10. ASSESSMENT OF TERRAIN EFFECTS

10.1 INTRODUCTION

Existing landforms as well as the nature and distribution of surficial materials have resulted from the interaction of three factors – bedrock geology, glacial history, and climate. Bedrock geology affected the elevation of major topographic elements and the character of surficial materials. Glaciation and postglacial activity affected the morphology of landforms and the horizontal sequence of deposits. Climate controlled and continues to control weathering, erosion and deposition of mineral material and the rates at which they operated throughout the history.

This section discusses the characteristics of bedrock types, landforms, and unconsolidated surficial sediments found in the study area. The potential effects on terrain and soil resulting from the Project include terrain stability, soil loss, and degradation of soil quality. All of these can result in the reduction or cessation of ecosystem functions.

A soils and terrain baseline report completed in 2012 is provided in Appendix 10-A. A terrain stability report completed in 2014 (including a terrain stability map) is provided in Appendix 10-B. Since production of the soils and terrain report, the Local Study Area (LSA) was extended to the northwest to include the entire extent of underground mining. A new set of maps reflecting the current extent of the LSA were produced. The terrain map is provided in Appendix 10-C, the surficial material and soil maps are provided in Appendices 10-D and 10-E, and the slope map of the LSA is provided in Appendix 10-F.

10.2 REGULATORY AND POLICY FRAMEWORK

Provincial and federal acts, along with best practice guidelines and standards direct resource development and conservation. Regulations applicable to the management of terrain during mine development are listed and described below.

- The *Mines Act* (1998);
- *Fisheries Act* (1985);
- Dawson Creek Land and Resource Management Plan;
- Treaty 8;
- *Forests and Range Practices Act* (2002);
- *Fish Protection Act* (1997); and
- *Water Act* (1996).

<u>The *Mines Act* (1998)</u>

The *Mines Act* (1998) requires that the stability of stream, river, wetland, and seepage area crossings (Sections 9.4 and 9.10) and the stability of man-made structures (e.g., impoundments, dumps, slopes), are planned in advance, inspected, monitored, and maintained throughout the operations and at the time of project closure (Sections 10.6 and 10.7).

The *Fisheries Act* (Canada)

The *Fisheries Act* (1985) provides the legal framework to protect fish habitat from flooding and potential loss of land due to stream erosion and instability. Section 35 establishes rules guiding development within the Fisheries Sensitive Zones and watercourses. Section 36 establishes rules for erosion control related to land development activities, such as clearing land, grading slopes, and road construction and maintenance.

Dawson Creek Land and Resource Management Plan

As part of sustainable resource management planning, the Province established a consensus driven process to help provide detailed land use planning at a sub-regional level. The LRMP document that was the result of these public planning processes is an important local planning tool. Relevant to the Project areas, the Dawson Creek LRMP provides a guide for managing and directing resource development and conservation for each of the region's Landscape Units (LUs). It was completed in 1999 as a strategic long-term planning framework for Crown land resource access, development and management (BC Ministry of Forests and Range 1999). It provides General Management Directions (GMDs) to guide the management of key resources, interests and activities throughout the planning area. Principles guiding GMDs include:

- sustainable use of renewable natural resources;
- management of any one resource will take into consideration other resource values, rights, tenures and development opportunities which recognize the biological and physical limitations of the land and resources;
- maintenance or enhancement of the quality of life, social and economic stability, employment opportunities including job creation, and the vitality of local communities;
- acknowledgement that communities located within the planning area should have the opportunities to benefit from the natural resources within the planning area; and
- land, water, air and all living organisms are integral parts of the ecosystem and should be sustained and accommodated by management plans (BC Ministry of Forests and Range 1999).

The goals, objectives, and GMD's served to guide the design and implementation of the ecosystem and vegetation baseline studies. Management direction relevant to terrain include, but are not limited to, the following:

- cultural heritage;
- connectivity at the landscape (watershed) level; and
- scenic areas (i.e., ecosystems) for tourism and visual quality.

Treaty 8

Treaty 8, the treaty between the Crown and First Nations of northern Alberta, includes the Project area as well as northeastern BC, northwestern Saskatchewan, and a southern portion of Northwest Territories near Great Slave Lake (Treaty No. 8 1966). Currently, the closest Indian Reserves to the Project belong to West Moberly First Nation and Saulteau First Nation, and McLeod Lake Indian Band. Additionally, there are also Cree and Métis communities at Kelly Lake.

Treaty 8 provides the signatories with the right to carry out their "usual vocations" of hunting, gathering, fishing, and trapping within the Treaty 8 area. This right is protected by section 35 of the *Constitution Act*, 1982, but is subject to the right of the Crown to "take up" lands for settlement, mining, lumbering, trading or other purposes. The treaty guarantees the First Nations the right to continue with the same means of earning a livelihood as existed pre-treaty (i.e., that the treaty would not lead to "forced interference with their mode of life" (BC EAO 2012).

The *Forest and Range Practices Act* (BC)

The *Forest and Range Practices Act* (*FRPA*) (2002) governs all forestry activities in BC, including logging, road building, reforestation and riparian area management. *FRPA* requires that all forestry-related development be conducted in accordance with the rules and regulations identified in the *Act* to ensure the protection of environmental values. This act applies constraints to when, where, and how forest clearing is undertaken, regulates construction activities (section 3) and the use of forest service roads. The *Act* requires that road construction adheres to codes provided in the Forest Service Road Use Regulation (BC Reg. 70/2004), which focuses extensively on erosion prevention. Riparian ecosystems are protected by the FRPA (Part 4, Division 3). Suggested riparian reserve zones range from 20 m (stream class S3), to 30 m (stream class S2), to 50 m (stream class S1) (BC Ministry of Forests and Range 2004).

Fish Protection Act and *Water Act* (BC)

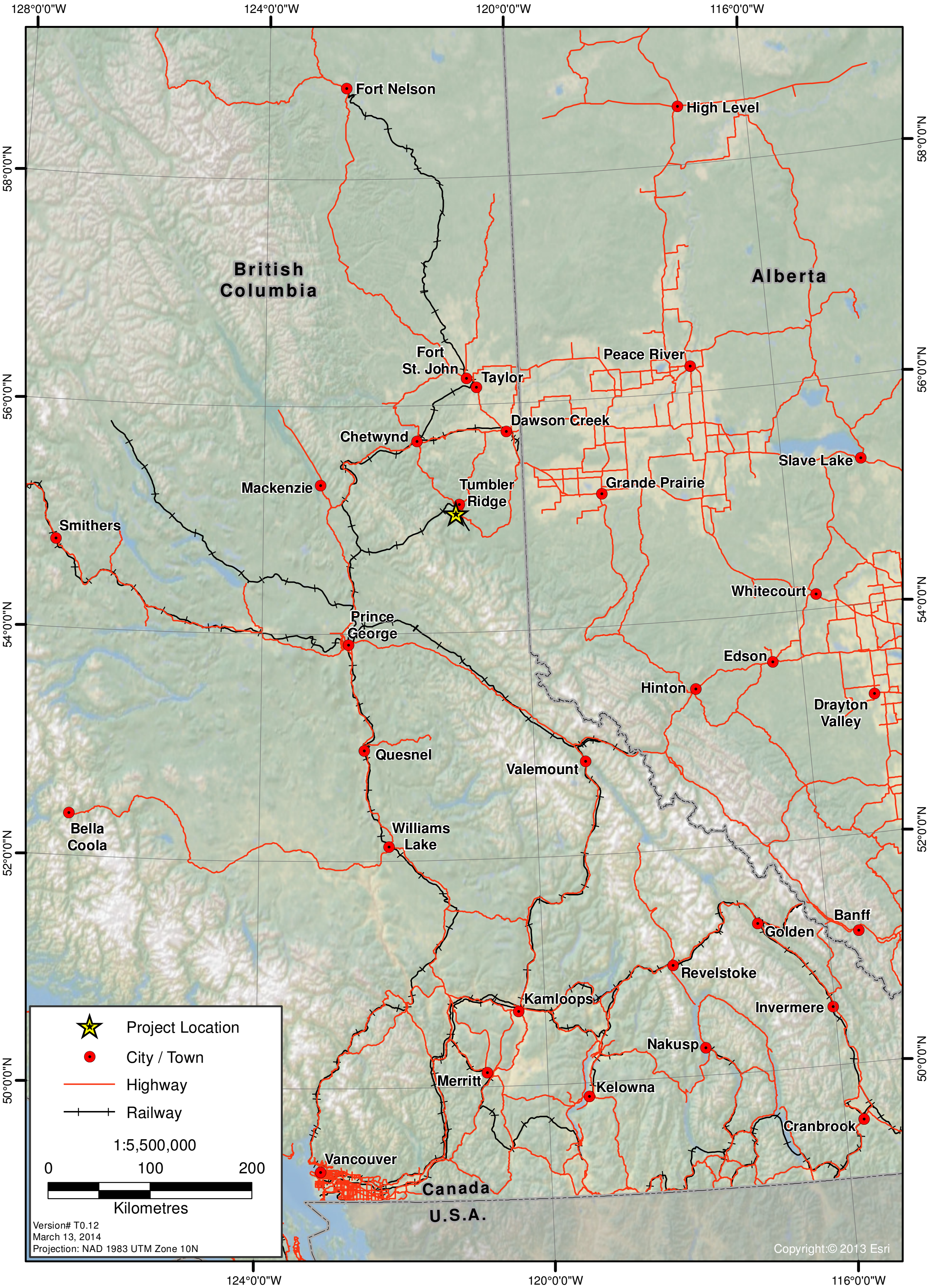
The *Fish Protection Act* (1997) and associated amendments to the provincial *Water Act* (1996) regulate provincial approvals of alterations and work in and around watercourses. The regulations focus on protection of riparian areas, which may be involved in vegetation removal and introduction of harmful debris (clay, silt, sand, rock, or any material, natural or otherwise) into the waterways. Terrain and soil information gathered during the baseline program can be used to design and guide Project development activities in vicinity of streams and rivers and to assess future changes in terrain associated with the Project development.

10.3 Regional Overview

The Project is located within the Municipal District of Tumbler Ridge, which is in the Rocky Mountain Foothills in northeastern BC (Figure 10.3-1). In terms of its ecological setting, it is part of the Central Canadian Rocky Mountain Ecoregion, the Sub-boreal Interior Ecoprovince and the Hart Foothills Ecosection (Demarchi 1995). The Hart Foothills are situated on the east side of the Rocky Mountains and consist of rounded mountains and wide valleys generally lower than the Rocky Mountains to the north and south. The Hart Foothills are in a relatively dry Ecosection, a result of Arctic air stalling in this area.

Figure 10.3-1

General Location of the Proposed Project



The bedrock is mostly composed of Cretaceous (65 to 145 million years old) sedimentary clastic rock, such as shale and mudstone, derived from mountain belts and deposited in troughs along mountain fronts (Natural Resources Canada 2009). While both types of rock weather rapidly and are easily eroded, bedrock layers differ in resistance to erosion, which creates "plateau and escarpment" topography (Valentine et al. 1978). The structural grain of the local bedrock results in elongated ridges oriented in the northwesterly direction (Holland 1976). Valleys erode along belts of softer rock and are generally wide.

There have been four major glaciations during the Quaternary period (about 2 million to 8.5 thousand years ago). These events produced the rounded summits and ridge crests and the undulating and rolling terrain at lower elevations. Morainal deposits blanket the sedimentary bedrock, except in areas where colluvial materials have collected on steeper slopes or recent fluvial deposits have altered valley floors (Valentine et al. 1978). Glaciolacustrine clays and fine silts present in the region are considered to be potentially vulnerable to landslides (Natural Resources Canada 2013). The Project is located in the low seismic hazard area (Natural Resources Canada 2013).

Precipitation averages between 450 and 550 mm per year, and is generally evenly distributed throughout the year. The majority of precipitation between November and April occurs as snow, and average snow depth ranges between 12 and 25 cm (Environment Canada 2013). Short summer rainstorms generate high intensity rainfall events. Consequently, the annual stream discharge record is dominated by spring snowmelt, with secondary high-flows resulting from summer rainstorms.

The major drainages originate in the Rocky Mountains, including Flatbed Creek, Bullmoose Creek, and Wolverine River. They flow northeast and merge into the Murray River near Tumbler Ridge. The Murray River then continues north, emptying into the Pine River near East Pine Provincial Park. The Pine River then flows north and east, joining the Peace River near the Town of Taylor, BC.

South of Tumbler Ridge, the Murray River is large and meanders through an incised floodplain between the remnants of benches from older floodplains. Through time, the valley has undergone a process of flattening, as the river has continued to rework the sand and gravel bed materials. North of its confluence with the Wolverine River, a study of tree ring data from the present floodplain indicated that the oldest trees are 150 years old, suggesting that in the past the river may have encompassed the entire floodplain (Thompson et al. 1978).

10.4 HISTORICAL ACTIVITIES

The proposed Project's License area is located within the Peace River Coalfield, known for producing metallurgical grade (hard coking) coal. In the 1950s and 1960s, 15 significant coal deposits were discovered in this region. In response to rising coal prices in the mid-1970s, the Government of Canada examined the viability of accessing and transporting coal to the Pacific Coast for export. In 1981, the governments of BC and Canada, two Canadian mining companies, and a consortium of Japanese steel mills signed an agreement to develop the mining industry in the area. As a result, the District of Tumbler Ridge was built as well as two coal mines (Quintette and Bullmoose), and highways 52 and 29 connecting the municipality with Highway 97. A power line from the W.A.C. Bennett Dam and a rail line through the Rocky Mountains were also built to support economic development in the region.

Several historic and current human activities are within close proximity to the proposed Project Area. These include mining exploration and production, oil and gas, forestry, tourism/recreation and hunting/trapping.

The Quintette Coal Mine, about 20 km south of Tumbler Ridge, was an open pit mine that operated between 1982 and 2000. The mine consisted of five open pits in three discrete areas: Sheriff (Wolverine and Mesa Pits), Frame (Shikano Pit) and Babcock (Windy and Window Pits). Mine permits for the Wolverine and Mesa Pits were issued in December 1982 and mining commenced from 1983 until 1998 (Wolverine) and 2000 (Mesa). Raw coal was transported via an overland conveyor from the Mesa and Wolverine Pits to the Quintette plant site for processing. The coal processing plant has been under care and maintenance since the end of mining in 2000; the overland conveyor, which previously crossed through a portion of HD Mining's Decline Site, was decommissioned by Teck in 2011. Teck is currently securing the necessary approvals to re-initiate mining in the Babcock area.

The Bullmoose Coal Mine operated from 1983 to 2003 and was the largest open pit coal mine at the time, producing between 2 and 3 million tons of metallurgical coal annually (MacMillan 1985). The operation consisted of an open-pit mine, a plant facility in the Bullmoose Creek valley below the mine, and a separate rail loadout facility on the B.C. Rail branchline.

