobblestone River valley (Figure 2-2) to the project site. The existing and proposed facilities and infrastructure are situated at the terminus of the Cobblestone River below north facing slopes (Figure 2-3) on the southern shores of Imuruk Basin.

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[1] All mention of the term ‘avalanches’ in this report refer to snow avalanches. ‘Rock avalanches’ or ‘debris avalanches’ are not discussed in this report.

Figure 2-1: View looking north through Mosquito Pass showing the approximate proposed access road alignment (dashed line).

Figure 2-2: View of the west-facing slopes above the terminus of the Cobblestone River showing the approximate proposed access road alignment (dashed line).

Figure 2-3: View of the north facing slopes above the project site showing the approximate footprint of the proposed pit.

The proposed access road alignment reaches a maximum elevation of 350 m at Mosquito Pass and a minimum elevation of 100 m at the project site terminus, while adjacent ridge crests and mountaintops reach a maximum elevation of 1200 m (Figure 2-2). The estimated facilities and proposed dump are at an elevation of approximately 100 m, while the proposed pit footprint ranges from approximately 150 m to 250 m with slopes above extending to 900 m (Figure 2-3).

Terrain capable of producing avalanches (i.e. "avalanche terrain") affecting the project infrastructure include large open alpine bowls that funnel into channelled tracks, and shorter broad open slopes. Avalanche starting zones are located on all aspects (the compass direction that the slope faces) and therefore have a variety of exposures to prevailing wind direction and sun. Due to the northerly latitude, exposure to sun becomes more prominent on all terrain during the end of winter and into spring.

Avalanche terrain is often described in terms of three vegetation-specific elevation bands (i.e. alpine, treeline, and below treeline) that normally display distinctly different avalanche characteristics. The project is in a Low Arctic environment with avalanche terrain entirely in the alpine where there is no vegetation to provide shelter from the effects of wind and sun. Most large dry slab avalanche start on slopes with inclined between 30° and 45°. Steeper slopes are often prone to frequent smaller loose-snow avalanches (i.e., sluffs), while wet avalanches can release in lower-angled terrain.

2.2 Avalanche Regime

Avalanche regime refers to the general character of climate factors that contribute to snowpack and avalanche formation (Haegeli & McClung, 2007). The region is in a continental avalanche regime, which is characterized by low snowfall, very cold temperatures, and frequent moderate to strong winds (McClung and Schaerer, 2023). Meteorological data acquired through sources listed in Table 2-1, were analyzed to determine avalanche characteristics, and determine when, and how often, threshold snow depths for avalanche hazard are exceeded. There are limited automatic weather stations providing quality meteorological data near the project site. The Checkers Creek SNOTEL site was the most relevant station providing snow depth data, and the Kelly Station SNOWTEL site provided supplementary data.

Table 2-1: Relevant weather stations assessed in the snow climate analysis.

Station (ID)	Source Organization	Years of Snow Depth Data	Elevation (m)	Coordinates (lat°, long°)	Approx. Distance from Project (km)
Checkers Creek (2213)	USDA (SNOTEL)	5 (2015-17 & 2022-23)	100	65.4, -164.72	55
Kelly Station (1175)	USDA (SNOTEL)	15 (1993-95, 2012-15 & 2017-24)	95	67.93, -162.28	350

2.2.1 Avalanche Season

Avalanche season is the time of year when avalanches may occur and is dependent on when the ground roughness in avalanche starting zones is covered by a threshold amount of snow, such that the roughness is smoothed-out into a uniform slope. According to Snow Water Equivalent (SWE) data from the Kelly

Station site, the snowpack starts to accumulate at the end of September, reaches a maximum in April, and typically melts by the end of May (Figure 2-4). For elevations above 500 m, avalanche season can extend further into summer season (i.e., from September into June), or potentially throughout the summer on lingering snowfields if cool conditions persist.

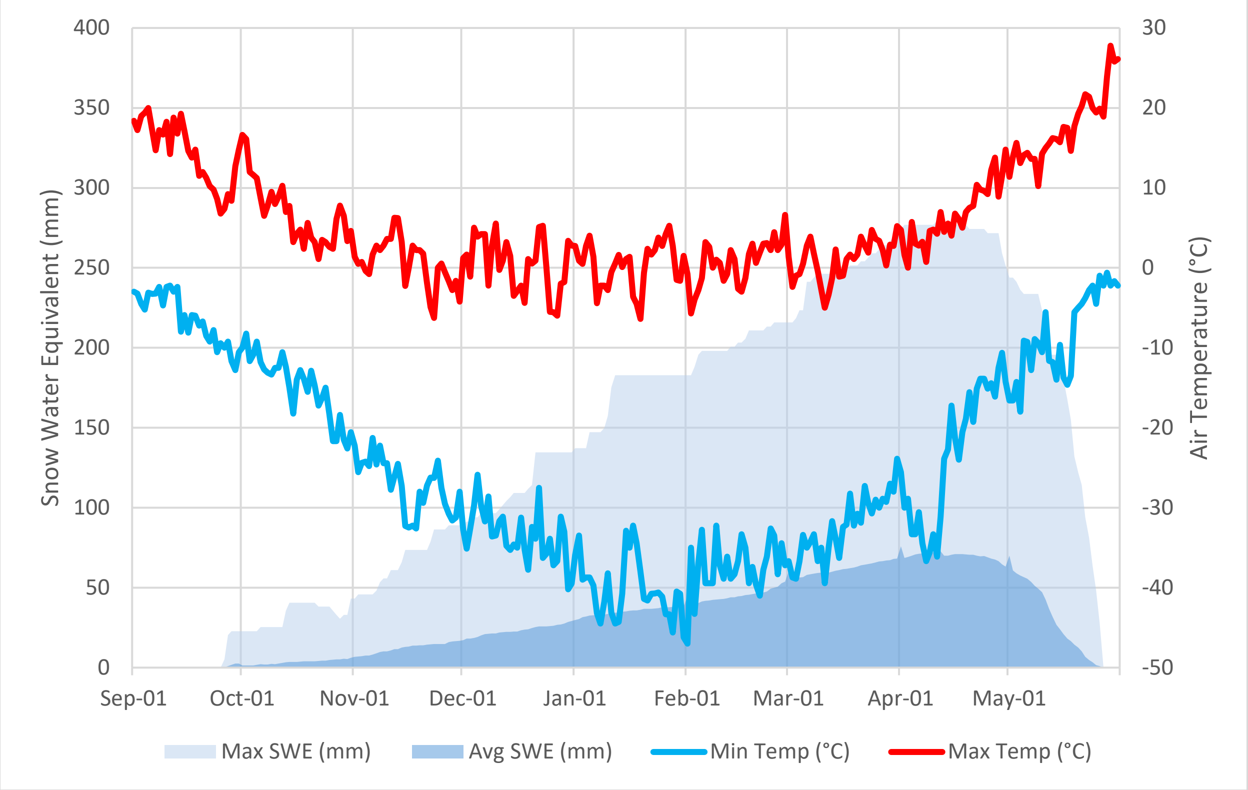

Figure 2-4: Time-series plot of average and maximum Snow Water Equivalent (SWE) as well as minimum and maximum air temperatures at the Kelly Station SNOTEL site.

