Appendix 10-B

Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results

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BRUCEJACK GOLD MINE PROJECT

POTENTIAL INTERACTIONS BETWEEN THE BRUCEJACK GOLD MINE PROJECT AND CHANNEL MORPHOLOGY: PRELIMINARY RESULTS

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BRUCEJACK GOLD MINE PROJECT

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Glossary and Abbreviations

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Glossary and Abbreviations

Terminology used in this document is defined where it is first used. The following list will assist readers who may choose to review only portions of the document.

LSA	Local Study Area
masl	Metres above sea level
NCD	Non-classified drainages
Q	Discharge
The Project	The Brucejack Gold Mine Project
TRIM	Terrain Resource Information Management

1. Introduction

1. Introduction

The proposed Brucejack Gold Mine Project (the Project) is located in a mountainous area in northwestern British Columbia (Figure 1-1). The mine site will be at about 1,400 masl, above the tree line. Access will be along an existing 75-km long exploration access road that commences at Highway 37 at about 400 masl, follows the drainages of Wildfire, Todedada, and Scott creeks to the Bowser River Valley and then ascends the Knipple Glacier to the mine site. This document provides a preliminary assessment of the influence of culverts and bridges along the existing Brucejack Access Road on drainage morphology and stability. The assessment is limited to the unglacierized portion of the access route.

The goal is to assess the sensitivity to disturbance of the drainages and channels that the access road crosses. Disturbance could be anthropogenic (e.g., construction and maintenance of gullies, culverts, and bridges, and human-induced alterations of the hydroclimate) or natural (e.g., snow avalanches and mass movements).

"Stability", as it applies to this document, is defined temporally, spatially, and in terms of stability constraints (Doyle and Harbor 2001). Over sufficiently long timescales, all channels are unstable; the temporal span considered here is the lifespan of the project, including the Construction (2 years), Operation (22 years), Closure (2 years) and Post-closure (3 years) phases of the Project. The spatial scale for bridges is the reach scale, and the stability constraint is any detrimental effect to the crossing structure, roadway or drainage morphology. For culverts the spatial scale and stability constraint are any land area likely to be affected by ponding, sediment erosion, transport or deposition as a result of the culverts.

There are a total of 246 culverts on the access road, and 14 bridges. In this analysis, culverts were grouped by their major watershed (Wildfire Creek, Scott Creek, Todedada Creek, and Bowser River), then summarized using a set of indicators. Drainages were graded according to the British Columbia Fish Classification System (British Columbia Forest Service 1998), which classifies according to channel, width, slope, and presence or absence of fish.

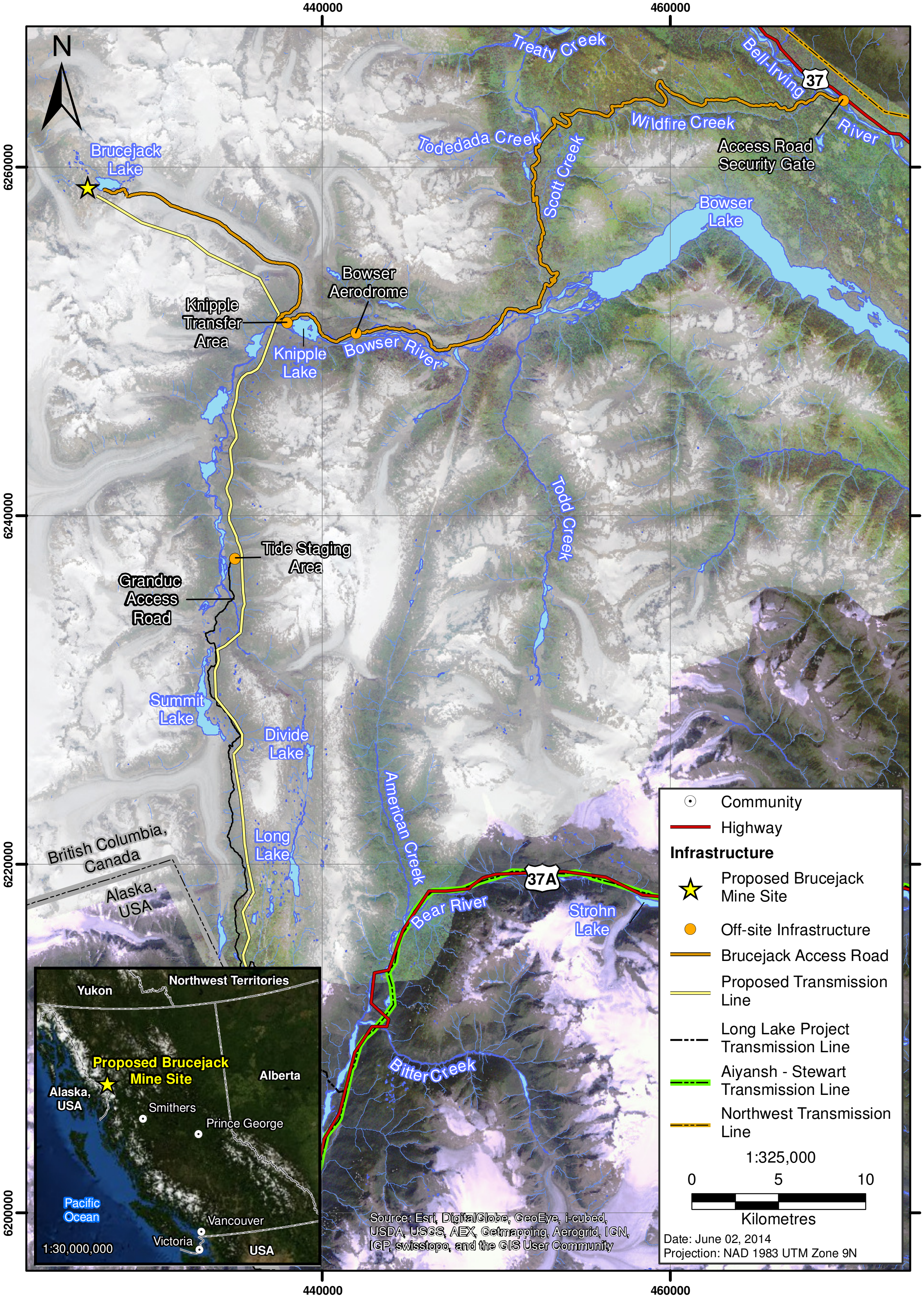
Culvert density (culverts/km^2) was used to assess the number of culverts in relation to the total watershed area and potential for disturbance. Culvert rate of occurrence along the road (culverts/km) was used to assess drainage potential. The gradient between the culvert and major waterway was used to assess the potential for mass wasting, and sediment regime (erosive, transport, or depositional). The distance to the nearest waterway was used to assess potential contributions of sediment to the waterway.

For bridge crossings, sufficient data were available to make preliminary channel classifications using two techniques: the Montgomery-Buffington typology (Montgomery and Buffington 1997), and the Johnson technique for channel stability assessment (Johnson, Gleason, and Hey 1999; Johnson 2005; Johnson 2006). The objective is to assess channel morphology and potential stability.

This document is largely based on a desktop-based study. Site visits were made to some bridge crossings (e.g., Bell-Irving, Todedada, Scott Creek, Bridges #20, 21), but not for the purpose of stability assessment. This limitation is addressed in Section 1.5 (Recommendations), and results presented here should be considered preliminary pending field-based observations.

The discussion begins with a site description that summarizes the regional climate, physiography, and hydrology. Next, culverts are assessed in aggregate, and finally each reach at bridge crossings is assessed individually.

Figure 1-1
Access Road Alignment



2. Site Description

2. Site Description

2.1 REGIONAL DESCRIPTION

The Brucejack property is located at 56°28'20" N latitude by 130°11'31" W longitude, which is approximately 950 km northwest of Vancouver, 65 km north-northwest of Stewart British Columbia (BC), and 21 km south-southeast of the closed Eskay Creek Mine. The Project is located within the Regional District of Kitimat-Stikine in the Coast Mountains. The site is currently accessed on ground by an exploration access road and by helicopter from staging sites along Highway 37 and the former Granduc mine site north of Stewart.

The Project is located in a mountainous area. The mine site is above the tree line with an elevation of 1,400 masl; surrounding peaks reach 2,200 masl. Glaciers and ice fields border the mineral deposits to the north, south, and east. Recent and rapid deglaciation has resulted in over-steepened and unstable slopes in many areas. Recently deglaciated areas typically have limited soil development, consisting of glacial till and colluvium. Lower elevation areas with mature vegetation may have a well-developed organic soil layer.

The regional climate of northwestern BC is dominated by weather systems developed over the Pacific Ocean (Rescan 2012). Climate in the Project area is also influenced by the local mountainous topography and glaciers, which produces large spatial climatic differences, in both horizontal distance and elevation. Mean annual air temperature at the Bob Quinn meteorology station (610 masl, 56 km N, ID 1200R0J) is 3.1^{o}C, and it receives 642 mm of precipitation per year on average. Precipitation increases with elevation and proximity to the coast. For example at the Unuk River Eskay Creek station, mean annual precipitation is about 2,000 mm (887 masl, ID 1078L3D). Precipitation events are frequent, but typically low-magnitude. In the Project area, at the Scott and Wildfire meteorology stations, precipitation exceeded 5 mm on 22-23% of days (stations are at 780 and 720 masl respectively).

