

APPENDIX 9-B

Red Mountain Geophysical Baseline



Red Mountain Geophysical Base Line

Final Report

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Prepared for:

IDM Mining Ltd.



SNC • LAVALIN

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Abbreviations

| | |
|-------------|---|
| AIR | Application Information Requirements |
| BP | Before Present (1950) |
| CMA | Coastal Mountain Alpine |
| CU.R | cumulic regosol |
| CWH | Coastal Western Hemlock |
| IDM | IDM Mining Ltd. |
| DSSD | Deep Seated Slope Deformation |
| DEM | Digital Elevation Model |
| EOA | Environmental Assessment Office |
| GeoLSA | Geohazards Local Study Area |
| GeoRSA | Geohazards Regional Study Area |
| GIS | Geographic Information System |
| Ha | Hectares |
| ka | Thousand years |
| KCC | Klohn Crippen Consultants |
| km | Kilometres |
| LiDAR | Light Detection and Ranging |
| LSA | Local Study Area |
| Ma | Million years |
| m asl | Metres Above Sea Level |
| MH | local Magnitude |
| ML | Mountain Hemlock |
| MoFLNRO | BC Ministry of Forests, Lands, and Natural Resources Operations |
| Ms | Surface-wave Magnitude |
| Mw | Moment Magnitude |
| QRP | qualified, registered professional |
| RFFA | regional flood frequency analysis |
| RIC | Resources Inventory Committee |
| RMM | Rapid Mass Movement |
| RSA | Regional Study Area |
| SEP | Soil erosion potential |
| SMM | Slow Mass Movement |
| SNC-Lavalin | SNC-Lavalin Inc. |
| TSF | Tailings Storage Facility |
| WSC | Water Survey of Canada |

1 Introduction

1.1 Background and Objectives

IDM Mining Ltd. (IDM) retained SNC-Lavalin Inc. (SNC-Lavalin) to complete a Geophysical Baseline Study in support of the Red Mountain Underground Gold Project (the Project) in northwestern British Columbia (BC). The Project, located in the Bitter Creek Valley on a contiguous group of mineral tenures known collectively as the Red Mountain Property, will involve developing and extracting high-grade gold and silver ore to be processed on-site (IDM, 2016 Rev.2). Mining infrastructure is anticipated to have a disturbance area of approximately 19.5 hectares (ha) for the associated buildings, stockpiles, and tailings storage facility (TSF), in addition to 26 km of access road and 19 km of power line, primarily within the lower valley and Goldslide Creek cirque. The geophysical baseline study for the Red Mountain Gold Project is intended to:

- › Fulfill BC Environmental Assessment Office (EAO) requirements as laid out in the Application Information Requirements (AIR) for geomorphology, surface hydrology and geophysical baseline work including surficial geology or terrain, soils, hazards such as landslides, erosion, floods and snow avalanches; the geophysical impacts of the proposed Project to the environment and the risk from those hazards to the Project; and,
- › Provide geophysical baseline information related to terrain, slope and fluvial hazards immediately usable by the Red Mountain Gold Project engineering programs and operations.

1.2 Scope of Work

This geophysical baseline study includes the following authorized scope of work (SNC-Lavalin (2014), updated work plan July 15, 2016):

- 1: Data Acquisition and Desktop Review;
- 2: Geohazards Inventory and Terrain Mapping in the Study Area:
 - (a) Provide a general description of the terrain, terrain hazards, snow avalanche hazards, fluvial system and fluvial hazards of the Project area; and,
 - (b) Document and provide maps of known instabilities, their proximity to proposed works, estimated magnitudes and runout, and their potential to adversely affect the project or the environment;
- 3: Field Work (terrain, fluvial and soil programs);
- 4: Preliminary Soil Classification and Soil Erosion Potential Mapping based on mapping techniques with minor field checking;
- 5: Geohazard Assessment and Encounter Probability for the LSA and Access Road (as per updated work plan July 15, 2016); including:
 - (a) Landslide inventory and encounter probability map, identifying likelihood of geohazards that could directly impact the access road;
 - (b) Provide a spatial risk assessment indicating likelihood of the project encountering a geohazard (AIR Section 4.3.2.7), and;
 - (c) Present high level mitigation options and alternatives for risk management;

- 6: Water Crossings Risk-Based Assessment, consisting of:
- (a) Describe watershed characteristics, including channel condition, confinement, geology and stream type;
 - (b) Identify features that may affect sediment transport;
 - (c) Identify seasonally flooded areas; and,
 - (d) Document and provide maps of river channel changes and fluvial hazards, their proximity to proposed works and their potential to adversely affect the Project or impact the environment.
 - (e) A qualitative risk-based assessment of the 15 main crossings by assigning a risk rank number based on watershed attributes and field indicators.
- 7: Report on findings, with appended drawings and maps.

2 Study Area General Description

2.1 Location and Site Description

Red Mountain is located approximately 18 kilometres northeast of Stewart, British Columbia (55°58'11.54"N and 129°42'7.11"W), (see Figure 2-1). Physically, the study area has been divided into two (2) distinct work areas: The Geohazards Regional Study Area (GeoRSA) and Geohazards Local Study Area (GeoLSA) (Figure 2-2). The GeoRSA includes slopes and water crossings adjacent to the deactivated mining road identified by the red polygon in Figure 2-2.

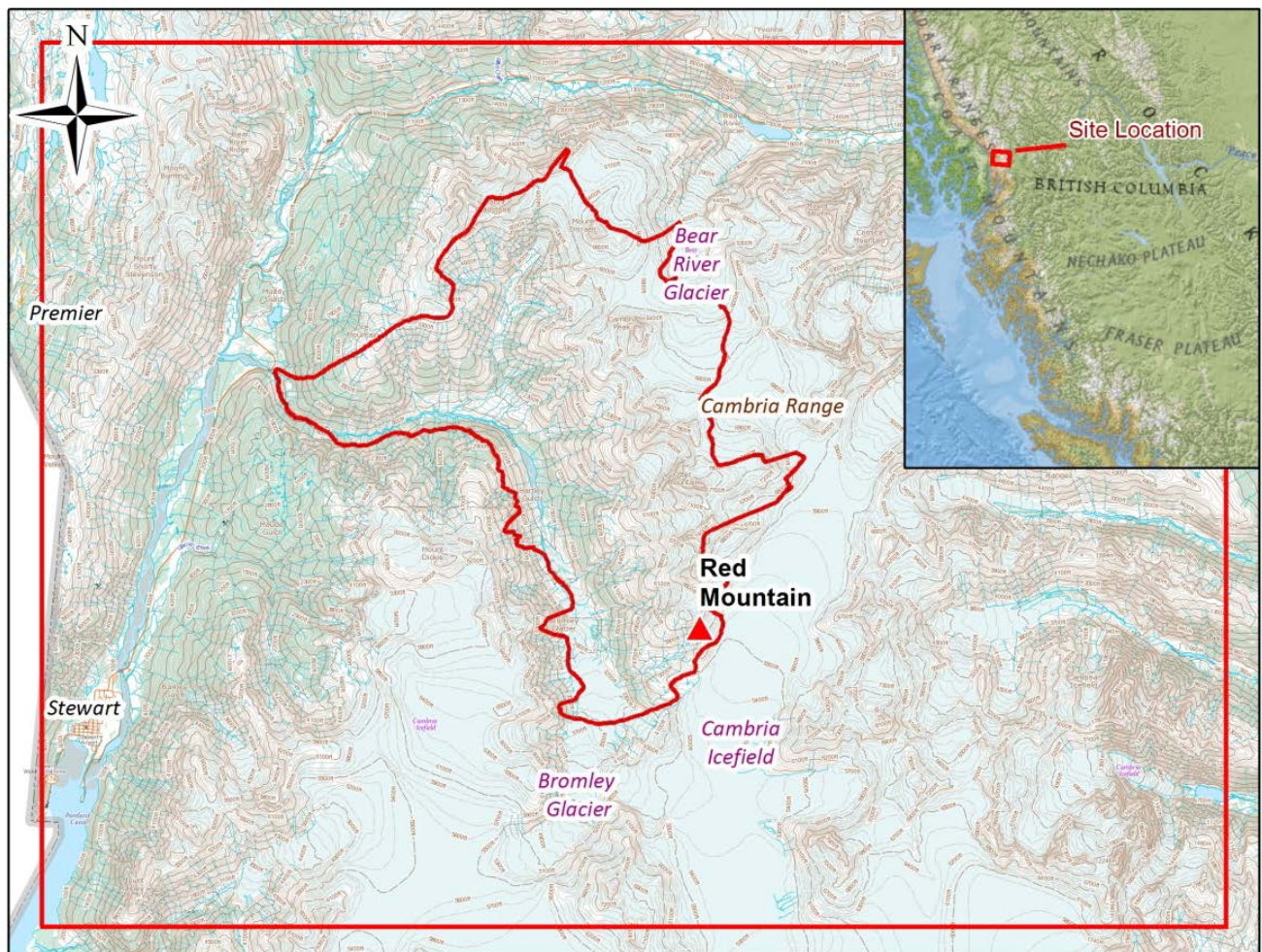


Figure 2-1: Red Mountain geographic location and Geohazards Regional Study Area (GeoRSA).

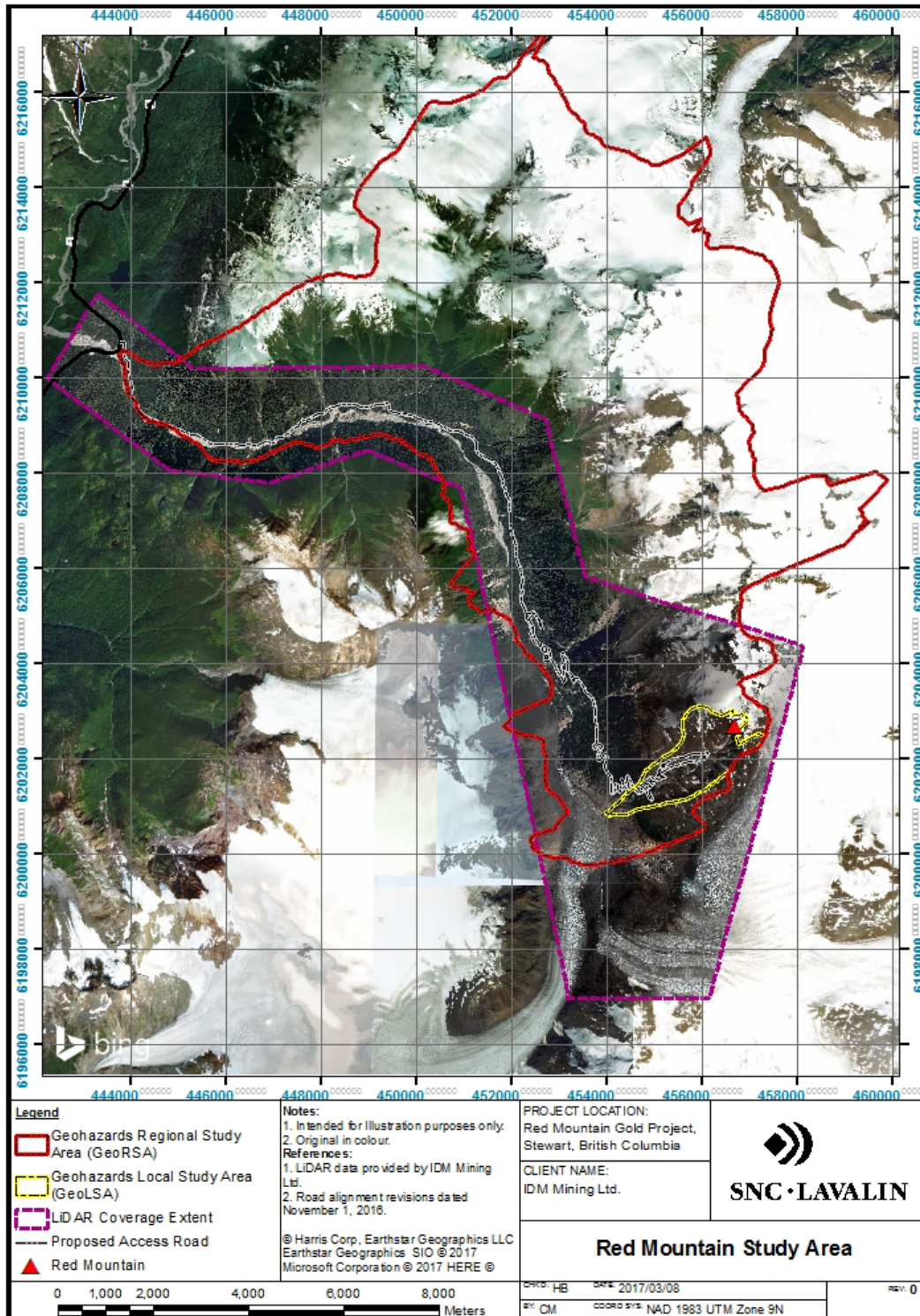


Figure 2-2: Geohazards Study Areas and LiDAR extent.

This GeoRSA starts near the confluence of Bitter Creek and Bear River off of Highway 37A (the access road will ascend approximately 12 km up the glacial valley along the north bank of Bitter Creek). Hazards that are likely to impact the road, tailings facility, and infrastructure are noted below in this report (e.g., floods and debris flows/debris floods at main water crossings, landslides and snow avalanches) (as per July 15, 2016 work plan update).

The GeoLSA includes the Goldslide Creek Watershed identified by the yellow polygon in Figure 2-2 and is where the mining facilities and access road will be located. Hazards that are reasonably likely to impact the mining facilities are debris flows/debris floods, landslide dam outburst floods, snow avalanches and landslides, and are mapped out at a scale of 1:5,000.

2.2 Physiography

Red Mountain is located within the Boundary Ranges of the Coast Mountain Physiographic Subdivision (Holland, 1976b); this is an area comprising of primarily rugged, northwest trending, granitic mountains along the Alaska panhandle and British Columbia (BC) boundary. The range has a granitic core but is flanked in the east by sedimentary and volcanic bedrock (Holland, 1976a). The Boundary Ranges extend from sea level to approximately 3,090 metres above sea level (m asl) at Mount Ratz, northwest of Red Mountain. The GeoRSA ranges in elevation from approximately 250 m asl to 2,692 m asl at Otter Mountain.

2.3 Regional Climate and Hydrology

The GeoRSA encompasses three Biogeoclimatic zones (BC Ministry of Forests, Lands, and Natural Resources Operations [MoFLNRO], 2016), where precipitation ranges from approximately 500 mm in the summer to 1300 mm during the winter months (Figure 2-3). The upper mountain and mine site rests within the Coastal Mountain Alpine (CMA) Tundra zone, which is characterized by long, cold winters and short, cool growing seasons dominated by dwarf shrubs, herbs, mosses and lichens. Below this, the Bitter Creek Valley is primarily within the Mountain Hemlock (MH) Biogeoclimatic zone, characterized by high snowfall and a short growing season. The forest consists of mountain hemlock, amabilis fir and varying amounts of yellow cedar. The lower Bitter Creek to Bear River is part of the Coastal Western Hemlock (CWH) Biogeoclimatic zone. Abundant rainfall and relatively warm temperatures make these forests some of the most productive in Canada and, though dominated by western hemlock and amabilis fir, several other species are also common and prolific.

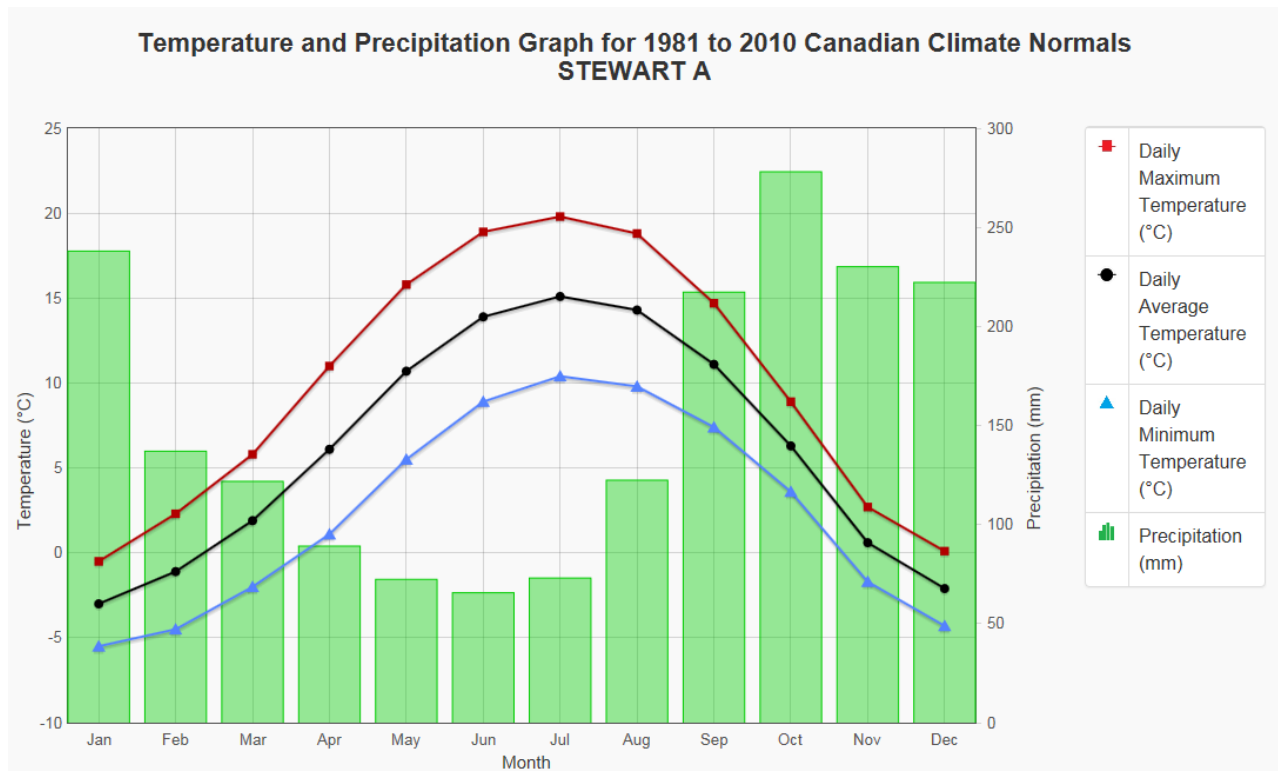


Figure 2-3: Climate normals for 1981 to 2010 at nearby Stewart British Columbia, 55°56'10.000" N, 129°59'06.000" W; 7.3 m asl. (Environment Canada website accessed January 4, 2017).





2.4 Bedrock Geology

The GeoRSA is located near the boundary of the Coast and Intermontane belts of the Canadian Cordillera, on the western margin of the Stikine Terrane and along the southwestern margin of the Bowser Basin (Metcalf, 2013; Klohn Crippen Consultants [KCC], 1994; Greig et al., 1994; Aldrick, 1993).

Detailed geologic descriptions can be found in Metcalf (2013). The general stratigraphy in the GeoRSA consists of well bedded, Jurassic (approximately [ca.] 157-174 million years [Ma]) marine clastic rocks of the Hazelton Group, which overlie and form a less competent structural cover to more massive and competent Paleozoic to Lower Jurassic (ca. 174-201 Ma) oceanic arc, volcanic and volcanoclastic basement rocks, also of the Hazelton Group (Greig et al., 1994). All are exposed by Late Jurassic (ca. 157 Ma) and Early Cretaceous to Tertiary (ca. 147-65 Ma) structural folding within the Skeena Fold Belt and intruded by Eocene and older (ca. 35-56 Ma) granitoid (granite, granodiorite and diorite) intrusions of the Coast Plutonic Complex (Metcalf, 2013; KCC, 1994) (Figure 2-4).

Mineralization in the GeoRSA is associated mainly with Jurassic island arc assemblages, altered by four magmatic episodes, each from 5-10 Ma in duration between Triassic and Eocene deformations (Anderson et al., 2003; Metcalf, 2013), identified as Red Mountain (Goldslide) Stock (Greig *et. al.*, 1994).

Bedrock Geology

-  ECPqm = Eocene (35-56 Ma)
Coast Plutonic Complex (?)
quartz monzonitic
intrusive rocks
-  muJHs = Middle to Upper
Jurassic (157-174 Ma)
Hazelton Group
Undivided Sedimentary rocks
-  EJGdr = Early Jurassic
(174-201 Ma)
Gamsby Complex or Red Mtn.
(Goldslide) Stock
dioritic intrusive rocks
-  IJHU = Early Jurassic to
Triassic (174-251Ma)
Hazelton Group -
Unuk River Formation
andesitic volcanic rocks

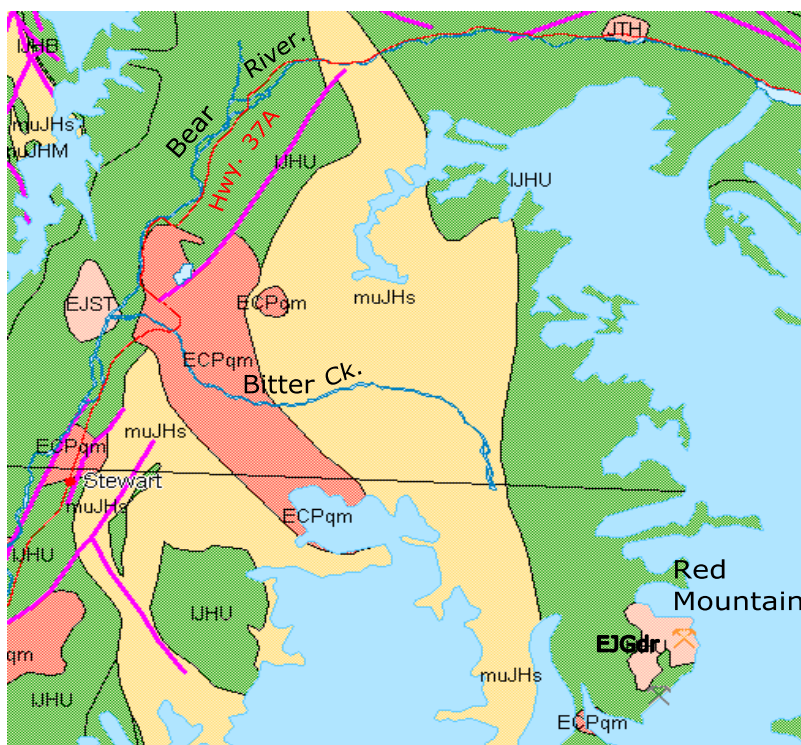


Figure 2-4: Simplified Geology of the Red Mountain Area
(<http://webmap.em.gov.bc.ca/mapplace/minpot/bcgs.cfm>)

2.5 Seismic History

The Pacific and North America plate boundary off the west coast of British Columbia is a complex system of faults capable of producing very large earthquakes (e.g., the 1949, 8.1 magnitude). The best known active fault in the greater Stewart region is the Queen Charlotte Fault, a strike-slip (or transitional [left-right]) fault, located approximately 400 kilometres southwest of Red Mountain. Historical records indicate five large earthquakes have been centred on the Queen Charlotte Fault area since 1920 (refer to black and white circles on Figure 2-5, including a 7.0 magnitude event in 1929, a 7.4 magnitude event in 1970; a magnitude 8.1 event in 1949, two 7.8 magnitude event earthquakes in October of 2012 [NRCan, 2013] and one 7.5 magnitude quake in 2013). Unlike the pre-2012 earthquakes, which released strain along the strike slip, Queen Charlotte Fault, the 2012 and 2013 earthquakes (Figure 2-5) confirmed that there is a subduction system in the Haida Gwaii area (Goldfinger et al., 2013).

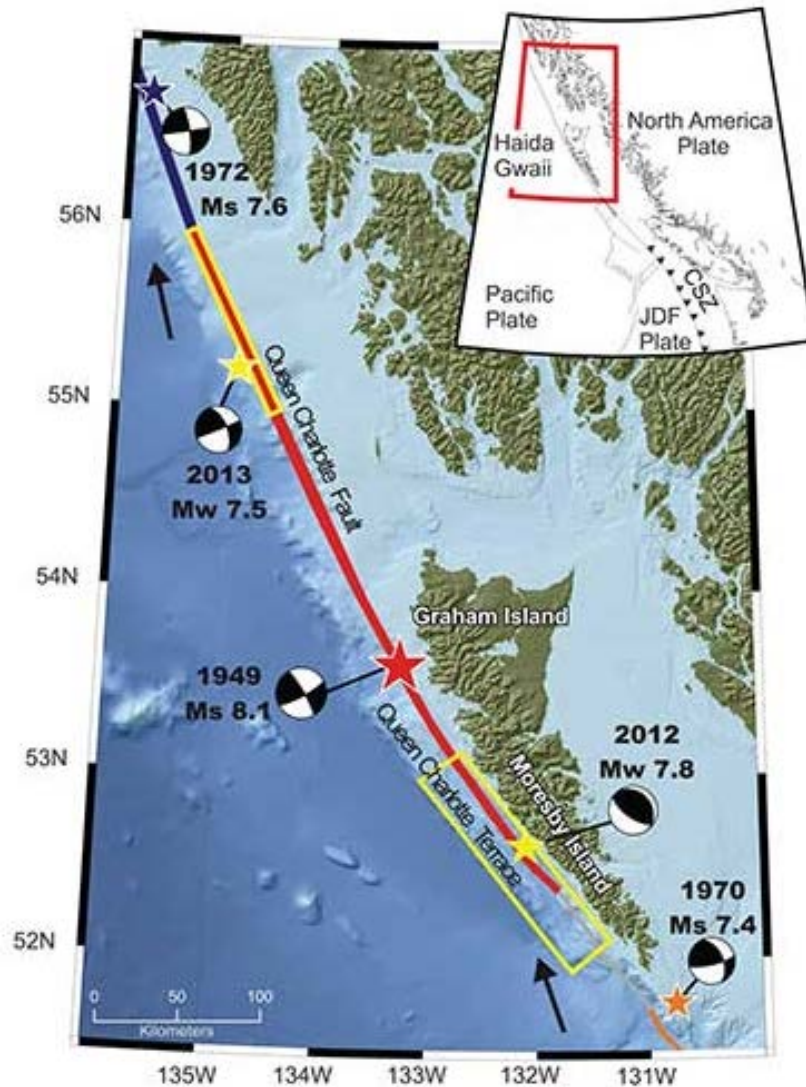


Figure 2-5: Map of the largest earthquakes along the Queen Charlotte fault system since 1985 (taken from Cassidy et.al., 2015).

A note on magnitude: Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as "Richter magnitude", (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types. All magnitude scales should yield approximately the same value for any given earthquake (United States Geological Survey [USGS], 2016).

Though larger earthquakes are infrequent along the fault, magnitude 4.0 and lower energy events occur almost daily (NRC, 2017). In the thirty days between December 9, 2016 and January 9, 2017, a total of 182 seismic events occurred, two of which were of a magnitude 4.0.

The effects of large earthquakes centered off the coast of Haida Gwaii are notable well inland of their epicenters as seen by the Modified Mercalli Intensity map of the August 22, 1949 (Figure 2-6). Though over 400 km away, this 8.1 magnitude earthquake registered as feeling like a magnitude 6.0 earthquake around Red Mountain (Lamontagne et al., 2007).

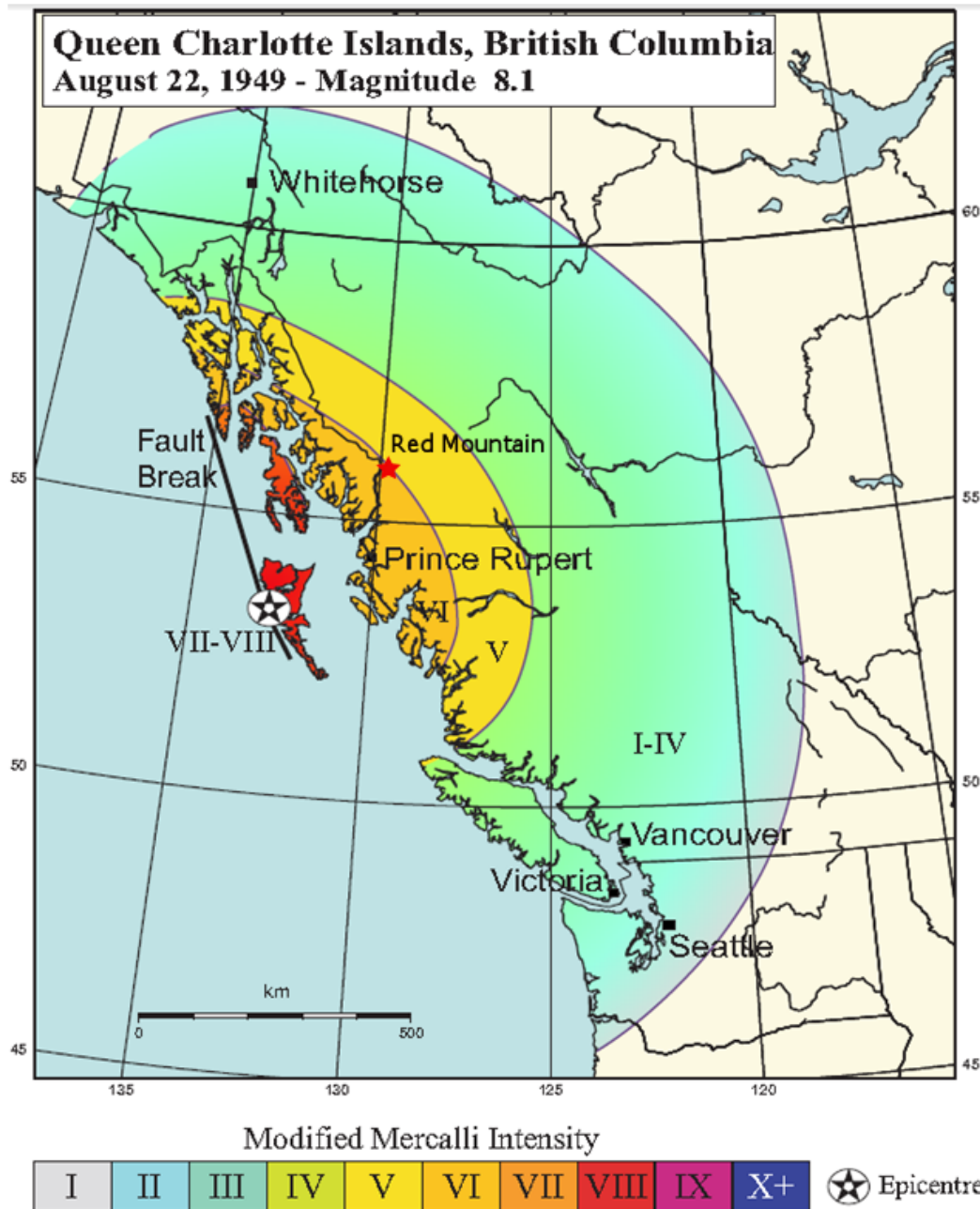


Figure 2-6: Map of the August 22, 1949, earthquake offshore of Haida Gwaii – Reported as Modified Mercalli Intensity effects (after: Lamontagne et al., 2007).

In terms of a hazard rating for seismic activity near Stewart, BC, the Geological Survey of Canada has created a relative seismic hazard rating map of Canada, which places Red Mountain in a moderately high hazard area (Figure 2-7). As such, it should be understood that seismic activity could trigger instability in marginally stable terrain within the GeoRSA.

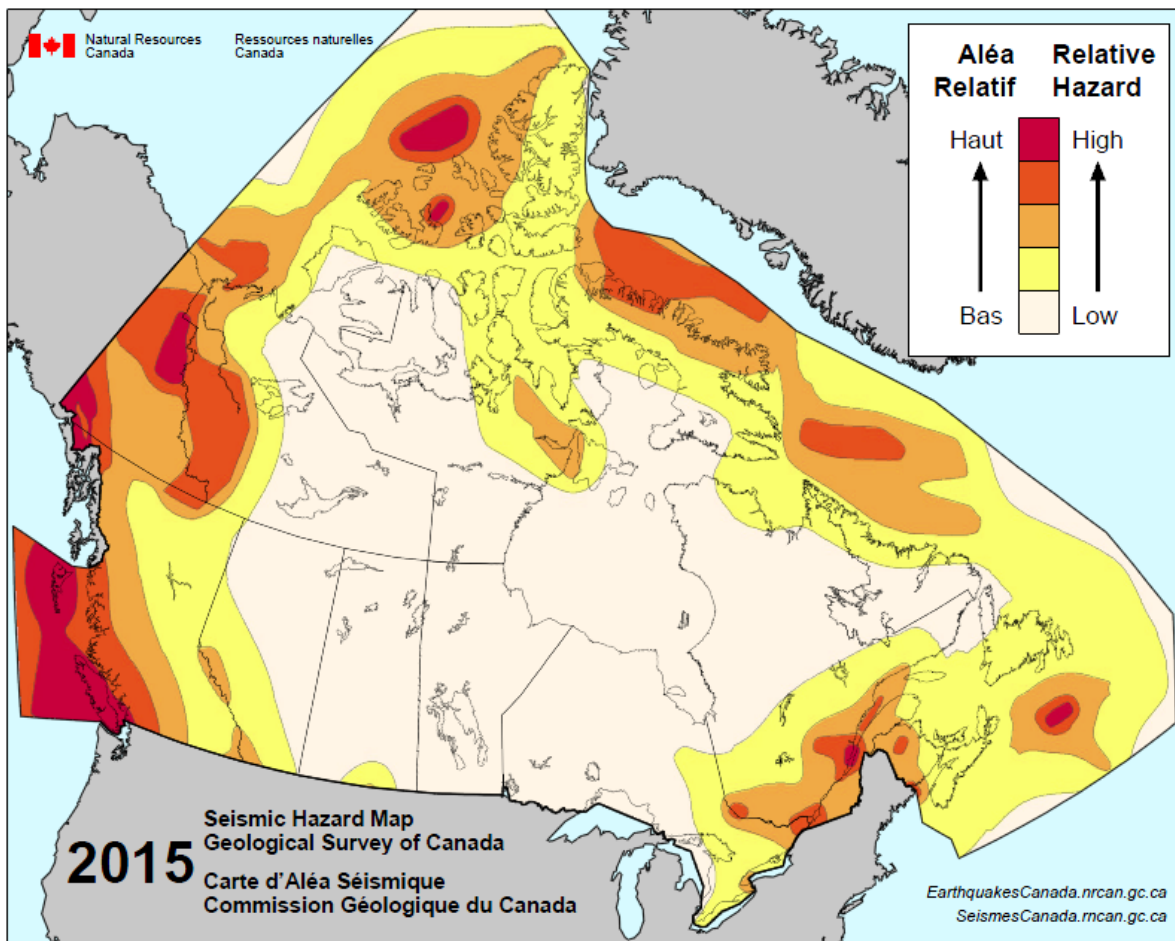


Figure 2-7: Seismic Hazard Map of Canada (NRC, 2017).

2.6 Surficial Geology and Geomorphology

The Bitter Creek Valley has undergone several phases of glaciation that have shaped the landscape. Glaciation produces distinct deposits and impacts such as oversteepening and debuttreassing slopes which exhibit important controls on the activity and spatial distribution of local geohazards.

The last major glacial period to impact the study area was the Fraser Glaciation with an onset approximately 25,000 – 30,000 years before present (25 – 30 ka). In the nearby Skeena Valley, Fraser deglaciation was complete sometime between 10.7 – 9.3 ka (Clague, 1984), and the timing is assumed to be comparable for the Bear River and Bitter Creek valleys. During this time, lateral moraines from the Bromley Glacier were deposited along the hillslopes at elevations as high as 1,200 m in the GeoRSA (KCC, 1994).

Through the Holocene, four periods of Bromley glacial advance have been documented between $2,470 \pm 30$ to 830 ± 30 years before present (BP), the most recent of these corresponding to early Little Ice Age expansion (Hoffman & Smith, 2013). The Bromley Glacier did not reach the same ice thickness in these expansions as it did during the earlier Fraser glaciations. As a result, recent advances have stripped away the lower elevations of prior lateral moraine deposits, and oversteepened these slopes (KCC, 1994).

Presently, local glaciers continue to modify the environment through ongoing glacial retreat. Glacial ice originating in the Cambria Icefield primarily enters the valley via the Bromley Glacier, which has been retreating at an average rate of 86 m/year over the hundred year period between 1910 to 2010 (Hoffman & Smith, 2013). High alpine glaciers that once coalesced with the Bromley Glacier have now withdrawn to the upper reaches of tributary valleys which slope steeply towards Bitter Creek. Lateral moraines are well preserved in many of these valleys.

At high elevations, hillslopes tend to be composed of veneers of colluvial or morainal material directly overlying bedrock. This bedrock is exposed on the steepest valley sides, such as the east facing slopes opposite Goldslide Creek, and in regions only recently uncovered by receding glaciers. The high slope gradients and sparse vegetation promote high rates of mass wasting and large volumes of colluvial material. As a result, many tributary valleys are supplied a functionally unlimited volume of sediment for transport, and have the potential to generate debris flows or debris floods whenever critical climate thresholds are exceeded (Jakob, 2005). Colluvial and fluvial fans resulting from this activity have formed at the mouths of many of these tributaries where they join Bitter Creek.

At the onset of various glaciations, till and glacial deposits were draped across the landscape. In the wake of the retreating alpine and Bromley Glaciers, large volumes of meltwater laden with sediment were released and transported to, and by, Bitter Creek. Erosional reaches are more prevalent near the terminus of the Bromley Glacier, while downstream, the creek exhibits several sections of floodplain aggradation, such as near the mouths of Hartley Gulch, and Roosevelt Creek.

It has been noted that historical expansions of the Bromley Glacier may have created conditions for the formation of a glacial lake behind the terminal moraines, but glaciolacustrine deposits had not yet been identified by 1994 (KCC, 1994). Subsurface glaciolacustrine material was observed in high cutbanks alongside Bitter Creek, near the mouths of Radio Creek and Unnamed Creek 3 during the 2014 field investigation for this project. These deposits were exposed by lateral bank erosion by Bitter Creek, which may have occurred after 1994. At both locations, slope failures were observed that have likely been triggered by removal of the toe of the slope by fluvial processes. Ongoing slope failures linked to the river undercutting sub-surface glaciolacustrine material are expected, although the exact extent of this material is unknown.

2.7 Data Sources

The data sources used in the following analyses are presented briefly below. Additional information available in the scientific literature was also used as background information to support the study area description and characterization.

2.7.1 Digital Elevation Model and Historical Imagery

A DEM with 1 m resolution was generated from LiDAR data provided by IDM and used in the terrain mapping and hazard analysis, as were the following sets of historic air photos (Table 2-1).

Table 2-1: Inventory of imagery used in the time series analysis.

| Imagery Date | Roll | Resolution/ Scale | Media |
|----------------|-----------------------|---|--|
| 2013-July-30 | N/A | 1.2 points/m ² ; 20 cm ground sample distance | Digital – LiDAR Imagery; Digital – Colour Photography |
| 1994-July-22 | BCB94030; BCB94036 | 1:15,000 | Film – Black and White Photography |
| 1972-August-16 | BCB5504; BCB5505 | 1:32,000 | Film – Black and White Photography |

Terrain characterizations were interpreted primarily using the 2013 LiDAR imagery where available, and utilizing the 1994 aerial imagery beyond the LiDAR footprint. A gap in stereo image coverage exists at the most northerly tip of the Roosevelt Creek watershed, and has been identified as no coverage in the following sections and excluded from analysis.

Fluvial characterizations were interpreted from the three years of stereo imagery separately.

3 Terrain Mapping and Slope Hazards Inventory

3.1 Terrain Mapping Inventory

Terrain mapping was performed using the standardized Terrain Classification System for British Columbia (Howes & Kenk, 1997) and in accordance with the Standard for Digital Terrain Data Capture in British Columbia (Resources Inventory Committee [RIC], 1998).

Terrain mapping is a system of classifying and documenting the surficial materials, landscape characteristics, and geomorphological processes as interpreted from field assessments, aerial or satellite imagery, and records of historic events. Areas of similar expression are termed terrain units, and are delineated into map polygons codified by a symbol which describes the characteristics of that unit as selected by the user.

Terrain unit polygons were identified in the heads-up 3D mapping software DAT/EM® Summit Evolution™, and digitized on-screen using ESRI® ArcMap™ at a scale of 1:20,000 within the GeoRSA and 1:5,000 within the GeoLSA. Where available, LiDAR data allowed refinement of the aerial photograph analysis, particularly where geomorphological features were obscured by vegetation. The minimum polygon size delineated is 0.125 Ha and 2 Ha, respectively. A brief description of the surficial material types encountered within the study area is presented in Table 3-1. For the complete list of surficial materials and map labelling conventions, refer to Appendix B.

