Appendix A2

Fluvial Geomorphology Assessment of Blairmore Creek and Gold Creek

Grassy Mountain Coal Project

Fluvial Geomorphology Assessment of Blairmore Creek and Gold Creek

December 22, 2016

Project No.: 638486

Prepared For:
Hatfield Consultants

SNC·LAVALIN

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Executive Summary

A baseline assessment was completed on Blairmore and Gold creeks using field data in support of an Instream Flow Assessment (IFA) for the Grassy Mountain Coal Project (the Project), proposed by Benga Mining Limited (Benga) a wholly owned subsidiary of Riversdale Resources Limited (Riversdale). The recent changes in land use were determined from an analysis of aerial photographs. Blairmore and Gold creeks were each divided into five (5) sections for analysis of the baseline geomorphology based on the locations where flow was predicted to change based on the current water management plan for the project. Analysis of sediment mobility was conducted at each section to assess predicted Project effects.

The majority of sediment in Blairmore Creek is organized in cascade-riffle pool and bedrock-step pool morphologies. The upper three sections are predominantly cascade-riffle pool, with the channel flowing through floodplain deposits typically 1 – 2 m thick, through relatively confined steep-sloped narrow valleys. Bank material is loose and non-cohesive, showing signs of erosion and some undercutting at all sites. The section is heavily influenced by Large Woody Debris (LWD) and large boulders that have become positioned within the channel and are controlling flow and sediment transport, by slowing velocities and allowing deposition, particularly in bars, and upstream of LWD. These boulders and LWD structures contribute to the overall stability of the system. Lower Blairmore Creek is predominantly bedrock controlled, and as such, is generally considered to be highly stable, with the exception that slope failures may cause instability by introducing sediment and LWD. Small-scale depositional zones were noted, particularly in pools and above bedrock waterfalls, where median grain sizes ranged from 25 to 95 mm. These finer sediments are likely flushed out during freshet, and deposited as flows wane following upland snowmelt. Large boulders were common in the channel. Reach gradients averaged 2.65% in Lower Blairmore Creek; however, knickpoints contributed to substantial discrete decreases in elevation along the bed. Banks are predominantly bedrock walls, and vegetation is generally more sparse than in upstream sections, particularly where steep slopes occur. No avulsions were observed on Blairmore Creek along the length of assessed channel.

The majority of sediment in Gold Creek is organized in riffle pool sequences. Cascade pool, step pool, and cascade-riffle pool morphologies are also common reach types in Gold Creek, where cascade and cascade-riffle structures are more prevalent in upper reaches of the mainstem, giving way to plane bed morphologies as the sub-dominant reach type. Riffle pool morphologies are generally less stable than step or cascade pool reach types because of the higher percentage of finer material that can be more easily mobilized. Evidence of instability was observed in the form of two ‘blowout’ zones where large volumes of fluvial material and LWD were deposited recently, causing channel bifurcations, avulsions, and are suspected to be responsible for disappearance of flow below the bed materials. Floodplain material cover is thin, and bank slopes are composed of bedrock or bedrock covered by thin alluvium.

Peak discharges are generally expected to decrease through the Project lifecycle (SRK, 2016a). The effects of decreased peak discharge were explored through analysis of sediment mobility. Channel beds are expected to become more stable through time due to decreases in peak flows. Gravel deposition will likely be enhanced in some locations but channel aggradation is not expected due to the nature of the steep channels. We therefore conclude that the physical habitat within Blairmore and Gold creeks are not anticipated to change due to water management throughout the mine life (construction, operations, reclamation, closure phases).

Low flows may increase in magnitude during the project lifecycle due to discharge of effluent from the mine site at discrete nodes. Stream channels are formed during peak discharges while sediment is mobile. Therefore, changes in low flows are not expected to alter the morphology of the stream channels due to the low shear stresses that result from these flows.

Table of Contents

Table of Contents (Cont'd)

In-Text Figures

Table of Contents (Cont'd)

In-Text Tables

Appendices

1 Introduction

Hatfield Consultants (Hatfield) are executing an Instream Flow Needs Assessment (IFA) for the Grassy Mountain Coal Project (the Project), proposed by Benga Mining Limited (Benga) a wholly owned subsidiary of Riversdale Resources Limited (Riversdale). The proposed Project site is located in the Crowsnest Pass region of southwest Alberta, 150 km south of Calgary, and 7 km north of the Town of Blairmore. As part of the IFA, Hatfield retained SNC-Lavalin Inc. (SNC-Lavalin) to conduct a baseline and effects assessment of the geomorphology of Blairmore Creek and Gold Creek, and their significant tributaries within the identified Local Study Area (LSA). The LSA is defined in Appendix A, Figure A-1.

Blairmore and Gold creeks are fish-bearing, containing isolated populations of Westslope Cutthroat Trout (WSCT). In 2009, WSCT populations were listed as threatened under the Government of Alberta's Wildlife Act, and in 2013 were listed as threatened under the Federal *Species at Risk Act* (SARA). In response to these designations, a joint federal-provincial panel was assembled to develop the Alberta Westslope Cutthroat Trout Recovery Plan (Alberta Westslope Trout Recovery Team, 2013; DFO, 2014). This plan identified four watercourses within the Project LSA, totalling a length of 16.5 km, as critical WSCT habitat containing a population that is, on average, 99% genetically pure. Three of these watercourses include almost 14 km in Gold Creek, and one is located in BCT04, a tributary to Blairmore Creek. A further 10 km's along the mainstem of Blairmore Creek were designated as containing near-pure WSCT populations. In November 2015, DFO issued a formal habitat protection order for designated areas in Gold Creek under SARA.

The geomorphic effects assessment explored potential changes in channel characteristics and geomorphic processes resulting from proposed flow changes throughout the lifetime of the mine and following closure, with an emphasis on changes that may impact aquatic and riparian habitat.

1.1 Project Overview

The proposed Project, an open pit mine operation at Grassy Mountain, will incorporate a Water Management Plan (WMP) that includes four sedimentation/release ponds, four surge ponds, and numerous contact water ditches. In addition, contact water will be routed into backfilled pits once they become available to create saturated zones suitable for attenuation of mine waste water.

As part of the Project's WMP, a series of ditches are proposed on the east slopes of the Blairmore Creek Watershed and the western slopes of the Gold Creek Watershed. These ditches will intercept groundwater and surface water and direct them towards sedimentation ponds. The collected water will then be discharged back into Blairmore Creek and Gold Creek at specific nodes to minimize impacts to flow, and in volumes proportional to the size of the catchment areas at each node.

As the mine footprint area increases over time, the undisturbed catchment area decreases and a reduction in peak flows in both Blairmore Creek and Gold Creek is predicted to occur. Estimates of temporal decreases in catchment area were obtained from SRK (2016a) and are listed in Table 1-1.

Table 1-1: Proposed decreases in combined catchment area for Blairmore Creek and Gold Creek to support project operations. Data provided by SRK (2016a).

Year	Undisturbed Catchment Area (km^2)	Diverted Catchment Area (km^2)
2010	114.2	0.0
2019	110.5	1.9
2020	105.3	6.0
2023	103.9	5.1
2026	103.3	3.3
2030	103.0	1.9
2033	102.5	0.9
2038	101.8	0.6
2041	101.8	0.6

The results from the flow analysis were provided to SNC-Lavalin by SRK (see memo in Appendix F). These flows were used to predict the range of possible Project effects on the geomorphic condition of the channels.

1.2 Project Location

The proposed Project is located in southwest Alberta, 7 km north of the town of Blairmore and approximately 150 km southwest of Calgary. The LSA for the geomorphological assessment is comprised of the adjacent watersheds of Blairmore and Gold creeks and is relatively aligned with the aquatic ecology and water quality LSA's. A map of the site, including the LSA boundary, is presented in Appendix A, Figure A-1.

The Project is situated on a ridge that divides the Blairmore Creek and Gold Creek Watersheds, with Blairmore Creek draining the west slopes and Gold Creek draining the east slopes.

Blairmore and Gold creeks are both third order streams that flow in a generally southward direction to join the Crowsnest River. The mainstem of Blairmore Creek flows approximately 12.1 km through a watershed covering an area of approximately 50 km^2. The mainstem of Gold Creek is approximately 15.4 km long and has a watershed area of approximately 60 km^2.

2 Scope of Work and Methodology

The objective of the fluvial geomorphology assessment is to provide a baseline description of Blairmore Creek and Gold Creek under their current hydrologic regimes and to assess the effects of the changes in hydrologic regimes expected due to alteration in flow from the proposed Project operations and corresponding WMP. The following scope of work was completed to meet these objectives:

1. Baseline geomorphic assessment including:
   a) Collection of field data to characterize baseline current conditions of the channels; and
   b) Land use change determined from aerial photograph analysis.
2. Geomorphic effects assessment including:
   a) Hydraulic analysis to determine thresholds of sediment mobility over the Project life.
3. This report, summarizing the field investigation, data analysis and providing a discussion of the results.

2.1 Baseline Assessment

The baseline assessment contains two main parts: analysis of the land use change in the LSA, and assessment of the existing (baseline) geomorphology of Blairmore and Gold creeks.

2.1.1 Baseline Assessment of Land Use Change Determined from Analysis of Aerial Photographs

Recent land use within the LSA was characterized through a time series analysis of three years of aerial photographs. The objective of this exercise was to characterize both the recent (1982 and 1996) and current (2015) condition of the watershed. Both recent and current land use were characterized within the LSA using a modification of standard land use classification methods (BC MoE, 1986). Alberta's Land-use Framework (SSRP, 2014) was developed as a tool for regional land use and resource planning for an area of 83,764 km^2. Recommended land use categories are less detailed than those suggested by the BC Ministry of Environment (MoE) (1986), as is suitable for their regional scale of analysis. The aim of land use change analysis within this assessment was to characterize recent and current condition of Blairmore Creek and Gold Creek Watersheds (total area assessed was 113.8 km^2). Therefore, preference was given to an approach that allowed for more detailed land use classification. Natural change in land cover was not differentiated (e.g., bare rock, glaciers). The definitions of assigned land use classes are provided in Table 2-1, below.

Table 2-1: Classes used to characterize land use within the LSA. Modified from BC MoE (1986).

Land Use	Code	Definition/Examples
Agricultural/Grazing	A000	Pasture or range
Unused, Former Dwelling Activities	B500	Land on which named activity is perceived to have taken place in the past but on which no activity is taking place at present
Unused, Former Manufacturing and Storage Activities	B700	Land on which named activity is perceived to have taken place in the past but on which no activity is taking place at present
Commercial Activities	C000	Land on which buying or selling merchandise or services occurs
Dwelling Activities	D000	Land where the primary activity is dwelling but does not include logging camps, extraction activity camps, or hunting lodges
Surface Extraction	E100	Areas of open pit mining of metals and coal and quarrying of stone and industrial minerals but not including on-site handling or processing
Pumping (Oil and Gas)	E310	Gas, oil, water, and well sites including equipment areas
Extraction Handling	E350	Land on which moving, crushing, washing, sorting and processing occurs. Includes extraction activity camp facilities
Logging	F110	Active logging area. Replanting not evident
Forest Management (Replanting)	F170	Planted or naturally regenerating forests
Transportation	H100	Transporting activities including roads, rail, pipeline, electricity, and other
No Perceived Activity	N000	Land on which no activity, either present or past, is evident. This does not imply that no activity is taking or has taken place, only that no activity is evident
Recreational	R000	Land dependent recreational activities

Metadata for aerial photographs used in the analysis are presented in Table 2-2, below. Polygons were mapped in 3D in Summit® and ArcGIS™ after stereo models for the aerial photographs were produced. An error in the stereo model made analysis unfeasible for 1982 and 1996 for a small area (1.74 km^2) in the southeastern-most region of the LSA.

Land use was classified for each year at a 1:20,000 scale. If evidence of previous land disturbance was later absent from the landscape, the area was classified to have 'No Perceived Activity'. Classifications for all years were combined into two classes, perceived activity and no perceived activity. Using the combined classes, both area of change in land use and total area of land use over the period of analysis were calculated.

Table 2-2: Metadata for aerial photographs used in land use mapping.

Date (Day/Month/Year)	Roll Number	Flightline	Frame	Nominal Scale/ Pixel Resolution
17/09/1982	2607	8	128, 130,132	1:60,000
03/09/1982		9	150,152, 154	
09/08/1996	4708	3	82, 84, 86, 88	
		4	116, 118, 120, 122	
19/08/2015	16-0029	13	34 – 42	25 cm
		14	34 – 45	
		15	24 – 39	
		17	29 – 45	

2.2 Baseline Assessment of Fluvial Geomorphology

2.2.1 Field Data Collection

The assessment of the baseline geomorphology of Blairmore and Gold creeks was informed by field data collected within both watersheds on two separate site visits: May 14 – 18, 2016, and July 25 - 27, 2016. Both watercourses were assessed by walking continuous lengths of the channels (12.6 km along Blairmore Creek from 682925E, 5509923N to 683626E, 5499965N; and 10.1 km along Gold Creek from 687515E, 5509577N to 688600E, 5501125N). In total, 37 sites were assessed on Blairmore Creek, and 44 sites on Gold Creek, as well as 3 sites on Caudron Creek, and two sites on tributaries that feed Gold Creek (GCT10 and GCT11). Spot points were recorded with a handheld GPS at sediment source, water source (tributaries and groundwater), and avulsion locations along the reach. A location map of the assessment sites is presented in Appendix A, Figure A-2.

The upper limit of assessment for both channels was determined by the upper extent of identified WSCT critical habitat (greater than 90% pure) in Gold Creek, and near pure WSCT population (95% to 99% pure) in Blairmore Creek (DFO, 2013). The reaches were further divided based on geographic features or major confluences, defined in Table 2-3.

Table 2-3: Labels and justifications for the divisions of Blairmore Creek and Gold Creek assessment sections.

Creek	Section	Relative Position	Lower Boundary
Blairmore	B1	Upper Blairmore	Confluence with BCT07; upper limit of project footprint
	B2	Middle Blairmore	Confluence of BCT01; Lower limit of near pure WCCT habitat
	B3	Lower Blairmore	Highway 3
Gold	G1	Upper Gold	Confluence with Caudron Creek
	G2	Upper-Middle Gold	Confluence with GCT07
	G3	Lower-Middle Gold	Confluence with Morin Creek
	G4	Lower Gold	Confluence with GCT04

The field assessment methodology was designed to conform to guidelines for collection and analysis of fish habitat data for the purpose of assessing impacts associated with alteration of flow regimes and described in detail in Lewis et al. (2004) and Hatfield et al. (2007). These guidelines have been developed based on methodologies recommended by the BC MoE and are intended to comply with the requirements of the *Fisheries Act*. These documents provide specific guidelines for requirements of a geomorphological assessment tailored specifically to compliment a fish habitat assessment. The Government of Alberta Water Act Codes of Practice does not provide similar guidelines for geomorphologic assessment of a stream.

The method of data collection in the field was adapted from the *Forest Practices Code of British Columbia's Channel Assessment Procedure Guidebook* (BC MoF, 1996). The procedures are designed for small- and intermediate-sized channels that are too small to be assessed using aerial photographs. No known Alberta-specific guidelines were available at the time of the analysis.

The following data were collected at each assessment site:

1. Reach type:

Reach types were defined by morphological characteristics of deposited sediment in Blairmore Creek and Gold Creek as per Church (1992). Based on this classification system, both creeks are classified as small mountain streams along the length assessed. In small mountain streams, sediment is derived predominantly from episodic external sediment inputs (e.g., from slope failure and bank collapse) and, to a lesser degree, more regular processes such as surface erosion (Benda & Dunne, 1987). Much of this sediment moves intermittently as bedload. Large Woody Debris (LWD) is common in these streams, and together with coarse material, exerts substantial control on channel morphology relative to hydraulic conditions (Hassan et al., 2005). These reaches typically lack sufficient stream power to move accumulations of coarser rocks and LWD that accumulate in the channel. The resulting sediment arrangements typically take on the pattern of a comparatively shallow, steeper, faster-flowing sub-reach (step, cascade, or riffle), followed by a deeper, flatter, slower-flowing pool sub-reach.

The reach types identified in Blairmore Creek and Gold Creek are described subsequently.

a. Step-pool morphology:

Individual stones form the dominant roughness elements in the channel, as individual stones or stone lines spanning a portion or the entire width of the channel. These form characteristic ‘steps’ between pools. The beds of these channels are typically stable due to the interlocking of the largest stones. These large stones may move, often as a result of large flood events or debris flows, or by undermining due to downstream scour. This sediment pattern typically occurs in steeper channel gradients.

b. Cascade-pool and riffle-pool morphology:

Characterized by sections of gentle gradient with deep pools, slow moving water and finer sediments, between steeper, shallower stretches with coarser sediments. Cascade- and riffle-pool morphologies are similar in structure; however, cascades contain a sequence of emergent boulders that span the channel, often diagonal to flow. Riffle morphologies tend to have finer sediments (gravels and cobbles) and individual stones typically do not break the water surface at bankfull flow. These morphologies typically develop bars in areas of flow divergence.

c. Bedrock morphology:

These channels are found in very steep reaches, and/or in areas of sediment starvation. Flow in these reaches is controlled by rock jointing and bedding. A reach is considered to be a bedrock channel when >50% of the boundary is exposed bedrock, or one that has a small veneer of sediment that is readily mobilized at high flows, and where the underlying bedrock still dominates the hydraulics and sediment movement (Tinkler & Wohl, 1998).

d. Plane bed morphology:

These reaches are relatively featureless stretches lacking roughness elements (e.g., large rocks or assemblages of finer material that form a riffle). Plane beds tend to form in relatively straight channel reaches. Bed sediment is typically mobile at high flows.

The classification system presents the distinct types of sediment morphologies; however, natural systems are often not so distinct. Blairmore Creek and Gold Creek are dynamic systems and because of this, reaches typically extended for a couple of sequences before a different morphology took over. For this reason, reaches were classified based on the most common reach types (e.g., cascade-riffle pool, bedrock-step pool, etc.).

2. Planimetric pattern:

This describes overall sinuosity of a reach, and provides information on the lateral stability of the channel. Church (1992) provides a continuum of planforms of increasing sinuosity, which include: straight, irregular wandering, irregular meandering, regular meandering, and tortuous meandering. Reaches containing multiple channels were documented during the field assessment, and were assessed individually for their planimetric morphology.

3. Median (D50) and ninetieth percentile (D90) grain size on the channel bed.

4. Channel stability:

An overall rating of the ability of a reach to resist change is assessed based on evidence of recent changes in deposition, erosion, and lateral stability. These include a stable bed, bed aggradation, degradation, entrenchment, and avulsion.

5. Bank sediment and presence of erosion:

An assessment of stability is derived from determination of basic texture (coarse or cohesive) and degree of compaction. Any evidence of bank erosion was documented, and, if applicable, the extent of undercutting was measured.

6. Vegetation presence and type:

A record of what type of vegetation was present on the banks (i.e., trees, shrubs, and/or grasses).

7. Large woody debris:

LWD in the channel can be a significant control on channel morphology in small- and intermediate-sized streams. Both the presence of LWD and degree of control it exerts on the channel were documented.

8. Sediment source:

Channel bed sediment source was deduced based on angularity, proximity to a colluvial source, similarity to bank sediments, and other available indicators.

9. Sediment storage:

This metric assesses depositional patterns of sediment that are likely mobile during peak flows, and deposited as freshet wanes. Common depositional patterns include deposition in lateral or medial bars, in the stoss (upstream side) and lee (downstream side) of boulders or other large obstructions within the channel.

10. Bedform spacing and channel gradient:

The distance between repeating bed features were measured for each assessment site. Measurements were taken from the water surface at the crest of the bedform (e.g., riffle crest, step-pool crest, etc.) to the water surface at the crest of the next bedform downstream. The slope of the channel was measured between bedforms.

11. Depth and width at bankfull discharge:

Bankfull level was determined at each site based on field indicators including the bank vegetation line or bar height to measure bankfull depth and width.

Additional metrics used included relative roughness and width to depth ratio. Relative roughness gives the ratio of water depth to particle size on the bed, and gives a relative indication of the strength of the frictional force exerted by bed particles on flow. The width-to-depth ratio provides a metric of channel shape that allows for relative comparisons between sites.

The measured and calculated metrics for each assessment site is provided in Appendix B, Table B-1.

2.3 Geomorphic Effects Assessment

The predicted changes in channel morphology associated with the proposed Project were assessed with regard to the impact on habitat features and lifecycles of fish species present in Blairmore Creek and Gold Creek.

Stream geomorphology results from the interaction between flow, sediment, and channel form, and, as such, alteration of one of these components can impact the other components and result in substantial changes to the characteristics of the reach. The proposed Project WMP will not involve direct extraction from the creeks, rather tributary and groundwater flow from the slopes will be diverted and reintroduced at nodes in Blairmore Creek (SRK, 2016b).

Reductions in peak flow, as predicted by SRK (2016a), have the potential to alter sediment transport within the channel. Corresponding changes in the current patterns of deposition and erosion may lead to alteration in the bed morphology (reach type) observed at each site during the field visits. In addition, the rate, volume and caliber of sediment delivered to Blairmore Creek and Gold Creek via hillslope flows (including surface and groundwater flows) may be altered.

2.3.1 Sediment Mobility Threshold Analysis

An analysis of sediment mobility was conducted to predict changes in bed morphology due to the predicted changes in flow. The analysis investigated how the threshold of motion of bed sediment may change as flows decrease over the lifecycle of the Project. The methodology estimates the median size of sediment that can be entrained for the predicted flows at discrete cross-sections. In general, entrainment, transport, and deposition of sediment along a river bed are functions of the shear stress exerted by flow on the bed sediments and the sediment size and distribution. To adequately analyze sediment mobility thresholds, both creeks were divided into sections based on the locations of the proposed flow diversion nodes. This resulted in five (5) sections on Blairmore Creek and four (4) sections on Gold Creek. Reach types and lengths within each of these sections were highly variable along both Blairmore Creek and Gold Creek, and so representative reaches were chosen based on the dominant morphologies present. Shear stresses for predicted flows were calculated from cross-sectional data provided by Hatfield, using slope and bed roughness values from nearby sites assessed by SNC-Lavalin. Data collection by Hatfield and SNC-Lavalin were carried out independently, and during separate field visits, and as a result, the site locations do not necessarily correspond exactly, and the site labeling systems used are different. Data from sites within reaches with congruous reach characteristics were used as appropriate.

Shear stresses were calculated using the U.S. Federal Highways Administration Hydraulic Toolbox (Version 4.20; http://www.fhwa.dot.gov/engineering/hydraulics/software/toolbox404.cfm). Input values used to calculate bed shear stress are cross-sectional geometry, bed slope of the reach, and discharge (2-year and 100-year). The timeline and magnitudes of changes in discharge were derived from data provided by SRK Consultants (see Appendix F-2).

The D_{50} entrained is calculated from the bed shear stress (τ_o) estimates using the Shield's Relation:

$$D_{50} = \frac{\tau_0}{g(\rho_s - \rho_f)\theta}$$

Where, D_{50} is the median grain size that can be entrained for a given shear stress (τ_o), g is acceleration due to the force of gravity (9.807 m/s^2), and ρ_s and ρ_f are the density of sediment (2650 kg/m^3) and the density of water (1000 kg/m^3), respectively. θ is the Shields Number, which is a ratio that describes the hydrodynamic forces acting on the bed and the submerged weight of the particle. A range of θ is cited in the literature that reflects factors such as sediment packing, sediment sorting, sediment hiding, etc. Since the value of θ in not known for each site, lower and upper values of θ found in the literature were applied to provide a range of sediment size likely to be entrained for each discharge.

The stability analysis was conducted for a large flow, estimated by the 100-year discharge, and the bankfull flow, estimated by the 2-year discharge. The D_{50} on the bed was then compared to the range in sediment entrainment values determined through time to assess incremental changes in channel bed stability.

3 Baseline Fluvial Geomorphology

3.1 Watershed Characteristics

The Project footprint is situated in a foreland thrust and fold belt within the Foreland Ranges of the Rocky Mountains, between the High Rock Range and the Livingstone Range. The general lithology within the LSA is interbedded fine-grained dolomitic mudstone, shale, siltstone, and sandy limestone (Cooley et al., 2007). The LSA is nestled amid rounded mountains with peak elevations ranging between 1,250 masl to the 2, 514 masl.

A review of regional surficial geology maps shows that surficial material along the channel is predominantly till, with patches of colluvium and exposed bedrock. Unconsolidated materials are generally less than 2 m thick. Closer to its confluence with the Crowsnest River, Blairmore Creek flows through intermittent deposits of finer glaciofluvial material, artificial till and legacy coal mine coal fines (Jackson & Leboe, 1998). Gold Creek flows through sedimentary deposits similar to those within the floodplain of Blairmore Creek, alternating between till and glaciofluvial deposits, with areas of exposed bedrock (Jackson & Leboe, 1998).