Project area bedrock is predominantly volcanic, though locally, within the Local Study Area (LSA), it is sedimentary. About 60% of the surficial cover that the access road traverses is moraine and colluvium, and 26% is fluvial or glaciofluvial (Chapter 11). The dominant mineral soils in the LSA are weakly developed Brunisols and Regosols.

Forested ecosystems dominate below about 1,100 masl, and are fairly continuous. Forests are either very wet, such as Coastal Western Hemlock, or cold and wet such as the subalpine Mountain Hemlock forests that occur on middle elevation slopes. Landscape disturbance can condition vegetation communities, for example along snow avalanche paths, river bars, and near mass movements.

With its proximity to the coast, the region is characterized by steep, rugged, high elevation topography with substantial glacier coverage. The humid climate and physical characteristics of the region result in dynamic streams and rivers with high annual runoff values (Rescan 2013). Channel geomorphology ranges from steep boulder-lined headwater channels with perennial and flashy flow, to braided low-gradient mainstems with abundant fine grained sediment deposits. Runoff is sourced from nival melt and rainfall-runoff, with variable glacial contributions. Winter runoff is minimal.

2.2 THE BRUCEJACK ACCESS ROAD

The Brucejack Access Road begins at Hwy 37 and enters the Wildfire Creek watershed at about 400 masl (Figure 2.1-1). The road crosses the Bell-Irving River (2,572 km^2 upstream drainage area) and Wildfire Creek near its mouth (67 km^2 upstream drainage area). The road rises to about 1,000 m elevation within the first 10 km. Terrain is dominated by morainal deposits until Bowser Lake, after which colluvium, glaciofluvial, and fluvial deposits are predominant.

The road turns south, descends briefly into the headwaters of the Scott Creek watershed, then into the Todedada Creek watershed, then again into the Scott Creek watershed, descending back to about 400 masl (Figures 2.1-2 and Figure 2.1-3). Glaciofluvial deposits become less common and glacial till predominates. Wetlands are particularly common in the portion of the Todedada Creek watershed that the access road traverses.

After the access road crosses Scott Creek, it turns west onto the Bowser River floodplain beginning at about kilometre 37 (Figure 2.1-4). The drainage area of the Bowser River at the Bowser Lake inlet is 819 km^2 and it is highly glacierized. Surficial cover is modern alluvium, the floodplain is braided, active bars are sparsely vegetated, and soils are thin or absent. The road is bounded by steep colluvial slopes on the north and the outflow floodplain on the south. The Bowser River floodplain is a low slope; the road only ascends about 11 m over 13 km.

The road traverses the north and east shores of Knipple Lake and crosses the outwash plain of Knipple Glacier about one kilometre from its terminus. Surficial cover is entirely alluvial material and bedrock, with little vegetation. The road switchbacks and ascends to the Knipple Glacier roll-on point at kilometre 67.

The characteristics of the access road, its bridges, culverts, and major watersheds are summarized in Table 2.1-1.

Table 2.1-1. Access Road Summary Table, Classified by Watershed

Indicator	Wildfire Creek	Scott Creek	Todedada Creek	Bowser River (at Inlet to Bowser Lake)	Sum
Watershed area (km^2)	67	75	61	819	1,022
Median elevation (m)	950	1,180	1,179	1,400	n/a
Q_2 (m^3/s)	44	48	41	325	n/a
Q_{100} (m^3/s)	155	168	145	933	n/a
Road length (km)	15.0	10.3	6.8	36.3	68.4
Road density (km/km^2)	0.22	0.14	0.11	0.04	n/a
Number of bridges	4	2	1	7	14
Bridge density (bridges / km^2)	0.04	0.03	0.02	0.01	n/a
Bridge rate of occurrence (bridges/km)	0.27	0.19	0.15	0.19	n/a
Number of culverts	106	63	52	25	246
Culvert density (culverts/km^2)	1.58	0.84	0.85	0.03	n/a
Culvert rate of occurrence (culverts/km)	7.04	6.10	7.66	0.69	n/a

