7.3 Terrain, Surficial Geology and Soils

7.3.1 Scope of Assessment

Issues and Selection of Valued Ecosystem and Cultural Components

Table 7.3-1 provides a list of the terrain, surficial geology and soil "Valued Ecosystem Cultural Components" (VECCs) that have been defined for this environmental assessment. This list is based on the selection process outlined in section 6.2 of this report.

Table 7.3-1 Terrain, Surficial Geology and Soil VECCs, Selection Rationale and Data Sources

VECC	Rationale for Selection	Linkage to EA Report Guidelines or Other Regulatory Drivers	Baseline Data for EA
Key terrain features	• General description of project geography • Linked to terrain hazards, erosion potential • Influences habitat capability	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Field Data • Surficial Geology Mapping
Surficial materials	• Linkage to terrain hazards and erosion potential • Construction will alter current baseline conditions and affect recreation potential and post closure ecosystems	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Surficial Geology Mapping program • Field Data • YZC and Gov't of YK baseline data
Permafrost presence	• Areas of specific concern to be defined for planning and management •	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Terrain Mapping program • Field Data • YZC and Gov't of YK baseline data
Key sediments with high erosion potential	• Areas of specific concern to be defined for planning and management • Linkage to potential sedimentation of aquatic habitat	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Terrain Mapping program • Field Data
Natural terrain hazards	• Areas of specific concern to be defined for planning and management	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Terrain Mapping program • Field Data • YZC and Gov't of YK baseline data
Sensitive soil types	• Areas of specific concern to be defined for planning and management • Construction will alter current baseline conditions, affect reclamation potential	• Information requested in the EA Report Guidelines and Biophysical Assessment Workplan	• Terrain Mapping program • Field Data • YZC and Gov't of YK baseline data

As identified in Table 7.3-1 and in addition to the criteria outlined in section 6.2 of this report, these VECCs were chosen for one or more of the following reasons:

- potential for project impacts was unclear
- construction will alter current baseline conditions
- impact of construction is unclear
- areas of specific concern to be defined

Temporal Boundaries

The temporal scope of this environmental effects assessment includes all project-related environmental and cultural effects for the 14-year life of the mine, including baseline, construction, operation, decommissioning, and closure as described in 6.3 of this report.

Study Area

The project area is located within the Northern Foothills of the Pelly Mountains on the Yukon Plateau, approximately 50 km northeast of the Tintina Fault (Gartner Lee Ltd. 2004). This project encompasses a total area of approximately 15,488.60 ha and is dominated by terrain common in areas subjected to glaciation - rounded mountains and broad, U-shaped valleys. Elevations vary from a low of approximately 900 m asl (meters above sea level) near the Robert Campbell Highway to a high of approximately 1940 m asl on the divide between Go Creek and Bunker Creek. Wolverine Lake and its tributaries (Wolverine, Campbell and Jasper creeks) are located in the northern portion of the study area. The remaining portion of the study area traverses the Go Creek basin and two unnamed tributaries, locally referred to as Bunker Creek (a tributary of Money Creek) and Light Creek (a tributary of the Finlayson River). All of these drainages form part of the larger Liard River system.

The Local Study Area (LSA) for the assessment of project effects on terrain, surficial geology and soils is defined as the potential project disturbance footprint (conservatively defined as the total of YZC’s claim areas directly affected by mine site facilities), buffered by 100 m to account for potential edge effects such as changes in drainage or induced localized instabilities (Figure 7.3-1). These buffers are large enough to accommodate potential changes in the development design and project footprint. They are also appropriate for the scale of interpretation conducted and can be predicted with a reasonable degree of accuracy and confidence to include the areas where impacts on terrain, surficial materials and soils are most concentrated.

Figure 7.3-1 Terrain, Survicial Geology and Soils - Local Study Area (Vol. 2)

A secondary, larger study area was identified for terrain, surficial materials and soils mapping to provide input to ecosystem mapping for wildlife habitat. This area is defined by the potential extent of project disturbance of wildlife (including noise, traffic and human activity), which extends beyond the area of potential ground disturbance (Section 7.10: Wildlife). Terrain, surficial materials and soils mapping for this larger area is illustrated along with the LSA mapping. A Regional Study Area (RSA) is not defined for the terrain and soils assessment as the project effects on terrain and soils will be very localized and are not expected to overlap or act cumulatively with effects of other projects or activities in the region.

7.3.2 Baseline Conditions

7.3.2.1 Methods

The objective of the baseline mapping and description was to describe terrain, surficial materials (geology) and soil conditions of the project area as a basis for the impact and environmental assessment. Terrain, surficial materials and soil conditions were interpreted through the use of existing maps and aerial photographs, supplemented with a field inventory reconnaissance program. Characterization of baseline conditions used a staged approach to build and refine the information presented. The stages are described briefly below.

Background Data Compilation

A significant amount of background data exists for this project area. Previous studies conducted for YZC and previous mineral lease holders have presented baseline information including the bedrock geology, surficial materials, terrain hazards, and soil characteristics of the project area. This material was reviewed and where applicable, used to maximize the quality of this report. For example, where practicable the mapping and style of this report follows that produced by Mougeot Geoanalysis (1996). The following references were reviewed and incorporated into baseline description, as appropriate:

- Surface Geology, Soils and Associated Interpretations. Wolverine Biophysical Surveys (Mougeot Geoanalysis 1996)
- Baseline Biophysical Survey Program, Wolverine Area (Access Mining Consultants Ltd. 1996)
- Pre-feasibility Study - Proposed Wolverine Tailings Impoundment 040901R-Wolverine Tailings Pre-feasibility-Draft (Crippen 2004)
- Wolverine Project Description Report (Gartner Lee Limited 2004)
- Wolverine Road Alignment Study, Wolverine (Gartner Lee Ltd. 2004)
- Geoprocess File. Summary Report Finlayson Lake (Anonymous 2002)
- Terrain Classification System for British Columbia (Howes and Kenk 1988)
- The Canadian System of Soil Classification, Third Edition (Soil Classification Working Group 1998)

Preliminary Aerial Photograph Interpretation

In this stage, 1992 black and white aerial photographs were organized into lines and interpreted to gain an understanding of the general terrain, landform, and vegetation features of the project area. These 1:40 000 scale aerial photographs were interpreted to delineate relatively homogeneous terrain units based on surficial materials, slope, drainage, aspect, geologic modifying processes (i.e., landslides, seepage, etc.) and vegetation patterns. The aerial photographs were also used to select potential sites for field traverses. Previous 1:75 000 mapping by Mougeot Geoanalysis (1996) was incorporated into the mapping, where applicable.

Field Inventory Reconnaissance

Field inventory reconnaissance is an essential component of the terrain and subsequent ecosystem mapping process. Field sampling data were used to develop and confirm map unit designations and boundaries. It also enabled the resulting classification to be extrapolated and applied to portions of the project area not sampled.

Prior to the field inventory program, a field sampling plan was prepared based on:

- timing / schedule of the field program, person days, crew composition
- access, including foot and helicopter transects
- number and types of plots to be established
- location of existing data
- field sampling priorities and logistics

The field-sampling program occurred during July 2005. Two types of field plots were established; detailed and visual plots. An initial overview helicopter flight was undertaken to provide an overview of the project area and refine possible site locations. Detailed plot data were recorded on <u>*Terrain and Soils Data Forms*</u>; these plots provide the most detailed surficial geology and soils data for a point sample. Data collected included descriptions of major pedological horizons, pH, textural and structural classification, drainage, aspect, slope gradient, surficial material and pertinent geomorphic processes; where noted, the presence of permafrost and depth to permafrost was also indicated. These plots are intended for soil, terrain, drainage and slope classification. A total of 38 detailed soil and terrain plots were completed within the project area. Visual inspections typically comprise a large portion of the field data component even though they are the least intensive method of field data collection. Their strength is that they allow field surveyors to quickly assess or confirm polygons for terrain attributes and/or record terrain component percentages, soil textures, soil depths, and slope, drainage; evaluate polygon boundaries; or note special features including bedrock outcrops. Visual inspections also allow surveyors to quickly assess large areas of terrain and can be conducted on the ground, from the air, or from viewscapes. However, in order to improve data reliability for this project, emphasis was placed on making inspections on the ground. In total, 33 soil and terrain visual inspections were performed.