Table 3-1: Summary of surficial material types encountered within the study area.

| Surficial material types encountered within the Red Mountain area | |
|---|--|
| Anthropogenic | Materials originating from, or strongly altered by human activity. |
| Bedrock | Solid rock underlying loose deposits. |
| Colluvial | Materials that have been deposited as a direct result of gravity-induced transport. Landforms include bedrock-derived veneers and cones, as well as deposits from specific mass wasting processes (rock fall, landslides, etc.). |
| Fluvial | Previously known as “Alluvial”. Material transported and deposited by flowing water. Deposits generally consist of well sorted sand and gravel, and include fan and delta landforms. |
| Glaciofluvial | Materials transported and deposited by glacial meltwater streams and outwash directly in front of, or in contact with glacial ice. |
| Glaciolacustrine | Materials deposited in or along the margins of glacial (ice-dammed) lakes and includes well sorted, fine sediments and some larger clasts released by floating ice (drop stones). |
| Morainal | May also be known as “Till”. Material and soils produced by the activity of glacial ice sheets. Deposits are typically diamictons, composed of poorly sorted particles/clasts within a fine-grained matrix. |
| Undifferentiated | Steep slopes typically ranging between 65 and 90%, with a complex, layered stratigraphy of three or more sediments. |

3.2 Terrain Stability Inventory

The Terrain Stability Ratings applied to each terrain polygon in the GeoRSA and GeoLSA are based on an assessment of the texture of surficial material(s), thickness of material(s), slope angle, slope configuration, drainage, the regional climate and the active geomorphic processes prevalent in the area (RIC, 1996). Some or all of the above factors influences each map unit to a varying degree and therefore each map unit is largely unique; however, generalizations can be and were applied by the mappers to guide both the application and interpretation of the stability ratings in the area.

Mapping results are outlined below in a five-class stability rating system (I - V). The criteria used in establishing each of the ratings was derived primarily from air photo observations, supplemented by LiDAR and experience in similar coastal environments. The stability criteria for the Red Mountain area are outlined below:

The complete list of terrain map label conventions used for the listed examples is provided in Appendix B.

3.2.1 Terrain Stability Criteria

I Well drained slopes with gradients of less than 10-15%. Other gently sloping, depressional map units generally less than 10% regardless of drainage. If fine textured sediments (silt-clay) are dominant then the maximum slope angle should be less than 10% (e.g., glaciolacustrine sediments). Minor active processes may occur within the polygon (e.g., stream activity). No evidence of instability observed.

e.g.: FGp; Cf; Ff; Ft; Fp; LGp; Op

II Slopes with gradients between approximately 15 and 40%. Predominantly moderate slopes within the polygon; however, discontinuous, short, steep slopes may occur within low angle polygons (e.g., minor scarps, **terrace** risers) to bump them to stability class II. Little to no evidence of instability observed.

e.g.: Ft, Fp, FGp; Mj

III Typically, slopes with gradients between 40 and 60%. Materials in polygons attributed this stability class vary widely as a function of texture, depth of the material, drainage, and slope configuration. Given a uniform slope, stability class III criteria are:

Tills *:

- › well drained tills are a class III on slopes up to 60%;
- › moderately drained tills are a class III on slopes up to 55-60%;
- › imperfectly drained tills are a class III on slopes up to 50-55%;
- › siltier tills, derived from local volcanic, sedimentary or metamorphic bedrock, typically reduce the 'stability III / IV' threshold angle; and,
- › active processes such as gullyng and soil creep, bump the polygon stability rating up to a IV (e.g., Mb - V).

Colluvium *:

- › finer textured, well drained rubbly colluvial blankets and colluvial cones with a sandy matrix are a class III on slopes up to 60%;
- › coarser textured, rapidly drained blocky colluvial blankets and colluvial cones are a class III on slopes up to 65-70%;
- › well drained colluvial veneers are a class III on slopes less than 55-60%;
- › moderately drained colluvial veneers are a class III on slopes less than 50 -55%; and,
- › moderate to imperfect drainage on colluvial blankets and cones reduce the class III delimiting slope angles by about 5% and 10%, respectively.

* Colluvium texture varies considerably within the GeoRSA depending on local source bedrock and this variation significantly influences the stability ratings given. The coarser blocky colluvial blankets found in the northwest of Red Mountain, and derived from intrusive granitic rock, are typically more stable than a similar sloped, finer grained colluvial blanket derived from a volcanic or sedimentary source found east of the Red Mountain.

Glaciofluvial:

- › Glaciofluvial slopes up to 55-60% are included in this class; and,
- › Unconsolidated, steeper glaciofluvial slopes (60-75%) are typically bumped up to a IV.

Glaciolacustrine:

- › Moderately to well-drained, relatively uniform glaciolacustrine deposits, generally with slopes between 20 and 40%.

IV Generally, identifies select materials on slopes with gradients greater than 60%, particularly those exhibiting long, steep, unbroken slopes. Stability class IV polygons often exhibit active slope processes such as gullying. Characteristically, however, failures are not evident on these slopes. Any failures evident in stability class IV terrains are directly attributable to existing road construction or development practices. Criteria for stability class IV materials include:

Tills:

- › moderate to well drained tills with slopes greater than 60-65%;
- › imperfectly drained tills with slopes greater than approximately 45%; and,
- › gullied morainal blankets, actively incising, with unstable gully walls greater than 55-60%.

Colluvium:

- › well to moderately drained colluvial veneers on slopes greater than 65%; and,
- › steeper colluvial cones, again 65 to 90%, especially on their steeper upper slopes.

Glaciofluvial:

- › unconsolidated glaciofluvial slopes greater than 70-75%.

Glaciolacustrine:

- › gentle to moderate gradient, fine-textured deposits (glaciolacustrine), generally with slopes greater than 40%; partially dissected by shallow and inactive stream channels and gullies; excavations removing toe-slope support may cause localized slumping or flow slides.

Undifferentiated:

- › steep slopes typically ranging between 65 and 90%, with a complex stratigraphy, often exhibiting seepage along upper contacts with impermeable units.

V Generally areas with evidence of past or ongoing natural mass movement. Typically, slopes which have gradients greater than 70-80% and exhibit some form of mass movement initiating within the polygon. A few steep slopes with no evident failures are given this rating if slope failure is judged to be imminent (e.g., an oversteepened till blanket undergoing basal undermining along a stream cut-bank).

3.3 Terrain Mapping Results

The surficial materials of the Red Mountain GeoRSA are best viewed on the accompanying map (Appendix E-001). In general, the highest elevations above approximately 1,650 m asl in the alpine and above 550 m asl at the lower Bromley Glacier is alpine and glacial ice (I = 24%). Below this, exposed on the mountain ridges and steepest valley sidewalls is bare bedrock (R = 15%) only recently exposed by glacial retreat. Bedrock is also dominant on the east facing slopes opposite Goldslide Creek, the upper reaches of the Rio Blanco and Otter Creeks, and on the steep slopes between Lim and Radio Creeks. The less steep, upper slopes tend to be covered in a veneer of colluvial material (C = 16%) directly overlying bedrock and interspersed with areas of accumulating colluvium.

Recent deglaciation is also responsible for steep slopes and sparse vegetation, which combined with the cold winters and high precipitation in the area, promote frost shatter as well as mass wasting and an abundance of colluvial material. On the more gentle upland slopes, receding alpine and valley glaciers have left a veneer of moraine or till (M = 30%), which generally thickens toward Bitter Creek and is commonly found beneath colluvium and glaciofluvial (FG = 2%) sediments in the lower valleys. During retreat, melting glaciers dropped their sediment load into rivers, leaving glaciofluvial fans, stranded at the mouths of each of the tributary rivers. Glaciofluvial sands and gravels are particularly evident at the mouths of Cambria and Roosevelt Creeks and in the upper reaches of Roosevelt Creek. More recent sediments, such as the colluvial debris fans and modern river (fluvial) (F = 2%) planes and fans, still actively cover the lower Bitter Creek valley and river mouth. Glacial lake (glaciolacustrine) sediments (LG) are not evident at surface in the GeoRSA area but subsurface glaciolacustrine material was observed in high cutbanks alongside Bitter Creek, near the mouths of Radio Creek and Unnamed Creek 3, which were exposed by the lateral erosion of Bitter Creek into undifferentiated (U = 0.04%) or layered, sediments. The upper elevation of this glaciolacustrine deposit is estimated to be 270 m asl based on field observations and LiDAR imagery, and possibly higher than 270 m in localized areas.

A note on Undifferentiated sediments:

- › Undifferentiated sediments commonly mapped as Us-VR's consist of interbedded sediment of various types, such as those found near the mouth of Radio Creek. The superpositioned units of varying textures are prone to failure for a variety of reasons. Landslides can initiate: 1) along planes of weakness within homogeneous sediments (e.g., LGb or zMb); 2) at the boundary of different textured materials where groundwater meets impermeable sediment and seepage occurs; or

3) where unconsolidated sediments are oversteepened and become prone to dry raveling. Undifferentiated sediments provide a particular stability concern where active fluvial undercutting or road building oversteepens slope angles, allowing for the occurrence of deep-seated slumps and/or surface failures. Care should be exercised to avoid undercutting or altering the natural drainage of these polygons.

Table 3-2 provides a summary of the estimated material types mapped within the GeoRSA.

Table 3-2: Surficial Material Summary within the GeoRSA

| Red Mountain Surficial Material Summary | | | | | |
|---|----------|-------------------|-------------------------------|-------------------|-------------------------------|
| Surficial Material ¹ | Map Code | Total GeoRSA (ha) | Percent of GeoRSA Terrain Map | Total GeoLSA (ha) | Percent of GeoLSA Terrain Map |
| Moraine | M | 3,442.62 | 34.56 % | 16.23 | 7.98% |
| Colluvium | C | 1,760.70 | 17.68 % | 56.95 | 28.03% |
| Ice | I | 2,659.46 | 26.70 % | 0.62 | 0.30% |
| Rock | R | 1,706.87 | 17.14 % | 128.59 | 63.28% |
| Fluvial | F | 182.00 | 1.83 % | 0 | 0 % |
| Glaciofluvial | FG | 203.16 | 2.04 % | 0 | 0 % |
| Anthropogenic | A | 1.47 | 0.01% | 0.82 | 0.40% |
| Undifferentiated | U | 4.43 | 0.04% | 0 | 0 % |
| Total Terrain Map Area | | 9960.72 | 100% | 203.21 | 100.00% |
| No Photo Coverage | N | 1,364.29 | | 0 | |
| Total Area | | 11,325.01 | | | |

¹ Based on leading surficial material decile

3.4 Terrain Stability Inventory Results

The five class terrain stability inventory of the Red Mountain GeoRSA is best viewed on the accompanying map(s) (Appendix E-002), however some stability concerns in the area are discussed in the text below (for place names, please refer to Appendix D-001). The following examples are by no means inclusive of all terrain stability issues within the Red Mountain GeoRSA. The recently glaciated nature of the area (Section 2.6) has oversteepened and undercut much of the drainage. It is a relatively active geologic environment.

General management implications of stability classes are outlined in the following Section (3.4.1). These mapped polygons are by no means prescriptions and cannot replace site-specific evaluation.

Map units are rated for stability based on the most sensitive identified terrain component; there are no complexes of stability ratings as there are for terrain components. In addition, the mapper is required to rate a map unit as class IV if there is significant uncertainty as to the stability of an otherwise class III designated unit. Conversely, within class I, II and III terrains there may be features identified in the field, not visible in the 1:20,000 scale imagery available for this project (e.g., tension cracks at the edge of a

class I terrain being undermined by a failing lower slope). As such, the reader should be aware that this mapping is intended as an overview to guide development.

3.4.1 Management Implications of Terrain Stability Classes

Designed for forestry roads, Table 3-3 below provides a reasonable estimation of potential road related issues associated with the five terrain stability classes. Where downslope consequences are high (e.g., infrastructure, fish bearing streams or transportation infrastructure), it may be advisable to seek the advice of a qualified, registered professional (QRP) even where the road layout is confined to class I, II and III terrain. During construction in 'flat over steep' situations, particular diligence should be used to maintain natural drainage regardless of stability class.

With respect to terrain stability class IV terrain, we recommend that on site field assessments be undertaken prior to development. Potential slope instability can be realized when cuts and fills associated with roads or other bladed trails are made in class IV terrain as well as within terrain stability class III terrain where seepage (-L) or gullyng (-V) is identified. As such, on site field assessments are also recommended for these sites. Though no signs of natural failure may be identified at the scale of this work (1:20,000 within the GeoRSA and 1:5,000 within the GeoLSA and along the road), within class III and IV terrain small inclusions of unstable terrain or very small historic slides or sloughs may exist. Consequently, there is a moderate likelihood of slope failure in these units with the loss of root strength, change in slope footing and/or changes to slope hydrology.

With respect to terrain stability class V terrain, we suggest avoiding all construction and land clearing activities within these units. If unavoidable, detailed terrain assessments and mitigation plans should be prepared by a QRP, prior to development.

Table 3-3: Road Related Implications of the Stability Classes

| Stability Class | Road-related Implications and Best Practices |
|-----------------|---|
| I | No instability expected from road construction. Roads crossing slopes of less than 5 - 10 % will usually be built by overlanding and little to no cutslope is created. |
| II | Roads crossing slopes of up to 25 - 45 %, with cutslopes up to 2 m high in granular material or, less commonly in bedrock, can expect to exhibit minor sloughing and ravelling of cutslopes during the first wet season following construction. |
| III | Roads crossing slopes of up to 50 - 65 %, with cutslopes greater than 2 m high in unconsolidated materials, can expect small cutslope failures (e.g., small sloughs or dry ravelling into the ditch) particularly during the first few wet seasons following construction. Emphasize clean subgrade construction — i.e., do not incorporate weathered soil, organics or debris into the subgrade; strip and dispose of these materials on the lower edge of the right of way. Ensure regular road inspection and maintenance. Promptly retire/deactivate road upon completion of project or the cessation of regular road maintenance. |

Table 3-3 (Cont'd): Road Related Implications of the Stability Classes

| Stability Class | Road-related Implications and Best Practices |
|--|--|
| <p style="text-align: center;">IV</p> | <p>Minimize roads through potentially unstable terrain. Plan construction work during the dry season. Anticipate the use of special construction methods, including full benching, endhauling, use of controlled blasting in heavy rock-cuts, support of high cutslopes, French drains etc. Such techniques will greatly reduce the likelihood of fill slope failures, providing there is adequate water control. Plan for the higher cost of construction that these methods require. Expect some on-going cutslope instability, particularly in high cuts in surficial materials. Plan for the higher level of maintenance that this requires. Consider pull back of any marginally unstable fill slopes (e.g., tension cracked road edges). Pile the pull-back material along inside of road if loss of road access can be tolerated; otherwise, endhaul to a safe disposal site. Leave a rough, irregular surface to reduce sheetwash and sediment production, and to facilitate revegetation. Promptly deactivate road upon completion of project and/or the cessation of regular road maintenance.</p> |
| <p style="text-align: center;">V</p> | <p>Avoid road construction through unstable terrain. Plan construction work during the dry season. Anticipate the use of special construction methods, including full benching, endhauling, use of controlled blasting in heavy rock-cuts, support or terracing of high cutslopes, French drains etc. Such techniques will greatly reduce the likelihood of fill slope failures, providing there is adequate water control. Plan for the higher cost of construction that these methods require. Expect some on-going cutslope instability, particularly in high cuts in surficial materials. Plan for the higher level of maintenance that this requires. Consider pull-back or re-sloping of any marginally stable sections of road. Place the retrieved material onto the road bench or end haul and ensure adequate cross drainage, with minimal ponding of water. Leave a rough, irregular surface to reduce sheetwash and sediment production, and to facilitate revegetation. Promptly deactivate on completion of the project and/or cessation of regular road maintenance.</p> |

3.4.2 Select Sites of Note

Notable locations with potential instability concerns associated with the access road and infrastructure include, but are not necessarily limited to:

- › There appear to be undercut slopes along Bitter Creek below the proposed road at Radio Creek (Figure 3-1);

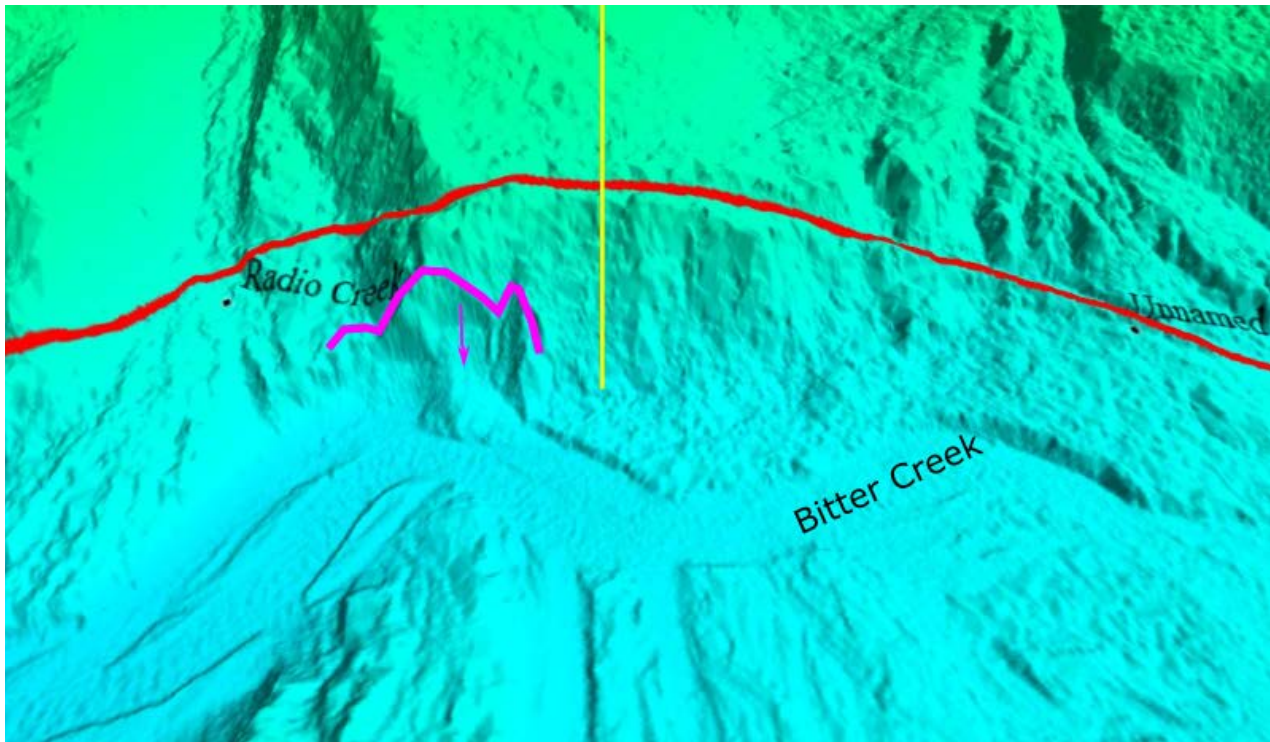


Figure 3-1: Radio creek slumping (pink arrow denotes direction of movement)

- › Tension crack and slumping features appear to exist at the road between Cambria Creek and Hartley Gulch (Figure 3-2);

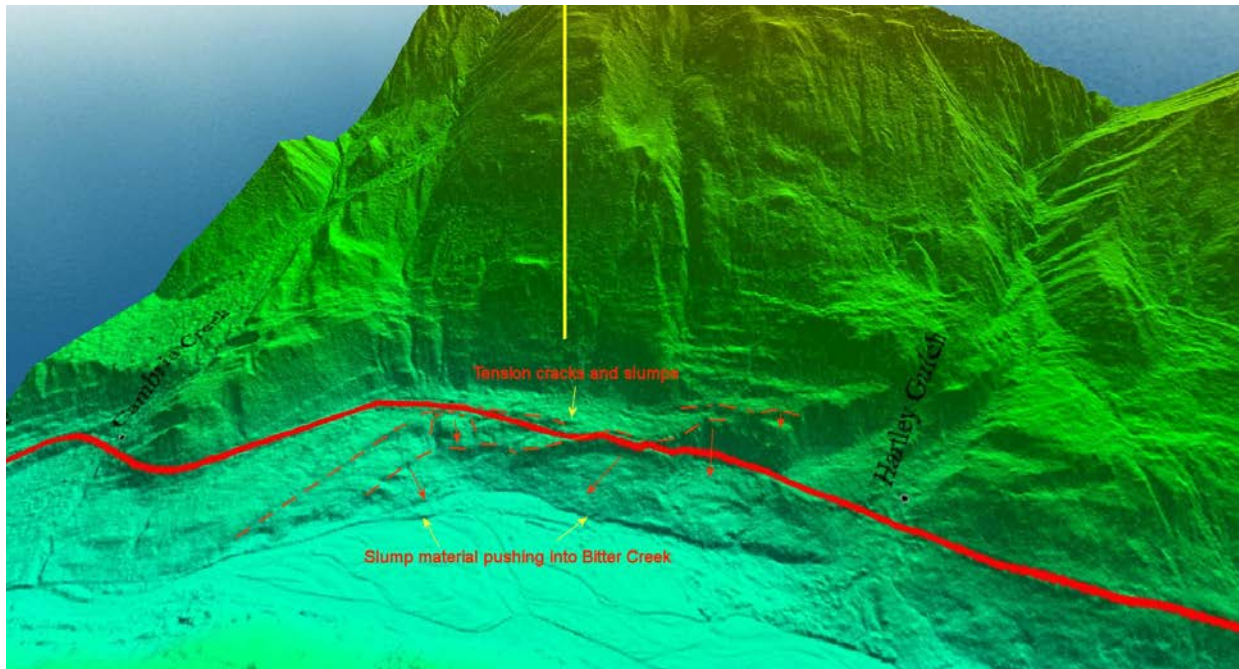


Figure 3-2: Appearance of tension crack and slumping between Cambria Creek and Hartley Gulch (Note: red arrows denote direction of movement; thick red line denotes access road).

- › LiDAR imagery shows the potential existence of a possibly pre-glacial, rotational rock slide (slump). The potential slide is evidenced by possible redirection of the Bitter Creek channel below the Bromley Humps and valley walls, dropped blocks and possible tension cracks upslope of the Bromley humps (Figure 3-3). Till and glacial striae, found along the proposed road at field location WP-73 (Figure 3-4 and Figure 3-5), indicate that this potential feature is likely pre-glacial. The material (bedrock, either in-situ or a displaced block/mass) is resting at valley bottom and is more than likely dormant. Core data provided to SNC-Lavalin, taken from recent drilling within the Bromley Humps area conducted by others, describe high fracture density, numerous broken and sheared and brecciated zones, and some slickensided joint faces. These descriptions indicate past deformation of the rock, which could have resulted from mountain building processes, glacial ice advances and recessions, rock sliding, or a combination of these processes. Engineering designs of the surface facilities in this area should evaluate the stability and activity of this site (at the north valley headwall and within the Bromley Humps).

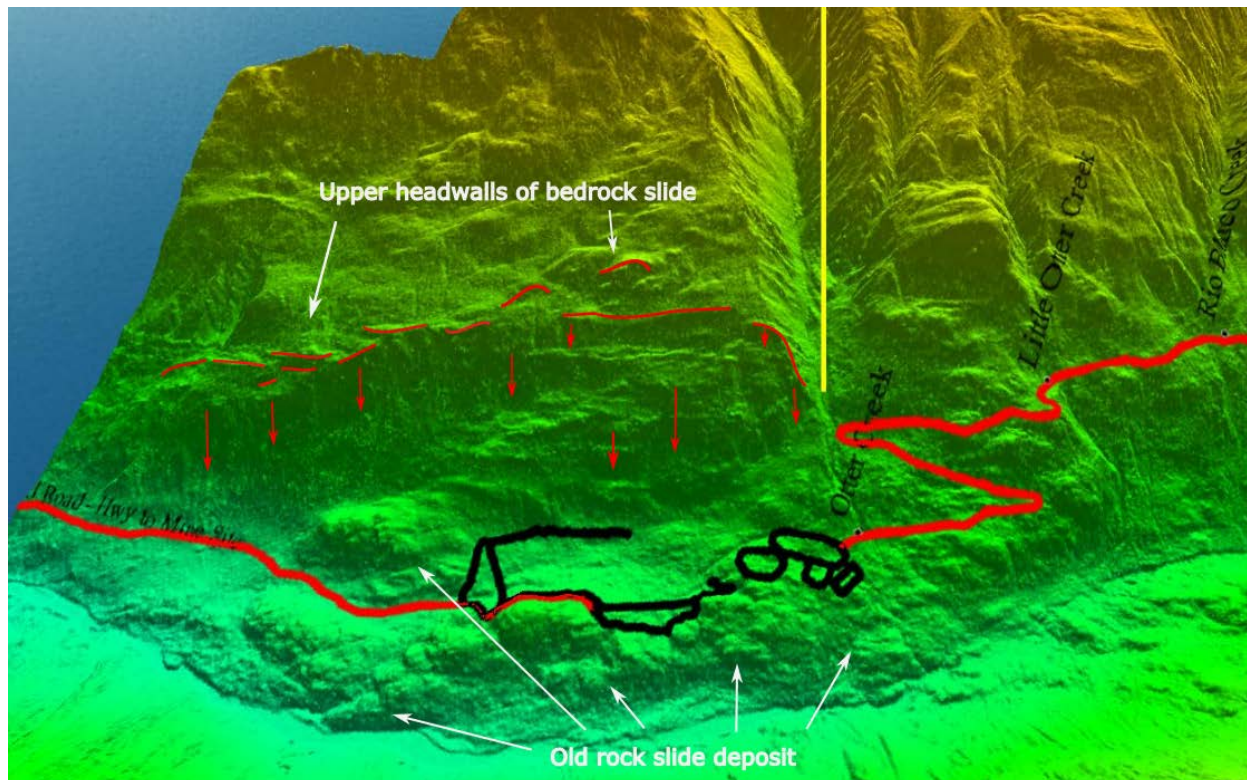


Figure 3-3: Possible bedrock displacement above Bitter Creek and the proposed road and infrastructure near Otter Creek (Note: red arrows denote direction of potential original slide movement from headwalls; white arrows denote the potential deposition zone; thick red and black lines denote access road and infrastructure, respectively).

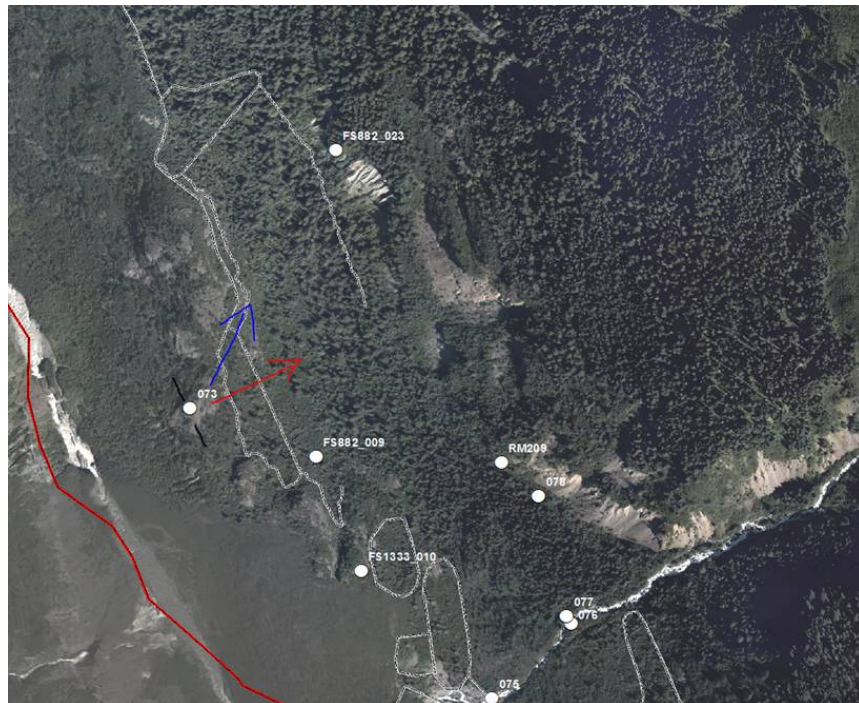


Figure 3-4: Bromley Humps and Otter Creek field sites. Blue arrow is the aspect of left photo below, red arrow is the aspect of right photo below, and black line shows the approximate trend of glacial striae and fluting at site.



Figure 3-5: Photos from WP-73 facing north-northeast towards Otter Mountain. Showing rotational surficial slides on the slopes of Otter Mountain on the right of the photograph and fluted and striations on rock trending roughly southeast to northwest.

- › Inactive (KCC, 1994) and potentially active bedrock rotational slides (slumping) at Red Mountain (Figure 3-6). The Red Mountain slide appears to be dormant upslope but may be more active down slope and as such, should be assessed to determine active state.

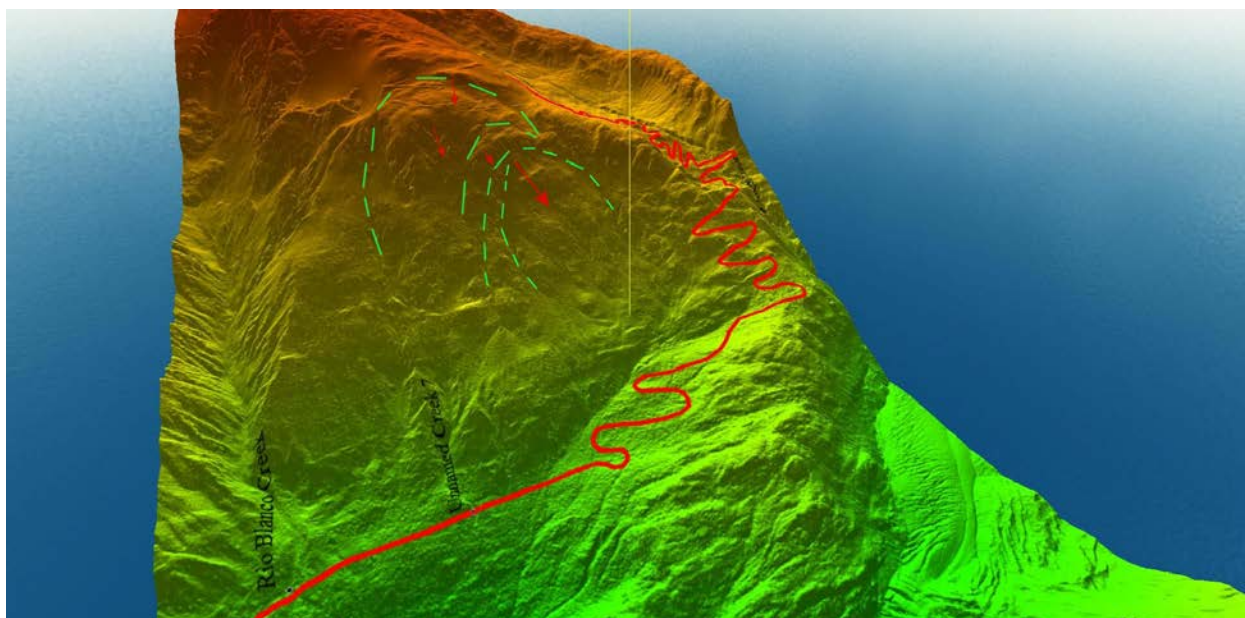


Figure 3-6: Inactive and potentially active bedrock rotational slide at Red Mountain
(Note: red arrows denote direction of movement; red line denotes access road).

3.5 Landslide Hazard Inventory

A detailed landslide inventory was created which documents the location, extent, type, terrain characteristics, and size of landslide processes. This approach delineated landslide polygons using aerial photographs in a heads-up 3D mapping environment, and digitized them on-screen using ESRI® ArcMap™. Where available, LiDAR data allowed refinement of the aerial photograph analysis, particularly where geomorphological features were obscured by vegetation.

The inventory considered only the terrain adjacent to the proposed access road between the height of land and the right bank of Bitter Creek. Landslides were mapped at a scale of 1:5,000 within the GeoLSA, and at a scale of 1:20,000 within the GeoRSA. The minimum polygon mapped was approximately 0.5 cm² at the printed map scale, corresponding to 0.125 Ha and 2 Ha, respectively. Where landslides were identified within 200 m of the access road, the minimum polygon size of 0.125 Ha was applied.

Landslide types were grouped into two main categories: i) rapid mass movements; and ii) slow mass movements and deformations. Where multiple minor failures below the minimum polygon size were observed in close proximity, the active landslide terrain was grouped into a single polygon. When scale allowed, landslide unit areas were further subdivided into the initiation zone or main scarp, and the displaced mass run-out area or accumulation zone.

3.5.1 Landslide Hazard Inventory Results

Quaternary deposits and bedrock in the study area have been altered and modified by a diverse range of landslides whose types are summarized in Sections 3.5.1.1 and 3.5.1.2. A total of 251 landslide polygons were identified and mapped within the RSA (Appendix E-003, E-004). The main characteristics of inventoried landslides are summarized in Table 3-4.

3.5.1.1 Rapid Mass Movements (RMM)

Rapid mass movements (RMM) within the GeoRSA comprise the majority of landslide failures with a total of 240 mapped polygons. The most common landslide types observed include rockfalls, debris avalanches, debris flows, and debris falls. Generally speaking, the majority of rapid mass movements are distributed amongst the steep colluvial, bedrock, and morainal slopes in the alpine and major tributary valleys. Failures are also more densely concentrated within recently deglaciated terrain, such as near the tongue of the Bromley Glacier, and other high alpine glaciers. Movements in this class tend to be un-vegetated or partially vegetated, and show indicators of recent activity.

Rock falls represent 55.3 % of rapid mass movements by area in the landslide inventory, and are limited to steeply sloping bedrock exposures. Rock falls also have the largest average polygon map unit largely due to expansive bedrock slopes among the higher elevations. The runout potential is relatively low in comparison to flows and slides, with most deposition occurring on slopes immediately below the initiation zone. However, the deposits provide an important source of debris within steep mountain creeks which may be entrained in a debris flow or debris flood event (Figure 3-7A). Potential impacts are primarily related to structures that are not permanently occupied (access road and transmission line). Regular road maintenance related to rock falls should be expected, particularly in the Goldslide Creek cirque where the road traverses a talus slope (Figure 3-7B).

Debris falls and debris avalanches represent the most numerous landslide types with a total of 95 mapped polygons. These movements lack a defined rupture surface and typically initiate from unconsolidated morainal and colluvial deposits. These failures are most commonly observed at high elevations in regions with sparse or absent vegetation cover. However, debris falls are also noted in the lower valley along steep river banks and on colluvial slopes above the proposed access road and tailings storage facility (Figure 3-7C).

Debris flows have the greatest runout distance of any rapid mass movement observed in the GeoRSA. The source areas are primarily located at high elevations within the steep mountain creek watersheds on the steep valley sides and in the channels where loose debris has accumulated (Figure 3-7A). Entrained material is transported through the major channels, and deposited in the lower valley on fans (Figure 3-7D, E, and F). Debris flows are therefore anticipated to impact the access road at crossings of these creeks and fans. Due to the high volume of sediment supply and availability, many of these watersheds are transport-limited, and debris flows may occur when critical climatic thresholds are exceeded (Jakob, 2005). Where debris flow activity is located in close proximity to permanently occupied structures, such as the Otter Creek fan near the TSF, further investigation and mitigation plans are warranted.

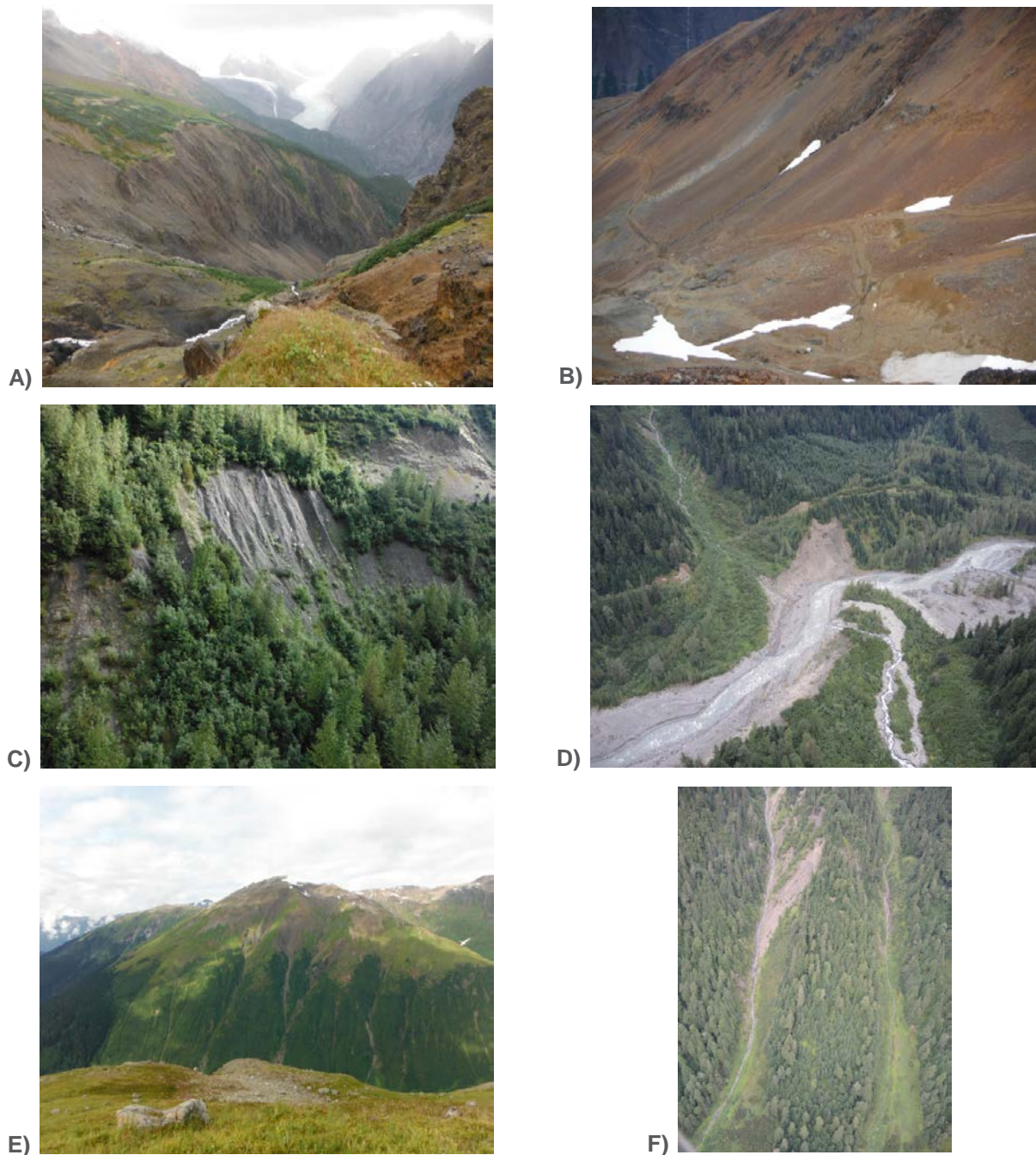


Figure 3-7: Landslides and Avalanches in the GeoRSA. A) Rock fall and debris flow source accumulation in Otter Creek; B) Rock fall in Goldslide Creek cirque above the access road; C) Debris falls in gullied till above the proposed TSF; D) Debris flow fan and rotational slide at Radio Creek; E) Mixed major and minor avalanche tracks and debris flow channels in the Roosevelt Creek watershed; F) Debris fall and debris flow channel with major avalanche tracks Unnamed Creeks 5 and 6.

3.5.1.2 Slow Mass Movements (SMM)

Slow mass movements represent a minority of the landslides identified in the GeoRSA with a total of 11 mapped polygons. Landslide types in this group include slow rotational sliding in unconsolidated material or bedrock, as well as lateral spreading in bedrock. Failures in this class may be well vegetated due to the slow rate of activity.

Slow mass movements were observed in proximity to proposed infrastructure in several locations. Rotational sliding in unconsolidated material was observed in the lower valley along the Bitter Creek banks which may undermine the stability of the access road (e.g., Figure 3-1). Two features with the appearance of deep-seated sliding in bedrock were observed near the Tailings Storage Facility (Figure 3-3) and near Red Mountain (Figure 3-4). The activity state of these features is not currently known.

Table 3-4: Characteristics of landslides inventoried in the GeoRSA.

| Type | Number of Polygons | Total Area (Ha) ⁱ | Percent of Total Mass Movement Area | Average Polygon Size (Ha) |
|---|--------------------|------------------------------|-------------------------------------|---------------------------|
| Rapid Mass Movements (RMM) – Rock fall, Rotational Failure in Bedrock | 87 | 1,322 | 55.3 % | 15.2 |
| Rapid Mass Movements (RMM) – Debris Flows, Falls, and Slides | 153 | 933 | 39.1 % | 6.1 |
| Slow Mass Movements (SMM) | 11 | 134 | 5.6 % | 12.2 |
| Total | 251 | 2,389 | 100 | - |

i: Includes run-out area.