Figure 2.1-1
Wildfire Creek Watershed and Access Road

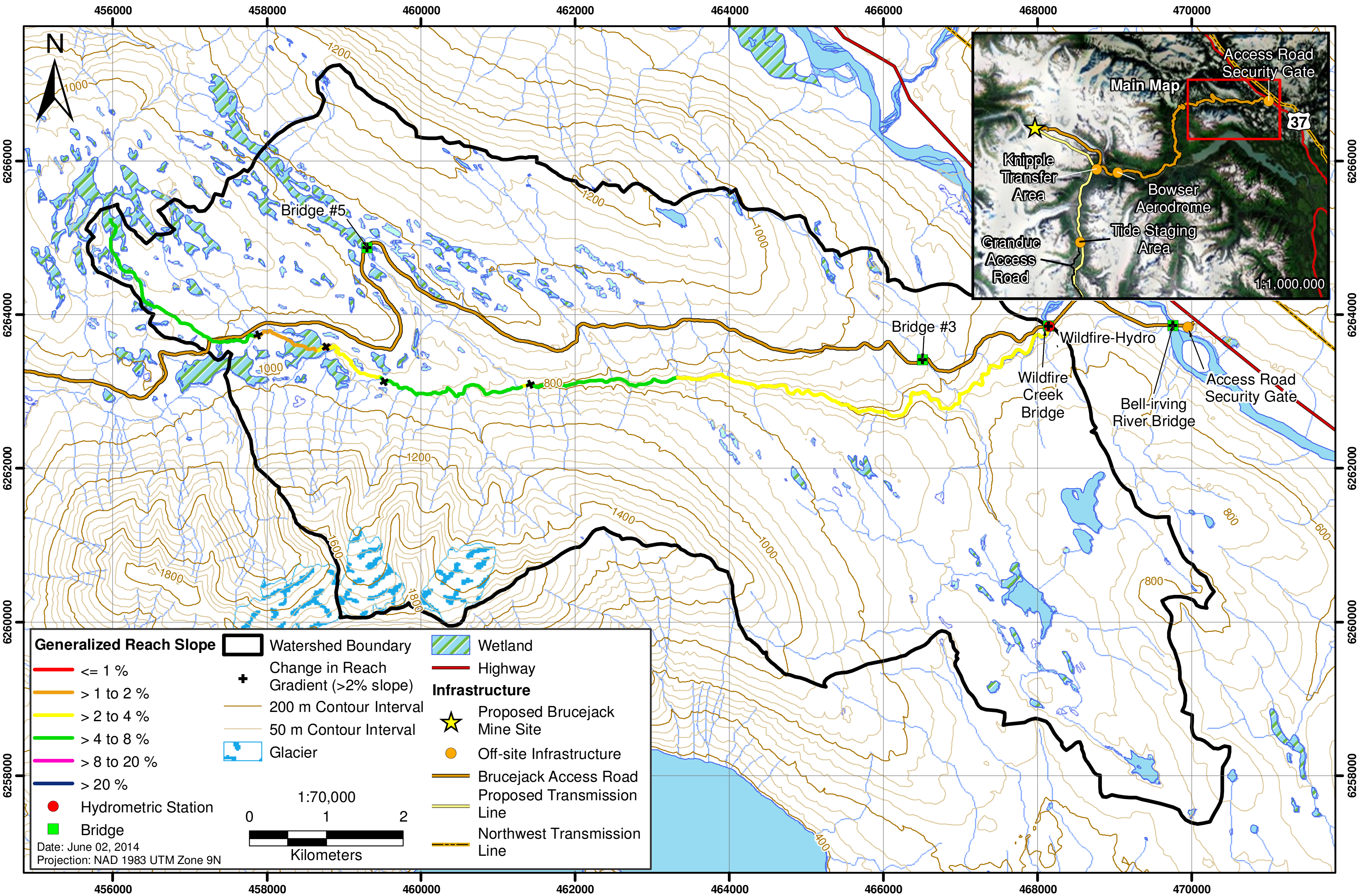


Figure 2.1-2
Scott Creek Watershed and Access Road

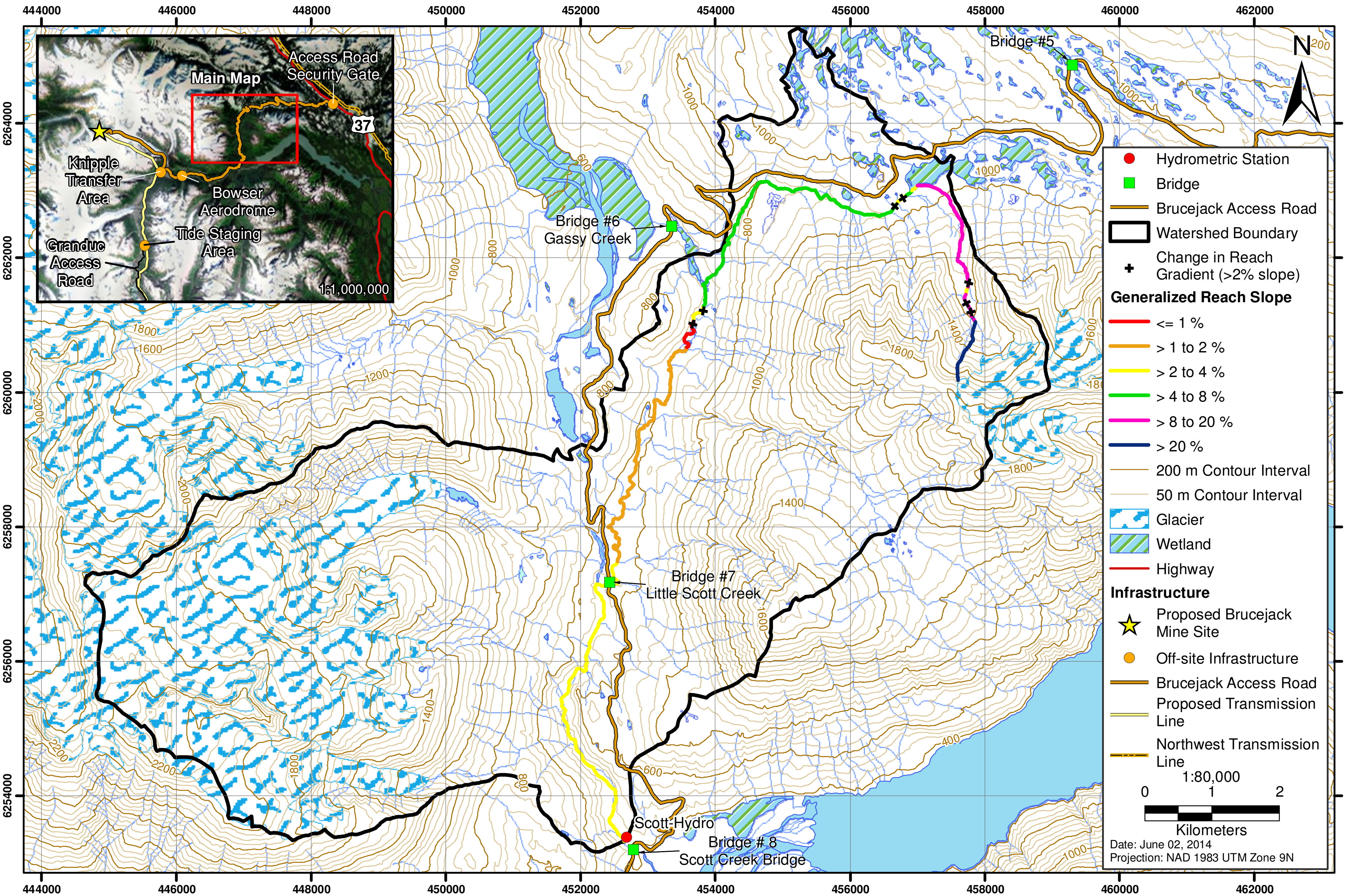


Figure 2.1-3
Todedada Creek Watershed and Access Road

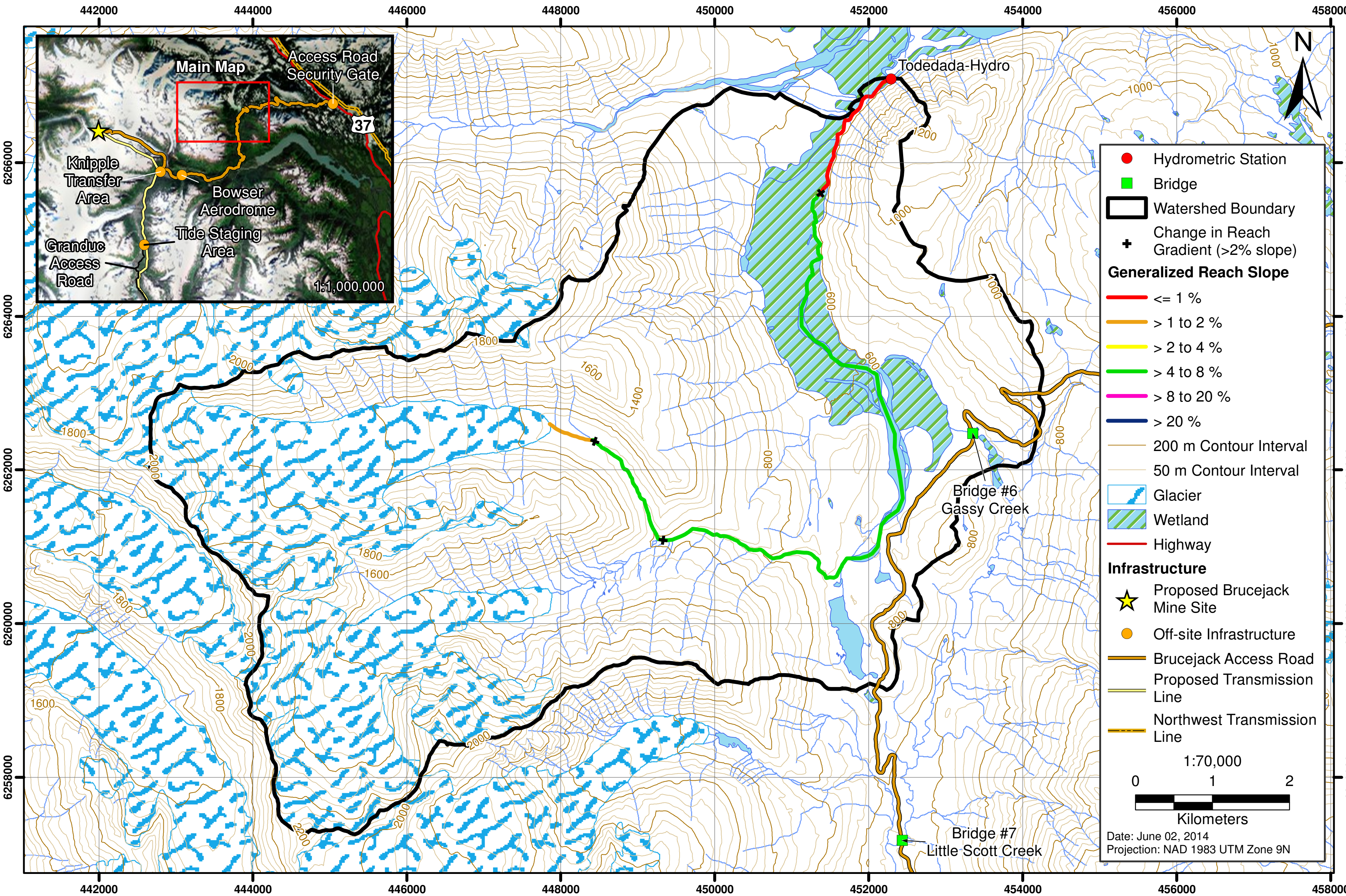


Figure 2.1-4

Upper Bowser River Watershed and Access Road

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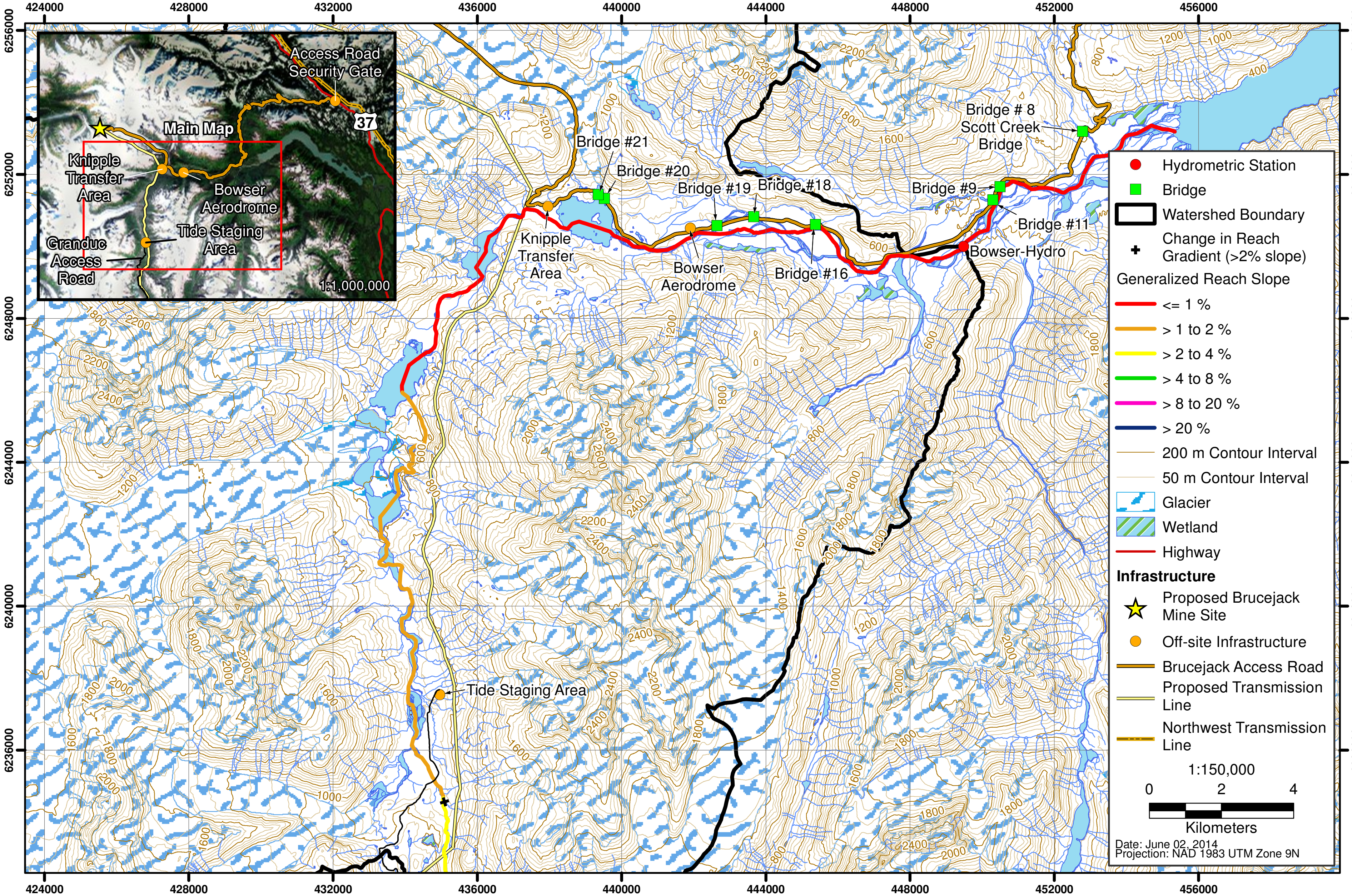