3.2 Historical Land Use Changes

For each year of analysis, the total area of land use class is presented in Table 3-1 below, and in Appendix C, Figures C-1 to C-3.

Table 3-1: Area of land use class for each year analyzed.

Land Use	Code	Total Area 1982		Total Area 1996		Total Area 2015	
		km^2	%	km^2	%	km^2	%
Agricultural/Grazing	A000	0.66	0.59	0.93	0.83	0.93	0.81
Unused, Former Dwelling Activities	B500	0.13	0.12	0.24	0.22	0.24	0.21
Unused, Former Manufacturing and Storage Activities	B700	0.60	0.54	0.13	0.12	0.13	0.11
Commercial Activities	C000	0.03	0.03	0.09	0.08	0.20	0.18
Dwelling Activities	D000	0.04	0.04	0.60	0.54	1.40	1.23
Surface Extraction	E100	2.14	1.91	1.96	1.75	1.96	1.72
Pumping (Oil and Gas)	E310	0.05	0.05	0.06	0.05	0.08	0.07
Extraction Handling	E350	1.46	1.30	1.30	1.16	1.30	1.14
Logging	F110	2.85	2.54	1.61	1.44	2.10	1.84
Forest Management (Replanting)	F170	1.07	0.96	8.08	7.21	9.83	8.64
Transportation	H100	1.15	1.03	1.48	1.32	1.69	1.49
No Perceived Activity	N000	101.56	90.66	94.90	84.71	93.26	81.97
Recreational	R000	0.29	0.26	0.64	0.57	0.64	0.57

Change in land cover over the two periods of analysis is presented in Table 3-2, below, and in Appendix C, Figures C-4 and C-5.

Table 3-2: Change in land cover over two periods of analysis: 1982 – 1996; and, 1996 – 2015.

Time Period	Area of Increase in 'Perceived Activity' (km^2)	Area of No Change (km^2)	Area of Decrease in 'Perceived Activity' (km^2)
1982 – 1996	8.09	104.34	1.33
1996 – 2015	2.49	111.08	0.20

The total area within the LSA classified to have perceived activity in any of the three years analyzed was 22.0 km^2. This represents 19.3% of the total area of the LSA (113.8 km^2). Total area is presented in Appendix C, Map C-6. Within the LSA, this activity is concentrated in valleys and on Grassy Mountain Ridge, an area of historical mining operations. It is assumed that areas of historic landscape disturbance may not have been captured due to vegetation regrowth and inability to distinguish evidence of past activity at the scale available through aerial photograph analysis.

3.3 Channel Assessment

A table containing the data collected during the field assessment of Blairmore and Gold creeks is presented in Appendix B. Blairmore and Gold creeks were each divided into five (5) sections for analysis of the baseline geomorphology based on the locations of effluent discharge nodes. The locations of these nodes and channel assessment sites are shown in Appendix A, Figure A-2. Maps showing the distribution of the reach types are presented in Appendix D, Figure D-1 (Blairmore Creek) and Figure D-2 (Gold Creek). Photos of characteristic reaches are provided in Appendix E.

3.3.1 Blairmore Creek

Blairmore Creek remains a small to intermediate stream for its entire length before flowing into the Crowsnest River. Figure 3-1 shows the percent distribution of each reach type in Blairmore Creek based on total channel length. Overall, the majority of sediment in Blairmore Creek is organized in cascade-riffle pool and bedrock-step pool morphologies. The upper three sections are predominantly cascade-riffle pool, with the channel flowing through floodplain deposits typically 1 to 2 m thick, through relatively confined steep-sloped narrow valleys. Bank material is loose and non-cohesive, showing signs of erosion and some undercutting at all sites. The section is heavily influenced by LWD and large boulders within the channel that control flow and sediment transport by slowing velocities and allowing deposition, particularly in bars, and upstream of LWD. These boulders and LWD structures contribute to the overall stability of the system.

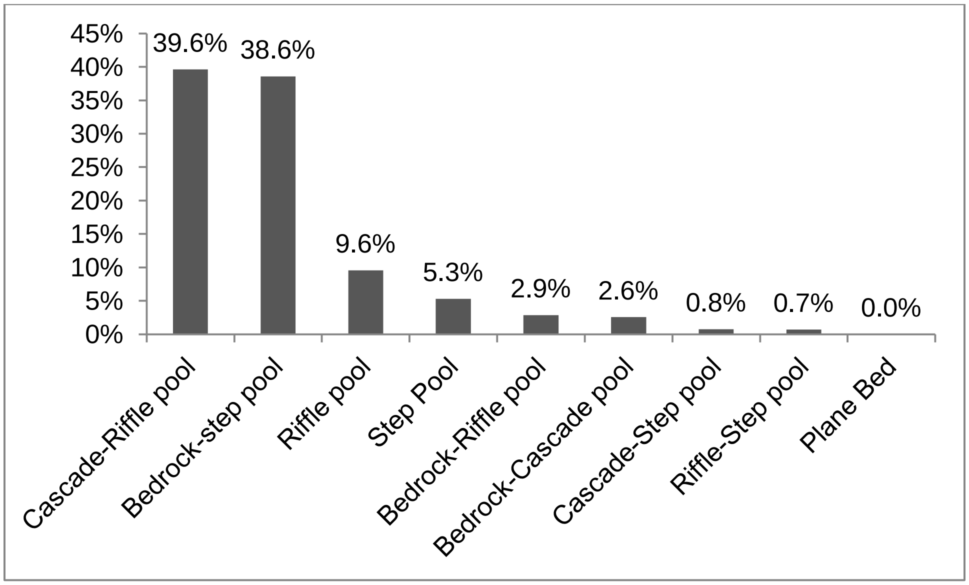

Figure 3-1: Distribution of reach type in Blairmore Creek based on total channel length.

Lower Blairmore Creek is predominantly bedrock controlled, and as such, is generally considered highly stable, with the exception that slope failures may cause instability by introducing large amounts of sediment and potentially large woody debris. Small-scale depositional zones were noted, particularly in pools and above bedrock waterfalls, where median grain sizes ranged from 25 to 95 mm. These finer sediments are likely flushed out during freshet, and deposited as flows wane following upland snowmelt. Large boulders were common in the channel, likely sourced from the surrounding slopes or high flow events.

Reach gradients averaged 2.65% in Lower Blairmore Creek; however, knickpoints contributed to substantial discrete decreases in bed elevation. Banks are predominantly bedrock walls, and vegetation is generally more sparse than in upstream sections, particularly where slopes were steep. No avulsions were observed on Blairmore Creek along the length of assessed channel.

3.3.1.1 Blairmore Creek: Confluence of BCT-10 and Blairmore Creek to BC-013

This section of Blairmore Creek has the largest number of reach types per length of section. The reaches, their lengths, and associated floodplain features and processes observed are presented in Table 3-3. The majority (51.8%) of Upper Blairmore Creek has a cascade-riffle pool morphology. Of the six bifurcations noted in this section, four occurred in cascade-riffle pool reaches. These reaches also contain all the LWD jams observed in this section. Channel-spanning logs form forced step-pools that control local sediment mobility. Of the four flow inputs (Tributaries BCT09, BCT08, and two smaller, unnamed tributaries), three are located just upstream of observed changes in reach type. The confluence of BCT-09 marks the transition from bedrock-step pool to riffle pool, suggesting that the tributary has delivered finer sediments to the channel. A transition from riffle pool to cascade-riffle pool occurs where BCT-08 joins Blairmore Creek; however, the median grain sizes measured in each of the reaches remains the same (D_{50} = 30 mm). As such, and given the small size of the contributing watershed, BCT-08 is not considered a significant source of sediment to the mainstem. No other substantial sites of sediment input were observed in the section.

Table 3-3: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between the upstream study limit and Node BC-013 in Blairmore Creek.

Reach Type	Length (m)	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Riffle pool	49.81	-	-	-	-	-	
Cascade-Riffle pool	212.73	-	1	1	-	-	
Riffle pool	54.81	-	1	-	-	-	
Cascade-Riffle pool	321.21	-	1	2	-	-	
Bedrock-Step pool	349.1	-	1	-	1	1	Includes confluence with BCT-09 (potential source of sediment)
Riffle pool	173.57	-	-	1	1	-	Includes confluence with BCT-08
Cascade-Riffle pool	334.02	-	2	-	2	-	Includes confluence with unnamed tributaries
Riffle pool	387.27	-	-	-	-	-	
Cascade-Riffle pool	221.38	-	-	-	-	-	
TOTAL	**2103.9**	**-**	**6**	**4**	**4**	**1**	

The channel typically flows through a narrow floodplain that is controlled on one or both sides by steep slopes or bedrock and is wide enough to allow for minor channel sinuosity. The average width-to-depth ratio of the assessment sites is 7.8, with bankfull widths ranging from 3.6 to 7.3 m, and bankfull depth at the thalweg between 0.5 and 0.9 m. The beds themselves are composed of predominantly gravels (D_{50} from 15 to 40 mm) but boulders are typically present and contribute as significant roughness elements in the channel in cascade-riffle pool and bedrock-step pool reaches. Average slope of the section is 3.1%, where the larger decreases in elevation are generally accommodated by drops created below step pools and LWD obstructions, and gentler slope decreases occur at riffles and pools.

3.3.1.2 Blairmore Creek: Nodes BC-013 to BC-07

This section is similarly dominated by cascade-riffle pool morphology (67.4% by length), but in general, has a higher presence of coarse-grain features such as step pools and cascades compared to the upstream section. The reaches, their lengths, and associated floodplain features and processes observed are presented in Table 3-4. One channel bifurcation occurs in the downstream portion of the lower cascade-riffle sequence in this section, but has not triggered any obvious change on the overall downstream reach type. LWD jams are located where the channel transitions from bedrock-cascade pool to cascade-riffle pool, and from cascade-riffle pool to riffle-step pool. Tributaries BCT-07 and BCT-06 both join Blairmore Creek from the left (east) slope, and are the only contributing surface flow observed in this section. The reach type changes from bedrock-cascade pool to cascade-riffle pool, median grain size decreases from 40 to 15 mm, and bedrock is no longer exposed at the channel bed. These observations suggest the bed is adjusting to sediment input from the tributaries. A landslide scar was observed 60 m upstream of the confluence of BCT-07, and appeared to contribute appreciable amounts of fine sediments to the channel. No significant change in reach type was observed downstream of the confluence of BCT-06.

Table 3-4: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes BC-013 and BC-07BC-07 in Blairmore Creek.

Reach Type	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Cascade-Riffle pool	101.64	-	-	1	-	-	-
Bedrock-Cascade pool	322.59	-	-	-	1	1	Includes confluence with BCT-07 (possible sediment input); landslide scar
Cascade-Riffle pool	294.06	-	-	-	-	-	-
Riffle-Step pool	89.44	-	-	1		-	-
Cascade-Riffle pool	674.24	-	1		1	-	Includes confluence with BCT-06
Step pool	104.51	-	-	-	-	-	-
TOTAL	**1586.48**		**1**	**2**	**2**	**1**	

The channel continues to flow through narrow valleys with narrow floodplain widths, although planimetric patterns in this section show the most variability, with a straight reach in the upper cascade-riffle reach, tortuous meandering in the riffle-step reach, and low sinuosity meanders in between. The average width-to-depth ratio is 10.7, with a higher variability of measured bankfull depths compared to the upper section. Bankfull channel widths range from 4.0 to 9.4 m, while bankfull depths range from 0.3 to 1.3 m. Average measured slope for the section is 3.7% and, similar to the upstream section, the majority of the decrease in elevation along the channel is in the drops following stone lines and cascades. The median grain size on the bed is consistently gravel at each site assessed in this section with measured values from 15 to 45 mm. Boulders ranging in size from 360 to 520 mm were abundant.

3.3.1.3 Blairmore Creek: Nodes BC-07 to BC-06

Cascade-riffle pool reaches are most prevalent in this section (59.8%), alternating with step pool reaches (29.7%) and one riffle pool reach. Table 3-5 provides individual reach lengths as well as reach features that may affect the channel morphology. Four channel bifurcations were observed, with one large one in the upper reach located at the transition between the step pool and cascade-riffle pool reaches, one located within the middle cascade-riffle reach, and one just below the transition between the lower riffle pool and cascade-riffle pool reaches. Flow enters the channel at the upstream node (BC-07) where the left-slope tributary BCT-05 enters Blairmore Creek. Change in the bed composition was not observed downstream of the confluence of BCT-05. Downstream flow inputs include two ground seeps, one in the upper cascade-riffle, and one in the middle cascade-riffle. A debris flow deposit was observed in the upper cascade-riffle reach, contributing slope materials to the channel.

Table 3-5: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes BC-07 and BC-06 in Blairmore Creek.

Reach Type	Length (m)	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Step pool	150.63	-	1	-	1	-	Includes confluence with BCT-05
Cascade-Riffle pool	575.01	-	-	1	1	1	Groundwater seep; debris flow deposit
Step pool	521.16	-	-	-	-	-	
Cascade-Riffle pool	506.61	-	1	2	1	-	Groundwater seep
Riffle pool	237.26	-	-	-	-	-	
Cascade-Riffle pool	271.1	-	2	2	-	-	
TOTAL	**2261.77**		**4**	**5**	**3**	**1**	

The floodplain is generally wider in this section compared to upstream sections, but is confined by steep valley walls on both sides. Bankfull width (ranging from 5.9 to 11.8 m) and bankfull depth (ranging from 0.5 to 1.3 m) increase from the upstream section, resulting in a slightly lower average width-to-depth ratio of 9.2. The average measured slope for the section is 2.6%; however, a narrower range of reach slope values were measured in this section. Median grain size was relatively consistent, with the bed composed of predominantly gravels with D_{50} from 15 to 60 mm. Cascades and steps are composed of boulders averaging 410 mm, and measuring up to 770 mm.

3.3.1.4 Blairmore Creek: Nodes BC-06 to BC-03

The dominant reach type shifts in this section compared to the upstream section, with 43.8% of the length of the channel being bedrock-step pool. Cascade-riffle pool morphology is still prevalent, covering 30.2% of the bed with the remaining bed lengths displaying bedrock-riffle pool (20.6%) and cascade-step pool (5.5%) sequences. Table 3-6 provides reach length and important features. A bifurcation was identified at the upstream end of the section, where Tributary BCT-04 enters the main channel flow. A second bifurcation occurs downstream at the transition between bedrock-step pool and bedrock-riffle pool. A large LWD obstruction, extending approximately 90 m, is present upstream of the transition from cascade-riffle pool to bedrock-riffle pool. A small unnamed tributary channel also enters Blairmore Creek at the downstream end of the log jam. Two other small unnamed tributaries were identified in this section: Tributary BCT-03 enters Blairmore Creek from the right (west slope), and BCT-02 from the left (east) slope. No changes in the channel were observed downstream of the confluences with BCT-04 and BCT-03. Downstream of the confluence of BCT-02, the channel morphology transitions from bedrock-step pool to cascade-riffle pool. The median grain size increases between these reach types, where a D_{50} of 30 mm was observed upstream, and a D_{50} of 110 mm was observed downstream. A decrease in slope was measured between the two reaches, and the change in morphology may be a result of decreased flow competence associated with the slope decrease. A bank failure was observed on the right slope near the transition of these reaches, which may also contribute to the change in reach type.

Table 3-6: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes BC-06 and BC-03 in Blairmore Creek.

Reach Type	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Cascade-Riffle pool	346.51	-	1	1	2	-	Includes confluence with BCT-04 and BCT-03
Bedrock-Riffle pool	364.14	-	1		1	-	Includes confluence with an unnamed tributary
Bedrock-Step pool	232.03	-	-	-	-	-	
Cascade-Step pool	97.05	-	-	-	-	-	
Bedrock-Step pool	543.97	-	-	-	1	1	Includes confluence with BCT-02; bank failure
Cascade-Riffle pool	188.11	-	-	-	-	-	
TOTAL	**1771.81**		**2**	**1**	**4**	**1**	

This section of Blairmore Creek is controlled by bedrock, and the channel is confined both vertically and laterally by steep bedrock slopes. The average width-to-depth ratio is similar to previous sections (10.2) with bankfull widths and depths generally lower. Bankfull widths range from 4.3 to 8.9 m, and bankfull depths range from 0.5 to 1.0 m. The average slope for the reach is 3.1%. Decreases in elevation are largely the result of drops in bed elevation where bedrock faulting has occurred. Finer sediments are collected in thin depositional layers in pools below these elevation drops, with median grain sizes (D_{50}) ranging from 20 to 120 mm. Boulders are common, and single boulder may take up the majority of the cross-sectional area in some reaches.

3.3.1.5 Blairmore Creek: Nodes BC-03 to BC-01

Bedrock dominates the bed and banks in the lower most section of Blairmore Creek with 74.1% of the length of the channel covered with bedrock-step pool morphology. The remaining channel length is cascade-riffle pool (19.6%) and riffle pool (6.3%) sequences. Refer to Table 3-7 for reach lengths and important features. Small channel bifurcations are present in the mid-section cascade-riffle pool, with the lower bifurcation associated with the presence of a large woody debris jam located at the upstream end of the transition to a bedrock-step pool reach. A large woody debris jam was observed at the confluence of Tributary BCT-01, entering Blairmore Creek from the left (east) slope. Two more large woody debris jams are located in the downstream portion of the lower bedrock-step pool sequence where it transitions into a cascade-riffle pool before joining the Crowsnest River. A dry tributary channel was observed in the upper reach of the section, approximately 525 m downstream from Node BC-03. In the lower bedrock-step pool reach, one small unnamed tributary, and one ground seep were noted. No changes in bed morphology were noted at or downstream of the flow inputs observed in this section.

The morphology in this section is similar to the upstream section; however, the average width-to-depth ratio is 14.3, indicating the bankfull widths are wider compared to depths. Measured bankfull widths range from 6.3 to 9.7 m, and bankfull depths range from 0.5 to 0.8 m. Average slope is 2.8%. Median grain size (D_{50}) in the pool deposits and riffles ranges from 25 to 95 mm, and the largest boulder in the section is 730mm.

Table 3-7: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes BC-03 and BC-01 in Blairmore Creek.

Reach Type	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Bedrock-Step pool	1263.96	-	-	-	1	-	Unnamed tributary
Cascade-Riffle pool	347.65	-	2	-	-	-	
Bedrock-Step pool	291.85	-	-	1	-	-	
Riffle pool	308.59	-	-	1	1	-	BCT-01
Bedrock-Step pool	1504.26	-	-	1	2	2	Unnamed tributary, groundwater seep.
Cascade-Riffle pool	511.41	-	-	1	-	-	
Bedrock-Step pool	590.9	-	-	-	-	-	
Cascade-Riffle pool	105.73	-	-	-	-	-	
TOTAL	**4924.35**		**2**	**4**	**4**	**2**	

3.3.2 Gold Creek

Gold Creek remains a small to intermediate stream for its entire length before flowing into the Crowsnest River. Figure 3-2 shows the percent distribution of each reach type based on length. Overall, the majority of sediment in Gold Creek is organized in riffle pool sequences. Cascade pool, step pool, and cascade-riffle pool morphologies are also common reach types in Gold Creek, where cascade and cascade-riffle structures are more prevalent in upper reaches of the mainstem, giving way to plane bed morphologies as the sub-dominant reach type downstream.

Floodplain alluvium is thin, and bank slopes are in large part exposed or thinly veiled bedrock, thus bedrock does exert control for the majority of the creek, at its strongest in the three small bedrock controlled reaches, and at its weakest, providing floodplain confinement through steeply rising valley walls. However, bedrock control in Gold Creek is not as significant as it is in Blairmore Creek.

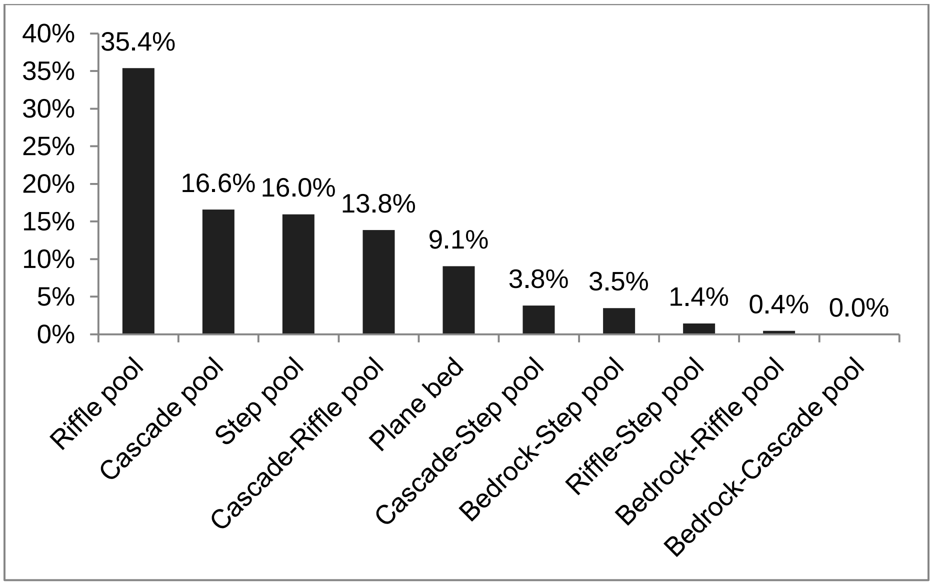

Figure 3-2: Distribution of reach type in Gold Creek based on total channel length.

Riffle pool morphologies are generally less stable than step or cascade pool reach types owing to a higher percentage of finer material that can be more easily mobilized. Evidence of instability was observed in the form of two 'blowout' zones where large volumes of fluvial material and large woody debris were deposited recently, causing channel bifurcations, avulsions, and disappearance of flow below the bed materials.

A higher proportion of the banks were observed to be composed of soft cohesive materials, making them more resistant to stream erosion than non-cohesive deposits. However, bank erosion and undercutting was still observed at nearly all assessment sites.

3.3.2.1 Gold Creek: Nodes GC-13 to GC-10

Upper Gold Creek is composed of a series of many short reaches. The upper section of the Gold Creek mainstem displays predominantly riffle-pool morphology, covering 44.4% of the bed by length. Cascade-riffle morphology is also prevalent in this section, covering 21.0% of the channel length. The remaining channel lengths are covered by morphologies that, individually, cover less than 10% of the bed. Reach lengths and important features are provided in Table 3-8.

No changes in bed character were noted immediately downstream of the confluence with GCT-12. The reach type changes from riffle pool to cascade-riffle pool at the confluence of GCT-11 with Gold Creek. Median grain size increases between the reaches (upstream D_{50} = 30 mm, compared to downstream D_{50} of 70 mm). Sediments on the bed of the tributary at the confluence are substantially finer, and do not appear to be contributing to Gold Creek bed material downstream.

An avulsion was identified in the cascade-riffle reach 100 m downstream of the confluence of GCT-11 and Gold Creek. This site is aggraded, with a large volume of cobble-sized sediment deposited on the floodplain. The floodplain is wider in this reach than sections upstream, and is likely the reason for the deposition. The main channel splits into three distinct channels that rejoin further downstream. The main flow path has shifted from the left channel to the right channel. Approximately 95 m downstream from the avulsion, a landslide scar was observed, which appears to be contributing fine and medium-size sediment to the channel. LWD is present in upper Gold Creek and has contributed to small-scale channel control through creation of steps and stability through bank support and sediment storage, but no substantial LWD jams were observed in this section.

Table 3-8: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes GC-13 and GC-10 in Gold Creek.

Sediment Morphology	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Step pool	60.46	-	-	-	-	-	
Cascade pool	28.46	-	-	-	-	-	
Riffle pool	40.89	-	-	-	-	-	
Cascade pool	61.68	-	-	-	-	1	Sloughing of left slope
Riffle pool	55.12	-	-	-	-	-	
Cascade-Riffle pool	144.72	-	-	-	-	-	
Cascade-Step pool	110.36	-	-	-	-	-	
Plane bed	60.26	-	-	-	-	-	
Step pool	48.37	-	-	-	1	-	Groundwater seep
Bedrock-Step pool	56.77	-	-	-	-	-	
Riffle pool	485.63	-	-	-	2	2	Includes confluence with GCT-12 and unknown tributary
Cascade-Riffle pool	202	1	-	-	3	2	Includes confluence with GCT-11, unknown tributary and groundwater seep
Riffle pool	151.3	-	-	-	1	1	Groundwater seep; bank failure
Riffle-Step pool	145.75	-	-	-	-	-	
TOTAL	**1651.77**	**1**			**7**	**6**	

The average width-to-depth ratio for this section for bankfull flows is 6.1. Bankfull widths range from 2.7 to 8.6 m, while depths range from 0.5 to 1.7 m. The average slope for the section is 3.0%. Decrease in bed elevation is mainly due to gentle reduction in elevation along riffles with occasional steeper drops with the presence of steps. The median grain size is highly variable, ranging from 30 to 120 mm in diameter. The largest grain on the bed varies from cobble (180 mm) to boulder (470 mm).