Previous exploration in the area included seismic lines and drilling for oil and gas wells which helped target areas for coal exploration. Twelve cutblock licenses exist within the LSA; three of these are held by the proponent. Large portions of the LSA have been recently harvested to remove pine-beetle affected timber.

Subsistence activities, such as trapping, hunting, and fishing are common land uses regionally. Three trapping tenures and four guide-outfitting tenures overlap the RSA. Multiple recreation tenures, as well as temporary and permanent residences exist within the Project area. The nearest trapline cabin is 1.7 km from the Project on the west bank of Murray River, the nearest campground is 9.5 km north from the Project (near Tumbler Ridge), the nearest hunt camp is 26 km west from the Project, and the nearest residential area (Tumbler Ridge) is located 12.4 km north from the Project.

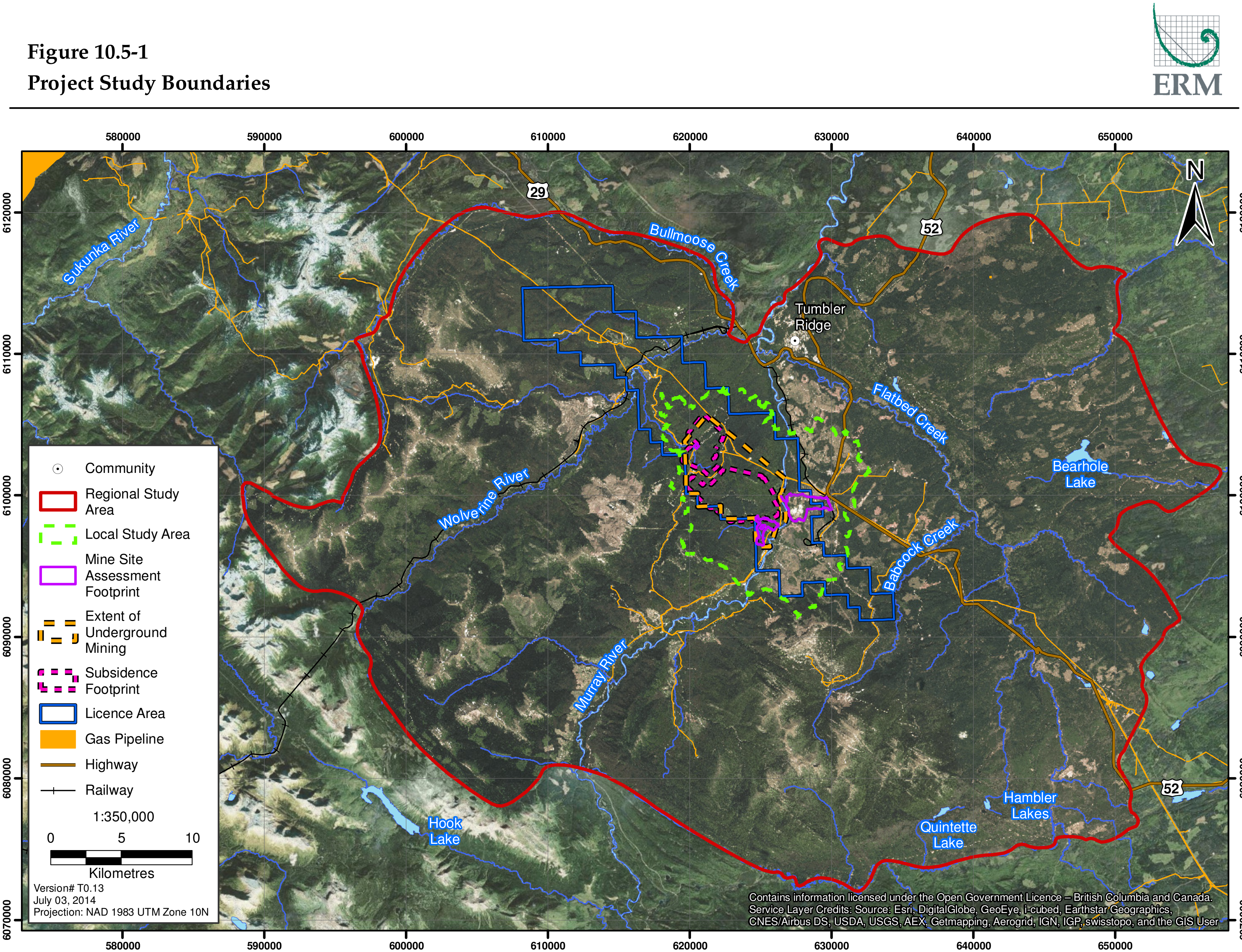
There are multiple previously recorded archaeological sites (pre-contact lithic scatters) within 5 km of the proposed Project infrastructure.

The Project is located near two provincial parks and protected areas. Bearhole Lake Provincial Park and Protected Area is located approximately 17 km east of the Project, and Monkman Provincial Park is located approximately 27 km south of the Project.

10.5 BASELINE STUDIES

Project baseline studies for terrain were conducted between 2010 and 2014. In order to guide the scope of baseline studies, regional and local study areas (RSA and LSA, respectively) have been delimited (Figures 10.5-1 and 10.5-2).

Figure 10.5-1
Project Study Boundaries



The RSA is intended to encompass the maximum area of influence of the Project on terrestrial environment, beyond which effects would not be expected. It is also intended to be ecologically relevant based on the home range of key wildlife species known to inhabit the region. The LSA encompasses an area surrounding the proposed Project infrastructure and the adjacent area, in which direct effects of the Project on terrain may be anticipated. Its periphery follows natural terrain and drainage boundaries in order to be ecologically relevant.

The goals of the baseline studies were to document current conditions and to provide a means of determining and assessing future changes to terrain related to the proposed Project. The specific objectives of the baseline program were to:

- review existing literature and data sources to describe the terrain and soil features of the RSA;
- characterize in detail and understand existing terrain and soil conditions in the LSA;
- conduct field surveys to guide terrain and soil mapping in the LSA;
- provide a benchmark for evaluating the potential effects of the Project; and
- characterize pre-disturbance conditions to guide reclamation activities.

Baseline data were collected and analyzed with the intention to use this information for the evaluation of the potential effects of the Project on terrain and soils, including assessment of potential geohazards.

10.5.1 Data Sources

The following sources of data were used to augment the baseline studies:

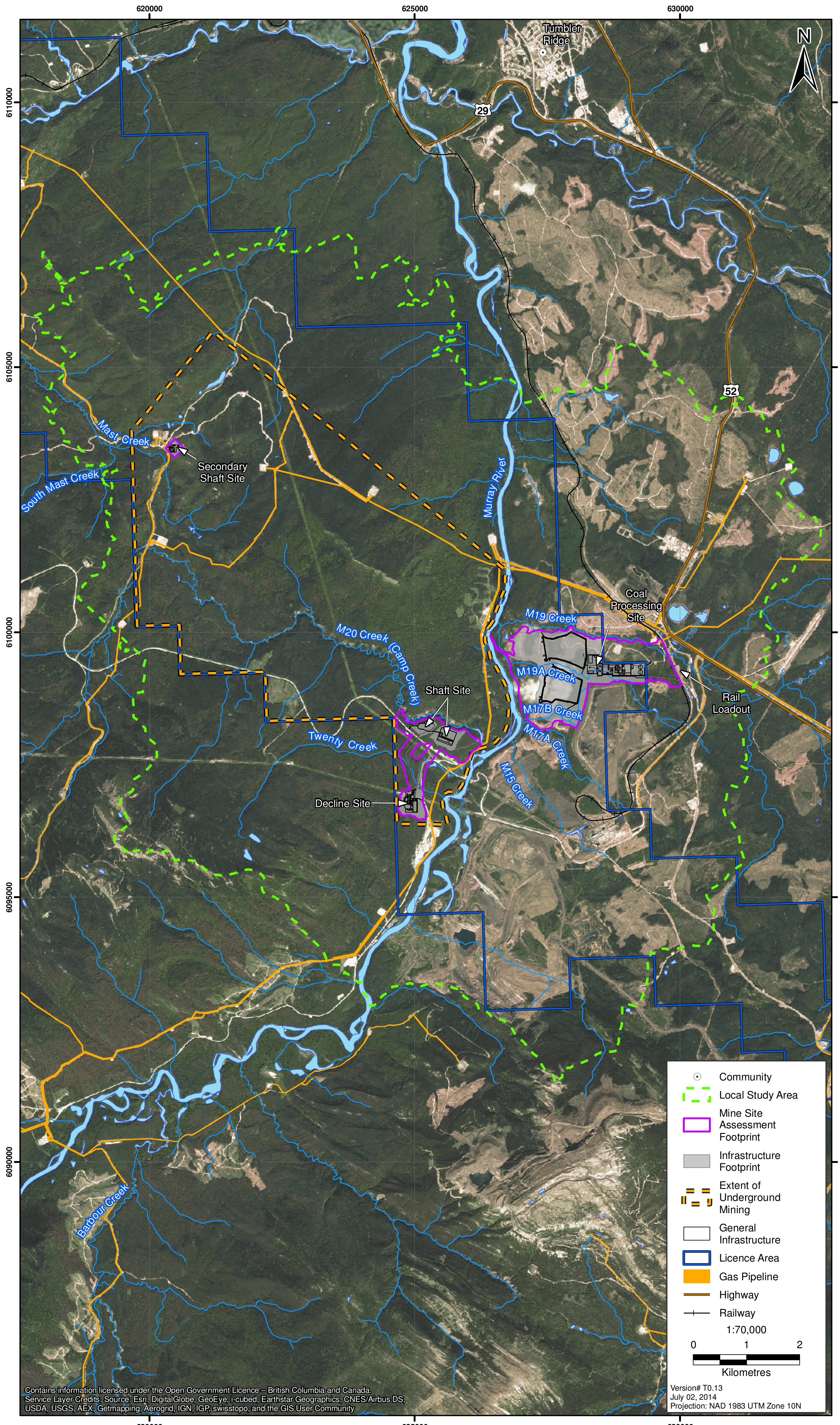
- Dawson Creek Land Resource Management Plan (LRMP);
- The Soil Landscapes of British Columbia (Valentine et al. 1978);
- Atlas of Canada, Natural Hazards maps (Natural Resources Canada 2013);
- Environment Canada climate station data located at Chetwynd;
- Terrain Inventory Mapping (TIM);
- Terrain Resource Inventory Mapping (TRIM);
- LiDAR data in .GRD format;
- Elevation data downloaded from Geogratis (20 m resolution).

10.5.2 Methods

Terrain and soil baseline studies were completed between the years 2010 and 2014 and included terrain and soil mapping, slope analysis, and the assessment of terrain stability, hazards, and constraints. The work involved review of background information, preliminary mapping, field surveys, data analysis, reassessment of produced maps, and preparation of assessment reports. Methods followed the AIR and EIS Guidelines.

Figure 10.5-2

Site Layout



10.5.2.1 *Baseline Study Area*

Terrain and soil baseline studies were completed between 2010 and 2014 within the RSA and LSA study areas (Figures 10.5-1 and 10.5-2). The RSA covers 227,579 ha and the LSA covers 12,092 ha.

10.5.2.2 *Terrain and Soil Mapping*

Terrain and soil mapping help stratifying the landscape into units that reflect combinations of similar attributes, such as slope gradient, surficial material type and depth, soil texture, moisture and organic content, and occurrence of any geomorphological processes. Terrain mapping is required to conduct an assessment of Project effects on the terrestrial environment and for the design and implementation of appropriate management plans. Soil mapping provides additional data relevant for the assessment of soil stability and erosion potential.

Terrain mapping was completed for the LSA using PurVIEW software within ArcMap. PurVIEW enables users to view stereo pairs of digital air photos in three dimensions at variable scales. A digital elevation model, created from the provincial Terrain Resource Inventory Mapping (TRIM) data, was used to provide a control on the vertical plane (z-axis) to enable on-screen digitizing of polygons that were photogrammetricly accurate (Government of British Columbia 2011).

Initial mapping involved identification and delineation of permanent terrain units (polygons) and assigning of general attributes to the individual polygons. Polygon attribute data included terrain modifiers such as texture, surficial material, surficial expression, geomorphological processes, and soil drainage. The attributes were later verified using the field data. The Terrain and Soils Field Program was carried out in the years 2010, 2011, and 2012. The field data were collected following the guidelines established in the *Field Manual for Describing Terrestrial Ecosystems* (BC MELP and BC MOF 1998). Detailed ground inspection forms were used for field data collection. Soil pits were excavated with a shovel and hand auger to a depth of approximately 100 cm or to the lithic contact. Terrain attributes were described using BC's Terrain System Classification for British Columbia (Howes and Kenk 1997), and recorded in a database linked to the ArcGIS terrain data. Soil attributes included parent material, texture, coarse fragment content, drainage, water table depth, and soil horizon designation and depth (Rescan 2013). Terrain mapping for the LSA was completed at the survey intensity level C (SIL-C, 28% of polygons field checked) and for the proposed footprint area at the SIL-B (62% of polygons field checked, RIC 1998). Soil mapping for the LSA was completed at the SIL-3 (approximately 80 ha per inspection site) and for the proposed infrastructure footprint at the SIL-2 (approximately 67ha per inspection site, Coen 1987). The analysis of gathered local terrain and soil information led to classification of the terrain polygons into soil mapping units (SMU). Detailed characterization of each SMU, including information on soil erosion potential was summarized in terrain and soil baseline report (Rescan 2013).

10.5.2.3 *Slope Analysis*

A slope gradient map was developed as part of the terrain assessment. The map was produced at a scale of 1:12,500 using digital information available from the provincial TRIM database (Government of British Columbia 2011). A geographic information system method using the Spatial Analyst extension in ArcGIS was used to generate a percent slope raster data set. This was based on the digital elevation model using a 20-m grid spacing for the TRIM-sourced data.

Slope classes were based on the Terrain Classification System for British Columbia (Howes and Kenk 1997). These classes were slightly modified to provide a better differentiation of relatively complex local slope conditions. In particular, the Howes and Kenk's (1997) "gentle" slope class, representing slopes between 5% and 26%, was sub-divided into two classes: gentle (5% to 15%) and moderately gentle (15% to 26%).

10.5.2.4 Slope Stability Classification

Slope stability classes were applied to the existing terrain polygons using the provincial standard five class system. Local criteria was established based on a combination of the slope stability mapping experience of the author and reviewer throughout the province, taking into account results from landslide attribute studies carried out in the coastal and southern interior regions of BC6. No landslide attribute studies are known to exist in the specific region of the study area. The criteria are based largely on: slope gradient; surficial material type; drainage; slope configuration; the presence of active geomorphological processes, and how terrain with similar attributes has responded to past resource development within the region (Appendix 10-B).