3. Culverts

3. Culverts

3.1 INTRODUCTION

Culverts are generally placed over low order headwater drainages that are often ephemeral. The effects of culverts on drainage and channel morphology vary depending on many factors. For example, climate-related factors include the seasonality and intensity/duration/frequency of precipitation, and air temperature and its inter-annual distribution. Physiography plays a role in terms of land-use, vegetation, surficial cover, slope, hillslope curvature, soil moisture, landscape disturbance, road type, and type and depth of ditches. The culverts themselves are important in terms of their design (size and type), and rate of spacing.

Ditches funnel water towards culverts. This increases peak flow at the culvert site compared to undeveloped conditions. Peak flow may increase in channels downstream of culverts as well, since they effectively increase the drainage density of the watershed (Wemple, Jones, and Grant 1996).

Culverts may drain into channels and gullies, or onto land that is not hydrologically connected to the stream network. Gullies can quickly connect flow intercepted by ditches to downslope stream channels. Adjacent to the gullies, soil moisture may decrease downslope of the road, since these areas would receive less recharge.

If culverts drain onto areas that are not hydrologically connected to the stream network, water that passes along ditches and through culverts will spill onto land, and travel as overland flow. In this case, soil moisture would increase, and water would be diverted from natural stream channels. These conditions promote erosion and generation of new gullies, particularly during peak flows, and particularly when slope exceeds 40% (Wemple, Jones, and Grant 1996).

When culverts increase peak discharge, the capacity for sediment transport also increases. If flow decelerates after passing through the culvert, capacity decreases, and sediment deposition occurs. Blockage is commonly caused by a buildup of bedload, snow (ice), or large woody debris. This may occur when drainage flows onto hydrologically unconnected areas, or when a break in slope occurs.

Sedimentation causing blockage is one cause of culvert failure; lack of proper maintenance contributes to this type of failure. Other causes include insufficient numbers, misplacement, and undersizing. Culverts tend to fail during peak flow events, and can lead to road washouts, stream diversions, and mass wasting: often in the form of large hillslope gullies (Weaver, Hagans, and Popenoe 1995).

3.2 POTENTIAL EFFECTS OF BRUCEJACK ACCESS ROAD CULVERTS ON DRAINAGES, STREAMFLOW, AND SEDIMENT

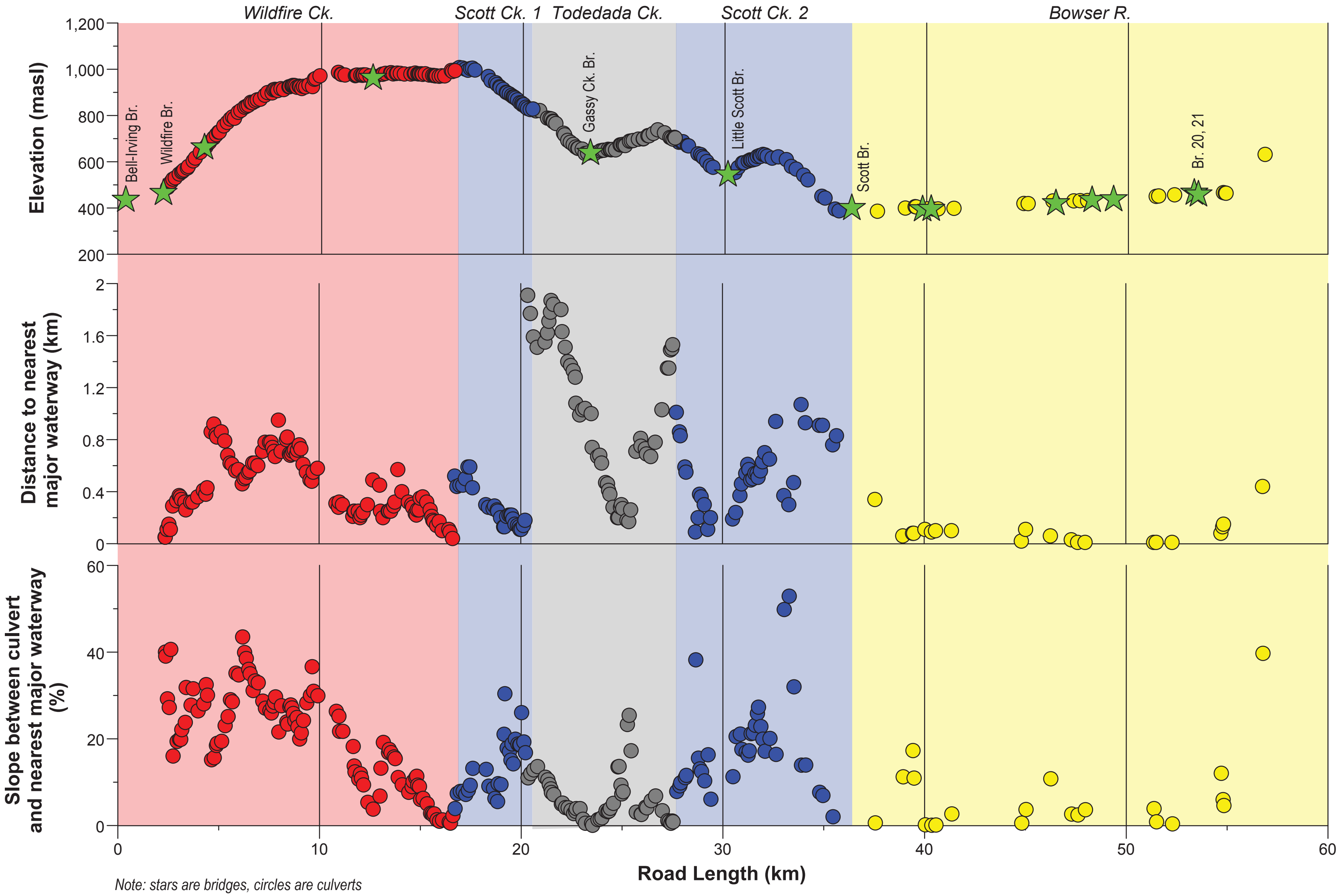
3.2.1 Overview

There are a total of 246 culverts on the Brucejack access road (Figure 3.2-1). Details of the road and culverts are presented in the Brucejack Exploration Site Access Plan (Cypress Forest Consultants 2011), but information pertinent to the effects of crossings on channel morphology is summarized below.

Culverts were designed to withstand a flood event with a 100 year return period (i.e., Q_{100}). For small drainages, 500 mm corrugated metal pipe was used (57% of culverts). Larger drainages necessitated larger-diameter culverts, up to 1,800 mm.

Figure 3.2-1

Elevation, Distance to Nearest Major Stream, and Downhill Slope for the Brucejack Access Road Drainage Crossings



Crossings are typically small headwaters: 94% are either non-classified drainages (NCD), cross-drainages (XDrain), or non-fish bearing streams that are less than 3 m wide, i.e., S6 streams (Figure 3.2-2). These drainages either do not meet the definition of being a stream, or are less than three metres width and are non-fish bearing (British Columbia Forest Service 1998).

Nine culverts (3.6% of all culverts) cross streams classified as S4 (fish-bearing and less than 1.5 m wide) or S3 (fish bearing and between 1.5 and 5 m wide). These culverts are typically open-bottom wood box culverts that allow fish passage (n = 9). Another two percent of drainages have bankfull widths greater than three metres wide, but are also not fish bearing (S5).

While culvert drainages are typically small or ephemeral, the effects on channel morphology are potentially large, especially during extreme runoff events, where culverts are insufficiently frequent, where sediment can block openings, and where ditches funnel water away from the road surface and into narrow culverts.

