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V1 December 10, 2021; V2 December 13, 2021

During the recent atmospheric river events (Nov 14-15; Nov 27-29; Nov 30-Dec 1; 2021), Jason Creek, at Ivey Lake, near Pemberton, BC experienced three extreme hydrogeomorphic events and washed out the Jason Creek culvert at Reid Road two times. The events were accompanied by overland flow flooding of several properties, localised bank erosion, minor damage to Portage Road, and threatened the CN Rail line.

On November 17-18, 2021, following the first washout at ~2100 hrs, November 15, Frontera Geotechnical conducted a site assessment documenting damages along the Jason Creek alluvial fan. Their report, dated November 23, 2021 provided the following conclusions and recommendations:

- Jason Creek may be vulnerable to debris flow activity, and such an event could force the creek to avulse directing it overland along a former course toward the properties 1781 and 1794 Reid Road.
- Debris jams along the lower reach of the Jason Creek above Reid Road should be cleared to reduce debris flow and avulsion hazard.
- A qualified professional should conduct a field review of upslope terrain to identify the source area and determine if a debris flow hazard exists.
- The SLRD approving officer should conduct a review of all background reports supporting subdivision and building permit applications to determine if development has followed professional advice.
- A hydrogeomorphic assessment should be conducted to ensure the Reid Road culvert is properly sized and to determine if a debris flow catchment structure may be required above Reid Road.

Subsequent to their report, the Reid Road culvert washed out again at ~0430 hrs on December 1, 2021. That morning Cordilleran Geoscience (Friele) was contacted by SLRD and asked to conduct an assessment of the upslope terrain, to determine if a landslide hazard existed and whether the risk merited evacuation alert and/or order. The field assessment was completed that afternoon, and an evacuation order was issued at 1500 hrs for lots 1793, 1794, 1781, 1788, 1791, 1802, 1812 & 1815 Reid Road. That evening at about 2200 hrs the creek washed out the road again, and overland flow affected many lots. On December 2, 2021 Cordilleran conducted a review of the affected areas on the Jason Creek fan, and recommended further channelization above Reid Road. That work was conducted December 3-5, 2021. December 8-9, 2021, Capilano

Highways installed a 1600 mm metal culvert. On December 12, 2021 Cordilleran conducted a final channel assessment to assess the residual hazard and advise on lifting the evacuation order.

This report presents a summary of several background reports documenting terrain hazards in the Jason Creek watershed, describes terrain conditions observed during field traverse of the Jason Creek ravine on December 1, 2021, the fan areas on December 2, 2021, the December 12, 2021 ravine channel assessment, and provides a preliminary assessment of the hazards affecting residential areas, and recommendations following therefrom.

In the field, observation waypoints were recorded on an iPad mini with internal GPS, and using Avenza PDFmaps software. Photographs were taken of select sites. Appendix 1 provides annotated photographs; they are presented in order from landslide source, to fan apex, then downstream along Jason Creek to Portage Road; impacts on properties are presented separately; the December 12, 2021 channel assessment photos are presented last. Raw field observations and their locational data (UTM, NAD83) are presented in Appendix 2. Figures 1 & 2 shows original mapping and a long profile by Baumann Engineering (1997); and Figure 3 shows the December 1-2, 12, 2021 mapping of the Jason Creek ravine, the upper and lower fan areas, with observations plotted for cross-reference with Appendices 1 & 2.

Background Review

Riddel 1992

Bedrock in the Ivey Lake area consists of Gambier Group (lKGP) Mesozoic to Lower Cretaceous, metamorphosed marine sedimentary and volcanic rocks. The rock ranges from hard, blocky to phyllitic, and in many areas, especially along Jason Creek, it is deeply altered (clayey), limonitic with grey, cream to orange colours (Photos 68, 69). The dominant structural strike is NW-SE parallel with the Owl Creek fault. Jason Creek evidently follows a shear zone resulting in the heavy alteration of the bedrock in this area and contributing to the instability in the Jason Creek ravine, as discussed below. The potential mineralization in the shear zone was targeted by prospectors years ago (Photo 77).