10.5.2.5 Terrain Stability, Hazard and Constraint Assessment

Preliminary hazard and stability interpretations were made by professional geoscientist using stereo colour imagery (2005) models with PurView 1.2 in ArcMap 9.3.1. The existing terrain mapping layer, TRIM contours and water features, a slope themed layer, a bedrock geology layer, and proposed infrastructure site plan were also reviewed at this stage. Field work was carried out in 2013. The level of field checking was appropriate for the size of the study area and scale of the mapping, with a total of 39 field sites recorded and approximately 34% of all mapped polygons being field checked (Terrain SIL C, RIC 1998). After field work was completed, all polygons within and directly adjacent to the proposed footprint were reassessed by professional geologist for hazard process and ratings, constraints, and slope stability class. A terrain hazard and constraint map was produced at the scale of 1:15,000 (Appendix 10-B).

<u>Hazard Classes</u>

A qualitative three class hazard rating system has been applied in this assessment (Low, Moderate, High). Criteria are project specific and are based on the likelihood of occurrence with no direct inference to potential magnitude. The class breaks used (likelihood of occurrences of 1/100 and 1/500) are common benchmarks used in landslide hazard analysis within British Columbia. These numeric values are intended to give the user a concept of the approximate annual likelihood of occurrence but do not represent exact values or infer a quantitative analysis. In comparison to example hazard rating tables presented in documents such as Land Management Handbook 56 Landslide Risk Case Studies in Forest Development Planning and Operations (Wise, Moore, and VanDine 2004) and the Forest Road Engineering Guidebook (BC MOF 2002), the three class system used in this project groups together the low and very low ratings as well as the high and very high ratings of their respective five class systems. Given the project scope this merging is considered appropriate.

10.5.3 Characterization of Terrain Baseline Condition

10.5.3.1 Topography

The LSA is located in the eastern foothills of the Rocky Mountains. Topography consists of hills and low mountains accented by elongated ridges, characteristically oriented in the northwesterly direction. Valleys eroded along broad belts of soft rock and are generally wide; however, their bottoms and slopes are often deeply incised by rivers and streams. In general, smooth landscapes predominate in the LSA. Plains and gentle slopes cover approximately 60% of the land. Undulating landscapes, defined as a sequence of smooth, non-linear rises and hollows, occur over approximately 25% of the LSA. Rolling topography (similarly smooth, but linear sequences of elongated rises and valleys that repeat in a wave-like pattern across the landscape) compose 5% of the surveyed area. Only about 10% of the LSA consists of irregularly shaped terrain with steep slopes such as ridges and hummocks.

While the mean slope gradients for individual terrain polygons range between 0% and 60%, the average slope gradient within the entire LSA is 15.5%. The maximum difference in elevation between the highest (1,380 m asl) and the lowest (760 m asl) terrain positions is 620 m.

The LSA has been divided into six slope classes (Table 10.5-1). The terrain generally considered accessible by heavy machinery (slopes below 26%) represents approximately 77% of the LSA. Detailed slope information is provided in the slope map (Appendix 10-F) and in terrain and soil baseline (Rescan 2013).

Table 10.5-1. Areal Extent of Slope Classes in the Local Study Area

Slope Class	Area (ha)	Proportion of LSA (%)
Class 1: 0% to 2% level	976	7
Class 2: 2% to 5% very gently sloping	2,027	14
Class 3: 5% to 15% gently sloping	5,049	34
Class 4: 15% to 26% moderately gently sloping	3,301	22
Class 5: 26% to 50% moderately sloping	2,700	18
Class 6: 50% to 70% moderately steeply sloping	552	4
Class 7: > 70% steeply sloping	247	2
Total	**14,853**	**100**

10.5.3.2 Local Surficial Materials

The analysis of local terrain and soil data led to the classification of terrain polygons into nine SMUs (Table 10.5-2; Figure 10.5-3). The characteristics of each of the units are described below in alphabetical order.

Due to considerable mining activity in the region, a relatively large proportion of the terrain in the LSA has been modified by people. These anthropogenic surficial materials, typically associated with mining activity or gravel extraction, cover almost 12% of the LSA. These materials have a wide range of physical properties (e.g., geo-morphological form, structure, and texture), but are generally shallow (range from 20-30 cm in depth). Texture varies between silt loam and clay loam, and coarse fragment content varies between 0 and 75%. Coarse fragments usually consist of gravels and cobbles that are rounded (e.g., near gravel pits) or angular (e.g., near waste rock disposal sites). Rapid mass movement and the evidence of localized soil erosion were occasionally recorded on or near steeper slopes. Anthropogenic materials are classified as non-soils.

Table 10.5-2. Distribution of Soil Mapping Units in the Local Study Area

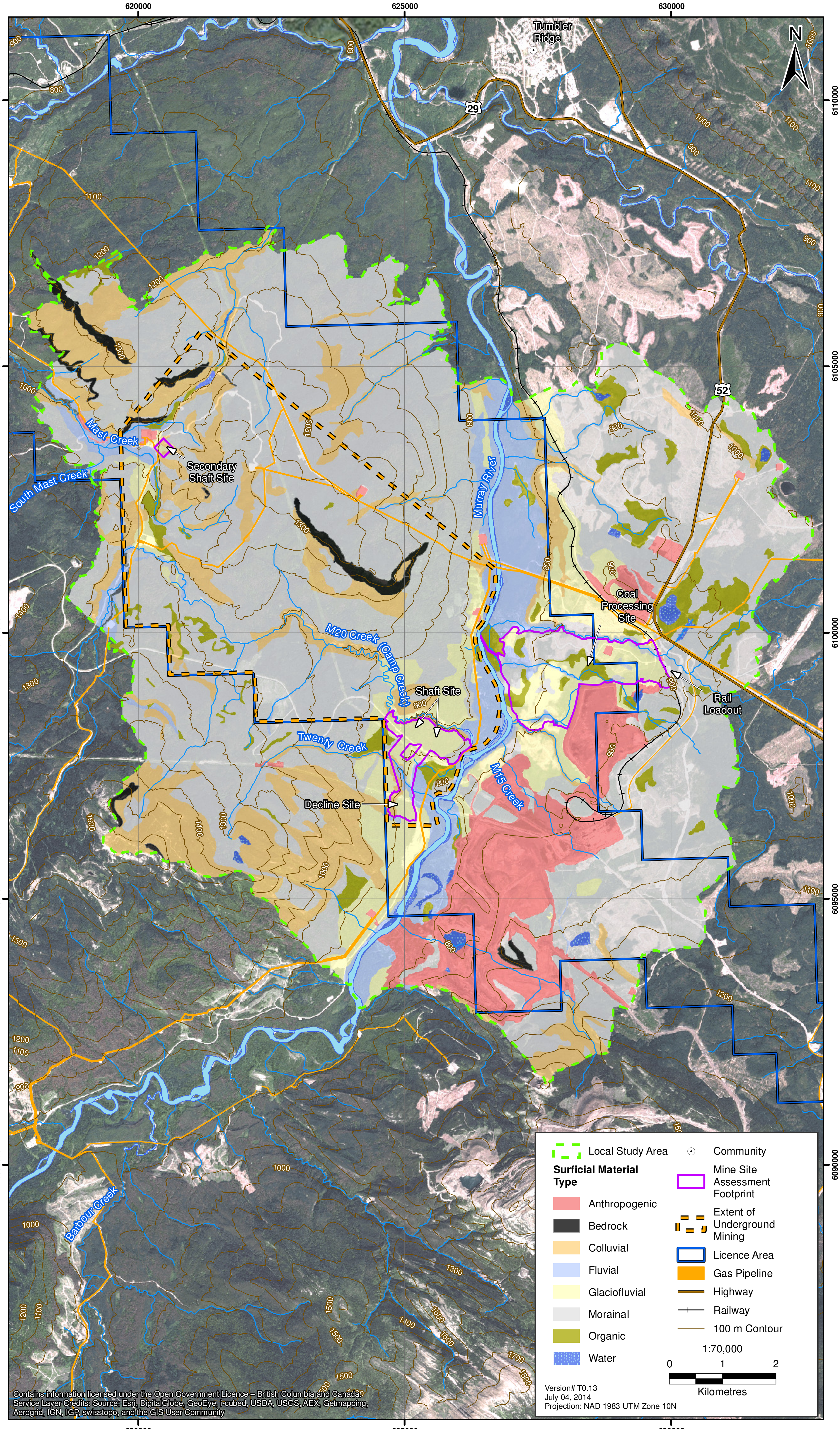
Parent Materials	Area (ha)	Proportion of the LSA (%)
Anthropogenic	1,747	11.8
Colluvial	2,097	14.1
Fluvial	1,026	6.9
Glaciofluvial	513	3.5
Glaciofluvial veneers over till	667	4.5
Morainal	8,177	55.1
Organic	208	1.4
Organic veneers over till	166	1.1
Open Water	203	1.4
Bedrock	47	0.3
Grand Total	**14,853**	**100.0**

Colluvial materials are the products of mass-wasting typically occurring on moderate to steep slopes. They are generally poorly sorted and contain a wide range of particle sizes. In the LSA, colluvial materials are commonly derived from unconsolidated Quaternary deposits. About 14% of the LSA has been mapped as colluvial terrain, which represents non-stratified, non-compacted colluvial veneers covering morainal or glaciofluvial materials deposited on moderate to steep slopes and in higher elevations. This unit is characterized by fine textured soils (e.g., clay loams) of high erodibility. Coarse fragments consist mainly of sub-angular to angular gravels (1 to 60%) and up to 20% of cobbles. The soils that developed on colluvial parent materials frequently display evidence of significant water erosion (e.g., slow or rapid mass movement and gullies). Most soils are classified as Brunisols, but there are also areas dominated by Podzols and Regosols.

Fluvial deposits dominate the relatively flat areas located at the bottom of the Murray River valley (about 7% of the LSA). The textures are often sandy or loamy. In the areas where streams are generally slow and on level floodplains at the bottom of the Murray River valley, fluvial materials contain a significant fraction of silt and clay. Fluvial deposits are generally well-sorted and display stratification with a high proportion of rounded gravels and cobbles. The typical soils include imperfectly drained Cumulic or Gleyed Regosols and peaty Gleysols. Due to their coarse texture and a high proportion of coarse fragments most fluvial soils are characterized by low erodibility. Nevertheless, finer materials deposited in slough areas may be highly erodible. While soil erodibility is mainly influenced by its texture and organic matter content, in case of fluvial deposits, site position in relation to fluvial currents may also have a significant effect on material erodibility.

Figure 10.5-3

Distribution of Surficial Material Types in the Local Study Area



Comprising 8% of the LSA, glaciofluvial materials have been deposited as blankets or veneers on both sides of the Murray River valley. They mainly consist of sandy and silty materials with a considerable component of rounded or sub-rounded coarse fragments. These well-sorted, often stratified, coarse materials are typically well drained and are characterized by low erodibility.

Glaciofluvial blankets are found mostly on the west side of Murray River, in slightly higher elevations and on steeper slopes than glaciofluvial veneers. They also contain a lower proportion of coarse fragments compared to veneers. The soils are typically well-drained, although moisture regimes may range from subxeric to subhygric depending on site slope position. Evidence of seepage, slow mass movement, and occasionally gullying has been recorded in these units. The typical soils include coarse, well-drained Eluviated Eutric Brunisols, with some Brunisolic Gray Luvisols and are generally characterized by low erodibility.

Glaciofluvial veneers and thin veneers deposited over gentle morainal slopes are typically found on the eastern side of Murray River. They are characterized by relatively high coarse fragment content (average 48%). The soil profiles typically feature a clear boundary between the coarser surficial horizons and the finer, more compacted, morainal horizons. The typical soils include coarse, well- to moderately well-drained Eluviated Eutric Brunisols and Gray Luvisols, with pockets of imperfectly drained Gleyed Eutric Brunisols and Gleyed Gray Luvisols in seepage zones. Most soils are characterized by low to moderate erodibility.

Morainal till generally consists of well-compacted, non-stratified material composed of a mixture of sand, silt, and clay, and it contains a heterogeneous mixture of sub-rounded to angular coarse fragments of different sizes. More than half of the surficial materials (55%) are of the morainal origin. Morainal deposits are typically found on gentle to moderate slopes on both sides of the Murray River valley. Soils contain a considerable proportion of angular coarse fragments. Textures vary widely (sandy to clayey), but most typically include clay loams and silty clay loams. While slow mass movement has been occasionally recorded in sloping areas, this soil unit typically does not display evidence of significant erosion. The typical soils include well- to moderately well-drained Brunisolic Gray Luvisols and Eluviated Eutric Brunisols, usually found on gentle slopes in the middle elevations, and their gleyed forms in imperfectly to poorly drained areas.

Organic materials are not common, occurring in less than 2% of the LSA. They result from accumulation of very slowly decomposing vegetation typically associated with wetland ecosystems. Organic veneers and blankets occur in the form of poorly or moderately decomposed peat layers (often more than 40 cm thick) that form in depressions, level areas, and in areas of intense seepage in toe or lower slope positions. The soils include very poorly drained Mesic Fibrisols, Typic Mesisols, poorly drained peaty Rego Humic Gleysols and gleyed Brunisols. Undisturbed organic materials do not display evidence of significant erosion, however, because they often develop on finely textured mineral materials, surficial disturbance may lead to soil erosion.

Bedrock dominated terrain comprises a relatively small portion of the LSA (< 1%) and consists of the cliffs along the mountain ridge located on the eastern side of the river valley. Some bedrock areas found on the western side of the valley were altered by past mining activity and are classified as anthropogenic material.

10.5.3.3 Terrain Stability Hazards

For this assessment, hazard is defined as a harmful or potentially harmful mass wasting or fluvial related event. The following sections discuss the hazard processes mapped within the LSA and the hazard class rating system used. In general, isolated areas of high hazard class terrain (primarily due to areas of rock fall, debris fall, debris slides, and soil creep) have been identified in the LSA. These areas are mainly located in steep polygons which have been incised by the present day rivers and creeks and on steep erosional slopes.

Slow Mass Movement

Slow mass movement (symbol F) refers to slope movement that occurs at a very slow rate and typically travels a relatively short distance. Soil creep (F″c) is the slow mass movement subclass, which describes a slow, down slope movement of soils. Within the LSA it has been mapped on some of the steeper erosional slopes in ravines (Shypitka 2013, Appendix 6-B). Slump in surficial material (F″u) is the sliding of surface material along a slip plane that is concave upward or planar. This process was identified in two polygons (84, 127) within the southern portion of the Infrastructure Footprint (see the map in Appendix 10-B).

Rapid Mass Movement

Rapid mass movement (e.g., R) refers to the rapid, gravity induced down slope movement by sliding, falling, rolling, or flowing of either bedrock or surficial material. The affected areas are exposed to up slope hazards, but may not have significant likelihood of landslide initiation within that polygon.