During its 13 years of data measurement (i.e., 2012 to 2024), the Kelly Station SNOTEL site has recorded a minimum air temperature of -47 °C, but above freezing temperatures are also possible for all months of the year. Prolonged arctic outflow conditions (i.e., cold, dry, and windy) combined with large temperature gradients within the snowpack will contribute to the development of persistent weak layers within the snowpack, and once buried, can act as a failure or sliding plane for large destructive slab avalanches.

2.2.2 Snow Supply

Based on the five years of snow depth data from the Checkers Creek SNOTEL site, the Graphite Creek Project area can expect maximum annual snowpack depths of 35 cm in sheltered areas at 100 m elevation. The maximum snowpack depth recorded at the Checkers Creek SNOTEL site was 58 cm in 2023. Using Gumbel extreme value analysis, the estimated maximum snowpack depths corresponding with longer return periods are plotted in Figure 2-5. These snowpack depths are greater than the ground roughness in avalanche staring zones surrounding the proposed access road and project facilities and infrastructure.

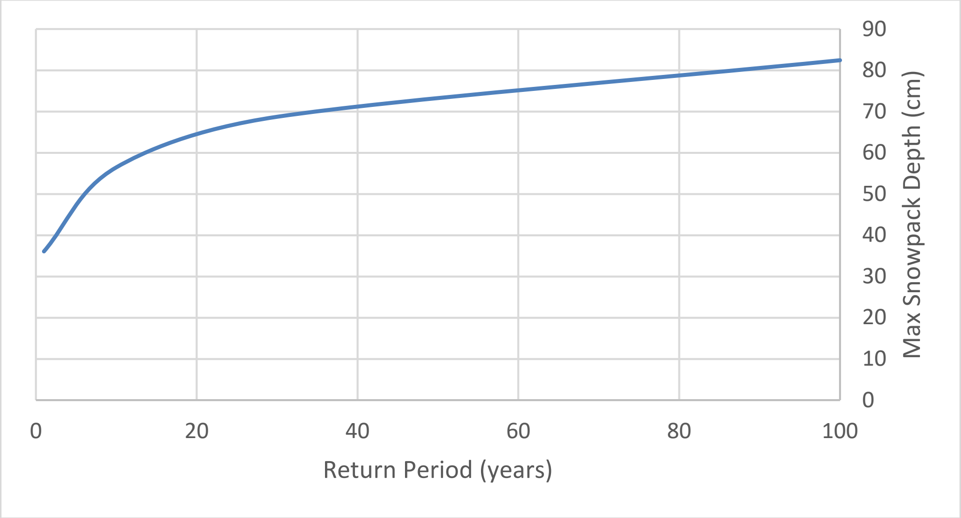

Figure 2-5: Estimated maximum snowpack depth plotted against corresponding return periods for the Checkers Creek SNOTEL site.

The project area also experiences significant variability in snowpack distribution due to the wind transport of snow, which can result in leeward starting zone snow heights three to five times the heights observed at level sheltered SNOTEL sites (Doorschot *et al.*, 2001). The prevailing winds are channelized into the main valley predominantly from the north through the Cobblestone Valley and Mosquito Pass.

2.2.3 Avalanche Characteristics

Avalanche paths that have the potential to affect the proposed roads, facilities, and project infrastructure are likely to develop frequent wind slab avalanches of Size D1 to D2 (Table A-1). Buried persistent weak layers, such as facets increase the potential for wide propagating fractures leading to larger destructive persistent slab avalanches to Size D2 to D3 magnitudes.

3 Avalanche Hazard Assessment

Avalanche paths were identified and mapped using the following methods:

- Terrain analysis using Geographic Information Systems and terrain data (e.g., LiDAR) provided by Graphite One and obtained through publicly available sources (e.g., USGS).
- Discussions with Graphite One Personnel familiar with the site.
- Review of historical aerial photographs and satellite imagery.
- Numerical avalanche modeling with the RAMMS - Rapid Mass Movement Simulation (Christen et al., 2010) physical-dynamic model.
- Aerial and ground-based field investigations completed by Cam Campbell from Alpine Solutions and Kelsey Stockert from Graphite One on April 8 and 9, 2024.

Twenty-five separate avalanche paths were identified as having the potential to affect the Graphite Creek Project's proposed access road, facilities, and infrastructure. Locations of each avalanche path, as well as estimated maximum dense flow extent (i.e. corresponding to a frequency of 1:100 (events:years) or more as per CAA (2016)), are illustrated on the avalanche path maps provided in Appendix B. The existing camp, proposed dump layout, and estimated facilities siting footprint are not exposed to avalanche hazard.

Avalanche hazard for exposed facilities and infrastructure was analysed in terms of magnitude and frequency of avalanches reaching project facilities and infrastructure. Magnitude is defined in terms of destructive potential according to the American Avalanche Association (AAA, 2022) avalanche size classification for destructive potential (Table A-1). Avalanche frequency is expressed as a ratio of avalanche events:years approximating a constant order of magnitude increase of 0.5 (i.e., 1:1, 1:3, 1:10, 1:30, etc.). However, the probability of avalanche occurrence during any given year is not uniform because it is dependent on snowpack and weather conditions, and independent of the time since the last event. Tables 3-1 and 3-2 list avalanche hazard for the access road and exposed facilities and infrastructure in terms of estimated frequency and magnitude of potential avalanche events affecting each element at risk. The resulting estimated avalanche size and corresponding frequency for each element at risk exceeds the thresholds for when mitigation should be considered provided in CAA (2016). The nature of the avalanche terrain in the proposed pit, and therefore the avalanche hazard, is expected to change throughout the construction and operation due to excavation.

Table 3-1: Estimated frequency of each size class (Table A-1) of avalanche originating from each path expected to impact the proposed access road alignment. The approximate length affected is also provided. Note that there were no avalanche paths identified with the potential to produce Size D4 or D5 avalanches that affect the proposed roads or infrastructure.