3.6 Snow Avalanche Hazard Inventory

A detailed snow avalanche inventory was generated which documents the location, extent, type, and size of avalanche processes using aerial photographs and LiDAR for the GeoRSA. This approach delineated visible avalanche tracks, and categorized them into four main classes using standardized Howes and Kenk (1997) geomorphic process symbols: i) active major avalanche tracks (Af); ii) zones of active minor avalanche tracks (Am); iii) zones of active mixed major and minor avalanche tracks (Aw); and iv) old avalanche tracks (Ao). Major avalanches are differentiated from minor avalanches based on track width, where major avalanche paths are wider than the height of nearby trees (Howes and Kenk, 1997). Where avalanche tracks were highly concentrated or inferred based on topographic slope and absent large vegetation, avalanche polygons were extended to include the active hillslope area.

Avalanches were mapped at a scale of 1:5,000 in the GeoLSA, and at a scale of 1:20,000 within the GeoRSA. The smallest polygon mapped for the avalanche inventory was approximately 2 Ha.

3.7 Snow Avalanche Results

A total of 92 polygons representing avalanche tracks and avalanche prone hillslopes were mapped within the GeoRSA (Appendix E-005). Mapped avalanches encompass an area of 2,614.8 Ha, which represents approximately 23 % of the GeoRSA. Inventoried avalanches are summarized in Table 3-5.

Snow avalanche processes are common along the steep hillslopes of the Bitter Creek Valley, as well as the valley sides and channels of the major tributary creeks (Figure 3-7E and F). Avalanche tracks are observed to run to valley bottom and intersect the proposed access road in numerous locations between Unnamed Creek 4 and the portal at Red Mountain. Operational guidelines and mitigation plans may be required where project infrastructure encounters identified avalanche tracks. No avalanche tracks were observed between Unnamed Creek 4 and the western edge of the GeoRSA.

Table 3-5: Characteristics of avalanches inventoried within the GeoRSA.

| Type | Number | Total Area | Percentage of Total Avalanche Area |
|--------------------------------------|-----------|-------------------|------------------------------------|
| Major Avalanche (Af) | 29 | 508.8 Ha | 19.5 % |
| Mixed Major and Minor Avalanche (Aw) | 45 | 1,718.6 Ha | 65.7 % |
| Minor Avalanche (Am) | 18 | 387.4 Ha | 14.8 % |
| Total Avalanche | 92 | 2,614.8 Ha | 100 |

3.8 Limitations of Terrain and Hazard Mapping

- › It bears noting that the width of the mapped polygon lines on a 1:20,000 scale map represents a real distance of approximately 20 m. End-users, therefore, must be cognizant of this fact when using this information, and field workers in particular must make allowances for this accuracy on the ground.
- › Due to the mapping scale, slope processes too small to be pulled out have not been included in the hazard inventories.
- › Finally, the information presented on the maps and in this report is based on observations of current terrain conditions in the project area and the prevailing understanding of geomorphic processes. Slope stability, however, is strongly influenced by not only surficial materials and slope configuration, but also by: 1) subsurface conditions not readily apparent in surface observations; 2) unpredictable extreme climate and seismic events; and 3) inappropriate land management practices. Therefore, the information presented herein cannot completely predict landslide occurrence. The maps and this report are intended to highlight potentially hazardous areas in which detailed on-site investigations by a QRP are required.

4 Hazard Encounter Probability Assessment

4.1 Encounter Probability

Encounter probability is used as a proxy to assess risk where the element at risk is measured by any part of the hazard (initiation or runout). It considers the percentage of each terrain polygon occupied by a particular hazard. Because terrain polygons are inherently homogeneous, it is a reasonable indication of the likelihood of encountering a particular hazard in each one. This approach is not a formal risk assessment. It is intended as a high-level analysis tool to guide the decision making process concerning further site-specific studies for risk analysis.

Encounter probabilities are estimated separately for each hazard type (i.e., slow mass movements, rapid mass movements, and snow avalanches). Four encounter probability maps were created for the GeoRSA: (i) rapid mass movements; (ii) slow mass movements; (iii) snow avalanches; and iv) multi-hazard (total hazard) encounter probability. These maps identify the spatial likelihood of geohazards that could directly impact project activities.

Where:

$$Ep = \frac{A_{HT}}{T_{UA}} [2]$$

Ep = Encounter probability

A_{HT} = Area per hazard type (e.g., rapid mass movement, slow mass movement and snow avalanche)

T_{UA} = Terrain unit area

Spatial risk mapping is obtained by intersecting the encounter probability maps with project infrastructure to identify the likelihood of geohazards impacts.

Seven classes of encounter probabilities were defined for each map from lowest to highest: < 0.001; 0.001-0.005; 0.005-0.002; 0.002- 0.100; 0.100- 0.200; 0.200-0.500; > 0.500. A value of 1.0 would constitute hazard occurrence throughout the entire polygon footprint.

4.2 Encounter Probability and Spatial Risk Results

The encounter probability maps for rapid mass movements, slow mass movements, avalanches, and multi-hazard spatial risk for the Red Mountain road and infrastructure conceptual design are provided in Appendix F. An index of the produced maps is listed below.

F-001. Rapid Mass Movement Encounter Probability

F-002. Slow Mass Movement Encounter Probability

F-003. Snow Avalanche Encounter Probability

F-004. Multi-Hazard Encounter Probability

F-005. Spatial Risk - Rapid Mass Movement

F-006. Spatial Risk - Slow Mass Movement

F-007. Spatial Risk - Snow Avalanche

F-008. Spatial Risk – Multi-Hazard

The results of the encounter probability mapping on project infrastructure are summarized in Table 4-1 below. Where project infrastructure intersects encounter probability hazards greater than 0.100, site specific assessments should be considered. Assessments should look at (a) whether the portion of the polygon is representative of the ground conditions at a detailed scale, and (b) the nature of the hazard, its level of activity and its possible effect on the proposed structure. Mitigation measures, if required, should be specific for hazard type and may vary from: avoidance, acceptance, operational and maintenance measures, to engineering design to protect structures and infrastructure.

Table 4-1: Total encounter probability and spatial risk for Red Mountain conceptual design.

| Infrastructure | Potential Encountered Geohazards | Total Hazard Encounter Probability | | | | | | |
|---|---|------------------------------------|--------------------|-------------------|-----------------|----------------|----------------|--------------|
| | | < 0.001 | > 0.001 – 0.005 | > 0.005 – 0.02 | > 0.02 – 0.1 | > 0.1 – 0.2 | > 0.2 – 0.5 | > 0.5 – 1 |
| Access Road (25.8 km) | <i>Rock fall, Debris Fall, Debris Flow, Debris Slide, Rotational Failure in Bedrock and Unconsolidated Material, Lateral Spreading in Bedrock, Tension Cracks, Major and Minor Avalanches</i> | 3.5 km | 0.5 km | 2.4 km | 4.6 km | 3.8 km | 3.0 km | 7.9 km |
| Powerline (18.6 km) | <i>Rock fall, Debris Fall, Debris Flow, Debris Slide, Rotational Failure in Bedrock and Unconsolidated Material, Tension Cracks, Major and Minor Avalanches</i> | 4.5 km | 0.1 km | 3.3 km | 1.9 km | 0.9 km | 1.0 km | 6.9 km |
| Tailings Storage Facility (TSF) & Embankment (15.0 Ha) | <i>Rock Fall, Debris Fall, Debris Flow, Rotational Failure in Bedrock, Tension Cracks, Major Avalanches</i> | 0.0 Ha | 0.0 Ha | 0.0 Ha | 12.0 Ha | 0.0 Ha | 0.0 Ha | 2.9 Ha |
| Buildings, Stockpiles & Pads (4.6 Ha) | <i>Rock Fall, Debris Fall, Debris Flow, Debris Slide, Rotational Failure in Bedrock, Lateral Spreading in Bedrock, Major and Minor Avalanches</i> | 0.1 Ha | 0.0 Ha | 0.0 Ha | 0.8 Ha | 0.0 Ha | 0.0 Ha | 3.7 Ha |

[†]Totals may slightly differ from infrastructure dimensions due to rounding.

Table 4 1 shows the extent of the access road (as of November 1, 2016) and infrastructure (as of October 6, 2016) intersecting terrain containing any of the identified slope and avalanche hazards. The access road and powerline traverse through diverse terrain, and are exposed to a wide range of geomorphic processes. Rock and debris falls and major avalanches are the primary processes with potential to impact the TSF; however, the possible bedrock displacement near the Bromley Humps also influences the encounter probability (described in Figure 3.3).

Buildings, Stockpiles & Pads are located in close proximity to several rock fall, avalanche, and debris flow processes, which contribute to a relatively high encounter probability. This table should be used only in conjunction with the Figures in Appendix F. Occupied or vulnerable structures may require mitigation or monitoring.

4.2.1 Limitations

Encounter probability maps are based on identified existing hazards. They do not predict hazards from terrain polygons where no associated hazards have been identified. Consequently, encounter probability maps are most useful when the map scale is not too detailed. In other words, the predictive nature of encounter probability maps lies in the identification and inclusion of terrain with similar characteristics to terrain that is failing. This provides some of the justification for the scale (fit-for-purpose) of mapping used herein.

Small footprint processes not captured at the mapping scale are not represented by encounter probability maps, however, they may still impact project infrastructure.

5 Soil and Soil Erosion Potential Classification

5.1 Preliminary Soil Classification

Soil classification mapping is a system of representing and documenting homogenous units of soils that have developed under similar climatic conditions and parent materials. Soil classification was completed at a preliminary level with the intent to document soil types in the field, and identifies trends in their distribution. The methodology consisted of four steps:

- › review of background information including related soil surveys in the Hazelton Mountains (Wittneben, 1984) and Pemberton Valley (Kuurne, 1980);
- › field work program;
- › terrain mapping; and,
- › soil classification mapping. A soil classification map was completed at a 1:20,000 scale for the GeoRSA.

The soil field program involved the description of 40 soil profiles characterized by a combination of SNC-Lavalin and Onsite personnel during site visits in August, 2014 and July, 2016, respectively. These profiles are located along terrain field traverses and within areas of interest such as the Access Road ROW and Goldslide Creek Watershed. Soils were classified in terms of their Order, Great Group, and Subgroup as described in the Canadian System of Soil Classification (1998). Soil classification was inferred from the interpretation of field soil profiles.

A quality control assessment was performed on the data to confirm the accuracy and field interpretation. Following this, nine profiles were found to be unsuitable for use in the preliminary soils map, and have been excluded from the following analysis. One profile was found to be a non-soil, and has been excluded. Six profiles were found to be incorrectly classified at the subgroup level, and were corrected.

Following the completion of the soil field program and terrain mapping, soil classifications were applied to terrain units. Where field checks were unavailable, soil classifications were estimated and applied using the elevation and aspect of the terrain polygon according to the relationship of field soil profiles shown in Figure 5-1. On east, south, and west aspects, field classifications were primarily found to be a mix of Orthic Regosols (O.R) and Orthic Dystric Brunisols (O.DYB). For the preliminary assessment, soils in the mixed category were classified as O.DYB when the vegetative cover of the terrain polygon equals or exceeds approximately 50% and O.R otherwise. Exceptions to this scheme include units where the primary surficial material was identified as fluvial on flat aspects, bedrock, or ice. These are classified as cumulic regosol (CU.R), rock, and ice respectively.

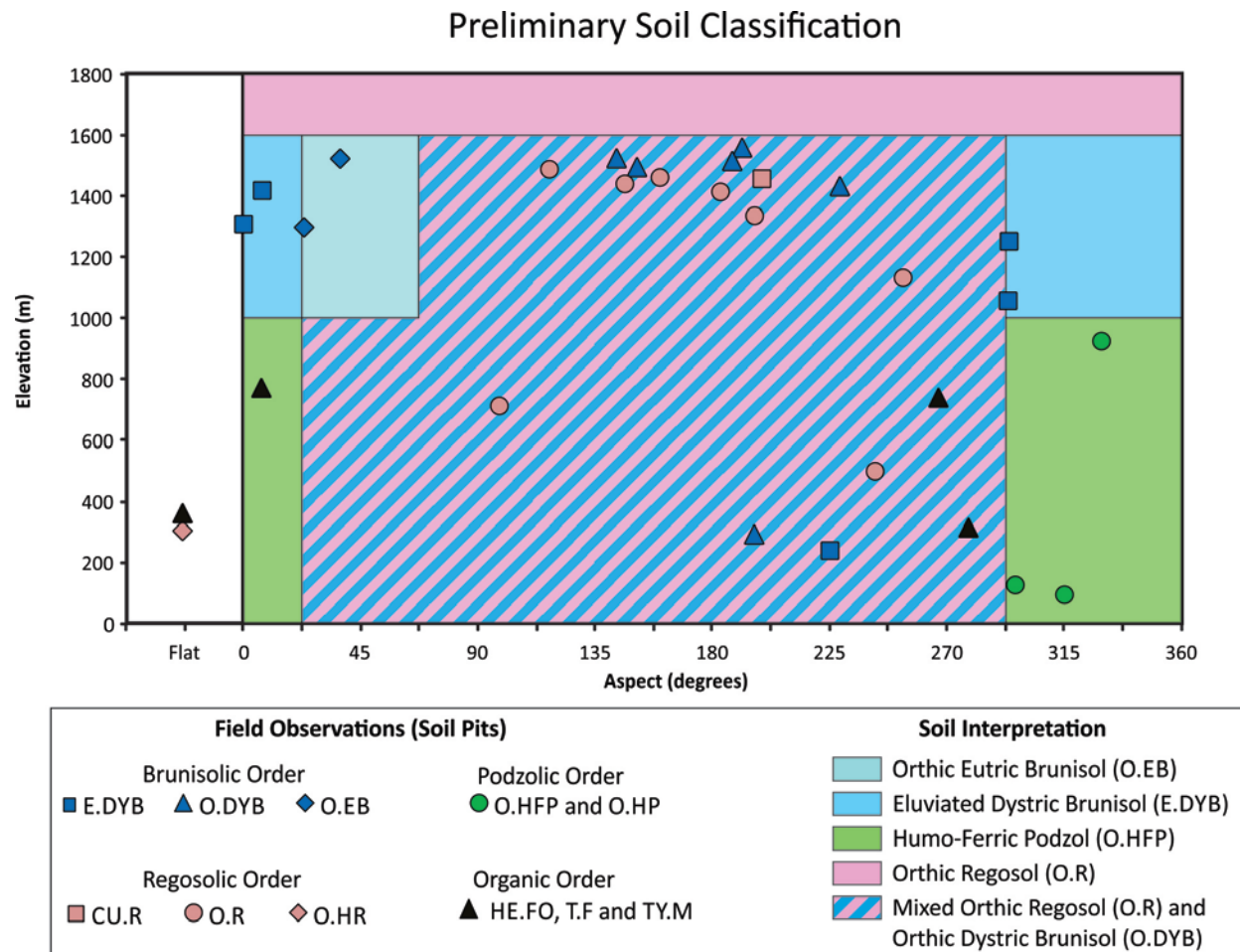


Figure 5-1: Soil profiles observed in the field and estimated soil interpretation for unchecked terrain units.

5.2 Soil Characterization Results

The distribution of soils observed in the study area involves three of the Canadian soil orders. A soil classification map based on order, great group, and subgroup was created (Appendix G-001). A summary of soil classification within the study area is presented in Table 5-1.

Table 5-1: Classification of soils encountered in the Red Mountain GeoRSA.

| Red Mountain GeoRSA Soils | | | | | | |
|----------------------------|-------------|----------------------------|----------------------|---------------------------|-----------------------|--------------------|
| Order | Great Group | Subgroup | Subgroup Soil Symbol | Percentage of Mapped Area | Area of polygons (ha) | Number of polygons |
| Brunisolic | Eutric | Orthic Eutric Brunisol | O.EB | 0.7 % | 70.5 | 4 |
| | Dystric | Orthic Dystric Brunisol | O.DYB | 30.5 % | 3,037.6 | 197 |
| | | Eluviated Dystric Brunisol | E.DYB | 1.3 % | 133.9 | 15 |
| Podzolic | Humo-Ferric | Orthic Humo-Ferric Podzol | O.HFP | 2.9 % | 286.5 | 39 |
| Regosolic | Regosol | Orthic Regosol | O.R | 18.7 % | 1,861.2 | 165 |
| | | Cumulic Regosol | CU.R | 1.3 % | 132.5 | 10 |
| Rock | N/A | N/A | N/A | 17.9 % | 1,779.1 | 111 |
| Ice | N/A | N/A | N/A | 26.7 % | 2,659.5 | 8 |
| Total Soil Map Area | | | | 100 % | 9960.7 | 549 |
| No Coverage | | | | | 1,364.3 | 1 |
| Total GeoRSA area | | | | | 11,325 | 550 |

Based on the Canadian System of Soil Classification (Ag.Can., 1998).

5.3 Soil Erosion Potential Classification

Soil erosion potential (SEP) is a five class rating system (Very Low, Low, Moderate, High to Very High) used to establish the likelihood of soil erosion occurring after disturbance. Soil erosion potential ratings depend on a number of factors but are primarily related to surficial material texture (not the organic soil), particle size, precipitation and slope angle (Lewis, 1991; Carr et al., 1991). Polygons containing sediments consisting of highly erodible and transportable silt and/or fine sand have a higher SEP rating than sediments consisting predominately of coarser, less mobile fragments or rock (Table 5-2). Pure clays tend to have reducing erosion potential as a result of cohesion and flocculation.

Table 5-2: Simple Soil Erosion Potential Classification

| Simple Soil Erosion Potential Classification by Texture (Particle Size) | | |
|---|------------------------------|-----------------------------|
| Surficial Deposit | Texture (Howes & Kenk, 1997) | SEP (Very Low to Very High) |
| Colluvium (C) | sr | M |
| | r | VL |
| | a | VL |
| | x | VL |
| | sd | M |
| Fluvial (F) | zs | H |
| | fine s | H |
| | med.-coarse s | M |
| | g | L |
| Glaciofluvial (F ^G) * | fine s | H |
| | m-c s | M |
| | g | L |
| | kb | L |
| Glaciolacustrine (L ^G)* | c | H |
| | z | VH |
| | fine s | H |
| | g | L |
| Morainal/Till (M)* | *kbz | M |
| | c matrix | M |
| | z matrix | M |
| | s matrix | L |
| Bedrock (R) | | VL |
| Undifferentiated (U) | zs | VH |
| | sg | H |

* The formation of erosion pavements due to high large clast content may reduce SEP classification in these surficial deposits.

To more closely mimic real conditions, slope and precipitation must be considered. As such, steeper polygons will tend to have a higher SEP rating than flat or gently sloping polygons and greater precipitation will influence erosion potential more than moist conditions (until arid conditions are encountered).

Criteria used to determine surface erosion potential in the Red Mountain area are based loosely on a forestry system established by Lewis et al. (1991). Local information on climate, slope, topography and sediment texture is gathering and a SEP rating is derived. Not all factors are available to make this comparison, nor is this a clear cut expected, however, this system does apply to bare earth or unvegetated soils, exposed by mining or road building.

The basic interpretation of SEP is based on the relative weights of soil texture (particle size), climate and topography, with climate information taken from the Biogeoclimatic classification of British Columbia (MoFLNRO, 2016) and modified by Carr et al. (1991) to reflect historic rainfall frequency, intensity, and duration and modified to account for snowmelt. The Biogeoclimatic zones of the Red Mountain GeoRSA (CMA, MH and CWH) are grouped in the highest rainfall factor (R) 12 averaging approximately 1,800 mm/year (MoFLNRO, 2016).

5.4 Soil Erosion Potential Results

In the Red Mountain GeoRSA the terrain polygon textures were established from field data, which was supplemented with experience of average textures for materials in the Coast Mountain physiographic region, resulting in the average textures of Red Mountain Soils (Surface Materials) (Appendix A).

The resulting SEP classification ratings, by particle size and slope, are outlined below in Table 5-3. Their estimated distribution throughout the GeoRSA is displayed in Appendix G-002.

Table 5-3: Soil Erosion Potential Classification

| Soil Erosion Potential Classification* (Very Low, VL to Very High, VH)** | | | | | | |
|--|---------------|-------------|---------------|-------------------|---------------------|---------------------|
| Surficial Deposit | Particle Size | Slope | | | | |
| | | Flat (0-5%) | Gentle (5-20) | Moderate (20-30%) | Mod. Steep (30-50%) | Very Steep (>= 50%) |
| Colluvium (C) | sr | L | M | M | H | VH |
| | r | n/a | L | L | M | H |
| | a | n/a | VL | VL | VL | VL |
| | x | n/a | L | L | H | VH |
| | sd | L | M | M | H | VH |
| Fluvial (F) | zs | H | VH | VH | VH | VH |
| | fine s | H | VH | VH | VH | VH |
| | med-crs s | L | M | M | H | H |
| | g | L | L | M | M | H |
| Glaciofluvial (F ^G) | fine s | H | VH | VH | VH | VH |
| | m-c s | L | M | M | H | H |
| | g | L | L | M | M | H |
| | kb | VL | L | L | L | L |

Table 5-3 (Cont'd): Soil Erosion Potential Classification

| Soil Erosion Potential Classification* (Very Low, VL to Very High, VH)** | | | | | | |
|--|---------------|-------------|---------------|-------------------|---------------------|---------------------|
| Surficial Deposit | Particle Size | SLOPE | | | | |
| | | Flat (0-5%) | Gentle (5-20) | Moderate (20-30%) | Mod. Steep (30-50%) | Very Steep (>= 50%) |
| Lacustrine (L) and Glaciolacustrine | c | L | M | H | VH | VH |
| | z | H | VH | VH | VH | VH |
| | fine s | H | VH | VH | VH | VH |
| | g | L | L | M | M | H |
| Morainal/Till (M) | c matrix | L | M | H | VH | VH |
| | z matrix | H | VH | VH | VH | VH |
| | s matrix | L | M | H | H | VH |
| Bedrock (R) | | VL | VL | VL | VL | VL |
| Undifferentiated (U) | zs | n/a | n/a | n/a | VH | VH |
| | sg | n/a | n/a | n/a | H | H |

Modified after: Lewis, Pers. Comm., (2016); Lewis et al. (1991) and Carr et al. (1991).

* Biogeoclimatic Zone of the Red Mountain GeoRSA (CMA, MH and CWH) (1,800 mm/year).

** This table applies to bare/exposed mineral soils. The ratings are relative to the climate and slope.

Table Note¹: An exposed silty sandy morainal or other material cut/fill slope can lose 3-5 mm of soil in the first winter. Prompt hydroseeding is needed (Lewis, pers. comm., 2016; Carr et al. 1991).

Table Note²: Most colluvium, though coarse at surface, has fine infillings at depth and as such only rarely has Very Low sediment erosion potential (Lewis, pers. comm., 2016).

The results of mapping indicate that the highest estimated soil erosion potential is associated with the silty and sandier fluvial, glaciofluvial, glaciolacustrine, till and undifferentiated sediments on moderate to steep slopes. Given the steep nature of the Bitter Creek valley, the high precipitation and the texture of sediments the majority of the mid to upper slopes have a very high sediment erosion potential.

5.5 Limitations

Some limitation of this mapping includes:

- › Soil order, great group and sub-group are applied to terrain units. Where generalization of the terrain map units occurred, some local condition of the soils may not be represented;
- › Soil identification was completed in the field;
- › Soils on unchecked map units were classified at a preliminary level based on observed trends in soil distribution within GeoRSA (Figure 5-1). Unchecked polygons may be generalized, and some local variations in soil type may not be represented;
- › Soil field data are not equally distributed within the study area and terrain polygons. Soil field program was conducted within the GeoLSA and along selected terrain traverses within the GeoRSA. Map validation is difficult outside these regions; and,
- › Soil erosion potential particle size is based on surficial geologic textures; both identified in the field and interpolated.

6 Fluvial Characterization

6.1 Time Series Fluvial Change Analysis

Historical aerial photographs along with LiDAR imagery were used to document channel morphology and assess changes in Bitter Creek. Fluvial mapping was completed within the Bitter Creek floodplain between the Highway 37A Bridge and the Bromley Glacier, herein referred to as the Bitter Creek Study Area (Figure 6-1). Morphological channel features were digitized for the years 1972, 1994, and 2013. A summary of the feature classifications and activity states are summarized below (Table 6-1).

Each mapped fluvial unit is assigned a relative numeric value linked to its activity state (i.e., active or dormant) and relative elevation above or below bankfull depth. The numeric values allow the use of spatial mathematics to compare multiple years and detect meaningful change such as quantifying erosion and deposition over time. The results are interpreted by the geomorphologist to describe the corresponding fluvial processes (Table 6-2).

For ease of description, a centerline of the main Bitter Creek channel in 2013 was created originating at the snout of the Bromley Glacier, and terminating at the Highway 37A bridge. The centerline is 17,070 m in length, and is marked by channel stations at 1,000 m intervals which are used to clarify regions of change.

Table 6-1: Feature identification and definitions used for river channel mapping.

| Component | Identification | Code | Description |
|---|----------------------|------|--|
| Channel Feature Classification | Main-channel | M | Flowing channel with distinct banks that carries the majority of river discharge. Usually a single thread; however, in wandering, braided and anastomosing reaches may be multiple threads flowing around bars. Feature activity is always active. |
| | Side-channel | S | Flowing channel with distinct banks that carries a portion of the river discharge less than the main-channel. Typically active in low to moderate flows. Feature activity is always active. |
| | Back-channel | B | Abandoned-channel with distinct banks whose downstream end is connected to the river but whose upstream end is plugged. Feature activity is always active. |
| Terrestrial Feature Classification | Flood-channel | F | Channel with distinct banks connected to a main- or side-channel only in overbank flood conditions. Flood-channels typically do not convey stream flow except under flood conditions. |
| | Lateral & point bars | L | Deposition of sand or gravel against the bank, deposited during high flows. |
| | Mid-channel bar | C | Deposition of sand or gravel within the channel, deposited during high flows. |
| | Floodplain | P | Flat area of overbank flow during flood events. |

Table 6-1 (Cont'd): Feature identification and definitions used for river channel mapping.

| Component | Identification | Code | Description |
|----------------|----------------|------|---|
| Activity State | Active | A | Indicates fluvial processes have acted on the feature within 1 to 2 years from the date of remote imagery or fieldwork; the floodplain and lateral, point or mid-channel bars are considered active until vegetation is established. |
| | Dormant | I | Indicates fluvial processes have not acted on the feature within 1 to 2 years from the date of remote imagery or field work; the floodplain and lateral, point or mid-channel bars are considered dormant when vegetation is present. |

6.2 Channel Change Detection Results

Fluvial features were mapped in detail for the years 2013, 1994, and 1972. Fluvial change was assessed from 1994 to 2013, 1972 to 2013, and 1972 to 1994. Interpretations and descriptions for the range of channel change processes are summarized in Table 6-2. The feature mapping results for 2013 are presented in Appendix H, and channel change detection results for the period from 1994 to 2013 are presented in Appendix I.

Table 6-2: Interpretation of channel change analysis.

| Interpretation | Description |
|---------------------|--|
| Colonization | Change in a terrestrial feature from a dormant state to an active state, often accompanied by the establishment of vegetation. |
| Denudation | Change in a terrestrial feature from an active state to a dormant state, often accompanied by the loss of vegetation. |
| High Deposition | Change of a channel feature to a dormant terrestrial feature (e.g., a vegetated point bar). |
| Moderate Deposition | Change of a channel feature to an active terrestrial feature (e.g., a main channel to an unvegetated medial bar). |
| Low Deposition | Change of a main channel feature to a side or back channel feature. |
| No Change | The feature has remained unchanged between years. May also include the change of one terrestrial feature to another with no accompanying change in activity state (e.g., an active medial bar to an active point bar). |
| Low Erosion | Change of a side or back channel feature to a main channel feature. |
| Moderate Erosion | Change of an active terrestrial feature to a channel feature (e.g., an active but empty flood channel to a side channel). |
| High Erosion | Change of a dormant terrestrial feature to a channel feature (e.g., a vegetated floodplain to a main channel). |
| Glacial Retreat | Retreat of the Bromley Glacier creating a new section of the Bitter Creek channel. |

6.2.1 Channel Change Reach Descriptions

The channel has been split into seven reaches within the Bitter Creek Study Area that share similar characteristics and trends in channel change over time (Figure 6-1). A summary of each reach is presented below. In several locations, the rate of lateral erosion between years has been extrapolated to provide estimated timelines for Bitter Creek to reach the proposed access road. However, road integrity may be impacted sooner than predicted following a major flood event or via retrogressive bank failures triggered by fluvial processes.



Figure 6-1: Bitter Creek Study Area (blue) and channel reaches.

6.2.1.1 Reach 1: 0+000 to 5+000

The uppermost channel reach originates at the Bromley Glacier and spans five kilometers downstream. The average stream gradient is approximately 4.0 %, which is the steepest section in the Bitter Creek Study Area. Much of the reach is bedrock controlled due to the recency of deglaciation which contributes to a high degree of lateral confinement. As a result, lateral erosion is limited, and most change is due to glacial retreat. Of important note are two regions of deposition on the right bank located between stations 3+700 and 4+200. These deposits are colluvial in nature, and are derived from the steep slopes above the left bank, indicating that large landslides have crossed Bitter Creek in the recent past (left bank denuded slopes in Appendix I-005).

The proposed access road is situated on an adjacent bedrock bench at least 50 m above the channel and Bitter Creek activity is not anticipated to impact the road in this reach. However, there is potential for large landslides to dam the creek between stations 3+700 and 4+200 which may release an outburst flood impacting downstream channel conditions and infrastructure.

6.2.1.2 Reach 2: 5+000 to 7+500

The Bitter Creek Valley widens and the channel takes on a meandering form in this reach. The average stream gradient drops to approximately 1.2 %, and the reach is aggradational. This section has been highly active since 1972, with channels and bars moving across the active floodplain which reaches 250 m across in some sections (see Appendix I-004 to I-005).

The proposed access road is set back from the active floodplain by 200 to 250 m in this reach, and sits at an elevation approximately 50 m above the creek. Based on observed changes to channel morphology, Bitter Creek is not anticipated to impact the access road in this reach.

6.2.1.3 Reach 3: 7+500 to 9+200

The meandering channel becomes more confined in this reach, and the stream gradient increases from Reach 2 to approximately 2.6 %. Lateral channel migration has caused erosion into the right bank toward the access road (examples at 7+900 and 8+500 in Appendix I-003 to I-004).

Between 1994 and 2013, the main channel has shifted northward into the glaciofluvial terrace by 25 m at station 8+500. If this rate holds constant, the main channel will erode into the access road in 40 years, which sits approximately 50 m away. However, impacts could be felt earlier due to undercutting of the terrace leading to bank failures.

6.2.1.4 Reach 4: 9+200 to 12+000

The valley widens to an active floodplain approximately 250 m across in this reach and the stream gradient lessens to approximately 2.1 %. Bitter Creek is joined by Roosevelt Creek, and the input of sediment contributes to the aggradational nature of the reach. At station 10+700, there is a slight constriction where the Swarm Creek fan extends into Bitter Creek, deflecting the channel into the right bank. Between 1994 and 2013, channel migration into the right bank has ranged between 10 and 20 m in several locations. From station 10+700 to 12+000, lateral erosion into softer glaciolacustrine banks is creating slope instabilities adjacent to the road (for example, at 10+800 in Appendix I-003 and Figure 6-2).



Figure 6-2: Bitter Creek bank failure in glaciolacustrine deposit, near Radio Creek (station 10+800). The headscarp is shown in white; dashed line shows approximate access road route.

Lateral erosion is presently undermining the pre-existing road where the proposed access road is slated to be built. This is apparent where the Bitter Creek channel is directed around the Swarm Creek fan toward the right bank at Radio Creek. This is triggering a failure in glaciolacustrine material as the toe of the slope is removed (Figure 6-2). As northward channel migration is expected to continue, this failure may retrogress toward the proposed access road as material is removed by the river. Additionally, at station 11+800, the main channel has shifted into the right bank by 50 m which has washed out a section of the previous road. Steep upper slopes confine the channel in this reach, which leaves little flexibility to set the road back from the erosive channel.

6.2.1.5 Reach 5: 12+000 to 13+800

In this reach, the valley constricts to an active floodplain less than 100 m across, while the stream gradient remains similar to Reach 4 (approximately 2.1 %). Bitter Creek is confined to a single meandering channel with erosion and deposition occurring at the outside and inside of meander bends, respectively. Lateral erosion ranged between 10 and 30 m between 1994 and 2013 (Appendix I-002).

Similar to the previous reach, lateral erosion is presently undermining the pre-existing road that the new access road will follow. The road has been undercut and washed out in several locations in this reach (near stations 12+300, 12+700, 12+950, and 13+600; Figure 6-3). At station 12+700, the proposed access road is within the main channel (see Appendix H-002). Natural fluvial processes will continue to erode laterally into the right bank and continue to undercut the access road unless protective measures are implemented. The steep confining hillslopes leave little flexibility to set the road back from the erosive channel.



Figure 6-3: Recent lateral erosion at A) Station 12+300; and B) 12+700 and 12+950. Black arrows denote direction of channel migration; dashed line shows approximate proposed access road route.

6.2.1.6 Reach 6: 13+800 to 14+900

Bitter Creek remains a meandering channel form in this reach as the active floodplain widens to approximately 150 m. Historically, Bitter Creek has altered between both sides of the floodplain from 1972 to 2013. Between 1994 and 2013, lateral erosion by the main channel has been concentrated on the left bank away from the access road. However, widespread vegetation loss (identified as denudation) suggests flood waters occupied and eroded the entire width of the active floodplain, reaching locally to within 10 m of the access road (Appendix I-001 to I-002).

There is the potential for road washout during flood events in this reach. While the main channel is presently located on the left side of the valley, recent activity indicates Bitter Creek should be expected to meander across the active floodplain. If this occurs, lateral erosion into the access road may become a concern.

6.2.1.7 Reach 7: 14+900 to 17+070

In this reach, the active floodplain constricts to approximately 100 m, and the stream gradient lessens to approximately 1.4 %. Channel migration was primarily toward the left bank between 1972 and 2013, and this is the side of greatest bank erosion. The banks of Bitter Creek have been armored by rip rap at the Highway 37A bridge, which will restrict lateral erosion at the downstream end of the reach (Appendix I-001).

There are two locations where the main channel encroaches to within 10 m of the proposed access road: station 15+000 and 15+800 (Figure 6-4). Since 1972, Bitter Creek has eroded into the right bank by 10 m at 15+000 and by 30 m at 15+800. At these rates, washouts of the proposed access road may be expected within 31 and 14 years respectively.



Figure 6-4: Lateral erosion and washout near station 15+000. Dashed line shows previous access road.

6.2.2 Limitations

Some limitations of this assessment are:

- › The scale and resolution of available aerial photographs limits the possible mapping detail;
- › The Bitter Creek stream stage at the time of imagery may be different between 1972, 1994, and 2013. This may create small over-prediction errors where features are close to the waterline (e.g., submergence or emergence of shallow floodplain features); and,
- › However, these limitations do not affect the conclusions drawn from the interpretation of the aerial photographs.

7 Water Crossing Risk-Based Assessment

Mountain creeks in the GeoRSA pose hydrogeomorphic hazards with the potential to adversely impact the proposed access road. These include water floods, debris floods, and debris flows. A spatial risk-based approach was applied as a screening tool to prioritize water crossings based on their relative likelihood that a hydrogeomorphic event will occur and have the potential to result in consequences to the proposed access road. The objective was to identify critical crossings for road construction and to evaluate sites for future site-specific assessments and monitoring.

This approach is considered risk-based because it accounts for the potential of the element at risk (i.e., the proposed access road) being impacted by different hazards. The method is predicated on the idea that not all risk is equal within the GeoRSA, and a preliminary risk-based assessment is possible by weighting characteristics of the potential hazards and their interactions with the proposed road. This is not a quantitative risk assessment. The assigned scores are based on grading the importance of the chosen factors rather than on numerical probabilities of hazard and severity of consequences.

Data used in the analysis included the following:

- › Field data, collected between August 25 and 30, 2014. Data collection was limited by access to the proposed water crossing sites. For this reason, certain sites were assessed by helicopter fly-over (Unnamed Creek 7 and Little Otter Creek);
- › Water Survey of Canada (WSC) hydrometric stations data (stations number 08EE008, 08EE012, and 08JD006);
- › Short duration Rainfall Intensity–Duration–Frequency data for Stewart BC station (BC 1067742);
- › Desktop-generated data: based on the analysis of LiDAR, field and air photos, to characterize current conditions of the channel and identify hazards, both present and potential;
- › Hydraulic analysis to determine thresholds of sediment mobility of each reach at the proposed road crossing and,
- › Proposed road alignment.

The methodology included five major steps: 1) hydraulic analysis; 2) hydrogeomorphic processes classification; 3) hazard potential evaluation; 4) elements at risk and exposure analysis; and (5) water crossing scoring and prioritization.

7.1 Watershed Hydraulic and Hydrogeomorphic Processes Classification

7.1.1 Hydraulic Analysis

The proposed road alignment crosses multiple watercourses. A total of 16 main streams were identified during the preliminary desktop assessment with the potential to impact the proposed access road. During the field investigation, no defined channel was observed to cross the access road at Crossing #1 (Unnamed Creek 1), and this creek has been excluded from the water crossing risk-based analysis as a result.

The remaining streams are all considered small mountain streams as per Church's (1992) classification, with the exception of Roosevelt Creek which displays characteristics of an intermediate type channel. Small mountain streams are typically small in dimension (width and depth) but have high stream power values owing to very steep slopes. Intermediate streams tend to have gentler slopes, and smaller grain size to depth of flow ratios.

The hydraulic analysis involved a characterization of main watershed features to determine thresholds of sediment mobility of each reach at the proposed road crossing. The paragraphs below describe methods used to delineate watersheds, conduct a regional flood frequency analysis (RFFA), calculate stream power, and bed shear stresses.

7.1.1.1 Regional Flood Frequency Analysis

Traditional RFFA was used to compare flow discharges of specific return intervals at each crossing. Despite the limitations of this tool in estimating flows at steep creeks (Jakob et al. 2016), it serves as a starting point and input to estimate debris flow or debris flood peak discharges (Holm et al., 2016). Three Water Survey of Canada (WSC) hydrometric stations were chosen for analysis from the surrounding region based on distance from the site (less than 200 km from site), length of record (greater than 15 years), elevation (less than 1,000 m asl), catchment area and acceptable data quality (Table 7-1). The instantaneous annual peak discharges were used for all calculations. Log-Pearson type III methodology was used for flood frequency analysis. Following the calculation of the flood frequency, a regional discharge-catchment area curve for each return period was developed (Figure 7-1).

Table 7-1: WSC hydrometric stations used in the RFFA

| Station Name | Station Number | Latitude (°N) | Longitude (°W) | Number of Years of Record | Catchment Area (km ²) |
|--------------------------------------|----------------|---------------|----------------|---------------------------|-----------------------------------|
| Goathorn Creek near Telkwa | 08EE008 | 54.65 | 127.12 | 31 | 125 |
| Simpson Creek at the Mouth | 08EE012 | 54.81 | 127.20 | 51 | 13.2 |
| Driftwood River above Kastberg Creek | 08JD006 | 55.98 | 126.68 | 33 | 403 |

The field visit coincided with the lowest flows on the annual hydrograph for 2014, based on discharge data accessed from the Water Survey of Canada¹.

Bankfull flow depth was estimated in the field or inferred from features observed in LiDAR data.