The rapid mass movement subclass rock fall (R″b) was identified in a few of the steeper polygons adjacent to M17 Creek, M19 Creek, M20 Creek, and along Murray River. It is typically present where exposed rock bluffs with near vertical slope gradients are located. Blocky talus slopes are common below these cliffs and are subject to rock fall from above (Rb). Debris fall subclass (R″f) refers to the rapid descent of a mass of surficial material by means of falling, bouncing, and rolling. Debris fall has been mapped in the study area in some of the same polygons that also contain rock fall adjacent to M20 Creek and Murray River (e.g., in polygons 15, 174, 190, 195; see the map in Appendix 10-B). Debris slides (R″s) consist of a sliding mass of surficial material. They typically occur on steep gradient slopes at times when pore water pressures within the soil are elevated due to high levels of runoff or precipitation. The sliding surface (shear plane) of debris slides is commonly bedrock where materials are thin, or at the contact between weathered soils and unweathered parent material where surficial material thickness are greater (commonly near 1 m depth in till soils within the region). Debris slides were identified in several polygons (e.g., 57, 69, 80, 184) within the Infrastructure Footprint.

Active Fluvial Processes

Active fluvial processes refer to hazards associated with **flooding, progressive bank erosion, and channel avulsion**. Within the LSA, active fluvial processes are predominantly situated along the Murray River floodplain and the M20 Creek fan (Appendix 10-B).

10.5.3.4 *Terrain Constraints*

For this assessment, terrain constraints are defined as terrain characteristics or features that are likely to pose a challenge to the construction, operation, or maintenance of infrastructure or access. Some constraint features may be sensitive to disturbance and could result in an increase in the likelihood of landslides resulting from resource development. This section outlines the terrain constraints that have been identified in the LSA.

Gullying

Gullies are ravines with a V-shaped cross section eroded into surficial material or bedrock by either water flow or mass movement processes. The presence of gullies indicates soil erosion and typically suggests a higher slope stability hazard rating compared with an otherwise similar non-gullied polygon. Within the LSA, gullying has been recorded in seven polygons (19, 27, 57, 184, 317, 564, 628; see map in Appendix 10-B).

Seepage Areas

In areas of substantial permanent or seasonal surface seepage soil drainage generally ranges from imperfect to very poor. Thin (< 1 m) organic veneers overlaying other surficial materials may develop in such sites. In general, these sites may represent construction or maintenance constraint due to the soil moisture content, elevated ground water tables, and associated elevated pore water pressures. Wet sites on steeper ground may be prone to slope instability and erosion when impacted by development. There are 31 polygons in the LSA poorly drained due to seepage (see map in Appendix 10-B).

Wetlands

Wetlands include poorly to very poorly drained organic and floodplain deposits typically inundated for a significant portion of the year and as such can present construction constraints due to high water tables. Twelve wetland polygons are located mostly along the Murray River floodplain and occasionally in the uplands (see map in Appendix 10-B).

10.6 ESTABLISHING THE SCOPE OF THE EFFECTS ASSESSMENT FOR TERRAIN

This section includes a description of the scoping process used to identify potentially affected Valued Components (VCs), select assessment boundaries, and identify the potential effects of the Project that are likely to arise from the Project's interaction with a VC. Scoping is fundamental to focusing the Application/EIS on those issues where there is the greatest potential to cause significant adverse effects. The scoping process for the assessment of terrain consisted of the following steps:

- *Step 1:* conducting a desk-based review of available scientific data, technical reports, and other Project examples to compile a list of potentially affected VCs in the vicinity of the Project;
- *Step 2:* carrying out detailed field baseline studies to fill information gaps and confirm presence/absence of VCs;
- *Step 3:* considering feedback from the EA Working Group on the proposed list of VCs included in the AIR and the EIS Guidelines;

- *Step 4:* defining assessment boundaries for each VC; and
- *Step 5:* identifying key potential effects on VCs.

10.6.1 Selecting Valued Components

Valued components (VCs) are components of the natural and human environment that are considered to be of scientific, ecological, economic, social, cultural, or heritage importance (CEAA 2006; EAO 2013). To be included in the EA, there must be a perceived likelihood that the VC will be affected by the proposed Project. Valued components are scoped into the environmental assessment based on issues raised during consultation on the dAIR and EIS Guidelines with Aboriginal communities, government agencies, the public and stakeholders. Consideration of certain VCs may also be a legislated requirement, or known to be a concern because of previous project experience.

10.6.1.1 Summary of Valued Components Selected for Assessment

Terrain Stability was identified as a Valued Component (VC) in the Application Information Requirements (AIR), and was identified as an issue of concern during the First Nations Community meetings held in April and May of 2013. Assessment of the potential effects of mining activity on terrain stability is also an important step for fulfilling the requirements of the *BC Mines Act* (1998), which requires that the stability of stream, river, wetland, and seepage area and the stability of man-made structures (e.g., impoundments, dumps, slopes), are planned in advance. Furthermore, considerable scientific evidence from North America (Darmody et al. 1989), Asia (Wu et al. 2009; Yi et al. 2010), Australia (Hebblewhite et al. 2008; J. A. Thompson et al. 2010) and Europe (Paukštys, Cooper, and Arustiene 1999; Donnelly 2013) ties underground coal mining with land subsidence and associated changes in terrain stability. Based on the above evidence, Terrain Stability was included in the Application/EIS process and listed in Table 10.6-1 below as a VC. No other VCs related to terrain have been identified by the Aboriginal groups, government, public, or professional experts.

Table 10.6-1. Terrain Valued Components Included in the Effects Assessment

	Identified by*				
Valued Components	AG	G	P/S	Other	Rationale for Inclusion
Terrain Stability	x	x		x	Potential effects resulting from subsidence and construction activity on terrain stability/ geohazards.

**AG = Aboriginal Group; G = Government; P/S = Public/Stakeholder*

10.6.2 Selecting Assessment Boundaries

Assessment boundaries define the maximum limit within which the effects assessment is conducted. They encompass the areas within, and times during which, the Project is expected to interact with the VCs, as well as the constraints that may be placed on the assessment of those interactions due to political, social, and economic realities (administrative boundaries), and limitations in predicting or measuring changes (technical boundaries). The definition of these assessment boundaries is an integral part in scoping for terrain, and encompasses possible direct, indirect, and induced effects of the Project on terrain as well as the trends in processes that may be relevant.

10.6.2.1 Spatial Boundaries

Infrastructure Footprint

All Project-related infrastructure is planned to be built within the Infrastructure Footprint.

Subsidence Footprint

To assess potential effects related to subsidence caused by longwall mining, polygons delineating the longwall mining panels were created in GIS. The polygons were drawn based on the mine plan, identifying the number of panels to be mined vertically. The final polygon boundaries indicate the location of all longwall mining areas and the number of panels to be mined vertically in each area. Based on recommendations, a 200 m buffer was applied from the panel edge to identify the potential extent of subsidence or horizontal displacement on the grounds surface (X-traction Science and Technology 2014). The Subsidence Footprint will be used to indicate where the effects of subsidence may be greatest. This is based on the premise that the magnitude of subsidence increases proportionally with the number of panels mined vertically.

Local Study Area

The LSA outline follows natural terrain and drainage boundaries surrounding the proposed Project infrastructure, within which direct effects from the Project may be anticipated. Because the extent of the effects of mining projects on terrain characteristics is typically local, the spatial boundaries within which the assessment of the Project effects on terrain stability is conducted follow the same outline as the LSA (Figure 10.5-1).

Regional Study Area

The RSA is the same as the one used for the baseline study (Figure 10.5-1). Due to local nature of terrain features, the assessment of Project effects on terrain stability is conducted at the LSA scale. The assessment of the cumulative effects is carried out within the RSA.

10.6.2.2 Temporal Boundaries

- **Construction**: 3 years;
- **Operation**: 25-year run-of-mine life;
- **Decommissioning and Reclamation**: 3 years (includes project decommissioning, abandonment and reclamation activities, as well as temporary closure, and care and maintenance); and
- **Post Closure**: 30 years (includes ongoing reclamation activities and post-closure monitoring).

The highest potential for adverse effects to terrain stability is expected to occur during Construction and Operation; however, the potential of geohazards associated with constructed slopes and effects of subsidence may persist for a number for years after the end of mining (ACARP 2001; Wise, Moore, and VanDine 2004) and may require continued monitoring.

10.6.2.3 Administrative Boundaries

No administrative boundaries were identified that are relevant to the assessment of terrain stability.

10.6.2.4 Technical Boundaries

Subsidence as a result of long wall mining will influence terrain stability. However, it is not possible at this time to predict potential effects at the individual site scale. Depending on many site specific details (e.g., slope, aspect, timing and direction of mining, etc.), it is possible that effects related to subsidence could be adverse (e.g., increase stability risks) or beneficial (e.g., reduce stability risks). As a conservative approach, for this assessment it is assumed that areas already subject to geohazards or geohazard potential (e.g., steeper terrain, unstable or complex stratigraphy, undercut slopes, etc.) will be adversely affected by surface subsidence. The amount of potential subsidence, and therefore the likelihood of effects occurring, will be proportional to the number of coal seams to be mined at any location. No attempt will be made to quantify the effects of subsidence; discussion will be restricted to qualitative terms (i.e., high risk, medium risk, low risk).

10.6.3 Identifying Potential Effects on Terrain

Potential geohazards that could result from the Project development are those related to mass movements (e.g., landslides, debris flows, rock falls, etc.), active fluvial processes (e.g., flooding, progressive bank erosion, and channel avulsion), and soil erosion (Table 10.6-2). Alteration of natural terrain conditions during Construction (e.g., surficial and underground construction activities), Operation (e.g., expansion of coal reject storage, or subsidence associated with underground mining), and Decommissioning and Reclamation could exacerbate baseline terrain stability, resulting in higher likelihood of adverse effects to terrain and existing infrastructure if design and mitigation are not adequate.

The likelihood of soil erosion and mass movement increases in disturbed soil surfaces from which vegetation has been removed. The potential magnitude of these effects is highly dependent on local terrain features (e.g., slope gradient, slope hydrology, deposit texture) and the total area of exposed soil surface. Roads, especially sections located on slopes, and all newly constructed earth structures (e.g., storage dumps, berms, etc.) tend to contribute most to the overall soil erosion.

When material (e.g., minerals, oil, water) is removed from below the surface of the earth, the reduction in volume causes the surface to subside. The mechanisms vary in nature and magnitude. When coal is extracted by the longwall mining method, the roof above the seam is allowed to collapse into the void that is created as a result of coal extraction. This results in fracturing and settlement of the overlying mineral material (overburden). The downwards movement of overburden results in sagging and bending of the land surface overlying the extracted longwall panels. The process of deformation to both the overburden and overlying land surface is called subsidence.

Subsidence associated with underground mining can destabilise cliff-lines and increase the probability of localised rock falls and cliff collapse (L. Holla and Barclay 2000; ACARP 2001, 2002). Subsidence can also decrease stability of slopes and escarpments and cause increased sedimentation, stream or river bank instability, changes to flood behaviour in the floodplain, and increased rates of erosion (Booth et al. 1998; Booth and Bertsch 1999; Gill 2000; Sidle et al. 2000; DLWC 2001; Stout 2003).

Table 10.6-2. Ranking Potential Effects on Terrain Stability

	Project Activities	Potential Effects on Terrain Stability: Mass Movement	Potential Effects on Terrain Stability: Active Fluvial Processes	Potential Effects on Terrain Stability: Soil Erosion
Construction	**Underground Mine**			
	Construction of Production Decline (2 headings - surface and underground)	L	L	L
	Haul of waste rock from Production Decline portal to Shaft Site	M	L	M
	Ventilation during construction	L	L	L
	Development mining of underground service bays, sumps, conveyor headings, etc.	M	M	M
	Construct underground conveyor system	L	L	L
	Coal Processing Site			
	Surface Preparation			
	Establish site drainage and water management	M	M	M
	Site clearing and stripping (CPP site, CCR North)	M	L	M
	Soil salvage for reclamation	M	L	M
	Upgrade access roads, parking and laydown areas	M	L	M
	Heavy machinery use	M	L	M
	Buildings and Services			
	Install domestic water system	L	L	L
	Install sanitary sewer system	L	L	L
	Install natural gas and electricity distribution network	L	L	L
	Construct main fuel station	L	L	L
	Construct buildings (e.g., maintenance, administration, warehouse)	L	L	L
	Construct raw coal and clean coal stockpile areas	L	L	L
	Construct coal preparation plant buildings and install/commission equipment	L	L	L
	Construct surface conveyor system	L	L	L
	Construct rail load-out facilities	L	L	L
	Shaft Site			
	Upgrades to infrastructure within existing site	L	L	L
	Addition of waste rock within existing storage area	M	L	M
	Management of runoff from waste rock pile and release to receiving environment (M20 Creek)	M	M	M
	Decline Site			
	Upgrades to infrastructure within existing site	L	L	L
	Management of water from underground activities and release by exfiltration to ground	M	M	M
	Traffic and Transportation			
	Transportation of materials to and from site	L	L	L
	Recycling and solid waste disposal	L	L	L
	Shuttling workforce to and from site	L	L	L
	Workforce and Administration			
	Hiring and management of workforce	N/A	N/A	N/A
	Taxes, contracts, and purchases	N/A	N/A	N/A

(continued)

Table 10.6-2. Ranking Potential Effects on Terrain Stability (continued)

	Project Activities	Potential Effects on Terrain Stability		
		Mass Movement	Active Fluvial Processes	Soil Erosion
Operations	**Underground Mine**			
	Longwall panel mining, and development mining	M	M	M
	Ventilation from underground	L	L	L
	Methane management	L	L	L
	Secondary shaft construction	L	L	M
	Underground seepage collection and water management	M	M	M
	Surface subsidence	H	H	H
	Coal Processing Site			
	Coal Processing Plant			
	Stockpiles of raw coal	M	L	L
	Operation of coal preparation plant and conveyor system	L	L	L
	Stockpiles of clean coal and middlings	M	L	L
	Operation of rail loadout	L	L	L
	CCR			
	CCR Pile development	M	M	M
	Site clearing and stripping (expansion of CCR North, construction of CCR South)	M	M	M
	Seepage collection system	M	M	M
	Water Management			
	Management of water brought to surface from underground	L	L	L
	Management of seepage from CCR	L	L	L
	Management of other site contact water	L	L	L
	Maintenance of site ditching and water management infrastructure	M	M	M
	Release of excess contact water to receiving environment	L	L	L
	Shaft Site			
	Maintenance of infrastructure within existing site	L	L	L
	Progressive reclamation of waste rock pile	M	M	M
	Management of runoff from waste rock pile and release to receiving environment (M20 Creek)	M	M	M
	Decline Site			
	Maintenance of infrastructure within existing site	L	L	L
	Secondary Shafts Site			
	Site preparation and construction of shafts	M	L	M
	Maintenance of infrastructure within existing site	L	L	L
	Utilities, Power, and Waste Handling			
	Electrical power use	N/A	N/A	N/A
	Natural gas use	N/A	N/A	N/A
	Domestic water use	N/A	N/A	N/A
	Domestic sewage handling	N/A	N/A	N/A
	Recycling and solid waste disposal	N/A	N/A	N/A