Final Mapping and Classification

After the completion of field work, soil and terrain data were tabled, analyzed and incorporated into the final mapping process. During the final mapping process, the following data was recorded for each terrain unit (or polygon): surficial materials, slope, soil drainage, soil classification, terrain stability and soil erosion potential as well as other applicable terrain symbology. Up to three terrain types were recorded for each terrain unit.

Terrain Stability

Terrain stability is a function of bedrock, surficial material, soil texture and thickness, surface expression, potential slip plains, slope, slope position, slope curvature, drainage, and vegetation. Individual map units were rated for terrain stability based on the criteria outlined in Table 7.3-2. This table, adopted from work completed in British Columbia (Anonymous 1999)**,** provides a brief interpretative description for each slope stability hazard class and outlines the major management implications expected of operations within the class.

Table 7.3-2 Terrain Stability Hazard Classification

Terrain Stability Class	Reconnaissance Stability Class	Interpretation
S	Stable	• Minor stability problems can develop • Vegetation removal should not significantly reduce terrain stability. There is a low likelihood of landslide initiation following vegetation removal • Minor slumping is expected along road cuts, especially one or two years following construction. There is a low likelihood of landslide initiation following road building • A field inspection by a terrain specialist is usually not required
P	Potentially unstable	• Expected to contain areas with a moderate likelihood of landslide initiation following vegetation removal and/or road construction. Wet season construction or construction on sites underlain by permafrost will significantly increase the potential for road-related landslides • A field inspection of these areas is to be made by a qualified terrain specialist prior to any development, to address the stability of the affected area
U	Unstable	• Expected to contain areas with a high likelihood of landslide initiation following vegetation removal or road construction. Wet season construction or construction on sites underlain by permafrost will significantly increase the potential for road-related landslides • A field inspection of these areas is to be made by a qualified terrain specialist prior to any development, to address the stability of the affected area

Source: Anonymous 1999

Potential Surface Erosion

Erosion via water is the predominate form of erosion in the project area and was the focus of this assessment. Water erosion generally results in the formation of gullies and, on moraine, in the development of gravel covered surfaces where finer particles have been washed away. Surface erosion potential is a qualitative assessment of the potential for sediment generation during and after vegetation removal and construction. Areas of major concern are sensitive landforms, roads, recent landslides, and sites subjected to excessive anthropogenic disturbance. Table 7.3-3, adopted from Anonymous 1999, provides a brief explanation for each surface erosion potential class mapped within the project area.

Factors influencing surface erosion include vegetative cover, soil texture, depth of surficial materials, vegetative cover, slope gradient and geometry, soil drainage and most importantly, surface water flow. The amount of surface water flow is a function of the amount of precipitation, soil permeability, and soil depth. In areas with high precipitation or snow melt, shallow soils and impermeable soils contribute to an increase in ground water flow which increases erosion.

Table 7.3-3 Surface Erosion Potential Classification

Surface Erosion Potential Classes	Surface Erosion Potential	Interpretation
L	Low	• Flat to gently sloping, short slopes including flood plains and organics • Disturbance of streams could initiate some bank and channel erosion • Expect minor erosion of fines from ditch lines and disturbed soils • Exercise care not to channelize water on more sensitive areas
M	Moderate	• Moderately steep and long slopes and erodible soil textures including fine-textured materials • Plan preventative remedial actions for disturbed slopes and sites underlain by permafrost • Expect problems with water channelized down road ditches and across disturbed areas • Expect problems associated with permafrost melt on site underlain by permafrost • Water management is critical • Plan for complete road deactivation • Grass seed all disturbed sites
H	High	• Moderately steep to steep slopes and highly erodible soil textures • Sites with active surface erosion or gullying • Major problems exist with water channelized on to or over these sites • Problem avoidance may permit road development • Immediate revegetation of all disturbed sites • Severe surface and gully erosion problems exist • Erosion concerns may take precedence over site disturbance

Source: Anonymous 1999

Vegetative cover helps prevent erosion by decreasing the rate at which precipitation reaches the ground via leaves and stems, by forming a protective layer of moss and litter directly on the ground surface, and by anchoring soil in its place via roots. Slope gradient and geometry also play a major role in determining erosion. Increasing slope steepness increases the speed and eroding potential of the surface water as it flows down the slope. An increase in speed also reduces the time that water has for infiltrating the ground thus contributing to increased surface flow. Erosion potential also increases with increasing slope length because longer slopes can receive and transmit a greater amount of rain or meltwater in total.

Soil texture not only influences soil permeability thus influencing surface water flow, but it also determines the ease by which the soil may be eroded. This is due to factors such as particle size and cohesiveness. Intermediate sized particles such as silt are the most easily eroded. Larger sand particles are not as easily eroded due to their higher cohesion values.

7.3.2.2 Results

Wolverine Geology

As stated in Gardner Lee Limited (2004), the Wolverine deposit and its host stratigraphy belong to the middle unit of the Layered Metamorphic Package (LMP). Gardner Lee Limited (2004) describes this package as being composed of (1) a lower Devonian and older quartz-mica±garnet schist and quartzite package with an upper marble/calcareous schist unit, (2) a middle dark siliceous to carbonaceous phyllite unit interlayered with mafic to felsic volcanic rocks of Devonian to mid-Missippian-age, and (3) an upper white carbonate/quartzite package of early Pennsylvanian to Permian-age.

Quaternary Geology – Regional Context

The landscape of the area is typical of an area that has undergone intense modification by ice and subsequent meltwater. Its glacial history is complex due to the history of multiple glaciations that have directly affected the area. Mougeot Geoanalysis (1996) described the Yukon as being subjected to four glacial episodes over the last two millions years; these glaciations include the Nansen and Klaza (oldest) glaciations and Reid and McConnell (youngest) glaciations. All have been described as moving in a northerly direction into central Yukon. The project area has also been modified by erosion, solifluction, and volcanic ash deposition. The Quaternary history of the project area however is dominated by the impact of the last ice age with periglacial, colluvial, fluvial and volcanic processes playing a lesser role.

During the last glacial period (McConnell Glaciation), between 14 000 and 35 000 years ago, ice including complex ice caps and cirque glaciers moved across the eastern part of the project area in a northwesterly to westerly direction and extended to heights of about 1,525 m (Hatch 2004 in Crippen 2004; Anonymous 2002). As the glaciers slowly retreated, they down-wasted and developed a complex network of ice tongues in the valley bottoms (Crippen 2004; Gartner Lee Limited 2004; Mougeot Geoanalysis 1996).

This resulted in morainal deposits dominating the lower slope and valley bottom positions, and to a lesser extent, created complex assemblages of glaciofluvial, glaciolacustrine and fluvial sediments. In lower slope areas where deposition is common, colluvial and fluvial deposits have masked pre-existing sediments. For example, colluvium has created cones and fans on the lower slopes that effectively mask the pre-existing sediments. Morainal materials also dominate mountain tops, depressions and smaller valleys (generally with a narrow band of fluvial materials). Upper slopes contain both colluvial and morainal materials intermixed with bedrock outcrops. The colluvium in this area originates from weathered and frost shattered bedrock as well as colluviated moraine. Steep upper slopes are dominated by colluvium and bedrock outcroppings that are often weathered and frost shattered. These features as well as avalanches can probably be attributed to slope steepening that occurred during glaciation. Gullying, active floodplains and organic soils are also found throughout the project area.