¹ <https://wateroffice.ec.gc.ca/>

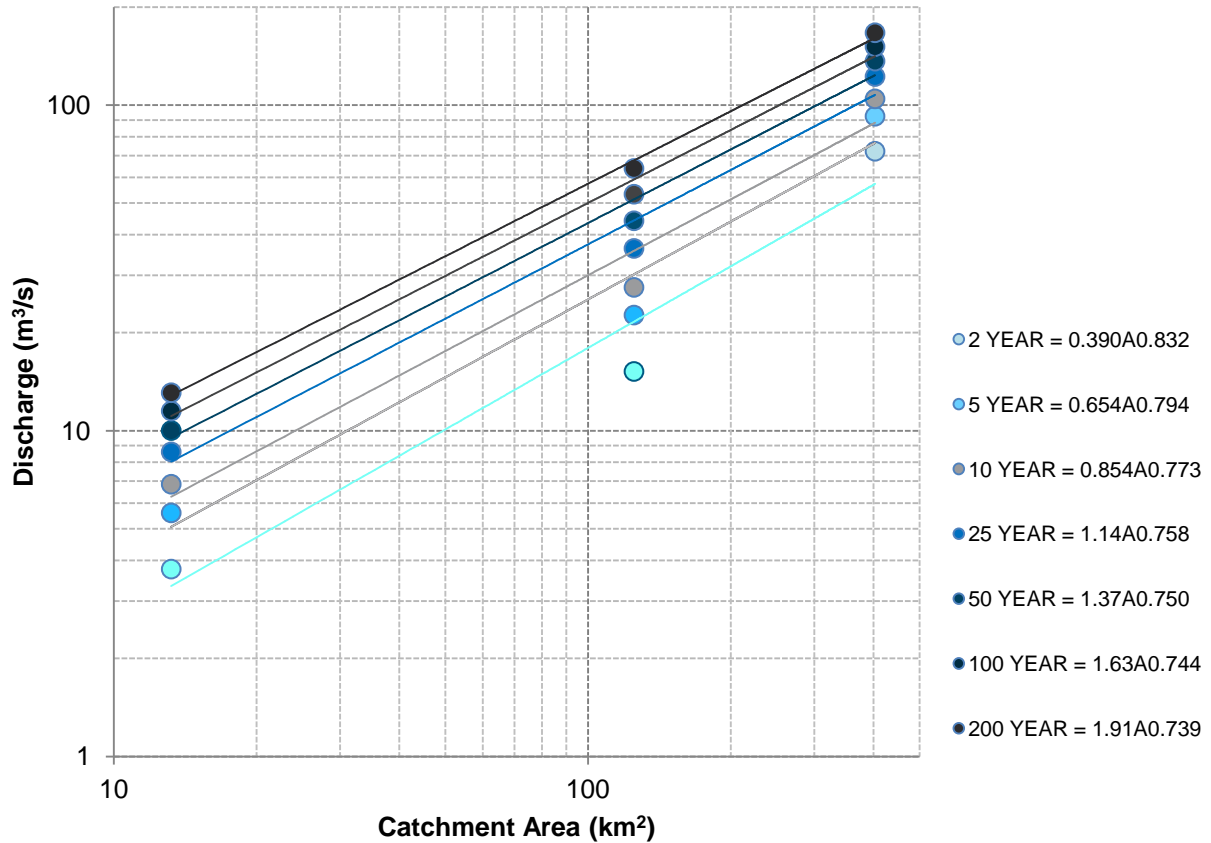


Figure 7-1: Regional Flood Frequency Curves developed from the WSC Stations listed in Table 7-1.

Table 7-2: Channel characteristics and estimated flow discharges for each stream crossing

| Stream Name | Catchment Area (km ²) | Bankfull Discharge (m ³ /s) | Bankfull Width (m) | Slope (m/m) | 100 Year Recurrence (m ³ /s) | 200 Year Recurrence (m ³ /s) |
|------------------|-----------------------------------|--|--------------------|-------------|---|---|
| Unnamed Creek 02 | 0.55 | 0.24 | 1.5 | 0.42 | 1.04 | 1.23 |
| Unnamed Creek 03 | 0.54 | 0.23 | 2 | 0.44 | 1.03 | 1.21 |
| Unnamed Creek 04 | 0.31 | 0.15 | 3 | 0.18 | 0.68 | 0.8 |
| Lim Creek | 0.65 | 0.27 | 4.5 | 0.62 | 1.18 | 1.39 |
| Radio Creek | 3.44 | 1.09 | 3.5 | 0.23 | 4.08 | 4.75 |
| Unnamed Creek 05 | 1.47 | 0.54 | 3 | 0.33 | 2.17 | 2.53 |
| Unnamed Creek 06 | 0.17 | 0.09 | 3 | 0.16 | 0.44 | 0.51 |
| Roosevelt Creek | 29.51 | 6.51 | 10 | 0.03 | 20.19 | 23.26 |
| Cambria Creek | 7.89 | 2.17 | 18 | 0.25 | 7.57 | 8.78 |

Table 7-2 (Cont'd): Channel characteristics and estimated flow discharges for each stream crossing

| Stream Name | Catchment Area (km ²) | Bankfull Discharge (m ³ /s) | Bankfull Width (m) | Slope (m/m) | 100 Year Recurrence (m ³ /s) | 200 Year Recurrence (m ³ /s) |
|--------------------|-----------------------------------|--|--------------------|-------------|---|---|
| Hartley Gulch | 7.65 | 2.12 | 6 | 0.29 | 8.84 | 10.35 |
| Otter Creek | 6.51 | 1.85 | 13 | 0.29 | 6.56 | 7.61 |
| Little Otter Creek | 0.34 | 0.16 | 2 | 0.18 | 0.73 | 0.86 |
| Rio Blanco | 2.9 | 0.95 | 7 | 0.47 | 3.6 | 4.19 |
| Unnamed Creek 07 | 0.25 | 0.12 | 1.25 | 0.34 | 0.58 | 0.68 |
| Goldslide Creek | 2.51 | 0.84 | 5 | 0.48 | 3.23 | 3.76 |

7.1.1.2 Stream Power Calculations

Stream power describes the energy dissipated against the channel bed and banks, including the energy available to do geomorphic work. It has been used as a predictive measure of bank erosion and channel migration (Hickin & Nanson, 1984; Nanson & Hickin, 1986), and of bedload transport (Bagnold, 1980; Martin & Church, 2000). The power available to erode and construct the bed is termed specific stream power (Bull, 1979), denoted by ω , and calculated as follows:

$$\omega = \rho g Q S$$

Where ρ is the density of flowing water (assumed to be 1,000 kg/m³), g is the acceleration due to gravity (9.807 m/s²), Q is discharge, and S is local slope of the channel bed.

Calculated stream power values are presented in Table 7-3 along with a hazard rating class based on an empirical analysis of an extensive river data set carried out by Nanson & Croke, (1992) (Table 7-4).

Table 7-3: Stream power calculations and hazard ratings for each stream crossing

| Stream Name | Stream Power per unit Width (W/m ²) | Stream Power Classification |
|------------------|---|-----------------------------|
| Unnamed Creek 02 | 652 | High |
| Unnamed Creek 03 | 504 | High |
| Unnamed Creek 04 | 87 | Moderate |
| Lim Creek | 369 | High |
| Radio Creek | 703 | High |
| Unnamed Creek 05 | 580 | High |
| Unnamed Creek 06 | 47 | Low |
| Roosevelt Creek | 192 | Moderate |
| Cambria Creek | 296 | Moderate |
| Hartley Gulch | 1004 | Extreme |

Table 7-3 (Cont'd): Stream power calculations and hazard ratings for each stream crossing

| Stream Name | Stream Power per unit Width (W/m ²) | Stream Power Classification |
|--------------------|---|-----------------------------|
| Otter Creek | 405 | High |
| Little Otter Creek | 140 | Moderate |
| Rio Blanco | 623 | High |
| Unnamed Creek 07 | 329 | High |
| Goldslide Creek | 790 | High |

Table 7-4: Hazard rating scheme for specific stream power in non-cohesive floodplains, from Nanson and Croke (1992)

| Specific Stream Power at bankfull discharge (W/m ²) | Hazard Rating | Dominant Processes | Landforms present | Description |
|---|---------------|--|---|--|
| > 1000 | Extreme | Substantial floodplain erosion and overbank vertical accretion; abandoned-channel accretion; minor lateral accretion | Boulder levees, sand and gravel splays; back-channels, abandoned channels, and scour holes. | Disequilibrium landforms that erode partially or completely in response to moderate or extreme events. Typically located in steep, upland watersheds, dominated by coarse entrainable material and steep slopes, leading to high susceptibility to erosion. Lateral migration is typically limited due to coarse alluvial or bedrock floodplain gulying. |
| 300 - 1000 | High | Substantial floodplain erosion and overbank vertical accretion | Large levees and deep back channels and scour holes | |
| 60 - 300 | Medium | Channel accretion and incision; overbank vertical accretion; minor lateral and abandoned channel accretion | Abandoned channels; braid-bars; islands and back channels. | Reaches in dynamic equilibrium with annual to decadal flow regime. Typically not affected by extreme events owing to overbank dissipation of energy in high flow events. |
| 10 - 60 | Low | Cut-bank erosion; lateral point-bar accretion; overbank vertical and abandoned channel accretion. Counterpoint accretion; minor oblique accretion. | Flat to undulating floodplain surface; oxbows; backswamps. | |
| 0 - 10 | Stable | Overbank accretion | Flat floodplains with low levees; backswamps. | Typically stable single-thread channels with low slopes and fine materials. |

7.1.1.3 Threshold of Sediment Transport

An analysis of sediment mobility was conducted to inform an assessment of channel stability under bankfull flow conditions. The methodology estimates the minimum size of sediment that can be entrained (set in motion) for the predicted flows at the proposed road crossing sites. In general, entrainment, transport, and deposition of sediment along a river bed are functions of the shear stress exerted by flow on the bed sediments and the sediment size and distribution. Bed shear stresses (τ_0) for predicted flows were calculated at each crossing site using the following equation:

$$\tau_0 = \rho g d S$$

Where d is bankfull flow depth, and the other parameters are the same as described above. Values for d and S were measured in the field, except for where indicated in Table 7-4.

The threshold of motion is determined as the minimum grain size, D , entrained for the given discharge magnitude, and is calculated from the bed shear stress (τ_0) estimates using the Shield's Relation:

$$D = \frac{\tau_0}{g(\rho_s - \rho_f)\theta}$$

Where ρ_s and ρ_f are the density of sediment ($2,650 \text{ kg/m}^3$) and the density of water ($1,000 \text{ kg/m}^3$), respectively. θ is the Shields Number, which is a ratio that describes the hydrodynamic forces acting on the bed and the submerged weight of the particle. A value of 0.07 was used for θ based on recommendations found in Knighton (1998).

The stability analysis was conducted for the bankfull flow, estimated by the 2-year discharge. This was chosen because it is considered the formative flow and has the largest influence over channel shape. The D_{50} and D_{90} estimated at each crossing site was then compared to the range in sediment entrainment values to determine the proportion of the bed that is expected to be in motion.

Table 7-5 presents the magnitude of these forces under bankfull conditions (shear stress), and the corresponding minimum grain size that these forces would entrain (D) along with the median (D_{50}) and largest (D_{90}) grain size observed on the bed.

Table 7-5: Results of sediment entrainment calculations and measured grain size values for each observed channel crossing

| Stream Name | Shear stress (N/m ²) | Minimum grain size entrained (m) | D_{50} (m) | D_{90} (m) |
|------------------|----------------------------------|----------------------------------|--------------|--------------|
| Unnamed Creek 02 | 824 | 0.7 | 0.12 | 0.3 |
| Unnamed Creek 03 | 1079 | 1.0 | 0.02 | 0.16 |
| Unnamed Creek 04 | 883 | 0.8 | 0.02 | 0.12 |
| Lim Creek | 1216 | 1.1 | 0.29 | 1.3 |
| Radio Creek | 902 | 0.8 | 0.07 | 0.3 |
| Unnamed Creek 05 | 1618 | 1.4 | 0.08 | 0.4 |
| Unnamed Creek 06 | 1255 | 1.1 | 0.04 | 0.1 |
| Roosevelt Creek | 588 | 0.5 | 0.12 | 1 |
| Cambria Creek | 2452 | 2.2 | 0.25 | 0.6 |
| Hartley Gulch | 4266 | 3.8 | 0.5 | 1 |

Table 7-5 (Cont'd): Results of sediment entrainment calculations and measured grain size values for each observed channel crossing

| Stream Name | Shear stress (N/m ²) | Minimum grain size entrained (m) | D ₅₀ (m) | D ₉₀ (m) |
|--------------------|----------------------------------|----------------------------------|---------------------|---------------------|
| Otter Creek | 4266 | 3.8 | 0.1 | 0.5 |
| Little Otter Creek | 1765 | 1.6 | 0.1 | 0.2 |
| Rio Blanco | 4609 | 4.1 | 0.12 | 0.3 |
| Unnamed Creek 07 | 333 | 0.3 | 0.06 | 0.09 |
| Goldslide Creek | 1412 | 1.2 | 0.3 | 0.75 |

The resulting calculated minimum grain sizes show that the entire range of bed material can be moved on all of the channels under bankfull flow conditions, with the exception of Lim Creek and Roosevelt Creek, where the largest grain size is not expected to be entrained, but the median grain size will be.

7.1.2 Hydrogeomorphic Processes Classification

The contributing watersheds above the identified main water crossings vary in size, relief, and available sediment supply. Because hydrogeomorphic processes are expected to behave differently in terms of flow mechanics (Table 7-6) and potential consequences, identifying the dominant processes at each water crossings is a significant first step in predicting the potential impacts of these hazards to the access road. For instance, while debris flows and debris floods can transport similar volumes of material, a debris flow may have a peak instantaneous discharge 40 times greater than an extreme flood, while a debris flood may have a peak instantaneous discharge only 1 to 2 times greater than that of an extreme flood (Hungry et al., 2001).

Three types of mechanisms are considered at road water crossing locations²: (1) clear-water floods; (2) debris floods; and (3) debris flows. Definitions for these processes are provided below.

- 1: Clear-water floods are any relatively high streamflow triggered by meteorological events that result in bank overtopping in any reach of a stream. In mountain creeks, such as the ones within the Bitter Creek watershed, floods are not conventional. In many cases, the water flow is accompanied by high volumes of sediment and the volumes of water are greater than the estimated meteorological event for the same return period (Jakob et al., 2016).
- 2: Debris floods are transitional processes between debris flow and clear-water floods, consisting of very rapid surging flow of water with high sediment concentration in a steep channel (Hungry et al. 2001). Solid concentration usually ranges between 20-47% by volume (Costa, 1988).
- 3: Debris flows are very rapid to extremely rapid flows of saturated non-plastic debris in a steep channel (Hungry, 2005). Sediment concentrations are over 50% solids by volume (Costa 1988; Jakob 2016), and mechanisms involve successive surges of solid-fluid mixtures (Iverson, 2005). Typical events require a gradient of at least 15° (Van Dine, 1985).

² Landslide dam outburst flood (LDOF) is a potential hazard in some water crossings. At locations where landslides travel to the valley floor, and the channel is constricted, there is the likelihood for channel blockage and formation of a dam and a temporary lake. Landslides dam fails shortly after they form creating peak discharges that are much larger than floods originating directly from snowmelt or rainfall (Costa & Schuster, 1988).

Table 7-6: Rheology characterization of flows in channels (adapted from Costa, 1988; Coussot and Meunier 1994)

| | Characteristic | Water flow | Debris flood | Debris flow |
|----------|-----------------------------------|---------------------------------|-------------------------------|---|
| Rheology | Sediment concentration | 1-40% by wt. 0.4-20% by vol. | 40-70 by wt. 20-47 by vol. | 50-90% by wt. 47-77% by vol. |
| | Bulk Density (g/cm ³) | 1.01-1.33 | 1.33-1.80 | 1.80-2.30 |
| | Type of fluid | Newtonian | Non-Newtonian | No plastic (plasticity index is less than 5%) |

Classification of the dominant hydrogeomorphic process at each main water crossing was interpreted from their watershed morphometrics (Table 7-7), interpretation of available imagery and LiDAR, as well as from field observation. The morphometric analysis incorporates the Melton ratio (the relation between watershed relief, as calculated from the fan apex, and the watershed area), watershed length (straight line from the fan apex to the watershed furthest edge), and average fan gradient. The original methodology was developed by Wilford et al. (2004) on a selection of nearby fans in west central British Columbia and refined by Holm et al. (2016) following observations made in the Canadian Rockies. In this report, the class limits to predict hydrogeomorphic types for watersheds with a mapped fan were used as defined by Holm et al. (2016).

Table 7-7: Class limits to predict hydrogeomorphic types for the assessed watersheds

| Process | Melton Ratio | Stream Length (km) | Fan Gradient (degrees) |
|---------------|--------------|--------------------|------------------------|
| Floods | <0.2 | all | < 3 |
| Debris Floods | <0.2 | all | >/ 3 |
| | 0.2 to 0.5 | all | all |
| | >/ 0.5 | </ 3 > 3 | </ 5 all |
| Debris Flows | > 0.5 | </ 3 | > 5 |

The watershed morphometric analysis resulted in ten crossings classified as debris flow prone and five crossings classified as debris flood prone (Table 7-8). From these crossings, nine were confirmed for debris flow and three for debris flood activity in the field. One crossing is not showing signs of debris flow activity (Unnamed Creek 2), and the two remaining crossings (Cambria Creek and Otter Creek) display activity for both, debris flow and debris flood processes. Description for these water crossings will be presented in the following section. Comments on Unnamed Creek 2 are presented below.

Unnamed Creek 2 (Crossing ID #2) exhibits typical features of a debris flow dominated channel based on Jakob (2005). The watershed is smaller than 5 km² with slope gradients greater than 15° (Table 7-8). At the time of the site visit, flow was present in the channel, but was minimal. The crossing is an ephemeral steep channel, with an existing, functional culvert at the proposed crossing location and rock berms lining the upstream banks to protect against lateral erosion (Figure 7-2). Directly upstream of the proposed

crossing location the channel bed is composed largely of bedrock with some colluvium. At present, there are not identifiable active landslides processes in the upper watershed suggesting that sediment supply and recharge rates are low. Bedrock control on the channel and limited sediment supply restrict debris flow development within the watershed. Conditions may change if slopes become active following an extreme hydrometeorological event.



Figure 7-2: Culvert outlet below former road at Unnamed Creek 2.

Table 7-8: Watershed Morphometric Summary Table for 15 Identified Creek Crossings

| Crossing ID # | Stream Name | Relief (km) | Watershed Length (km) | Watershed Area (km ²) | Melton Ratio | 100 Year Recurrence (m ³ /s) | 200 Year Recurrence (m ³ /s) | Stream Power per unit Width (Wm ²) | Fan Gradient (°) | Interpretation |
|---------------|--------------------|-------------|-----------------------|-----------------------------------|--------------|---|---|--|------------------|---------------------------|
| 2 | Unnamed Creek 2 | 1.27 | 2.4 | 0.55 | 1.68 | 1.04 | 1.23 | 652 | 23.9 | Debris Flow |
| 3 | Unnamed Creek 3 | 1.09 | 1.9 | 0.54 | 1.39 | 1.03 | 1.21 | 504 | 16.7 | Debris Flow ¹ |
| 4 | Unnamed Creek 4 | 1.03 | 1.6 | 0.31 | 2.13 | 0.68 | 0.8 | 87 | 6.3 | Debris Flow ¹ |
| 5 | Lim Creek | 1.27 | 2.2 | 0.65 | 1.39 | 1.18 | 1.39 | 369 | 26.4 | Debris Flow ¹ |
| 6 | Radio Creek | 1.41 | 2.8 | 3.44 | 0.81 | 4.08 | 4.75 | 703 | 15 | Debris Flow ¹ |
| 7 | Unnamed Creek 5 | 1.36 | 2.5 | 1.47 | 1.42 | 2.17 | 2.53 | 580 | 13.5 | Debris Flow ¹ |
| 8 | Unnamed Creek 6 | 1.42 | 2.7 | 0.17 | 1.71 | 0.44 | 0.51 | 47 | 15.4 | Debris Flow ¹ |
| 9 | Roosevelt Creek | 2.16 | 8 | 29.51 | 0.4 | 20.19 | 23.26 | 192 | 3.7 | Debris Flood ² |
| 10 | Cambria Creek | 1.98 | 4.5 | 7.89 | 0.71 | 7.57 | 8.78 | 296 | 7.3 | Debris Flood ³ |
| 11 | Hartley Gulch | 2.34 | 5.1 | 7.65 | 0.85 | 8.84 | 10.35 | 1004 | 15.3 | Debris Flood ² |
| 12 | Otter Creek | 2.01 | 4.5 | 6.51 | 0.81 | 6.56 | 7.61 | 405 | 19.8 | Debris Flood ³ |
| 13 | Little Otter Creek | 1.04 | 2 | 0.34 | 1.79 | 0.73 | 0.86 | 140 | 20.5 | Debris Flow ¹ |
| 14 | Rio Blanco Creek | 1.49 | 2.9 | 2.9 | 0.89 | 3.6 | 4.19 | 623 | 23.5 | Debris Flow ¹ |
| 15 | Unnamed Creek 7 | 0.89 | 1.3 | 0.25 | 1.61 | 0.58 | 0.68 | 329 | 24.8 | Debris Flow ¹ |
| 16 | Goldslide Creek | 1.41 | 3.4 | 2.51 | 0.83 | 3.23 | 3.76 | 790 | 21.2 | Debris Flood ² |

Notes: (1) Debris flow activity corroborated in the field. (2) Evidence in the field suggests that debris floods are dominant processes over debris flows. (3) Debris flow and debris flood are both active processes within the watershed. Blue shaded rows are debris flood prone streams; yellow shaded rows are debris flow prone streams.

7.1.3 Hazard Potential Evaluation

Hydrogeomorphic hazard potential was assessed and weighted qualitatively based on: 1) geomorphic evidence of past and potential debris flow and debris flood activity within the watersheds and fans; and, 2) relative hazard frequency ratings as they relate to rainfall thresholds for initiation of channelized debris flows.

7.1.3.1 Geomorphic evidence for hydrogeomorphic processes at each crossing

Analyzing the geomorphic evidence is a key step to determine if debris floods and debris flows are existing hazards on a fan (Jackson et al. 1987; Jakob 2005). Debris flows, in particular, print unique signatures on the transport zone and fan deposits that are observable several years later after the occurrence of the event. Field indicators of hydrogeomorphic processes activity within the watershed and fans are shown in Table 7-9, and specific examples for observations within the study area are summarized in the paragraphs below.

Table 7-9: Field indicators of flows in steep channels (adapted from Jackson et al. 1987; Costa, 1988 and Jakob, 2005)

| Hydrogeomorphic Process | Landforms, Deposits and Activity signs | Sedimentary Structures | Sedimentary Characteristics |
|-------------------------|---|--|---|
| Clear-water floods | Bars, fans, sheets, splays, channels have large width to depth ratio | Horizontal or inclined stratification to massive; weak to strong imbrications; cut an fill structures; upgraded to graded | Clast-supported; normally distributed rounded clasts; wide range of particle sizes |
| Debris Floods | Similar to clear – water flood | Weak horizontal stratification to massive; weak imbrications; thin gravel lenses; normal and re-verse grading | Clast-supported open-work texture; predominantly coarse sand |
| Debris Flows | Source Areas: Active landslides (e.g. debris slides, debris avalanches and rock fall) recharging the channel; presence of erodible debris deposits | Weak grading to inverse grading, lack of sorting and imbrications, inverse grading of fan or levee deposits, normal grading near top | Matrix supported, angularity of boulders, extreme range of particle sizes; larger blocks and megaclasts |
| | Transport Zone: unvegetated channel, in-channel stored sediments, well-defined boulder trains and step sided levees, scour marks, mudlines and debris impact scars on living trees well above the clear-water flood limit | | |
| | Fan: marginal levees, terminal lobes, large size boulders | | |

As discussed in Section 7.3.1, the water crossing streams display typical characteristics of small mountain streams and are dominated more by hydrogeomorphic processes than by fluvial processes. For this reason, the geomorphic evidence documented here focuses on debris floods and debris flow activity only. The watersheds have been broken down into three distinctive areas to facilitate the analysis: 1) Initiation (source) areas; 2) transport zone; and, 3) deposition zone (fan).

- › Initiation (source) areas: upper section of the watersheds characterized by the presence of active landslides (continuous production of debris) and the potential for further slope instability (See Section 3.7 for details). Erodible surficial deposits occupy large areas and include different sources such as talus at the base of steep bedrock slopes, regolith, and colluvium/hill wash material (Figure 7-3). Glacial retreat seems to be playing a key role as a causative factor of slope instability in this section, providing a continuous supply of debris.
- › Transport zone: this is the area where mobilization and entrainment of material is expected to occur. In the debris flow prone watersheds, this section is characterized by steep and unvegetated channel filled with debris. Levees are visible in some watersheds (Figure 7-4).
- › Deposition zone: fans vary in size and activity. Active fans within the GeoRSA are generally unvegetated or covered with low pioneer vegetation; lobes and levees are visible on ground or LiDAR, boulders on levees and debris flow deposits are very loose (Figure 7-4).

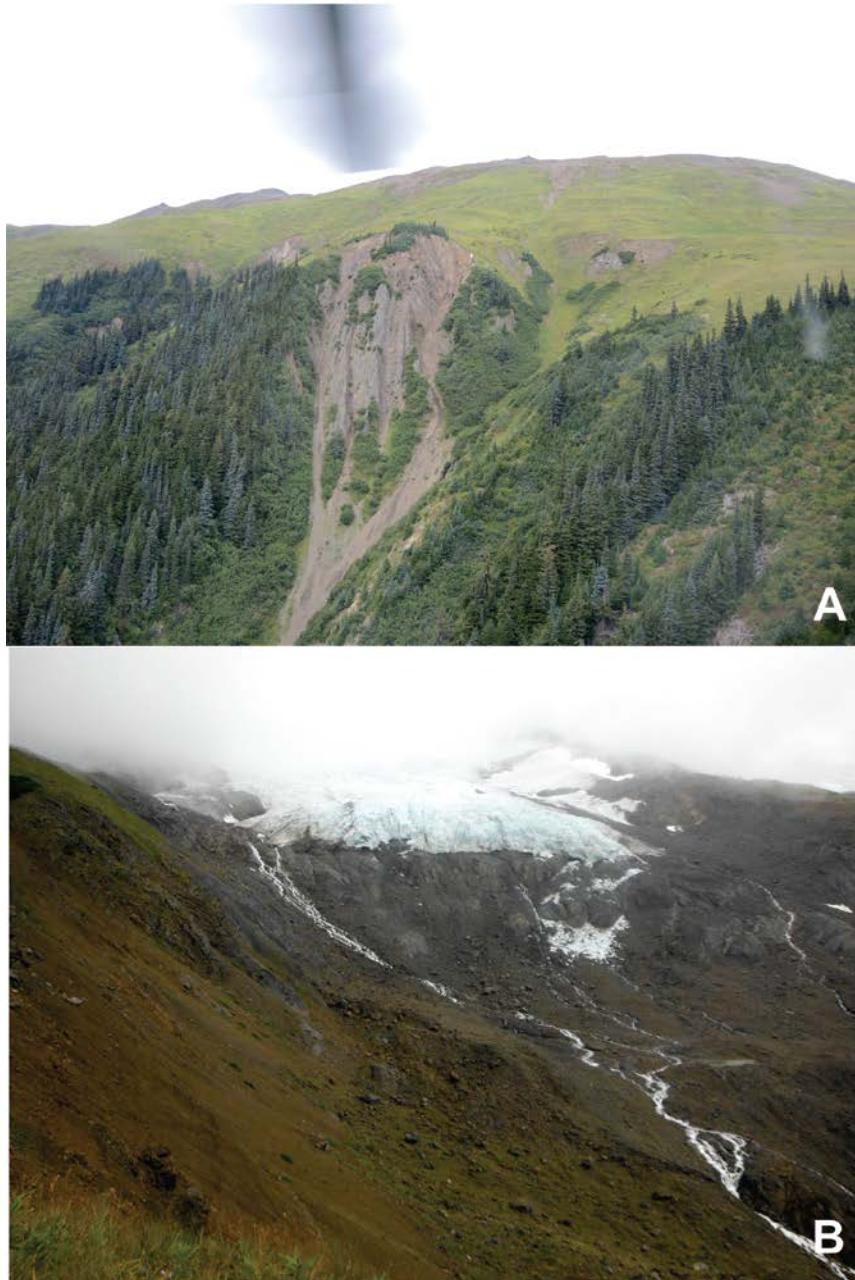


Figure 7-3: Examples of actively eroding areas and transport-limited watersheds. A) Debris flow channel with multiple branches and significant accumulation of debris mobilized by water run-off (Unnamed Creek 6). B) Unvegetated slope showing unconsolidated rock fragments, covering bedrock (Otter Creek)



Figure 7-4: Some examples of debris flow evidence within the transport and fan zone. A) Debris flow deposit at Cambria Creek. Note range of particle sizes and angularity of boulders. B) Bare fan displaying large boulders and step-sided levees (Otter Creek)

7.1.3.2 Relative Hazard Frequency

The probability of occurrence of a debris flow is a combination of three factors: 1) availability of erodible sediments within the watershed system; 2) probability of landslide occurrence; and 3) the probability at which hydrometeorological thresholds are exceeded (Jakob, 2005). The relative frequency of hydrogeomorphic events occurring in the watershed was determined using a three-step qualitative approach.

The first step consisted of classifying the watersheds into supply-limited and transport-limited based on the consideration of sediment availability (i.e. active sources areas, sediments stored in channel and generation potential) (Table 7-11). Supply-limited watersheds are those in which the debris sources areas and channels contain a limited amount of erodible sediments, and recharge depends on weathering and mass wasting processes following a debris flow. Transport-limited (supply-unlimited) watersheds contain an unlimited supply of sediments and, channels are quickly recharged before a hydrometeorological threshold is exceeded (Jakob, 1996 and Jakob, 2005). Implications to frequency are related to sediment recharge time. While transport-limited watersheds can experience a debris flow almost every time that a hydrometeorological threshold is exceeded, supply-limited watersheds will need more time to recharge before the next event could occur.

Frequency data for hydrogeomorphic processes is not available for the GeoRSA and an estimation of absolute frequency was beyond the scope of this study. However, because the majority of the watersheds are transport-limited, and sediment supply is not a constraint, it is reasonable to expect that the probability of hydrogeomorphic events for the water crossings would be highly controlled by the probability at which hydrometeorological thresholds is exceeded. The second step in the frequency analysis consisted of a review of short duration rainfall intensity–duration–frequency data for the closest climate station (Stewart A BC, 1067742), followed by a comparison with minimum rainfall initiation thresholds for debris flows. The main objective of this step was to have a better understanding of the frequency of heavy rains and how they compare with shallow landsliding and debris flow initiation. Figure 7-5 shows intensity-duration-frequency (IDF) curves plotted for the maximum rainfall for the period 1978-2013. All IDF curves for the selected return periods plotted above of the selected rainfall thresholds for debris flow initiation (Crosta, 2001; Jakob 2003 and Guzzetti, 2008). This indicates that debris-flow triggering storms may occur more than once in a given year, and whether debris flows initiate or not will also depend on the antecedent rain. Research by different authors showed that a 1- to 4-week time frame was required to reach soil saturation levels conducive to debris flow initiation [Jakob & Weatherly (2003); Chleborad (2000); and White and Schwab (2005)].

The third step consisted of assigning hazard scores to each water crossing based on the qualitative frequency (Table 7-10) and the percentage of active landslide area. Results are shown in Table 7-11.

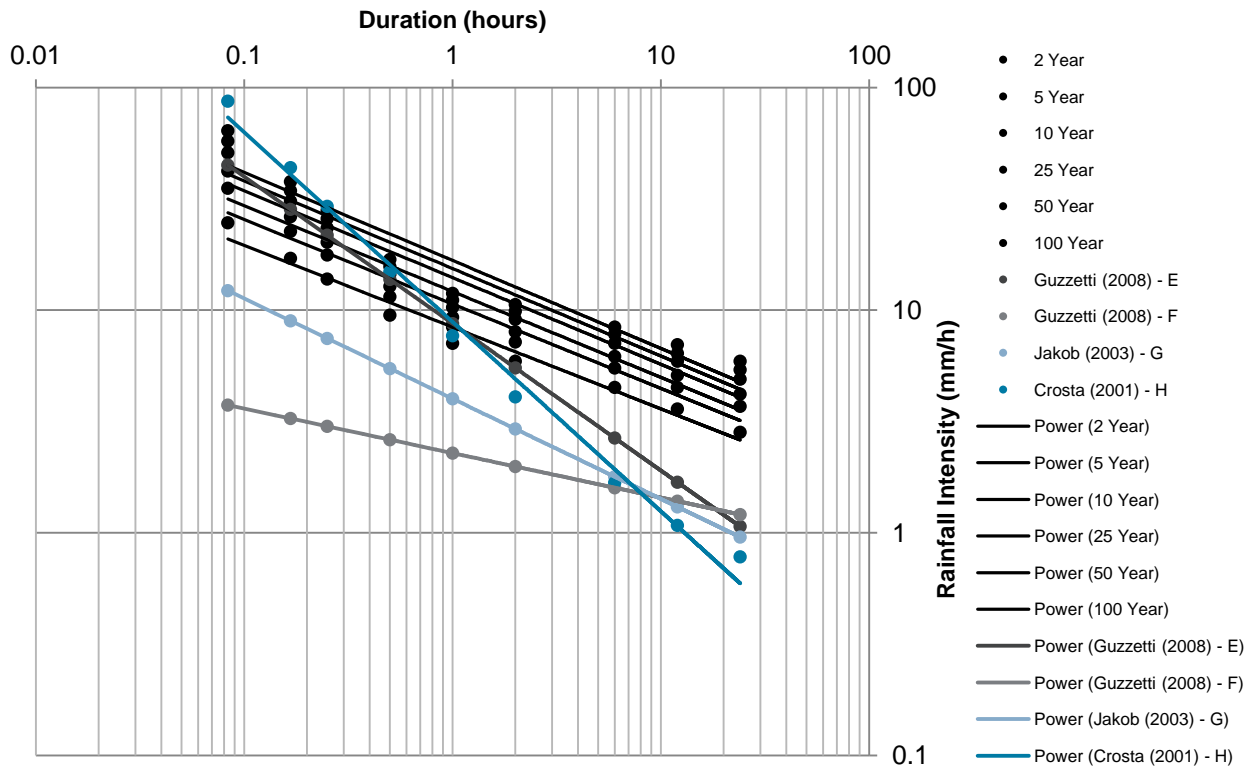


Figure 7-5: Short Duration Rainfall Intensity–Duration–Frequency curves for Stewart A BC (1067742) and rainfall thresholds for debris flow initiation (Crosta, 2001; Jakob 2003 and Guzzetti, 2008)

Table 7-10: Qualitative frequency categories and rating scores for hydrogeomorphic events (Adapted from Hungr, 1997; Lee and Jones, 2004)

| Class Frequency | Description | Range of Expected Annual Probability | Score |
|-----------------|---|--------------------------------------|-------|
| Very High | Transport-limited watershed with indicators of recent activity. Clear fresh signs of hazard are present (bare fans, levees and lobes visible on ground and LiDAR). Hazard is imminent, and very likely to occur within the design lifetime of the Project | Lower than 1/20 | 4 |
| High | Hazard is likely within the design lifetime of the Project | 1/20 to 1/100 | 3 |
| Moderate | Supply-limited watershed (with limited or no activity in the sources areas). Hazard is possible within the design lifetime (10% in 50 years is used as a standard by the British Columbia Ministry of Transportation) | 1/100 to 1/500 | 2 |
| Low | Supply-limited watershed (with limited or no activity in the sources areas). Channel and fans are vegetated. Other debris flow indicators such as levees and lobes are not visible on the ground and/or LiDAR. Hazard is highly unlikely, but not impossible within the design lifetime | Greater than 1/500 | 1 |

Table 7-11: Scores for hydrogeomorphic hazard at each site location

| Crossing ID # | Stream Name | % of unstable terrain class ¹ (A) | Basin Differentiation | Class Frequency (B) | Hazard Score (P _H = A * B) | Hazard Class (P _H) |
|---------------|------------------------------|--|-----------------------|---------------------|---------------------------------------|--------------------------------|
| 2 | Unnamed Creek 2 | Low (1) | Supply-limited | Moderate (3) | 3 | Low |
| 3 | Unnamed Creek 3 | Low (1) | Supply-limited | Moderate (3) | 3 | Low |
| 4 | Unnamed Creek 4 | Moderate (2) | Supply-limited | Moderate (3) | 6 | Moderate |
| 5 | Lim Creek | Low (1) | Supply-limited | High (3) | 3 | Low |
| 6 | Radio Creek | Moderate (2) | Transport limited | High (3) | 6 | Moderate |
| 7 | Unnamed Creek 5 | Moderate (2) | Transport limited | High (3) | 6 | Moderate |
| 8 | Unnamed Creek 6 | Low (1) | Transport limited | High (3) | 3 | Low |
| 9 | Roosevelt Creek | Moderate (2) | Transport limited | High (3) | 6 | Moderate |
| 10 | Cambria Creek | High (3) | Transport limited | Very High (4) | 12 | Very High |
| 11 | Hartley Gulch | High (3) | Transport limited (2) | Very High (4) | 12 | Very High |
| 12 | Otter Creek | High (3) | Transport limited | Very High (4) | 12 | Very High |
| 13 | Little Otter Creek | High (3) | Transport limited | High (3) | 9 | High |
| 14 | Rio Blanco Creek | High (3) | Transport limited | Very High (4) | 12 | Very High |
| 15 | Unnamed Creek 7 | High (3) | Transport limited | Very High (4) | 12 | Very High |
| 16 | Goldslide Creek ² | High (3) | Transport limited | Very High (4) | 12 | Very High |

Notes: (1) % of unstable terrain. Low= less than 15%; Moderate= 15-35%; High= greater than 35%. Blue shaded rows are debris flood prone streams; yellow shaded rows are debris flow prone streams.

7.1.4 Elements at Risk and Exposure Analysis

Elements at risk include all infrastructure, population, environment, activities and processes that may be negatively impacted by a hazardous event in a particular area (Cuervo and Guthrie, 2013). As the proposed road is a static element at risk, the probability that a hydrogeomorphic event will occur and have the potential to threaten the road will highly depend on: 1) the spatial location of the access road with respect to the hazard (i.e. location within the watershed system); and, 2) hazard characteristics and related damaging processes at that location. The spatial probability of flow impact is called exposure.

The road exposure was evaluated by weighting the potential occurrence of channel and bank erosion, impact of debris, and avulsion. For each water crossing, a location was selected (i.e. transport zone, fan apex, fan mid-section or fan distal-section) and a score assigned (Table 7-12). The final exposure score was calculated as follows:

$$P_E = \sum C_{es} + B_{es} + I_{ds} + A_{ps}$$

Where:

- P_E = Numerical score for road exposure
- C_{es} = Weighting for channel erosion
- B_{es} = Weighting for bank erosion
- I_{ds} = Weighting for impact of debris
- A_{ps} = Weighting for avulsion potential

Table 7-12: Criteria and scores used to weight potential damaging processes that may impact the road during a hydrogeomorphic event

| Potential damaging processes | Description | Section | | | | Classes | | |
|---|--|---------|----|----|----|--|--|--|
| | | TZ | FA | MS | DS | High (Score = 3) | Moderate (Score= 2) | Low (Score = 1) |
| Channel erosion (C_{es}) ¹ | Lowering of the channel bed through sediment removal over long reaches of the channel | x | x | | | Specific Stream Power at bankfull discharge (W/m^2) > 300. Substantial bed erosion and overbank vertical accretion is expected in highly erodible bed substrates (e.g. fine sands, silt and clays) | Specific Stream Power at bankfull discharge (W/m^2) 60-300. Bed erosion is expected to be moderate in beds composed of gravels and cobbles | Specific Stream Power at bankfull discharge (W/m^2) < 60. Bed erosion is expected to be minor in low erodibility bed substrates (e.g., bedrock gully, and boulders) |
| Bank erosion (B_{es}) ¹ | Removal of bank materials either as grain-by-grain entrainment or by mass-movement such as sliding or toppling | x | x | x | x | Specific Stream Power at bankfull discharge (W/m^2) > 300. Bank erosion is expected to be high in vegetated and unvegetated banks composed of highly erodible material (e.g. fine sands, silt and clays) | Specific Stream Power at bankfull discharge (W/m^2) 60-300. Bank erosion is expected to be moderate in well vegetated banks composed of less erodible material (e.g., gravels and cobbles) | Specific Stream Power at bankfull discharge (W/m^2) < 60. Bank erosion is expected to be minor in low erodibility (e.g., bedrock and boulders) and/or well vegetated banks |

Table 7-12 (Cont'd): Criteria and scores used to weight potential damaging processes that may impact the road during a hydrogeomorphic event

| Potential damaging processes | Description | Section | | | | Classes | | |
|---|--|---------|----|----|----|---|---|--|
| | | TZ | FA | MS | DS | High (Score = 3) | Moderate (Score= 2) | Low (Score = 1) |
| Impact of debris (I_d_s) ² | Impact pressures that result from the impact of debris. Frontal impact is dominant in the apex section of the fan and debris accumulation and abrasion, are dominant in the distal section | x | x | x | x | Area in which the flow surges are expected to travel. Risk of impact and damage from larges particles (boulders) is expected to be high | Include areas in which later debris surges may be diverted and/or through which after-flow may travel and accumulate sediment. Risk of impact is expected to be lower | Areas exposed to flooding as a result of main channel blockage by large debris. Risk of impact is low |
| Avulsions (A_p_s) ^{2, 3} | Abrupt change in channel pathway where the original channel is abandoned and a new one is formed | | x | x | x | Areas with evidence of previous avulsion and/ or poorly confined channel sections. Unoccupied side channels. Avulsions are expected | Channel sections where confinement could be reduced during an event. Avulsions are possible | Channel is totally confined within the section (laterally contained) or channel banks are made up of bedrock. Avulsions are unlikely |

Notes: TZ= Transport Zone; FA= Fan Apex; MS= Mid Section; DS= Distal Section. (1) Stream Power was used as a proxy of channel bed and bank erosion. (2) Interpreted from LiDAR and field data. (3) Criteria based on Kellerhals and Church (1990).