Of the four major catchments that the access road traverses, 44% of culverts are in the Wildfire Creek watershed, 12% are in Scott Creek watershed, 34% are in Todedada Creek watershed, and 10% drain directly into Bowser River (Figure 3.2-2).

Each watershed has unique culvert placement, and unique physiography, leading to unique potential effects on channel morphology. The following sections present culvert characteristics in each watershed using a set of available statistics and physiographic data.

3.2.2 Wildfire Creek

From Highway 37, the road climbs, travels westward, and passes along the north valley wall of Wildfire Creek for about 15 km (Figures 2.1-1 and 3.2-1). There are a large number of culverts in this watershed (n = 106), and watershed size is moderate (Table 2.1-1), leading to the highest culvert density (culverts/km^2) of any watershed that the access road traverses (Figure 3.2-2). Culvert rate of occurrence is similar to other watersheds. All but two of the crossings are NCD, cross-drainages, or S6.

Culverts on the north wall of the Wildfire valley are not particularly close to the creek (~400 m median distance), signifying that sediment delivery to the creek will not be direct, but slopes downhill of the culverts are steep (Figure 3.2-1). Although no snow avalanche paths exist in the area, numerous small linear gullies or channels are evident on the north slope of Wildfire valley, particularly downslope of the road. The land cover is mostly forested, implying relatively stable slopes. However, where gullies approach the creek, slope increases, and several mass movement scars and colluvial deposits are evident. These directly, but locally, supply the creek with coarse grained sediment (BGC Engineering Inc 2013).

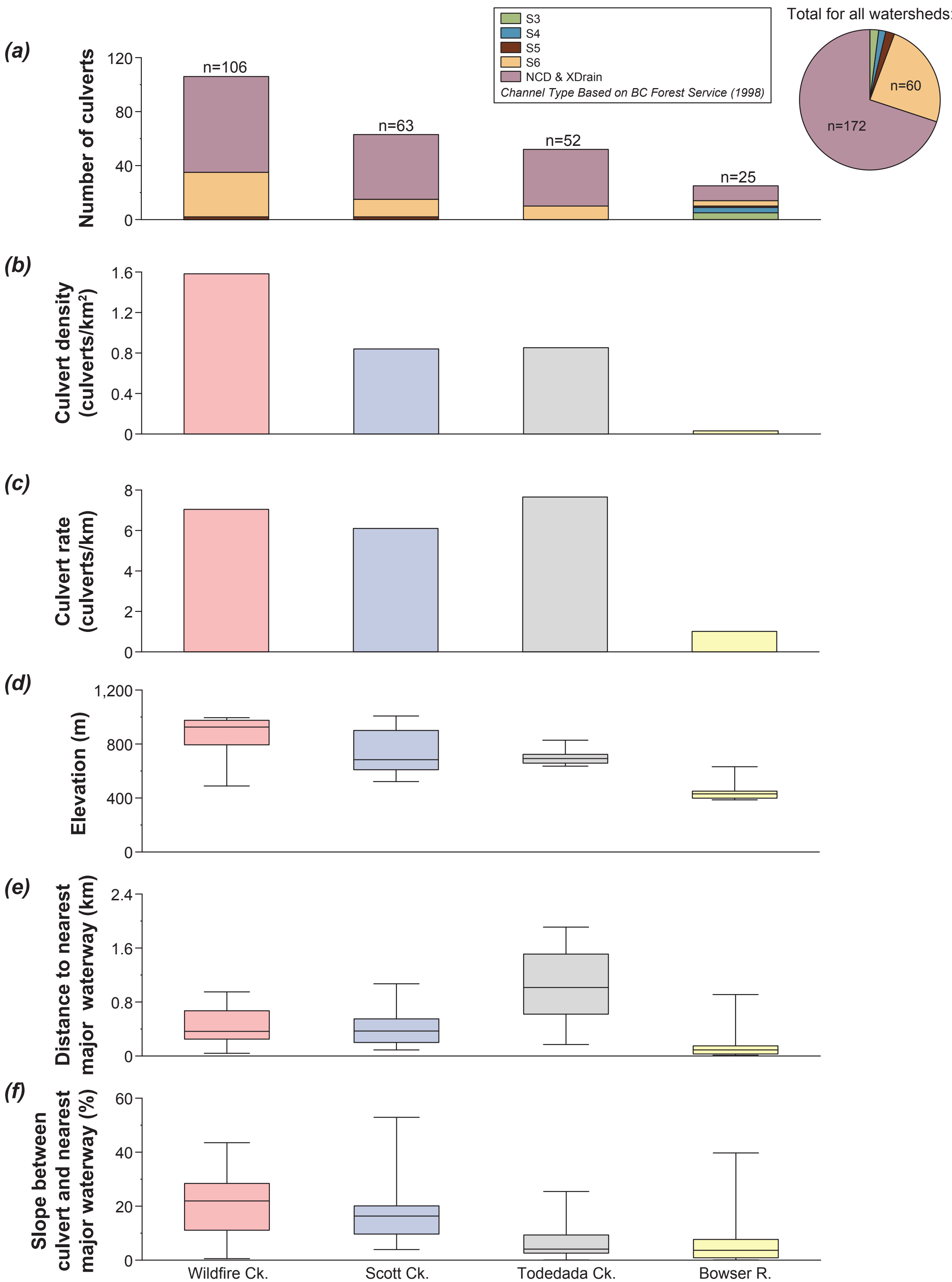
Logging has occurred relatively recently on land that drains into Wildfire Creek from the south, adding to watershed disturbance and the potential for channel morphology changes.

Wildfire Creek is steep relative to the other major drainages that the road crosses, so fine grained sediment transport in the stream might be relatively rapid. No major bedforms are evident along the channel. A typical channel reach is shown below (Plate 3.2-1).

Due to the steep slopes, high culvert density, evidence of mass movements, and potential logging-related impacts, Wildfire Creek is the likeliest of the Project area watersheds to experience channel morphology changes associated with drainage by culverts. This is especially true for the first 10-15 km of the road, where down-drainage slopes are steep (Figure 3.2-1). Increased gully formation and potentially increased downslope mass movements would be expected in this area.

Figure 3.2-2

Summary Statistics for Culverts on the Brucejack Access Road



Note: In panels 'd' to 'f', whiskers are max. and min., boxes are quartiles, and horizontal line is median

Plate 3.2-1. Wildfire Creek near the "Wildfire-hydro" hydrologic station. View is upstream. Note the coarse-grained bed and treefalls on the right bank (left in photo). Photo taken May 2013.

3.2.3 Scott Creek

After passing out of the Wildfire Creek watershed, the road travels through the upper, steeper reaches of Scott Creek. Beyond this point, the road crosses into the Todedada Creek watershed for slightly over seven kilometres before passing again into the Scott Creek watershed, this time in its lower, flatter reaches (Figures 2.1-2 and 3.2-1).

For the first passage of the road into the Scott Creek watershed, the physiography and culvert characteristics are somewhat similar to that of the Wildfire Creek watershed. Culverts are relatively close to Scott Creek. However, slope downstream of culverts is moderate relative to Wildfire Creek, and there is no evidence of mass movements along this portion of the north wall of the Scott Creek valley (BGC Engineering Inc 2013). Fine grained sediment deposited into these headwater portions of Scott Creek is likely transported quickly during freshet and storm events due to the relatively high reach slopes in this area (Figure 3.2-1).

By the time the road passes into the Scott Creek watershed for the second time, the creek reach slope has diminished (Figure 2.1-2). The road descends from about 680 masl to 440 masl, where it passes into the Bowser River watershed (Figure 3.2-1). It crosses Little Scott Creek at kilometre 30.1, and Scott Creek near Bowser River at kilometre 36.3 (both crossings are bridges).

Generally the lower Scott Creek valley is broad. Slopes downstream of culverts are variable. The distance of culverts to Scott Creek is also variable, as the road approaches the creek from its west (right) bank, then crosses onto the east bank at Little Scott Creek. There is evidence of mass movement along most downstream reaches of Scott Creek, close to Bowser River.

Although the valley is broad, channel morphology is influenced by avalanches originating on the slopes of Mount Anderson to the east (BGC Engineering Inc 2013). Two run-out zones have been mapped that terminate near the road. The western slope of Mount Anderson is unforested except near the valley bottom, which is a likely indication of historic avalanche activity. Avalanches have the potential to deliver woody debris and coarse sediment, particularly to upslope areas adjacent to the road, which could be conveyed to culverts. However, a valley bottom hummock on the side of Mount Anderson shields the road and its culverts from some avalanches (Cypress Forest Consultants 2011).

Culvert density is moderate compared to other watersheds that the road crosses. Culvert rate of occurrence is similar to that for Wildfire and Todedada creeks. Overall, Scott Creek culverts are placed in variable settings, and crossing morphologies will likely reflect this variability.

3.2.4 Todedada Creek

Water drains west and north towards Todedada Creek for 7.7 km, between segments where water flows into Scott Creek. Drainage slopes are generally low, and the distance to major waterbodies is far. The landscape is dotted with wetlands, which are close to the road near Gassy Creek (bridge #6). This area does not contain major avalanche run out zones, or show evidence of major debris flows, reflecting the low slopes of the area.