Avalanche Path	Approx. Length Affected (m)	Estimated Frequency (events:years)	
		Size D2	Size D3
AR 1.0	650	1:3	1:10
AR 2.0	500	1:3	1:10
AR 3.0	550	1:3	1:10
AR 4.0	400	1:3	~
AR 5.0	1000	1:3	1:10
AR 6.0	350	1:3	1:10
AR 7.0	270	1:3	1:10
AR 8.0	270	1:3	1:10
AR 9.0	500	1:1	1:10
AR 10.0	500	1:1	1:10
AR 11.0	200	1:1	1:10
AR 12.0	250	1:1	1:10
AR 13.0	220	1:1	1:10
AR 14.0	550	1:1	1:10
AR 15.0	570	~	1:10
AR 16.0	630	1:3	1:10
AR 17.0	600	1:3	1:10

Table 3-2: Estimated frequency of each size class (Table A-1) of avalanche originating from each path expected to impact the specified facilities or infrastructure. Note that there were no avalanche paths identified with the potential to produce Size D4 or D5 avalanches that affect the proposed roads or infrastructure.

Infrastructure Affected	Avalanche Path	Estimated Frequency (events:years)		Comments
		Size D2	Size D3	
G1_Plant_2021 Layout (from PFS)	AR 18.0	1:3	~	
	MS 1.0	1:1	~	
	MS 2.0	1:1	~	
	MS 3.0	1:1	1:10	
	MS 4.0	1:1	~	Only 150 m of western extension of footprint exposed
Existing Drill Trails	MS 1.0	1:1	~	Only 30-50 m of eastern spurs exposed
	MS 2.0	1:1	~	
	MS 3.0	1:1	1:10	
	MS 4.0	1:1	1:10	
	MS 5.0	1:1	1:10	
	MS 6.0	1:1	1:10	
	MS 7.0	1:1	~	
Proposed Pit	MS 1.0	1:1	~	Small section of proposed pit in avalanche starting zone; modified with pit development.
	MS 2.0	1:1	~	Avalanche starting zone and track modified with pit development.
	MS 3.0	1:1	1:10	Avalanche track modified with pit development.
	MS 4.0	1:1	1:10	Avalanche starting zone and track modified with pit development.
	MS 5.0	1:1	1:10	Avalanche track modified with pit development.
	MS 6.0	1:1	1:10	Avalanche track modified with pit development.
	MS 7.0	1:1	~	Avalanche starting zone and track with proposed pit development.

Several proposed crossing structures as well as materials sites (i.e., borrows and quarries) were also found to be exposed to potential avalanche hazard. These are indicated on the avalanche path maps provided in Appendix B.

4 Avalanche Risk Mitigation Measures

Avalanche mitigation measures can be described according to the duration in which the mitigation occurs, and normally include both short-term (e.g. generally ongoing day-to-day) and long-term (i.e., policy-based or fixed engineering) measures. These measures may be direct (i.e., acting on the hazard through operational or engineering solutions) or indirect (i.e., managing the exposure and vulnerability of the element at risk).

Avalanche risk mitigation is best considered at the planning phase of a project when the locations of structures, facilities and infrastructure can be optimized to avoid avalanche hazard. Facilities that cannot be located away from avalanche hazard can then be considered for implementation of further mitigation measures. Then during the construction and operational phases, short-term measures are applied to control the residual risk after planning-level mitigation has occurred. Normally avalanche risk mitigation strategies include a combination of long-term and short-term measures, and the following sections describe some of the options.

A cost-benefit analysis is often used to determine the optimal approach, and the balance between long- and short-term measures. Costs normally include initial capital expenditures as well as annual operating and long-term maintenance expenditures. Benefits are typically based on risk reduction values, reliability (i.e., reduction in closure times that lead to loss of production capacity), and worker safety.

4.1 Short-term Mitigation Measures

Short-term mitigation measures are applied either on a seasonal basis or within a timescale related to the fluctuation of snow and weather conditions (i.e., hours to days, or in some circumstances, weeks to months). This includes:

- Seasonal closures to facilities or hazard areas.
- Avalanche hazard forecasting.
- Restricted access during periods of elevated hazard.
- Hazard reduction through artificial avalanche triggering of avalanches with explosives control.
- Avalanche rescue plan.

These measures are described in more detail in the following subsections and are normally guided by the procedures dictated in an Avalanche Safety Plan.

4.1.1 Seasonal Closures

Seasonal closures of areas and facilities exposed to avalanche hazard is generally the most effective avalanche risk mitigation measure for worker safety as it essentially eliminates the risk. However, the effectiveness of this mitigation measure depends on the ability to accurately forecast the beginning and end of avalanche season and the ability to enforce the closure, as well as the tolerance for closure from an operational perspective. This may be appropriate for areas in the project that are used very intermittently, and there is flexibility for when they need to be accessed.

4.1.2 Avalanche Hazard Forecasting

Most short-term measures rely on daily or ongoing avalanche hazard forecasting in order to be effective. A reliable avalanche forecasting program typically includes:

- Experienced avalanche forecasters.
- Regular monitoring and observations of weather, snowpack conditions, and avalanche activity, and associated record keeping in order to analyze trends and longer-term hazard.

- Ongoing communication with the project planning team in order to ensure exposure and vulnerability is taken into account on a daily basis, and modified as the project progresses.

4.1.3 Restricted Access

An operational avalanche hazard forecasting program can be implemented with a policy that provides a threshold hazard level for which evacuation of the area is required and access is restricted. Many mine sites, roads, and ski areas implement effective restricted access policies within their programs, but they require qualified and experienced avalanche forecasters, and these programs are not without residual risk.

4.1.4 Avalanche Explosive Control

Artificial triggering of avalanches is a commonly employed risk mitigation measure. Avalanches are triggered either with hand-charging (i.e., from ground-based locations), helicopter explosive control, or with higher reliability by using Remote Avalanche Control Systems (RACS). RACS are control systems that are installed in avalanche starting zones and can be activated regardless of weather or time of day. Examples of three separate RACS systems are provided in Figure 4-1. Qualified and experienced avalanche forecasters are generally required for an effective avalanche explosive control program.

Figure 4-1: Three separate RACS systems for triggering avalanches – Gazex (left), Avalanche Guard (center), and Wyssen Tower (right)

Although artificial triggering coupled with evacuation measures is typically used for worksites and roads where exposure can be easily controlled, this type of mitigation is not commonly considered to protect fixed structures, facilities, or infrastructure from being damaged. However, depending on the lifespan of the facility, the return frequency of the hazard, and the acceptance to the financial loss associated with any damage, this may be a feasible option.