Table 7-13: Prioritization scores for potential damaging processes on the proposed access road water crossings

| Crossing ID # | Stream Name | Road Crossing Section | Stream Power Classification | Exposure to potential damaging processes (EPDP) ¹ | | | | EPDP Score | EPDP Class |
|---------------|-----------------|-----------------------|-----------------------------|--|--------------------------|------------------------------|--------------------------------|------------|------------|
| | | | | Channel Erosion Score (C_e_s) | Bank erosion (B_e_s) | Impact of debris (I_d_s) | Avulsion potential (A_p_s) | | |
| 2 | Unnamed Creek 2 | Fan Apex | High | Low (1) | Low (1) | High (3) | Low (1) | 6 | Low |
| 3 | Unnamed Creek 3 | Distal Section | High | Low (1) | Low (1) | High (3) | Moderate (2) | 7 | Low |
| 4 | Unnamed Creek 4 | Distal Section | Moderate | Low (1) | Moderate (2) | Moderate (2) | High (3) | 8 | Moderate |

Table 7-13 (Cont'd): Prioritization scores for potential damaging processes on the proposed access road water crossings

| Crossing ID # | Stream Name | Road Crossing Section | Stream Power Classification | Exposure to potential damaging processes (EPDP) ¹ | | | | EPDP Score | EPDP Class |
|---------------|------------------------------|-----------------------|-----------------------------|--|---------------------------------|-------------------------------------|---------------------------------------|------------|------------|
| | | | | Channel Erosion Score (Ce _s) | Bank erosion (Be _s) | Impact of debris (Id _s) | Avulsion potential (Ap _s) | | |
| 5 | Lim Creek | Distal Section | High | Low (1) | Low (1) | High (3) | Low (1) | 6 | Low |
| 6 | Radio Creek | Mid Section | High | High (3) | Moderate (2) | High (3) | Low (1) | 9 | Moderate |
| 7 | Unnamed Creek 5 | Distal Section | High | Low (1) | Low (1) | High (3) | High (2) | 7 | Low |
| 8 | Unnamed Creek 6 | Distal Section | Low | Low (1) | Low (1) | Low (1) | High (3) | 6 | Low |
| 9 | Roosevelt Creek | Fan Apex | Moderate | Moderate (2) | High (3) | Moderate (2) | High (3) | 10 | Moderate |
| 10 | Cambria Creek | Fan Apex | Moderate | Moderate (2) | Moderate (2) | High (3) | High (3) | 12 | High |
| 11 | Hartley Gulch | Fan Apex | Extreme | High (3) | High (3) | High (3) | Moderate (2) | 11 | High |
| 12 | Otter Creek | Mid Section | High | High (3) | High (3) | High (3) | High (3) | 12 | High |
| 13 | Little Otter Creek | Transport Zone | Moderate | Moderate (2) | Moderate (2) | High (3) | Very Low (0) | 8 | Moderate |
| 14 | Rio Blanco Creek | Transport Zone | High | High (3) | Low (1) | High (3) | Very Low (0) | 8 | Moderate |
| 15 | Unnamed Creek 7 | Transport Zone | High | High (3) | Low (1) | High (3) | Very Low (0) | 7 | Low |
| 16 | Goldslide Creek ² | Transport Zone | High | High (3) | Low (1) | High (3) | Very Low (0) | 7 | Low |

Note: (1) Scores were assigned to the proposed access road alignment, as of November 1, 2016. (2) Proposed access road crosses Goldslide Creek in two different locations. Assessment was conducted at the further downstream crossing. Blue shaded rows are debris flood prone streams, yellow shaded rows are debris flow prone streams.

7.1.5 Water Crossing Scoring and Prioritization

Water crossings were ranked based on the relative likelihood that a hydrogeomorphic process will impact the road. A priority score was calculated as follows:

$$P_{HP} = P_H \times P_E$$

Where:

P_{HP} = Numerical priority score for hydro-geomorphic processes

P_H = Numerical score for hazard likelihood

P_E = Numerical score for road exposure

The hazard frequency and consequence ratings for the access road were combined using a priority matrix scheme (Table 7-14). A class of Low, Moderate, or High was assigned to each water crossing (Table 7-15). The summary of the water crossing risk-based assessment) and potential implications related to risk management during construction and operation is presented in Table 7-16.

Table 7-14: Priority classes matrix scheme (unmitigated condition)

| Hazard Class | Hazard Description | Exposure Class | | |
|--------------|---|---|---|--|
| | | Low (1) | Moderate (2) | High (3) |
| | | Access road is partially exposed to hydrogeomorphic hazards and consequences from damaging processes are expected to be low. Minor impact from debris. Treatment following an event may include removal of debris and minor repairs | Access road is exposed to hydrogeomorphic hazards and consequences from damaging processes are expected to be moderate. Road overtopping is likely. Damage to the surface road and stream related infrastructure may include impact of large debris (boulder size), scour and blockage of bridges | Access road is exposed to hydrogeomorphic hazards (e.g. fan apex or transportation zone) and consequences from damaging processes are expected to be high. Washout of the surface road and major structural damage to total destruction of stream related infrastructure at the crossing is expected |
| Low (1) | Hazard is highly unlikely, but not impossible within the design lifetime. Probability is lower than 1/500 | Low (1) | Moderate (2) | Moderate (3) |
| Moderate (2) | Hazard is likely within the design lifetime of the Project. Probability ranges 1/100 to 1/500 | Moderate (2) | Moderate (4) | High (6) |
| High (3) | Hazard is possible within the design lifetime. Probability ranges from 1/20 to 1/100 | Moderate (3) | High (6) | Very High (9) |

Table 7-14 (Cont'd): Priority classes matrix scheme (unmitigated condition)

| Hazard Class | Hazard Description | Exposure Class | | |
|---------------|--|---|---|--|
| | | Low (1) | Moderate (2) | High (3) |
| | | Access road is partially exposed to hydrogeomorphic hazards and consequences from damaging processes are expected to be low. Minor impact from debris is expected. Treatment following an event may include removal of debris and minor repairs | Access road is exposed to hydrogeomorphic hazards and consequences from damaging processes are expected to be moderate. Road overtopping is likely. Damage to the surface road and stream related infrastructure may include impact of large debris (boulder size), scour and blockage of bridges | Access road is exposed to hydrogeomorphic hazards (e.g. fan apex or transportation zone) and consequences from damaging processes are expected to be high. Washout of the surface road and major structural damage to total destruction of stream related infrastructure at the crossing is expected |
| Very High (4) | Hazard is imminent, and very likely to occur within the design lifetime of the Project. Probability is greater than 1/20 | Moderate (4) | Very High (8) | Very High (12) |

Table 7-15: Main water crossings prioritization within the GeoRSA (Based on November 1, 2016 proposed access road alignment)

| Crossing ID # | Stream Name | Hazard Class (P _H) | Exposure Class (P _E) | Numerical Priority Score (P ^{HP}) | Priority Class |
|---------------|-----------------|--------------------------------|----------------------------------|---|----------------|
| 2 | Unnamed Creek 2 | Low (1) | Low (1) | 1 | Low |
| 3 | Unnamed Creek 3 | Low (1) | Low (1) | 2 | Low |
| 4 | Unnamed Creek 4 | Moderate (2) | Moderate (2) | 6 | Moderate |
| 5 | Lim Creek | Low (1) | Low (1) | 1 | Low |
| 6 | Radio Creek | Moderate (2) | Moderate (2) | 4 | Moderate |
| 7 | Unnamed Creek 5 | Moderate (2) | Low (1) | 2 | Moderate |
| 8 | Unnamed Creek 6 | Low (1) | Low (1) | 1 | Low |
| 9 | Roosevelt Creek | Moderate (2) | Moderate (2) | 4 | Moderate |
| 10 | Cambria Creek | Very High (4) | High (3) | 12 | Very High |
| 11 | Hartley Gulch | Very High (4) | High (3) | 12 | Very High |
| 12 | Otter Creek | Very High (4) | High (3) | 12 | Very High |

Table 7-15 (Cont'd): Main water crossings prioritization within the GeoRSA (Based on November 1, 2016 proposed access road alignment)

| Crossing ID # | Stream Name | Hazard Class (P _H) | Exposure Class (P _E) | Numerical Priority Score (P ^{HP}) | Priority Class |
|---------------|--------------------|--------------------------------|----------------------------------|---|----------------|
| 13 | Little Otter Creek | High (3) | Moderate (2) | 6 | High |
| 14 | Rio Blanco Creek | Very High (4) | Moderate (2) | 8 | Very High |
| 15 | Unnamed Creek 7 | Very High (4) | Low (1) | 4 | Moderate |
| 16 | Goldslide Creek | Very High (4) | Low (1) | 4 | Moderate |

Table 7-16: Priority level implications for risk management (unmitigated case) during construction and operation

| Priority Class | Potential implications for road construction and operation |
|----------------|--|
| Low | Water crossings in this category include ephemeral streams with low sediment potential and debris recharge rates. The level of risk is expected to be acceptable and can be managed by current standard practices. Continue to monitor and maintain to prevent changes that may alter current dynamics. Design considerations: peak clear-water flow may not be sufficient to design culverts. Consider dominant hydrogeomorphic events and their potential for sediment accumulation to size stream related infrastructure. |
| Moderate | The risk level is expected to be tolerable (provided that adequate mitigation is in place). Some crossings in this category may require detailed investigation to plan for mitigation and risk reduction (e.g. Roosevelt and Radio Creeks). Design considerations: engineering design needs to consider potential hydrogeomorphic events and their potential for sediment accumulation to size stream related infrastructure. The Q ₂₀₀ peak discharge has proven to be insufficient to design infrastructure in debris flood/debris flow prone watersheds. |
| High | Water crossings in this category displayed evidence of hydrogeomorphic hazards that warrant careful consideration at the engineering design stage. Detailed investigations on the magnitude of potential events should be conducted to properly size stream related infrastructure and reduce risk to acceptable levels. Potential hydrogeomorphic processes, debris flows in particular, on the access road could damage vehicles and injure personnel. It could also cause temporary road closure, resulting in a disruption to mining activities. Risk- reduction measures are required at construction and operation stages. |
| Very High | |

- › Priority classes presented in Table 7-16 are only valid for the proposed access road alignment as of November 1, 2016. Changes to water crossings location, may result in changes to the priority risk-based class. Any changes to road alignment, in subsequent stages of the Project development, should be reassessed for debris flood and debris flow hazard.

7.1.6 Limitations

Some limitations to the water crossing risk-based assessment include:

- › The proposed risk-based methodology is a screening tool based on a semi-quantitative exercise. This approach is only intended to provide a preliminary risk assessment to identify critical water crossings for further site-investigation. Absolute probabilities of hazard and risk were not estimated.
- › A detailed magnitude-frequency assessment and runout analysis of hydrogeomorphic events at each site was not conducted and it is considered beyond the scope of this project. Interpretations for hazard frequency are derived from geomorphic evidence and supported on the review of IDF climate data. Local thresholds for debris flow initiation are not available.
- › Subsurface investigations, fan stratigraphy, or detailed upper basin inspections were not completed. Interpretations of fan deposits and source areas are based on visual observations and analysis of LiDAR data.
- › Landslide dam outburst floods are potential hazards within the GeoRSA. Possible damaging processes from these hazards were not incorporated in the analysis.

7.1.7 Summary

A water crossing risk-based assessment has been completed for the proposed access road of the Project. The proposed access road as of November 1, 2016 is exposed to hydrogeomorphic processes in the form of debris floods and/or debris flows at fifteen water crossing locations. There is potential for undesired consequences to the Project at eleven of these locations (unmitigated scenario), including damage to the surface of the road and vehicles, injuries to drivers and construction workers, disruption to the mine access resulting in project delays.

8 Conclusions

The Geophysical Baseline Study documents the main terrain, slope and fluvial geomorphologic characteristics and hazards related to the Red Mountain Project. A multi-stage approach was completed to provide relevant information for the design and environmental impact assessment of the project. The main findings are discussed in the following sections:

8.1 Terrain

The Bitter Creek Valley has undergone several phases of glaciation during the Quaternary (2.6 ma), the largest recent glaciation being the Fraser Glaciation, approximately 30,000 to 9,300 years before present (30 – 9.3 ka) which was followed by four periods of Bromley glacial advance between approximately 2,500 to 800 years BP. Each glacial period is responsible for scouring and over steepening the Bitter Creek Valley and depositing thick sequences of glacial sediments and colluvium upon their retreat.

Surficial geology in the upper elevations consists of alpine ice (I = 24%), which is still dominant above 1,650 m asl and Bromley Glacial ice above 550 m asl. Bare bedrock (R = 15%), only recently exposed by glacial retreat, is exposed on the mountain ridges and steepest valley sidewalls. Colluvium (C = 16%) dominates the less steep, upper bedrock slopes and down slope depositional sites. On the more gentle upland slopes receding alpine and valley glaciers have left abundant glacial till or moraine (M = 30%), which is generally thick in the lower Bitter Creek valley and thins up slope. Melting glaciers are also responsible for the glaciofluvial (FG = 2%) sediments, and to a lesser extent, subsurface glaciolacustrine and undifferentiated (U = 0.04%) sediments at the mouths of the creeks such as Cambria, Roosevelt and Radio Creeks. Recent sedimentation is derived from the active colluvial and fluvial (F = 2%) fans and plains along the lower Bitter Creek Valley.

8.2 Slope Hazards and Encounter Probability

Landslides and snow avalanche hazards are widespread, with a total of 251 landslides and 92 avalanches were identified within the GeoRSA. Of the landslides, rapid mass movements constitute 94.4% of the failures, while 5.6% are slow mass movements, all of which cover a total area of 2,389 ha or 21% of the GeoRSA. Of the avalanches mapped, 65.7% were a mix of major and minor avalanches, 19.5% major and 14.8% minor; covering a total area of 2615 ha or 23% of the 11,325 ha GeoRSA.

The recently glaciated nature of the GeoRSA has oversteepened and undercut much of the drainage. It is still a relatively active geologic environment. Proposed roads and infrastructure in the GeoRSA need to be considered within a landscape context since the resulting changes, particularly changes to hydrology and slope footing, can engender instability, if not at one location, potentially at some distance down slope. Of particular concern in this region is the interception and concentration of water from roads, excavations or bladed skid-trails that can result in the redirection of additional surface or subsurface (seepage) flows onto areas of steep surficial sediments. During construction in 'flat over steep' situations, particular diligence should be used to maintain natural drainage regardless of stability class. Where down slope consequences are high (e.g., infrastructure, fish bearing streams or transportation infrastructure), it may be advisable to seek the advice of a QRP even where the layout is confined to class I, II and III terrain. With respect to terrain stability class IV terrain, we recommend on site field assessments be undertaken prior to development. With regard to stability class V terrain, we recommend avoiding all construction and

land clearing activities within these polygons but if unavoidable, detailed terrain assessments and mitigation plans should be prepared by a qualified, registered professional, prior to development.

Due to stability issues related to glaciolacustrine material, we recommend subsurface investigation along the access road in the lower reaches of the Bitter Creek Valley, until the extent and thickness of the deposit is understood.

This mapping exercise found potential bedrock-hosted instability near Red Mountain and the Bromley Humps. The presence and level of activity of these potentially unstable sites should be evaluated in detailed engineering designs.

Encounter probability and spatial risk are used to assess risk where the element at risk is measured by any part of the hazard (initiation or run-out) as it may affect proposed infrastructure and roads (November 1, 2016 road alignment; October 6, 2016 project infrastructure). The results of the spatial risk analysis on project infrastructure are summarized in Table 4-1.

8.3 Soils Classification and Soil Erosion Potential Mapping

Elevation, climate and parent material are the primary factors controlling soil development. The distribution of soils observed in the study area involves three of the Canadian soil orders: **brunisol**s, which were mostly found above 1,000 m asl facing roughly north; **podzols**, which were below 1,000 m asl, less common; and **regosols**, which can be found between 400 to 1,600 m asl on southern to northwestern exposures.

A five-class soil erosion potential rating was developed for the area based on surficial sediment texture, slope and local climate. The highest soil erosion potential is associated with the silty and sandier fluvial, glaciofluvial, glaciolacustrine, till and undifferentiated sediments on moderate to steep slopes. Given the steep nature of the Bitter Creek valley and the high precipitation the majority of the mid to upper slopes have very high sediment erosion potential. As such, care should be taken to limit vehicle activity or excavation beyond the chosen road and infrastructure sites, and sediment erosion control measures should be planned and established prior to development.

8.4 Channel Change Detection

Bitter Creek presents a number of hazards to the proposed access road primarily via lateral erosion and flood events. Channel change detection has identified a number of locations where Bitter Creek is migrating towards the access road and actively eroding into the right bank.

Perhaps the most hazardous section lies between Radio Creek and Unnamed Creek 3 (Reaches 4 and 5 in Section 6.2.1). Here, the pre-existing road (which the proposed access road is slated to follow in part) has been washed out in a number of places due to lateral erosion by Bitter Creek. At Radio Creek, the right bank is underlain by glaciolacustrine silts and clays which are actively failing as material is removed by the river at the toe of the slope. The access road may need to be re-routed in this section to avoid future washouts and retrogressing bank failures. Armoring the right bank or other remedial methods at this location would be prudent.

Completion of studies into potential flood discharge, extent, and power may be beneficial where the proposed access road will be constructed at a similar elevation to the active floodplain, for example, near the confluence with Roosevelt Creek (Reach 4 in Section 6.2.1).

Bitter Creek is not anticipated to impact the access road upstream of the Cambria Creek crossing.

8.5 Water Crossing Risk-Based Assessment

The proposed access road crosses fifteen main mountain creeks. These streams vary in size, relief, and available sediment supply and are expected to behave differently in terms of flow mechanics and the likelihood of adverse consequences. A multi-step water crossing risk-based methodology was applied to the proposed access road (as of November 1, 2016) as a screening tool to identify critical crossings for road construction and to evaluate sites for future site-specific assessments and monitoring. The risk-based assessment involved the identification of potential hazards (hydrogeomorphic processes) and the estimation of the likelihood that a hazard event will occur, impact the road, and cause some type of damage. Four priority levels (low, moderate, high, and very high) were classified based on relative risk and potential implications for risk management identified. Assessment of these crossings resulted in four crossings being classified as low priority, 6 crossings classified as moderate priority, 1 crossing classified as high priority and four crossings as very high priority. For both, high and very high priority crossings risk-reduction measures are warranted at construction and operation stages.

9 Closure

This Geophysical Baseline Study is intended to aid in the planning and development of the Red Mountain Mining Project. For planning, this information may be best utilized as a contributing layer in a multi-layer interdisciplinary Geographic Information System (GIS). In this manner, system queries may be generated by various users to address specific planning issues. For general use, this information is best used in the field to identify the varying terrain conditions, and help crews to identify and avoid hazardous sites and situations. All users of geohazard maps must be aware, however, that conditions within a particular terrain polygon are locally variable. Ratings are based on observations of the current terrain environment, and indicate typical conditions for each polygon. Yet locally steeper slopes, atypical drainage, recent fluvial changes and other factors may predispose site-specific portions of an area to reduced stability or unaccountable hazards. Consequently, layout crews should be alert to variable conditions and seek the advice of a qualified registered professional in any areas of concern.

We trust that this report meets your requirements. Should you have any questions or comments please contact us 250-716-9000.

Submitted by:

SNC-LAVALIN INC.

Environment & Geoscience

Infrastructure

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Appendix A

Sediment Texture Characteristics

Sediment Texture Characteristics:

| Average Textures of Red Mountain Surficial Deposits | |
|---|--------------------|
| Materials | Suggested Textures |
| Colluvium (C) | Cc=x |
| | Cf=x |
| | Cv=zsx |
| | Cb=dsx |
| Fluvial (F) | kzs |
| Glaciofluvial (FG) | sg |
| Glaciolacustrine (LG) | pcz |
| Lacustrine (L) | sz |
| Moraine (M) | zsd |

| Mineral Terrain Texture | | |
|-------------------------|---|--|
| blocks | a | |
| boulders | b | |
| cobbles | k | |
| pebbles | p | |
| sand | s | |
| silt | z | |
| clay | c | |
| mixed fragments | d | |
| angular fragments x | | |
| gravel | g | |
| rubble | r | |

| Grain Diameter | | | Wentworth Size Class | |
|----------------|---------|------|----------------------|------------|
| millimeters | microns | phi | | |
| 256 | | -8.0 | Boulder | Gravel |
| 64 | | -6.0 | Cobble | |
| 4.0 | 4000 | -2.0 | Pebble | |
| 2.0 | 2000 | -1.0 | Granule | |
| 1.41 | 1410 | -0.5 | vcU vcL | Sand |
| 1.0 | 1000 | 0.0 | Coarse sand | |
| .71 | 710 | 0.5 | | |
| 0.5 | 500 | 1.0 | Medium sand | |
| 0.35 | 350 | 1.5 | | |
| 0.25 | 250 | 2.0 | Fine sand | |
| 0.177 | 177 | 2.5 | | |
| 0.125 | 125 | 3.0 | Very fine sand | |
| 0.088 | 88 | 3.5 | | vfU vfL |
| 0.0625 | 62.5 | 4.0 | | Mud |
| 0.002 | 2.0 | 9.0 | Silt Clay | |

After: Howes and Kenk (1997) and Wentworth (1929)



Appendix B

Map Labelling Conventions

Map Labelling Conventions (After Howes & Kenk, 1997)

| <u>Mineral Terrain Texture</u> | <u>Organic Terrain Texture</u> | <u>Parent Material</u> | <u>Surface Expression</u> | | | | |
|--------------------------------|--------------------------------|------------------------|---------------------------|------------------------|----|-----------------------|---|
| blocks | a | fibric | e | Colluvium | C | moderate slope | a |
| boulders | b | mesic | u | Weathered bedrock | D | blanket (1-3 m) | b |
| cobbles | k | humic | h | Eolian | E | cone(s) | c |
| pebbles | p | | | Fluvial | F | depression(s) | d |
| sand | s | | | Glaciofluvial | FG | fan(s) | f |
| silt | z | | | Ice ¹ | I | hummock(s) | h |
| clay | c | | | Lacustrine | L | gentle slope | j |
| mixed fragments | d | | | Glaciolacustrine | LG | moderate steep slope | k |
| angular fragments | x | | | Non classified (water) | N | rolling | m |
| gravel | g | | | Moraine (till) | M | plain | p |
| rubble | r | | | Organic | O | ridge(s) | r |
| | | | | Bedrock | R | steep slope | s |
| | | | | Volcanic | V | terrace(s) | t |
| | | | | Marine | W | undulating | u |
| | | | | Glaciomarine | WG | veneer (< 1 m) | v |
| | | | | | | thin veneer (< 20 cm) | x |

Areas mapped as ice may include areas of permanent snow pack.

Application of Textural Terms

| Number of Symbols | Example | Subordinate 2 | Subordinate 1 | Dominant |
|-------------------|-------------------------------|----------------|-----------------|-----------------|
| 1 | s (sand) | - | - | 80 – 100 % sand |
| 2 | gs (gravelly sand) | - | 20 – 50% gravel | 50 – 80 % sand |
| 3 | bgs* (bouldery gravelly sand) | < 30% boulders | 25 – 40% gravel | 40 – 60% sand |

* In this example, the term gravel indicates pebbles and cobbles

Geomorphological Processes

Erosional Processes

Karst K
Gully erosion V
Washing W

Mass Movement Processes

Snow avalanche(s) A
Slow mass movements F
Rapid mass movements R

Hydrologic Processes

Inundation U
Surface seepage L

Deglacial Processes

Channeled by meltwater E
Kettled H

Fluvial Processes

Braided channel B
Irregularly sinuous channel I
Anastomosing channel J
Meandering channel M

General periglacial processes
Cryoturbation
Nivation
Solifluction
Permafrost processes

Periglacial Processes

Z
C
N
S
X

Subclasses for Mass Movement Processes

| | | |
|--------------------------------------|---|--|
| Initiation zone | “ | |
| mixed major and minor tracts, active | w | |
| old avalanche tracks | o | |

Slow mass movement (F)

| | |
|-----------------------------|---|
| Rock creep | g |
| Tension cracks accompanying | k |
| Lateral spread in bedrock | p |
| Lateral spread in material | j |

Rapid Mass Movement (R)

| | |
|-------------------------|---|
| debris fall | f |
| rockfall | b |
| debris flow | d |
| debris floods (torrent) | t |

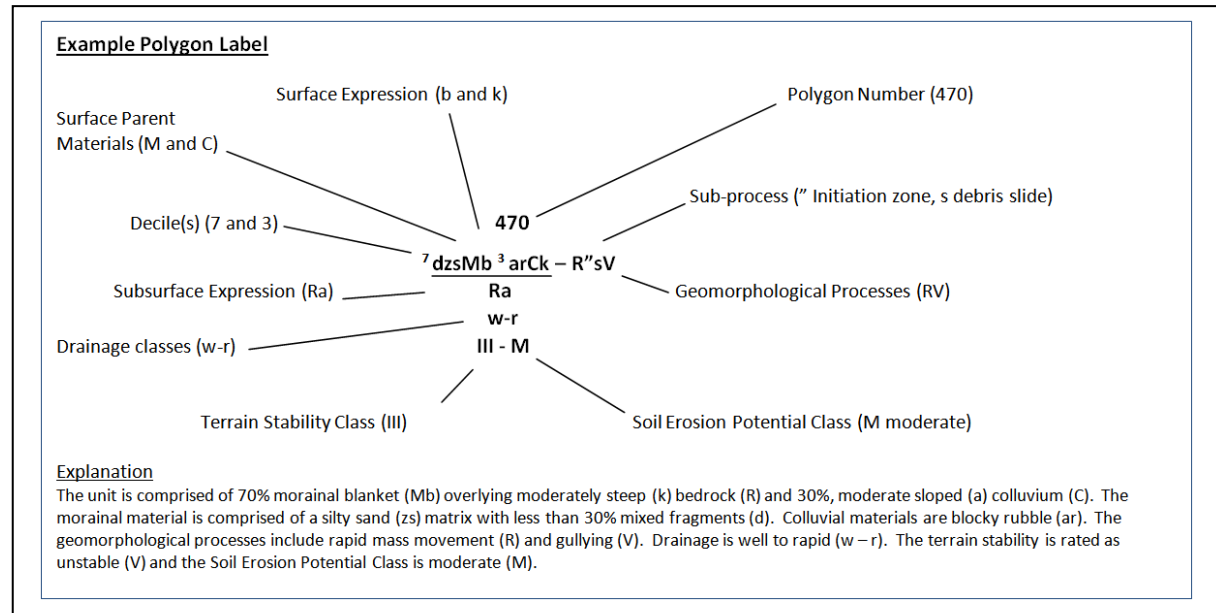
Subclasses for Snow Avalanches (A)

| | |
|--------------------------------|---|
| major avalanche tracts, active | f |
| minor avalanche tracts, active | m |

Note: Subclasses codes are not included in label; they are included in database

Slow or Rapid Mass Movement (F or R)

| | |
|--------------------------|---|
| earthflow | e |
| slump in bedrock | m |
| slump in material | u |
| slump - earthflow | x |
| debris avalanche (slide) | s |
| rockslide | r |



Slope Classes

- 0 – 5 % plain (p)
- 6 – 26 % gentle slope (j)
- 27 – 49 % moderate slope (a)
- 50 – 70 % mod. steep slope (k)
- >70% steep slope (s)

Drainage Classes

- very rapid x
- rapid r
- well w
- moderately well m
- imperfect i
- poor p
- very poor v

Note: Not all symbols are used on all maps.

We have made a modification to the standard guidelines by adding three subclasses to the Gullying Process. These are major gullying; minor gullying; and mixed major and minor gullying and summarized below:

Subclasses for Gullying Processes: use the following symbols with -V

| Subclass Name | Map Symbol | Definitions |
|--------------------------------|------------|---|
| Major gullying | f | Zones where gullies are deeply incised into the topography; generally, the individual gully comprises greater than 50 % of the polygon area. |
| Minor gullying | m | Gullying processes similar to above, however, gullies are more numerous, comparatively narrow, and often form in parallel; rill erosion is included in this category. |
| Mixed major and minor gullying | w | Polygon includes both major and minor gullying processes; for example, a major gully with multiple parallel gullies forming on the side slopes. |



Appendix C

Background Technical Reports

Background Technical Reports

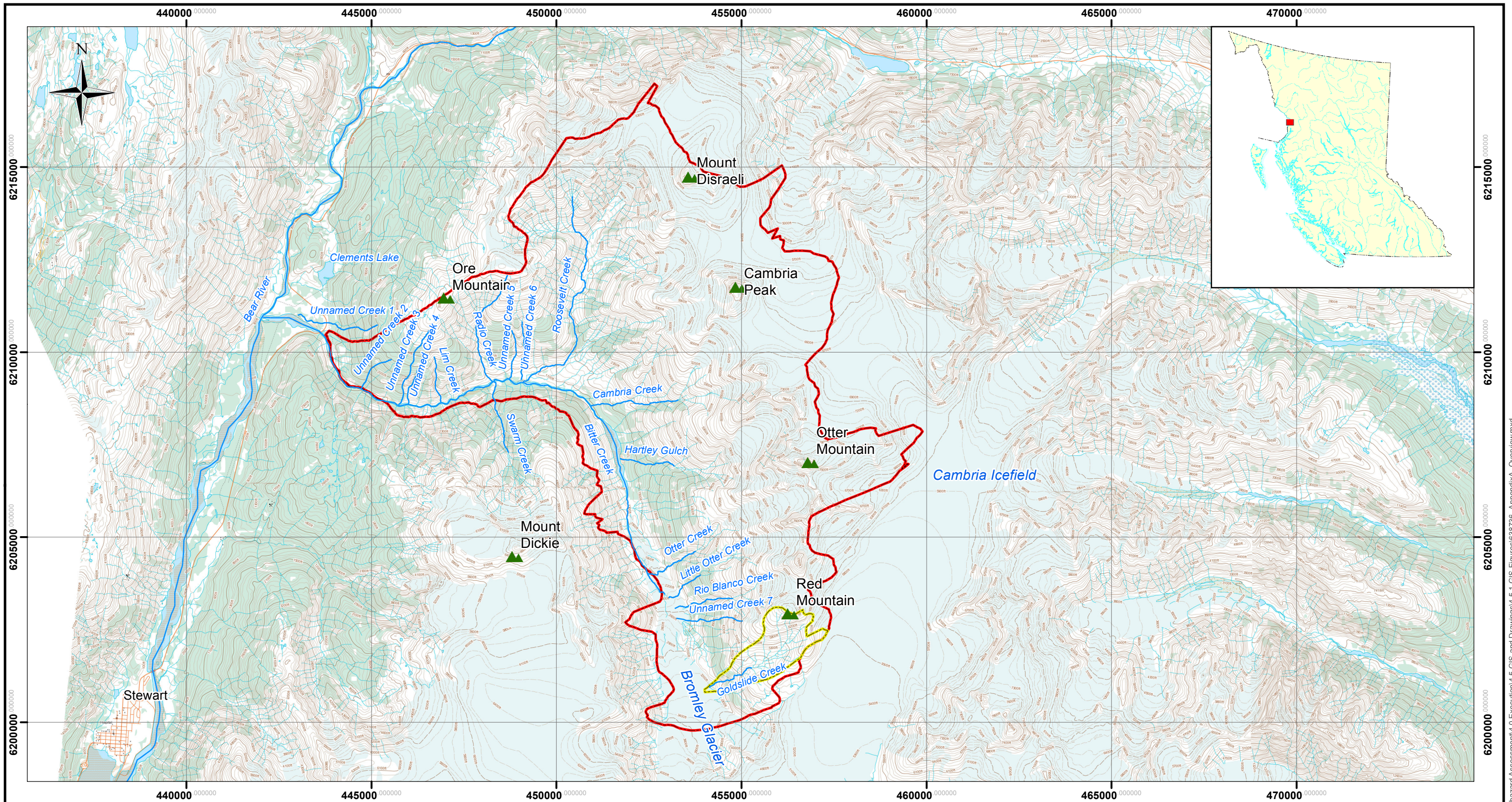
Previous works related to the Red Mountain Gold Project that include some component of terrain stability and/or geohazard assessment:

- › Bear Enterprises Ltd. (1990). Report on the first stage of 1990 Red Mountain Avalanche. Prepared for Bond Gold Canada Inc.
- › Golder Associates Ltd. (1996). Bitter Creek road application for special use permit. Prepared for Royal Oak Mines Ltd.
- › Golder Associates Ltd. (2000). Engineering feasibility assessment: Routing and costing for the Red Mountain mine access road, Stewart, BC. Prepared for North American Metals Corp.
- › IDM Mining Ltd. (2016 Rev. 2 March 17, Draft) Red Mountain Underground Gold Project, Valued Components Selection p. 36.
- › Knight Piesold Consulting Engineers (1993) Conceptual design of access road and ore and waste stockpiles. Prepared for LAC Minerals Inc.
- › Klohn-Crippen Consultants Ltd. (1994). Red Mountain Project: Landslide hazard assessment. Prepared for LAC Minerals Ltd.
- › Klohn-Crippen Consultants Ltd. (1994). Tailings management report: Cirque tailings facility site. Prepared for LAC North America Ltd.
- › McElhanney Engineering Services Ltd. (1993). Design report: Bitter Creek access road Red Mountain Project. Prepared for LAC Minerals Ltd.
- › R.E. Graham Engineering Ltd. (1990). Access road study via Bitter Creek Valley to Red Mountain mining property. Prepared for Bond Gold Canada Inc.
- › SRK Consulting (2005). Results of 2004 field investigations: Red Mountain Project, British Columbia. Prepared for Seabridge Gold Inc.



Appendix D

Project Area Overview Map



Legend

- Mountain
- Creek
- Geohazards Local Study Area (GeoLSA)
- Geohazards Regional Study Area (GeoRSA)

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

REFERENCES:

1. Basemaps from ESRI, DeLorme, USGS, NPS

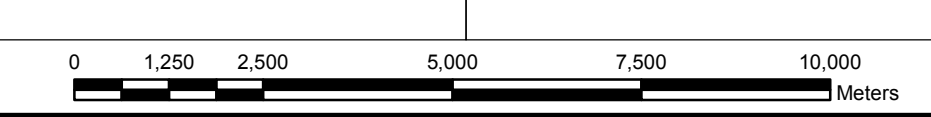
REVISIONS:

0

CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia

Appendix D-001. Project Area Overview

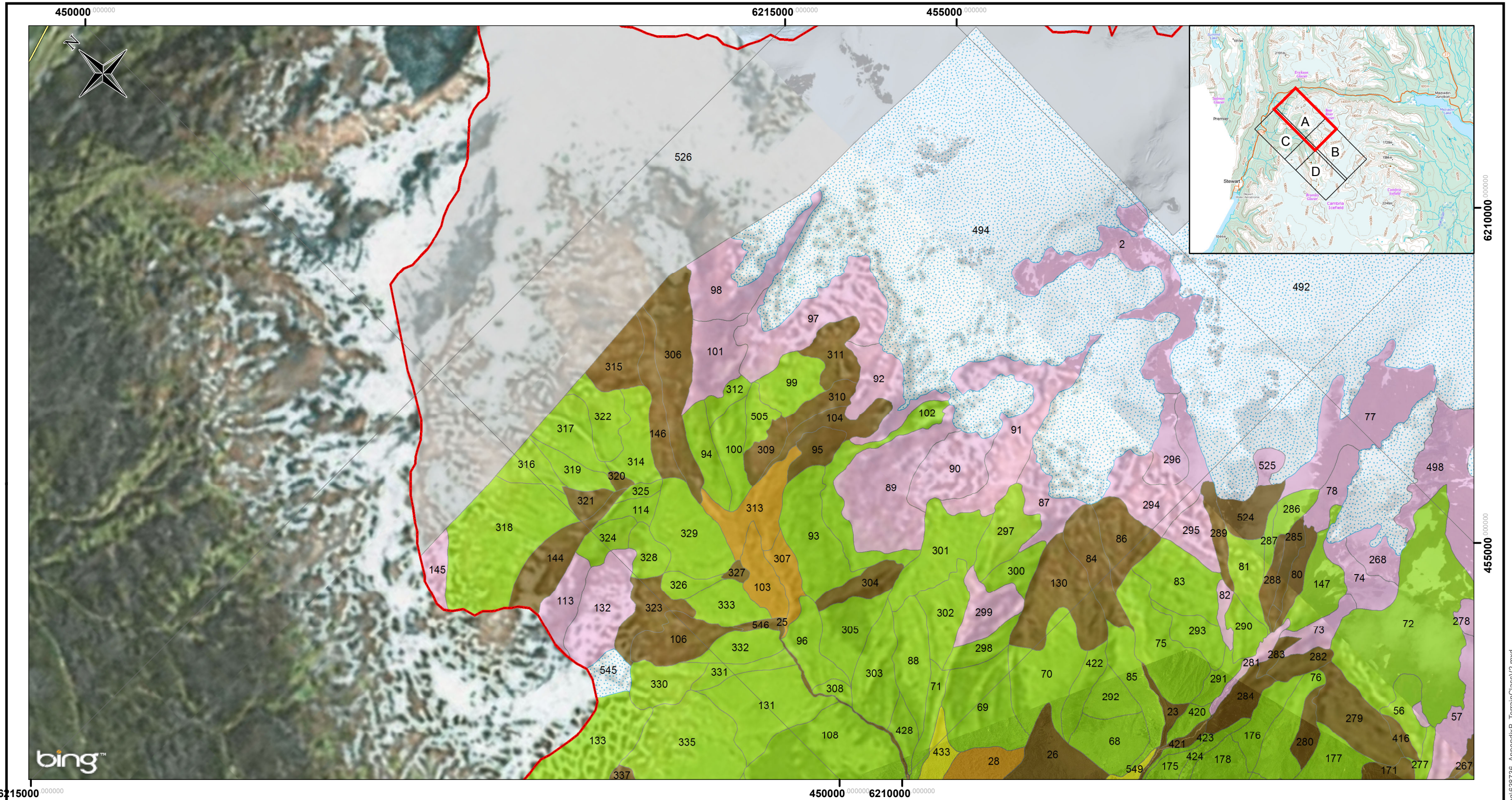


| | | | | |
|----------|--------------------------------------|------------------|--------------|--------|
| BY: CM | SCALE: 1:100,000 | DATE: 2017/01/19 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-D-001 | |



Appendix E

Terrain Map and Slope Hazards Inventory Maps



Legend

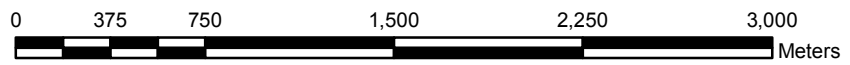
| | | | |
|-----------------------------------|----------------------------|--|--------------------|
| Primary Surficial Material | Undifferentiated Sediments | Access Road (16-11-01) | 135 Polygon Number |
| Anthropogenic | Ice | Project components (16-10-06) | |
| Colluvial | No Air Photo Coverage | Powerline Route | |
| Fluvial | GeoLSA | Administration Facilities | |
| Glaciofluvial | GeoRSA | Buildings, Stockpiles & Pads | |
| Morainal | Lower Portal | Tailings Storage Facility & Embankment | |
| Bedrock | Upper Portal (Existing) | Highway 37A | |

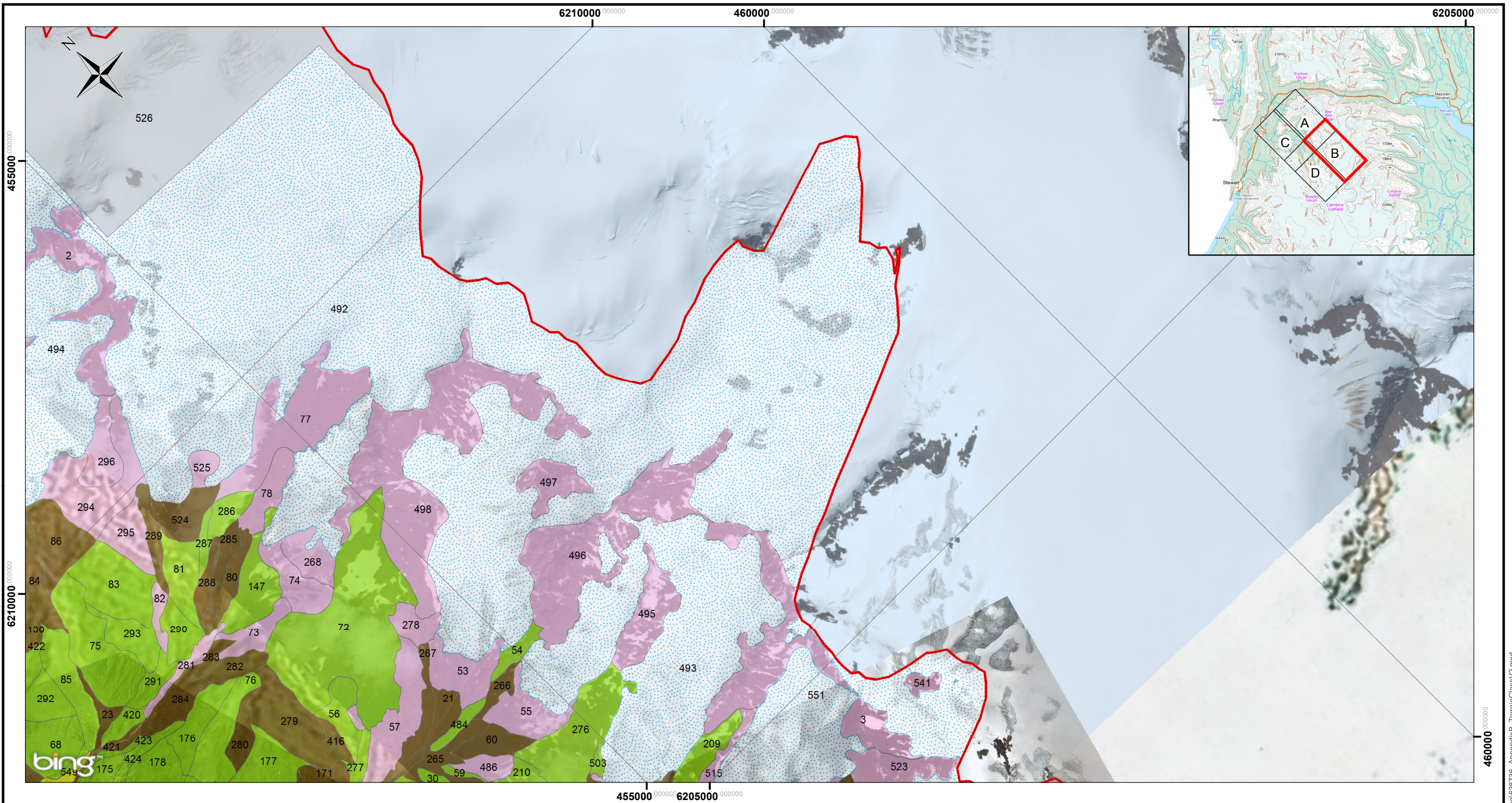
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Surficial Material based on leading decile.
 5. Data presented are in draft.