The presence of permafrost was difficult to determine at the survey intensity level of this study. This is complicated by the fact that the project area is located within the northern part of the discontinuous permafrost zone (Burns 2002). Mougeot Geoanalysis (1996) estimated that permafrost was extensive and described mud and stone circles, stripes and pushed up stones at high elevations and solifluction and soil creep on many slopes. Mougeot Geoanalysis (1996) also described the large peat palsas (up to 2.5 meters thick) occurring southeast of the project. This study also found evidence of cryoturbated soils in the floodplain immediately east of the airstrip and in all alpine areas (mountain tops) visited during the field inventory reconnaissance program. All of the following periglacial processes were found in the alpine areas of this study: solifluction lobes, blockfields, sorted polygons, stripes and pushed up stones. Ground ice was also found overlain by organic materials in one of the high elevation soil profiles sampled. Crippen (2004) also described permafrost as occurring within the overburden (0 m to 7.9 m) in the log of Puck Drillhole PK96-6. A thermokarst feature was also found in the glaciolacustrine materials of Light Creek. In general, this study found that permafrost was more or less continuous in the alpine areas (mountain tops) and discontinuous in the upper elevational valleys and the headwaters of Go Creek. There is likely less permafrost present in the lower elevations of the Bunker and Light Creek valleys.

Quaternary Geology – Map Unit Descriptions

Morainal materials are the most widespread sediment type, occupying approximately 64% of the project area. These materials were deposited directly by glacier ice in a sub, or supra-glacial setting. Colluvial surficial materials are also common, occupying about 24% of the project area. These materials are most common on steeper slopes. Organic and fluvial materials co-dominate valley bottoms and lower slopes each representing approximately five percent of the total project area. Lesser amounts of glaciolacustrine (<1%), glaciofluvial (about 2%) and lacustrine (<1%) materials are also present. Bedrock outcroppings account for <1% of the study area.

Figure 7.3-2 provides a simplified visual representation on how the surficial materials are distributed in the project area. These surficial materials are described below based on soil texture, landform, soil types, as well as possible terrain hazards, and/or active modifying processes. Where applicable, the potential of these materials for construction purposes or as foundation materials is discussed.

Morainal materials (M)

Geologic Description

Morainal materials in the study area had textures that varied from loamy sand to sandy clay loam and highly variable coarse fragment contents as suggested described below.

- the moraine found in the watershed of Light Creek was dominated by sandy loam textures with coarse fragment contents that varied from 25-50%
- morainal materials of Bunker Creek watershed were very coarse with textures varying from loamy to loamy sand and coarse fragment contents varying from 40-75%
- high elevational moraines were dominated by coarse fragments (50-90%) and had varying textures (e.g., loamy sand, silt loam, loam, silty clay loam, sandy clay loam)
- the soil profiles of the morainal materials found in the Go Creek watershed were dominated by loamy and sandy clay loam textures and had highly variable coarse fragment contents (35-80%)

Overall, coarse-textured morainal materials were found extensively (approximately 64%) throughout the project area, occurring on a variety of landscapes with thicknesses varying from being thick enough to mask the underlying bedrock topography to thin enough that it just caps it.

Figure 7.3-2 Surficial Materials Distribution in the Wolverine Project Area (Vol. 2)

Associated Soils

Soils belonging to the Brunisolic Order were the most commonly mapped soil on moraine. These soils have sufficient development to exclude them from the Regosolic Order but lack the degree or kind of horizon development specified for soils of the other orders. This group includes soils of various colours with both Ae (an upper surface horizon showing evidence of leaching) and weakly expressed B (a horizon under showing little evidence of clay, mineral and organic matter accumulations) horizons showing weak accumulations of aluminum or iron (Bfj) or an accumulation of clay (Btj). The most distinguishing characteristic of the Brunisolic Order is a brownish coloured Bm horizon of at least five centimeters.

Both Eutric and Dystric Great Groups of the Brunisolic order were classified and mapped within the project area. These Great Groups are separated based on the pH of the uppermost 25 cm of soil. Dystric Brunisols have a pH less than 5.5 in the uppermost 25 cm while Eutric Brunisols have a pH of 5.5 or greater in the uppermost 25 centimeters. The occurrence of Eutric and Dystric Great Groups reflects the bedrock geology of the region as the pH of the bedrock strongly influences the pH of the surficial materials. Moreover, Dystric Brunisols are commonly associated with coarse igneous rocks at higher elevations whereas Eutric Brunisols are most often associated with sandy loam morainal materials. In this study, Dystric Brunisols on all materials were only found on the slopes east of Go Creek and west of Bunker Creek. Orthic Eutric Brunisols was the most common soil found on morainal materials. This was evident in the Light Creek watershed where both morainal materials and Orthic Eutric Brunisols dominated. Eluviated Eutric Brunisols were more common on well-drained, moraine especially in upper and crest slope positions.

Cryosolic (soils influenced by permafrost) soils have also developed within morainal materials, especially on mountain tops. Both Turbic and Static Cryosols were identified in the project area. The profiles of Turbic Cryosols are cryoturbated. This was commonly observed in higher elevational morainal materials in the form of sorted and non-sorted nets, circles, polygons, and stripes. Soil exhibiting cryoturbation generally have permafrost within two meters of the soil surface whereas Static Cryosols have permafrost within one meter of the soil surface.

Soils of the Regosolic Order were also classified within morainal materials. These soils lack the well-developed profiles of the other soil orders. This poor development is the result of a number of factors including the youthfulness of the material and the impact of periglacial processes such as solifluction (slow gravitational downslope movement of saturated non-frozen overburden across a frozen or otherwise impermeable substrate. Within the project area, Regosolic soils on morainal materials were only mapped on mountain tops. This includes soils belonging to the Regosolic and Humic Regosolic Great Groups. These Great Groups differ in that Humic Regosols have an Ah horizon of at least ten centimeters thick.

Soils of the Gleysolic order were also occasionally mapped on morainal materials. These soils have features indicative of periodic or prolonged saturation by water; as such they are typified by reducing conditions. Gleysolic soils are usually associated with either a high groundwater table at some period of the year or temporary saturation above a relatively impermeable layer. Gleysolic soils often produce different vegetation communities than the surrounding soils due to the high moisture content and poor internal drainage. Both Orthic Regosols and Orthic Humic Regosols (Ah horizons of at least 10 cm) were mapped on morainal materials.

Considerations for Development

With the exception of morainal materials exhibiting cryoturbation (and other associated permafrost features), the morainal materials found in the project area provide for a stable base. The coarse nature of most of this material is also conducive to selective borrowing and use as construction material. For example, the morainal material found next to the Robert Campbell Highway has already been used for construction materials.

Permafrost in morainal materials is typically sporadic and often limited to mountain tops, north slopes or on sites with thin organic veneers. In this study, permafrost was only discovered on mountain tops. Its presence within the lower slopes and valley bottoms however, can only be confirmed by more intensive investigations. If present, the risk from frost damage on undulating to gentle slopes is low especially on shallow materials. Drainage however can be an issue, especially in depressions. It is also important to note that any development on slopes underlain by permafrost may result in slumping that can damage roads, dams, buildings and equipment, particularly if the development cuts through a drainage system.

Colluvial Materials (C)

Geologic Description

Approximately 24% of the project area was identified as colluvium. This included sites with steep topography, especially where thin unconsolidated materials overlie steeply sloping bedrock (i.e., slopes in excess of 50%), as well as sites located in lower and toe slope positions. Colluvium is the result of mass wasting, dominated by the downward movement of materials due to gravity. This includes sites where the combination of porewater infiltration and gravitational forces induce rapid mass movement in certain sediments (i.e., slumping, debris flows) and bedrock (induced by frost shattering), the later of which was identified in the project area. Slow mass movements such as soil creep (i.e., slope wash) were also identified in the project area.