(continued)

Table 10.6-2. Ranking Potential Effects on Terrain Stability (completed)

Project Activities		Potential Effects on Terrain Stability: Mass Movement	Potential Effects on Terrain Stability: Active Fluvial Processes	Potential Effects on Terrain Stability: Soil Erosion
Operations (*cont'd*)	**Heavy Machinery, Traffic, and Transportation**			
	Shuttling workforce to and from site	L	L	L
	Transportation of materials to and from site	L	L	L
	Surface mobile equipment use	L	L	L
	Road maintenance	L	L	L
	Fuel storage	L	L	L
	Workforce and Administration			
	Hiring and management of workforce	N/A	N/A	N/A
	Taxes, contracts, and purchases	N/A	N/A	N/A
Decommissioning and Reclamation	**Infrastructure Removal and Site Reclamation**			
	Facility tear down and removal	L	L	M
	Reclamation of plant site	M	L	M
	Reclamation of on-site roads and rail lines	M	L	M
	Recycling and solid waste disposal	L	L	L
	Heavy Machinery, Traffic, and Transportation			
	Shuttling workforce to and from site	L	L	L
	Transportation of materials to and from site	L	L	L
	Surface mobile equipment use	L	L	L
	Fuel storage	L	L	L
	CCR			
	Reclamation of CCR	M	M	M
	Seepage collection system	M	M	M
	Site water management and discharge to receiving environment	M	M	M
	Underground Mine			
	Infrastructure tear down and removal	M	L	M
	Geotechnical and hydrogeological assessment and bulkhead installation	L	L	L
	Groundwater monitoring	L	L	L
	Workforce and Administration			
	Hiring and management of workforce	N/A	N/A	N/A
	Taxes, contracts, and purchases	N/A	N/A	N/A
Post Closure	**Shaft Site**			
	Waste rock pile seepage monitoring	M	M	M
	CCR			
	Seepage collection system	M	M	M
	Site water management and discharge to receiving environment	M	M	M
	Underground Mine			
	Groundwater monitoring	L	L	L

L	*Negligible to minor adverse effect expected; implementation of best practices, standard mitigation and management measures; no monitoring required; no further consideration warranted.*
M	*Potential moderate adverse effect requiring unique active management/monitoring/mitigation; warrants further consideration.*
H	*Key interaction resulting in potential significant major adverse effect or significant concern; warrants further consideration.*

It is expected that the subsidence associated with the proposed Project activity will result in changes in terrain morphology and increased likelihood of adverse effects to terrain stability in the areas overlying the longwall panels. The effects of subsidence are expected to be contained within the Subsidence Footprint.

While the Project related activities with the greatest potential to contribute to mass movement events are expected to occur primarily during Construction and Operation, it may take many years for the resulting mass movement to occur (ACARP 2001). Unless properly designed, constructed slopes (e.g., waste rock storage) also have the potential for development of unstable terrain over time (Wise, Moore, and VanDine 2004).

One of the concerns raised during the public consultation related to potential effects of an earthquake on terrain stability in the LSA (Table 4.2-1 in the approved AIR and the EIS Guidelines). While it may be expected that an earthquake will likely exacerbate the effects of the Project on terrain stability and increase the potential of mass movement occurrence, nevertheless, the general level of seismic hazard in the study area is low (see Section 10.3 and Chapter 23).

10.6.3.1 Summary of Potential Effects to be Assessed for Terrain Stability

Alteration of natural terrain conditions during Construction and Operation could exacerbate baseline terrain stability, resulting in higher risks of adverse effects to terrain and existing infrastructure, including mass movement of surficial material (landslides, debris flows, rock falls, etc.), active fluvial processes (e.g., flooding, progressive bank erosion, and channel avulsion), and soil erosion.

Construction of sedimentation ponds, coarse coal reject piles, and roads, as well as construction activities in the hydrologically active areas may increase the risk of adverse effects on terrain stability.

Predicted subsidence resulting from longwall mining appears to be the key factor that can affect terrain stability in the LSA during and after Operation.

10.7 EFFECTS ASSESSMENT AND MITIGATION FOR TERRAIN

10.7.1 Key Effects on Terrain Stability

10.7.1.1 Mass Movement of Surficial Material

Mass movements occur naturally on slopes and are commonly triggered by periods of intense rainfall or snowmelt, resulting in oversaturation and weakening of sediment bond, and by slope undercutting (e.g., by erosion). The rate at which such instability occurs can be exacerbated by Project-related activities.

Construction activities that could potentially affect terrain stability include those that destabilize the integrity of surficial materials on slopes, affect slope hydrology, and create steep terrain.

During Operation, terrain stability will be affected by subsidence, CCR and overburden storage, water transport and storage, as well as road use and maintenance. The CCR piles will continue to increase in size over the mine life; however, they have been designed with 2.5:1 slopes and benching to reduce risks of failure. Similarly, water storage structures and the roads will be designed in such way that the risk of their failure will be minimal. The greatest potential to increase the likelihood of mass movement of surficial materials will be associated with subsidence. It is expected that subsidence will influence geohazard rating in the affected areas by changing the existing slope gradients and by altering natural drainage pathways.

The assessment of potential effects on terrain stability resulting from subsidence was based on the assumption that the extent of surficial changes (i.e., subsidence or horizontal displacement of the land surface) will be limited to the area of the underground longwall mining panels surrounded by a 200 m buffer. This buffer width was based on the approximate distance at which according to the modelling (X-traction Science and Technology 2014) subsidence was less than 30 cm. The 200 m buffer incorporates both single seam and multiple seam mining. Table 10.7-1 summarizes the areas of varying stability classes affected by the predicted subsidence. Extension of the buffer to 200 m allowed merging of the areas associated with individual panels into the Subsidence Footprint shown in Figure 10.7-1. This figure shows the spatial distribution of the areas where potential terrain instability may manifest. These areas include terrain polygons characterized as stability class III or higher falling within the Subsidence Footprint.

Table 10.7-1. Areas of Varying Stability Classes within the Subsidence Footprint

Stability Class	Total Buffered Area within the Subsidence Footprint
I (no significant stability problems)	854
II (very low likelihood of landslides or slumping)	723
III (minor stability problems can develop)	258
IV (moderate likelihood of landslide)	209
V (high likelihood of landslide)	217
Non-Classified	4
Total Area	**2,264**

Note: The areas are provided in hectares.

The expression of subsidence in areas of high geomorphological relief is complex. While subsidence predictions have been calculated for a few key cross sections (Appendix 3-C), the predictions are based on a model calibrated to mines in the eastern US, and may not be directly applicable to northeast BC. There are currently no comparable underground coal mines in BC or Canada against which to calibrate such a model. Ultimately the results of the model are considered reasonable for planning purposes. Detailed subsidence monitoring will be conducted during Operation, and the results will be used to calibrate a site-specific model which will be used to support advance planning related to mitigation of subsidence effects.

In general, it is expected that increasing slope gradients and changes in lateral tension will result in increased likelihood of adverse effects to terrain stability. It is however possible, that long-term changes in slope drainage patterns associated with gradual changes in surficial morphology will complicate these predictions by creating additional, unexpected factors affecting slope stability (e.g., new seepage areas, slumps, or gullies). For this assessment, it was assumed that the existing geohazard risks will increase within the area affected by surface subsidence.

During Decommissioning and Reclamation, terrain stability may be affected by road decommissioning, construction of the CCR storage cover, and by the re-distribution of surficial materials and soil. Residual subsidence may still be active during this phase.

Some effects on terrain stability may extend to Post Closure. Project-related activities with the greatest potential to contribute to mass movement events occur primarily during Construction and Operation, however, the resulting mass movements may not occur until many years later. For example, road construction or subsidence may alter natural drainage pathways by changing overland water flow pattern, and lead to creation of new seepage areas, slumps, or gullies several years after the end of mining activity.

10.7.1.2 Active Fluvial Processes

Dynamic watercourses that show evidence of channel migration and exhibit a wide range of morphological features such as pools and riffles, active gravel bars and varied river bank types are particularly vulnerable to interventions, such as bank disturbance, culvert installation, realignment, and construction on the adjacent floodplain. Accelerated fluvial activity, such as an increase in bank erosion or channel incision, may occur in response to Construction activities planned in the vicinity of several ravines located in the central portion of the LSA (e.g., M-19A Creek or M-20 creek). Construction specifications are developed to minimize these occurrences.

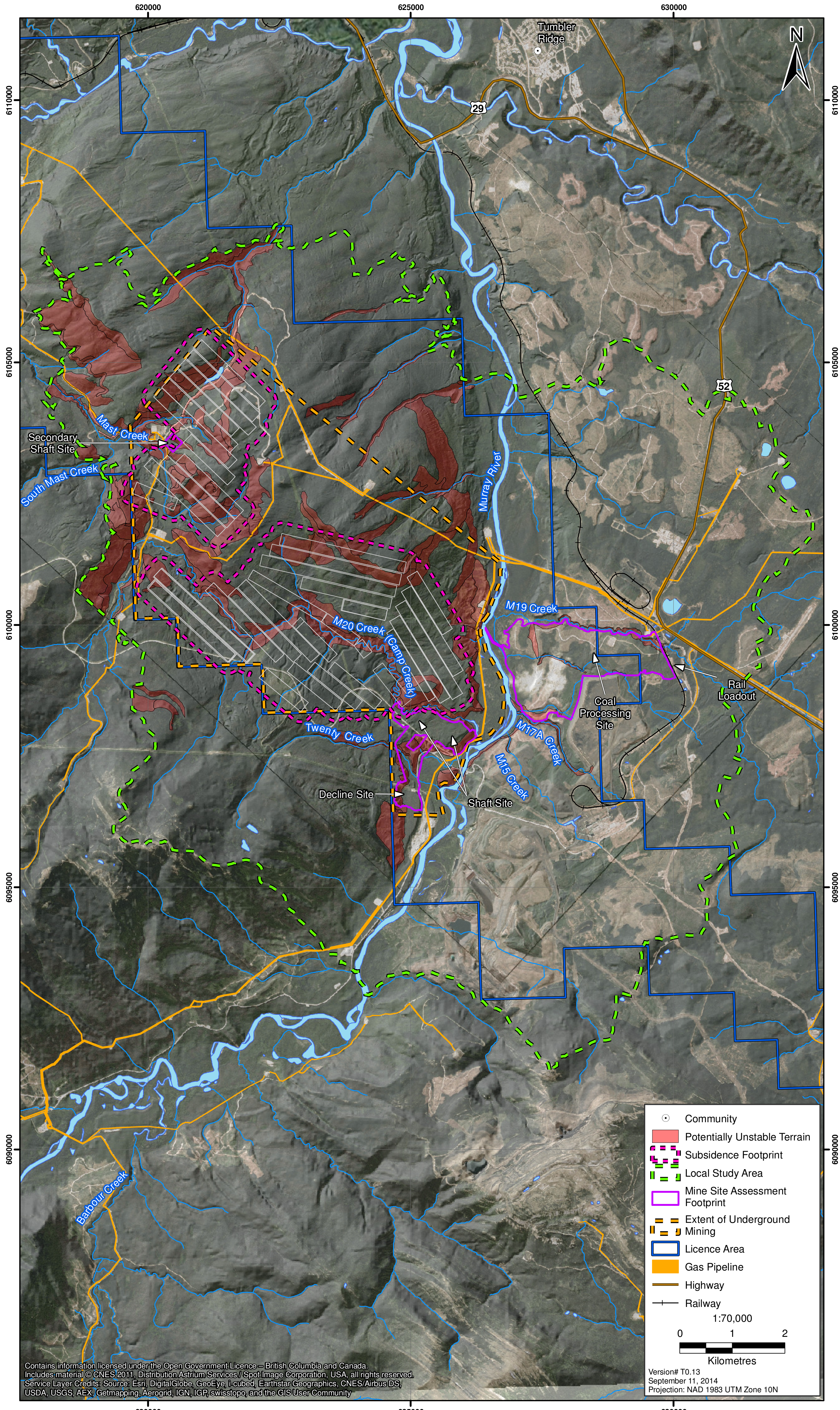
Lateral movement of surficial rock strata may occur as a result of horizontal stress associated with subsidence. The floors of gorges or narrow V-shaped valleys affected by this stress are susceptible to shearing and uplift (L. Holla 1997). These phenomena can result in surficial fractures that affect active fluvial processes and can direct surface water into underground aquifers (NSW Department of Planning 2008). Mass movement of a substantial amount of mineral material into one of the creeks may cause temporary flow blockage and result in localized flooding and other fluvial processes.

Subsidence and lateral tension resulting from underground coal extraction in the central, northern and western sections of the LSA may thus affect the flow of M-20 creek (Camp Creek) and the headwaters of Mast Creek. Camp Creek fluvial fan located between the Mast Road and the Murray River is very active during spring snowmelt and, episodically, during summer thunderstorm or intense rainfall events. Mast Creek is located in the western section of the LSA and is associated with several wetland areas.

Existing data do not allow site specific predictions of the extent of potential changes in active fluvial processes; however, potential effects could include channel avulsion, progressive bank erosion, flooding of the adjacent land, or temporary loss of surface water to groundwater aquifers. Effects of subsidence are specific to the hydrogeological characteristics at a site level and their assessment requires detailed information on the predicted change in slope gradient, characteristics of fissures and cracks in underlying geological strata, distribution of perched water tables, and connectivity with ground water aquifers.

Figure 10.7-1

Terrain Polygons (Stability Class 3 or Higher) within the Subsidence Footprint



Studies from other longwall coal mines have shown unexpected results such as increases in soil moisture on ridges due to increased connectivity to groundwater sources, while wetlands and creeks have been dewatered in other cases (Hutcheson et al. 2000; Cherry et al. 2004). Responses to alterations in slope gradient can cause hydrological changes that vary from no change, to ponding, to draining of surficial water bodies. Since it is difficult to predict how subsidence might affect hydrological regimes near the ground surface, continuous monitoring of water bodies, wetlands, and seepage areas is the recommended approach to identify, and where appropriate mitigate, specific effects at the site level.

10.7.1.3 Soil Erosion

Disturbed areas from which vegetation has been removed (e.g., infrastructure footprint, laydown areas, sedimentation ponds, salvaged soil storage berms, and roads) are typically associated with soil erosion and bulk soil losses. The magnitude of these losses is highly dependent on soil texture, slope gradient, the total area of exposed soil surface, and the quality and the timeliness of preventive mitigation measures.