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|------------------------------|
| CLIENT: IDM Mining Ltd. | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix E-001A. Terrain Classification | | |
| BY: CM | SCALE: 1:30,000 | DATE: 2017/01/18 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-E-001A |





Legend

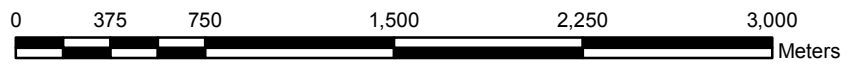
| | | | |
|-----------------------------------|----------------------------|--|--------------------|
| Primary Surficial Material | Undifferentiated Sediments | Access Road (16-11-01) | 135 Polygon Number |
| Anthropogenic | Ice | Project components (16-10-06) | |
| Colluvial | No Air Photo Coverage | Powerline Route | |
| Fluvial | GeoLSA | Administration Facilities | |
| Glaciofluvial | GeoRSA | Buildings, Stockpiles & Pads | |
| Morainal | Lower Portal | Tailings Storage Facility & Embankment | |
| Bedrock | Upper Portal (Existing) | Highway 37A | |

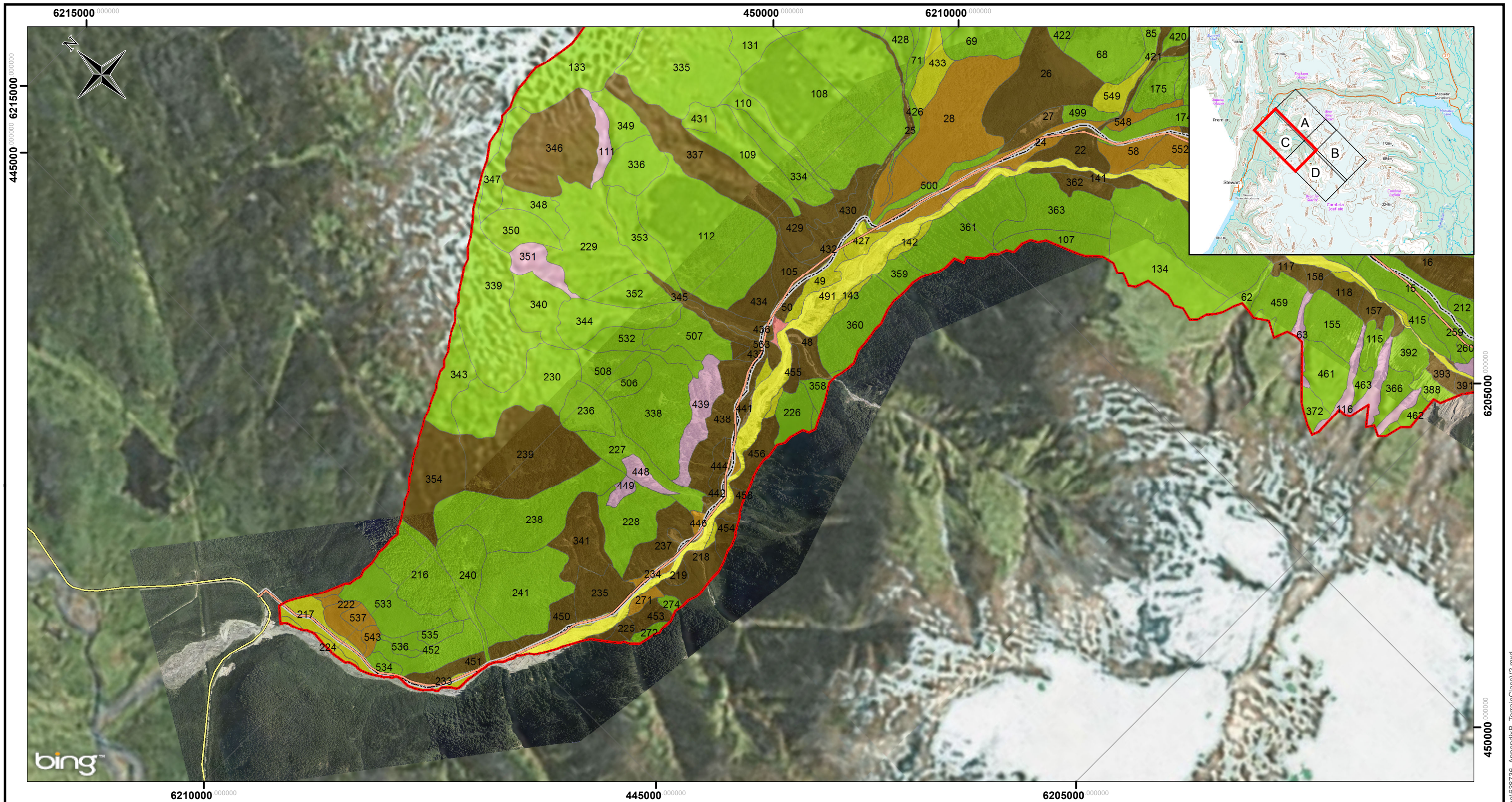
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Surficial Material based on leading decile.
 5. Data presented are in draft.

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | | |
|--|--------------------------------------|------------------|----------------------|
| CLIENT: IDM Mining Ltd. | | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | | |
| Appendix E-001B. Terrain Classification | | | |
| BY: CM | SCALE: 1:30,000 | DATE: 2017/01/18 | REF No: REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-E-001B |





Legend

| | | | |
|-----------------------------------|----------------------------|--|--------------------|
| Primary Surficial Material | Undifferentiated Sediments | Access Road (16-11-01) | 135 Polygon Number |
| Anthropogenic | Ice | Powerline Route | |
| Colluvial | No Air Photo Coverage | Project components (16-10-06) | |
| Fluvial | GeoLSA | Administration Facilities | |
| Glaciofluvial | GeoRSA | Buildings, Stockpiles & Pads | |
| Morainal | Lower Portal | Tailings Storage Facility & Embankment | |
| Bedrock | Upper Portal (Existing) | Highway 37A | |

NOTES:

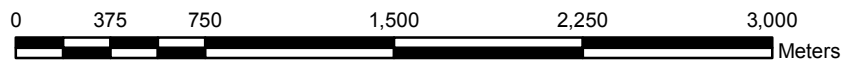
1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Surficial Material based on leading decile.
5. Data presented are in draft.

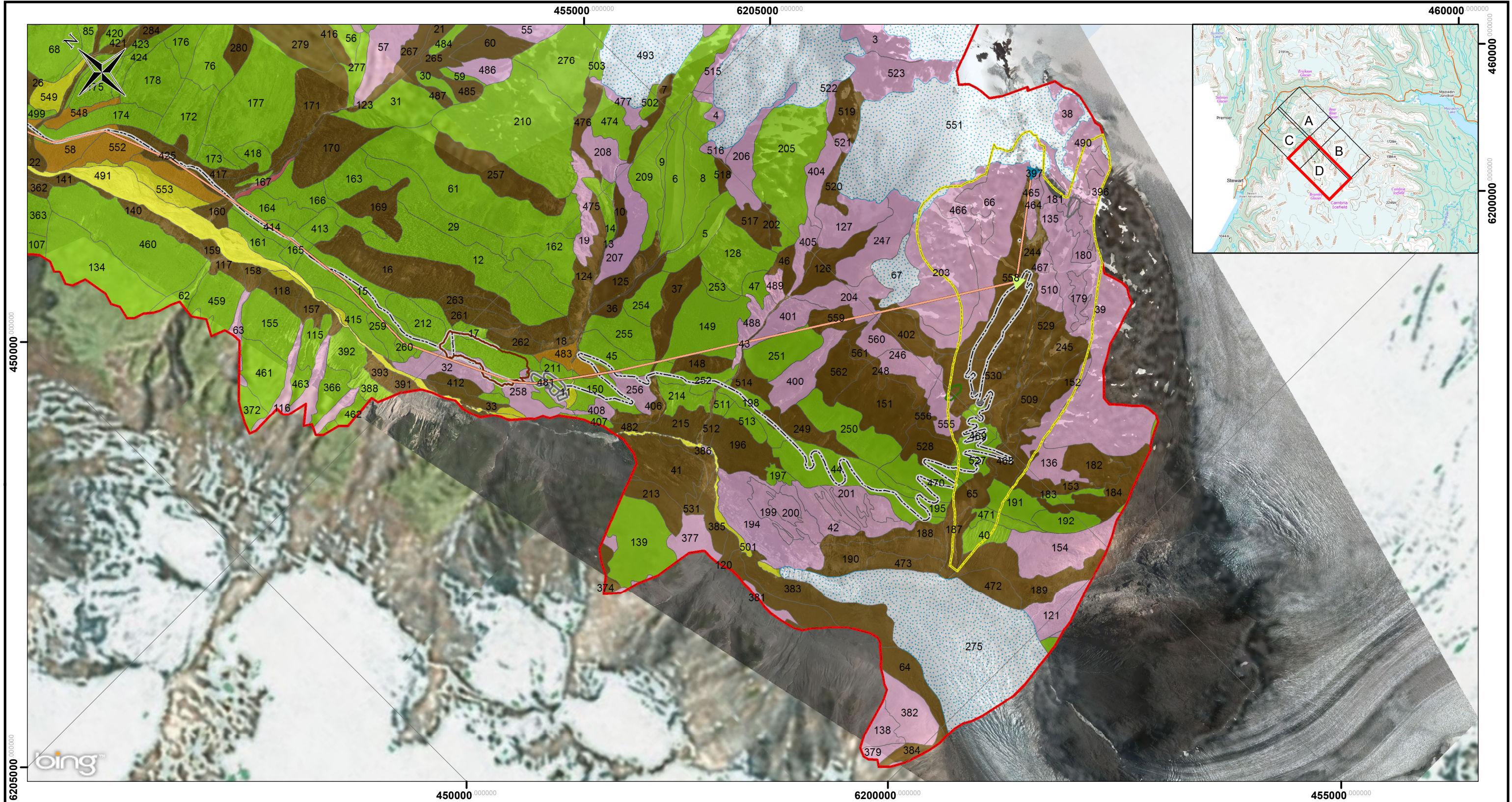
REFERENCES:

1. LIDAR data provided by IDM Mining Ltd.
2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
0

| | | | |
|--|--------------------------------------|------------------|----------------------|
| CLIENT: IDM Mining Ltd. | | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | | |
| Appendix E-001C. Terrain Classification | | | |
| BY: CM | SCALE: 1:30,000 | DATE: 2017/01/18 | REF No: REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-E-001C |





Legend

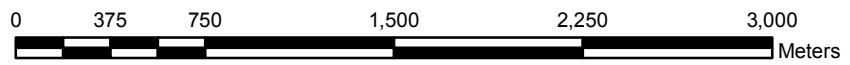
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|-----------------------------------|----------------------------|--|--------------------|
| Primary Surficial Material | Undifferentiated Sediments | Access Road (16-11-01) | 135 Polygon Number |
| Anthropogenic | Ice | Powerline Route | |
| Colluvial | No Air Photo Coverage | Project components (16-10-06) | |
| Fluvial | GeoLSA | Administration Facilities | |
| Glaciofluvial | GeoRSA | Buildings, Stockpiles & Pads | |
| Morainal | Lower Portal | Tailings Storage Facility & Embankment | |
| Bedrock | Upper Portal (Existing) | Highway 37A | |

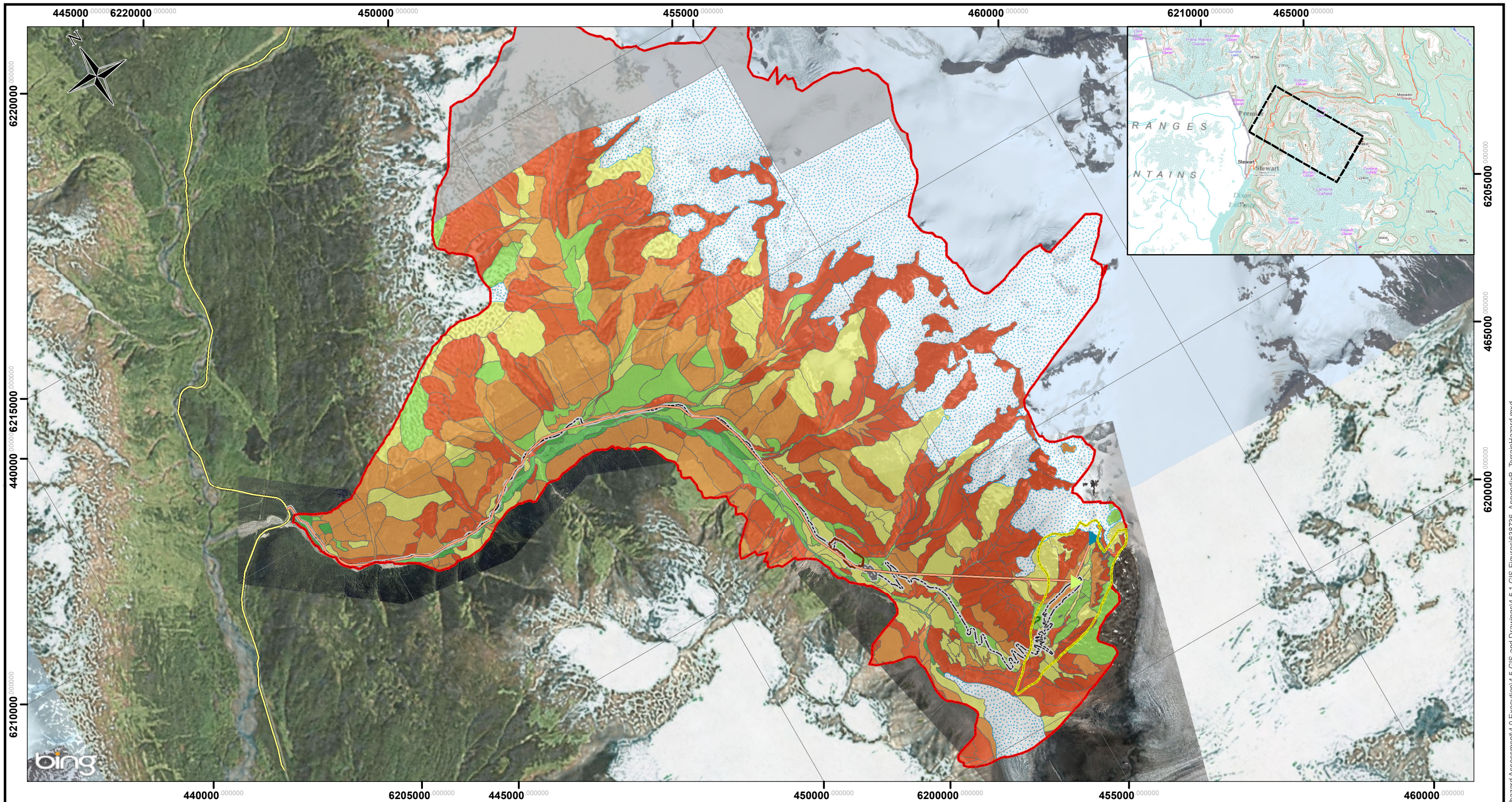
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Surficial Material based on leading decile.
 5. Data presented are in draft.

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | | |
|--|--------------------------------------|------------------|----------------------|
| CLIENT: IDM Mining Ltd. | | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | | |
| Appendix E-001D. Terrain Classification | | | |
| BY: CM | SCALE: 1:30,000 | DATE: 2017/01/18 | REF No: REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-E-001D |





Legend

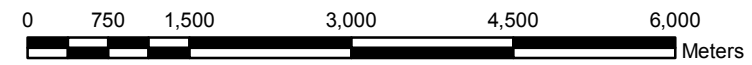
| | | |
|--------------------------------|-------------------------|--|
| Terrain Stability Class | No Air Photo Coverage | Project components (16-10-06) |
| I | GeoLSA | Powerline Route |
| II | GeoRSA | Administration Facilities |
| III | Lower Portal | Buildings, Stockpiles & Pads |
| IV | Upper Portal (Existing) | Tailings Storage Facility & Embankment |
| V | Access Road (16-11-01) | Highway 37A |
| - | | |

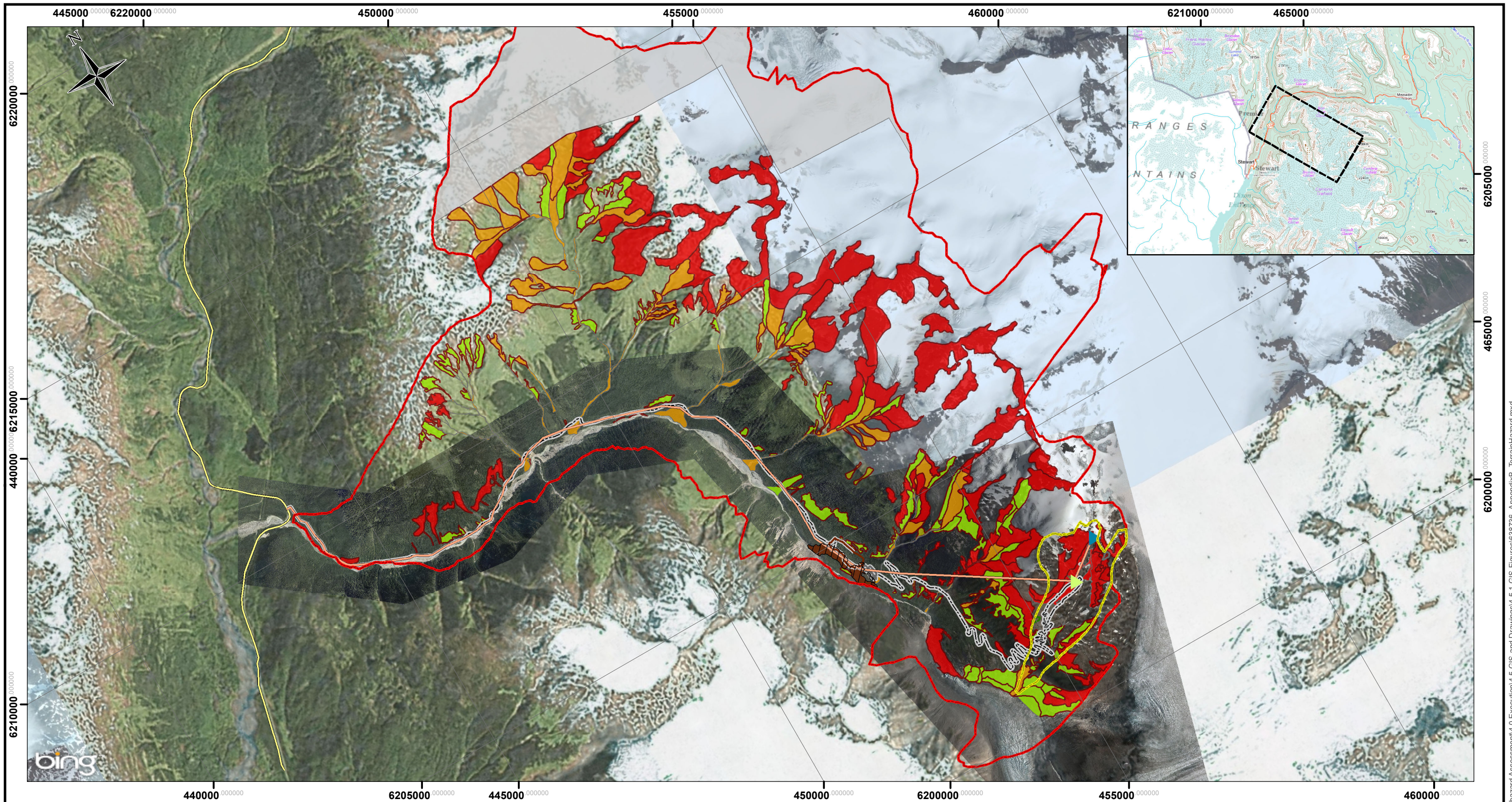
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|-----------------------------|
| CLIENT: IDM Mining Ltd. | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix E-002. Terrain Stability Classification | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/13 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-E-002 |
| | | REV: 0 |





Legend

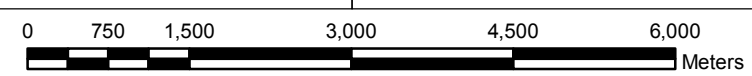
| | | | |
|----------------------------|-------------------------|--|--------------------------------------|
| Rockfall (Rb, Rbf, Rbd) | Deposition Zone (R) | Potentially Inactive Failure | Access Road (16-11-01) |
| Debris Flow (Rd, Rdb) | No Air Photo Coverage | GeoLSA | Project components (16-10-06) |
| Debris Fall (Rf, Rfb, Rfd) | GeoRSA | Administration Facilities | Buildings, Stockpiles & Pads |
| Debris Slide (Rs, Rsb) | Lower Portal | Tailings Storage Facility & Embankment | Highway 37A |
| Bedrock Slump (Rm, Rmr) | Upper Portal (Existing) | | |
| Initiation Zone (R") | | | |

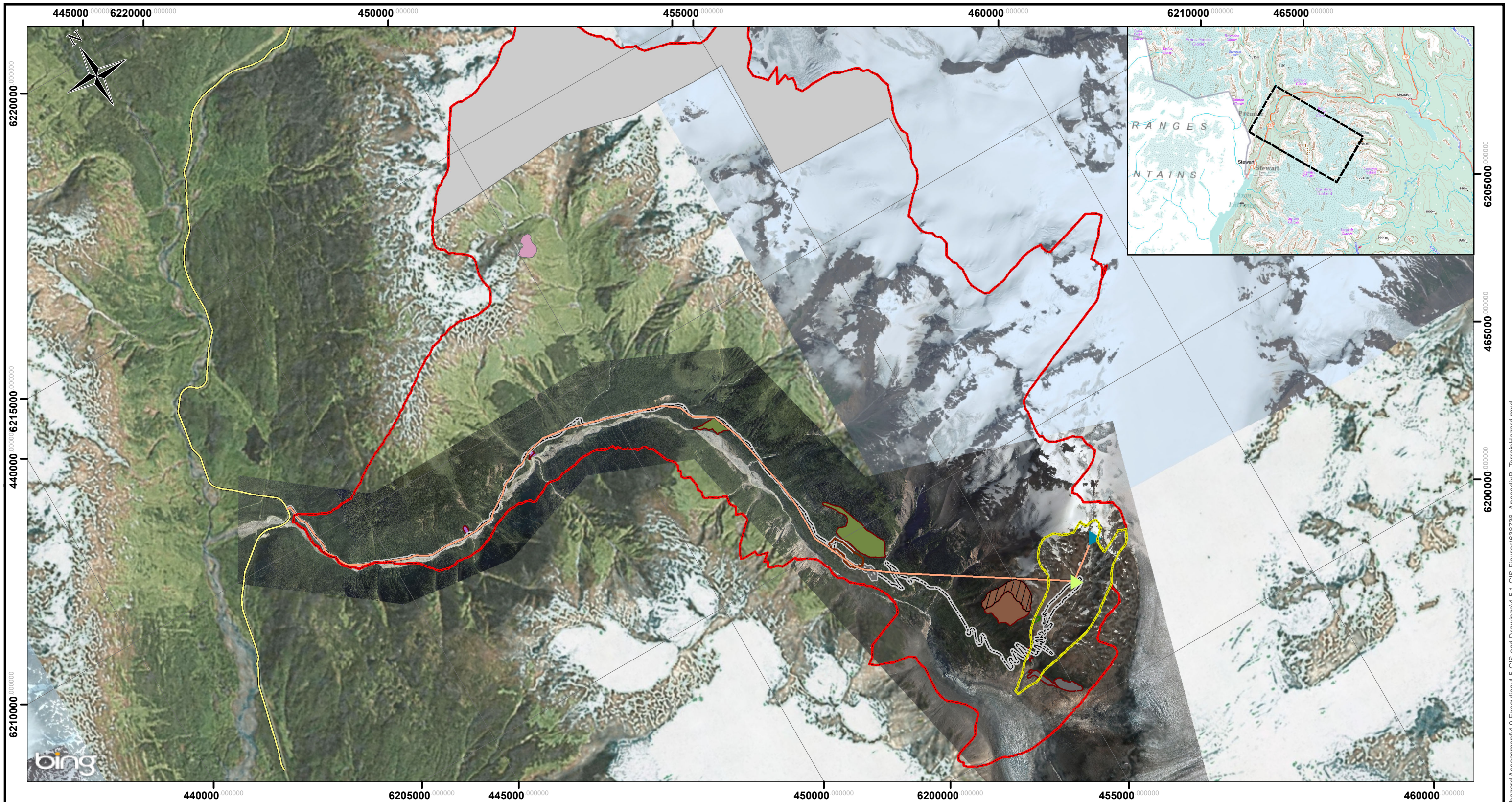
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|-----------------------------|
| CLIENT: IDM Mining Ltd. | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix E-003. Rapid Mass Movement Inventory | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/13 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-E-003 |





Legend

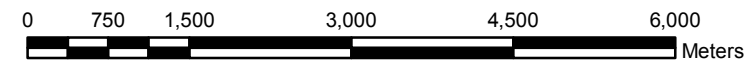
| | | | |
|-------------------------------------|------------------------------|--------------------------------------|--|
| Slow Mass Movement Inventory | Deposition Zone (F) | Upper Portal (Existing) | Tailings Storage Facility & Embankment |
| Lateral Spread in Bedrock (Fp) | Potentially Inactive Failure | Access Road (16-11-01) | |
| Surficial Material Slump (Fu) | No Air Photo Coverage | Project components (16-10-06) | Highway 37A |
| Tension Cracks (Fk, Fkmu) | GeoLSA | Powerline Route | |
| Bedrock Slump (Fmk) | GeoRSA | Administration Facilities | |
| Initiation Zone (F") | Lower Portal | Buildings, Stockpiles & Pads | |

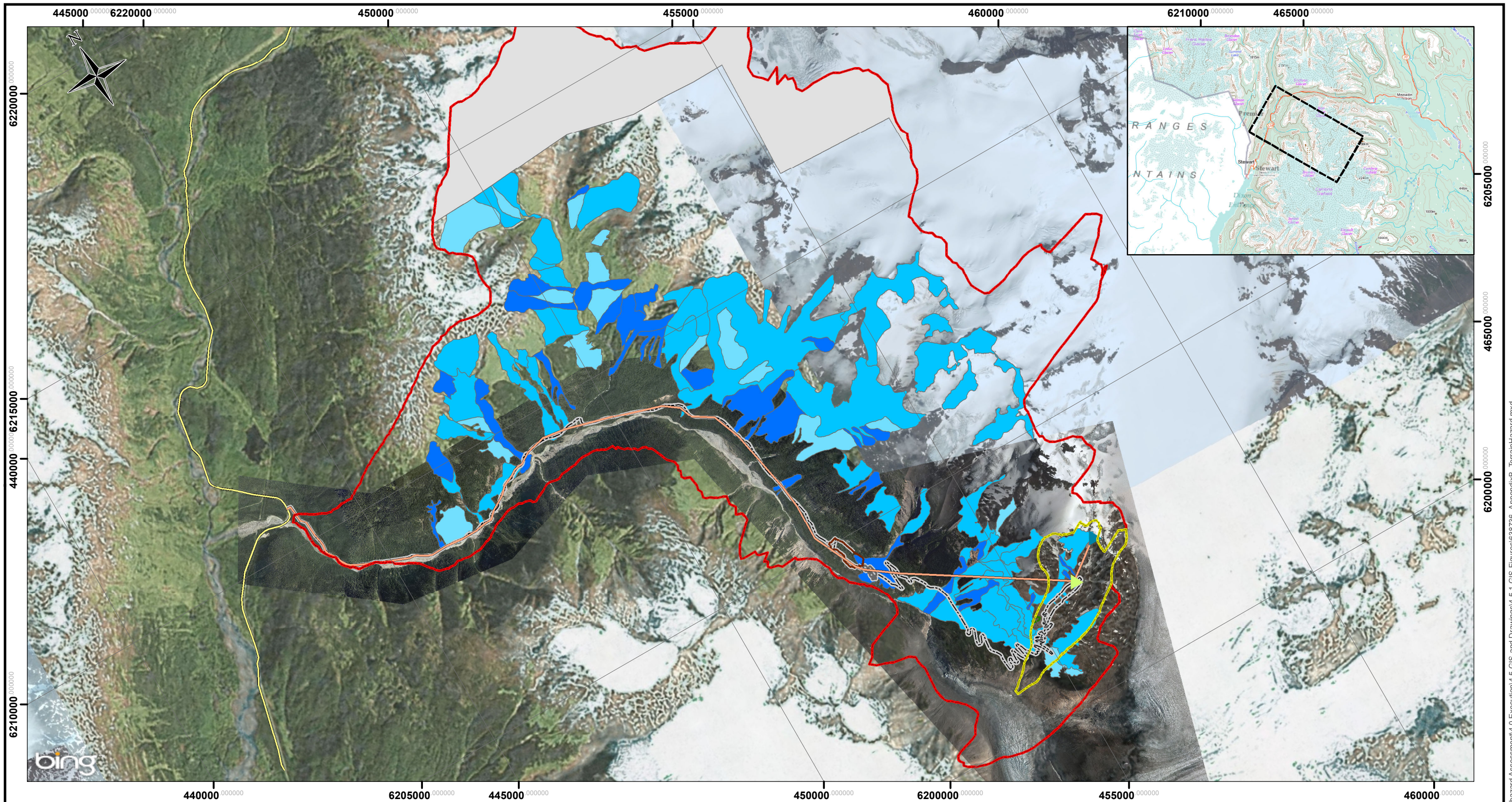
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | | | |
|--|--------------------------------------|------------------|---------------------|--------|
| CLIENT: IDM Mining Ltd. | | | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | | | |
| Appendix E-004. Slow Mass Movement Inventory | | | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-E-004 | |





| Legend | |
|----------------------------------|--|
| Snow Avalanche Inventory | — Access Road (16-11-01) |
| ■ Major Avalanche (Af) | Project components (16-10-06) |
| ■ Major and Minor Avalanche (Aw) | — Powerline Route |
| ■ Minor Avalanche (Am) | ■ Administration Facilities |
| ■ GeoLSA | ■ Buildings, Stockpiles & Pads |
| ■ GeoRSA | ■ Tailings Storage Facility & Embankment |
| ▲ Lower Portal | — Highway 37A |
| ▲ Upper Portal (Existing) | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

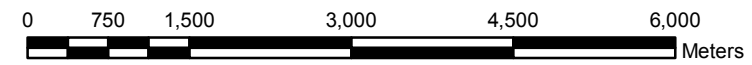
CLIENT:
 IDM Mining Ltd.

PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix E-005. Snow Avalanche Inventory

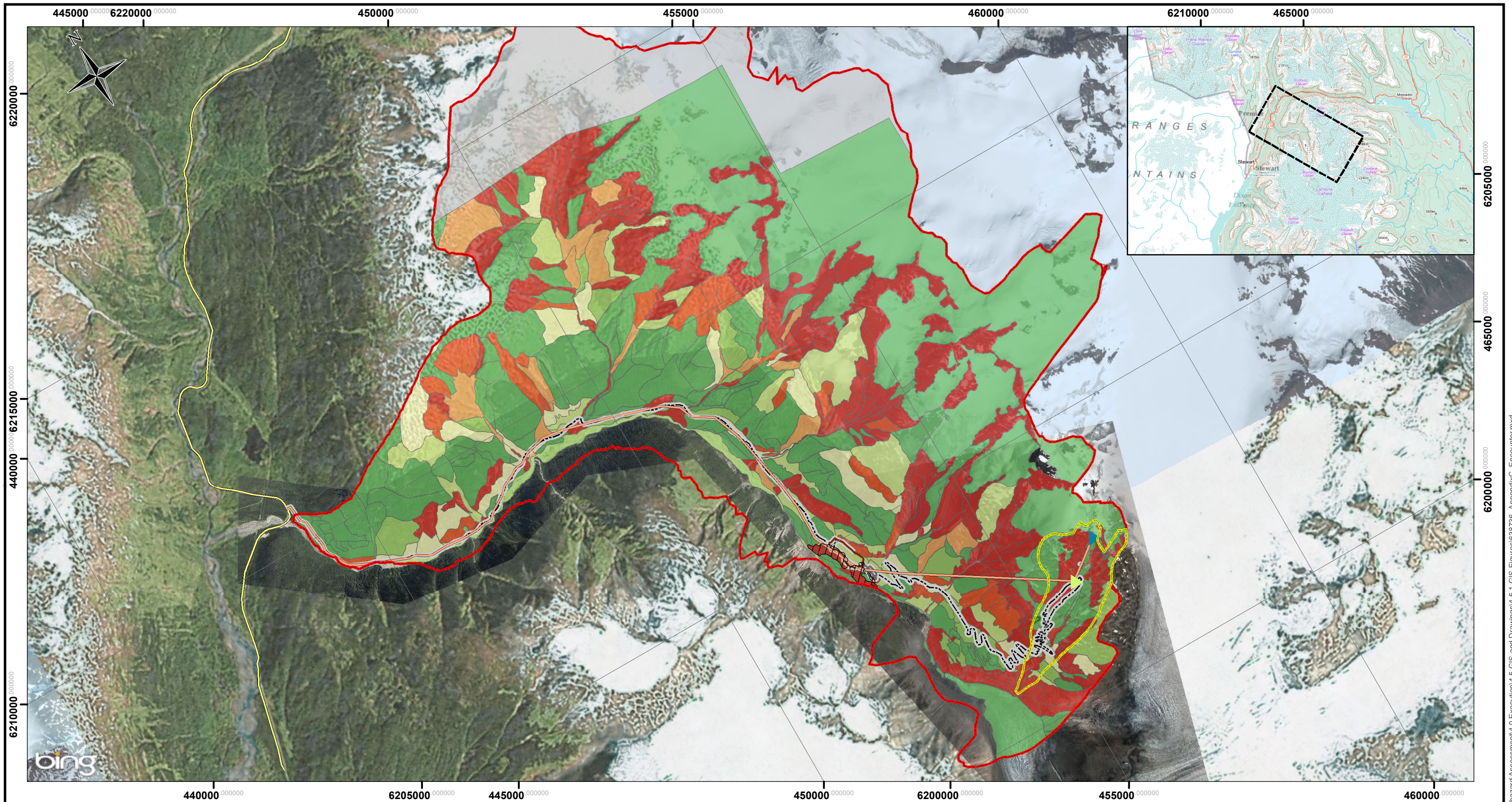
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|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-E-005 | |





Appendix F

Encounter Probability and Spatial Risk Maps



Legend

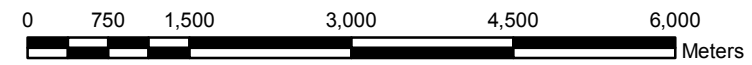
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|--|------------------------------|--|
| Rapid Mass Movement Encounter Probability | Potentially Inactive Failure | Project components (16-10-06) |
| Outside Air Photo Coverage | GeoLSA | Powerline Route |
| 0.000 - 0.001 | GeoRSA | Administration Facilities |
| > 0.001 - 0.005 | Lower Portal | Buildings, Stockpiles & Pads |
| > 0.005 - 0.020 | Upper Portal (Existing) | Tailings Storage Facility & Embankment |
| > 0.020 - 0.100 | Access Road (16-11-01) | Highway 37A |
| > 0.100 - 0.200 | | |
| > 0.200 - 0.500 | | |
| > 0.500 - 1.000 | | |

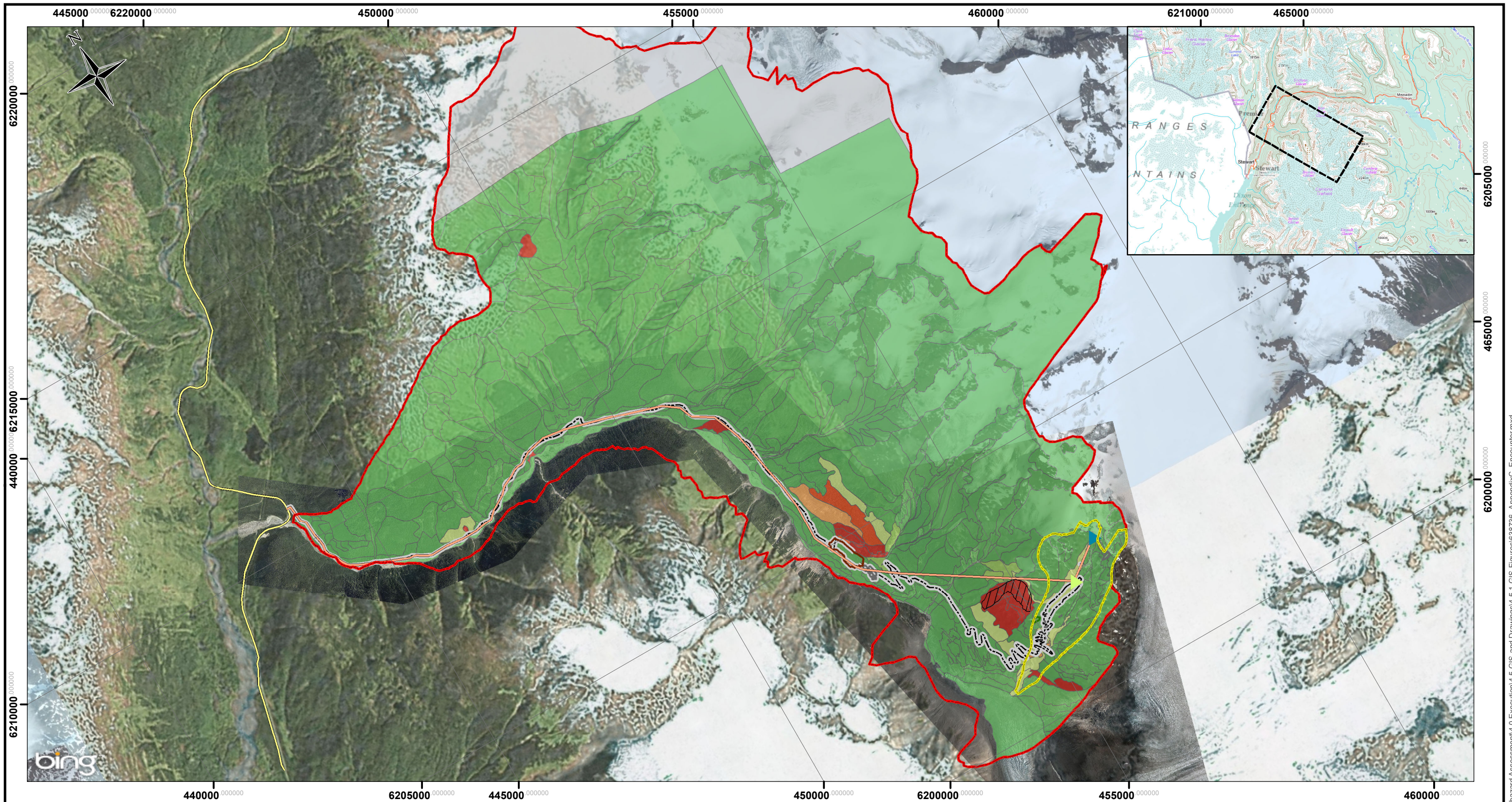
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|---|--------------------------------------|-----------------------------|
| <p>CLIENT: IDM Mining Ltd.</p> | | <p>SNC · LAVALIN</p> |
| <p>PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia</p> | | |
| <p>Appendix F-001. Rapid Mass Movement Encounter Probability</p> | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/12 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-F-001 |
| | | REV: 0 |