Project area colluvial materials were generally unsorted, of variable-texture (silt loam to loam) and depending on the source area, often had a coarse fragment content greater than 50%. On upper slope positions, colluvium was generally less than 100 cm in thickness, while on mid and lower slope positions, colluvium was often thick enough to mask the underlying bedrock materials. For example, colluvial fans and cones were noted along lower valley positions.

Associated Soils

Colluvium was dominated by soils of the Regosolic Order. The poor development of these soils is the result of the instability of the material. Of the Regosolic Order, only soils belonging to the Regosolic Great Group, which lacks an Ah horizon at least ten centimeters thick, were mapped on colluvial materials. This included Orthic and Cumulic subgroups with Cumulic subgroups having buried mineral-organic layers and organic surface horizons of variable thicknesses. In general, most Regosols identified within the project area were found on colluvium. Both Eutric and Dystric Great Groups of the Brunisolic order were also identified to a lesser extent. Although not found in this study, the potential for Turbic Cryosols also exists on north facing, poorly drained lower slopes underlain with permafrost (e.g., avalanche deposits).

Considerations for Development

As described in Mougeot Geoanalysis (1996), all colluvial fans and cones should be closely examined prior to construction in order to avoid areas that show evidence of debris flows and/or debris torrents. Caution should also be given when developing on colluvial slopes underlain by permafrost. Development on these slopes may result in slumping that can damage roads, dams, buildings and equipment, particularly if the development cuts through a drainage channel (Mougeot Geoanalysis 1996).

Organic Materials (O)

Geologic Description

Within the study area, organic accumulations were found in association with lacustrine, morainal and fluvial materials. Organic materials accounted for approximately 5% of the study and were most commonly associated with meadows, lower slopes and floodplains.

Associated Soils

Soils belonging to the Organic order occur throughout the project area. These soils are composed largely of organic materials and include soils commonly known as peat, muck, or bog soils. Organic soils generally occur in very poorly drained areas with long-term to permanent soil saturation. They are derived from the local vegetation and contain at least 30% organic matter by weight and classified based on the level of decomposition of the organic matter. The soil classes, based from least to most decomposed, are folic, fibric, mesic, and humic.

The four stages of decomposition are defined by the von Post scale of decomposition and the classification at the great group level is based on the properties of the second tier (~80 cm deep). Mesisols, which are composed primarily of partially decomposed organic materials, were most commonly found within the project area. Fibrisols, composed largely of non-decomposed organic materials, were also identified and mapped. Organic Cryosols, which have permafrost within 1m of the soil surface, were also described in the project area. The presence of these soils was confirmed during the field sampling portion of the project when ice-rich permafrost was identified within an organic soil profile (plot number WZ 10). This site was found at approximately 1200 m west of Light Creek.

Considerations for Development

Organic soils are generally stable with drainage often being the only major issue. Development on organic soils underlain by permafrost however can be extremely problematic and may result in thermokarst subsidence and increase the magnitude of issues associated with poor drainage and fluctuating water tables.

Fluvial Materials (F)

Geologic Description

Fluvial materials were most commonly found within the valley floors flanking contemporary streams, gently inclined slopes and fans at the base of slopes. These sediments, which accounted for approximately five percent of the study area, were generally well-sorted and consist of stratified gravel, sand and silt. Seepage within these materials is often not a concern due to the ease of pore water movement through the sediment. Most of the contemporary stream channels are irregular in form and generate marginal fluvial plains with occasional back channels.

Associated Soils

Cumulic Regosols and Humic Regosols are generally found on fluvial materials. These soils may have well-developed organic veneers and/or buried mineral-organic layers (as a result of periodic flooding) and organic surface horizons of variable thickness. Gleysolic soils are also common on fluvial materials as these areas are typically subjected to fluctuating water tables, period saturation and groundwater discharge. The field inventory reconnaissance did not provide a description of fluvial materials in the project area.

Considerations for Development

Developments on fluvial materials are subjected to very poor drainage. Permafrost however, is typically absent below active channels.

Lacustrine Materials (L)

Geologic Description

Recent lacustrine sediments were noted along the shores of both Wolverine and Little Wolverine lakes. These materials were limited in extent (less than one percent of the project area) and typical of shoreline deposits subjected to periodic wave and ice action.

Associated Soils

These sites are most-likely dominated by Regosolic, Organic and Gleysolic Soils.

Considerations for Development

Development on these materials is unlikely.

Glaciofluvial Materials (FG)

Geologic Description

Glaciofluvial materials in the project area were deposited by meltwater either in direct contact with the ice or beyond the ice margin as outwash. These deposits, which occupied about two percent of the project area, varied in thickness from thin veneers to blankets of several meters. They were typically coarse-grained (gravel and sand), stratified and sorted. Glaciofluvial terraces generally formed the highest terraces preserved within the valleys; this feature was evident in the unnamed tributary of Finlayson River. Other glaciofluvial deposits were also found and described in this tributary as well as the Go Creek watershed.

Associated Soils

Eutric Brunisols were the only soils identified on glaciofluvial deposits within the project area. These soils tended to be well to rapidly drained and free of permafrost.

Considerations for Development

These materials, albeit limited in extent, are generally conducive to development.

Glaciolacustrine Materials (LG)

Geologic Description

Glaciolacustrine materials were only found in the Light Creek valley and accounted for less than one percent of the project area. These materials were less than 100 centimeters thick and underlain by glaciofluvial materials. They were also massive and dominated by silty loam soil textures; they lacked coarse fragments and were typically moderately well drained. Soils displaying these characteristics are often underlain by permafrost; the field inventory reconnaissance portion of this project confirmed this potential by discovering thermokarst subsidence in the Light Creek valley.

Associated Soils

Only Eutric Brunisols were described and mapped on glaciolacustrine materials. The potential for Turbic Cryosols also exist in glaciolacustrine materials as evidenced by the presence of a thermokarst feature (Figure 7.3-3) in the watershed of Light Creek.

Figure 7.3-3a A Thermokarst Feature Found in the Watershed of the Unnamed Tributary of Finlayson River

Considerations for Development

Development on glaciolacustrine materials in the discontinuous permafrost zone is often problematic due to the potential for permafrost. Development on these soils when underlain by permafrost may cause thermokarst collapse and thaw slides. Because of this, all glaciolacustrine materials should be closely examined prior to construction in order to avoid or plan mitigative measures on sites underlain by permafrost.

Terrain Hazards

Approximately 59% of the project area was classified as "stable". Figure 7.3-3 provides a simplified visual representation on terrain stability within the project area. This includes the majority of Light Creek watershed and a large portion of the Bunker Creek watershed. Although minor stability problems can develop on these sites, vegetation removal should not significantly reduce terrain stability. Minor slumping may occur along road cuts, especially one or two years following construction. There is however, a low likelihood of landslide initiation following road building.

Figure 7.3-3 Terrain Stability in the Wolverine Project Area (Vol. 2)

The majority (about 59%) of the Wolverine Project area was classified as being stable. This includes the majority of the Light Creek and Chip Creek valleys. The second most common stability rating was "potentially unstable" with approximately 28% of the project area receiving this rating. Sites with slope gradients steeper than 60% were typically classified as being potentially unstable as they are very close to the angle of internal friction (however this could be refined through a more thorough analysis of materials). Most of these sites included gully sidewalls, upper slope positions with colluvium and morainal deposits, and colluvial cones. Sites with slopes gradients of less than 60% were rated as potentially unstable if they showed evidence of slope movement such as soil creep, avalanches and/or debris torrents. This included the slopes east of the airstrip and various colluvial fans and cones located throughout area. The stability of these slopes is strongly dependant on sub-surface water conditions. Because of this, groundwater control is integral to any development. Geographically, most potentially unstable sites were located within the mid to upper elevations of the Go Creek and Wolverine tributaries as well as Chip Creek.