Soil erosion is closely linked with slope stability and can be viewed as a low magnitude form of a spectrum of potential geomorphological events, of which more severe forms include slope failures and landslides. It is also important to note that the cause and effect of soil erosion and slope failure are closely associated because they usually influence each other's dynamics. Landslides often originate from episodic erosion processes and are typically followed by small-scale erosion processes that infill the failure area by the deposition of hillslope material (Sakals 2010).

Slope stability issues and erosion control will be particularly important within the portion of the Infrastructure Footprint characterized by moderate to steep slopes (Section 10.5.3.1). Vegetation clearing and soil salvage during Construction as well as gradual removal of soil from the stockpile berms and spreading it over reclaimed areas during Decommissioning and Reclamation will expose the soils to a high likelihood of erosion. All constructed slopes, such as salvaged soil stockpiles, berms around the sedimentation ponds, and coal reject storage dumps also will be exposed to erosion of fine material.

Because roads act as surface drainage networks that increase runoff and concentrate surficial flow (especially sections located on slopes), they tend to contribute considerably to the overall soil loss. The other areas characterized by an increased likelihood of erosion include buffers along the roads and water crossings.

While preventive mitigation measures are expected to strongly affect the magnitude of soil erosion, they will not prevent it entirely, especially in the areas characterized by moderate to steep slopes. Table 10.7-2 summarizes the expected management implications of Project development in the areas characterized by specific surficial materials and slopes.

It is also expected that, in the areas affected by subsidence, changes in slope gradient and slope hydrology will be associated with increased soil erosion. Again, the precise prediction of the extent of this process is not possible. Regular monitoring of erosion and sedimentation is recommended as the best approach to identify specific effects at the site level and to design appropriate mitigation response.

Table 10.7-2. Expected Management Implications Associated with Surficial Material Erodibility

Rating	Example Criteria	Management Implications
Low	Blocky colluvial deposits on low gradient slopes Terrain dominated by competent bedrock Morainal veneers; most rubbly colluvial deposits with high coarse fragment content	Expect none or minor surface erosion of fines in ditch lines and on disturbed soils.
Moderate	Morainal blankets on slopes less than 50% and less than 26% if gullied or poorly drained Glaciofluvial or fluvial deposits with low bulk density, slopes less than 26% Fine textured lacustrine (silts & clays), glaciolacustrine, glaciomarine, glaciofluvial or aeolian silts on slopes less than 16% Soft, friable bedrock	Significant erosion problems can be created when water is channeled onto or over exposed soil on these sites.
High	Some morainal blankets steeper than 50%, or steeper than 26% if gullied or poorly drained Fine textured lacustrine (silts and clays), glaciolacustrine, glaciofluvial or aeolian silts on slopes steeper than 16%, or gullied or poorly drained. Glaciofluvial or fluvial sands with low bulk density, steeper than 26% or gullied or poorly drained Colluvial deposits derived from the above materials with the same slope or moisture criteria Colluvial deposits steeper than 50% or steeper than 26% if gullied	Severe surface and gully erosion problems can be created when water is channeled onto or over these sites.

10.7.2 Mitigation Measures for Terrain Stability

10.7.2.1 Mitigation of Increased Likelihood of Mass Movement

Although subsidence is a phenomenon that inevitably follows longwall mining, the associated terrain stability risks can be managed through thorough planning and monitoring. As outlined in the Project Description (Section 3.8.2), the mining process will start with two single panels in Block 1 (Panel J1201 and Panel D1101). These panels are located in areas characterized by lower likelihood of terrain instability (Figure 10-7-1). The results of subsidence monitoring during this early phase of mining (see Section 24.15) will be used to re-assess potential effects in adjacent areas with higher likelihood of mass movement and other terrain stability risks. Opportunities to modify the mine plan (e.g., rate or direction of mining, specific panel dimensions/layout) may be possible to reduce potential effects resulting from subsidence.

Construction in areas classified as potentially unstable has been avoided where possible. In cases where this approach is not possible, some of the following engineering techniques may be employed to make the slope more stable:

- Grading of steep slopes or terracing to reduce the slope gradient.
- Building retaining walls to stabilize a slope.

- Inserting pipes into the slope to improve drainage and avoid increases in fluid pressure, increased soil weight, and the possibility of soil liquefaction.
- Planting of vegetation on bare slopes to increase soil surface cohesiveness and evapotranspiration.
- Covering steep slopes with wire mesh and shotcrete to prevent rock falls.

According to the results of ongoing monitoring, slope stabilization techniques such as installing bioengineering structures may also be used on highly erodible soils and on long or steep slopes.

For all constructed slopes (e.g., sedimentation pond berms, coal reject storage) and road construction sections in which soils cuts traverse slopes greater than 34° or fill slopes greater than 20 m height, a detailed geotechnical design and construction plan will be completed to ensure the slope stability during and after construction is achieved in the most economical manner with the least environmental impact.

Where rock cut is necessary, it will be scaled concurrently with construction, and a qualified registered professional engineer will inspect the scaling and make a determination if additional slope stabilization measures are required.

During Decommissioning and Reclamation, the long-term stability of the CCR storage will be assessed and re-contoured as necessary. The surface will be reclaimed with salvaged topsoil material and re-vegetated. A long-term monitoring program would be established to inspect the integrity of the storage pile and reclamation cover. The surface facilities will be dismantled or demolished and then sites will be scarified, reclaimed with salvaged topsoil material, and re-vegetated.

10.7.2.2 Mitigation of Changes in Active Fluvial Processes

The condition of surficial waterbodies located within the Subsidence Footprint will be monitored. If any significant anomalies in the creek flows are reported, HD Mining will commission an appropriately qualified professional to investigate the causes and recommend any remedial actions. The remediation may involve stabilization of creek banks, construction of stable diversion channels, provision of rip rap on the outside bends, introduction of large woody debris in the bed to help trap bed sediment, and planting of dense riparian vegetation to stabilize the banks.

The unlikely event of mass movement of a substantial volume of material into any of the affected creeks may cause temporary flow blockage and result in localized flooding. Eventually the creek would scour the blockage, but this process could be expedited by excavation.

10.7.2.3 Mitigation of Increased Soil Erosion

Erosion control measures will focus on preventing soil loss associated with the action of wind, water, and gravity. Where possible, surface disturbance will be avoided in areas where soil erodibility is known to be high (Section 10.5.3.2, Appendices 10-D and 10-E). In areas where disturbance of soil surface is required (e.g., on soil stockpiles, road cuts, embankments, and in ditches), erosion control measures will include seeding of exposed soils with an erosion control seed mix or hydro-seeding with a mix of seed, mulch, and a tackifier as soon as practicable.

Where required, more intensive soil erosion control measures will be adopted, such as the installation of erosion control blankets or fibre matrices bonded onto the soil surface. Rock material, willow bundles, or gabions will also be used, as required, to protect erodible channel banks. Silt fences may be used to prevent sediments from eroding off-site or entering waterways.

At the end of Operation the surface facilities will be dismantled or demolished and then sites will be scarified, reclaimed with salvaged topsoil material and re-vegetated. During Post Closure, the project site surface will be inspected to ensure permit compliance and to confirm that erosion control, seeding and re-vegetation have been successfully implemented.

Roads will be constructed according to the Forest Road Engineering Guidebook (BC MOF 2002) and maintained to ensure low likelihood of landslide and continuous, efficient, controlled water drainage. When the road is no longer required, it will be deactivated according to the Forest Road Engineering Guidebook standards and reclaimed.

An erosion monitoring system will be established at the beginning of Construction to verify proper implementation and effectiveness of mitigation measures. If monitoring data indicate that the mitigation methods are not adequately controlling soil erosion, adaptive management measures directed towards identification and implementation of a new or modified mitigation approach will be promptly initiated (CEAA 2013).

Please refer to the Soil Erosion and Sediment Control Management Plan (Section 24.5) for a more detailed description of the erosion and sedimentation control program and mitigation methods.

10.8 RESIDUAL EFFECTS ON TERRAIN STABILITY

The preceding section described three potential effects related to terrain stability: mass movement; fluvial processes; and soil erosion. For the remainder of this assessment, these three effects are merged into a single residual effect termed “increased likelihood of terrain instability” (Table 10.8-1). The assessment considers this as a single residual effect because the analysis of potential effects is driven by a footprint analysis of the overlap between mapped terrain stability polygons and Project infrastructure. Based on the scale of this assessment, it is possible for one, two, or all three of these effects to occur at each identified polygon.

10.9 CHARACTERIZING RESIDUAL EFFECTS, SIGNIFICANCE, LIKELIHOOD AND CONFIDENCE ON TERRAIN STABILITY

10.9.1 Definitions of the Assessment Criteria

Residual effects are characterized according to standard criteria such as the magnitude, geographic extent, duration, frequency, reversibility, and ecological context. In this section the general definitions of the criteria used in the assessment of the residual effects of the Project development on the terrain stability are explained (Table 10.9-1).

Table 10.8-1. Summary of Residual Effects on Terrain Stability

Valued Component	Project Phase (timing of effect)	Project Component/Physical Activity	Description of Cause-Effect	Description of Mitigation Measure(s)	Description of Residual Effect
Terrain Stability	Construction	Vegetation clearing, soil salvage, road construction, grading, construction of water sediment pond, drainage, runoff ditches, CCR storage	Construction of steep terrain (berms, rock dumps), construction in areas affected by seepage, and disturbance of soil surface increase the risk of mass movement.	Construction work will be led by professional engineers. Where possible, construction in areas classified as potentially unstable will be avoided. Best management practices and the provisions outlined in the Soil Management and Erosion Prevention Plans will be followed. Slope stabilization techniques will be applied. Potential soil erosion and sedimentation of water bodies will be monitored and mitigated during construction phase.	No residual effects are expected.
		Construction activities (e.g., road, bridge, rock storage) planned in the vicinity of several ravines located in the central portion of the LSA.	Accelerated fluvial activity, such as an increase in bank erosion or channel incision, may occur in response to construction near ravines.		No residual effects are expected.
		Infrastructure footprint, laydown areas, sedimentation ponds, salvaged soil storage berms, and roads.	Disturbed areas from which vegetation has been removed are exposed to soil erosion and lead to bulk soil losses.		No residual effects are expected.
	Operation	CCR development and overburden storage, road use and maintenance	Slope gradient, horizontal tension and hydrological changes associated with subsidence increase the risk of mass movement	CCR development will be led by professional engineers. Road maintenance will follow best management practices and the provisions outlined in the Soil Management and Erosion Prevention Plans.	No residual effects are expected.
		Underground coal extraction	Subsidence may trigger mass movement, or changes in active fluvial processes.	Monitoring of subsidence will allow for identification of new areas of instability. Since the extent or location of occurrence is difficult to predict, management and mitigation of effects will reflect the required response level at the time of potential event.	Increased risk of geohazards (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence.
	Decommissioning and Reclamation	Road decommissioning, re-distribution of salvaged soil, construction of CCR and overburden storage cover	Distribution of large quantities of unconsolidated soil increases the risk of mass movement	Best management practices and the provisions outlined in the Soil Management Plan will be followed.	No residual effects are expected.
		Re-contouring/reclamation of CCR, storage areas, decommissioning of roads, bridge, drainage/spillway.	Mass movement of a substantial amount of mineral material into one of the creeks may cause temporary flow blockage and flooding.	Decommissioning, re-contouring and earthwork associated with reclamation will be led by professional engineers. Best management practices and the provisions outlined in the Soil Management and Reclamation Plans will be followed. Potential effects on fluvial processes will be monitored and where possible mitigated during mine closure.	No residual effects are expected.
		Delayed effects of underground coal extraction	Residual terrain instability resulting from subsidence several years after the end of mining activity.	Monitoring of subsidence over the mine life will allow for better prediction of potential areas of instability. Closure planning will take into account management and mitigation of potential known residual instability.	No residual effects are expected.

Table 10.9-1. Definitions of Characterization Criteria for Residual Effects on Terrain Stability

						Likelihood of Effects	
Magnitude	Duration	Frequency	Geographic Extent	Reversibility	Ecological Context	Probability	Confidence Level
How severe will the effect be?	*How long will the effect last?*	*How often will the effect occur?*	*How far will the effect reach?*	*To what degree is the effect reversible?*	*How resilient is the receiving environment or population?*	*What is the current condition of the ecosystem and how commonly is it represented in the LSA?*	*How certain is this analysis?*
Minor: differing from the average value for baseline conditions to a small degree, but within the range of natural variation and well below a guideline or threshold value	**Short-term**: an effect that lasts approximately 1 to 5 years	**Once**: an effect that occurs once during any phase of the Project	**Local**: an effect is limited to the Project footprint	**Reversible short-term**: an effect that can be reversed within 25 years	**Low**: the ecosystem has no unique attributes or it is not sensitive (is neutral) to changes in terrain stability	**High:** It is highly likely that this effect will occur.	**High:** < 80% confidence. There is a good understanding of the cause-effect relationship and all necessary data are available for the Project area. There is a low degree of uncertainty and variation from the predicted effect is expected to be low.
Moderate: differing from the average value for baseline conditions and approaching the limits of natural variation, but below or equal to a guideline or threshold value	**Medium–term**: an effect that lasts between 6 to 25 years	**Sporadic**: an effect that occurs at sporadic or intermittent intervals during any phase of the Project	**Landscape**: an effect extends beyond the Project footprint to a broader (e.g., watershed) area	**Reversible medium-term**: an effect that can be reversed within 25 to 50 years	**Moderate**: the ecosystem has few unique attributes which may show some limited sensitivity to changes in terrain stability	**Medium:** This effect is likely, but may not occur.	**Medium:** 50 to 80% confidence. The cause-effect relationships are not fully understood, there are a number of unknown external variables, or data for the Project area are incomplete. There is a moderate degree of uncertainty; while results may vary, predictions are relatively confident.
Major: differing from baseline conditions and exceeding guideline or threshold values so that there will be a detectable change beyond the range of natural variation (i.e., change of state from baseline conditions)	**Long-term**: an effect that lasts between 26 and 50 years	**Regular**: an effect that occurs regularly during any phase of the Project	**Regional**: an effect extends across the regional study area	**Reversible long-term**: an effect that can be reversed but the recovery may take more than 50 years	**High**: the ecosystem is considered to be unique and potentially sensitive to changes in terrain stability	**Low:** This effect is unlikely but could occur.	**Low:** < 50% confidence. The cause-effect relationships are poorly understood, there are a number of unknown external variables, and data for the Project area are incomplete. High degree of uncertainty and final results may vary considerably.
	Far Future: an effect that lasts more than 50 years	**Continuous**: an effect that occurs constantly during any phase of the Project	**Beyond Regional**: an effect that extends possibly across or beyond the province of BC	**Irreversible**: an effect cannot be reversed (i.e., is permanent)			

10.9.2 Residual Effects Characterization for Terrain Stability

It is expected that most of the residual effects of the Project development on terrain stability will be associated with subsidence and lateral stress on surficial strata. These phenomena may potentially cause mass movement of the surficial deposits, affect intensity of active fluvial processes and induce soil erosion. All these effects were included in the following assessment of magnitude, geographic extent, duration, frequency, reversibility and ecological context of the effects associated with Project development.