Legend

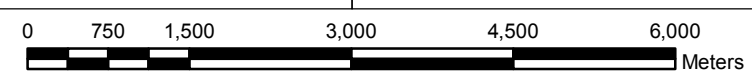
| | | |
|---|------------------------------|--|
| Slow Mass Movement Encounter Probability | Potentially Inactive Failure | Project components (16-10-06) |
| Outside Air Photo Coverage | GeoLSA | Administration Facilities |
| 0.000 - 0.001 | GeoRSA | Buildings, Stockpiles & Pads |
| > 0.001 - 0.005 | Lower Portal | Tailings Storage Facility & Embankment |
| > 0.005 - 0.020 | Upper Portal (Existing) | Highway 37A |
| > 0.020 - 0.100 | Access Road (16-11-01) | Powerline Route |
| > 0.100 - 0.200 | | |
| > 0.200 - 0.500 | | |
| > 0.500 - 1.000 | | |

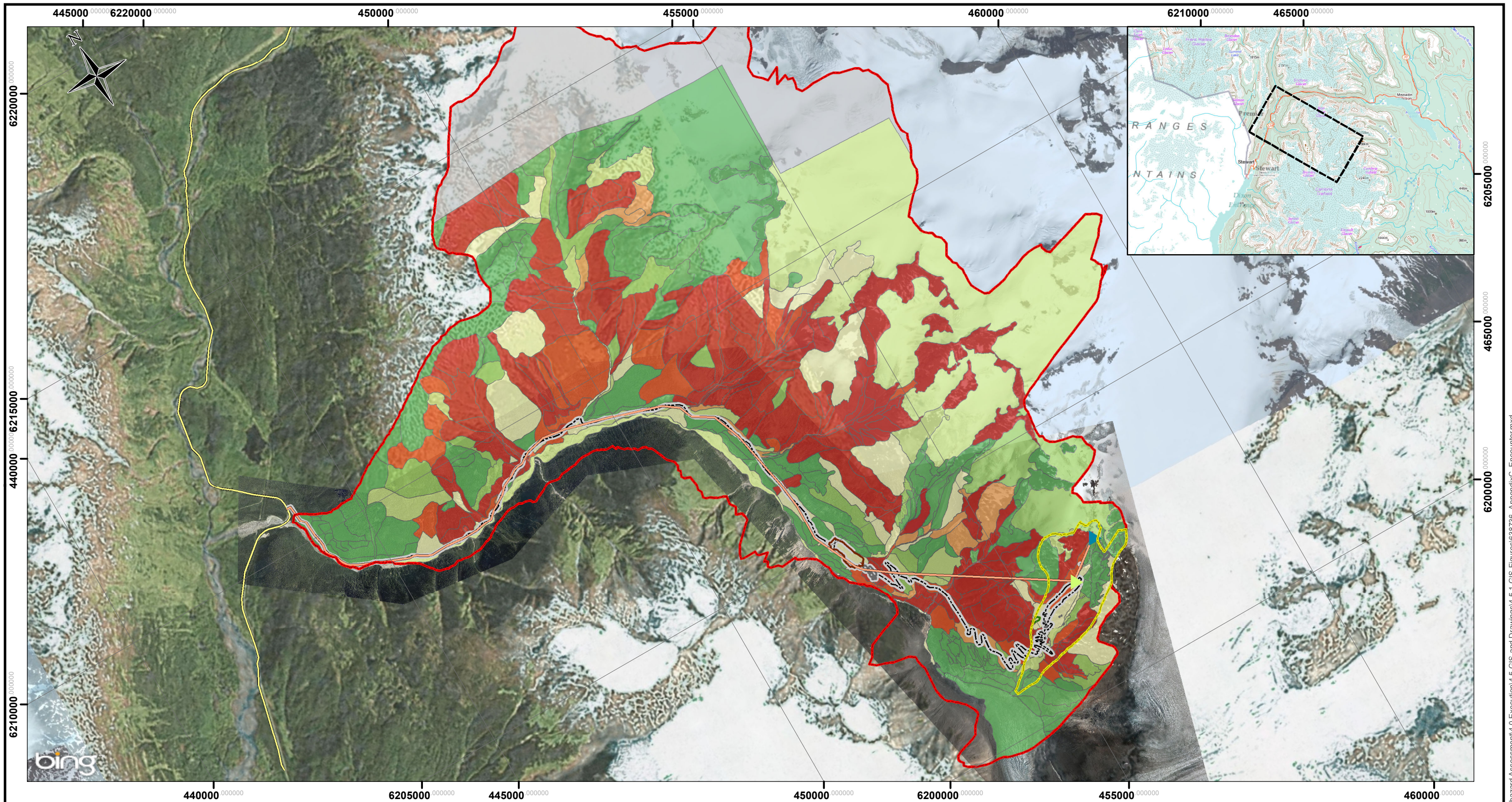
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|-----------------------------|
| CLIENT: IDM Mining Ltd. | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix F-002. Slow Mass Movement Encounter Probability | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/12 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-F-002 |
| | | REV: 0 |





Legend

| | | |
|---|-------------------------|--|
| Snow Avalanche Encounter Probability | GeoLSA | Project components (16-10-06) |
| Outside Air Photo Coverage | GeoRSA | Powerline Route |
| 0.000 - 0.001 | Lower Portal | Administration Facilities |
| > 0.001 - 0.005 | Upper Portal (Existing) | Buildings, Stockpiles & Pads |
| > 0.005 - 0.020 | Access Road (16-11-01) | Tailings Storage Facility & Embankment |
| > 0.020 - 0.100 | | Highway 37A |
| > 0.100 - 0.200 | | |
| > 0.200 - 0.500 | | |
| > 0.500 - 1.000 | | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
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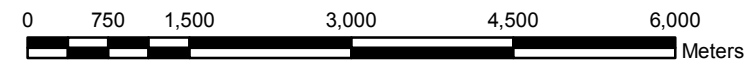
CLIENT:
IDM Mining Ltd.

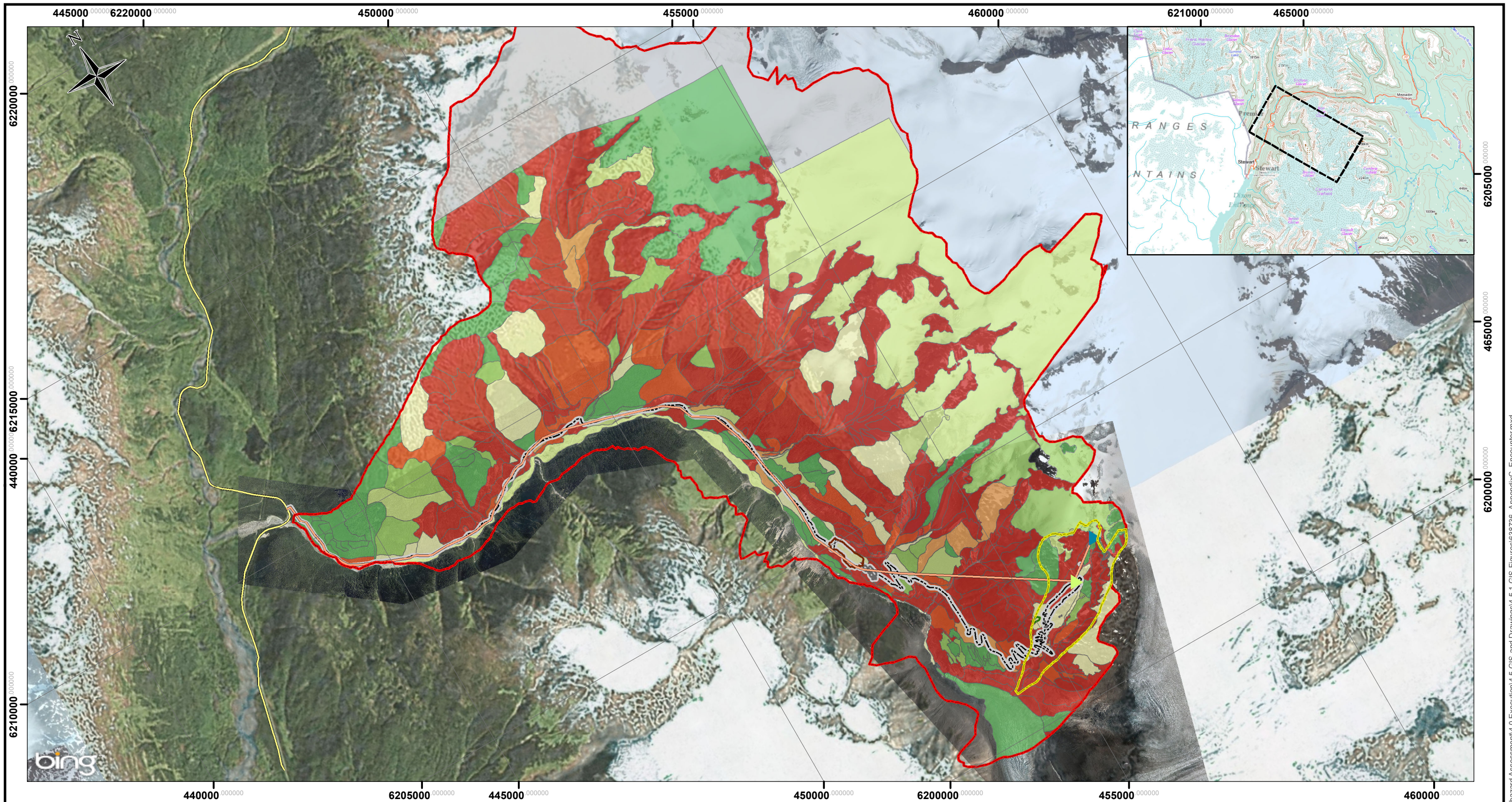
PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia



Appendix F-003. Snow Avalanche Encounter Probability

| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/12 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-F-003 | |





Legend

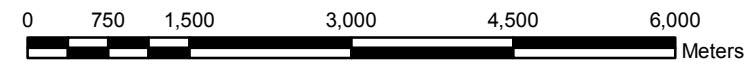
| | | |
|--|------------------------------|--|
| Landslide and Avalanche Encounter Probability | Potentially Inactive Failure | Project components (16-10-06) |
| Outside Air Photo Coverage | GeoLSA | Powerline Route |
| 0.000 - 0.001 | GeoRSA | Administration Facilities |
| > 0.001 - 0.005 | Lower Portal | Buildings, Stockpiles & Pads |
| > 0.005 - 0.020 | Upper Portal (Existing) | Tailings Storage Facility & Embankment |
| > 0.020 - 0.100 | Access Road (16-11-01) | Highway 37A |
| > 0.100 - 0.200 | | |
| > 0.200 - 0.500 | | |
| > 0.500 - 1.000 | | |

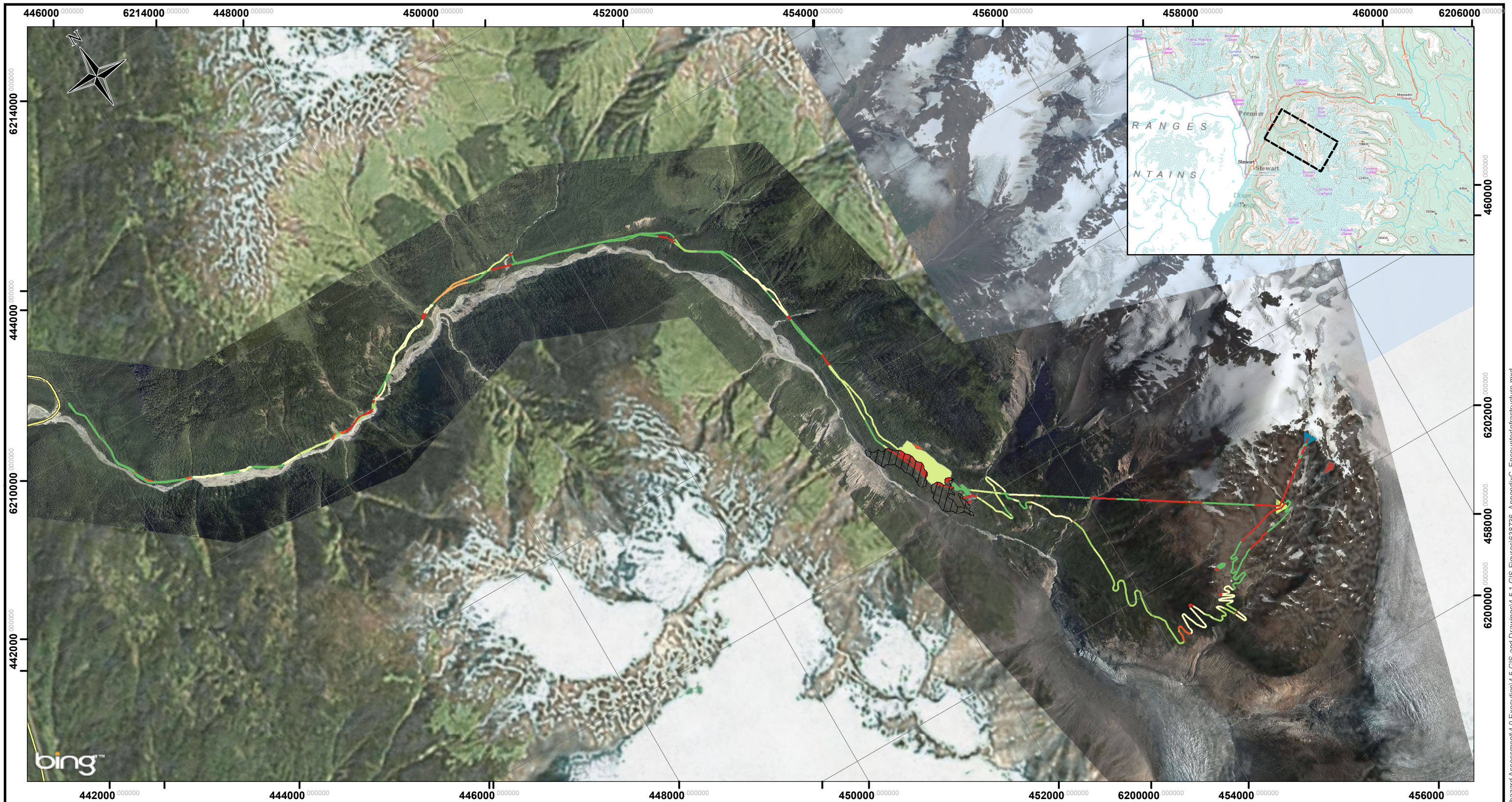
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
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 2. Conceptual design provided by IDM Mining Ltd.
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 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|-----------------------------|
| CLIENT: IDM Mining Ltd. | | SNC · LAVALIN |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix F-004. Multi-Hazard Encounter Probability | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/12 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-F-004 |
| | | REV: 0 |





Legend

Rapid Mass Movement Encounter Probability

| | | | |
|--|-----------------|--|------------------------------|
| | 0.000 - 0.001 | | > 0.200 - 0.500 |
| | > 0.001 - 0.005 | | > 0.500 - 1.000 |
| | > 0.005 - 0.020 | | Potentially Inactive Failure |
| | > 0.020 - 0.100 | | Highway 37A |
| | > 0.100 - 0.200 | | |

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

REFERENCES:

1. LIDAR data provided by IDM Mining Ltd.
2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

0

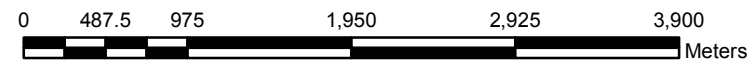
CLIENT:
IDM Mining Ltd.

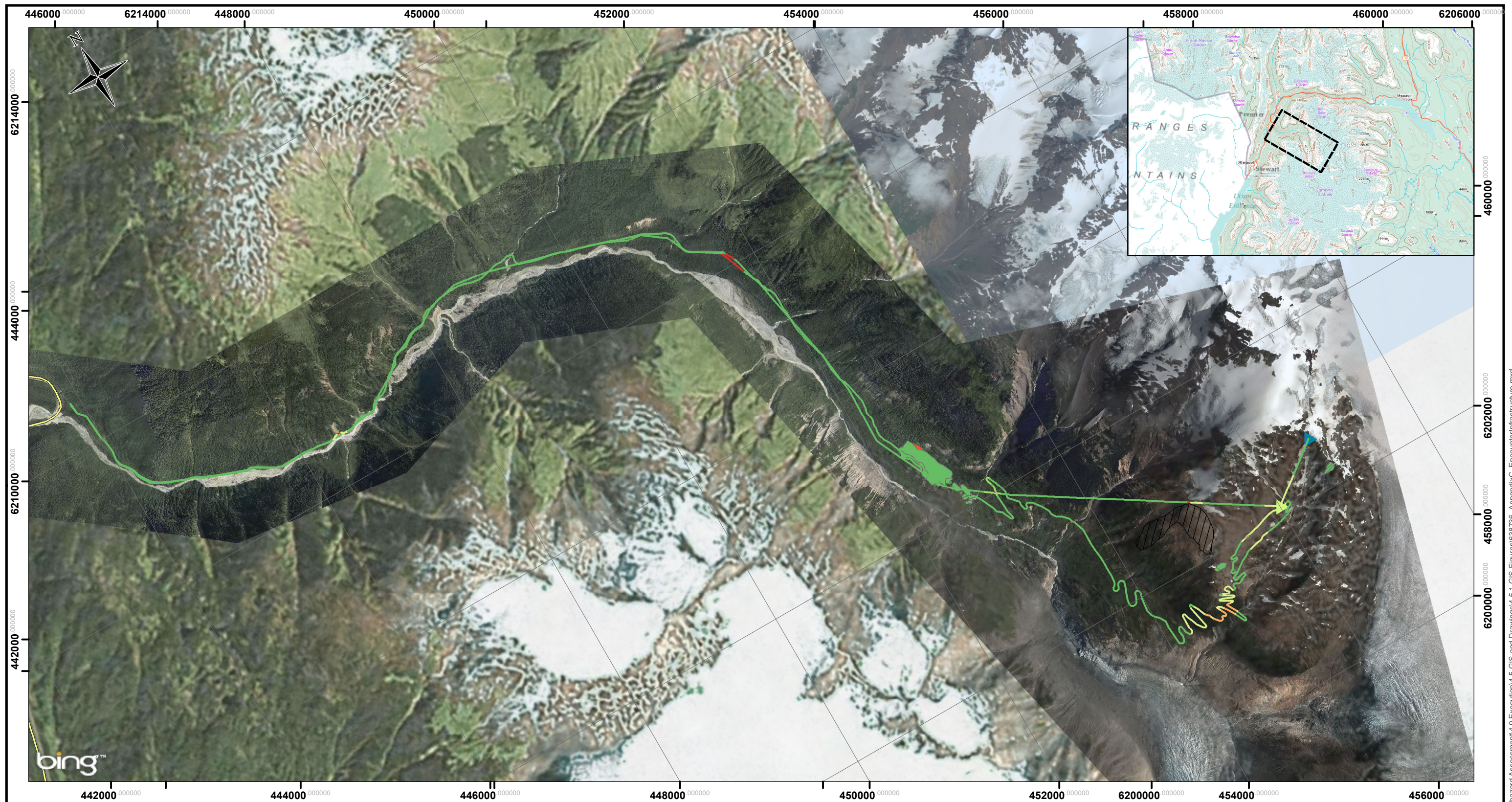
PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia

SNC · LAVALIN

Appendix F-005. Spatial Risk - Rapid Mass Movement

| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:45,000 | DATE: 2017/01/12 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-F-005 | |





Legend

Slow Mass Movement Encounter Probability

| | | | |
|--|-----------------|--|------------------------------|
| | 0.000 - 0.001 | | > 0.200 - 0.500 |
| | > 0.001 - 0.005 | | > 0.500 - 1.000 |
| | > 0.005 - 0.020 | | Potentially Inactive Failure |
| | > 0.020 - 0.100 | | Highway 37A |
| | > 0.100 - 0.200 | | |

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

REFERENCES:

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2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

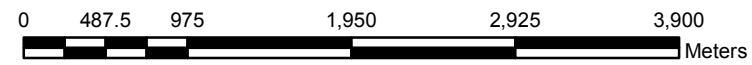
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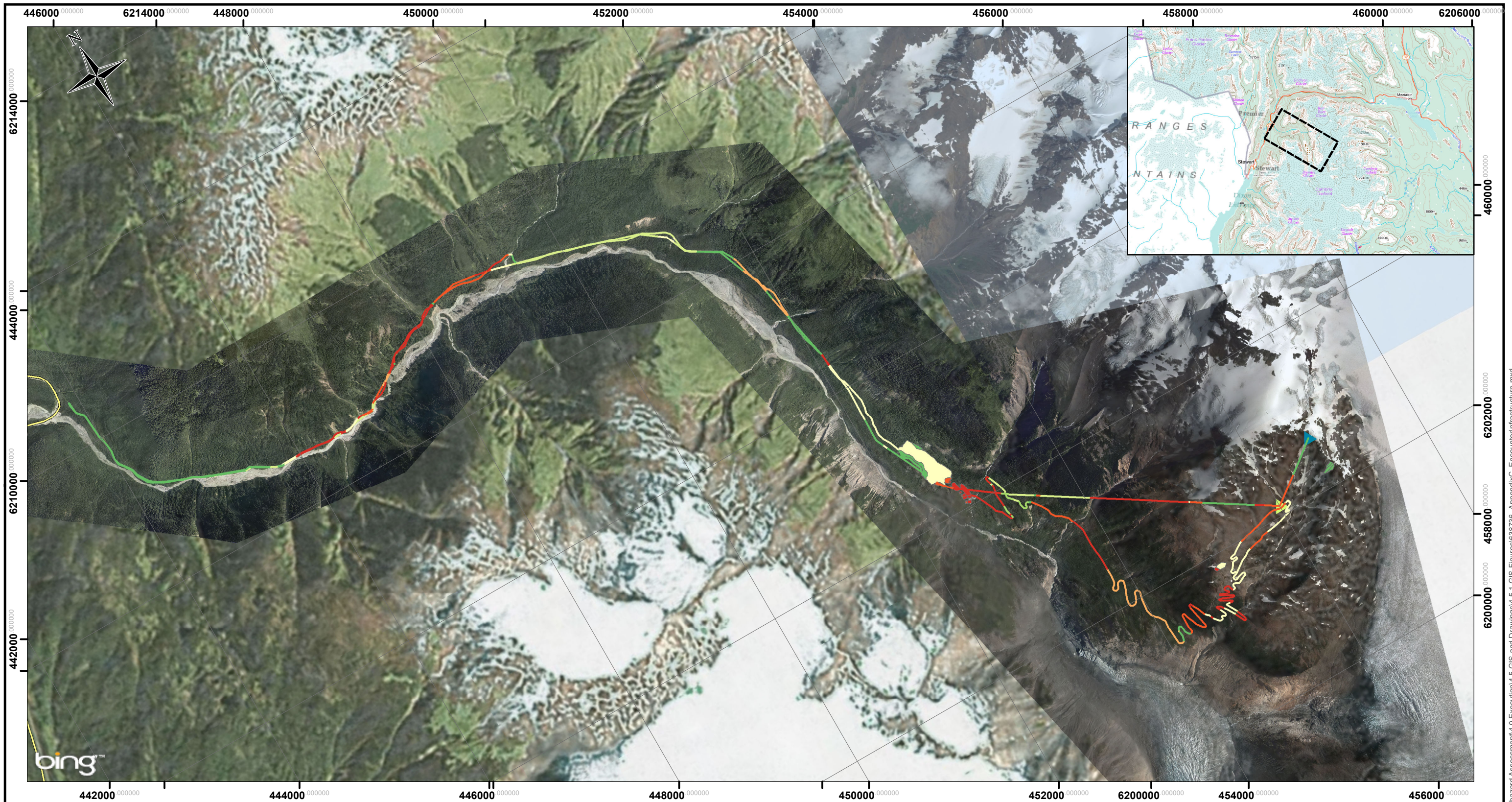
CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia

Appendix F-006. Spatial Risk - Slow Mass Movement









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| BY: CM | SCALE: 1:45,000 | DATE: 2017/01/12 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-F-006 | |





Legend

Snow Avalanche Encounter Probability

| | | | |
|---|-----------------|---|-----------------|
|  | 0.000 - 0.001 |  | > 0.200 - 0.500 |
|  | > 0.001 - 0.005 |  | > 0.500 - 1.000 |
|  | > 0.005 - 0.020 |  | Highway 37A |
|  | > 0.020 - 0.100 | | |
|  | > 0.100 - 0.200 | | |

NOTES:


1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

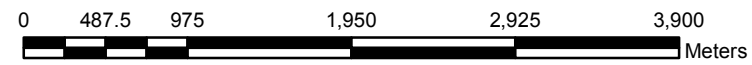
REFERENCES:

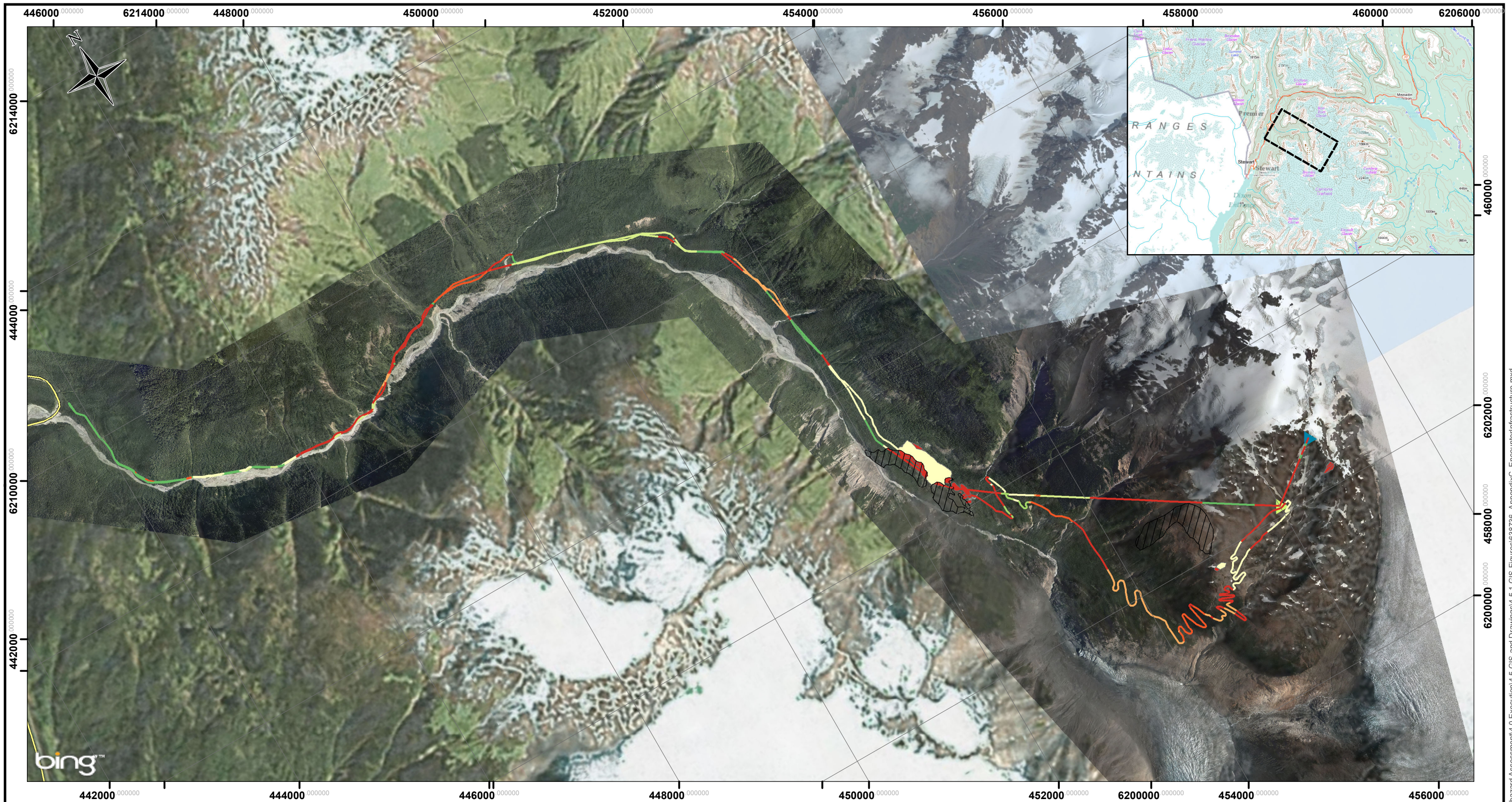
1. LIDAR data provided by IDM Mining Ltd.
2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

0

| | | |
|--|--------------------------------------|---|
| CLIENT: IDM Mining Ltd. | |  SNC · LAVALIN |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix F-007. Spatial Risk - Snow Avalanche | | |
| BY: CM | SCALE: 1:45,000 | DATE: 2017/01/12 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | |
| REF No: 638736-F-007 | | REV: 0 |





Legend

Landslide and Avalanche Encounter Probability

| | | | |
|--|-----------------|--|------------------------------|
| | 0.000 - 0.001 | | > 0.200 - 0.500 |
| | > 0.001 - 0.005 | | > 0.500 - 1.000 |
| | > 0.005 - 0.020 | | Potentially Inactive Failure |
| | > 0.020 - 0.100 | | Highway 37A |
| | > 0.100 - 0.200 | | |

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

REFERENCES:

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2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

0

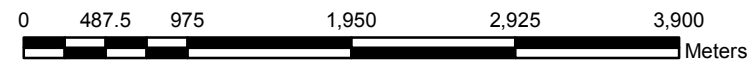
CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia

SNC · LAVALIN

Appendix F-008. Spatial Risk - Multi-Hazard

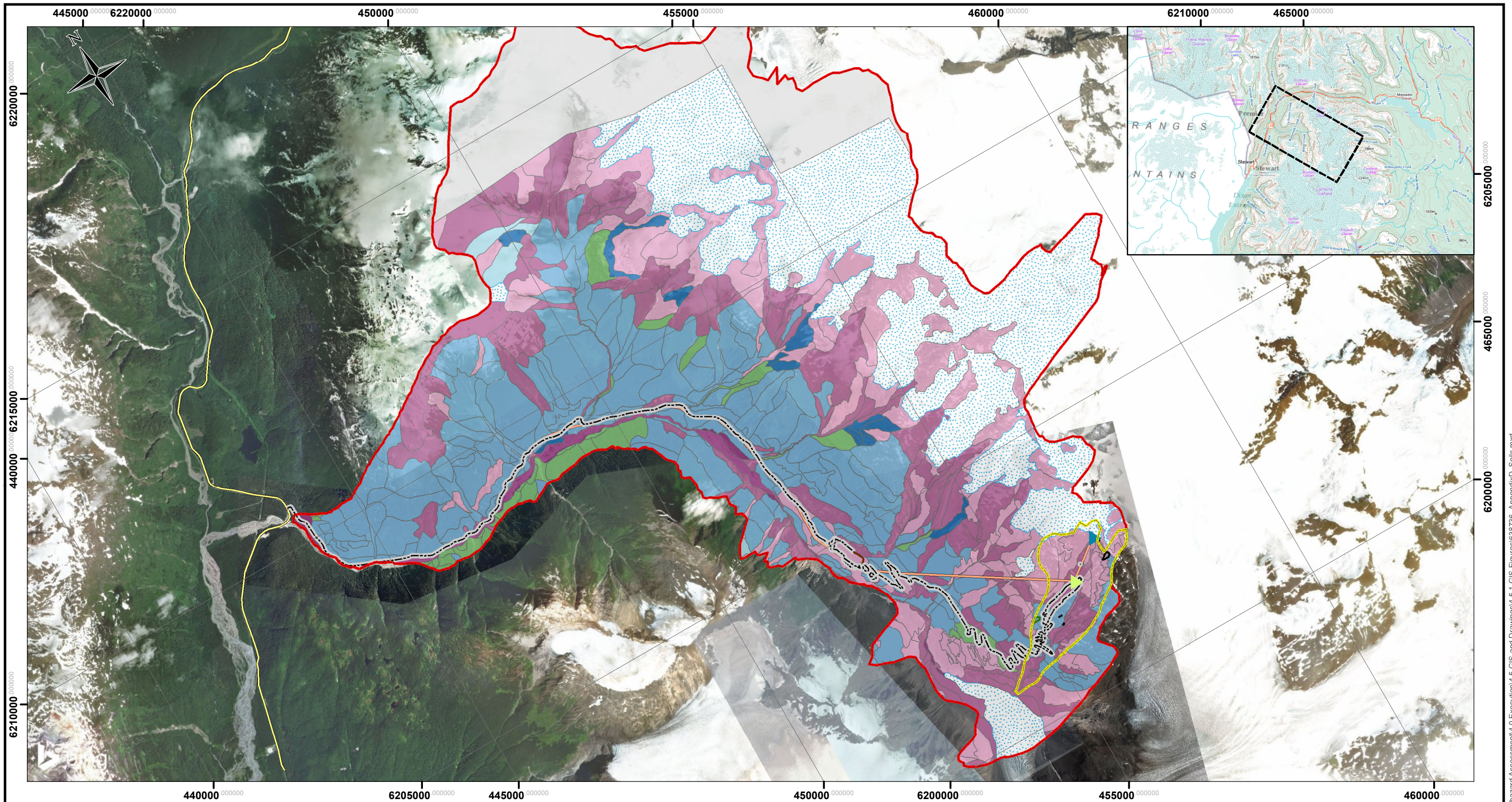
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|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:45,000 | DATE: 2017/01/12 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-F-008 | |





Appendix G

Soil Classification and Soil Erosion Potential Maps



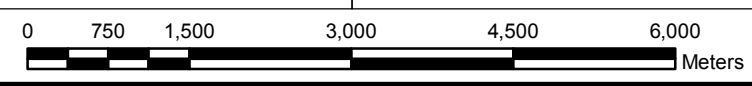
| Legend | |
|--|--|
| Preliminary Soil Classification | |
| | Orthic Eutric Brunisol (O.EB) |
| | Orthic Dystric Brunisol (O.DYB) |
| | Eluviated Dystric Brunisol (E.DYB) |
| | Orthic Humo-Ferric Podzol (O.HFP) |
| | Orthic Regosol (O.R) |
| | Cumulic Regosol (CU.R) |
| | Bedrock |
| | Ice |
| | No Coverage |
| | GeoLSA |
| | GeoRSA |
| | Lower Portal |
| | Upper Portal (Existing) |
| Project components (16-10-06) | |
| | Access Road (16-11-01) |
| | Powerline Route |
| | Administration Facilities |
| | Buildings, Stockpiles & Pads |
| | Tailings Storage Facility & Embankment |
| | Highway 37A |

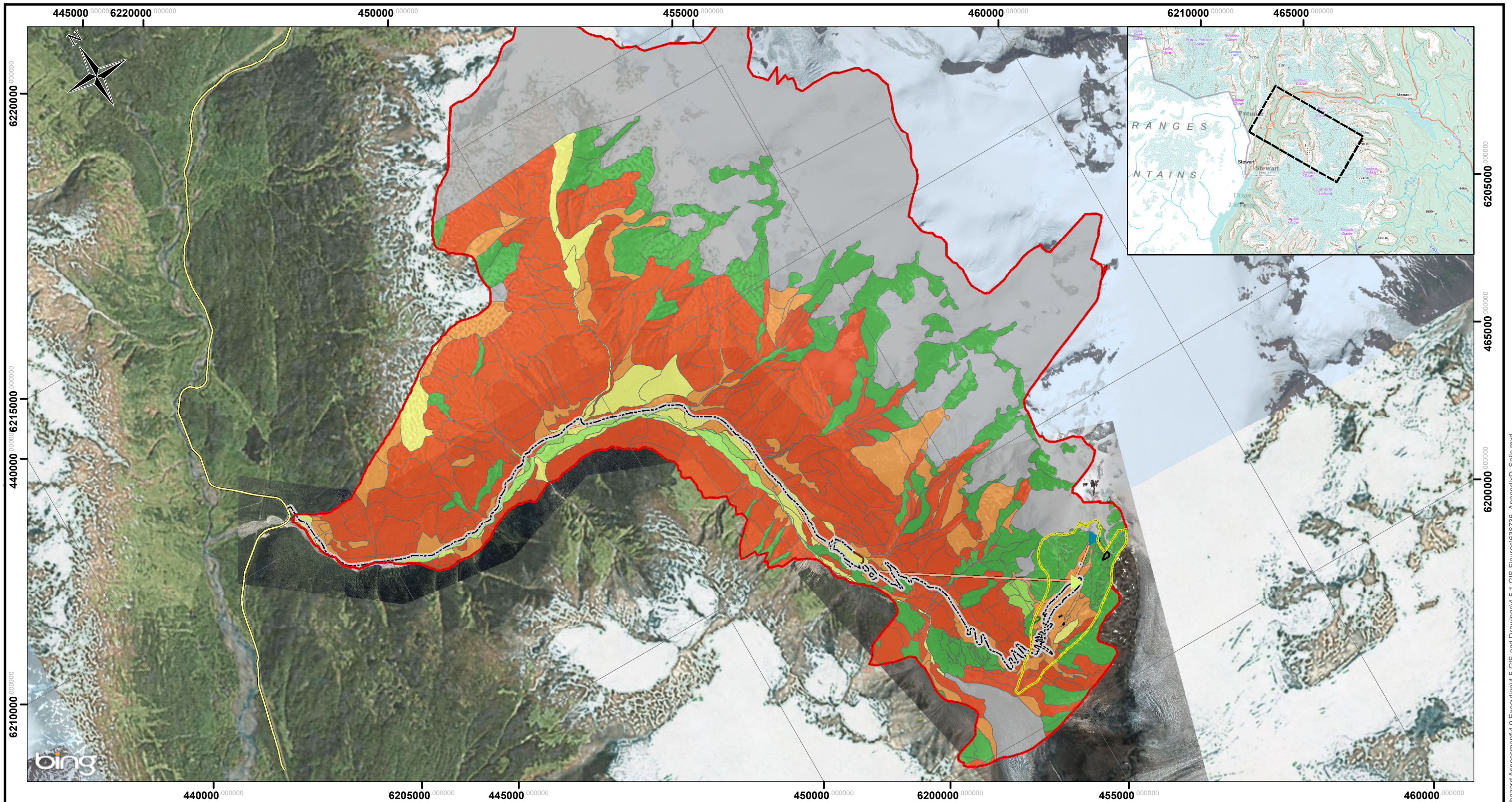
NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Project components revision dated October 6, 2016.
 5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:
 0

| | | |
|--|--------------------------------------|-----------------------------|
| CLIENT: IDM Mining Ltd. | | |
| PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia | | |
| Appendix G-001. Preliminary Soil Classification | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/03/10 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-G-001 |
| | | REV: 0 |





Legend

| | | |
|-------------------------------|--|--|
| Soil Erosion Potential | <ul style="list-style-type: none"> Not Applicable Very High High Moderate Low Very Low | <p>Project components (16-10-06)</p> <ul style="list-style-type: none"> Powerline Route Administration Facilities Buildings, Stockpiles & Pads Tailings Storage Facility & Embankment Lower Portal Upper Portal (Existing) Access Road (16-11-01) Highway 37A |
|-------------------------------|--|--|

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

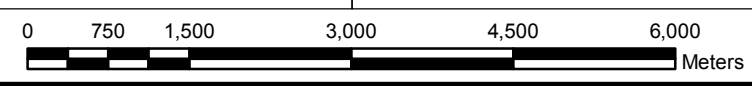
REFERENCES:

1. LIDAR data provided by IDM Mining Ltd.
2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Project components revision dated October 6, 2016.
5. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

0

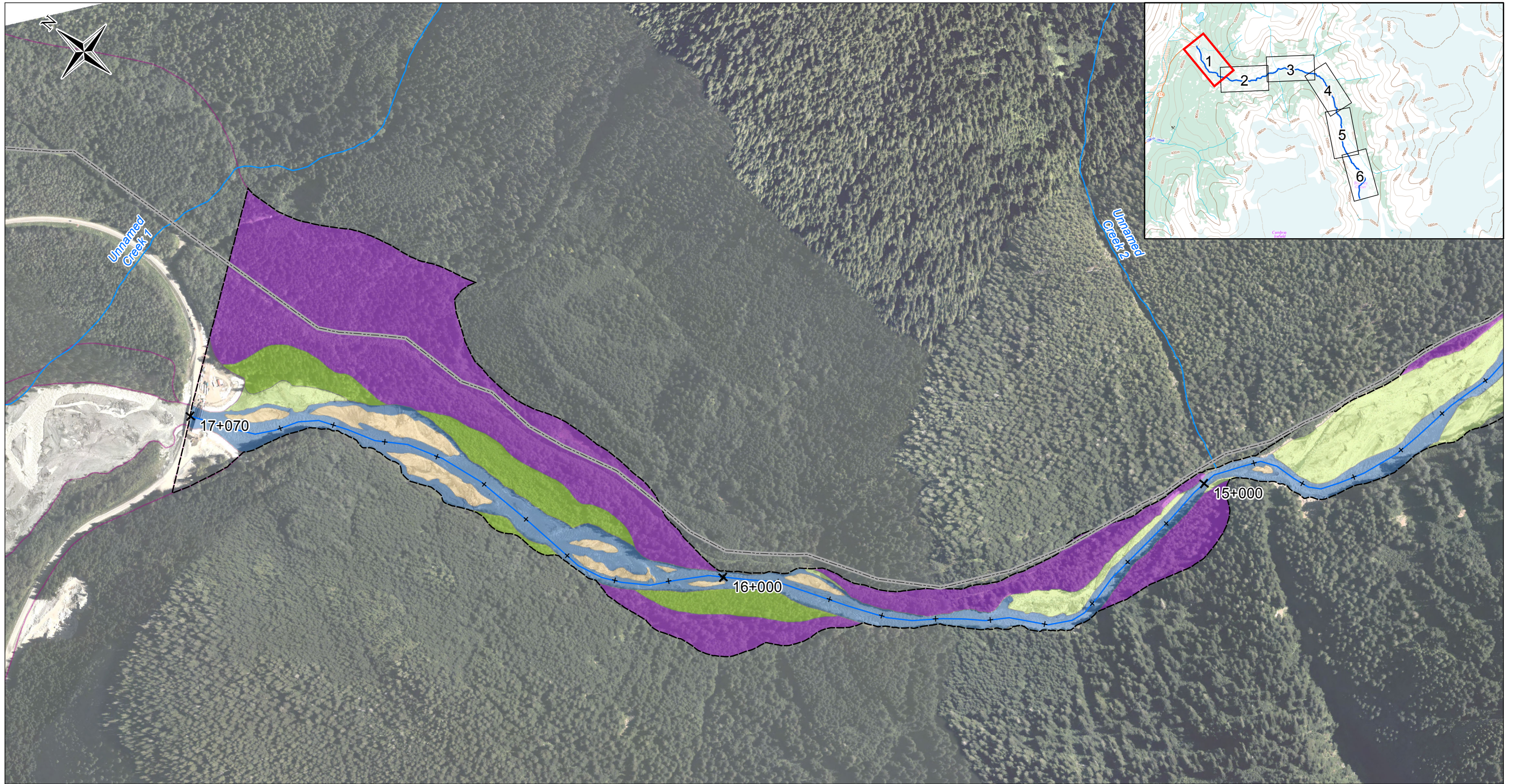
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|---|--------------------------------------|-----------------------------|
| <p>CLIENT: IDM Mining Ltd.</p> | <p>SNC · LAVALIN</p> | |
| <p>PROJECT LOCATION: Red Mountain Gold Project, Stewart, British Columbia</p> | | |
| <p>Appendix G-002. Soil Erosion Potential</p> | | |
| BY: CM | SCALE: 1:70,000 | DATE: 2017/01/13 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | REF No: 638736-G-002 |
| | | REV: 0 |





Appendix H

Fluvial Feature Maps



Legend

| | | |
|-------------------------|----------------------|-------------------------|
| Fluvial Features | Inactive Lateral Bar | Channel Station |
| Main Channel | Active Flood Channel | Creek |
| Side Channel | Active Floodplain | Bitter Creek Study Area |
| Active Medial Bar | Inactive Floodplain | Access Road (16-11-01) |
| Inactive Medial Bar | Rock Outcrop | |
| Active Lateral Bar | Rip Rap | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

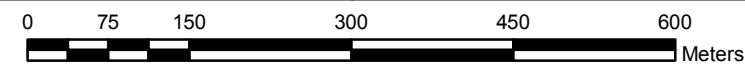
REVISIONS:
 0

CLIENT:
 IDM Mining Ltd.