Gullies were commonly classified as being potentially unstable to unstable. These gullies, which constitute less than five percent of the project area, are susceptible to failures because of their steep slopes and concentrated seepage conditions. General characteristics of unstable or potentially unstable gullies include:

- gully sidewalls steeper than 70%
- gully channel steeper than 45%
- deep materials in gully sidewalls
- wet soils and lots of seepage
- sidewall slumps
- disturbed vegetation patterns
- oversized fans at toe of gully

Numerous surficial materials of various slopes and depths were rated as potentially unstable if they showed signs as being underlain by permafrost. This is significant because approximately 22% of the project area was estimated as being underlain by permafrost, with the majority of this occurring on mountain tops. Permafrost can cause failures in unconsolidated deposits including thaw slides, thermokarst subsidence and drainage issues. As stated in Gartner Lee Limited (2004), these failures can be rapid and involve large volumes of material, or they can occur slowly on small surfaces. A field inspection of these areas should be made by a qualified terrain specialist prior to any development. Materials underlain by dry permafrost (permafrost with little or no ice) tend to be more stable. These materials are typically either shallow (to bedrock) or have coarse textured soils. If these cases, conventional construction techniques can be used.

It is difficult to differentiate between dry and 'ice rich' permafrost without a detailed field inspection. If permafrost is ice-rich, passive or active design construction methods must be employed. This includes using thick fill to prevent ground thaw. If thaw cannot be prevented, structures such as roads or airstrips must be built on piles of gravel. The exact depth of this gravel however, can be difficult to estimate and requires on-site design. For example, if the gravel layer is too thin, ice-rich permafrost may melt causing the ground to subside or slump. If the gravel layer is too thick, the permafrost active layer may actually rise, causing the structure to heave or breakup.

The remaining 13% of the project area was classified as "unstable". The following sites possess the greatest potential of failures following development:

- steep bedrock slopes (>70%)
- slopes showing evidence of past failures including soil creep, avalanches and debris torrents (about 5% of the project area)
- morainal and colluvial slopes with a gradient >50%
- gullies, colluvial cones and fans
- surface materials underlain by permafrost

As described in Mougeot Geoanalysis (1996), slope failures in steep (greater than 70%) bedrock and thin colluvial deposits represent the highest risk hazard. For example, Mougeot Geoanalysis (1996) cited the north and east facing walls of the cirque located directly east of the airstrip as being a high risk hazard. Because of this, most sites with slopes greater than 70% were rated as unstable. These sites were generally restricted to upper slope positions and gully sidewalls. In addition, the majority of rock walls showed evidence of large active rock falls, as indicated by the large number and volume of talus cones and aprons beneath them. Development in all these areas should be discouraged.

In summary, the main areas of concern with respect to project development include the slopes adjacent to the airstrip and materials underlain by permafrost. This includes the glaciolacustrine sites located in the Light Creek valley, upper elevational areas underlain by permafrost, and steep to moderately steep upper slopes. In these situations, a detailed assessment is recommended before any development takes place.

Finally, it is important to note that the inherent nature of 1:30 000 to 1:40 000 mapping does not allow any detailed statements or predictions regarding terrain stability to be made with any degree of confidence; it is strictly an "overview". Critical terrain features used to assess terrain stability are slope gradient and the occurrence of features indicating mass movement (i.e., slides, soil creep, thermokarst subsidence, etc.). A critical factor influencing slope stability, which is not available at this level of intensity, is sub-surface water and depth to permafrost. Although, it is possible to detect some wet sites and signs of permafrost on air photos and via field reconnaissance, the lack of field data does not allow a reliable assessment of these parameters on stability.

Flooding Hazards

As stated in Gartner Lee Limited (2004), floods related to ice-jams, snowmelt and summer rainstorms are possible hazards in lower reaches of most streams in the area. Steep fluvial and colluvial fans as well as cones may also be subjected to flooding as well as mud and debris flows during and following storm events. The potential for flooding however is low considering these sites occupy less than five percent of the project area.

Erosion Potential

Forty-seven percent of the project area was rated as having a low erosion potential due to the coarse-textured nature of the dominant surficial material (moraine) and the occurrence of gently to moderately sloping terrain with short slopes in the valley bottoms and on mountain tops. Figure 7.3-4 provides a simplified visual representation on erosion potential within the project area.

Figure 7.3-4 Surface Erosion Potential in the Wolverine Project Area (Vol. 2)

Approximately 35% of the study area was classified as having a moderate erosion potential. This included sites with long, moderately sloping topography (primarily colluvium and moraine) and those underlain by permafrost. For example, long slopes with gradients greater between 50 and 70% were generally rated as having moderate erosion potentials. Sites with unfavorable textures (silts and fine sands), such as those found in the glaciolacustrine sediments of Light Creek, were also given this rating. In all these situations, preventative remedial action should be planned before any disturbance takes place.

Only 17% of the study area was rated as having a high erosion potential. This included sites with slopes greater than 70%. These sites were automatically rated as having high erosion potentials due to the role that slope gradient plays in erosion potential. In situations with slopes greater than 70%, surface vegetation should be protected and/or immediate revegetation should be planned following disturbance.

Gully sidewalls also inherently have high surface erosion potentials due to surface and subsurface water flows. Surface materials underlain by ice-rich permafrost may also have high surface erosion potentials if development causes the ice to melt to an extent that it results in drainage problems and thermokarst subsidence. This potential increases if surface vegetation is removed, especially in situations with saturated soils and deep organic materials.

In summary, the main areas of concern with respect to project development include the glaciolacustrine sediments of Light Creek, sites with long, moderately sloping topography (primarily colluvium and moraine), sites with slopes greater than 70%, gully sidewalls and those underlain by permafrost.

7.3.3 Effects Assessment Methodology

The objective of this assessment is to predict project and cumulative effects of the project on terrain, surficial materials and soils and identify mitigation measures to both minimize adverse effects and associated impacts to terrestrial and aquatic habitat, and support sound project design. In terms of selected VECCs, this assessment concentrates on project effects on:

- surficial materials – alterations to existing surficial material affects local topography, drainage and soil character with associated effects on capacity to support vegetation and related ecological values
- permafrost – the presence of permafrost has implications for project design and disturbance of permafrost can have result in erosion and ecological values
- erosion potential – this is a key issue with any project involving ground disturbance with implications for design of water management systems and protection of aquatic environments
- terrain hazards – this is of concern with respect to both project effects on terrain stability and effects of terrain stability on design and maintenance of facilities

Information on the key terrain features (mountains, river valleys) VECC has been integrated in the mapping of terrain hazards and erosion potential. Further, there are no notable or unique terrain features that will be affected by the project. Information on the sensitive soils VECC has been integrated into the assessment of effects on the other four VECCs.

Potential interactions between project facilities locations and activities and identified VECCs are discussed along with mitigative best practices and requirements for site-specific follow-up investigations. Residual project effects, assuming implementation of mitigation measures and follow-up investigations are characterized using the definition of effects attributes provided in Table 7.3-4. Implications of effects to reclamation and capacity for site revegetation are discussed in Section 3.4: Decommissioning and Closure Activities. The ecological context for identified effects on terrain, surficial materials and soils is discussed in Section 7.5: Surface Water and Sediment Quality; Section 7.7: Periphyton and Benthos; Section 7.8: Fish Resources; Section 7.9: Vegetation; and Section 7.10: Wildlife.

Determination of Effects Significance

A residual project or cumulative effect on terrain, surficial materials and soils will be considered significant if it is;

- a high magnitude adverse effect unless it is local in geographic extent
- a high magnitude adverse effect that is local in geographic extent and far future in duration

Otherwise, effects will be rated as not significant.