According to the subsidence modelling results (Appendix 3-C), where the maximum predicted subsidence would occur (up to 29 feet / 8.84 m), it occurs over the length of about 1,200 feet (366 m). This results in an increase to the existing slope gradient by approximately 2.5%. While such change in the surficial morphology will differ from current baseline conditions, the resulting slope gradients will remain within the range of natural variation observable in the LSA. The majority of the area within the Subsidence Footprint has slope gradients varying between 0 and 15% (Appendix 10F – slope map). Predicted changes in land geomorphology (e.g., creation of several 2 km long, several hundreds of metres wide and 1 to almost 9 m deep, roughly rectangular depressions extending in the NW to SE direction) will, however, likely exceed the range of topographic patterns typical of the LSA.

Nevertheless, described above changes in slope gradients and surficial topography provide only a framework of expected measurable factors influencing terrain stability. Assessment of the range of patterns associated with changes in slope hydrology is more challenging. Current drainage patterns have continuously evolved on local slopes since deglaciation. Over the millennia, surficial and ground water flows gradually reached equilibrium with the local precipitation patterns. Disruption of this balance can lead to instabilities even on terrain that would normally be considered stable (Shypitka 2013).

The area in which the predicted level of subsidence is the highest (two parallel sets of five overlapping panels 2201 and 2202) is especially difficult to assess, because it is characterized by active and inactive fluvial processes, seepage, water ponding, and organic material accumulation (Appendix 10-D). Underlying geological deposits are predominantly glacial till, which generally have relatively high clay content, low permeability, and are more plastic than sands and gravels; as such they are generally expected to restrict water percolation to deeper geological strata. Under such conditions the range of potential effects of subsidence on surficial hydrology is broad. Consequently, it is very difficult to assess how the combination of predicted changes in local topography and hydrology will affect terrain stability (i.e., mass movement of surficial materials, fluvial processes, or soil erosion) in the affected areas and how that new potential risk compares to the range of naturally occurring geohazards within the LSA.

To evaluate the magnitude of the potential adverse effects to terrain stability, the mapped area of the various terrain stability classes (I through V) within the Subsidence Footprint was considered. Currently 30% (683.5 ha) of the area within the Subsidence Footprint has a terrain stability class of III or higher; while 19% of the footprint is class IV or V (“potentially unstable” and “unstable”). Under the very broad assumption that subsidence effects could cause each polygon to increase one class rating, this could result in the proportion of “potentially unstable” and “unstable” terrain within the Subsidence Footprint increasing from 19% to 30%. If this assumption is true, the magnitude of the potential effects of Project development on terrain stability is moderate (i.e., differing from the average value of baseline conditions, but within the limits of natural conditions found in the LSA).

Due to the fact that subsidence will take place outside of the Project footprint but will not affect areas outside of the LSA, the effects on terrain stability are predicted to attain the geographic extent of a landscape.

While the changes in terrain morphology will take place sporadically (spatially) during Operation and likely stabilize in the short term, their potential effects on local hydrology and thus on terrain stability may last continuously into the far future (more than 50 years).

Although the topographic changes induced by the subsidence will be irreversible, their effects on terrain stability are expected to stabilize in the long term (the recovery will likely take more than 50 years).

It is assumed that most of the anticipated changes in the terrain stability will affect ecosystems that historically were characterized by some level of geohazard risk and thus are neutral or display limited sensitivity to potential of increased instability (Table 10.9-2).

10.9.3 Significance of Residual Effects on Terrain Stability

The significance of residual effects of the Project is founded on a comparison of the current (baseline) characteristics of the VC, with the predicted state of the VC if the Project proceeds, after consideration of all mitigation measures described in Section 10.7.2.

Since the predicted magnitude of the potential effects of Project development on terrain stability is moderate, the effects have the geographic extent of a landscape, are expected to last continuously into the far future, may be distinguishable at the ecosystem level in the long term, and because affected ecosystems are expected to display limited sensitivity, the overall significance of effects of the Project development on terrain stability is considered Not Significant (Moderate).

10.9.4 Characterization of Likelihood and Confidence for Residual Effects

Scientific and technical literature indicates that the likelihood of subsidence and horizontal displacement of surficial materials resulting from proposed longwall coal mining activity is high (Mehnert, Van Roosendaal, and Bauer 1992; Shea-Albin 1994; Booth et al. 1998; L. Holla and Barclay 2000; Bauer 2008; Hu Beibei et al. 2009; Wu et al. 2009; J. A. Thompson et al. 2010). Modelling of ground deformations predicted as a result of the proposed Project (Appendix 3-C) confirms this prediction. Nevertheless, while there are many examples of reduced terrain stability associated with subsidence (Shea-Albin 1994; Wu et al. 2009; Yi et al. 2010), the severity and the form of potential geohazards is difficult to predict precisely as the outcomes depend highly on a combination of complex geological and hydrological features of the affected sites. Consequently, the assessment of environmental effects of the Project on terrain stability is based on a general assumption that the likelihood of terrain instability will increase in areas affected by the subsidence and carries high degree of uncertainty. In view of the discussed factors, the likelihood of occurrence is evaluated as medium but the confidence in the specific predicted outcome is low.

Table 10.9-2. Characterization of Significance, Confidence and Likelihood of Residual Effects on Terrain Stability

Residual Effect	Residual Effects Characterization Criteria						Significance of Adverse Residual Effects	Likelihood and Confidence	
	Magnitude (*minor, moderate, major*)	Duration (*short, medium, long, far future*)	Frequency (*once, sporadic, regular, continuous*)	Geographic Extent (*local, landscape, regional, beyond regional*)	Reversibility (*reversible short-term; reversible long-term; irreversible*)	Context (*low, neutral, high*)	*Not significant (minor, moderate); Significant (major)*	Probability (*low, medium, high*)	Confidence (*low, medium, high*)
Increased risk of geohazards (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence.	Moderate	Far Future	Continuous	Landscape	Reversible long-term	Neutral	Not Significant (Moderate)	Medium	Low

10.10 SUMMARY OF RESIDUAL EFFECTS ASSESSMENT AND SIGNIFICANCE FOR TERRAIN STABILITY

It is expected that most of the residual effects of the Project development on terrain stability will be associated with subsidence and lateral stress on surficial strata. These phenomena may potentially cause mass movement of the surficial deposits, affect intensity of active fluvial processes and induce soil erosion. Some residual soil erosion is also expected to result from surface disturbances during Construction, Operation, and Decommissioning and Reclamation.

The predicted magnitude of the potential effects of Project development on terrain stability is moderate. The geographic extent of effects occurs at landscape scale, effects are expected to last continuously into the far future, and may be distinguishable at the ecosystem level in the long term. The affected ecosystems are expected to display limited sensitivity to geohazards (Table 10.10-1). The overall significance of effects of the Project development on terrain stability is considered Not Significant (Moderate).

Table 10.10-1. Summary of Residual Effects, Mitigation, and Significance on Terrain Stability

Residual Effects	Project Phase	Mitigation Measures	Significance
Terrain Stability			
Increased risk of geohazards (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence.	Construction, Operation, Closure and Reclamation	Monitoring of subsidence will allow for identification of new areas of instability. Since the extent or location of occurrence is difficult to predict, management and mitigation of effects will reflect the required response level at the time of potential event.	Not Significant (Moderate)

10.11 CUMULATIVE EFFECTS ASSESSMENT

10.11.1 Introduction

Cumulative effects result from interactions between the effects associated with the proposed Project and the effects of other human actions: past, current and future.

Cumulative effects are assessed in each of the assessment chapters, as required by the BC EAO (2013). A synthesis of these sections is provided in Chapter 21, to address CEA Agency (2013) requirements.

The method for assessing cumulative effects includes the following steps:

- scoping and identification of potential effects;
- description of potential effects and mitigation measures;
- identification and characterization of residual cumulative effects; and
- determination of effect significance.

10.11.2 Establishing the Scope of the Cumulative Effects Assessment

Only residual effects from the Project-specific effects assessment are considered in the CEA. They are assessed in combination with the residual effects of all other past, present, and future human actions that may interact with them. The following two criteria for the relevance of evidence pertaining to other human actions are considered in the scoping of the CEA:

- it must be demonstrated that a residual effect of the Project operates cumulatively with the effects of another human action; and
- the other human action must be known to have been carried out, or it must be probable (using best professional judgement) that it will be carried out.

Cumulative effects can interact in the number of ways. The following types of interactions are considered in this assessment:

- Additive – combined effects equal the sum of the individual effects. For example, several, isolated rockfall events that do not affect any common area or process, may lead to a gradual accumulation (increased proportion) of the areas affected by high likelihood of terrain instability within the region.
- Synergistic – combined effects collectively result in an effect that is higher than the sum of individual effects. For example, the effect of altered slope hydrology may induce higher likelihood of slope failure associated with road construction. The geohazard may not have existed if each of the effects occurred in isolation.

10.11.2.1 Spatial Boundaries

Spatial boundaries for the CEA comprise the area within which the terrain stability affected by the Project could also be affected by past, present, or future human actions (Effects Assessment Methodology, Section 5.10). Because terrain stability is a very site-specific phenomenon, it is assumed that the spatial extent of the Project's residual effects have to physically overlap with the extent of another human action (or at least contact it) to cause an interaction. Consequently, while the typical extent of spatial boundaries for terrestrial disciplines corresponds to the RSA, the assessment of the cumulative effects on terrain stability will be focused on projects and human actions that spatially contact the predicted extent of effects associated with the proposed Project.

10.11.2.2 Temporal Boundaries

The temporal boundaries evaluated as part of the CEA include the following temporal categories:

- **Past** (closed) human actions;
- **Present** (continuing and active) human actions; and
- **Future** human actions, which may be:
  - **certain actions:** those actions that have received regulatory authorizations but are not as yet built or operating; and

- **reasonably foreseeable actions:** those actions that are currently in some stage of a regulatory authorization process, and for which a general concept is available from which potential cumulative effects may be anticipated.

The potential cumulative effects of hypothetical actions that are conjectural but probable, (e.g., leases, licences, and extrapolations from historical development patterns) are discussed only on a conceptual basis in this CEA.

10.11.3 Other Human Actions Considered in the CEA

An initial list of past, present, and future human actions to be considered in the CEA was developed as part of the Murray River Land Use Baseline Report via desk-based review of existing information and field research conducted between 2010 and 2014 (Appendix 16-A). This list was augmented with information on past historic mining operations retrieved from the BC Ministry of Energy, Mines, and Natural Gas, information on current and future hydroelectric projects from BC Hydro, FortisBC, and Columbia Power Corporation, and information on future actions from the BC EAO and the BC Ministry of Forests, Lands, and Natural Resource Operations. A complete list of human actions considered in the CEA is presented in Chapter 5, Section 5.10, Table 5.10-1.

Figure 10.11-1 shows the spatial distribution of current developments in the RSA. The footprints of other projects were digitized from maps or other materials prepared by the relevant proponents. Where a project footprint was not explicitly delineated in the documentation available, the full extent of the proponent's tenure was used as a conservative estimate of the potential dimensions of the associated disturbance. Table 10.11-1 lists past, present, and reasonably foreseeable future human actions recorded within the RSA. The table also shows which of the listed projects are expected to produce effects on terrain stability that will interact with those associated with the Murray River Project.

10.11.4 Description of Potential Cumulative Effects

It is expected that the residual effects of the Murray River Project development on terrain stability will be associated with subsidence and lateral stress on surficial strata. These phenomena may potentially cause mass movement of the surficial deposits, affect intensity of active fluvial processes and induce soil erosion.

Potential interactions of these effects with the residual effects from other past, present, or future project or activities in the CEA study area were identified through reviews of relevant data (e.g., Project description, data made available from First Nations and local stakeholders, scientific literature, data acquired via data sharing agreements, government documents, and publically available data associated with relevant adjacent projects) and professional judgement of the author.

Potential interactions between the residual effects of the projects are expected to modify terrain stability (Table 10.11-2). Due to predominantly local extent of geomorphological processes, the accumulation of changes contributed by individual projects and activities is expected to have mainly additive character.

10.11.5 Mitigation Measures to Address Cumulative Effects on Terrain Stability

To minimize unwanted effects on terrain stability, a wide range of management and mitigation strategies has been, and will continue to be, employed by the past, present, and future projects. When project development involves soil disturbance, soil and overburden management plans are commonly designed and used to avoid or minimize the potential impacts. The Soil Erosion and Sediment Control Management Plan for Murray River Project is provided in Section 24.5. It is also expected that project plans take into consideration the goals and objectives outlined in the local *LRMPs, such as Dawson Creek Land & Resource Management Plan (BC ILMB 1999)* and follow best management practices recommended in their respective fields (e.g., Bittman 1995; Predika, Dawson, and Stephenson 1999; Neville 2003; BC MEMPR 2008; BC MOE 2010).

In addition, it is assumed that present and future project proponents will:

- avoid activities in areas classified as potentially unstable;
- avoid or minimize the spatial and temporal extents of soil disturbance through adoption of appropriate project development design, strategic planning, and coordination of activities;
- employ experienced, professional engineers to plan and oversee construction work;
- monitor environmental impacts and the effectiveness of mitigation methods;
- collaborate and implement data sharing agreements, including assessment of the effectiveness of mitigation and monitoring methodologies and actions taken to improve them.

Monitoring and mitigation methods established for the protection of terrain stability within the Murray River Project LSA are discussed in Section 10.7.2 and in Section 24.5.

10.11.6 Characterization of Residual Cumulative Effects on Terrain Stability

Terrain disturbed by subsidence and areas from which vegetation has been removed (e.g., construction and laydown areas, borrow pits, soil stockpiles, and especially roads) are typically associated with soil erosion and increased likelihood of mass movement of surficial materials. It is thus expected that vegetation removal, tree harvesting, skid trail and road construction, and subsidence will have a synergistic effect of slope hydrology and stability, on fluvial processes and on soil erosion.

While mitigation efforts play a significant role in reducing the magnitude of these processes, the effects of land development on terrain stability cannot be entirely eliminated. At a regional scale, the magnitude of cumulative effects on terrain stability is highly dependent on the proportion of disturbed soil surface (Oldeman 1992; US FWS 1998; Jakob 2000; Sloat and Redden 2005; Porter et al. 2012). Therefore, the proportion of anthropogenically disturbed land was used to assess the potential cumulative effect of past, existing and future projects on terrain stability.