4.1.5 Avalanche Rescue Plan

Most short-term measures also include an avalanche rescue plan to account for residual risk associated with avalanche hazard forecasting. These plans typically include:

- Basic avalanche awareness and rescue training for workers, normally completed annually.
- Advanced avalanche rescue training for rescue personnel.
- Avalanche-specific rescue equipment including transceivers, probes and shovels either carried by personnel or stored in strategically located caches.

- Detailed written procedures for avalanche rescue including a list of external rescue resources.

4.2 Long-term Measures

Long-term measures are forms of mitigation that generally involve engineered measures that reduce avalanche magnitude and frequency or eliminate the hazard altogether. These measures typically include the incorporation of structural protection, either in avalanche starting zones or runout zones. Specific measures may involve the following:

- Location planning.
- Snowpack supporting structures (e.g., avalanche fencing) in avalanche starting zones.
- Runout zone measures including:
    - Deflection walls and berms.
    - Stopping walls and catchment dams or ditches.
    - Retarding mounds, breakers, or arrestors.

4.2.1 Location Planning

Locating structures, facilities, and infrastructure outside of avalanche hazard areas is a long-term indirect form of avalanche risk management. For areas where important (e.g., occupied) structures must be placed close to the edge of a runout area, this measure would incorporate an Avalanche Hazard Zone Map, which is a type of map that delineates avalanche hazard into zones for long term planning of buildings. The development of avalanche hazard zone maps requires the analysis of runout and impact pressures be completed to the high level of accuracy in order to be used with confidence for higher risk scenarios.

4.2.2 Snowpack Supporting Structures

Supporting structures involve the installation of structural 'fence' or snow net systems that retain and support the snow in the starting zone (Figure 4-2). They may result in the elimination of the avalanche hazard if the design involves sufficient coverage of starting zone areas. However, due to the high cost of installing supporting structures, the length of supporting structures is sometimes reduced or optimized, which can result in sufficiently reduced hazard to the element at risk.

Figure 4-2: Snowpack supporting structures (i.e., flexible snow nets) in an avalanche starting zone.

4.2.3 Runout Zone Measures

Runout zone measures mitigate avalanches by diverting, containing, channeling, or slowing down the flow in some way to reduce or eliminate the chance (or force) of avalanche impact. This includes avalanche catchment dams (Figure 4-3) or ditches, stopping walls (Figure 4-4), deflection berms, or retarding mounds (Figure 4-5). Effective performance of runout zone measures sometimes depends on regular maintenance, such that they remain free of avalanche deposit and other debris.

Figure 4-3: Avalanche diversion berm constructed with onsite cut-fill loose rock material with upslope and downslope angles at approximately 34^{o} (photo Ross and Johnson, 2019).

Figure 4-4: Avalanche stopping wall to stop small to medium size avalanches from impacting a highway.

Figure 4-5: Retarding mounds to slow avalanches above a highway.

5 Background Information on Slush Flows

Slush flows (i.e., the rapid mass movement of water-saturated snow) have been identified by Graphite One as a potential hazard to proposed facilities and infrastructure. Although they are outside of the scope for this snow avalanche hazard assessment, this section provides some background information that may be considered for a hazard-specific assessment of slush flows.

Unlike snow avalanches, slush flows do not require steep slopes in the starting zone to initiate movement. Onesti's (1985) observations of slush flows in the central Brooks Range of Alaska showed that starting zone slope angles averaged approximately 17° in gullies, and as little as 2° in channels on broad open floodplains. Furthermore, Luckman (1977) suggested that slush flows are unlikely on slopes which are too steep to permit the snowpack to accumulate water, and Gude and Scherer (1998) demonstrated that preferred release areas are low-angled depressions, where meltwater inflow is higher than outflow. Typically triggered by heavy rainfall, above-freezing temperatures, and intense solar radiation, slush flow frequency is partially dependant on the permeability of the underlying ground (Hestnes, 1998), with hard smooth surfaces (e.g., rock slab or ice) commonly acting as a bed surface.

Slush flows also tend to travel farther than snow avalanches in a given path. Alpha angles (i.e., the steepness of the path, measured from the toe of the deposit to the top of the starting zone) for slush flows can be as low as 3° (Hestnes, 1998), while alpha angles for avalanches in Coastal Alaska are rarely less than 19° (McClung and Mears, 1991). Numerical models calibrated for wet snow avalanches tend to underestimate slush flow runout extent (Clark and Seppälä, 1988), and Alpine Solutions is not aware of any published parameters for simulating slush flow dynamics and estimating runout distance. As a result, slush flow hazard mapping relies more on observations and evidence of historical occurrences rather than runout modelling.

6 Recommendations

Based on the findings of the assessment summarized in this report, Alpine Solutions recommends the following:

1. Avalanche risk mitigation should be considered for the proposed access road, facilities and infrastructure exposed to avalanche hazard. Mitigation may include short- or long-term measures, as described in Section 4, or a combination of these. A risk assessment and cost-benefit analysis are normally used to determine the optimal approach to mitigation.
2. For occupied structures or other high-risk elements that are near the edge of avalanche areas, an avalanche hazard zone map should be developed in order to optimize structure locations, and/or to locate safe/unsafe areas for where workers frequently congregate (e.g. parking area).
3. If structural mitigation is considered, further study should be undertaken to consider the nature of structural protection, which includes the geometry, the ability to absorb peak impact pressures, and the influence of various heights of previous snow on the ground for the design event.
4. Avalanche hazard should be reassessed during construction and operations as new avalanche terrain is created due to excavation, fill, and other artificial and natural alterations to the terrain.
5. The project area should continue to be monitored for signs of avalanche activity. If possible, records should follow observation guidelines and recording standards as per guidelines outlined in AAA (2022). This will assist with future studies and help to reduce uncertainty in avalanche hazard assessment and forecasting.
6. An assessment of slush flow hazard should be completed for the project facilities and infrastructure. Background information on the nature of slush flows can be found in Section 5.

7 Closure

This document was prepared by Alpine Solutions for the account of Graphite One Inc. The material in it reflects Alpine Solutions' best judgment in light of the information available to Alpine Solutions at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Alpine Solutions accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions, based on this report.

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We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

ALPINE SOLUTIONS AVALANCHE SERVICES (EGBC Permit to Practice #1000214)

per:

June 14, 2024
Association of Professional Engineers and Geoscientists of the Province of British Columbia
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Appendix A – Background on Avalanches

Avalanches generally occur in areas where there are steep open slopes or gullies, and deep (e.g. deeper than 50 cm) mountain snow packs. Risks associated with avalanches are normally due to exposure to the high impact forces that occur, as well as the effects of extended burial for any person caught in an avalanche. Impact forces vary significantly depending on avalanche size. Although the smallest avalanches can be insignificant to a human, larger avalanches may produce impact forces capable of destroying trucks, buildings, or several hectares of mature forest.