The access road crosses a small portion of the Todedada watershed, making culvert density low. Culvert rate of occurrence is similar to other road sections.

The largest culvert-related risk to drainages in this area is likely water backing up behind blocked culverts causing ponding during wet periods, or when snow and ice block culverts in spring.

3.2.5 Bowser River

After the Scott Creek bridge crossing, the road continues over the braided Bowser River floodplain until it reaches the Knipple Glacier roll-on point. The Bowser River watershed is larger than other watersheds along the road, and it has only 25 culverts, so culvert density is very low (Figure 3.2-1).

When the road traverses the floodplain, it is often distant from valley walls (Figure 2.1-4), so the culverts likely do not drain water flowing down the Bowser River valley walls. Not many culverts per kilometer along the road are needed. However, the largest streams crossed by culverts are in this watershed. It contains all S3 (n = 5) and S4 (n = 4) culvert crossings (Figure 3.2-2). These are open-bottom wood culverts. The culverts on the floodplain have low downstream slopes, and are close to Bowser River (Figure 3.2-1).

There is evidence of rockslides close to the road on the north wall of the Bowser River valley (BGC Engineering Inc 2013). Avalanche runout zones occur, but they are north of Knipple Lake closer to the roll-on point, and no culverts exist in that area.

Given the relatively large size of the Bowser River, the low number and density of culverts, and the low downstream slopes, culverts are unlikely to significantly affect Bowser River channel morphology. The possible exception is where the road passes near rockslides.

4. Bridges

4. Bridges

4.1 OVERVIEW

There are a total of 14 bridges on the Brucejack access road, varying in span from 12 m (Bridge #5, Pinch Point Creek) to 52 m (the Bell-Irving River). Four bridges span crossings that drain into Wildfire Creek, two drain into Scott Creek, one drains into Todedada Creek, and seven drain into Bowser River. The watershed areas upstream of the bridges vary from 0.8 km^2 (Bridge #6) to about 2,600 km^2 (Bell-Irving River).

4.2 ASSESSMENT METHODOLOGY

Assessing the effects of bridges on channel morphology had three components. First, all available and relevant data were compiled for each bridge (Table 4.2-1). This included aerial and satellite photographs, field photographs, topographic maps, GIS-based Terrain Resource Information Management (TRIM) program data (GeoBC 2013), landscape maps (Chapter 11), bridge blueprints (Cypress Forest Consultants 2011), and terrain hazard mapping (BGC Engineering Inc 2013).

Next, the assembled datasets were used to classify reaches near bridges using the Montgomery-Buffington (1997) system. This system uses process-based observations and morphologic observations to classify streams into one of seven channel types. This provides a means for assessing response potential to changes in sediment supply and discharge (Montgomery and Buffington 1997). The system was developed for mountainous catchments in the Pacific Northwest, and has been widely applied in that region.

Bridges were also classified using a channel stability rating index (Johnson, Gleason, and Hey 1999; Johnson 2005). A series of geomorphic, hydrologic, and hydraulic assessments were made. These assessments included the stability of the watershed and floodplain, flow habit, channel type and confinement, bed material, bar development, channel obstructions, bank soil, bank slope, protection, and incision, mass wasting, and position of the bridge relative to meanders (Table 4.2-2). The index is a tool for the rapid and systematic assessment of channel stability near bridges, and for determining whether more detailed follow-up studies are required (e.g. hydrologic and hydraulic concepts and modelling). The system has been applied to natural and engineered channels in most physiographic regions of the continental United States, including the Pacific Coastal region. The method is now incorporated as part of the Federal Highway Administration's manual on stream stability at bridges (HEC-20; Lagasse et al 2012). Each category is graded, and given a value between 1 and 12. The summed grade and its interpretation are region-specific (Doyle and Harbor 2001), but regional ranges have been published (Johnson 2005). Unstable channels receive high grades and stable channels receive low grades. Stability indices and Montgomery-Buffington classifications presented in this study are preliminary.

4.3 ASSESSMENT RESULTS

Data collected for each bridge crossing are summarized in Table 4.2-1. These data were used to score reaches with the Johnson technique, and results are presented in Table 4.3-1.

Summed scores range between 56 (Bridge #5) and 130 (Bridge #21). In a survey of five Pacific Coastal reaches, scores ranged between 63 and 116 (Johnson 2005). These reaches were apparently all in California, in settings such as arroyos, alluvial fans, and beaches (Johnson 2006), making comparison difficult with results presented here.

However, ranking each reach relative to others provides a means to assess relative reach stability. Summed scores are lowest for bridges crossing low gradient, unconfined, perennial streams. Scores are highest for reaches in the Bowser River valley, especially those spanning active floodplains or braided systems such as Bridge #21. Bridge #20 is immediately adjacent, but receives a lower score, primarily because it is partially confined by bedrock (Plate 4.3-1). Some bridges, such as #3, receive low scores due to their steep gradient, small watershed size, and/or flashy flow regime. The Bell-Irving Bridge receives a low score (i.e., low channel stability risk) despite the large upstream watershed size, due to the lack of instream footings and bedrock banks (Plate 4.3-2).

Plate 4.3-1. Bridges 20 on the right and bridge 21 on the left. The Knipple Glacier terminus is in the background. Photo taken July 2013.

Plate 4.3-2. Bridge over the Bell-Irving River. Photo taken April 2013. Downstream is in the foreground.

Table 4.2-1. Summary of Fluvial Geomorphology Data for the Fourteen Bridges on the Brucejack Access Road

Distance (m)	Bridge	Bridge Span and Construction	UTM E	UTM N	Upstream Watershed Area (km^2)	Q_2 (m^3/s)	Q_{10} (m^3/s)	Q_{100} (m^3/s)	Slope (%)	Slope Source	Channel Width at Time of Mapping (m)	Channel High Water Width (m)	Sinuosity	Bed Material	Fish Stream Classification	Bank Material	Bank Slope	Bank Reinforcement	Valley Wall Confinement?	Near Snow Avalanche Path?	Near Debris Flow Path?	Near Flood-plain?	Braided Channel?	Riparian Vegetation	Bars?	Alluvial Reach Classification (Montgomery-Buffington)	Notes
289.1	Bell-Irving River Bridge	52 m Steel Span w Jump span	469,757	6,263,859	2,571.7	810	1,343	2,120	1	C	23	n/d	1.1	Clay, sand, gravel?	S1	LB bedrock. RB bedrock & gravel bench: sandy gravels & rubble, relatively unsorted and well drained	Steep LB and RB	Mostly bedrock banks	y	n	n	n	y	Wooded	y (mid-channel, 150 m downstream)	dune ripple	There is bedrock present on both sides of the crossing, downstream of a shallow canyon that is incised through bedrock.
2,156.6	Wildfire Creek Bridge	52 m Steel Span	468,140	6,263,855	66.9	44	92	155	2	C	24	n/d	1.3	Gravel, cobbles, small boulders	S1	Vegetated bedrock, alluvium	Steep LB , shallow RB	n/d	n (only on LB)	n	n	n	n	Wooded	n (mid-channel bar ~175 m d/s)	plane bed	The river usually carries a heavy silt load.
4,192.5	BRIDGE #3	18.288 m Steel Span	466,505	6,263,416	2.2	n/d	n/d	n/d	11	T	n/d	5	1.1	Cobbles, boulders, woody debris	S5	Bedrock visible on LB and RB	moderate LB and RB	n/d	y	n	n	n	n	Wooded	n	cascade	Large amounts of woody debris in channel.
12,551.9	BRIDGE #5 (Pinch Pt. Ck.)	12.000 m Concrete Span	459,298	6,264,875	5.5	n/d	n/d	n/d	1	T	n/d	4	1.1	n/d	S6	'Wet ground' nearby	Steep LB and RB	100 kg rip-rap	n	n	n	n	n	Wooded	n	plane bed	In an open meadow. Wetland immediately d/s.
23,326.1	BRIDGE #6 GASSY CREEK	15.240 m Steel Span	453,350	6,262,477	0.8	n/d	n/d	n/d	5	T	n/d	6	n/a	n/d	S5	Scrub vegetation. Alluvial material (meander)	Shallow LB and RB	100 kg rip-rap	y?	n	n	n	n	Scrub & wooded	y (lateral)	n/d	4 m waterfall over bedrock about 25 m d/s. Open meadow u/s. No photos.
30,146.6	BRIDGE #7 LITTLE SCOTT CREEK	21.336 m Steel Span	452,435	6,257,180	36.3	27	59	100	2	T	5	8	1.1	10% sand&silt, 25% gravel, 50% cobble, 10% boulder, 5% block.	S5	Sandy gravels	Steep LB, shallow RB	100 kg rip-rap at crossing and upstream. Sediment fencing.	n	n	y	n	n	Disturbed near bridge	n	n/d	A volatile system that is subject to upstream avalanche activity and creek diversions that could amplify flows. No photos.
36,285.7	BRIDGE # 8 SCOTT CREEK BRIDGE	24.384 m Steel Span	452,785	6,253,200	74.8	48	100	168	3	T	10	18	1.2	Fluvial boulders, gravels, cobbles. Minimal fines.	S1	Gravel lateral bar on RB. Scrub veg on LB.	At crossing: steep RB and LB. U/S: steep RB, shallow LB. D/S: shallow LB and RB.	100 kg rip-rap	y	n	n	y	n	Wooded u/s, scrub d/s	Mid-channel cobble bars with LWD. Lateral gravel bars.	plane bed	Hydrology station
39,795.5	BRIDGE #9	15.24 m Steel Span	450,495	6,251,660	19.1	16	37	63	<1	T	6	n/d	n/d	Fluvial boulders, gravels, cobbles. Minimal fines.	S2	Scrub veg. covering alluvial sediments.	Moderate LB and RB	100 kg rip-rap	y	y	n	y	y	Scrub	n	plane bed	Flood channel
40,221.6	BRIDGE #11	15.24 m Steel Span	450,302	6,251,293	n/a	n/d	n/d	n/d	<1	T	4	n/d	1.1	35% silts&sands, 45% gravels, 18% cobbles, 2% boulders	S2	Scrub veg. covering alluvial sediments.	shallow LB and RB	n/d	n	n	n	y	y	Scrub & small trees	n	pool riffle	Side channel. beaver dam and pond u/s, Bowser R. d/s
46,405.8	BRIDGE #16	15.24 m Steel Span	445,377	6,250,607	2.0	n/d	n/d	n/d	<1	T	9	n/d	n/d	65% silts & sands, 10% cobbles, 5% boulders	S2	Gravel	Moderate LB and RB	100 kg rip-rap	n	n	y	y	y	Scrub & small trees	y	pool riffle	Overhead rockfall hazard along short mid-slope headwall scarps above road, and movement is conditional on natural erosion processes. Evidence of failures include some medium to large boulders along road corridor. Beaver pond upstream of crossing. Gravel plain prone to flooding.
48,200.5	BRIDGE #18	27.432 m Steel Span	443,662	6,250,824	n/a	n/d	n/d	n/d	<1	T	20	n/d	n/a	15% silts & sands, 45% gravels, 35% cobbles, 5% boulders	S1	Bedrock and boulders, cobbles, gravel	Moderate LB and RB	100 kg rip-rap	n	n	y	y	y	Scrub & small trees	y (mid-channel)	plane bed	Flood channel. Prone to major flooding conditions and possible realignment of the channel.