7.3.4 Project Effects

Potential effects on VECCs for terrain, surficial materials and soils are discussed by project phase in the following sections. Effects will be greatest during the construction phase and generally persist until decommissioning and site reclamation. The project has been designed to minimize the disturbance footprint as much as possible. Within the LSA, specific areas of ground disturbance will include:

- the mine portal and industrial complex in the upper Wolverine Creek drainage

- the camp, borrow area, airstrip extension and tailings facility in the Go Creek drainage above Hawkowl Creek
- the mine access road right-of-way which traverses the upper Go, Chip Creek, Bunker Creek and Light Creek drainages

Table 7.3-4 Effect Attributes for Terrain, Surficial Geology and Soils

Attribute	Definition
Direction	
Positive	Condition of VECC is improving
Adverse	Condition of VECC is worsening or is not acceptable
Neutral	Condition of VECC is not changing in comparison to baseline conditions and trends
Magnitude	
Low	Effect occurs that might or might not be detectable, but is within the range of natural variability and does not compromise economic or social/cultural values
Moderate	Clearly an effect but unlikely to pose a serious risk to the VECC but does require specific management from a geotechnical, ecological, economic or social/cultural standpoint
High	Effect is likely to pose a serious risk to the VECC and represents a significant challenge from a geotechnical, ecological, economic or social/cultural standpoint
Geographic Extent	
Site-Specific	Effect on VECC confined to a single small area within the Local Study Area (LSA)
Local	Effect on VECC within Local Study Area (LSA)
Regional	Effect on VECC within Regional Study Area (RSA)
Duration	
Short term	Effect on baseline conditions or VECC is limited to <1 year
Medium term	Effect on baseline conditions or VECC occurs between 1 and 4 years
Long term	Effect on baseline conditions or VECC lasts longer than 4 years but does not extend more than 10 years after decommissioning and final reclamation
Far future	Effect on baseline conditions or VECC extends >10 years after decommissioning and abandonment
Frequency (Short Term duration effects that occur more than once)	
Low	Effect on VECC occurs infrequently (< 1day per month)
Moderate	Effect on VECC occurs frequently (seasonal or several days per month)
High	Effect on VECC occurs continuously
Reversibility	
Reversible	Effect on VECC will cease to exist during or after the project is complete
Irreversible	Effect on VECC will persist during and/or after the project is complete
Likelihood of Occurrence[1]	
Unknown	Effect on VECC is not well understood and based on potential risk to the VECC, effects will be monitored and adaptive management measures taken, as appropriate
High	Effect on VECC is well understood and there is a high likelihood of effect on the VECC as predicted

Notes: 1. Characterizes the investigator’s confidence that effect will occur as predicted based on the status of scientific or statistical information, experience and/or professional judgment of the author.

To the extent possible all disturbed areas that become redundant to project activities (spent borrow areas, redundant access roads, laydown areas, etc.) will be progressively reclaimed during the active life of the mine. Accordingly effects on surficial materials and soils should gradually decrease over the mine life. Major site facilities will be reclaimed in two stages during the decommissioning phase. At the end of operations the mine portal and ore processing plant and related site drainage facilities will be decommissioned and the site recontoured and reclaimed as much as possible. The water treatment plant is expected to remain in operation for five years following initial decommissioning as part of the tailings facility decommissioning process. After that period final decommissioning and reclamation of the site will be completed. The tailing impoundment will remain as a permanent pond feature with passive drainage to Go Creek. The road and airstrip will be left in service at closure.

7.3.4.1 Construction

Surficial Materials

The construction phase will have the greatest incremental impact on the terrain, surficial geology, and soil VECCs in the project area. Project effects in this phase include minesite and road building processes such as land consumption, movement and alteration of surficial materials and corresponding reductions in soil capability. This includes alteration of the road and project facilities sites, as well as impacts caused by the removal of aggregate from borrow pits for use in surfacing the roads. Aggregate from borrow pits will also be used for construction material and to stabilize sites underlain by permafrost where required. Reduction of soil capability can be caused by a number of factors including loss of topsoil, creation of impermeable layers during overburden replacement, and soil compaction (e.g., bottom of borrow pits).

Various mitigation measures will be employed to minimize these effects. The project has been designed to minimize the disturbance footprint. Much of the minesite and industrial complex will be located in an area that has been previously modified by licensed pre-mining assessment activities. The borrow pit is on relatively level ground which will facilitate reclamation. Other measures, outlined in Table 7.3-5, include topsoil salvage and stockpiling for use during reclamation, limiting soil compaction where applicable, by limiting clearing and site disturbance to periods when the soil is dry or frozen, and progressive reclamation of disturbed areas during construction (spent borrow areas, laydown areas, road right-of-way). Follow-up studies will be conducted to test soils and develop detailed quantities and remediation requirements, if any, for reclamation purposes (Section 3.4: Decommissioning and Closure Activities). Progressive reclamation throughout the life of the project will provide the opportunity to test reclamation approaches and modify them as required to optimize productive capacity of reclaimed areas.

Based on these mitigation measures effects on surficial materials and soil capability are characterized as adverse, moderate magnitude (effects are not expected to give rise to a geotechnical, economic, ecological or socio/cultural management issue beyond identified best practices), local, far future (the road and airstrip will remain in place at closure for an undetermined period of time) and ultimately reversible. The likelihood of effects as predicted is high based on observations of effects and mitigation effectiveness at other similar developments.

Table 7.3-5 Mitigation Measures for Effects on Terrain, Surficial Geology and Soils

Potential Project Effect	Mitigation Measures
• Soil compaction and reduction in soil capability during all phases of the project.	• Pre-site inspections will allow avoidance, where applicable, of sensitive soil types • Site clearing will be timed to minimize soil compaction. To the extent possible, disturbances will be restricted to times when soils are dry or frozen. Where possible, top soil will by removed and stored • Where possible, borrow pit locations will be selected based on sites that can be easily reclaimed • Where possible, disturbed sites will be promptly revegetated (progressive reclamation) with appropriate plant materials and fertilization • During the decommissioning and closure phases, overburden (surficial materials) will be re-sloped and laid down to avoid the creation of impermeable material • Site clearing will be minimized during all project phases
• Terrain stability concerns during all phases of the project	• Most disturbances will be restricted to times when soils are dry • Where possible, disturbed slopes will be re-sloped to a 2:1 ratio • Where possible, subsurface and surface drainage will be controlled to prevent slope instability. This includes re-establishing surface drainage as soon as possible • Pre-site inspections will allow avoidance, where applicable, of unstable or potentially unstable sites
• Changes in permafrost depth	• Pre-site inspections will allow avoidance, where applicable, of sites underlain by permafrost • Special construction and operation techniques on sites underlain by permafrost will be employed. This includes, where applicable, constant monitoring of permafrost and employing adaptive management techniques to maintain, where possible, consistent permafrost depths. For example, overburden depths over sites underlain by permafrost will be adjusted if monitoring determines changes in the “active layer” and/or vegetation will be re-established and fertilized as soon as practicable on sites underlain by permafrost
• Soil erosion following disturbance during all project phases	• Sites will be assessed for soil erosion potential and measures to minimize the effects of any such erosion will be employed • Installation of the site water management system (Section 2.9) during construction and operation throughout the project will minimize drainage and erosion from disturbed areas • Implementation of the erosion and sedimentation control plan (Section 9: Environmental Management Plan) throughout the life of the project will reduce soil erosion • Immediate revegetation with appropriate plant materials and fertilization on all disturbed sites (except roads and mining sites) will minimize this effect • Where possible, disturbed slopes will be re-sloped to a 2:1 ratio • Sites will be cleaned up and progressively revegetated with appropriate plant species when no longer in use
• Soil erosion on roads	• Detailed design of the access road will identify requirements for structural elements required for road drainage management, including standard stormwater catchbasins and/or various forms of check-dams or fords designed to slow drainage • Implementation of the erosion and sedimentation control plan (Section 9: Environmental Management Plan) throughout the life of the project will reduce soil erosion • Where practicable, water barring of roads will also be employed • Extraneous roads will be reclaimed as soon as practicable. This includes roads used for deposit sites and borrow pits, material treatment areas, quarries and other facilities. For example, progressive reclamation techniques will be employed. That is sites and roads will be reclaimed as portions of the project area are decommissioned and closed. Main roads within the project site will be open until all sites have be decommissioned and closed. This will provide access for reclamation equipment. Once these sites have been reclaimed, applicable roads will be decommissioned, revegetated and fertilized

Permafrost

Any disturbance can influence the permafrost 'active layer'. For example, when developing on sites underlain by permafrost a beneficial management practice is to overlay the site with aggregate. The thickness of this layer is critical. If the layer is too thick, the permafrost 'active layer' may actually rise in the soil profile. This may cause freeze-thaw and/or uplifting of the site surface resulting in numerous problems including unsafe conditions or stability issues. For example, if the site impacted is a road surface, the uplift in the road may make it impassable. If the aggregate layer is too thin, melting of the permafrost layer may cause stability issues including thaw slides or thermokarst subsidence. The impact of the project on permafrost is important because approximately 15% of the LSA was identified as being underlain by permafrost during this study. This number could be higher considering the scale of this study prohibited accurate permafrost assessments.