A.1 Characteristics of Snow Avalanches

Avalanches can release as either loose unconsolidated snow, known as “loose-snow avalanches” or as cohesive layers of snow, known as “slab avalanches”. Each of these release types can be sub-classified based on formation process, failure depth, and moisture content as follows:

- **Dry Loose** - Avalanches that release as dry unconsolidated snow and typically occur within layers of soft snow near the surface of the snowpack.
- **Wet Loose** - Avalanches that release as wet unconsolidated snow or slush, and typically occur within layers of wet snow near the surface of the snowpack, but may quickly gouge into lower snowpack layers.
- **Storm Slab** - Avalanches that release as a cohesive layer (i.e. “slab”) of new snow that breaks within new snow or on the old snow surface.
- **Wind Slab** - Avalanches that release as a cohesive layer of snow formed by the wind.
- **Persistent Slab** - Avalanches that release as a cohesive layer of snow in the middle to upper snowpack, when the bond to an underlying persistent weak layer breaks.
- **Deep Persistent Slab** - Avalanches that release as a very thick cohesive layer of hard snow, when the bond breaks between the slab and an underlying persistent weak layer deep in the snowpack.
- **Cornice Fall** – Avalanches that release as an overhanging mass of snow (i.e. “cornice”) that forms in the downwind or “leeward” side as the wind moves snow over a sharp terrain feature, such as a ridge.
- **Glide Avalanche** - Avalanches that release of the entire snow cover as a result of tension created by sliding (i.e. “gliding”) over the ground.

Although an avalanche may start in dry snow, it could become moist or wet during its descent. Wet avalanche flow can be deflected and often channeled by terrain features, including gullies. Conversely, large, fast-flowing dry avalanches tend to flow in a straighter path and may overrun terrain features.

Most large dry avalanches consist of a dense component that flows primarily along the ground, and a less dense powder component that travels above and sometimes ahead of the flowing component. In some cases, these components can separate and move independently. The dense-flowing component and powder component may reach speeds up to 60 m/s (200 km/h). Impact pressures from dense flows are much greater than the powder component due to higher density. In the case where an avalanche flows over a cliff, gains considerable speed and impacts the runout zone at an abrupt transition, a destructive “air-blast” can develop ahead of (and therefore extend further than) the dense flow and powder component.

The primary terrain factors in avalanche formation are incline, slope orientation (aspect) with respect to wind and sun, slope configuration and size, and ground surface roughness. Avalanche terrain is usually associated with steep, open slopes in the mountains that allow an accumulation of snow before it releases in a destructive event. In addition to the steep slopes that the snow accumulates on, any area exposed to this release of snow is also considered avalanche terrain. Terrain is often subdivided into features that are connected, which generally contain or channel the volume of avalanche events into a common deposition area. These features are called avalanche paths.

A.2 Avalanche Path

An avalanche path generally consists of a starting zone, a track and a runout zone. Avalanches start and accelerate in the starting zone, which typically has a slope incline greater than 30°. Downslope of the starting zone, most large avalanche paths have a distinct track in which the slope angle is typically in the range of 15 to 30°. Large avalanches decelerate and stop in the runout zone where incline is usually less than 15°. Smaller avalanches may decelerate and even stop on steeper slopes (15 to 24°).

Within forested terrain, larger avalanche paths are often discernible as vertically oriented swaths of open forest terrain, bordered by trim lines (mature forest on either side of the swath). Smaller avalanches, however, can occur in more subtle paths, and can occur on large cut banks above a road.

Runout zones generally have vague trim lines, and analysis is required by an experienced avalanche specialist to determine estimates of maximum avalanche extent, which can often be into mature forest. In terrain around cliffs, some avalanche paths can be much subtler to observe, and can be confused with rock fall and/or geotechnical events.

A.3 Avalanche Frequency

Avalanche frequency is the expected number of avalanches per unit of time reaching or exceeding a location. It is the reciprocal of the return period, and typically has units of avalanche(s) per year(s), which is expressed as a ratio approximating a constant order of magnitude increase of 0.5 (e.g. 1:1, 1:3, 1:10, 1:30, etc.). However, the probability of avalanche occurrence during any given year is not uniform because it is dependent on snowpack and weather conditions, and independent of the time since the last event.

A.4 Avalanche Magnitude

Avalanche magnitude is typically described by the destructive potential as defined according to the American Avalanche Association (AAA) avalanche size classification system (Table A-1). This classification system provides a general description of destructive potential, as well as typical values for avalanche mass and path length associated with each avalanche size class.

Table A-1: American Avalanche Association (AAA) avalanche size classification system based on destructive potential (AAA, 2016). For each size class, the table lists: a description of the destructive potential, typical mass in tonnes (t) and typical path length in metres (m).

Data Code	Avalanche Destructive Potential	Typical Mass (t)	Typical Path Length (m)
D1	Relatively harmless to people.	< 10	10
D2	Could bury, injure or kill a person.	10^2	100
D3	Could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees.	10^3	1000
D4	Could destroy a railway car, large truck, several buildings, or a substantial amount of forest.	10^4	2000
D5	Could gouge the landscape. Largest snow avalanche known.	10^5	3000