The area affected by soil disturbance currently covers approximately 5.3% of the RSA and the cumulative area disturbed by all the past, current and future (certain and reasonably foreseeable) projects is expected to cover 9.4% of it. The contribution of the Murray River Project to the increase of the disturbed area will be 1,180 ha (495 ha from the Mine Site Assessment Footprint plus, very conservatively, 648 ha from Stability Class III to V polygons within the Subsidence Footprint). This represents 12% of the contribution provided by all future projects.

Figure 10.11-1
Spatial Distribution of Human Activities

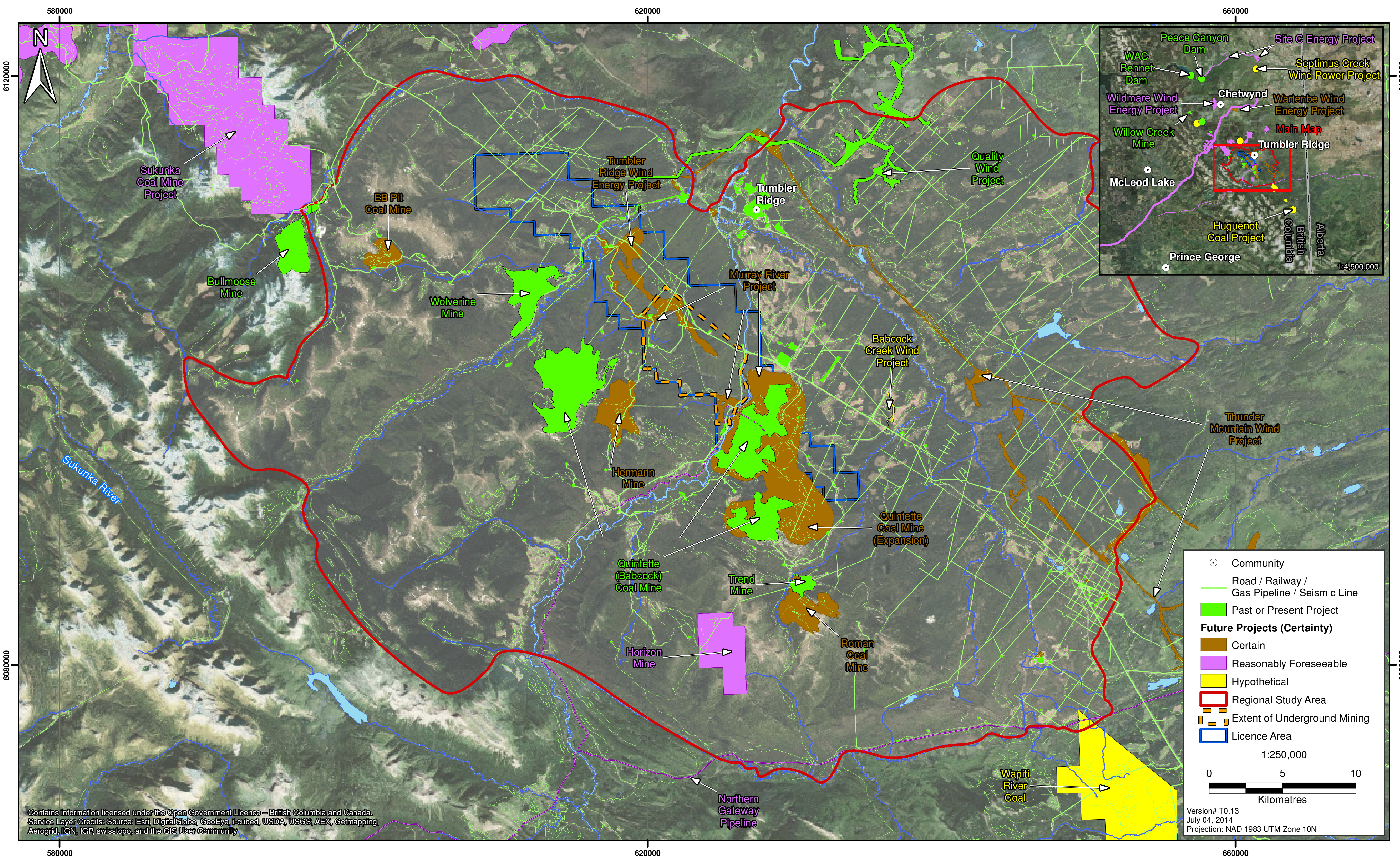


Table 10.11-1. Screening for Residual Effects to Interact Cumulatively with Effects of Other Human Actions on Terrain Stability

Murray River Coal Project Residual Effect	Potential for Cumulative Effect with Other Human Actions																		
	Time Frame																		
	Past						Present							Future					
	Historic		Recent											Certain					
	Hasler Coal Mine	Sukunka (Bullmoose) Mine	Bullmoose Mine	Dillon Coal Mine	Quintette (Babcock) Mine	Willow Creek Mine	Brule Mine	Trend Mine	Quality Wind Project	Peace Canyon Dam	Wolverine Mine (Perry Creek) and EB Pit	WAC Bennett Dam	HF Nodes Construction (gravel pit)	Hermann Mine	Quintette Mine	Roman Mine Project	Thunder Mountain Wind Park	Tumbler Ridge Wind Project	Wartenbe Wind Project
Terrain Stability	-	-	-	-	L	-	-	-	-	-	-	-	L	O	L	-	-	L	-

Murray River Coal Project Residual Effect	Potential for Cumulative Effect with Other Human Actions *(cont'd)*																			
	Time Frame *(cont'd)*																			
	Future *(cont'd)*																			
	Reasonably Foreseeable													Hypothetical						
	Echo Hill Mine	Coastal Gaslink Project	Horizon Mine	Meikle Wind Energy Project	Northern Gateway Pipeline	Rocky Creek Energy Project	Site C Clean Energy Project	Sukunka Coal Mine Project	Sundance Wind Project	Wildmare Wind Energy Project	Forestry and manu-facturing	Industrial roads, rail, pipelines, seismic lines, power lines	Transport (road and rail access and traffic)	Babcock Creek Wind Project	Belcourt Saxon Coal Project	Huguenot Mine	Moose Lake Wind Power	Septimus Creek Wind Power Project	Suska Mine	Wapiti River Coal Project
Terrain Stability	-	-	-	-	-	-	-	-	-	-	M	M	L	-	-	-	-	-	-	-

Notes:

-	*No spatial or temporal overlap.*
O	*Spatial and temporal overlap, but no interaction anticipated; no further consideration warranted.*
L	*Negligible to minor adverse effect expected; implementation of best practices, standard mitigation and management measures; no monitoring required; no further consideration warranted.*
M	*Potential moderate adverse effect requiring unique active management/monitoring/mitigation; warrants further consideration.*
H	*Key interaction resulting in potential significant major adverse effect or significant concern; warrants further consideration.*

Table 10.11-2. Summary of Residual Cumulative Effects

Valued Component	Murray River Activity	Other Human Action Activity	Description of Potential Cumulative Effect	Description of Mitigation Measure(s)	Description of Residual Cumulative Effect
Terrain Stability	Land subsidence, constructed slopes, storage areas, construction and use of roads, water crossings, soil disturbance.	Quintette (Babcock) Mine	Synergistic effects of terrain re-contouring, vegetation removal, and road construction on slope hydrology and stability.	It is assumed that present and future project proponents will: • follow soil and overburden management plans and follow best management practices; • take into consideration the goals and objectives outlined in the local LRMPs ; • avoid activities in areas classified as potentially unstable; • avoid or minimize the spatial and temporal extents of soil disturbance through adoption of appropriate project development design, strategic planning, and coordination of activities; • employ experienced, professional engineers to plan and oversee construction work; • monitor environmental impacts and the effectiveness of mitigation methods; • collaborate and implement data sharing agreements, including assessment of the effectiveness of mitigation and monitoring methodologies and actions taken to improve them.	Increased risk of terrain instability (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence and soil disturbance.
		HF Nodes Construction (gravel pit)	Synergistic effects of vegetation removal, and road construction on soil erosion.		
		Tumbler Ridge Wind Project	Synergistic effects of vegetation removal in the ROW, road/trail construction and subsidence on slope hydrology and stability.		
		Forestry and manufacturing	Synergistic effects of tree removal, skidding, trail construction, and subsidence on slope hydrology and stability, on fluvial processes and on soil erosion.		
		Industrial roads, rail, pipelines, seismic lines, power lines	Synergistic effects of vegetation removal in the ROW, road/trail construction and subsidence on soil erosion, slope hydrology and stability.		

Roads, especially those located on slopes, tend to affect terrain stability and soil erosion considerably (Swanson and Dyrness 1975). The ratio of the total length of roads within a given area (in km per km^2 or miles per square mile) is commonly used in the scientific literature to assess that effect. A threshold value of 0.28 km per km^2 was suggested by the U.S. Fish and Wildlife Service as the road density above which stream sedimentation is so high that it adversely affects fish populations in Oregon (US FWS 1998). Recommended road densities on unstable/steep slopes (e.g., slopes greater than 60%) should remain below 0.12 km/km^2 and in riparian areas below 0.16 km/km^2 (Porter et al. 2012). The current road density in the RSA is 0.79 km/km^2 and as such, it has already exceeded the recommended guidelines. The predicted road density resulting from the development of all current and future (certain and reasonably foreseeable) projects in the RSA is 0.81 km/km^2.

The predicted increase in the proportion of anthropogenically altered terrain is expected to decrease terrain stability within the RSA. Based on the review of the provided data, the predicted magnitude of the cumulative effects on terrain stability is assessed as medium. Since the intensity of human activity in the region is expected to gradually increase, the duration of the effects will extend continuously into far future at a regional scale. While the morphological changes associated with land development are usually irreversible, their effects on terrain stability are reversible in the long term. The resiliency of the affected land is likely dependant on the intensity of future development, and specifically the relationship between the stabilization of disturbed terrain vs. destabilization of the newly disturbed areas. The current existence of naturally unstable terrain and the projected 4.9% increase of the area of disturbed land in the RSA suggest that the resiliency of the receiving environment will be neutral.

Overall, the cumulative effects on terrain stability in the RSA are expected to be Not Significant (Moderate). The potential that the effects of land development will be manifested in decreased terrain stability is highly probable; however, due to a large number of interacting factors, the confidence in the predicted outcomes (e.g., magnitude and extent of the effects and resiliency of the environment) is low (Table 10.11-3).

10.12 EFFECTS ASSESSMENT CONCLUSIONS FOR TERRAIN STABILITY

It is expected that the development of the Murray River Project will affect terrain stability in the LSA. The main effects will result from soil disturbances associated with construction of Project infrastructure and with the mining subsidence predicted in the north-western section of the LSA.

Mitigation will involve the implementation of best management practices and soil and overburden management plans, employment of professional engineers to plan and oversee construction work, minimization of the spatial and temporal extents of soil disturbance, avoidance of the areas classified as potentially unstable, and introduction of programs to monitor environmental impacts and the effectiveness of mitigation methods. On the regional scale, mitigation efforts will also include consideration of the goals and objectives outlined in the local LRMPs as well as promotion of collaboration and implementation of data sharing agreements between various proponents.

Table 10.11-3. Characterization of Residual Cumulative Effects, Significance, Confidence and Likelihood on Terrain Stability

Cumulative Residual Effect	Residual Cumulative Effects Characterization Criteria							Significance of Adverse Residual Cumulative Effects	Likelihood and Confidence	
	Magnitude	Duration	Frequency	Geographic Extent	Reversibility	Resiliency	Context		Probability	Confidence
Increased risk of terrain instability (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence and soil disturbance.	Medium	Far Future	Continuous	Regional	Reversible long-term	Neutral	Neutral	Not Significant (Moderate)	High	Medium

Since practical mitigation options against subsidence are limited, it is expected that the underground coal extraction will be associated with changes in surface morphology and will generate horizontal tensions within the surficial mineral deposits. These phenomena will potentially affect terrain stability in the Subsidence Footprint. It is also expected that, despite the application of the best management practices and mitigation methods, the negative effects of Project development on terrain stability cannot be entirely eliminated.

The residual effects of Project development may include such geomorphological phenomena as mass movement of the surficial deposits, altered intensity of active fluvial processes and soil erosion. Most of these effects will be associated with subsidence and lateral stress on surficial geological strata induced by underground mining. Some will result from soil disturbances, especially during Project Construction and Decommissioning and Reclamation, and from salvage, storage, and re-distribution of soil. The expected magnitude of these effects is moderate, their temporal extent will last continuously into the far future, and their geographic extent will be manifested on a landscape scale. The effects will be reversible in the long term. It is assumed that most of the anticipated changes in the terrain stability will affect ecosystems that historically were characterized by some level of geohazard risk and thus are neutral or display limited sensitivity to potential of increased instability. Overall, it is expected that the residual effects of the Project on terrain stability will be Not Significant (Moderate).

Due to predominantly local extent of geomorphological processes, the accumulation of similar effects contributed by a number of past, current and future projects and activities within the RSA is expected to have mainly additive character. The predicted magnitude of the cumulative effects on terrain stability is assessed as medium. The effect duration will extend continuously into far future at a regional scale. The effects on terrain stability are reversible in the long term and the expected resiliency of the receiving environment will be neutral. Overall, the cumulative effects on terrain stability in the RSA are expected to be Not Significant (Moderate).

The potential that the effects of land development will be manifested in decreased terrain stability is highly probable, however, due to a large number of interacting factors, the confidence in the predicted outcomes (e.g., magnitude and extent of the effects and resiliency of the environment) is low (Table 10.12-1).

Table 10.12-1. Summary of Project and Cumulative Residual Effects, Mitigation, and Significance for Terrain Stability

Residual Effects	Project Phase	Mitigation Measures	Significance of Residual Effects	
			Project	Cumulative
Terrain Stability				
Increased risk of geohazards (mass movement of surficial materials, active fluvial processes, or soil erosion) resulting from subsidence and soil disturbance.	Construction, Operation, Closure and Reclamation	It is assumed that present and future project proponents will: • follow soil and overburden management plans and follow best management practices; • take into consideration the goals and objectives outlined in the local LRMPs; • avoid activities in areas classified as potentially unstable; • avoid or minimize the spatial and temporal extents of soil disturbance through adoption of appropriate project development design, strategic planning, and coordination of activities; • employ experienced, professional engineers to plan and oversee construction work; • monitor environmental impacts and the effectiveness of mitigation methods; and • collaborate and implement data sharing agreements, including assessment of the effectiveness of mitigation and monitoring methodologies and actions taken to improve them.	Not Significant (Moderate)	Not Significant (Moderate)

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