(continued)

Table 4.2-1. Summary of Fluvial Geomorphology Data for the Fourteen Bridges on the Brucejack Access Road (completed)

Distance (m)	Bridge	Bridge Span and Construction	UTM E	UTM N	Upstream Watershed Area (km^2)	Q_2 (m^3/s)	Q_{10} (m^3/s)	Q_{100} (m^3/s)	Slope (%)	Slope Source	Channel Width at Time of Mapping (m)	Channel High Water Width (m)	Sinuosity	Bed Material	Fish Stream Classification	Bank Material	Bank Slope	Bank Reinforcement	Valley Wall Confinement?	Near Snow Avalanche Path?	Near Debris Flow Path?	Near Flood-plain?	Braided Channel?	Riparian Vegetation	Bars?	Alluvial Reach Classification (Montgomery-Buffington)	Notes
49,267.0	BRIDGE #19	27.432 m Steel Span	442,641	6,250,579	n/a	n/d	n/d	n/d	<1	T	n/d	n/d	n/a	5% silts & sands, 80% cobbles, 15% boulders	S2	Fluvial boulders, cobbles, gravel	shallow LB and RB	100 kg rip-rap	n	n	n	y	y	Scrub & small trees	y (mid-channel)	plane bed	Side channel that flows on a seasonal basis. Gravel flood plain is prone to flooding. Rip-rap required to protect substructure and the approaches from extreme flood impacts and directing channeling under the bridge on a long-term basis.
53,266.1	BRIDGE #20	21.336 m Steel Span	439,523	6,251,334	n/a	n/d	n/d	n/d	n/d		n/d	12	n/a	Bedrock. Also boulders, cobbles, gravel, sands, clays	S5	Bedrock LB and bedrock/till/ outwash RB	LB and RB are steep	Upstream rip-rap berms, heavy rip-rap to stabilize channel. Bridge banks reinforced with rip-rap	y	n	n	y	y	Minimal	y (mid-channel)	bedrock	Though the gap in the causeway continues to release flows, recent flooding activity has occurred and the bypass channel continues to function.
54,470.2	BRIDGE #21	36.576 m Steel Span	439,350	6,251,441	n/a	n/d	n/d	n/d	n/d		43	n/d	n/a	Gravel bars, boulders, cobbles	S5	Bedrock and rip-rap	Shallow LB and RB. This is the Knipple Ck floodplain	Upstream rip-rap berms, heavy rip-rap to stabilize channel. Bridge banks reinforced with rip-rap	n	n	n	y	y	Minimal	y (mid-channel)	dune-ripple	Floodplain engineering required to encourage flow in a single channel.

Notes:

All bridges are single span.

UTM zone is 9V.

Alignment and crossing locations were provided to Rescan in July 2013.

bridges 11, 18, 19, 20, 21 are over river branches, and only receive a portion of the total river flow, so no estimates of peak flow passing under these bridges can be made.

Return periods were estimated using regional analysis (Rescan 2013).

Return periods were not estimated for waterhseds less than 10 km^2 since smallest watershed in the the regional dataset is ~40 km^2.

For slope source: c=Cypress access plan report (2011); t=TRIM data (GeoBC 2013).

n/d = no data; n/a = not applicable

LB = left bank; RB = right bank

?' represents a designation with a high degree of uncertainty, requiring field-based observation.

Table 4.2-2. Stability Indicators, Descriptions, and Ratings for Bridges for the Johnson Classification System

Stability Indicator	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)
Watershed and floodplain activity and characteristics	Stable, forested, undisturbed watershed	Occasional minor disturbances (spatially and/or temporally) in watershed, including cattle activity (grazing and/or access to stream), construction, logging, or other minor deforestation; limited agricultural activities	Frequent disturbances (spatially and/or temporally) in watershed, including cattle activity, landsliding, channel sand or gravel mining, logging, farming, or construction of buildings, roads, or other infrastructure; urbanization over significant portion of watershed	Continual disturbances (spatially and/or temporally) in watershed. Significant cattle activity, landsliding, channel sand or gravel mining, logging, farming, or construction of buildings, roads, or other infrastructure; highly urbanized or rapidly urbanizing watershed
Flow habit	Perennial stream with no flashy behavior	Perennial stream or ephemeral first-order stream with slightly increased rate of flooding	Perennial or intermittent stream with flashy behavior	Extremely flashy; flash floods prevalent mode of discharge; ephemeral stream other than first-order stream
Channel pattern	Straight (non-engineered) to meandering with low radius of curvature; primarily suspended load	Meandering, moderate radius of curvature; mix of suspended and bed loads; well-maintained engineered channel	Meandering with some braiding; tortuous meandering; primarily bed load; poorly maintained engineered channel	Braided; primarily bed load; unmaintained engineered channel
Entrenchment/channel confinement	Active floodplain exists at top of banks; no sign of undercutting infrastructure; no levees	Active floodplain abandoned, but is currently rebuilding; minimal channel confinement; infrastructure not exposed; levees are low and set well back from river	Moderate confinement in valley or channel walls; some exposure of infrastructure; terraces exist; floodplain abandoned; levees are moderate in size and have minimal setback from river	Knickpoints visible downstream; exposed water lines or other infrastructure; channel width to top of banks ratio small; deeply confined; no active floodplain; levees are high and along channel edge
Bed material; F_s=approximate portion of sand in bed	Assorted sizes tightly packed, overlapping, and possibly imbricated; most material >4 mm; F_s <20%	Moderately packed with some overlapping; very small amounts of material <4 mm; $20<F_s<50\%$	Loose assortment with no apparent overlap; small to medium amounts of material <4 mm; $50<F_s<70\%$	Very loose assortment with no packing; large amounts of material <4 mm; $F_s>70\%$
Bar development	For $S<0.02$ and $w/y>12$, bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles; for $S>0.02$ and $w/y<12$, no bars are evident	For $S<0.02$ and $w/y>12$, bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of bar; for $S>0.02$ and $w/y<12$, no bars are evident	For $S<0.02$ and $w/y>12$, bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated; bars forming for $S>0.02$ and $w/y<12$	Bar widths are generally greater than one-half of stream width at low flow; bars are composed of extensive deposits of fine particles up to coarse gravel with little to no vegetation; no bars for $S<0.02$ and $w/y>12$

(continued)

Table 4.2-2. Stability Indicators, Descriptions, and Ratings for Bridges for the Johnson Classification System (continued)