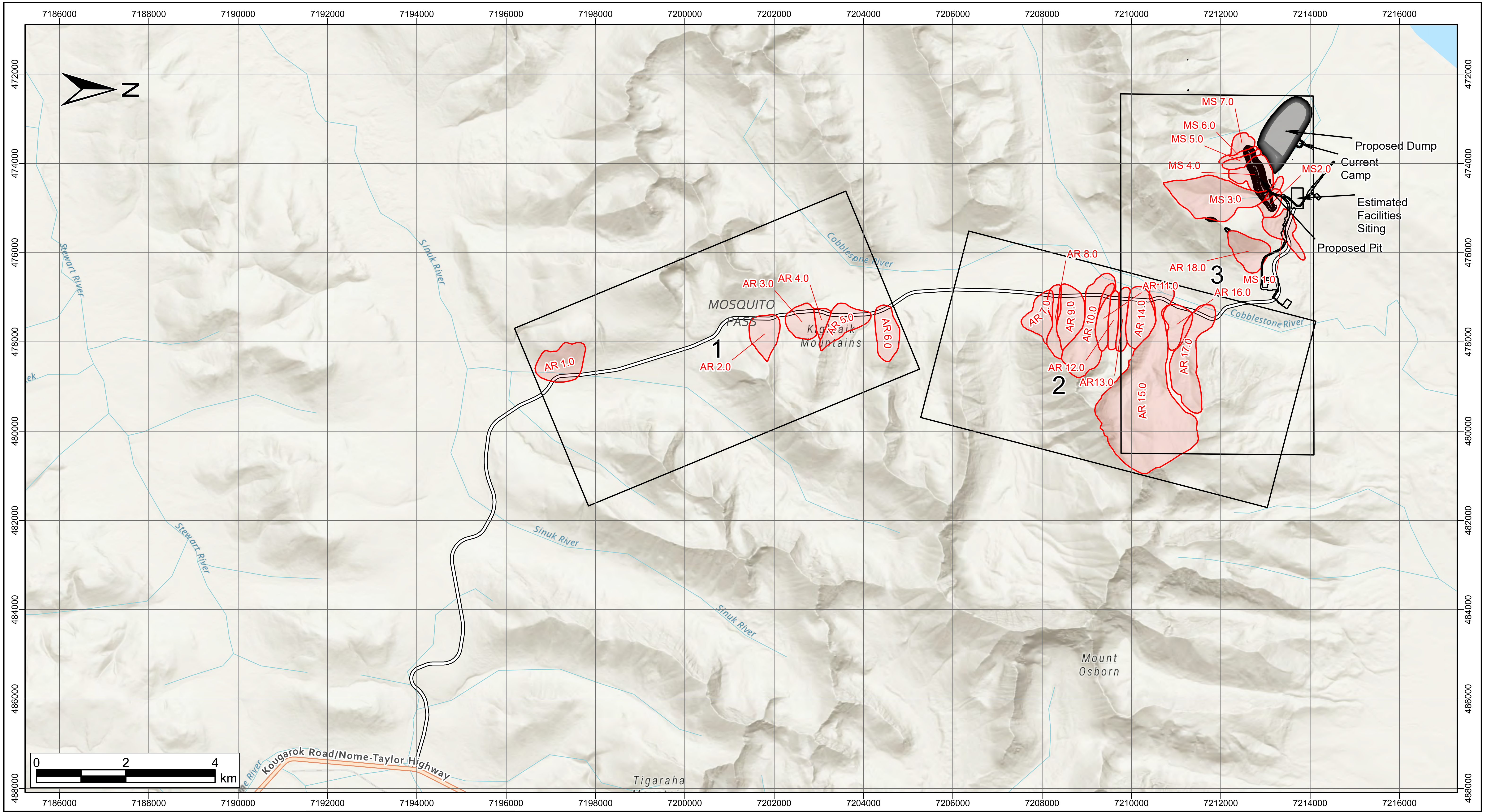
Avalanche magnitude can also be defined in terms of impact pressure at a specific point or element at risk. A range of avalanche impact pressures with corresponding potential damage descriptions are provided in Table A-2.

Table A-2: Avalanche impact pressures and corresponding examples of potential damage.

Impact pressure (kPa)	Potential damages
1	Breaks windows
5	Pushes in doors
30	Destroys wood-frame structures
100	Uproots mature spruce
1000	Moves reinforced concrete structures

Magnitude is often related to frequency. In general, large destructive avalanches occur less frequently, while smaller ones occur on a more regular basis. Magnitude and frequency are also co-related to a specific location in an avalanche path. For example, a road location near the toe of an avalanche path will be affected by avalanches on a less frequent basis, but they will be larger avalanches. Both low-frequency large avalanches and higher-frequency small avalanches may affect a road crossing that is higher up in the avalanche path.

Appendix B - Avalanche Path Maps



LEGEND

🟥 AVALANCHE PATH

▨ INFRASTRUCTURE AND FACILITY FOOTPRINTS

═ PROPOSED ACCESS ROAD

━ HIGHWAY

☐ MAP FRAME

MAP NOTES:

1) DATUM: NAD83 PROJECTION: TRANSVERSE MERCATOR. UTM ZONE: 3N
2) THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:80,000 FOR 11" X 17" ("B" SIZE) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.
3) IMAGERY/DATA/BASEMAP SOURCE: GRAPHITE ONE, ESRI.
4) THIS MAP SHOULD ONLY BE READ WITH THE ACCOMPANYING REPORT.
5) AVALANCHE PATH BOUNDARIES REPRESENT A GRADUAL TRANSITION FROM HAZARD TO NO HAZARD. ANY NEW FACILITIES PLACED NEAR PATH BOUNDARIES SHOULD BE ASSESSED FOR AVALANCHE HAZARDS.
6) ONLY AVALANCHE PATHS THAT HAVE THE POTENTIAL TO AFFECT MINE FACILITIES AND INFRASTRUCTURE WITH SIZE D2 OR LARGER AVALANCHES ARE INCLUDED ON THIS MAP.
7) AVALANCHE PATH BOUNDARIES REPRESENT THE ESTIMATED MAXIMUM EXTENT OF DENSE SNOW AVALANCHE FLOW. SLUSH FLOWS OR THE POWDER COMPONENT OF DRY SNOW AVALANCHES ARE NOT CONSIDERED.
8) THIS MAP REPRESENTS A SNAPSHOT IN TIME. REASSESSMENT OF AVALANCHE HAZARD SHOULD OCCUR IF THERE IS ANY CHANGE TO THE NATURE OR LOCATION PROPOSED PROJECT INFRASTRUCTURE OR FACILITIES.
9) ANY ARTIFICIAL OR NATURAL ALTERATION OF THE LANDSCAPE DUE TO EARTHWORKS (E.G. CUT AND FILL), MINING ACTIVITIES, LANDSLIDES, ETC. MAY CHANGE THE NATURE OF AVALANCHE HAZARD AND REQUIRE REASSESSMENT.