3.3.2.2 Gold Creek: Nodes GC-10 to GC-04

The three dominant reach types are present in this section of Gold Creek: cascade-riffle pool (27.0%), step pool (24.9%), and cascade pool (22.1%). Refer to Table 3-9 for a list of reach lengths and important features. The node denoting the upstream limit of this section is located at the confluence of GCT10, the site of a LWD jam and a landslide that contribute sediment to the channel. This area displays a transition from riffle-step pool to riffle pool. Sediment is stored in bars downstream of the confluence, and median bed material decreases to 35 mm from 85 mm. The average slopes are the same in the riffle-step pool to riffle pool reaches, and the change in bed composition and structure is likely due to sediment inputs from the tributary and the landslide deposits.

Table 3-9: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes GC-10 and GC-04 in Gold Creek.

Sediment Morphology	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Riffle pool	365.11	-	-	1	2	2	Includes confluence with GCT10, groundwater seep
Step pool	256.08	-	-	-	-	-	
Cascade pool	499.4	1	-	-	1		Groundwater seep
Step pool	642.26	-	1	-	1	1	Small bifurcation; includes confluence with unnamed tributary; loose sediment from exposed steep slope
Cascade-Riffle pool	60.08	-	-	-	1	-	Includes confluence with Caudron Creek
Step pool	65.03	-	-	-	-	-	
Bedrock-Step pool	87.09	-	-	-	-	-	
Cascade-Riffle pool	537.3	-	-	-	-	-	
Cascade-Step pool	274.06	-	-	1	2	-	Includes confluence with GCT08, unnamed tributary

Table 3-9 (Cont'd): Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes GC-10 and GC-04 in Gold Creek.

Sediment Morphology	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Riffle pool	279.64	-	-	-	-	-	
Cascade pool	358.9	-	-	-	-	-	
Cascade-Riffle pool	450.51	-	-	-	1	1	Includes confluence with GCT07, bank failure
TOTAL	**3875.46**	**1**	**1**	**2**	**8**	**4**	

Caudron Creek is the largest tributary to Gold Creek. Its confluence with Gold Creek marks a transition from riffle pool to cascade-riffle pool. The cascade-riffle pool sequences extend downstream approximately 60 m before transitioning back to riffle pool. The bed material in the cascade-riffle reach is similar to the material in the downstream reaches of Caudron Creek. It is likely that this short reach is composed of alluvial deposits from Caudron Creek which are likely mobilized under high flow conditions.

Tributary GCT-08 enters Gold Creek form the right (west) slope and its confluence marks the upstream transition from cascade-riffle pool to cascade-step pool. Measured median grain size values show a slight decrease in D_{50} values between the two reaches from 40 mm to 30 mm, but an increase in the proportion of larger boulders.

Where GCT-07 flows into Gold Creek, the bed morphology changes from cascade pool to cascade-riffle pool. The median grain size increases to fine cobble (D_{50} = 85 mm) from medium gravel (D_{50} = 45 mm) with little change in average slope.

Measured bankfull channel widths are generally greater in this section compared to upstream (ranging from 4.2 to 10.0 m), while depth measurements remain similar (0.7 to 1.5 m). The average width-to-depth ratio is 8.3. The floodplain remains similarly narrow to the upstream section, with steep slopes on either side. The average bed slope is higher than upstream reaches, at 4.0%, with the steepest slopes being recorded in the step pool reaches. Median grain size is finer than upstream, ranging from 20 to 85 mm, likely owing to numerous fine sediment inputs from tributary channels and bank failures. D_{90} values range from 210 to 650 mm.

3.3.2.3 Gold Creek GC-04 to GC-02

This section marks the shift from high variability of sediment morphologies over small reaches, to longer stretches of a particular morphology. The length of this section is covered by riffle-pool sequences (69.2%), stretches of plane bed (21.0%), and step-pools (9.8%). Channel lengths and important reach features are presented in Table 3-10. No avulsions were documented in this section. Two bifurcations occur in this section, with one extending 58 m at the transition between riffle pool and plane bed reaches, and one measuring 43 m at the transition to riffle pool from plane bed. A substantial LWD blowout occurs at the end of the first reach where the bed changes from step pool to riffle pool. The only potential source of sediment in this section was is from tributary GCT06, though it did not create any observable changes in bed sediment patterns downstream of the confluence.

Table 3-10: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes GC-04 and GC-02 in Gold Creek.

Sediment Morphology	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Step pool	135.63	-	-	1	-	-	
Riffle pool	630.46	-	1	-	-	-	
Plane bed	290.09	-	1	-	1	-	Includes confluence with GCT06
Riffle pool	327.51	-	-	-	-	-	
TOTAL	**1383.69**		**2**	**1**	**1**		

General channel shape remains consistent and similar to upstream dimensions, with a width-to-depth ratio of 8.3. Average bankfull width ranges from 3.2 to 11.5 m, and depths range from 0.7 to 1.1 m. The average slope is steeper, at 4.2%. Median and largest grain size values are similar to upstream; D_{50} ranges from 35 to 80 mm, while D_{90} ranges from 240 to 540 mm.

3.3.2.4 Gold Creek GC-02 to GC-01

Riffle pool sequences dominate the downstream section of Gold Creek, covering 38.8% of its length. Cascade pool (22.8%) and plane bed (17.8%) sequences make up significant morphologies in this section. Refer to Table 3-11 for reach lengths and important features.

The riffle pool reaches are dominated by large accumulations of sediment in bars, and in some cases full bed aggradation. Two large channel blowouts occur in this section with widespread deposition of gravel and cobble material and large woody debris, and causing channel bifurcations. In the downstream blowout, flow infiltrates the aggraded material and flow is predominantly subsurface for approximately 200 m. The confluence with Morin Creek does not appear to affect the morphology of the bed significantly.

The general channel shape in this section is substantially different than previous reaches. This is attributed to large blowout sections where channels are not bound by banks and flow relatively wide and shallow as they work through sediment deposits. The average width-to-depth ratio is 13.5, with bankfull widths ranging from 2.6 to 7.0 m, and depths from 0.2 to 1.0 m. The average channel slope is lower than previous sections at 2.1%. The median grain size is smaller, ranging from 20 to 50 mm, but predominantly in the 20 to 30 mm range. D_{90} ranges from 100 to 640 mm. The large boulders are found mostly in the bedrock-dominated section, where most of the finer material is stored in pools.

Table 3-11: Distribution of reach type based on channel length and list of features and processes affecting channel morphology between Nodes GC-02 and GC-01 in Gold Creek.

Sediment Morphology	Length	Avulsions	Bifurcations	LWD	Flow Input	Sediment Input	Notes
Plane bed	260.21	-	1	1	-	-	Blowout 1
Riffle pool	916.92	-	-	-	1	-	Groundwater seep
Bedrock-Riffle pool	45.22	-	-	3	4	-	Groundwater seeps, includes confluence with Morin Creek
Plane bed	301.13	-	-	-	-	-	
Riffle pool	310.49	-	1	1	1	1	Blowout 2; small lake with tributary to Gold Creek
Cascade pool	719.84	-	-	-	-	1	Slope failure
Bedrock-Step pool	208.08	-	-	-	-	-	
Step pool	400.15	-	-	-	2	-	
TOTAL	**3162.04**		**2**	**5**	**8**	**2**	

4 Assessment of Incremental Effects to Fluvial Geomorphology Under Proposed Flow Changes

Peak discharges are generally expected to decrease through the Project lifecycle as a result of mining operations and water management (SRK, 2016a). The decrease in peak discharges through time is the main input into the analysis of sediment mobility. Channel beds are expected to become more stable through time due to decreases in peak flows. Gravel deposition will likely increase in some locations but channel aggradation is not expected due to the nature of the steep channels.

Base flows may increase during the project lifecycle due to the implementation of the WMP. Stream channels are formed during peak discharges while sediment is mobile; therefore, the changes in low flows are not expected to alter the morphology of the stream channels due to the low shear stresses that occur during these flows.

4.1 Incremental Effects Determined from Analysis of Sediment Mobility Thresholds

The results of the sediment mobility threshold calculations are presented and discussed below. The cross-sections are referred to by the station name assigned by Hatfield, with SNC-Lavalin's station name included in brackets for reference.

4.1.1 Blairmore Creek

4.1.1.1 Blairmore Creek: Confluence of BCT-10 and Blairmore Creek to BC-13

Data from one cross-section, BC-15 (SNC-Lavalin B1-09), is located in this reach. The cross-section is located in a cascade-riffle pool reach type in the lower portion of the section. The project footprint does not extend to the tributaries in this section, and therefore, flows are not expected to be altered as a result of the Project. Therefore, no incremental effect is expected in this section.

Figure 4-1 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the lifecycle of the Project. The calculated range of mobile sediments under the current hydraulic regime range from 110 to 250 mm under bankfull flow conditions, and from 190 to 440 mm under 100-year flow conditions. The median grain size measured on the bed in 2016 was 40 mm and it is expected that the bed will be mobile at bankfull flows. The coarsest grain size measured in this reach was 540 mm, which would remain stable at all predicted flow scenarios.

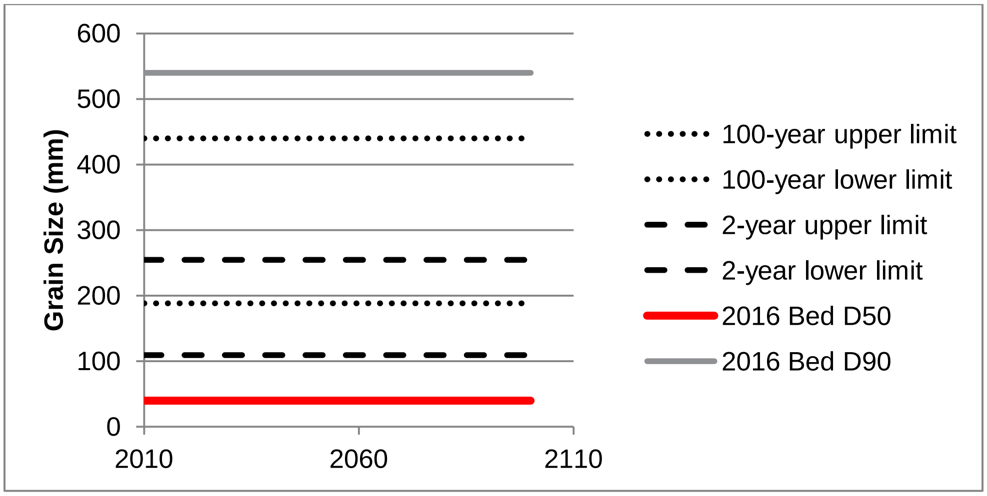

Figure 4-1 Sediment entrainment threshold ranges for cross-section BC-15.

The bed mobility calculations suggest that the finer fraction of the bed is mobile under bankfull conditions.

4.1.1.2 Blairmore Creek: Nodes BC-013 to BC-07

Two geomorphologically representative cross-sections were analyzed for this section: BC-14 (SNC-Lavalin reference B1-10) and BC-11 (SNC-Lavalin reference B2-02), located within a bedrock-cascade pool reach and a cascade-riffle pool reach, respectively. These reaches represent the two dominant morphologies in this section. This section is stabilized by large woody debris structures and abundance of assemblages of large boulders. No changes to flow are predicted above Node BC-07, and therefore no changes to these reaches are anticipated.

In the bedrock-cascade reach where data were collected for cross-section BC-14, D_{50} is 40 mm. Figure 4-2 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the lifecycle of the Project. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 130 to 300 mm, and 230 to 520 mm under 100-year flow conditions.

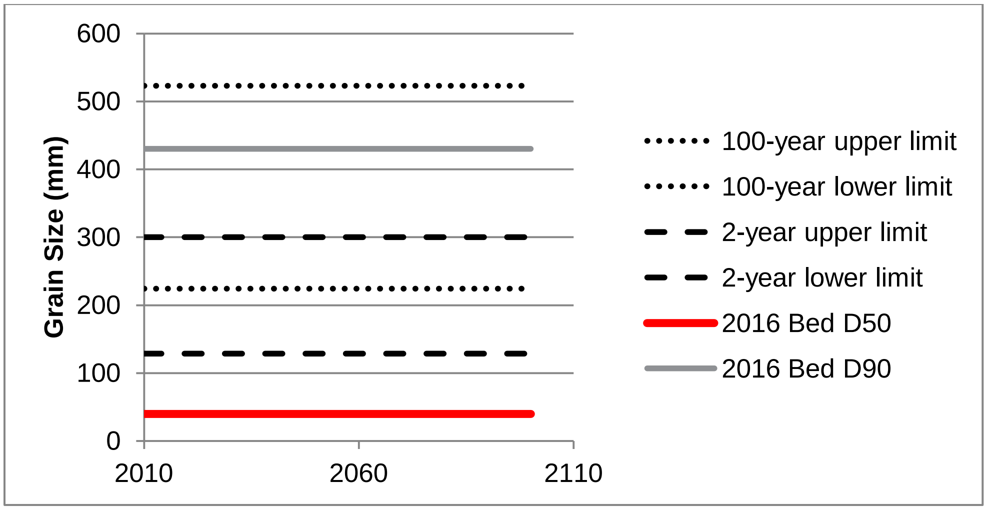

Figure 4-2: Sediment entrainment threshold ranges for cross-section BC-14.

The bed of the cascade-riffle pool reach at cross-section BC-11 has a median grain size of 35 mm and a maximum grain size of 430 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 130 to 300 mm, and under 100-year flow conditions, the range is 230 to 540 mm (Figure 4-3).

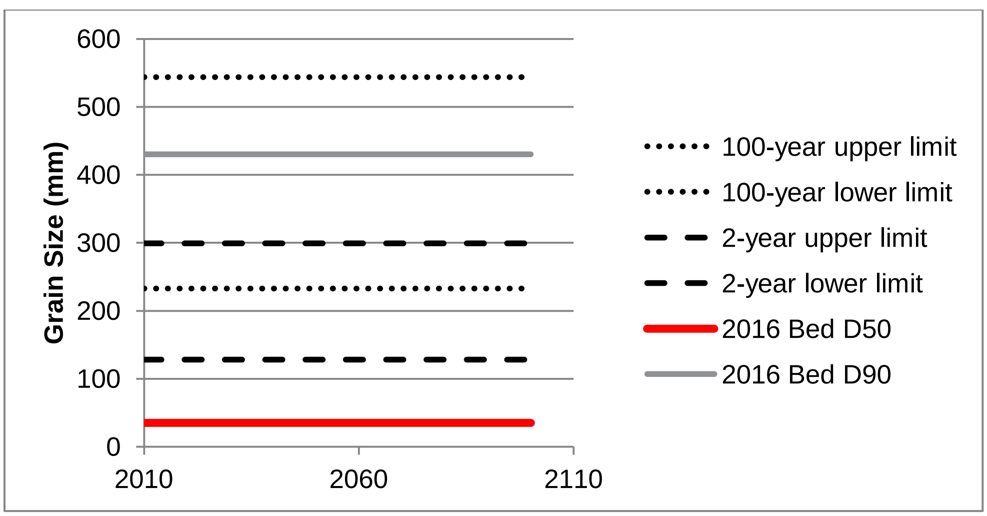

Figure 4-3: Sediment entrainment thresholds for cross-section BC-11.

With no anticipated changes to flow, the current reach type channel morphologies are not expected to change through the lifecycle of the Project. Identified sediment inputs come from upstream, from a landslide scar, and from Tributary BCT-07. Upstream reaches are not expected to be disturbed, and the landslide scar will likely continue eroding sediment into the creek.

4.1.1.3 Blairmore Creek: Nodes BC-07 to BC-06

Three geomorphologically representative cross-sections were assessed in this section to capture sediment mobility thresholds for each reach type in this section. Planned incremental flow decreases at Node BC-07 will occur in 2020 and 2021. Bed sediment is largely mobile during the Project lifecycle but the largest, channel forming material remains immobile through the study period.

Data for cross-section BC-09 (SNC-Lavalin B2-05) were collected in the upstream part of a cascade-riffle pool reach where the channel transitions from a step pool morphology. D_{50} on the bed is 30 mm and the D_{90} measured in the channel is 480 mm. Under the current hydraulic regime, flows associated with bankfull conditions result in sediment mobility threshold ranges from 30 to 60 mm, and under 100-year flow conditions, it ranges from 80 to 180 mm. Decreases in peak flows will result in a decrease in the mobility thresholds to 30 to 50 mm under bankfull flows, and to 70 to 160 mm under 100-year flow conditions. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. See Figure 4-4 for the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

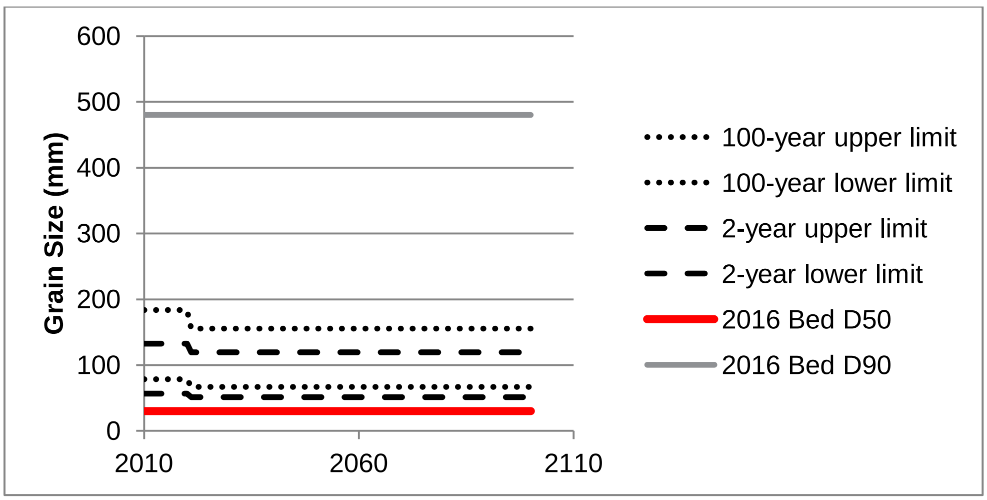

Figure 4-4: Sediment entrainment threshold ranges for cross-section BC-09.

Cross-section BC-08 (SNC-Lavalin B2-07) is located in a step pool reach. Median grain size on the bed is 40 mm and the largest grain size measure in the channel is 500 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 70 to 170 mm, and under 100-year flow conditions, the range is 90 to 200 mm. Decreases in peak flows will decrease the threshold to 60 to 150 mm at bankfull flow and 80 to 190 mm at the 100-year flow. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Figure 4-5 shows the calculated sediment entrainment ranges for both bankfull and 100-year flows over the Project lifecycle.

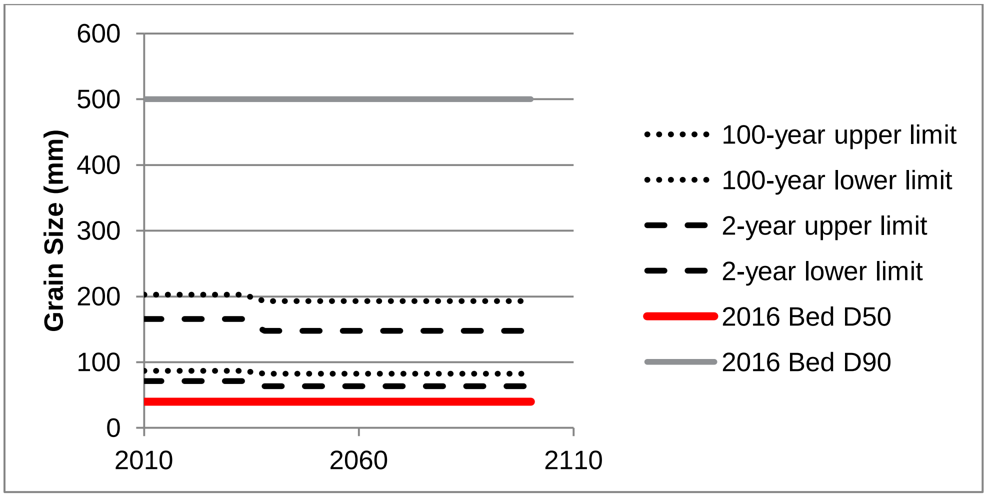

Figure 4-5: Sediment entrainment threshold ranges for cross-section BC-08.

Cross-section BC-05 (SNC-Lavalin B2-10) is located in a riffle pool reach. Median grain size on the bed is 15 mm and the largest grain size measured in the channel was 110 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 20 to 50 mm, and 40 to 80 mm under 100-year flow conditions. Calculated sediment mobility threshold values with the predicted flow decrease at Node BC-07 dropped to 20 to 40 mm under bankfull conditions, and 30 to 70 mm under 100-year flow conditions. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Refer to Figure 4-6 for the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

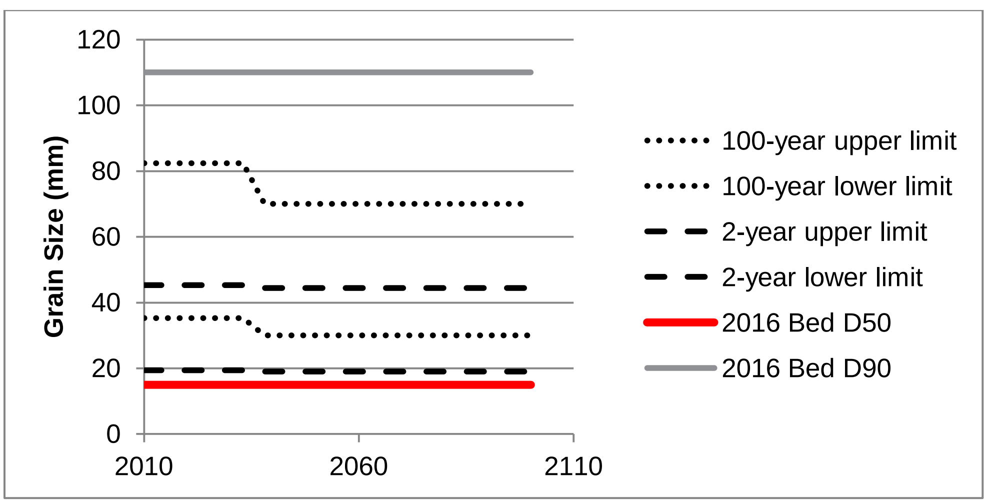

Figure 4-6: Sediment entrainment threshold ranges for cross-section BC-05.

This section is expected to respond to proposed flow changes in a similar manner to the upstream section. Present entrainment thresholds are capable of moving the finer fraction of the bed, yet the larger sediments present are relatively stable channel features. The estimated entrainment thresholds resulting from decreased flows remain on the same order of magnitude as the current conditions. Tributary BCT-05 enters Blairmore Creek from the east slope and will be impacted by the proposed changes to flow. The reach type does not appear to be affected by the tributary at or downstream of its confluence with Blairmore Creek.

4.1.1.4 Blairmore Creek: Nodes BC-06 to BC-03

Data for two geomorphologically representative cross-sections were available in this section, where flows at Node BC-06 are scheduled to decrease in 2020, 2021, 2023, 2026, 2030, and finally in 2033.

Cross-section BC-02 (SNC-Lavalin B2-14) occurs in a bedrock-riffle pool reach. The median grain size on the bed is 50 mm and the largest grain size measure in the channel is 320 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 50 to 70 mm, and under 100-year flow conditions, the range is 140 to 330 mm (Figure 4-7). With decreased flows, the threshold drops to a range of 60 to 140 mm at bankfull flow and 120 to 290 mm at the 100-year flow. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows flowing the first years of operation (Figure 4-7).

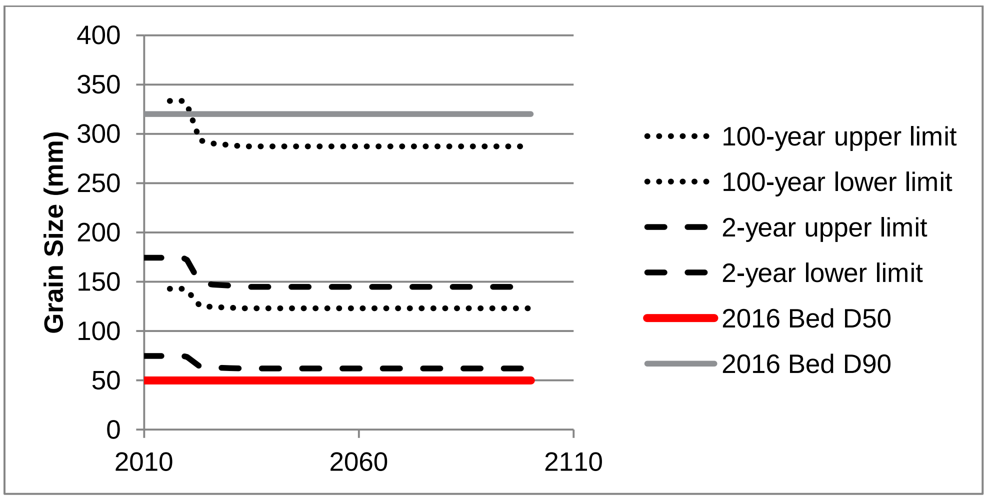

Figure 4-7: Sediment entrainment threshold ranges for cross-section BC-02.