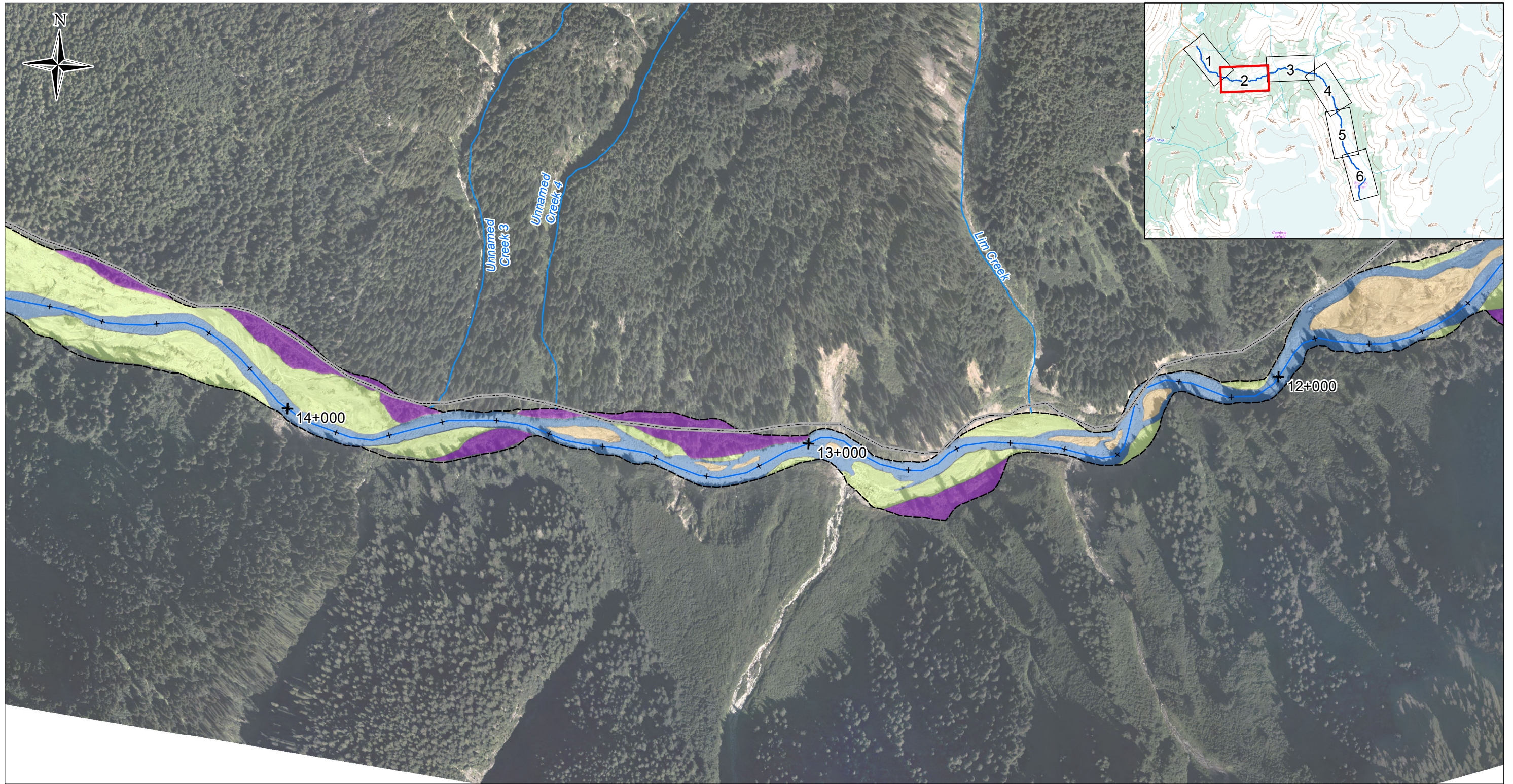
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix H-001. Fluvial Feature Classification, 2013



| | | | | |
|----------|--------------------------------------|------------------|--------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-001 | |



Legend

| | | |
|-------------------------|----------------------|-------------------------|
| Fluvial Features | Inactive Lateral Bar | Channel Station |
| Main Channel | Active Flood Channel | Creek |
| Side Channel | Active Floodplain | Bitter Creek Study Area |
| Active Medial Bar | Inactive Floodplain | Access Road (16-11-01) |
| Inactive Medial Bar | Rock Outcrop | |
| Active Lateral Bar | Rip Rap | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
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 4. Data presented are in draft

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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

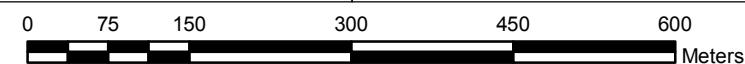
REVISIONS:
 0

CLIENT:
 IDM Mining Ltd.

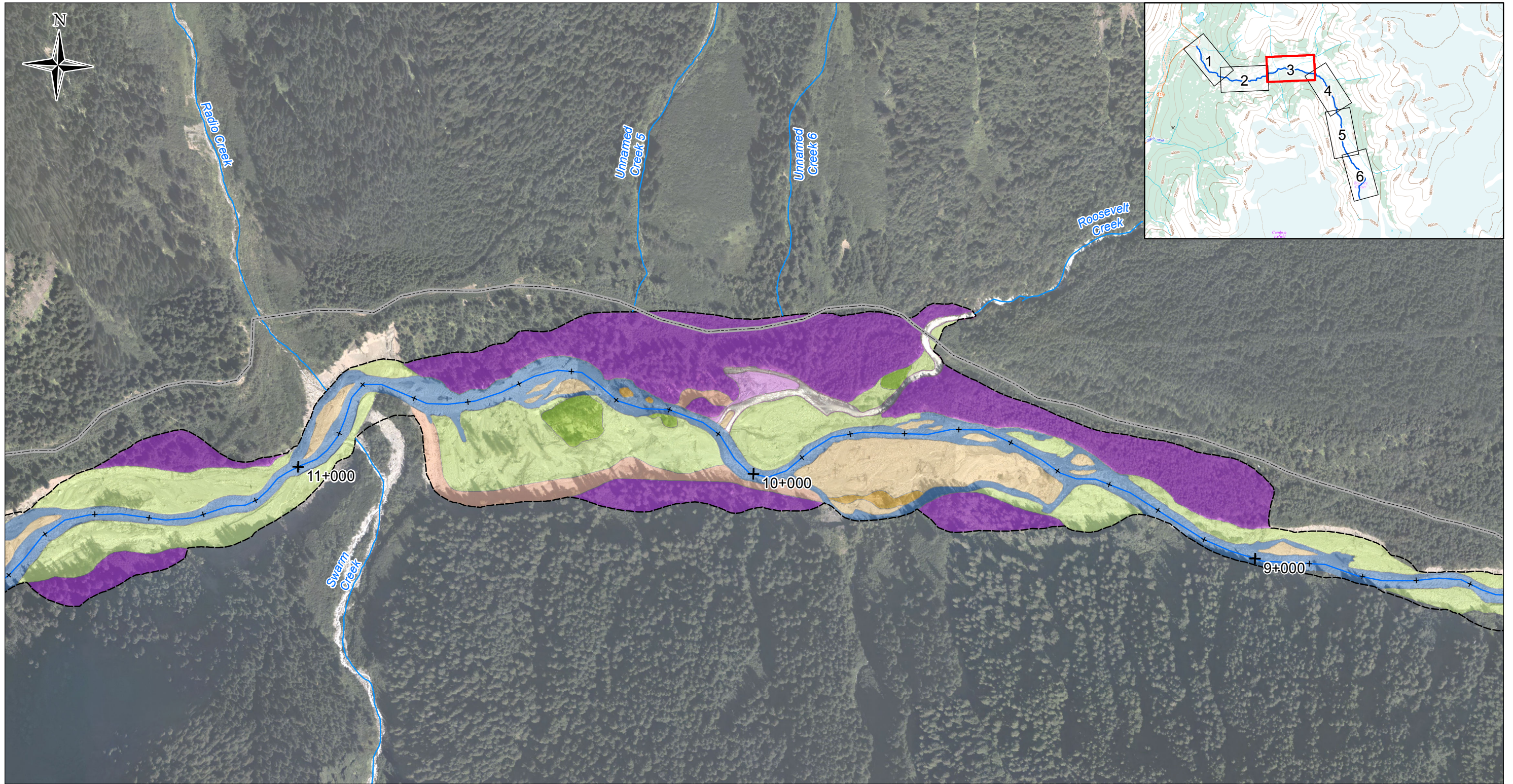
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix H-002. Fluvial Feature Classification, 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-002 | |



Legend

- | | | |
|-------------------------|----------------------|-------------------------|
| Fluvial Features | Inactive Lateral Bar | Channel Station |
| Main Channel | Active Flood Channel | Creek |
| Side Channel | Active Floodplain | Bitter Creek Study Area |
| Active Medial Bar | Inactive Floodplain | Access Road (16-11-01) |
| Inactive Medial Bar | Rock Outcrop | |
| Active Lateral Bar | Rip Rap | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

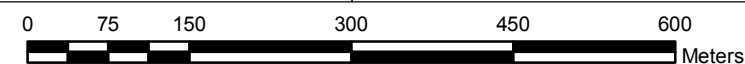
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

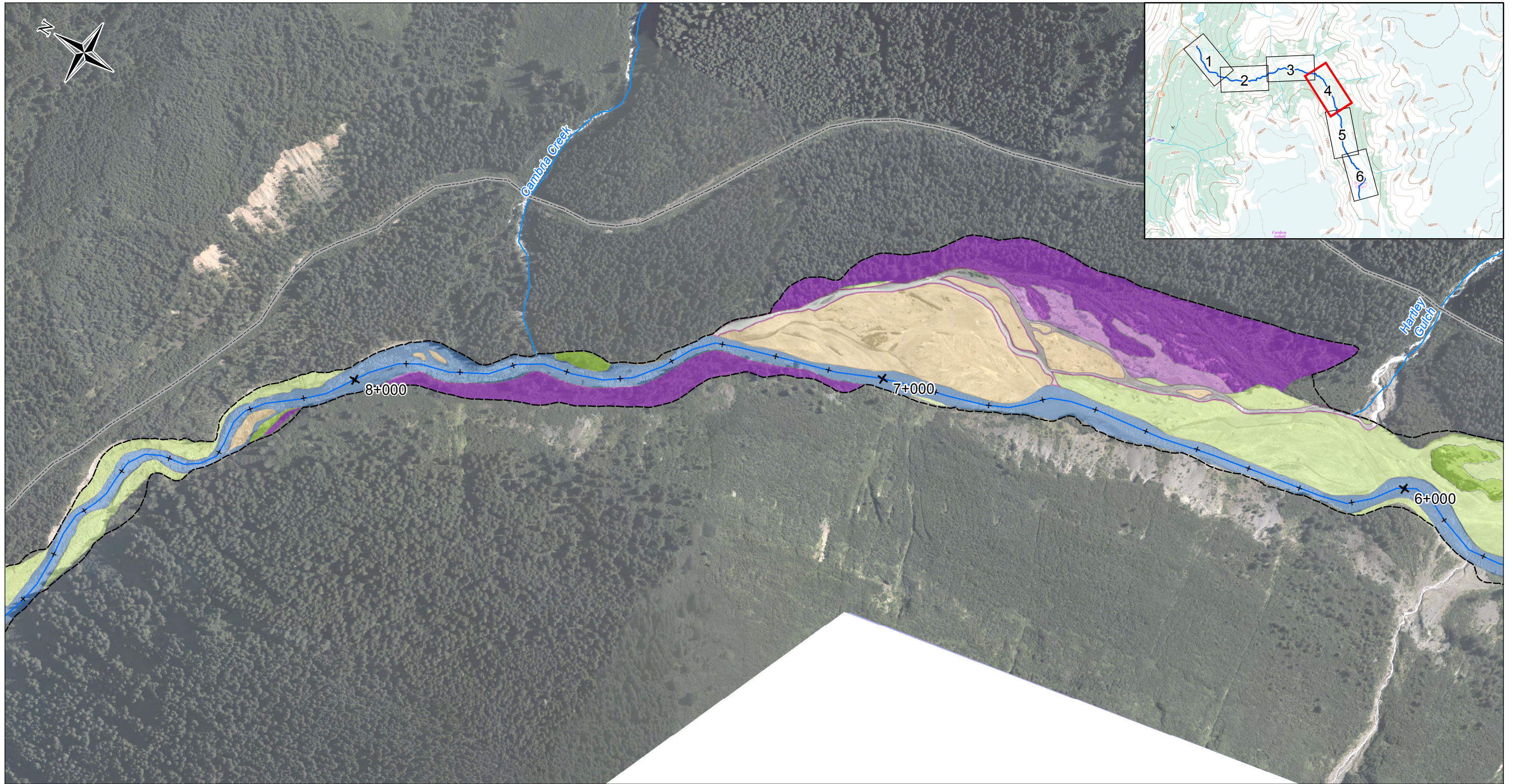
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix H-003. Fluvial Feature Classification, 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-003 | |



Legend

- | | | |
|-------------------------|----------------------|-------------------------|
| Fluvial Features | Inactive Lateral Bar | Channel Station |
| Main Channel | Active Flood Channel | Creek |
| Side Channel | Active Floodplain | Bitter Creek Study Area |
| Active Medial Bar | Inactive Floodplain | Access Road (16-11-01) |
| Inactive Medial Bar | Rock Outcrop | |
| Active Lateral Bar | Rip Rap | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

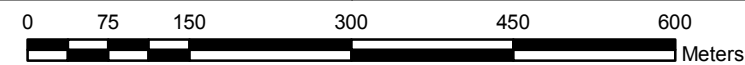
REVISIONS:
 0

CLIENT:
 IDM Mining Ltd.

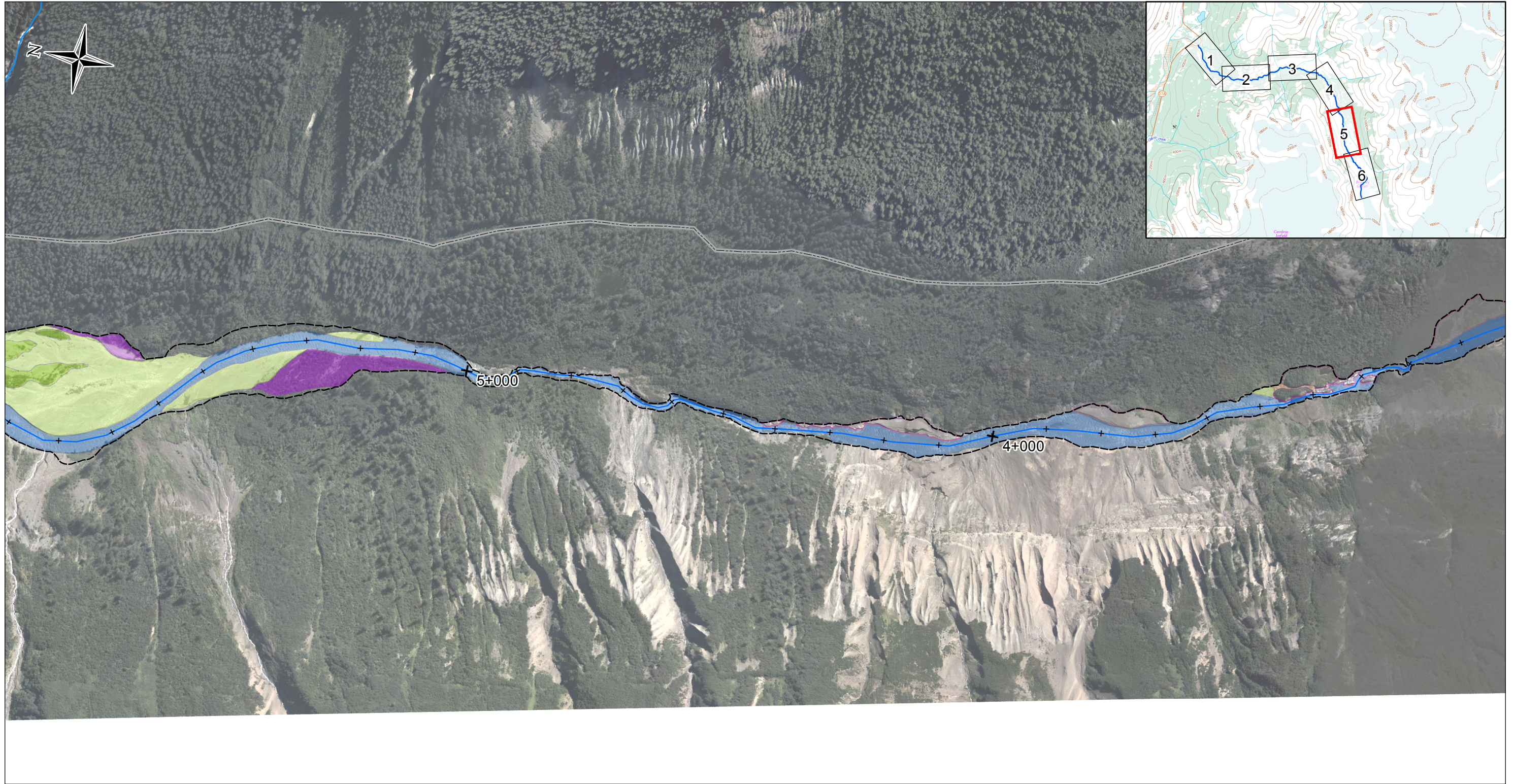
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix H-004. Fluvial Feature Classification, 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-004 | |



Legend

- | | | |
|-------------------------|----------------------|-------------------------|
| Fluvial Features | Inactive Lateral Bar | Channel Station |
| Main Channel | Active Flood Channel | Creek |
| Side Channel | Active Floodplain | Bitter Creek Study Area |
| Active Medial Bar | Inactive Floodplain | Access Road (16-11-01) |
| Inactive Medial Bar | Rock Outcrop | |
| Active Lateral Bar | Rip Rap | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

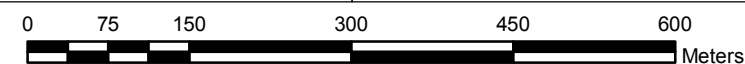
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix H-005. Fluvial Feature Classification, 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-005 | |



Legend

Fluvial Features

- Main Channel
- Side Channel
- Active Medial Bar
- Inactive Medial Bar
- Active Lateral Bar
- Inactive Lateral Bar
- Active Flood Channel
- Active Floodplain
- Inactive Floodplain
- Rock Outcrop
- Rip Rap
- Bitter Creek Study Area
- Access Road (16-11-01)
- Channel Station
- Creek

NOTES:

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Data presented are in draft

REFERENCES:

1. LIDAR data provided by IDM Mining Ltd.
2. Conceptual design provided by IDM Mining Ltd.
3. Road alignment revision dated November 1, 2016.
4. Basemaps from ESRI, DeLorme, USGS, NPS

REVISIONS:

0

CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia



SNC • LAVALIN

Appendix H-006. Fluvial Feature Classification, 2013

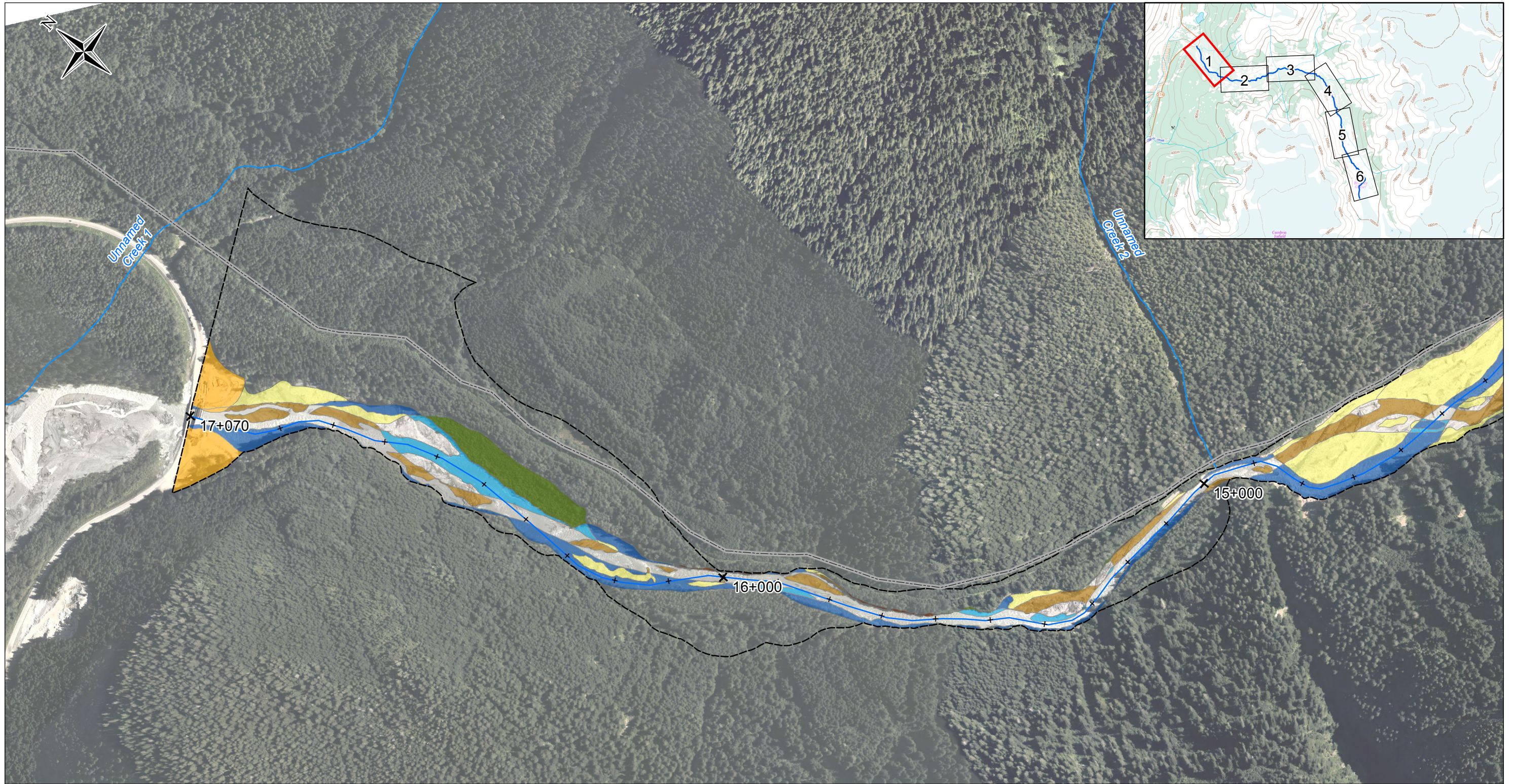


| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-H-006 | |



Appendix I

Fluvial Channel Change Maps



Legend

- | | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

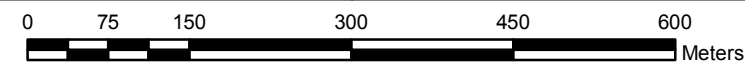
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

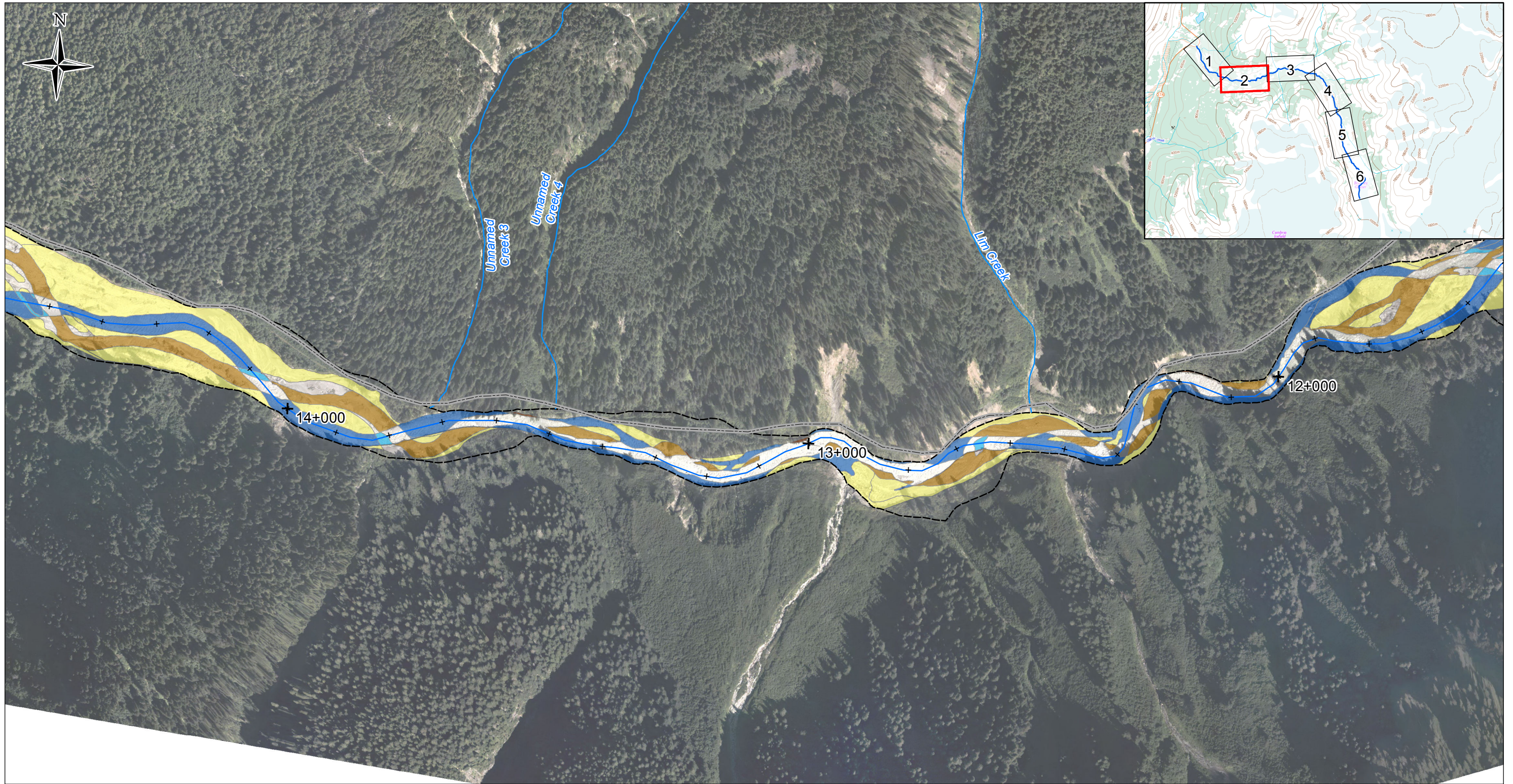
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix I-001. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-001 | |



Legend

| | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

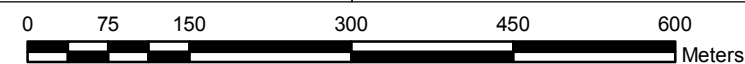
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

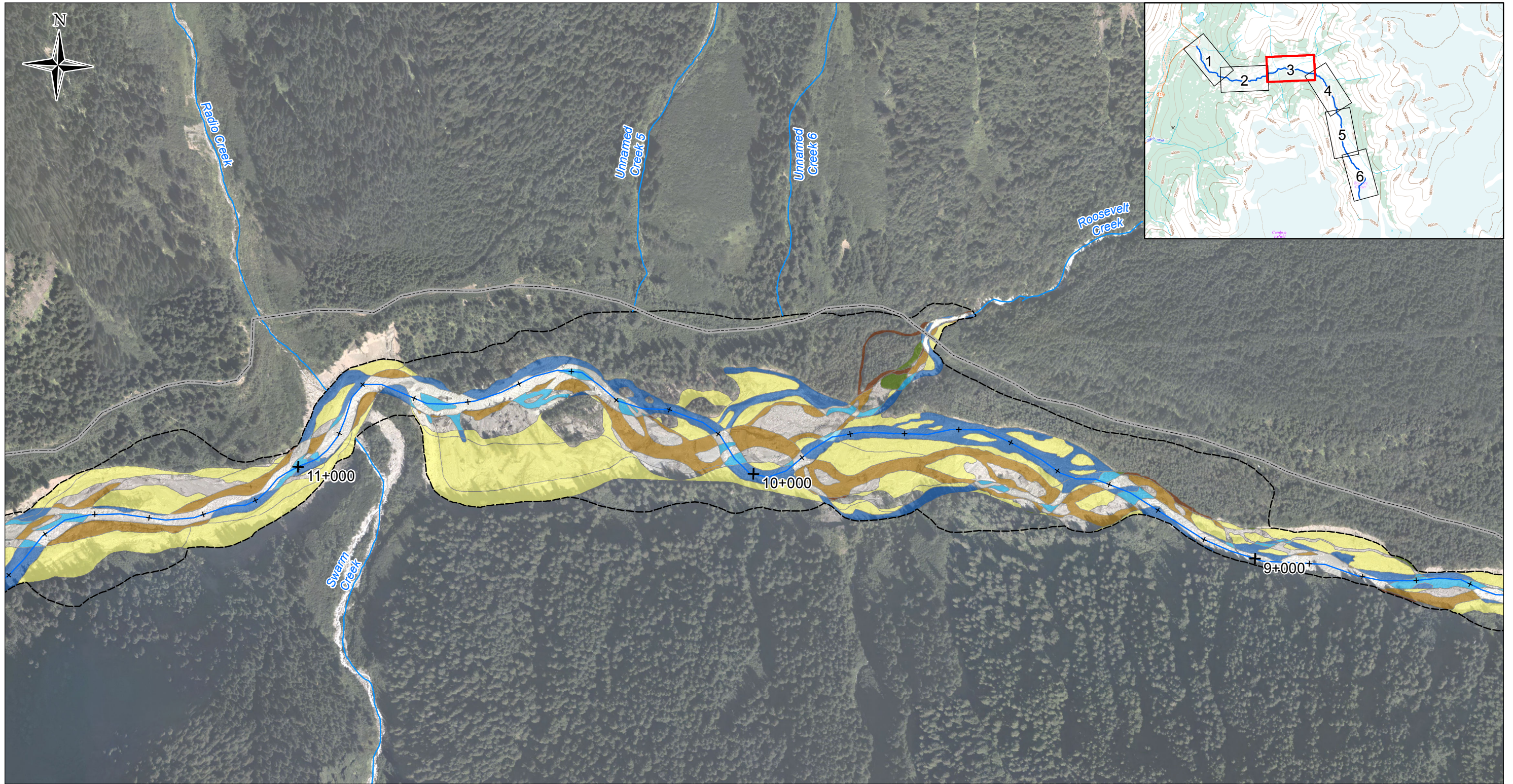
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix I-002. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-002 | |



Legend

| | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

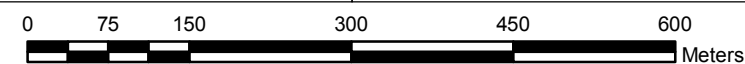
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

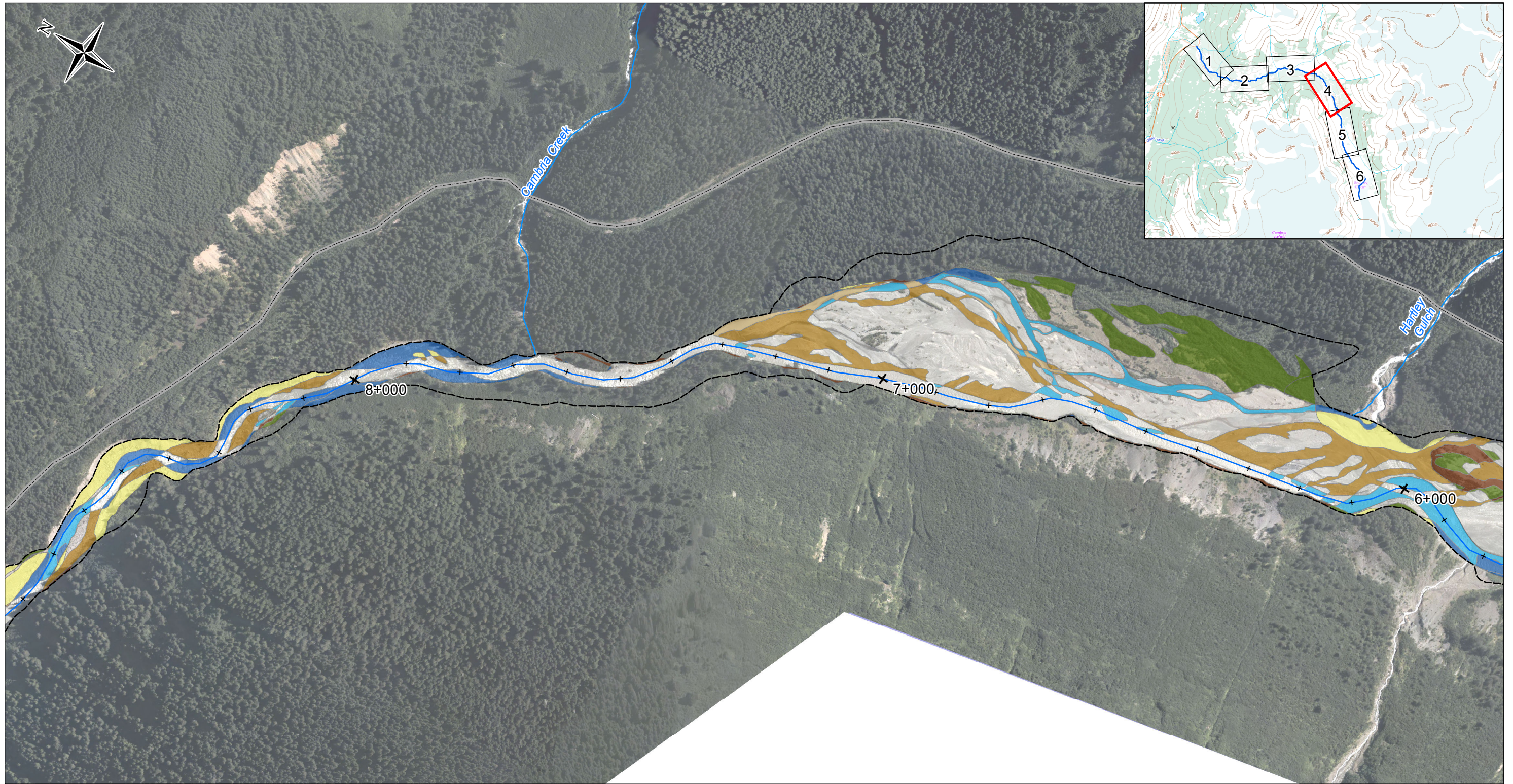
PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix I-003. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-003 | |



Legend

- | | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

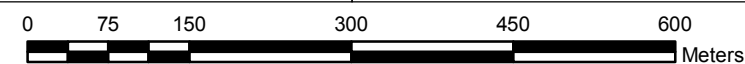
REVISIONS:
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CLIENT:
 IDM Mining Ltd.

PROJECT LOCATION:
 Red Mountain Gold Project,
 Stewart, British Columbia



Appendix I-004. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-004 | |



Legend

- | | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
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 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

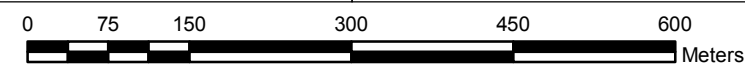
REVISIONS:
 0

CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia



Appendix I-005. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-005 | |



Legend

- | | | |
|------------------------------------|----------------------|-------------------------|
| Bitter Creek Channel Change | Colonization | Channel Station |
| High Erosion | Low Deposition | Creek |
| Moderate Erosion | Moderate Deposition | Bitter Creek Study Area |
| Low Erosion | High Deposition | Access Road (16-11-01) |
| Denudation | Glacial Retreat | |
| No Change | Anthropogenic Change | |

NOTES:
 1. Original in colour.
 2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
 3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
 4. Data presented are in draft

REFERENCES:
 1. LIDAR data provided by IDM Mining Ltd.
 2. Conceptual design provided by IDM Mining Ltd.
 3. Road alignment revision dated November 1, 2016.
 4. Basemaps from ESRI, DeLorme, USGS, NPS

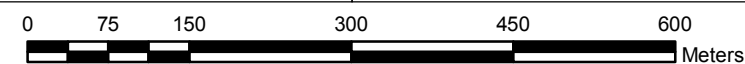
REVISIONS:
 0

CLIENT:
IDM Mining Ltd.

PROJECT LOCATION:
Red Mountain Gold Project,
Stewart, British Columbia



Appendix I-006. Fluvial Channel Change, 1994 - 2013



| | | | | |
|----------|--------------------------------------|------------------|---------------------|--------|
| BY: CM | SCALE: 1:7,000 | DATE: 2017/01/13 | REF No: | REV: 0 |
| CHKD: HB | Proj Coord Sys: NAD 1983 UTM Zone 9N | | 638736-I-006 | |



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