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APPROVED:	CC

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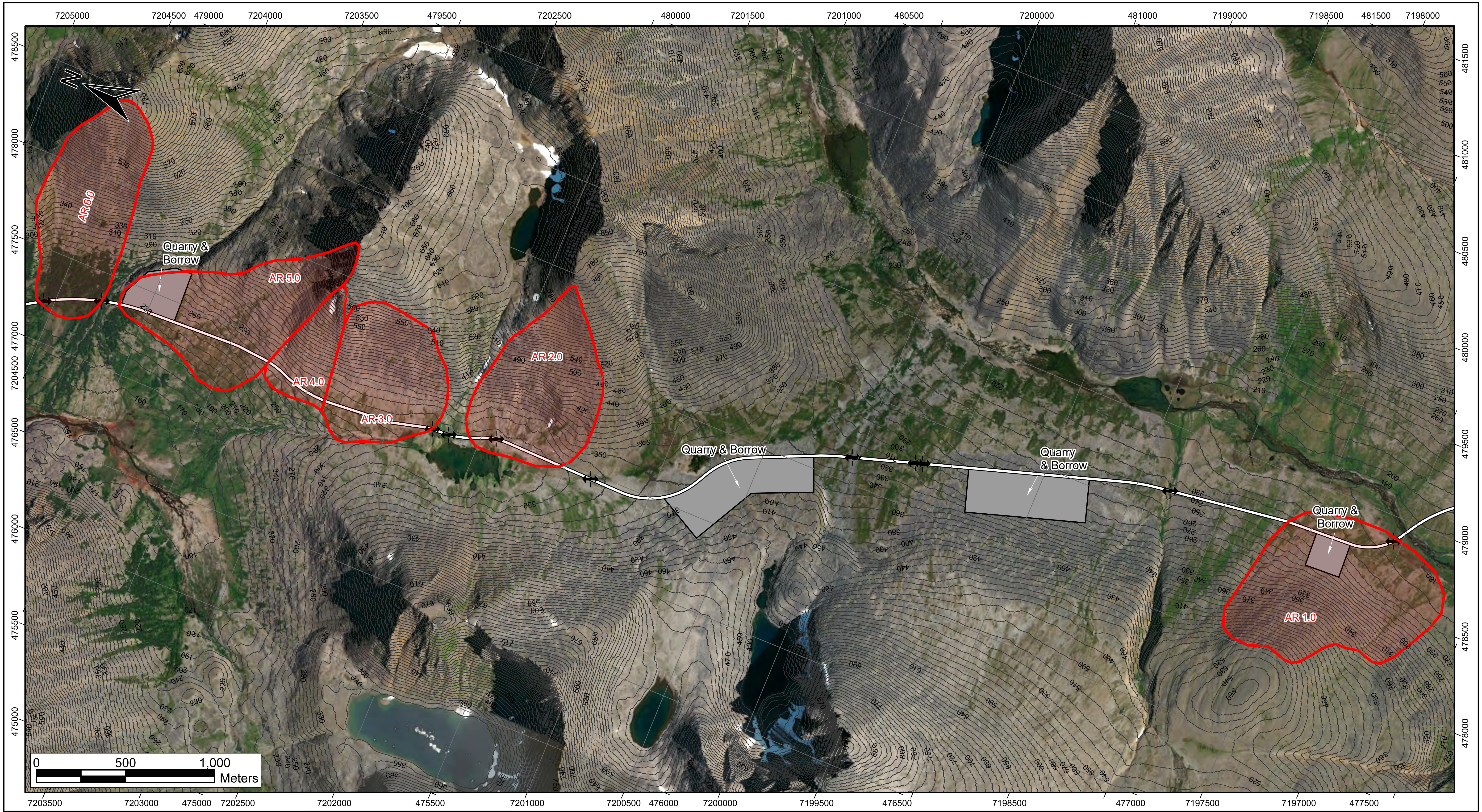
PREPARED BY: ALPINE SOLUTIONS

PROJECT: GRAPHITE CREEK PROJECT

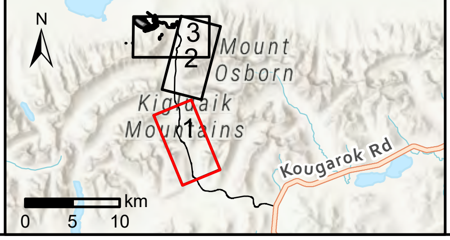
TITLE: AVALANCHE PATH KEY MAP

PROJECT NO:	MAP NO:	REV:
2386-001	-	1



LEGEND

🟥	AVALANCHE PATH
═	PROPOSED ACCESS ROAD ("G1_ACCESS_CL_CURRENT_240108")
▨	INFRASTRUCTURE AND FACILITY FOOTPRINTS
↔	CROSSING STRUCTURES



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PROJECT:
GRAPHITE CREEK PROJECT

TITLE:
PROPOSED ACCESS ROAD AVALANCHE PATH MAP

PROJECT NO:	MAP NO:	REV:
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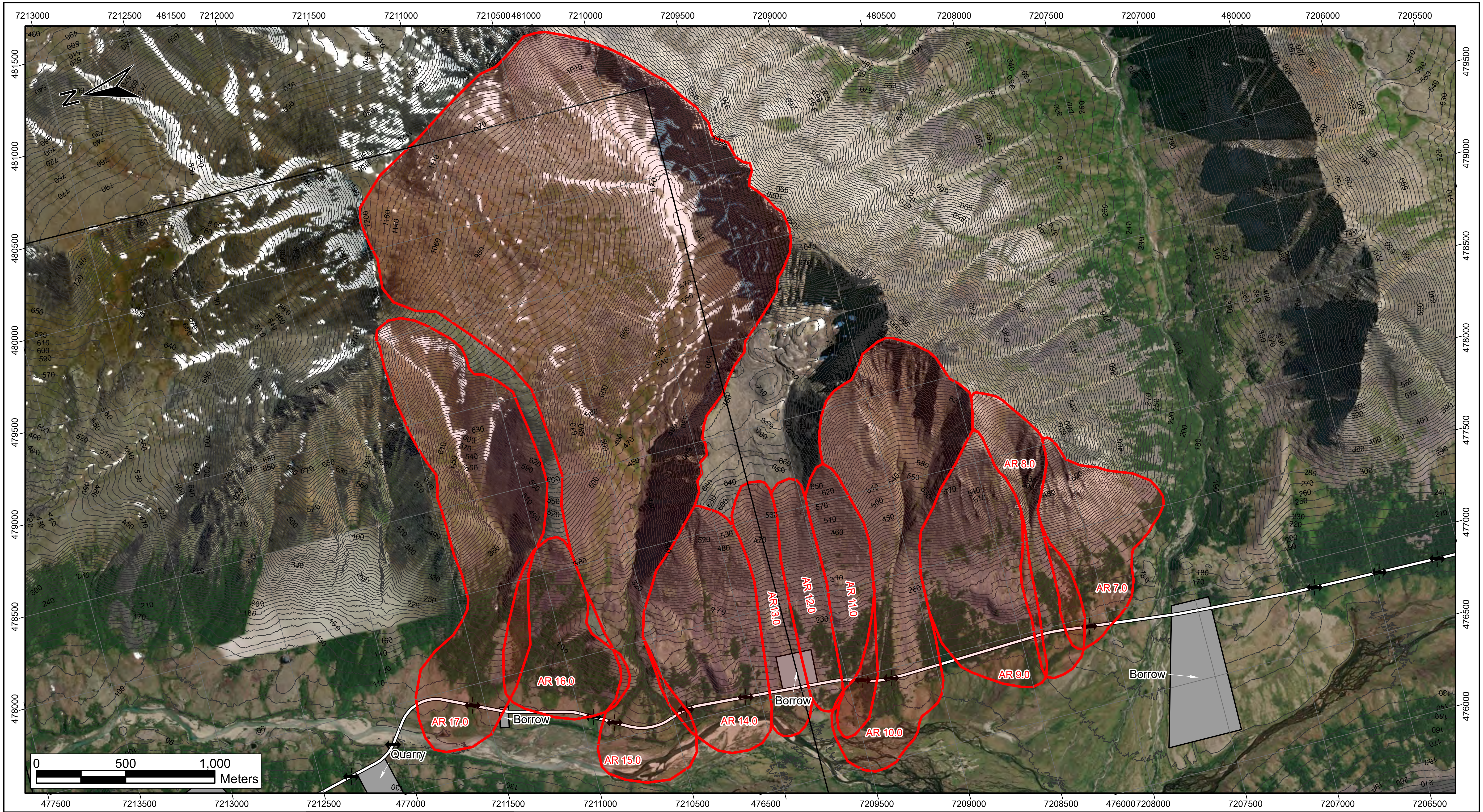
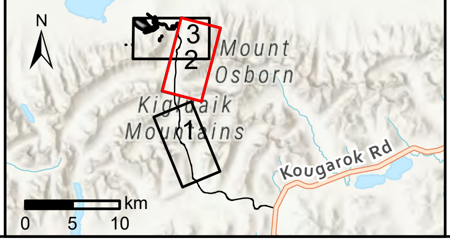