Data for cross-section BC-01 (SNC-Lavalin B2-15) were collected in a cascade-step pool reach. Median grain size on the bed is 120 mm and the largest grain size measure in the channel is 750 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 120 to 280 mm, and 190 to 440 mm under 100-year flow conditions. Calculated sediment mobility threshold values with the predicted flow decrease at Node BC-06 drop to 100 to 240 mm under bankfull conditions, and 170 to 390 mm under 100-year flow conditions. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Figure 4-8 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

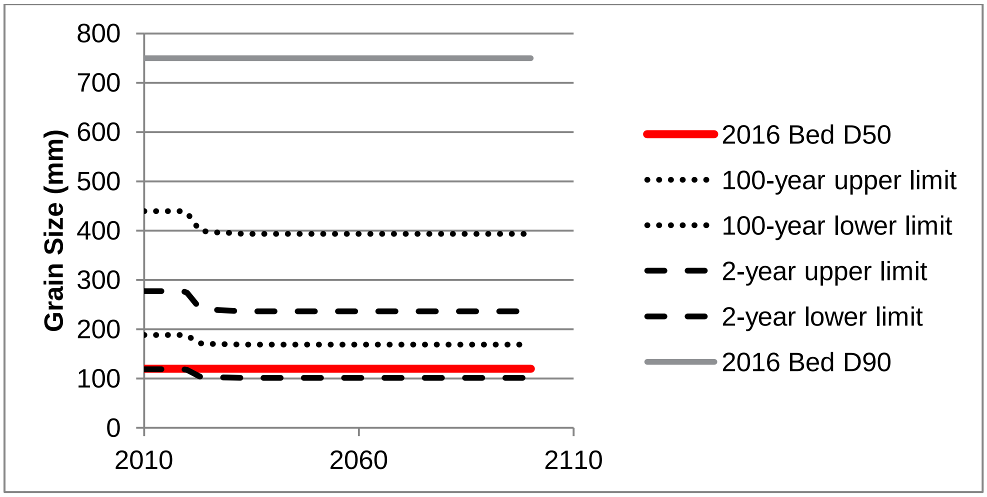

Figure 4-8: Sediment entrainment threshold ranges for cross-section BC-01.

This section of Blairmore Creek is largely sediment transport capacity limited due to bedrock control on the channel bed and banks, creating steep slopes, and narrow channels. Sediment is largely stored in deep scour pools carved into bedrock below knickpoints or other obstructions. The predicted entrainment thresholds are still capable of moving the majority of the bed material present in these pools, and it is not anticipated that the bed morphology will alter due to proposed flow changes.

The only significant tributary affected is BCT-02; BCT-04 and BCT-03 that enter from the west slope. BCT-02 does appear to contribute finer sediments to Blairmore Creek as the morphology of the mainstem channel bed changes from a bedrock-step pool to a cascade-riffle pool below the confluence. This is not expected to change due to the alteration in flow as the large bed and bank forming clasts are not mobile under the current or future flow regimes.

4.1.1.5 Blairmore Creek: Nodes BC-03 to BC-01

Flows at Node BC-03 are expected to decrease in 2020, 2021, 2023, 2026, 2030, and finally in 2033. No cross-sectional data were available in this reach for the hydraulic analysis. The reaches in this section, as well as the magnitude and timing of the decreases are similar to those in Section 3.3.1.4 upstream and therefore the morphology of this section is not expected to change.

4.1.2 Gold Creek

4.1.2.1 Gold Creek: Nodes GC-13 to GC-10

The upper section of Gold Creek contains a predominantly cascade-riffle pool and riffle pool reach types. Geomorphically representative cross-sectional data for one cascade-riffle pool reach and two separate riffle pool reaches were assessed for potential changes to reach type under incremental flow changes proposed for 2023, 2026, 2030, 2033, 2038, 2039, 2041, and 2100.

Data for cross-section GC-26 (SNC-Lavalin G1-07) was collected in the lower part of a cascade-riffle pool reach. Median grain size on the bed is 115 mm and the largest grain size measured in the channel is 330 mm. Under the current hydraulic regime, flows associated with bankfull conditions generate sediment mobility threshold ranges from 100 to 240 mm, and from 200 to 470 mm under 100-year flow conditions.

Flow decreases are small enough that only subtle changes in estimated mobility thresholds were calculated under bankfull flow conditions. The lower limit of the range of threshold values does not change for the 100-year flow, and the upper limit decreases to 460 mm. D_{50} bed material is mobile during 2-year flows, and the D_{90} bed material may be mobile during 100-year flows. See Figure 4-9 for the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

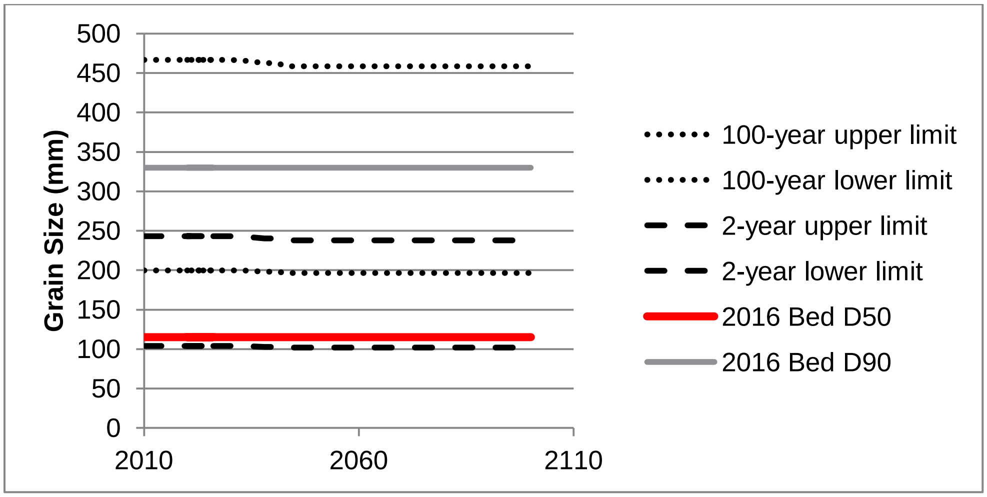

Figure 4-9: Sediment entrainment threshold ranges for cross-section GC-26.

Cross-section GC-25 (SNC-Lavalin G1-12) is located in a riffle pool reach. Median grain size on the bed is 30 mm and the largest grain size measured in the channel is 270 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 120 to 280 mm, and under 100-year flow conditions, the range is 210 to 500 mm. No change in calculated sediment entrainment occurs with this flow decrease for the bankfull flow range, nor for the lower limit of the 100-year range, but the upper limit of the 100-year range decreases to 490 mm. D_{50} bed material is predicted to be mobile during 2-year flows and, D_{90} bed material may be mobile during the 100-year flow and perhaps even the 2-year flow. Figure 4-10 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

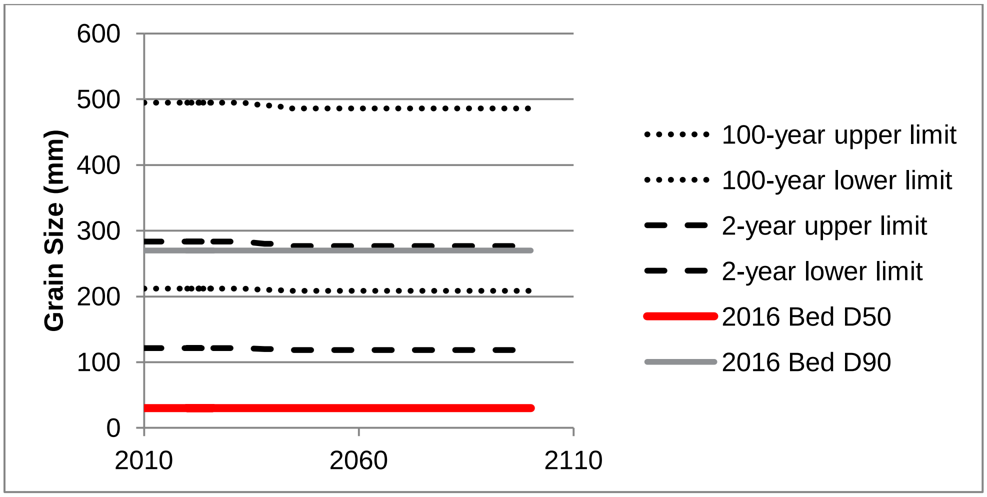

Figure 4-10: Sediment entrainment threshold ranges for cross-section GC-25.

Cross-section GC-24 (SNC-Lavalin G1-14) is also located in a riffle pool reach. Median grain size on the bed is 40 mm and the largest grain size measure in the channel is 400 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 60 to 140 mm, and 90 to 200 mm under 100-year flow conditions. Entrainment thresholds did not change for the proposed flow values of either the bankfull flow or the 100-year flow. D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Refer to Figure 4-11 for the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

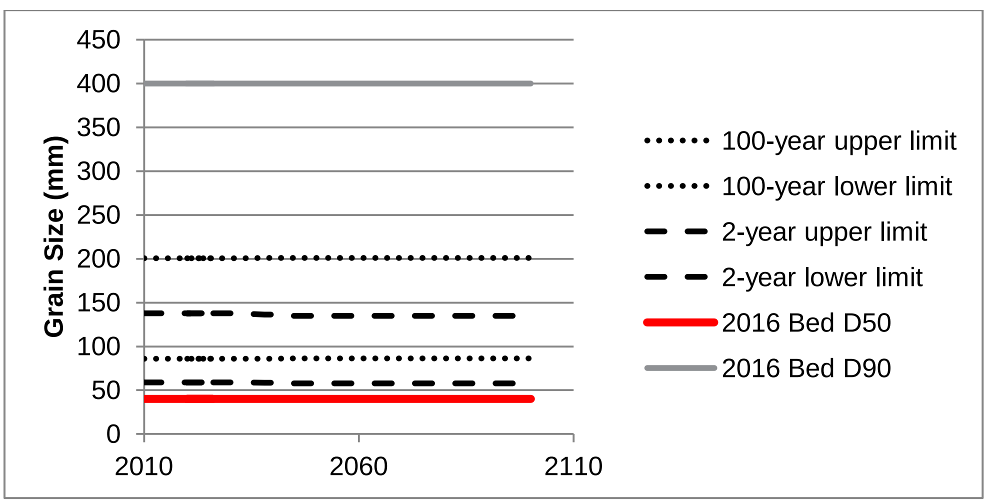

Figure 4-11: Sediment entrainment threshold ranges for cross-section GC-24.

The changes to flow in this section are nominal and no changes to sediment erosion, transport, and deposition dynamics are expected. As a result, the current channel morphology is not expected to change under the new flow regime and the input is not predicted to change from baseline. Present identified inputs come from upstream, from a sloughing of slope material, and from Tributaries GCT-12 and GCT-11.

GCT-12 is located on the eastern slope of Gold Creek watershed and is not expected to be disturbed. GCT-11 will be affected by the Project, with water is extracted from both groundwater and from surface water, and discharged back into the creek as surface water. However, the addition of discharge at nodes will increase low flows when shear stresses are expected to be low and, therefore, alteration to the geomorphology of the creek is not expected.

4.1.2.2 Gold Creek: Nodes GC-10 to GC-04

Six geomorphically representative cross-sections were assessed in this section to capture sediment mobility thresholds for each of the morphology types in this section, including riffle pool, step pool (two individual step pool reaches were assessed), cascade pool, cascade-riffle pool, and cascade-step pool. Planned incremental flow decreases at Node GC-10 will occur in 2023, 2026, 2030, 2033, 2038, 2039, 2041, and 2100.

Data for cross-section GC-22 (SNC-Lavalin G1-16) were collected at the location of Node GC-10 in the upstream part of a riffle pool reach. Median grain size on the bed is 20 mm and the largest grain size measure in the channel is 260 mm. Under the current hydraulic regime, flows associated with bankfull conditions, the sediment mobility threshold ranges from 60 to 140 mm, and under 100-year flow conditions, it ranges from 100 to 230 mm. Flow decreases will result in a decrease in the mobility thresholds to 55 to 130 mm under bankfull flows, and to 95 to 225 mm under 100-year flow conditions (Figure 4-12). D_{50} bed material is predicted to be mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows.

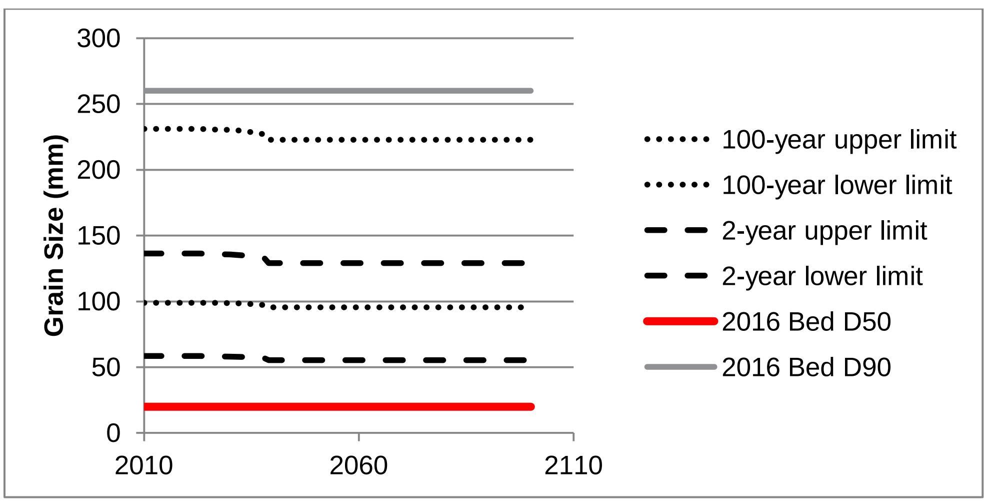

Figure 4-12: Sediment entrainment threshold ranges for cross-section GC-22.

Cross-section GC-20 (SNC-Lavalin G1-17) is located in a step pool reach. Median grain size on the bed is 35 mm and the largest grain size measure in the channel is 290 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 65 to 145 mm, and under 100-year flow conditions, the range is 105 to 250 mm. With decreased flows, the lower limit of the threshold decreases to 60 mm while the upper limit remains at 145 mm at bankfull flow and only the upper limit decreases to 240 mm at the 100-year flow. D_{50} bed material is mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Figure 4-13 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

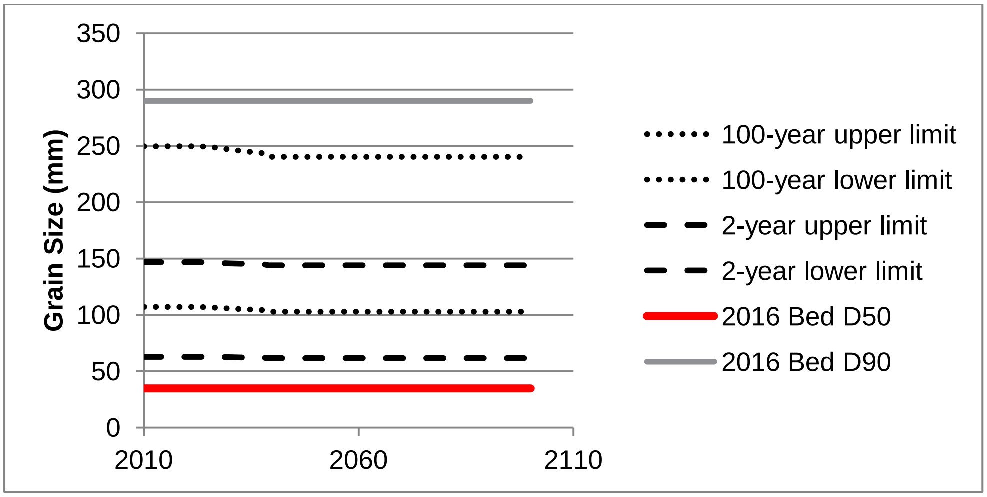

Figure 4-13: Sediment entrainment threshold ranges for cross-section GC-20.

Cross-section GC-19 (SNC-Lavalin G1-19) is located in a cascade pool reach. Median grain size on the bed is 30 mm and the largest grain size measure in the channel is 470 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 105 to 240 mm, and 145 to 340 mm under 100-year flow conditions. Calculated sediment mobility threshold values with the predicted flow decrease at Node GC-10 dropped to between100 and 235 mm under bankfull conditions, and 140 to 330 mm under 100-year flow conditions. D_{50} bed material is mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. See Figure 4-14 for a graphic of the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

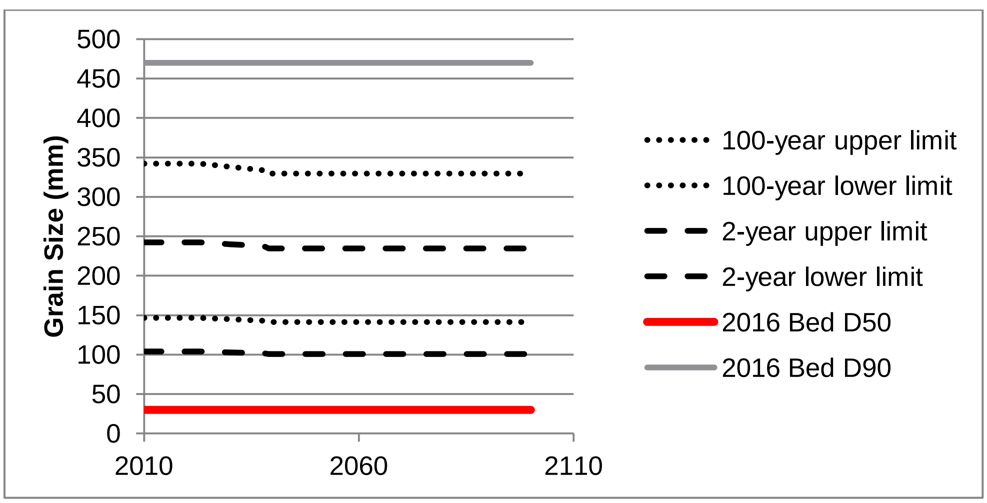

Figure 4-14: Sediment entrainment threshold ranges for cross-section GC-19.

Data for cross-section GC-15 (SNC-Lavalin G1-21) were collected near the confluence of GCT-09 in a step pool reach. Median grain size on the bed is 40 mm and the largest grain size measured in the channel is 550 mm. Under the current hydraulic regime, flows associated with bankfull conditions, the sediment mobility threshold ranges from 110 to 250 mm, and under 100-year flow conditions, it ranges from 130 to 305 mm. D_{50} Bed material is mobile during 2-year flows; however, D_{90} bed material is not predicted to be mobile, even during 100-year flows. Flow decreases will result in a decrease in the mobility thresholds to 105 to 245 mm under bankfull flows, and to 95 to 223 mm under 100-year flow conditions (Figure 4-15).

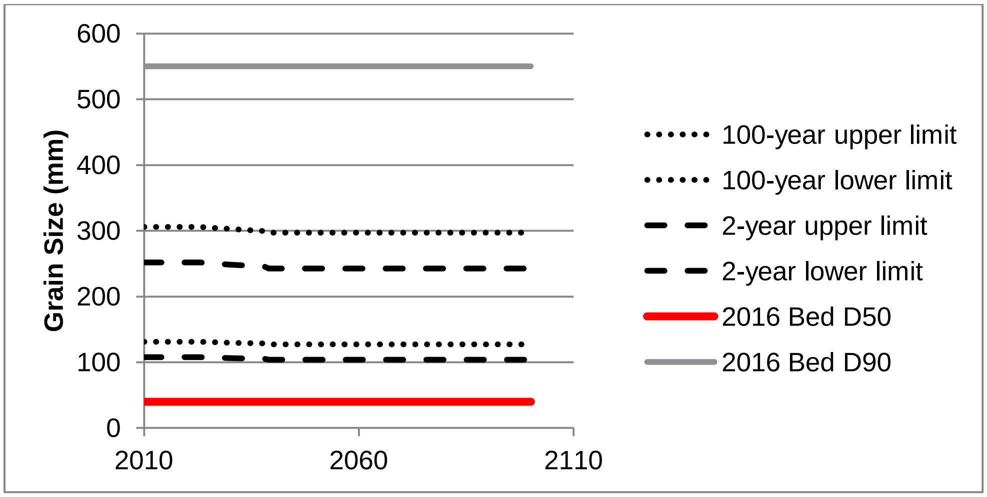

Figure 4-15: Sediment entrainment threshold ranges for cross-section GC-15.

Cross-section GC-12 (SNC-Lavalin G2-02) occurs in a cascade-riffle pool reach just downstream of the confluence of Gold and Caudron creeks. The median grain size on the bed is 55 mm and the largest grain size measure in the channel is 206 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 205 to 480 mm, and under 100-year flow conditions, the range is 325 to 755 mm. With decreased flows, the threshold decreases to a range of 200 to 465 mm at bankfull flow and 310 to 720 mm at the 100-year flow. D_{50} bed material is mobile during 2-year flows, and the D_{90} bed material may be mobile during 100-year flows. Refer to Figure 4-16 for the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

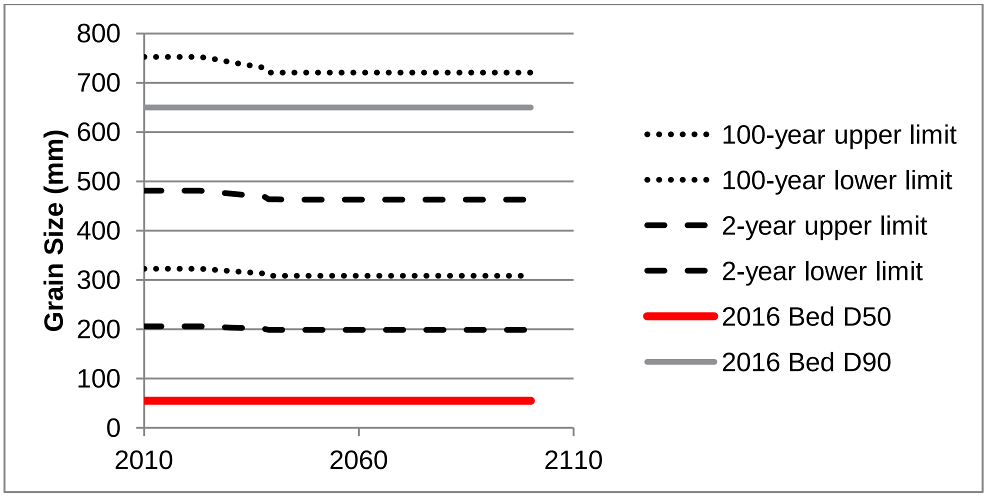

Figure 4-16: Sediment entrainment threshold ranges for cross-section GC-12.

Data for cross-section GC-09 (SNC-Lavalin G2-05) were collected in a cascade-step pool reach. Median grain size on the bed is 30 mm and the largest grain size measure in the channel is 430 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 165 to 390 mm, and 285 to 660 mm under 100-year flow conditions. Estimates of sediment mobility threshold values decrease to 160 to 375 mm under altered bankfull conditions, and to 275 to 645 mm under 100-year flow conditions. D_{50} bed material is mobile during 2-year flows, and the D_{90} bed material may be mobile during 100-year flows. Figure 4-17 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle.