Stability Indicator	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)
Obstructions, including bedrock outcrops, armor layer, LWD jams, grade control, bridge bed paving, revetments, dikes or vanes, riprap	Rare or not present	Occasional, causing cross currents and minor bank and bottom erosion	Moderately frequent and occasionally unstable obstructions cause noticeable erosion of channel; considerable sediment accumulation behind obstructions	Frequent and often unstable, causing continual shift of sediment and flow; traps are easily filled, causing channel to migrate and/or widen
Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam; minor amounts of noncohesive or unconsolidated mixtures; layers may exist, but are cohesive materials	Sandy clay to sandy loam; unconsolidated mixtures of glacial or other materials; small layers and lenses of noncohesive or unconsolidated mixtures	Loamy sand to sand; noncohesive material; unconsolidated mixtures of glacial or other materials; layers or lenses that include noncohesive sands and gravels
Bank slope angle (where 90° is a vertical bank)	Bank slopes<3H:1V (18° / 32.5%) for noncohesive or unconsolidated materials to <1:1 (45°) in clays on both sides	Bank slopes up to 2H:1V (27°) in noncohesive or unconsolidated materials to 0.8:1 (50° / 119%) in clays on one or occasionally both banks	Bank slopes commonly steep; to 1H:1V (45° / 100%) in noncohesive or unconsolidated materials to 0.6:1 (60° / 173%) in clays common on one or both banks	Bank slopes consistently steep over 45° (100%) in noncohesive or unconsolidated materials or over 60° (173%) in clays common on one or both banks
Vegetative or engineered bank protection	Wide band of woody vegetation with at least 90% density and cover; primarily hard wood, leafy, deciduous trees with mature, healthy, and diverse vegetation located on bank; woody vegetation oriented vertically; in absence of vegetation, both banks are lined or heavily armored	Medium band of woody vegetation with 70–90% plant density and cover; majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on bank; woody vegetation oriented 80–90° from horizontal with minimal root exposure; partial lining or armoring of one or both banks	Small band of woody vegetation with 50–70% plant density and cover; majority of soft wood, piney, coniferous trees with young or old vegetation lacking in diversity located on or near top of bank; woody vegetation oriented at 70–80° from horizontal, often with evident root exposure; no lining of banks, but some armoring may be in place on one bank	Woody vegetation band may vary depending on age and health, with less than 50% plant density and cover; primarily soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegetation located off of bank; woody vegetation oriented at less than 70° from horizontal with extensive root exposure; no lining or armoring of banks
Bank cutting	Little or none evident; infrequent raw banks, insignificant percentage of total bank	Some intermittently along channel bends and at prominent constrictions; raw banks comprise minor portion of bank in vertical direction	Significant and frequent on both banks; raw banks comprise large portion of bank in vertical direction; root mat overhangs	Almost continuous cuts on both banks, some extending over most of bank; undercutting and sod-root overhangs

(continued)

Table 4.2-2. Stability Indicators, Descriptions, and Ratings for Bridges for the Johnson Classification System (completed)

Stability Indicator	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)
Mass wasting or bank failure	No or little evidence of potential or very small amounts of mass wasting; uniform channel width over entire reach	Evidence of infrequent and/or minor mass wasting; mostly healed over with vegetation; relatively constant channel width and minimal scalloping of banks	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks; channel width quite irregular and scalloping of banks is evident	Frequent and extensive mass wasting; potential for bank failure, as evidenced by tension cracks, massive undercutting, and bank slumping, is considerable; channel width is highly irregular and banks are scalloped
Upstream distance to bridge from meander impact point and alignment	More than 35 m; bridge is well aligned with river flow	20–35 m; bridge is aligned with flow	10–20 m; bridge is skewed to flow or flow alignment is otherwise not centered beneath bridge	Less than 10 m; bridge is poorly aligned with flow

Source: Johnson (2005).

Table 4.3-1. Preliminary Classification and Stability Scores for Bridge Reaches

Stability Indicator	Bell-Irving River Bridge	Wildfire Creek Bridge	BRIDGE #3	BRIDGE #5 (Pinch Pt. Ck.)	BRIDGE #6 GASSY CREEK	BRIDGE #7 LITTLE SCOTT CREEK	BRIDGE # 8 SCOTT CREEK BRIDGE	BRIDGE #9	BRIDGE #11	BRIDGE #16	BRIDGE #18	BRIDGE #19	BRIDGE #20	BRIDGE #21
Montgomery-Buffington	dune ripple	plane bed	cascade	plane bed	n/d	n/d	plane bed	plane bed	pool riffle	pool riffle	plane bed	plane bed	bedrock	dune-ripple
Watershed and floodplain activity and characteristics	Good (6)	Good (4)	Excellent (3)	Excellent (3)	Excellent (3)	Good (4)	Good (4)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)
Flow habit	Good (4)	Good (6)	Poor (10)	Good (5)	Fair (8)	Good (5)	Good (4)	Poor (10)	Fair (9)	Fair (9)	Fair (9)	Poor (11)	Poor (12)	Poor(11)
Channel pattern	Good (5)	Good (5)	Good (4)	Good (5)	Good (5)	Good (4)	Good (4)	Good (4)	Good (5)	Good (4)	Poor (10)	Poor (10)	Poor (10)	Poor (11)
Entrenchment/ channel confinement	Fair (9)	Fair (9)	Good (5)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Good (4)	Poor (10)
Bed material; F_s=approximate portion of sand in bed	Fair (7)	Excellent (2)	Excellent (3)	Good (5) est.	Good (5) est.	Good (5)	Excellent (2)	Excellent (3)	Good (5)	Fair (8)	Excellent (3)	Excellent (2)	Fair (8)	Fair (8)
Bar development	Fair (8)	Excellent (3)	Excellent (2)	Excellent (2)	Good (4)	Good (4)	Fair (8)	Excellent (3)	Excellent (3)	Good (5)	Fair (8)	Fair (8)	Fair (8)	Fair (8)
Obstructions, including bedrock outcrops, armor layer, LWD jams, grade control, bridge bed paving, revetments, dikes or vanes, riprap	Excellent (3)	Good (4)	Fair (7)	Good (5)	Good (6)	Fair (8)	Excellent (3)	Good (4)	Fair (7)	Good (4)	Excellent (2)	Good (4)	Good (4)	Good (4)
Bank soil texture and coherence	Excellent (3)	Fair (8)	Good (6)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Fair (8)	Excellent (3)	Good (4)
Bank slope angle (where 90° is a vertical bank)	Excellent (3)	Fair (8)	Good (4)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Excellent (3)	Poor (11)	Excellent (3)
Vegetative or engineered bank protection	Good (5)	Fair (8)	Excellent (2)	Good (5)	Good (5)	Good (6)	Good (5)	Good (5)	Good (6)	Fair (7)	Poor (10)	Poor (10)	Poor (12)	Poor (12)
Bank cutting	Excellent (2)	Good (6)	Good (5)	Excellent (3)	Good (5) est.	Good (5)	Good (6)	Good (5)	Good (5)	Good (6)	Good (6)	Fair (8)	Good (4)	Poor (12)
Mass wasting or bank failure	Excellent (3)	Good (6)	Good (4)	Excellent (2)	Excellent (3) est.	Excellent (3) est.	Good (5)	Excellent (3)	Excellent (3)	Excellent (3)	Good (4)	Excellent (3)	Fair (8)	Poor (10)
Upstream distance to bridge from meander impact point and alignment	Good (4)	Good (6)	Good (6)	Good (6)	Good (4)	Good (4)	Excellent (3)	Good (4)	Good (4)	Good (4)	Good (6)	Good (6)	Good (6)	Good (6)
Sum	**62**	**75**	**61**	**56**	**63**	**63**	**59**	**59**	**65**	**68**	**76**	**80**	**93**	**130**

Note: "est." is estimated and uncertain. Based on areal photographs and topographic maps.

5. Recommendations

5. Recommendations

This assessment could be updated by field visits to complete the assessment of culverts and bridges on channel morphology, however, the preliminary results serve to direct maintenance towards areas of expected higher risk. To update the assessment would require field visits during both peak flow and a low-flow period when channels are snow-free. A visit during peak flow would serve to determine the potential for erosion and hydrologic connectivity, culvert plugging (including the potential for plugging by snow and ice), and upstream flooding. A visit during low flow would serve to determine if ephemeral drainages can be identified and bed material can be assessed.

For bridges, visits could review channel reaches identified as being potentially unstable (bridges 18 to 21) and reaches identified as data-poor (bridges 5, 6, and 7). For culverts, visits would focus on areas assessed to be at high risk, such as the first 10-15 km of the access road in the Wildfire Creek watershed. Field work may also identify culverts at risk of causing channel modifications that are not apparent in this desktop-based study.

For culverts, field-based assessments would focus on identifying:

- gradients upstream and downstream of culverts;
- culverts that empty into gullies vs. hydrologically unconnected areas;
- sediment erosion and deposition;
- mass wasting and gullying;
- up-gradient ponding;
- culvert blockage;
- large woody debris; and
- effectiveness of ditches.

For bridges, field-based assessments would focus on refining channel parameters estimated here, including determining:

- channel width and depth at bankfull and at low flow;
- bed material and determination of particle size;
- Obstructions;
- bank material, incision, undercutting, mass wasting, vegetation;
- reach sinuosity and slope;
- identification of upstream and downstream hydrologic controls; and
- occurrence of channel bars.

The Johnson classification system is a “level one” approach, designed to identify crossings that require more detailed assessments (Johnson, Gleason, and Hey 1999; Johnson 2005; Lagasse et al. 2012). While preliminary in nature it does serve to highlight those areas of greater risk and thereby will be used to focus maintenance and monitoring on these areas.

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