Pre-site inspections will allow avoidance, where applicable, of sites underlain by permafrost. If sites cannot be avoided then special construction techniques should limit the impact of construction on this VECC. In addition, constant monitoring of sites underlain by permafrost and the implementation of adaptive management techniques to maintain, where possible, consistent permafrost depths should limit fluctuations in the permafrost 'active layer'. For example, overburden depths over sites underlain by permafrost will be adjusted if monitoring determines changes in the "active layer" and/or vegetation will be re-established as soon as practicable on sites underlain by permafrost.

Based on opportunities to avoid or mitigate effects on the permafrost 'active layer' and given the range of variability in permafrost conditions due to natural causes, including fire, avalanches, slumps as well as changes in climatic conditions, any project related effects on permafrost are expected to be of low magnitude. However because potential effects require monitoring and special geotechnical and ecological management techniques, the magnitude is rated as adverse, moderate, and site specific. The duration of these impacts however will be medium term. That is, the effect on the VECC will generally be limited to between one and four years until mitigative measures take effect (e.g., overburden management, revegetation). The likelihood of effects is unknown until pre-site investigations are conducted. Depending on the nature of the effect, there could be localized vegetation and habitat changes. Again in the context of natural variability these would not likely be measurable.

Erosion Potential

Approximately 42% of the LSA was classified as having a medium erosion potential and approximately 16% was rated as having a high erosion potential. Collectively this makes up about 58% of the study area. These sites are found throughout the LSA with the glaciolacustrine surficial materials of Light Creek, and all gullies and materials with slopes greater than 50% posing the greatest risk. Areas of high erosion potential include the slopes east of the mine portal and industrial complex area in the pass between Wolverine and Go Creeks, the slopes north east of the airstrip and above the camp area and sections of the access route in the Chip Creek and Bunker Creek drainages.

Mitigation measures include limiting the amount of disturbance and implementation of the erosion and sediment control plan (Section 9: Environmental Management Plan). The site water management plan (Section 2.9) will minimize the drainage catchment for disturbed sites and provide settling pond to minimize effects on receiving stream. If disturbance does occur, sites will be promptly revegetated with appropriate plant materials (e.g., grass mix for quick cover). Sites will be assessed for soil erosion potential and measures to minimize the effects of any such erosion will be employed. Finally, artificial slopes will also be kept to 2:1 ratios, where possible (Table 7.3-5).

Road erosion will be addressed through detailed planning and design. These processes will outline structural modifications needed during the design of the roadway including standard stormwater catchbasins and/or various forms of check-dams or fords needed to slow drainage. Where practicable, water barring of roads will also be employed and roads will be reclaimed when no longer in use (i.e., exhausted borrow pits, deposit sites, material treatment areas, other facilities, etc.).Impacts on construction on areas of high erosion potentials are expected to be adverse, moderate magnitude, medium term and irreversible. The likelihood of effects as predicted is high based on observations of effects and mitigation effectiveness at other similar developments.

Natural Terrain Hazards

Terrain stability concerns may also occur during this phase of the project. This is significant because approximately 29% of the LSA was classified as being potentially unstable and approximately seven percent was classified as being unstable. The primary areas of concern include the slopes and floodplains that flank the current road to the portal and airstrip as well as both slopes and the floodplain that flank the entire airstrip. The other areas of concern (primarily because of permafrost) include the height of land between Go Creek and Chip Creek. The glaciolacustrine surficial materials of the unnamed tributary of Finlayson River are also a concern.

The mapping component of this project combined with pre-site inspections will allow avoidance, where applicable, of unstable or potentially unstable sites and appropriate design to minimize risks to project facilities as a result of terrain hazards. Site disturbance, where practicable, will also be timed (i.e., dry soils) to minimize stability issues. Artificial slopes for the most part will also be kept to 2:1 ratios. Where possible, subsurface and surface drainage will also be controlled. This includes re-establishing surface drainage as soon as possible (Table 7.3-5).

Impacts associated with terrain stability will be potentially problematic throughout all project phases. For example, moderate slumping can be expected for the first two years following any disturbance. Accordingly effects of construction on terrain hazards are expected to be adverse, moderate, site specific, long term and ultimately reversible. The likelihood of effects is unknown until pre-site investigations are conducted.

7.3.4.2 Operations

During operation, there will be little incremental disturbance of surficial materials or terrain hazards or increased erosion. Effects attributes are expected to be similar to the construction phase although some reductions in magnitude are expected as a result of progressive reclamation. Similar mitigation measure will continue to be applied.

Monitoring the impact of development on permafrost will be crucial during the operational phase. Seasonal determination of permafrost depth should limit this reversible impact to the short term. Any changes in depth will be mitigated by one or all of the following strategies: manipulation of overburden depths; re-establishment of vegetation; and/or discontinuation of land use.

7.3.4.3 Decommissioning

Surficial Sediments

During the decommissioning phase, the majority of impacts on surficial materials are positive with the possible exception of soil compaction. Mitigation measures for soil compaction include operating on sites when soils are relatively dry. The improvements will be the result of the replacement, re-sloping and revegetating of overburden (including top soil). Overburden will be placed to ensure that an impermeable layer is not created. On sites that have been contaminated or otherwise adversely affected, soils will be removed, placed in the landfill and replaced with moraine.

Permafrost

The effect of decommissioning on permafrost is expected to be inconsequential. Any impacts that do occur will be neutral in direction, low in magnitude, site specific in extent and short term in nature. It is expected that overburden replacement, re-sloping (2:1 ratio) and revegetation will return the permafrost in the LSA to pre-disturbance conditions.

Sediments with High Erosion Potential

Most impacts on soil erosion will be positive during this phase of the project. Once again, these changes will be the result of topsoil replacement, re-sloping (2:1 ratio) and revegetation. Some short term site-specific increases in erosion may occur in areas of ground disturbance to decommission facilities and before re-vegetation. Site water management will remain in place as long as possible during decommissioning to minimize the drainage catchment in these areas prior to restabilization. During this phase, mine roads will be utilized and maintained for the use of reclamation equipment. Once decommissioning of facilities is complete, extraneous minesite roads will be water barred, re-contoured, revegetated and fertilized. The mine access road and airstrip will remain in place. Stabilization and establishment of vegetation on disturbed areas associated with these facilities during operations will provide ongoing erosion control at closure.

Natural Terrain Hazards

Decommissioning may result in terrain stability issues. If they occur, these issues will be negative and residual. Mitigation measures include re-sloping, revegetating and controlling subsurface and surface drainage.