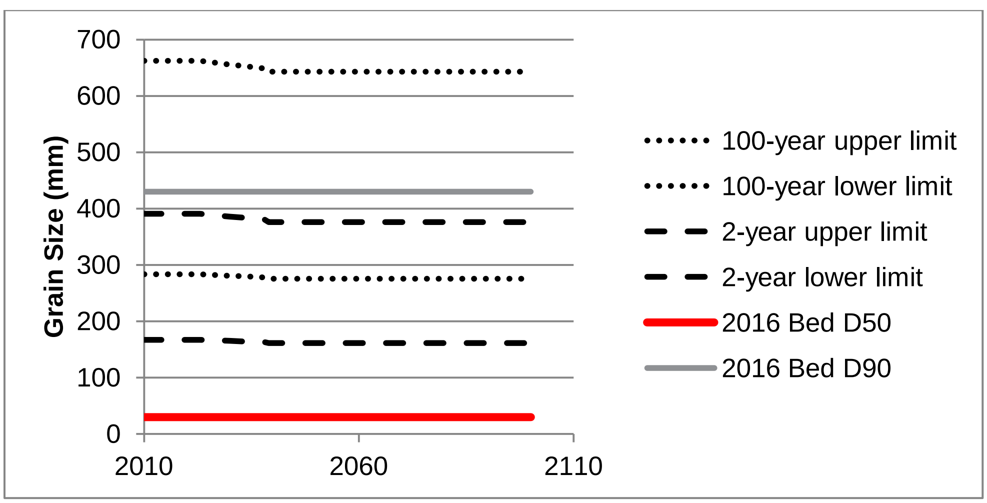

Figure 4-17: Sediment entrainment threshold ranges for cross-section GC-09.

Present entrainment thresholds are capable of moving the finer fraction of the bed, yet the larger sediments present are relatively stable channel features. The estimated entrainment thresholds resulting from decreased flows remain on the same order of magnitude as the current conditions and are not likely to result in changes to bed morphologies that define reach type. Caudron Creek enters Gold Creek from the east slope near the middle of the length of the section and will not be impacted by the proposed changes to flow. It is likely that sediment inputs from Caudron Creek influence the bed morphology downstream of the confluence.

4.1.2.3 Gold Creek: Nodes GC-04 to GC-02

Three geomorphically representative cross-sections were assessed to represent dominant morphologies in this section: a cascade-riffle pool reach, a step pool reach, and a plane bed reach. Flows at GC-04 are expected to decrease incrementally in 2023, 2026, 2030, 2033, 2038, 2039, 2041, and 2100.

In the cascade-riffle pool reach where data were collected for cross-section GC-08 (SNC-Lavalin G2-80), D_{50} is 85 mm and D_{90} is 560 mm. The calculated range of mobile sediments with the present bed structure under bankfull flow conditions is 215 to 500 mm, and 380 to 885 mm under 100-year flow conditions. Calculated sediment mobility threshold values with the predicted flow decrease at Node GC-04 decreased to 210 to 495 mm under bankfull conditions, and 370 to 860 mm under 100-year flow conditions (Figure 4-18). D_{50} bed material is predicted to be mobile during 2-year flows, and the D_{90} bed material is predicted to be mobile during 100-year flows.

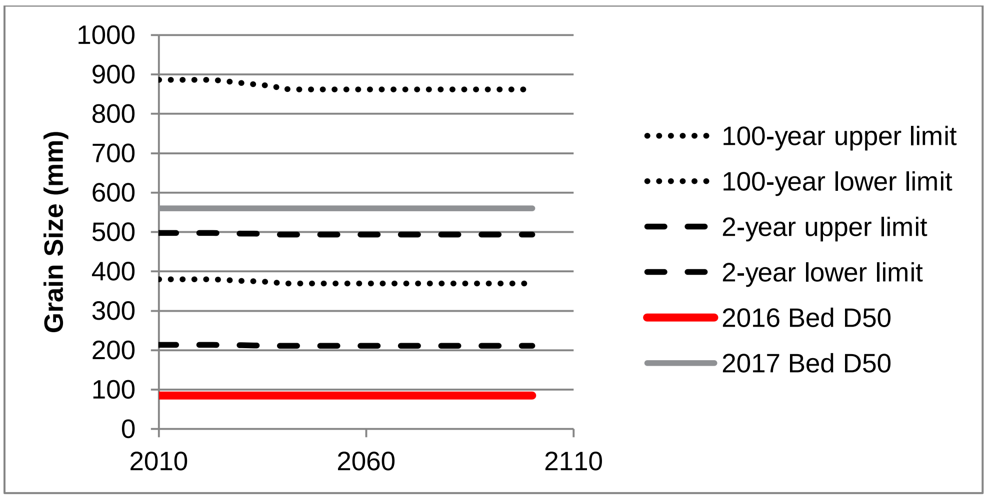

Figure 4-18: Sediment entrainment threshold ranges for cross-section GC-08.

The bed of the step pool reach at cross-section GC-07 (SNC-Lavalin G2-09) has a median grain size of 35 mm and a maximum grain size of 540 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 225 to 530 mm, and under 100-year flow conditions, the range is 330 to 765 mm. With decreased flows, the threshold is lowered to a range of 225 to 520 mm at bankfull flow and 295 to 690 mm at the 100-year flow. D_{50} bed material is predicted to be mobile during 2-year flows, and the D_{90} bed material is predicted to be mobile during 100-year flows. Figure 4-19 shows a graphic of the sediment entrainment threshold ranges.

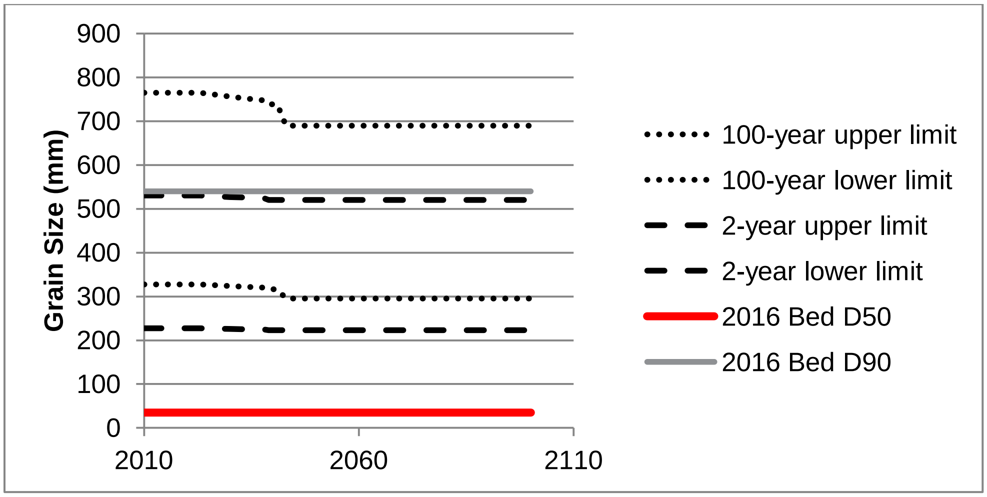

Figure 4-19: Sediment entrainment threshold ranges for cross-section GC-07.

Cross-section GC-03 (SNC-Lavalin G3-03) occurs in a plane bed reach in the lower portion of the section. The median grain size on the bed is 40 mm and the largest grain size measure in the channel is 290 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 70 to 160 mm, and under 100-year flow conditions, the range is 150 to 350 mm. With decreased flows, the threshold decreases to a range of 65 to 155 mm at bankfull flow and 145 to 335 mm at the 100-year flow (Figure 4-20). D_{50} bed material is predicted to be mobile during 2-year flows, and the D_{90} bed material is predicted to be mobile during 100-year flows.

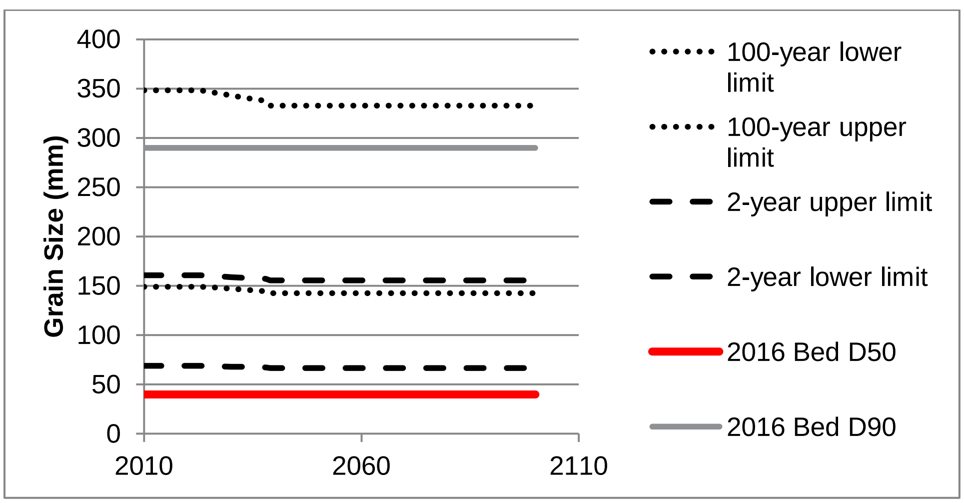

Figure 4-20: Sediment entrainment threshold ranges for cross-section GC-03.

The results of the entrainment assessment suggest that changes to sediment erosion, transport, and deposition dynamics will be minor in this section. The decrease in grain size expected under the new flow regime is small and is not likely contribute to a change in the sediment patterns seen in the reaches of this section. The bed is expected to be mobile at peak discharges, but sediment winnowing is not expected.

4.1.2.4 Gold Creek: Nodes GC-02 to GC-01

One geomorphically representative cross-section was analyzed in the lower section of Gold Creek: GC-00 (SNC-Lavalin G4-01). It is a riffle pool reach type, which is the dominant morphology in this section. Figure 4-21 shows the calculated sediment entrainment ranges for bankfull and the 100-year flows over the Project lifecycle. Incremental flow decreases are proposed for 2023, 2026, 2030, 2033, 2038, 2039, 2041, and 2100.

The median grain size on the bed is 30 mm and the largest grain size measure in the channel is 640 mm. With the present hydraulic conditions, the mobility threshold under bankfull conditions ranges from 65 to 145 mm, and under 100-year flow conditions, the range is 135 to 315 mm. With decreased flows, the lower limit of the threshold decreases to a range of 60 mm, but the upper limit remains at 145 mm at bankfull flow and the range decreases to 130 to 300 mm at the 100-year flow. D_{50} bed material is predicted to be mobile during 2-year flows, and the D_{90} bed material is not predicted to be mobile during 100-year flows.

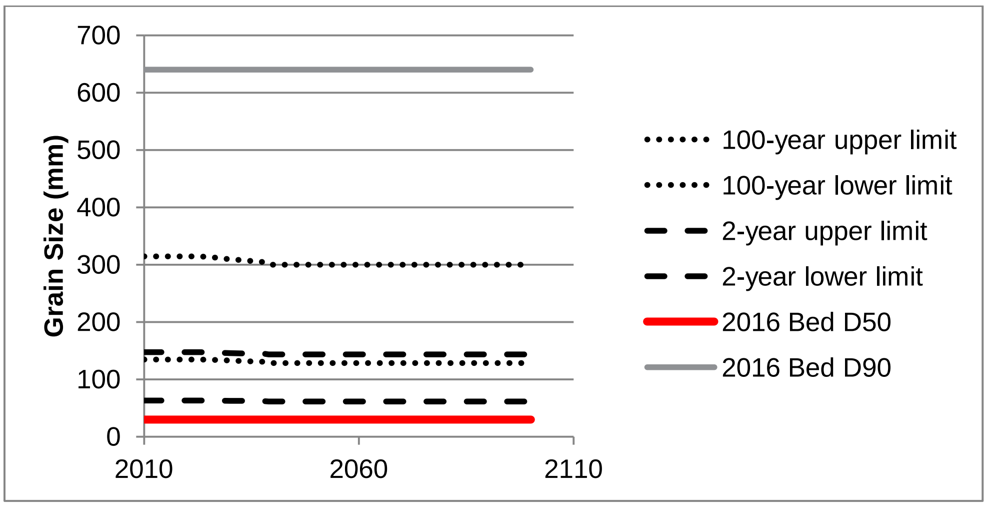

Figure 4-21: Sediment entrainment threshold ranges for cross-section GC-00.

This section contains a range of reach types, but the morphology is relatively stable and is not expected to be affected by the proposed flow alterations. The section contains large blowout reaches where flow is adjusting to recent bed aggradation and this is expected to continue through the Project lifecycle.

5 Summary

A baseline assessment was completed on Blairmore and Gold creeks using field data. Recent changes in land use were determined from an analysis of aerial photographs. Blairmore and Gold creeks were each divided into five (5) sections for analysis of the baseline geomorphology based on the locations of effluent discharge nodes. Analysis of sediment mobility was conducted for each section to assess predicted project effects on geomorphological characteristics of the creeks.

Overall, the majority of sediment in Blairmore Creek is organized in cascade-riffle pool and bedrock-step pool morphologies. The upper three sections are predominantly cascade-riffle pool, with the channel flowing through floodplain deposits typically 1 – 2 m thick, through relatively confined steep-sloped narrow valleys. Bank material is loose and non-cohesive, showing signs of erosion and some undercutting at all sites. The section is heavily influenced by LWD and large boulders that have become positioned within the channel and are exerting control on flow and sediment transport, by slowing velocities and allowing deposition, particularly in bars, and upstream of LWD. These boulders and LWD assemblages contribute to the overall stability of the system. Lower Blairmore Creek is predominantly bedrock controlled, and as such, is considered highly stable, with the exception that slope failures may cause instability by introducing large amounts of sediment and potentially large woody debris. Small-scale depositional zones were noted, particularly in pools and above bedrock waterfalls, where median grain sizes ranged from 25 to 95 mm. These finer sediments are likely flushed out during freshet, and deposited as flows wane following upland snowmelt. Large boulders were common in the channel. Reach gradients averaged 2.65% in Lower Blairmore Creek; however, knickpoints contributed to substantial discrete decreases in bed elevation. Banks are predominantly bedrock walls, and vegetation is generally more sparse than in upstream sections, particularly where slopes were steep. No avulsions were observed on Blairmore Creek along the length of assessed channel.

Overall, the majority of sediment in Gold Creek is organized in riffle pool sequences. Cascade pool, step pool, and cascade-riffle pool morphologies are also common reach types in Gold Creek, where cascade and cascade-riffle structures are more prevalent in upper reaches of the mainstem, giving way to plane bed morphologies as the sub-dominant reach type. Floodplain materials are thin, and slopes are in large part exposed or thinly veiled bedrock, thus bedrock does exert control for the majority of the channel. However, bedrock control in Gold Creek is not as significant as Blairmore Creek.

Riffle pool morphologies are generally less stable than step or cascade pool reach types because of a higher percentage of finer material that can be more easily mobilized. Evidence of instability was observed in the form of two 'blowout' zones where large volumes of fluvial material and large woody debris were deposited recently, causing channel bifurcations, avulsions, and disappearance of flow below the bed materials.

Peak discharges are generally expected to decrease through the project lifecycle (SRK, 2016a). The decrease in peak discharges through time is the primary driver of the analysis of sediment mobility. Channel beds are expected to become more stable through time due to decreases in peak flows. Gravel deposition will likely be enhanced in some locations but channel aggradation is not expected due to the nature of the steep channels. We therefore conclude that the physical habitat within Blairmore and Gold creeks are not anticipated to change due to water management throughout the mine life (construction, operations, reclamation, closure phases).

Under the current WMP, and in particular in Blairmore Creek, low flows may increase during the Project lifecycle to discharge of effluent from the mine site at discrete nodes. However, stream channels are formed during peak discharges while sediment is mobile, therefore, the changes in low flows are not expected to alter the morphology of the stream channels due to the low shear stresses that result from these flows.

6 Notice to Reader

This report has been prepared and the work referred to in this report has been undertaken by SNC-Lavalin Inc. (SNC-Lavalin), for the exclusive use of Hatfield Consultants (Hatfield), who has been party to the development of the scope of work and understands its limitations. The methodology, findings, conclusions and recommendations in this report are based solely upon the scope of work and subject to the time and budgetary considerations described in the proposal and/or contract pursuant to which this report was issued. Any use, reliance on, or decision made by a third party based on this report is the sole responsibility of such third party. SNC-Lavalin accepts no liability or responsibility for any damages that may be suffered or incurred by any third party as a result of the use of, reliance on, or any decision made based on this report.

The findings, conclusions and recommendations in this report (i) have been developed in a manner consistent with the level of skill normally exercised by professionals currently practicing under similar conditions in the area, and (ii) reflect SNC-Lavalin's best judgment based on information available at the time of preparation of this report. No other warranties, either expressed or implied, are made with respect to the professional services provided to Hatfield or the findings, conclusions and recommendations contained in this report. The findings and conclusions contained in this report are valid only as of the date of this report and may be based, in part, upon information provided by others. If any of the information is inaccurate, new information is discovered or project parameters change, modifications to this report may be necessary.

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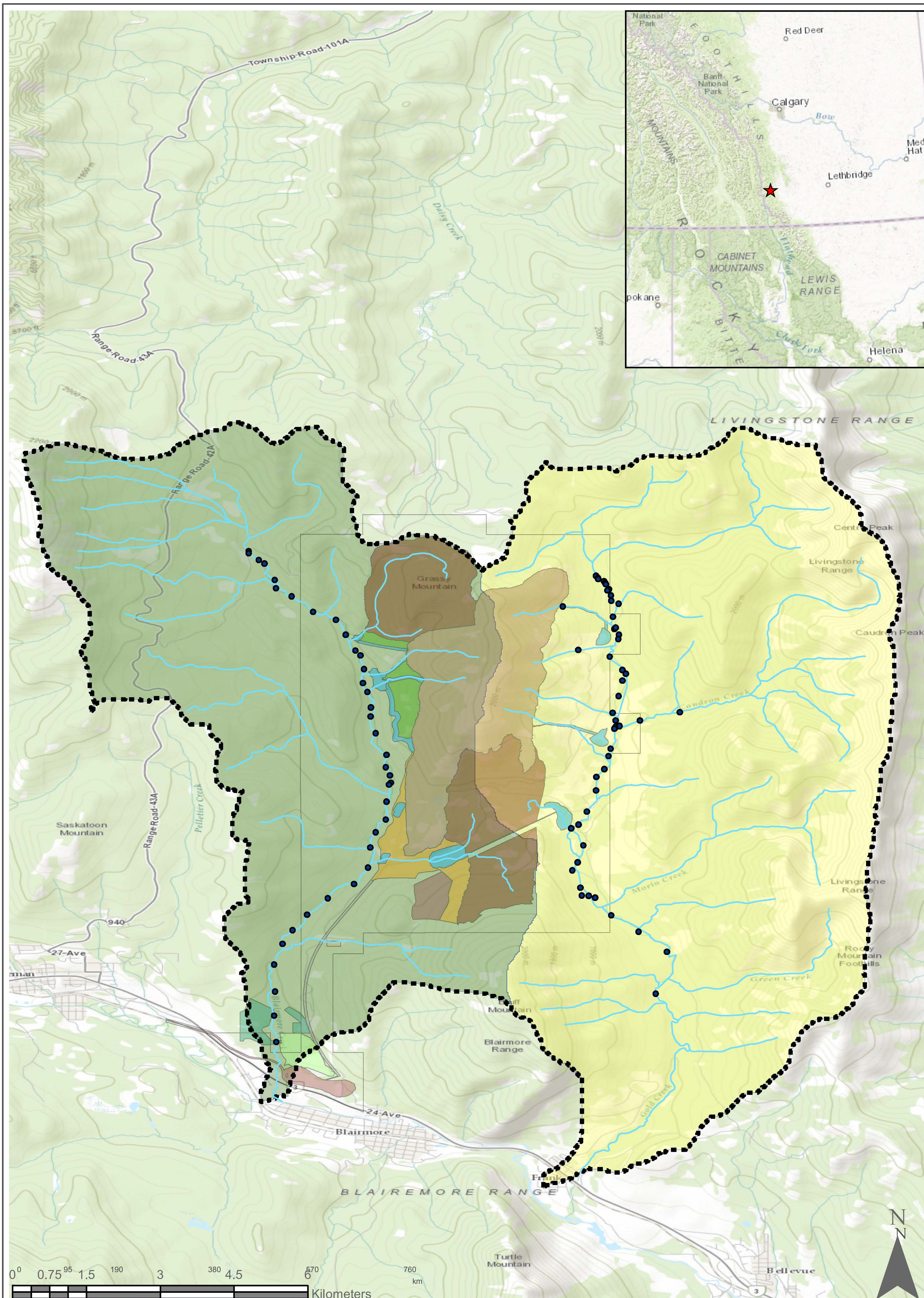
Appendix A

Study Area Maps



LEGEND

- Blairmore Watershed
- Gold Watershed
- Ponds and Ditches
- Non-Disturbed Area
- CHPP Facilities
- Construction Camp
- Topsoil Storage
- Proposed Conveyor Access Powerline ROW
- Existing Golf Course Area
- Proposed Golf Course Area
- Railway Loop
- Proposed Pipeline Service Road
- Ultimate Dump Extent
- Ultimate Pit Extent
- Mine Permit Boundary
- Local Study Area Boundary
- Creeks
- SNC Assessment Sites

NOTES

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

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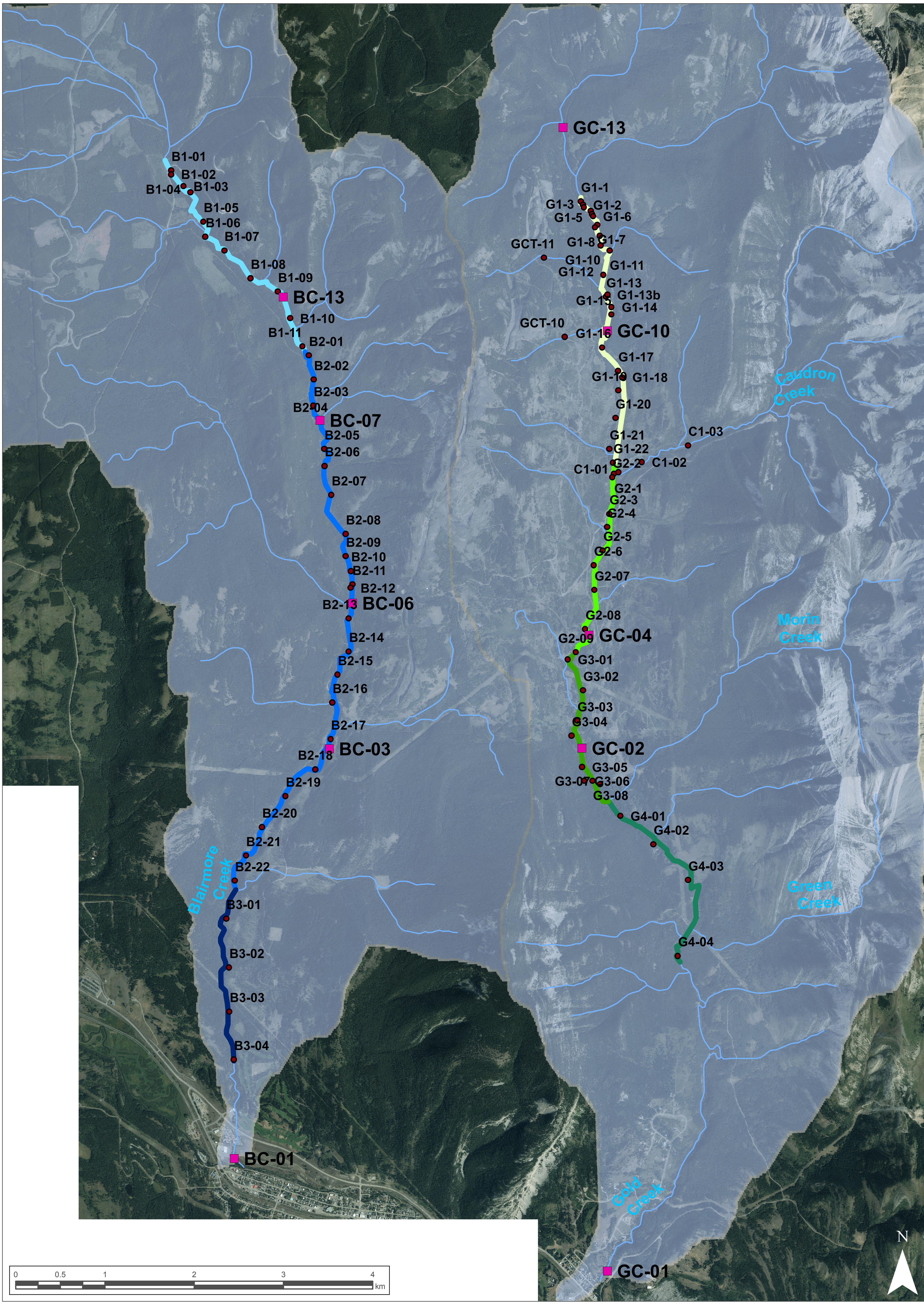
CLIENT NAME:	PROJECT LOCATION:
Benga Mining Ltd.	Blairmore, AB

Figure A-1: Site Location
Grassy Mountain Coal Project

BY: M. Hendershot	DATE: 12/13/2016	REF No: 638486-001
CHK'D: L. Burge	SCALE: 1:73,640	REV: 0

MXD Path: C:\Users\hendm10\Desktop\Templates\Tabloid Portrait Gray Text and Boxes - Downsav



LEGEND

- Nodes
- Field Assessment Sites
- Creeks
- Watershed Boundaries
- G1, G2, G3, G4
- B1, B2, B3

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthopotographs taken in 2015.