LEGEND

- AVALANCHE PATH
- PROPOSED ACCESS ROAD ("G1_ACCESS_CL_CURRENT_240108")
- INFRASTRUCTURE AND FACILITY FOOTPRINTS
- CROSSING STRUCTURES



MAP NOTES:

1) DATUM: NAD83 PROJECTION: TRANSVERSE MERCATOR. UTM ZONE: 3N
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TITLE: PROPOSED ACCESS ROAD AVALANCHE PATH MAP

PROJECT NO:	MAP NO:	REV:
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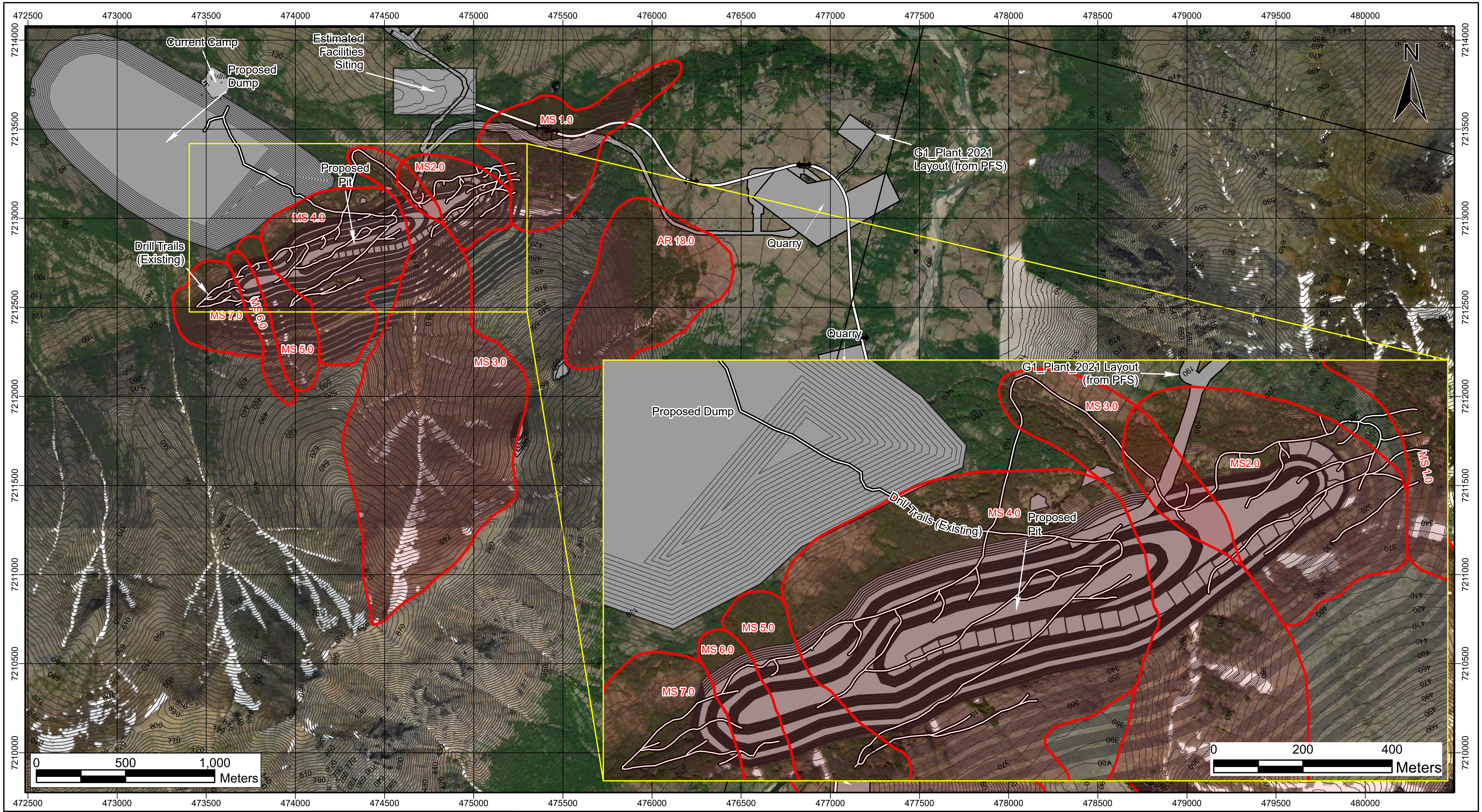


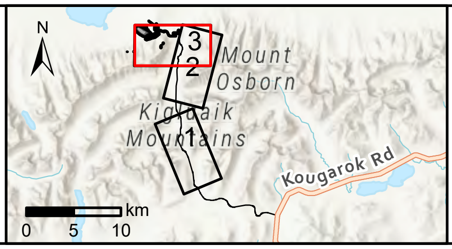
LEGEND

🟥 AVALANCHE PATH

▨ INFRASTRUCTURE AND FACILITY FOOTPRINTS

═ ROADS

↔ CROSSING STRUCTURES



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PREPARED BY: ALPINE SOLUTIONS

PROJECT: GRAPHITE CREEK PROJECT

TITLE: PROPOSED MINE SITE AVALANCHE PATH MAP

PROJECT NO: 2386-001
MAP NO: 3
REV: 1