7.3.4.4 Closure

No further effects on terrain, surficial materials and soils are expected at closure when all the facilities sites have been stabilized and reclamation is complete

7.3.4.5 Residual Project Effects and Significance

As noted above effects on terrain, surficial materials and soils are expected to be greatest during the construction phase. At worst the residual effects on the selected VECCs (surficial materials and soil capability, permafrost, erosion potential and terrain hazards are expected to adverse, moderate magnitude, long term to far future (effects of the road and airstrip) and ultimately reversible. Most impacts are also avoidable or manageable through planning, pre-disturbance field inspections, ongoing monitoring throughout the operational phase and the implementation of mitigation measures identified in Section 7.4.4.1. Using the criteria in Section 7.3.3 these effects are determined to be not significant. Based on previous studies, science, observations elsewhere and professional experience there is a high likelihood that these effects will manifest as predicted.

7.3.5 Cumulative Effects

Residual effects on terrain, surficial geology, and soil VECCs are stationary in nature and were all classified as being either site specific or local in extent. There are no other past, present or reasonably foreseeable projects which will overlap with or increase the magnitude of the effect within the LSA Accordingly, no cumulative effects expected.

7.3.6 Mitigation Measures

Table 7.3-5 provides a summary of mitigation measures.

7.3.7 Monitoring and Follow-up

Follow-up Studies

Table 7.3-6 provides a summary of proposed follow-up baseline studies needed to improve predictive capabilities or understanding of baseline conditions. These studies include:

- A baseline study to determine soil chemistry on sites that are scheduled to be disturbed. This study is needed to assess soil chemistry and determine if there are any constraints or limitations to achieving vegetation restoration and initiate contingency plans to address unexpected effects, as required (Section 3.4: Decommissioning and Closure Activities).
- A baseline study to determine soil physical conditions on sites scheduled to be disturbed. This study is needed to assess soil physical conditions and determine reclamation suitability and the approximate volume of suitable soil materials for reclamation (Section 3.4: Decommissioning and Closure Activities.
- Detailed terrain stability assessments are needed to determine site-specific stability issues and develop contingency plans to initiate construction techniques to mitigate these issues.
- Detailed soil erosion potential assessments are needed to identify surficial materials with high erosion potentials and develop contingency plans to initiate construction techniques to mitigate these issues.

Table 7.3-6 Monitoring and Follow-up Programs for Terrain, Surficial Geology and Soils

Potential Project Effect	Program Objectives	General Methods	Reporting	Implemen-tation
Follow-Up Programs				
Soil chemical conditions limiting reclamation success	• Determine soil chemistry • Initiate contingency plans to address unexpected effects, as required	• Soil sampling and chemical analysis prior to construction and soil salvage	• Internal • YTG as required	Proponent
Soil physical conditions limiting reclamation success	• Determine soil physical conditions • Initiate contingency plans to address unexpected effects, as required • Refine materials balance for reclamation planning	• Soil test pits and trenches to characterize physical conditions, parent materials, depths and approximate volume of suitable soil materials for reclamation	• Internal • YTG as required	Proponent
Terrain stability concerns	• Perform on site terrain stability assessments prior to development • Initiate contingency plans to address unexpected effects, as required	• Terrain stability assessments will determine site specific stability issues	• Internal • YTG as required	Proponent
Soil erosion concerns	• Identify surficial materials with high erosion potentials • Initiate contingency plans to address unexpected effects, as required	• Erosion potential assessments will determine site specific erosion issues	• Internal • YTG as required	Proponent
Monitoring Programs				
Changes in permafrost depth	• Determine if project has an impact on permafrost depth • Initiate contingency plans to address unexpected effects, as required	• Seasonal determination of permafrost depth	• Internal	Proponent
Terrain stability	• Determine if project has had an impact on terrain stability • Initiate contingency plans to address unexpected effects, as required	• Seasonal terrain stability assessments will determine site specific stability issues	• Internal	Proponent
Soil erosion	• Determine if project has resulted in the erosion of surficial materials • Initiate contingency plans to address unexpected effects, as required	• Seasonal erosion assessments will determine site specific erosion issues	• Internal report	Proponent

Monitoring Programs

Table 7.3-6 provides a summary of proposed programs that have been identified for monitoring project effects (construction, operation, decommissioning, and closure phases). These programs include:

- A seasonal monitoring program to determine changes in permafrost depth under disturbed sites. This program is needed to determine if the construction and operational phases have an impact on permafrost. Contingency plans will need to be implemented if unexpected effects occur.
- A seasonal terrain stability assessment monitoring program is needed in identified areas of potential risk to determine if facilities have an impact on terrain stability. Contingency plans will need to be implemented if unexpected effects occur.
- A seasonal soil erosion monitoring program is needed to check the effectiveness of site water management and the erosions and sedimentation control plan and determine if the construction and operational phases have resulted in the erosion of surficial materials. Contingency plans will need to be implemented if unexpected effects occur.

7.3.8 Summary of Effects

Table 7.3-7 provides a tabular summary of the project effects on terrain, surficial geology and soils.

Table 7.3-7 Program Effects on Terrain, Surficial Geology and Soils

Potential Effect	Level of Effect[1]						Effect Rating[2]	
	Direction	Magni tude	Extent	Duration/ Frequency	Reversi- bility	Like- lihood	Project Effect	Cumulative Effect
Construction								
Damage to key terrain features	No effect	No effect	No effect	No effect	No effect	No effect	Not significant	N/A
Modification of surficial materials and reduction in soil capability	Adverse	Moderate	Local	Long term to far future (access road and airstrip)	Reversible	High	Not significant	N/A
Changes in the permafrost depth	Adverse	Moderate	Site specific	Medium term	Reversible	Unknown	Not significant	N/A
Increased soil erosion	Adverse	Moderate	Local	Medium term	Reversible	High	Not significant	N/A
Terrain stability concerns	Adverse	Moderate	Local	Long term	Reversible	Unknown	Not significant	N/A
Operations								
Damage to key terrain features	No effect	No effect	No effect	No effect	No effect	No effect	Not significant	N/A
Modification of surficial materials and reduction in soil capability	Adverse	Moderate	Local	Medium term to far future (access road and airstrip)	Yes	High	Not significant	N/A
Changes in the permafrost depth	Neutral	Moderate	Site specific	Medium term	Yes	Unknown	Not significant	N/A
Increased soil erosion	Positive	Moderate	Local	Medium term	Yes	High	Not significant	N/A
Terrain stability concerns	Adverse	Moderate	Local	Long term	Yes	Unknown	Not significant	N/A
Decommissioning								
Damage to key terrain features	No effect	No effect	No effect	No effect	No effect	No effect	Not significant	N/A
Modification of surficial materials and reduction in soil capability	Positive	Low	Local	Medium term to far future (access road and airstrip)	Yes	High	Not significant	N/A
Changes in the permafrost depth	Neutral	Low	Site specific	Medium term	Yes	Unknown	Not significant	N/A
Increased soil erosion	Positive	Low	Local	Short term	Yes	High	Not significant	N/A
Terrain stability concerns	Adverse	Moderate	Local	Short term	Yes	Unknown	Not significant	N/A

Table 7.3-7 Program Effects on Terrain, Surficial Geology and Soils (cont'd)

Potential Effect	Level of Effect[1]						Effect Rating[2]	
	Direction	Magni tude	Extent	Duration/ Frequency	Reversi-bility	Like-lihood	Project Effect	Cumulative Effect
Closure								
Damage to key terrain features	No effect	No effect	No effect	No effect	No effect	No effect	Not significant	N/A
Modification of surficial materials and reduction in soil capability	No incremental effect	No incremental effect	No incremental effect	Far future (access road and airstrip)	No incremental effect	No incremental effect	Not significant	N/A
Changes in the permafrost depth	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	Not significant	N/A
Increased soil erosion	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	Not significant	N/A
Terrain stability concerns	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	No incremental effect	Not significant	N/A

Notes:
1 Based on criteria in Table 7.3-4
2 Based on criteria in Sections 6.7 and 7.3.3
N/A = not applicable