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CLIENT NAME: Benga Mining Ltd.	PROJECT LOCATION: Blairmore, AB

Figure A-2: Locations of Field Assessment Sites on Blairmore Creek and Gold Creek

BY: Megan Hendershot	DATE: 12/13/2016	REF No: 638486-002
CHK'D: Leif Burge	SCALE: 1:41,000	REV: 0

Appendix B

Field Data

Table B-1: Field Assessment Data from Gold Creek

Reach Name	Easting	Northing	Reach Type	Channel Planform	D_{50} (mm)	D_{90} (mm)	Depth, Bankfull (m)	Width, Bankfull (m)	W:D	D/d	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																	LB	RB	LB	RB	
G1-1	687515	5509577	Step pool	Irregular meander	60	250	1	5.5	5.50	0.25	3.5	11	Functioning	Fluvial	Riffles	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees
G1-2	687540	5509538	Cascade pool	Irregular wandering	70	180	1.7	7.1	4.18	0.11	3.5	6	Functioning	Fluvial, colluvial	Bars	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees
G1-3	687549	5509511	Riffle pool	Irregular wandering	110	390	1.1	4.9	4.45	0.35	3.5	6	Present	Fluvial	Riffles	Stable	Soft cohesive	Soft cohesive		+	Trees
G1-4	687627	5509470	Cascade pool	Irregular wandering	110	470	0.6	6.2	10.33	0.78	1.8	5.2	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+	+	Trees
G1-5	687641	5509436	Riffle pool	Irregular wandering	87	320	1.4	4.9	3.50	0.23	1.8	8	Functioning	Fluvial	Riffles	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-6	687652	5509412	Cascade-riffle pool	Straight	110	270	0.8	2.7	3.38	0.34	3.5	6	Present	Fluvial, colluvial	Riffles	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-7	687698	5509313	Cascade-riffle pool	Irregular wandering	120	330	0.8	4.7	5.88	0.41	1.8	-	Present	Fluvial	Riffles	Stable	Soft cohesive	Loose non-cohesive	+	+	Trees
G1-8	687676	5509287	Cascade-step pool	Irregular meander	90	370	1.1	3.6	3.27	0.34	5.2	5.6	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive		+	Trees
G1-9	687728	5509191	Plane bed	Irregular wandering	20	290	0.8	8.6	10.75	0.36	1.8	38	Present	Fluvial	Bed	Stable	Soft cohesive	Soft cohesive			Trees and Shrubs
G1-10	687737	5509083	Bedrock-step pool	Irregular meander	85	420	1	8	8.00	0.42	3.5	-	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+		Trees and Shrubs
G1-11	687836	5509026	Riffle pool	Irregular meander	50	400	0.9	4	4.44	0.44	3.5	10	Present	Fluvial	Riffles	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G1-12	687769	5508753	Riffle pool	Irregular wandering	30	270	0.9	5.2	5.78	0.30	1.8	-	Present	Fluvial	Riffles	Stable	Soft-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G1-13	687797	5508509	Cascade-riffle pool	Irregular meander	70	320	0.5	3.6	7.20	0.64	3.5	-	Present	Fluvial	Bars and riffles	Aggraded	Loose non-cohesive	Loose non-cohesive			Trees and Shrubs
G1-13b	687812	5508533	Riffle pool	Irregular wandering	35	210	0.7	4.7	6.71	0.30	3.5	10.2	Functioning	Fluvial	Bars and riffles	Aggraded	Loose non-cohesive	Soft-cohesive	+	+	Trees and Shrubs
G1-14	687860	5508393	Riffle pool	Irregular meander	40	400	1	6.3	6.30	0.40	1.8	9	Present	Fluvial	Bars	Stable	Soft cohesive	Soft cohesive	+	+	Trees
G1-15	687857	5508309	Riffle-step pool	Irregular wandering	65	450	0.8	6.8	8.50	0.56	3.5	6.1	Functioning	Fluvial	Bars and riffles	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-1	687515	5509577	Step pool	Irregular meander	60	250	1	5.5	5.50	0.17	3.5	11	Functioning	Fluvial	Riffles	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees
G1-2	687540	5509538	Cascade pool	Irregular wandering	70	180	1.7	7.1	4.18	0.40	3.5	6	Functioning	Fluvial, colluvial	Bars	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees
G1-3	687549	5509511	Riffle pool	Irregular wandering	110	390	1.1	4.9	4.45	0.60	3.5	6	Present	Fluvial	Riffles	Stable	Soft cohesive	Soft cohesive		+	Trees
G1-4	687627	5509470	Cascade pool	Irregular wandering	110	470	0.6	6.2	10.33	0.59	1.8	5.2	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+	+	Trees
G1-5	687641	5509436	Riffle pool	Irregular wandering	87	320	1.4	4.9	3.50	0.25	1.8	8	Functioning	Fluvial	Riffles	Stable	Soft cohesive	Soft cohesive	+	`+	Trees and Shrubs
G1-6	687652	5509412	Cascade-riffle pool	Straight	110	270	0.8	2.7	3.38	0.11	3.5	6	Present	Fluvial, colluvial	Riffles	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-17	687931	5507679	Step pool	Irregular wandering	35	290	0.72	6.8	9.44	0.35	1.8	12.7	Present	Fluvial	Bars and riffles	Stable	Soft cohesive	Soft cohesive		+	Trees and Shrubs

Table B-1 (Cont'd): Field Assessment Data from Gold Creek

Reach Name	Easting	Northing	Reach Type	Channel Planform	D_{50} (mm)	D_{90} (mm)	Depth, Bankfull (m)	Width, Bankfull (m)	W:D	D/d	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																	LB	RB	LB	RB	
G1-18	687979	5507607	Cascade pool	Irregular wandering	25	480	0.8	6.1	7.63	0.78	1.8	11	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive		+	Trees and Shrubs
G1-19	687936	5507459	Cascade pool	Irregular wandering	30	470	0.8	5.6	7.00	0.23	0	10	Present	Fluvial, banks	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+		Shrubs
G1-20	687902	5507149	Step pool	Irregular wandering	50	590	0.9	4.2	4.67	0.66	3.5	10	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-21	687833	5506803	Step pool	Irregular wandering	40	550	0.7	6.2	8.86	0.79	1.8		Present	Fluvial, banks	Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs
G1-22	687877	5506650	Bedrock-step pool	Irregular meander	50	630	0.7	6.6	9.43	0.90	3.5	14	Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
G2-1	687886	5506526	Cascade-riffle pool	Irregular wandering	50	410	0.7	8.9	12.71	0.59	7	2.9	Present	Fluvial, colluvial	Bars, lee of D_{90}	Stable	Loose non-cohesive	Soft cohesive	+		Trees and Shrubs
G2-2	687868	5506488	Step pool	Irregular wandering	55	650	0.9	5.1	5.67	0.72	12.3	2.5	Present	Fluvial, banks	Bed, stoss of D_{90}	Stable	Loose non-cohesive	Soft-cohesive		+	Trees and Shrubs
G2-3	687833	5506076	Cascade-riffle pool	Irregular wandering	45	210	1.1	14	12.73	0.19	3.5	17	Controlling	Banks, colluvial	Bed	Avulsed	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G2-4	687810	5505927	Cascade-riffle pool	Irregular meander	40	340	0.9	8.1	9.00	0.38	5.2		Present	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Loose non-cohesive	Soft-cohesive		+	Trees and Shrubs
G2-5	687762	5505666	Cascade-step pool	Irregular wandering	30	430	1.1	10	9.09	0.39	3.5	11	Functioning	Banks, fluvial	Bars, lee of D_{90}	Stable	Loose non-cohesive	Soft-cohesive	+	+	Trees
G2-6	687660	5505500	Riffle pool	Irregular wandering	30	310	0.8	9.2	11.50	0.39	3.5	26	Present	Fluvial, banks	Bars	Stable	Soft-cohesive	Loose non-cohesive		+	Trees and Shrubs
G2-7	687666	5505223	Cascade pool	Irregular wandering	45	380	1.1	7.7	7.00	0.35	5.2	15	Functioning	Banks, fluvial	Bars, stoss of D_{90}	Stable	Soft-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G2-8	687562	5504786	Cascade-riffle pool	Irregular meander	85	560	0.9	6.2	6.89	0.62	5.2	19	Present	Banks, fluvial	Riffles	Stable	Loose non-cohesive	Soft-cohesive		+	Trees and Shrubs
G2-9	687460	5504525	Step pool	Irregular meander	35	540	1.1	6.6	6.00	0.49	5.2	15	Functioning	Banks, fluvial	Stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G3-1	687368	5504445	Riffle pool	Irregular meander	50	450	0.8	11.5	14.38	0.56	5.2	17.5	Functioning	Fluvial, banks	Bars and riffles	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees and Shrubs
G3-2	687539	5504099	Riffle pool	Irregular wandering	40	240	1.2	8	6.67	0.20	3.5	19.6	Functioning	Fluvial	Riffles	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
G3-3	687475	5503758	Plane bed	Irregular wandering	40	290	0.7	3.2	4.57	0.41	2.6	N/A	Functioning	Banks, fluvial	Bed	Degraded	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
G3-4	687412	5503591	Riffle pool	Irregular meander	80	430	0.9	8.8	9.78	0.48	4.4	24.4	Functioning	Banks, fluvial	Bars and riffles	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
G3-5	687529	5503240	Plane bed	Irregular meander	20	110	0.2	5.5	27.50	0.55	4.4	N/A	Functioning	Fluvial	Bed	Aggraded	Loose non-cohesive	Loose non-cohesive			Trees and Shrubs
G3-6	687553	5503085	Riffle pool	Irregular wandering	25	190	0.3	6.5	21.67	0.63	0.9	11.4	Present	Fluvial	Bars and riffles	Stable	Loose non-cohesive	Loose non-cohesive			Trees and Shrubs
G3-7	687731	5503047	Riffle pool	Irregular meander	20	100	1	5.2	5.20	0.10	3.5	10.2	Functioning	Fluvial	Bars	Stable	Soft-cohesive	Loose non-cohesive	+		Trees and Shrubs
G3-8	687646	5503084	Riffle pool	Irregular wandering	25	310	0.6	2.6	4.33	0.52	0.9	7.7	Present	Fluvial	Riffle, Lee/stoss of D_{90}	Stable	Soft cohesive	Soft cohesive			Trees and Shrubs
G4-1	687958	5502694	Bedrock-riffle pool	Regular meander	30	640	0.7	6.3	9.00	0.91	0.9	5.2	Present	Fluvial, banks	Bars	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
G4-2	688328	5502375	Plane bed	Irregular wandering	50	230	0.4	6.1	15.25	0.58	0.9	N/A	Present	Fluvial, banks	Bed	Stable	Soft cohesive	Soft cohesive		+	Trees and Shrubs

Table B-1: (cont'd) Field Assessment Data from Gold Creek

Reach Name	Easting	Northing	Reach Type	Channel Planform	D_{50} (mm)	D_{90} (mm)	Depth, bankfull (m)	Width, bankfull (m)	W:D	D/d	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																	LB	RB	LB	RB	
G4-3	688715	5501974	Cascade pool	Irregular wandering	30	230	0.7	7	10.00	0.33	1.8	24	Present	Fluvial, colluvial	Bars	Stable	Loose non-cohesive	Soft-cohesive			Trees and Shrubs
G4-4	688600	5501125	Step pool	Irregular meander	50	460	0.4	6	15.00	1.15	3.5	28	Functioning	Fluvial, colluvial	Bars, pools, lee of D_{90}	Stable	Soft cohesive	Soft cohesive	+	+	Trees and Shrubs

Table B-2: Field Assessment Data from Blairmore Creek

Reach Name	Easting	Northing	Reach Type	Channel Planform	D_{50} (mm)	D_{90} (mm)	Depth, bankfull (m)	Width, bankfull (m)	W:D	D/d	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																	LB	RB	LB	RB	
B1-01	682925	5509923	Riffle pool	Irregular meander	25	320	0.8	6.5	8.13	0.40	3.5	9	Functioning	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B1-02	682924	5509881	Cascade-riffle pool	Irregular meander	20	280	0.8	3.6	4.50	0.35	5.2	9	Controlling	Banks, fluvial, colluvial	Bars, above logs	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B1-03	683064	5509746	Riffle pool	Irregular meander	40	230	0.6	4.2	7.00	0.38	1.8	12	Functioning	Banks	Bed	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B1-04	683139	5509677	Cascade-riffle pool	Regular meander	40	390	0.9	4.9	5.44	0.43	3.5	12	Present	Banks, fluvial	Lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B1-05	683288	5509350	Step pool	Regular meander	Bedrock	Bedrock	0.7	4.1	5.86	N/A	5.2	N/A	Present	N/A	N/A	Stable	Soft-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B1-06	683308	5509181	Riffle pool	Irregular meander	30	240	0.7	5.4	7.71	0.34	1.8	16	Present	Fluvial	Bar	Stable	Soft cohesive	Loose non-cohesive		+	Trees, shrubs, and grass
B1-07	683521	5509027	Cascade-riffle pool	Regular meander	30	390	0.7	6.5	9.29	0.56	1.8	9	Present	Banks	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive		+	Trees and Shrubs
B1-08	683814	5508715	Riffle pool	Regular meander	30	390	0.8	7.3	9.13	0.49	1.8	30	Present	Banks, fluvial	Bars	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B1-09	684120	5508566	Cascade-riffle pool	Irregular meander	40	540	0.5	6.6	13.20	1.08	3.5	N/A	Functioning	Banks	Bars, lee/stoss of D_{90}	Aggraded	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B1-10	684259	5508268	Bedrock-Cascade pool	Straight	40	430	0.8	4	5.00	0.54	5.2	10	Functioning	Fluvial, colluvial	Lee/stoss of D_{90}	Stable	Bedrock	Loose non-cohesive		+	Trees and Shrubs
B1-11	684279	5508188	Cascade-Riffle pool	Irregular meander	15	360	0.4	5.3	13.25	0.90	3.5	10	Functioning	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B2-01	684467	5507852	Riffle-step pool	Tortuous meander	30	380	1.3	8.8	6.77	0.29	3.5	13	Functioning	Banks, Bars	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B2-02	684523	5507581	Cascade-riffle pool	Irregular wandering	35	360	0.26	6.4	24.62	1.38	4.4	5.8	Present	Banks, fluvial	Lee of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees
B2-03	684520	5507290	Cascade-riffle pool	Irregular meander	30	520	1.1	9.4	8.55	0.47	1.8	21	Present	Banks, colluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Grass
B2-04	684584	5507113	Step pool	Irregular meander	45	360	1.1	6.5	5.91	0.33	3.5	9	Controlling	Banks	Bars, lee/stoss of D_{90}	Presently infilling (Log jam)	Loose non-cohesive	Loose non-cohesive	+	+	Trees
B2-05	684640	5506804	Cascade-riffle pool	Irregular wandering	30	480	1.1	11.8	10.73	0.00	1.8	16	Functioning	Banks, fluvial, colluvial	Bars, stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive			Trees and Grass

Table B-2 (Cont'd): Field Assessment Data from Blairmore Creek

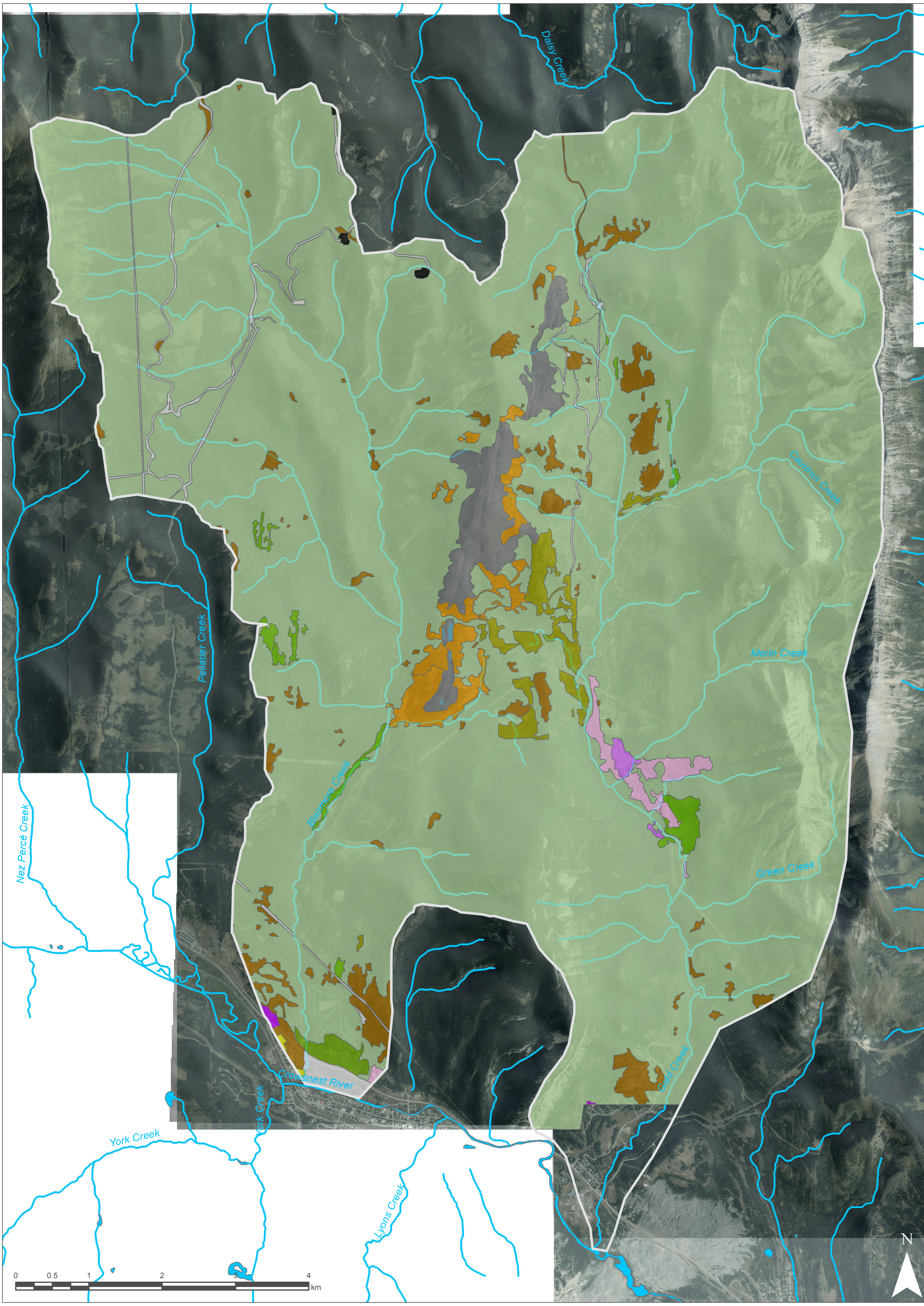
Reach Name	Easting	Northing	Reach Type	Channel Planform	D50 (mm)	D90 (mm)	Depth, bankfull (m)	Width, bankfull (m)	W:D	D/d	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																	LB	RB	LB	RB	
B2-06	684644	5506614	Cascade-riffle pool	Irregular meander	30	400	1.3	11.1	8.54	3.08	1.8	20	Functioning	Colluvial, banks	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B2-07	684721	5506289	Step pool	Irregular wandering	40	500	0.5	6.6	13.20	10.00	1.8	8	Present	Banks, fluvial	Stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees, shrubs, and grass
B2-08	684880	5505851	Cascade-riffle pool	Irregular meander	30	310	0.74	6.8	9.19	4.19	3.5	22	Controlling	Fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive			Trees and Shrubs
B2-09	684879	5505602	Cascade-riffle pool	Irregular wandering	60	770	1	5.9	5.90	7.70	5.2	6	None	Banks, fluvial	Bars	Stable		Loose-coarse and bedrock	+		Trees and Shrubs
B2-10	684939	5505437	Riffle pool	Irregular meander	15	110	0.8	9.8	12.25	1.38	0	12	Controlling	Fluvial	Bars	Aggraded	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B2-11	684955	5505287	Cascade-riffle pool	Irregular wandering	25	380	1.1	6.8	6.18	3.45	3.5	10	Functioning	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B2-12	684934	5505248	Cascade-riffle pool	Regular meander	30	350	0.8	6.2	7.75	4.38	3.5	14	Present	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive			Trees
B2-13	684913	5504903	Cascade-riffle pool	Regular meander	35	330	0.8	7.1	8.88	4.13	1.8	26	Present	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees and Shrubs
B2-14	684916	5504534	Bedrock-riffle pool	Regular meander	50	320	0.6	8.9	14.83	5.33	1.8	6.6	Present	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B2-15	684791	5504276	Bedrock-step pool	Irregular wandering	50	340	0.8	6.5	8.13	4.25	5.2	N/A	Present	Fluvial	Bars and pools	Stable		Bedrock		+	Trees and Shrubs
B2-16	684791	5504276	Bedrock-step pool	Irregular wandering	30	1030	0.9	6	6.67	11.44	3.5	11	Present	Fluvial, banks	Bar	Stable		Loose-coarse and Bedrock			Trees
B2-17	684714	5503553	Cascade-riffle pool	Irregular wandering	110	390	0.47	6.1	12.98	8.30	1.8	9	Present	Banks	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees
B2-18	684541	5503215	Bedrock-step pool	Irregular wandering	120	750	0.5	4.3	8.60	15.00	3.5	4.5	Present	Banks, fluvial	Banks	Stable	Loose non-cohesive	Loose non-cohesive	+	+	Trees
B2-19	684207	5502915	Bedrock-step pool	Irregular wandering	75	330	0.9	6.5	7.22	3.67	3.5	12	Present	Banks, colluvial	Bars, lee/stoss of D_{90}/bed	Stable		Bedrock			Trees and Shrubs
B2-20	683942	5502568	Bedrock-step pool	Irregular wandering	50	590	1	7.3	7.30	5.90	3.5	13	Present	Banks, fluvial	Bar	Stable	Loose non-cohesive	Loose non-cohesive	+		Trees and Shrubs
B2-21	683764	5502249	Bedrock-step pool	Irregular wandering	20	370	0.5	8.8	17.60	7.40	3.5	31	Present	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable		Loose-coarse and bedrock		+	Trees
B2-22	683638	5501967	Riffle pool	Irregular meander	30	240	0.4	9.8	24.50	6.00	3.5	38	Present	Fluvial	Bars	Stable	Loose non-cohesive	Loose non-cohesive			Trees and Shrubs
B3-01	683542	5501542	Bedrock-step pool	Irregular wandering	70	450	0.8	9.7	12.13	5.63	1.8	-	Present	Fluvial, colluvial	Bars, pools, lee of D_{90}	Stable		Loose non-cohesive/ bedrock			Trees

Table B-2 (Cont'd): Field Assessment Data from Blairmore Creek

Reach Name	Easting	Northing	Reach Type	Channel Planform	D50 (mm)	D90 (mm)	Depth, bankfull (m)	Width, bankfull (m)	W:D	Slope (%)	Bedform Spacing (m)	LWD	Sediment Source	Sediment Storage	Channel Stability	Bank Material		Bank Erosion		Floodplain Vegetation
																LB	RB	LB	RB	
B3-02	683574	5500996	Bedrock-step pool	Irregular wandering	55	730	0.5	6.3	12.60	14.60	3.5	15	Present	Fluvial, colluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive/bedrock			Trees
B3-03	683578	5500500	Bedrock-step pool	Irregular wandering	25	540	0.7	7	10.00	7.71	1.8	10	Present	Fluvial, banks	Bars	Stable	Loose non-cohesive			Trees and Shrubs
B3-04	683626	5499965	Bedrock-step pool	Irregular wandering	95	600	0.7	8.7	12.43	8.57	3.5	6	Present	Fluvial, colluvial	Bars, pools, lee/stoss of D_{90}	Stable	Loose non-cohesive/bedrock			Shrubs
B1-01	682925	5509923	Riffle pool	Irregular meander	25	320	0.8	6.5	8.13	4.00	3.5	9	Functioning	Banks, fluvial	Bars, lee/stoss of D_{90}	Stable	Loose non-cohesive	+		Trees and Shrubs
B1-02	682924	5509881	Cascade-riffle pool	Irregular meander	20	280	0.8	3.6	4.50	3.50	5.2	9	Controlling	Banks, fluvial, colluvial	Bars, above logs	Stable	Loose non-cohesive	+	+	Trees and Shrubs
B1-03	683064	5509746	Riffle pool	Irregular meander	40	230	0.6	4.2	7.00	3.83	1.8	12	Functioning	Banks	Bed	Stable	Loose non-cohesive	+	+	Trees and Shrubs
B1-04	683139	5509677	Cascade-riffle pool	Regular meander	40	390	0.9	4.9	5.44	4.33	3.5	12	Present	Banks, fluvial	Lee/stoss of D_{90}	Stable	Loose non-cohesive	+		Trees and Shrubs

Appendix C

Land Use Maps



LEGEND

- Local Study Area
- Watercourse
- Waterbody

Land Use

- Agricultural/Grazing
- Former Dwelling
- Former Manufacturing and Storage
- Commercial
- Dwelling
- Surface Extraction
- Pumping (Oil and Gas)
- Extraction Handling
- Logging
- Forest Management
- Transportation
- No Perceived Activity
- Recreational

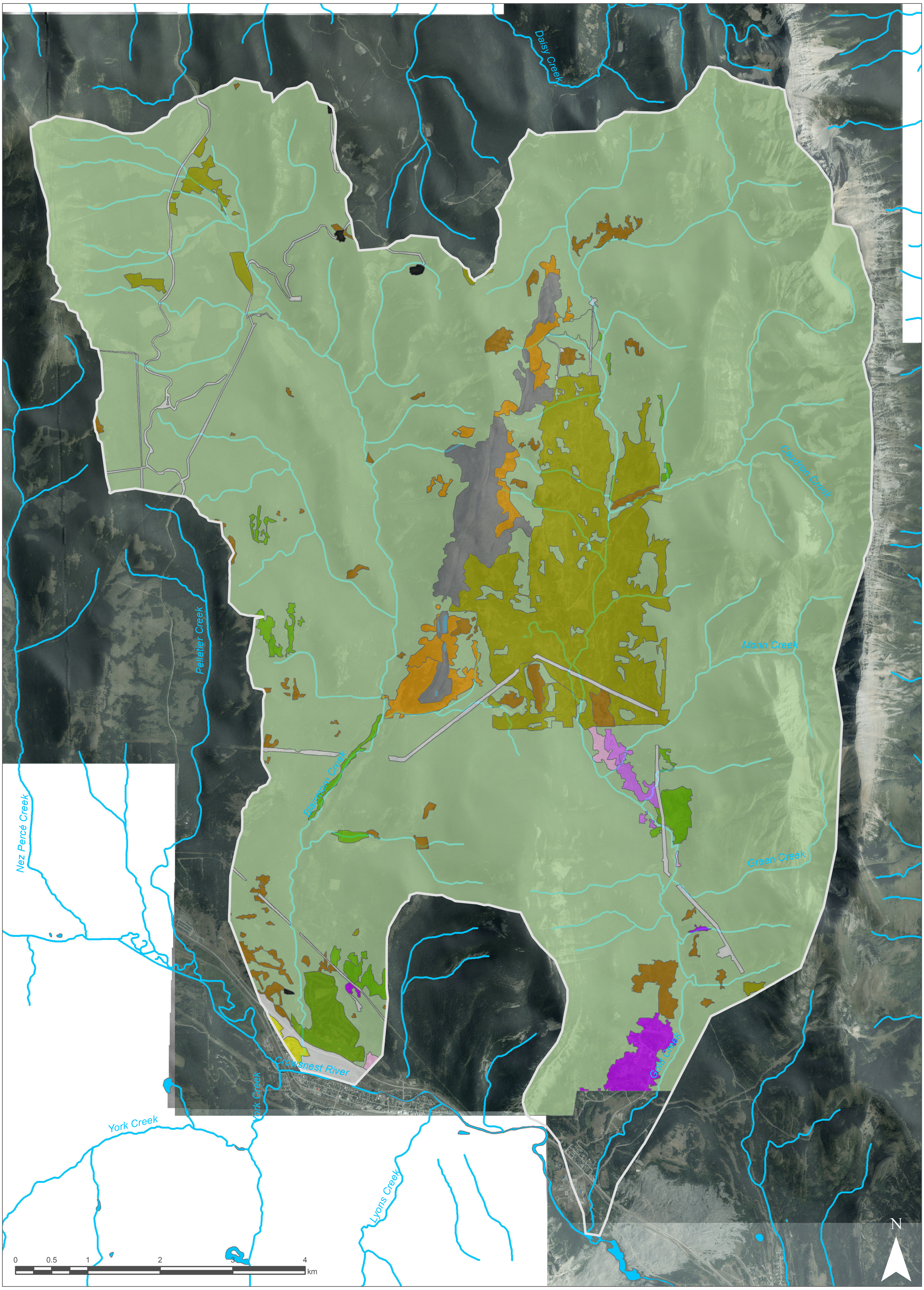
NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

SNC·LAVALIN

CLIENT NAME: Benga Mining Ltd.	PROJECT LOCATION: Blairmore, AB	
Figure C-1: Grassy Mountain Coal Project 1982 Land Use Map		
BY: Hawley Beaugrand	DATE: 2016/11/27	REF No: 638486-003
CHK'D: Leif Burge	SCALE: 1:50,000	REV: 0

MXD Path: C:\Users\BEAUH6.SLI\Documents\Projects\Hatfield\GIS\GrassyMountainMaps.mxd



LEGEND

Local Study Area	
Watercourse	
Waterbody	

Land Use

- Agricultural/Grazing
- Former Dwelling
- Former Manufacturing and Storage
- Commercial
- Dwelling
- Surface Extraction
- Pumping (Oil and Gas)
- Extraction Handling
- Logging
- Forest Management
- Transportation
- No Perceived Activity
- Recreational

NOTES

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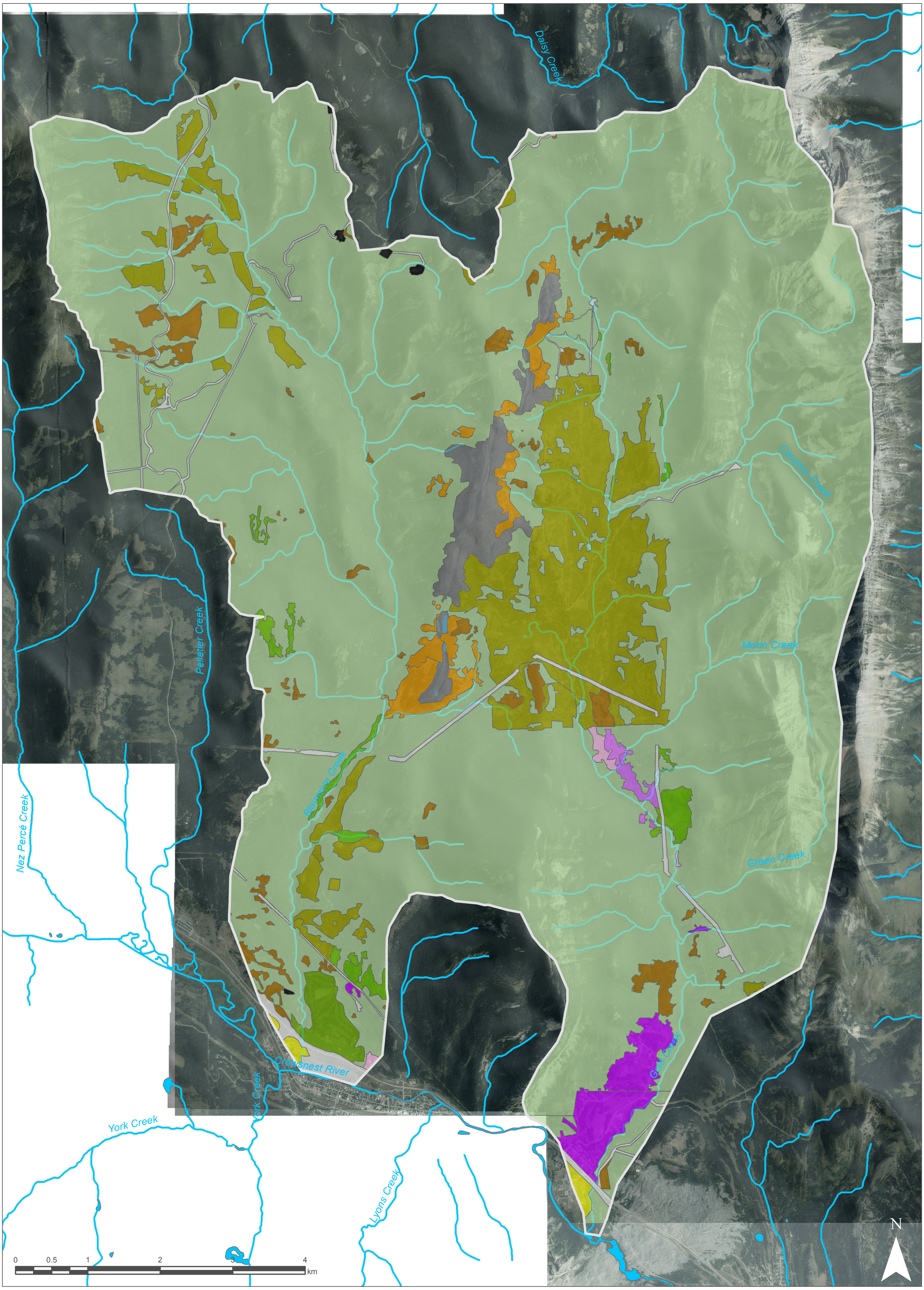
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

SNC·LAVALIN

CLIENT NAME: Benga Mining Ltd.
PROJECT LOCATION: Blairmore, AB

Figure C-2: Grassy Mountain Coal Project 1996 Land Use Map

BY: Hawley Beaugrand	DATE: 2016/11/27	REF No: 638486-004
CHK'D: Leif Burge	SCALE: 1:50,000	REV: 0



LEGEND

- Local Study Area
- Watercourse
- Waterbody

Land Use

- Agricultural/Grazing
- Former Dwelling
- Former Manufacturing and Storage
- Commercial
- Dwelling
- Surface Extraction
- Pumping (Oil and Gas)
- Extraction Handling
- Logging
- Forest Management
- Transportation
- No Perceived Activity
- Recreational

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

SNC·LAVALIN

CLIENT NAME: Benga Mining Ltd.

PROJECT LOCATION: Blairmore, AB

Figure C-3: Grassy Mountain Coal Project 2015 Land Use Map

BY: Hawley Beaugrand	DATE: 2016/11/27	REF No: 638486-005
CHK'D: Leif Burge	SCALE: 1:50,000	REV: 0

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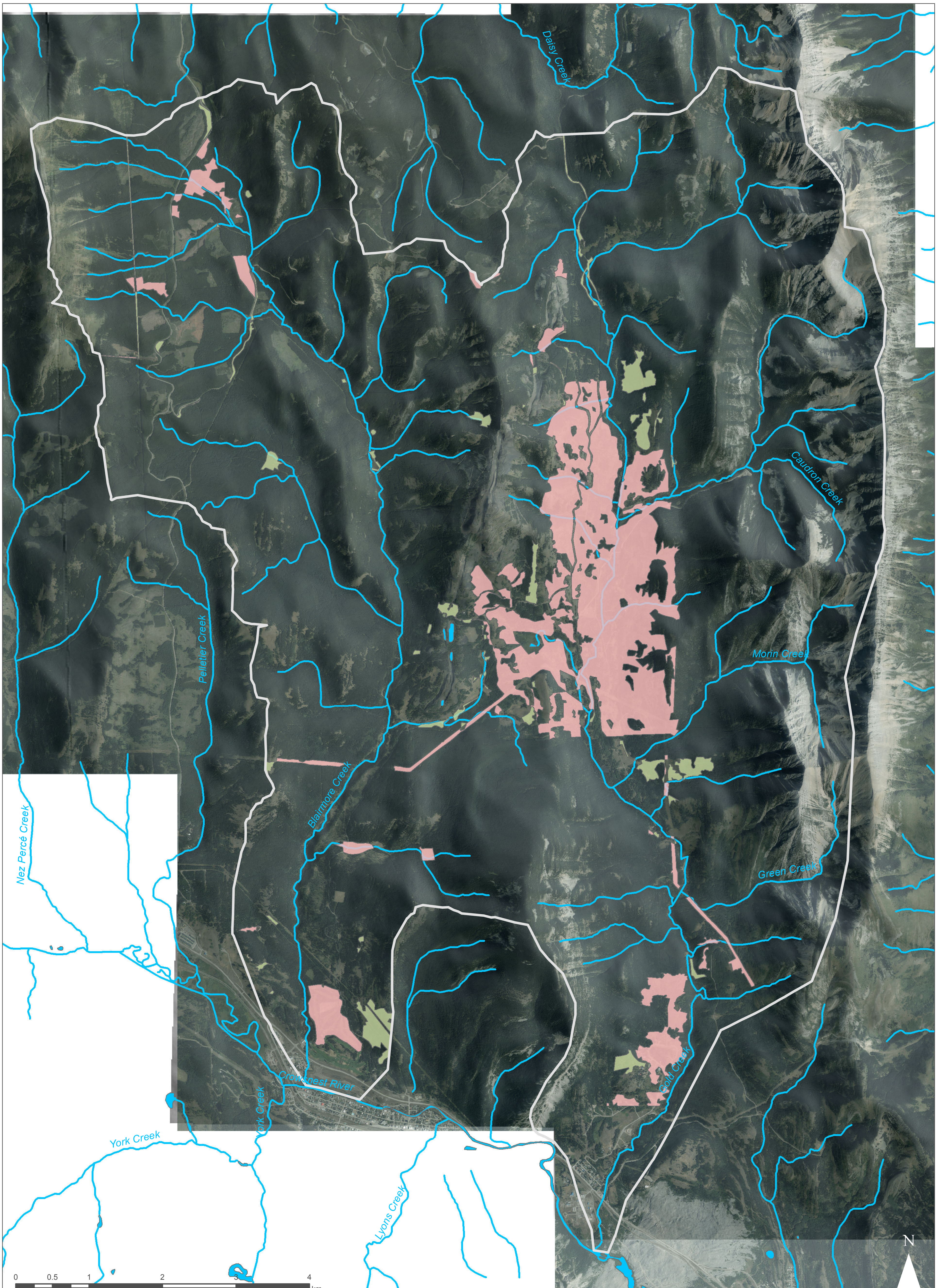


LEGEND

- Local Study Area
- Watercourse
- Waterbody

Land Use Change

- Decrease Perceived Activity
- No Change
- Increase Perceived Activity

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

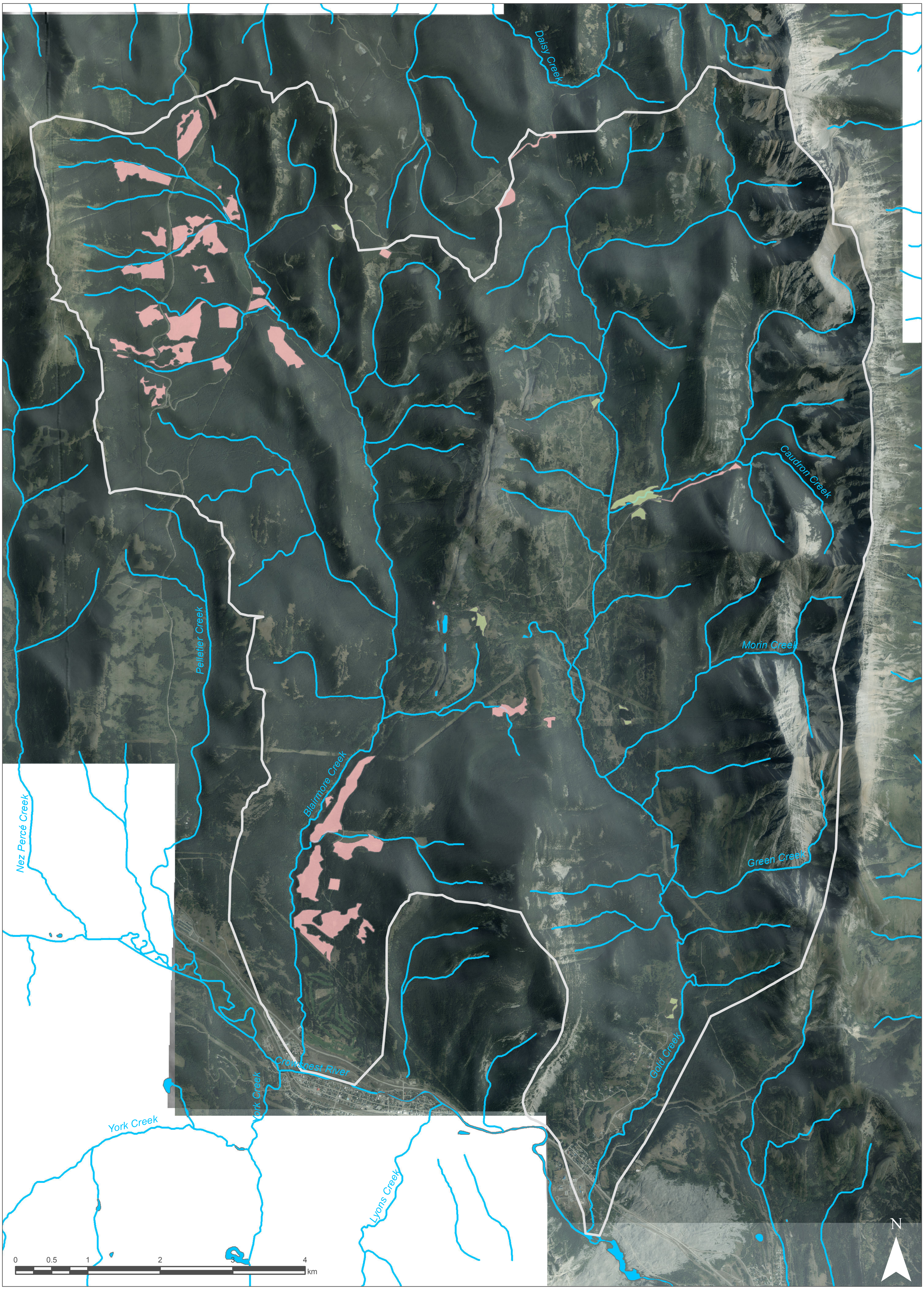
SNC·LAVALIN

CLIENT NAME:	PROJECT LOCATION:
Benga Mining Ltd.	Blairmore, AB

Figure C-4: Grassy Mountain Coal Project Land Use Change 1982 - 1996

BY: Hawley Beaugrand	DATE: 2016/11/27	REF No: 638486-006
CHK'D: Leif Burge	SCALE: 1:50,000	REV: 0

MXD Path: C:\Users\BEAUH6.SLI\Documents\Projects\Hatfield\GIS\GrassyMountainMaps.mxd



LEGEND

Local Study Area
Watercourse
Waterbody

Land Use Change

Decrease Perceived Activity
No Change
Increase Perceived Activity

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

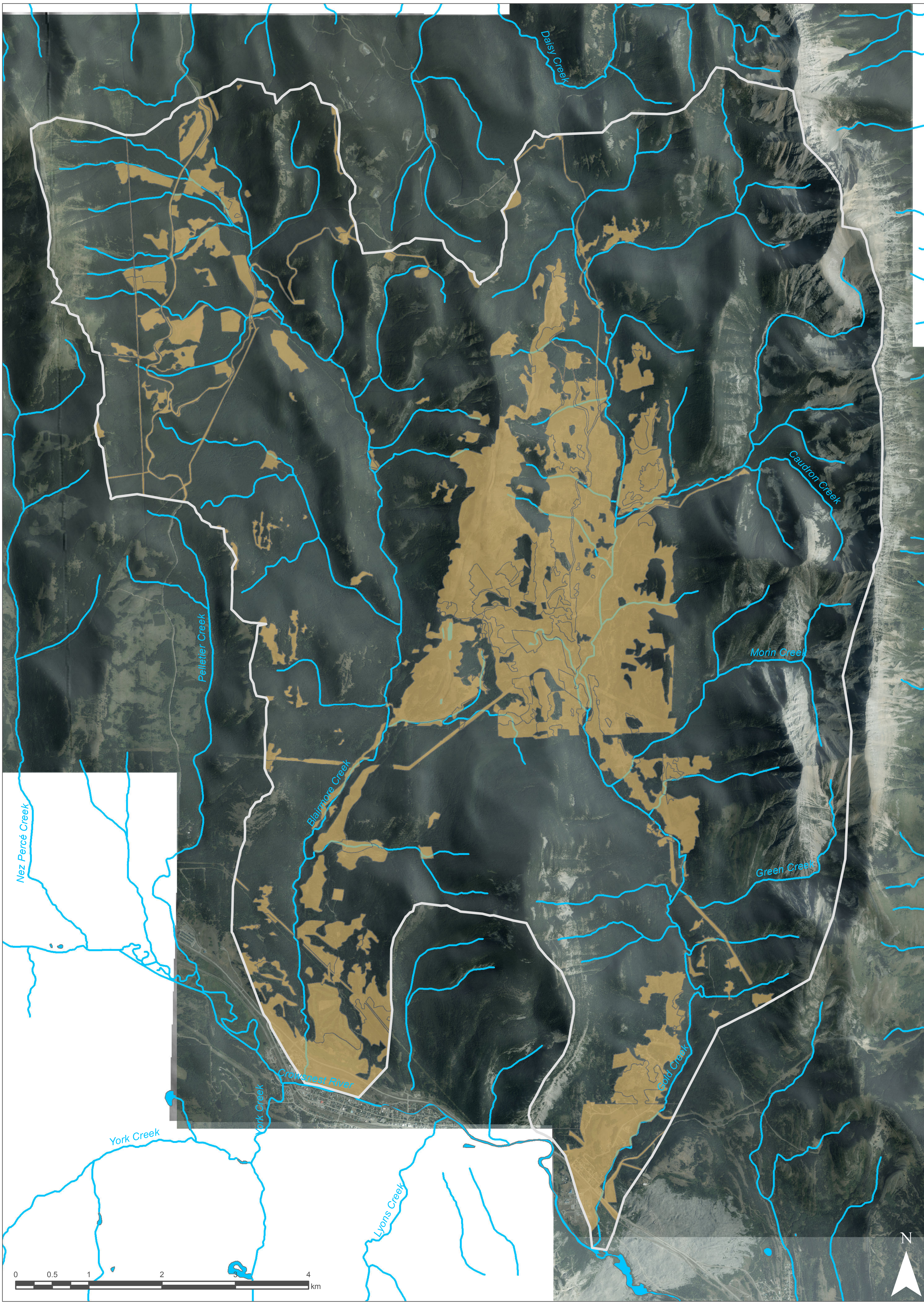
SNC·LAVALIN

CLIENT NAME: Benga Mining Ltd.
PROJECT LOCATION: Blairmore, AB

Figure C-5: Grassy Mountain Coal Project Land Use Change 1996 - 2015

BY: Hawley Beaugrand | DATE: 2016/11/27 | REF No: 638486-007
CHK'D: Leif Burge | SCALE: 1:50,000 | REV: 0

MXD Path: C:\Users\BEAUH6.SLI\Documents\Projects\Hatfield\GIS\GrassyMountainMaps.mxd



LEGEND

- Local Study Area
- Watercourse
- Waterbody

Land Use

- Perceived Activity
- No Perceived Activity

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthophotographs taken in 2015.

SNC·LAVALIN

CLIENT NAME:	PROJECT LOCATION:
Benga Mining Ltd.	Blairmore, AB

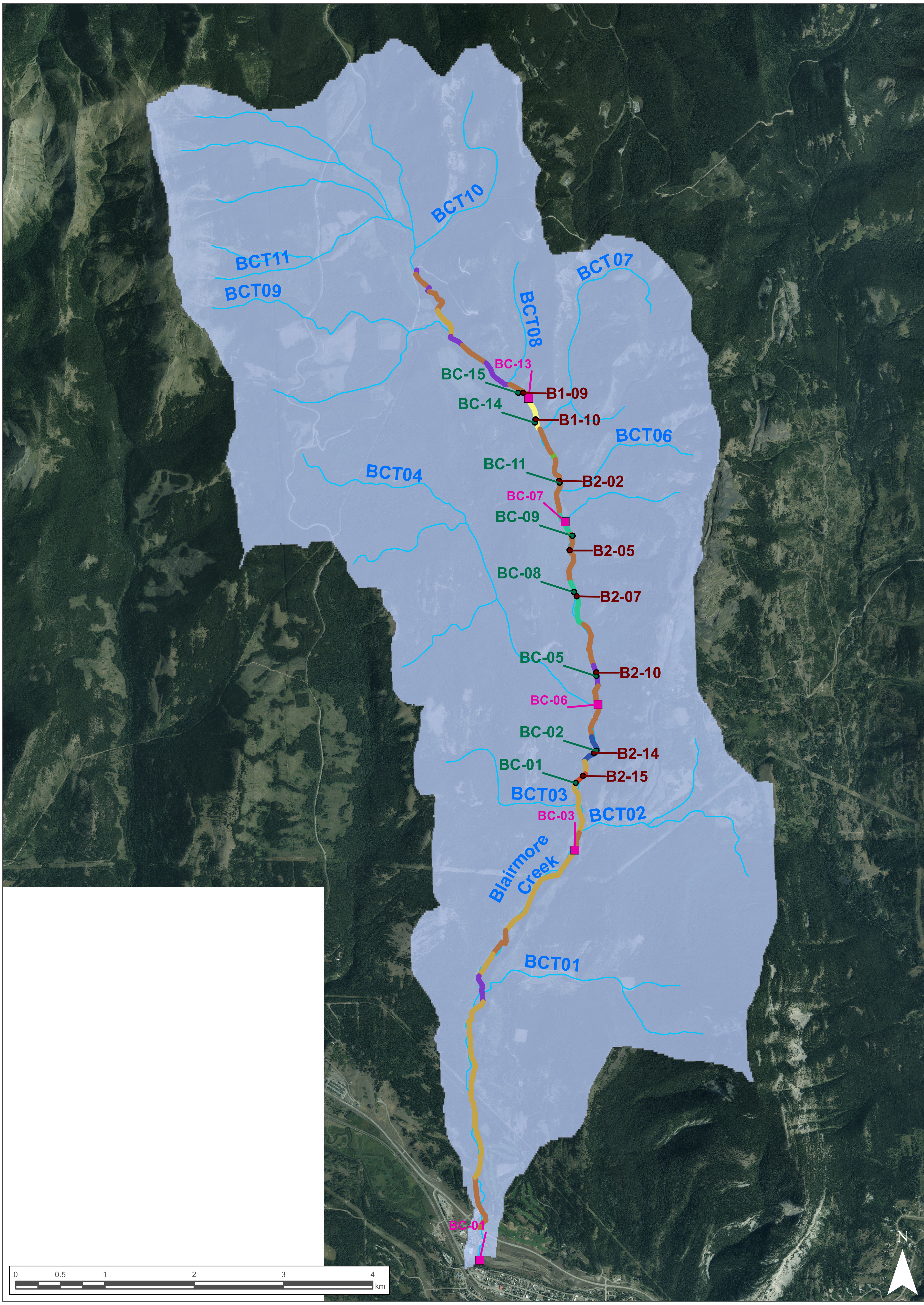
Figure C-6: Grassy Mountain Coal Project Total Land Use 1982 - 2015

BY: Hawley Beaugrand	DATE: 2016/11/27	REF No: 638486-008
CHK'D: Leif Burge	SCALE: 1:50,000	REV: 0

MXD Path: C:\Users\BEAUH6.SLI\Documents\Projects\Hatfield\GIS\GrassyMountainMaps.mxd

Appendix D

Reach Morphologies



LEGEND

- Bedrock-Cascade pool
- Bedrock-Riffle pool
- Bedrock-Step pool
- Cascade pool
- Cascade-Riffle pool
- Cascade-Step pool
- Plane bed
- Riffle pool
- Riffle-Step pool
- Step pool
- Tributaries
- Nodes
- Hatfield Sites
- SNC Sites

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthopotographs taken in 2015.

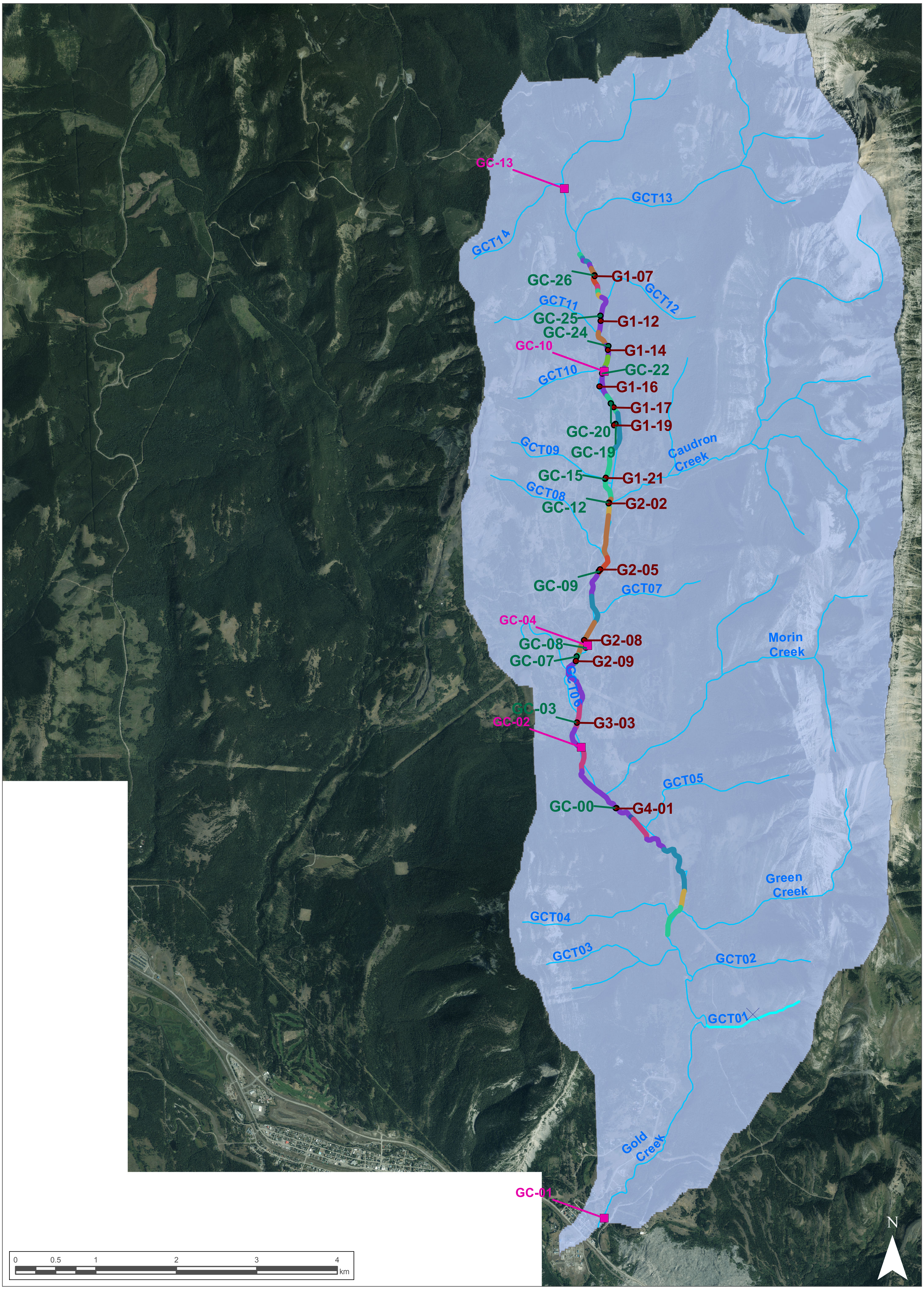
SNC·LAVALIN

CLIENT NAME:	PROJECT LOCATION:
Benga Mining Ltd.	Blairmore, AB

Figure D-1: Reach Morphologies on Blairmore Creek

BY: Megan Hendershot	DATE: 12/12/2016	REF No: 638486-009
CHK'D: Leif Burge	SCALE: 1:41,000	REV: 0

MXD Path: C:\Users\hendm10\Desktop\Blairmore Gold Creeks\4.0 Execution\4.5 GIS and Drawings\GIS\Megan_GIS\AppendixD.mxd



LEGEND

- Bedrock-Riffle pool
- Bedrock-Step pool
- Cascade pool
- Cascade-Riffle pool
- Cascade-Step pool
- Plane bed
- Riffle pool
- Riffle-Step pool
- Step pool
- Tributaries
- Nodes
- Hatfield Sites
- SNC Sites

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.
4. Orthopotographs taken in 2015.

SNC·LAVALIN

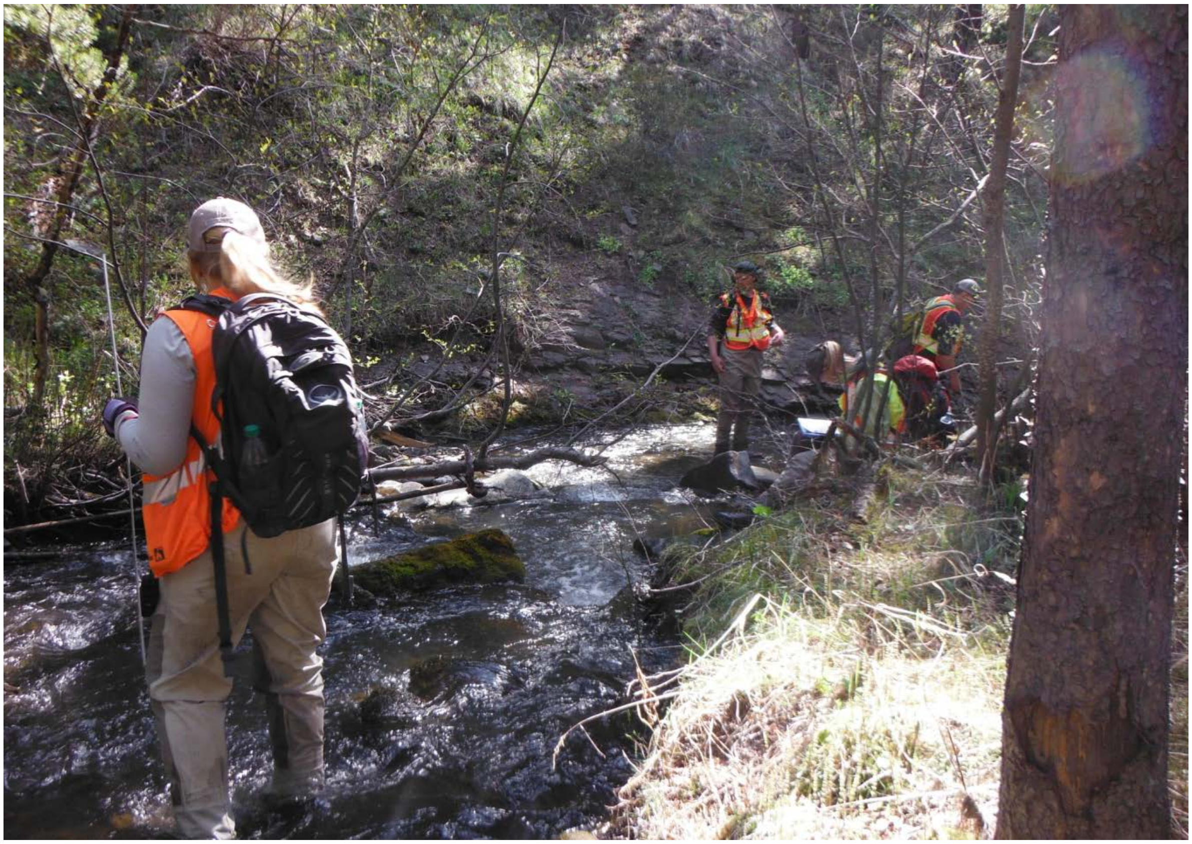
CLIENT NAME:	PROJECT LOCATION:
Benga Mining Ltd.	Blairmore, AB

Figure D-2: Reach Morphologies on Gold Creek

BY: Megan Hendershot	DATE: 12/12/2016	REF No: 638486-010
CHK'D: Leif Burge	SCALE: 1:45,000	REV: 0

Appendix E

Field Photographs



F- 2 Cascade flowing into a riffle section near site B1-04.

F- 3 Rejoining of a bifurcation in a cascade-riffle pool reach on Blairmore Creek near B1-07.

1.1 Blairmore Creek

1.1.1 Confluence of BCT-10 and Blairmore Creek to Node BC-13

F- 1 LWD-forced cascade-riffle section on Blairmore Creek near B1-02.

F- 4 Riffle pool morphology at site B1-09 on Blairmore Creek.

F- 5 Looking downstream toward a bedrock-cascade pool reach on Blairmore Creek near site B1-10.

F- 6 Downstream-facing view of a riffle with bedrock confinement on the left bank. Image taken near site B2-02.

1.1.2 Node BC-07 to Node BC-06

F- 7 Step pool morphology near site B2-07 on Blairmore Creek.

F- 8 Riffle pool sequence with lateral bars at site B2-10 on Blairmore Creek.

1.1.3 Node BC-06 to Node BC-03

F- 9 Bedrock-riffle pool with a lateral bar near site B2-14.

1.1.4 Node BC-03 to Node BC-01

F- 10 Bedrock-step pools near site B3-01 on Blairmore Creek.

1.2 GOLD CREEK

1.2.1 Node GC-13 to Node GC-10

F- 11 Step pool morphology in Upper Gold Creek near site G1-01.

F- 12 Cascade with LWD jam near site G1-04 on Gold Creek.

F- 13 Upper Gold Creek riffle pool reach with lateral bars at site G1-12.

F- 14 Step pool transition into riffle pool at site G1-15.

1.2.2 Node GC-10 to Node GC-04

F- 15 Looking downstream toward a step pool sequence at site G2-01 on Gold Creek.

F- 16 Cascade run near site G2-02.

F- 17 Riffle pool transitioning to a cascade at G2-05.

1.2.3 Node GC-04 to Node GC-02

F- 18 Plane bed morphology in Gold Creek upstream of site G3-02.

F- 19 Avulsed channel on Gold Creek near Site G3-03. Note the mature conifers submerged in flow.

1.2.4 Node GC-02 to Node GC-01

F- 20 Bedrock-cascade near site G4-01 on Gold Creek.

F- 21 Plane bed morphology at site G4-02 on Gold Creek.

Appendix F

SRK Memos

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Vancouver, BC V6E 3X2

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F: +1.604.687.5532
vancouver@srk.com
www.srk.com

Memo

To:	Lief Burge, Stantec		
From:	Francis Smith	**Project No:**	1CM029.007
Cc:	Cory Bettles, Hatfield	**Date:**	November 28, 2016
Subject:	Grassy Mountain Peak Discharge Changes		

A request was made by Hatfield Consultants on 31/10/2016 requesting data for the different return period flows for each node of the water balance, as presented in the SRK Water and Load Balance Model Report (2016a), for both the base case and project case scenarios.

Utilising the unit peak flows, as presented within the SRK Baseline Hydrology Report (2016b), a simple catchment reduction assessment was made. For key stages of the life of mine, the contributing catchment area to each node was multiplied by the unit peak flow to estimate the resulting instantaneous peak flow at each node. These catchment areas are determined by changes in the mine footprint. The assumption in this assessment methodology is that storm runoff is limited to the immediate sheet flow runoff response within the natural catchment, and that contact water within the mine footprint will be subject to retention and settlement prior to discharge to the environment, and thus would not form part of the storm pulse resulting from extreme rainfall events. No inclusion of average flows within the drainage network has been included within this analysis. Due to the minor effect these small flows would have on the high magnitude storm events a more complex approach to include these within the analysis was not taken.

The changing peak flow response for each node of the water balance are presented in Figure 1-1 and Figure 1-2.

YEAR	B1						B2						B3					
	BL03						BC07						BL02					
	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100
1/1/2010	3.60	5.13	6.44	8.19	9.53	10.93	5.18	7.37	9.25	11.77	13.70	15.71	5.84	8.30	10.43	13.26	15.43	17.70
1/1/2019	3.60	5.13	6.44	8.19	9.53	10.93	5.18	7.37	9.25	11.77	13.70	15.71	5.84	8.30	10.43	13.26	15.43	17.70
12/31/2019	3.60	5.13	6.44	8.19	9.53	10.93	5.17	7.35	9.23	11.74	13.66	15.67	5.71	8.12	10.20	12.97	15.10	17.32
1/1/2020	3.60	5.13	6.44	8.19	9.53	10.93	5.17	7.35	9.23	11.74	13.66	15.67	5.71	8.12	10.20	12.97	15.10	17.32
12/31/2020	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.64	6.60	8.29	10.55	12.28	14.08
1/1/2023	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.64	6.60	8.29	10.55	12.28	14.08
12/31/2023	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.53	6.44	8.09	10.29	11.97	13.74
1/1/2026	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.53	6.44	8.09	10.29	11.97	13.74
12/31/2026	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.47	6.36	7.98	10.15	11.82	13.56
1/1/2030	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.47	6.36	7.98	10.15	11.82	13.56
12/31/2030	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
1/1/2033	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
12/31/2033	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
1/1/2038	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
12/31/2038	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
12/31/2040	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
1/1/2041	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
12/31/2041	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
1/1/2043	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
1/1/2100	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49
12/31/2100	3.60	5.13	6.44	8.19	9.53	10.93	4.11	5.85	7.35	9.35	10.88	12.48	4.45	6.33	7.94	10.10	11.76	13.49

YEAR	B4						B5					
	BC03						BC01					
	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100
1/1/2010	9.79	13.93	17.50	22.25	25.90	29.71	12.17	17.31	21.74	27.64	32.17	36.90
1/1/2019	9.79	13.93	17.50	22.25	25.90	29.71	12.17	17.31	21.74	27.64	32.17	36.90
12/31/2019	9.34	13.28	16.68	21.22	24.69	28.33	11.71	16.66	20.92	26.60	30.96	35.52
1/1/2020	9.34	13.28	16.68	21.22	24.69	28.33	11.71	16.66	20.92	26.60	30.96	35.52
12/31/2020	8.20	11.67	14.66	18.64	21.69	24.89	10.57	15.04	18.89	24.02	27.96	32.08
1/1/2023	8.20	11.67	14.66	18.64	21.69	24.89	10.57	15.04	18.89	24.02	27.96	32.08
12/31/2023	7.89	11.22	14.09	17.92	20.85	23.92	10.26	14.59	18.32	23.30	27.12	31.11
1/1/2026	7.89	11.22	14.09	17.92	20.85	23.92	10.26	14.59	18.32	23.30	27.12	31.11
12/31/2026	7.82	11.12	13.97	17.76	20.67	23.71	10.19	14.49	18.20	23.15	26.94	30.90
1/1/2030	7.82	11.12	13.97	17.76	20.67	23.71	10.19	14.49	18.20	23.15	26.94	30.90
12/31/2030	7.78	11.06	13.90	17.67	20.57	23.59	10.15	14.44	18.13	23.06	26.83	30.78
1/1/2033	7.78	11.06	13.90	17.67	20.57	23.59	10.15	14.44	18.13	23.06	26.83	30.78
12/31/2033	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
1/1/2038	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
12/31/2038	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
12/31/2040	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
1/1/2041	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
12/31/2041	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
1/1/2043	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
1/1/2100	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78
12/31/2100	7.78	11.06	13.89	17.67	20.56	23.59	10.15	14.44	18.13	23.05	26.83	30.78

Figure 1-1. Peak flow response (m3/s) for select LOM stages for nodes within the Blairmore Catchment.

YEAR	G1						G2						G3					
	GC13						GC10						GC04					
	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100
1/1/2010	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
1/1/2019	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
12/31/2019	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
1/1/2020	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
12/31/2020	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
1/1/2023	1.16	1.65	2.07	2.63	3.06	3.51	4.55	6.48	8.14	10.33	12.03	13.80	9.76	13.91	17.47	22.17	25.82	29.61
12/31/2023	1.16	1.65	2.07	2.63	3.06	3.51	4.53	6.45	8.10	10.28	11.97	13.73	9.67	13.78	17.31	21.97	25.59	29.35
1/1/2026	1.16	1.65	2.07	2.63	3.06	3.51	4.53	6.45	8.10	10.28	11.97	13.73	9.67	13.78	17.31	21.97	25.59	29.35
12/31/2026	1.16	1.65	2.07	2.63	3.06	3.51	4.50	6.42	8.06	10.23	11.91	13.66	9.54	13.59	17.07	21.66	25.23	28.93
1/1/2030	1.16	1.65	2.07	2.63	3.06	3.51	4.50	6.42	8.06	10.23	11.91	13.66	9.54	13.59	17.07	21.66	25.23	28.93
12/31/2030	1.15	1.64	2.07	2.62	3.05	3.50	4.46	6.35	7.98	10.13	11.80	13.53	9.45	13.47	16.91	21.47	25.01	28.67
1/1/2033	1.15	1.64	2.07	2.62	3.05	3.50	4.46	6.35	7.98	10.13	11.80	13.53	9.45	13.47	16.91	21.47	25.01	28.67
12/31/2033	1.13	1.62	2.03	2.57	3.00	3.44	4.33	6.17	7.75	9.84	11.46	13.14	9.31	13.26	16.65	21.13	24.62	28.23
1/1/2038	1.13	1.62	2.03	2.57	3.00	3.44	4.33	6.17	7.75	9.84	11.46	13.14	9.31	13.26	16.65	21.13	24.62	28.23
12/31/2038	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.39	9.38	10.92	12.53	9.10	12.97	16.29	20.67	24.08	27.62
12/31/2040	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.39	9.37	10.92	12.52	9.10	12.97	16.29	20.67	24.08	27.61
1/1/2041	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.39	9.37	10.92	12.52	9.10	12.97	16.29	20.67	24.08	27.61
12/31/2041	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.38	9.37	10.92	12.52	9.10	12.97	16.28	20.67	24.08	27.61
1/1/2043	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.38	9.37	10.92	12.52	9.10	12.97	16.28	20.67	24.08	27.61
1/1/2100	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.38	9.37	10.92	12.52	9.10	12.97	16.28	20.67	24.08	27.61
12/31/2100	1.11	1.58	1.99	2.52	2.94	3.37	4.13	5.88	7.38	9.37	10.92	12.52	9.10	12.97	16.28	20.67	24.08	27.61

YEAR	G4						G5					
	GC02						GC01					
	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100
1/1/2010	10.86	15.47	19.43	24.66	28.73	32.95	18.93	26.97	33.88	42.99	50.09	57.43
1/1/2019	10.86	15.47	19.43	24.66	28.73	32.95	18.93	26.97	33.88	42.99	50.09	57.43
12/31/2019	10.33	14.72	18.48	23.46	27.33	31.34	18.40	26.22	32.93	41.79	48.68	55.82
1/1/2020	10.33	14.72	18.48	23.46	27.33	31.34	18.40	26.22	32.93	41.79	48.68	55.82
12/31/2020	10.33	14.72	18.48	23.46	27.33	31.34	18.40	26.22	32.93	41.79	48.68	55.82
1/1/2023	10.33	14.72	18.48	23.46	27.33	31.34	18.40	26.22	32.93	41.79	48.68	55.82
12/31/2023	10.24	14.60	18.33	23.26	27.10	31.07	18.32	26.09	32.77	41.59	48.45	55.56
1/1/2026	10.24	14.60	18.33	23.26	27.10	31.07	18.32	26.09	32.77	41.59	48.45	55.56
12/31/2026	10.11	14.40	18.09	22.95	26.74	30.66	18.18	25.90	32.53	41.28	48.09	55.14
1/1/2030	10.11	14.40	18.09	22.95	26.74	30.66	18.18	25.90	32.53	41.28	48.09	55.14
12/31/2030	10.02	14.28	17.93	22.76	26.51	30.40	18.09	25.78	32.37	41.09	47.87	54.89
1/1/2033	10.02	14.28	17.93	22.76	26.51	30.40	18.09	25.78	32.37	41.09	47.87	54.89
12/31/2033	9.88	14.07	17.67	22.43	26.13	29.96	17.95	25.57	32.11	40.76	47.48	54.44
1/1/2038	9.88	14.07	17.67	22.43	26.13	29.96	17.95	25.57	32.11	40.76	47.48	54.44
12/31/2038	9.67	13.78	17.31	21.97	25.59	29.34	17.74	25.28	31.75	40.30	46.94	53.83
12/31/2040	9.67	13.78	17.31	21.96	25.59	29.34	17.74	25.28	31.75	40.29	46.94	53.82
1/1/2041	9.67	13.78	17.31	21.96	25.59	29.34	17.74	25.28	31.75	40.29	46.94	53.82
12/31/2041	9.67	13.78	17.30	21.96	25.58	29.34	17.74	25.28	31.75	40.29	46.94	53.82
1/1/2043	9.67	13.78	17.30	21.96	25.58	29.34	17.74	25.28	31.75	40.29	46.94	53.82
1/1/2100	9.67	13.78	17.30	21.96	25.58	29.34	17.74	25.28	31.75	40.29	46.94	53.82
12/31/2100	9.67	13.78	17.30	21.96	25.58	29.34	17.74	25.28	31.75	40.29	46.94	53.82

Figure 1-2. Peak flow response (m3/s) for select LOM stages for nodes within the Goldcreek catchment.

1 References

SRK Consulting Ltd. (2016a). *Grassy Mountain Water and Load Balance Model.* Report Prepared for Millennium EMS Solutions Ltd: SRK, August 2016.

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