Piteau 1981

As part of the subdivision approval process for DL2679, Piteau Associates (May 1981) provided an assessment of the rockfall & landslide hazard associated with the prominent rock bluffs above Reid Road (Photo 1). They noted ongoing rockfall activity affecting the talus slopes, and identified a prehistoric rockslide deposit that had run out onto the base of slope (Photo 2). They described the toe of the deposit as having reached/filled a NW-SE trending trough. Although they did not identify it as such, this trough is the east margin of the Jason Creek alluvial fan. They believed that the landslide risk was significant enough that a hazard covenant area should be delimited affecting all or part of proposed lots 8-11 (note: not final numbering system).

Blunden 1981

Blunden (December 1981) provided a subsequent report for the proposed subdivision of DL4100 & DL2679. In part, the Blunden report was requested by the owner Templar Holdings to provide a second opinion on the rockslide hazard affecting Lots 3, 8-11. Blunden downplayed the

probability of a future rockslide on the basis that the prehistoric rockslide deposit was most certainly deglacial/immediate post glacial in origin (ie., paraglacial), the argument being that under extant hydrogeomorphic conditions the rockslide hazard did not exist.

With respect to "recent" deposits, Blunden noted "small slides of surficial material occur within the [Jason Creek] stream ravine," and "immediately downstream of the ravine are fan deposits with evidence of boulder gravel spreads." Further, "within the past 30-years the main branch of Jason Creek has developed a tendency to flood into the development area." "Examination of the main branch ravine found gaping fissures subparallel to the creek at about the 760 m altitude. These fissures occur in both bedrock and morainic materials." "Small volume slumps into the ravine have been an ongoing process since deglaciation. The form of the ravine and evidence of former slides indicate the outflow of slide debris to be entirely contained within the ravine or on the alluvial fan."

In this writer's view, the paraglacial age of the rockslide specified by Blunden was not founded on evidence. MoTI also disagreed and the landslide covenant was imposed as a condition of subdivision approval. Despite various arguments presented by consultants (PK Read 2016), MoTI has refused to significantly amend the original covenant area.

Despite the observations regarding the instabilities within the Jason Creek ravine and the associated alluvial fan hazards, apparently no recommendations to mitigate alluvial fan hazards were incorporated into the subdivision approval.

Baumann Engineering 1997

Baumann Engineering (1997; author Friele) conducted detailed terrain mapping of the Ivey Lake watershed at 1:5000 scale. The area mapped consists of the crown land above DL4100 and DL2679, including the Mungye and Jason Creek watersheds. On the terrain map (Figure 1), the Jason Creek alluvial fan was delineated. Several debris flows affecting Jason Creek alluvial fan were identified from evidence of tree scars and local anecdote: past debris flows occurred on or about ~1900, ~1952, ~1970, and 1990, on average every 25 years. It was concluded "the entire fan area (upper fan; Figure 1) was considered active and [potentially] subject to debris flow activity." "At the apex [above Reid Road], an old channel diverges off to the eastward, and a high probability for channel avulsion exists in this area."

The Jason Creek ravine, extending from the fan apex at 455 m to 1000 m elevation, was mapped and found to contain evidence of both smaller scale sidewall slumping and larger scale bedrock instability (Figures 1 & 2). In particular, at 650 m elevation there is the confluence of the main Jason Creek ravine and a tributary from the east. Between these channels, extending up to about 800 m elevation, an unstable bedrock area was identified consisting of a slow moving or sagging slope (Figure 1). At the crest is a bedrock bluff that is deeply fractured and appears to be spreading southward (Photo 3); below the bluff is a talus slope that has been truncated across the contour by a normal fault, resulting from slow failure of the material below into Jason Creek (Figures 1, 3). These lower failing slopes are the source for the 1990 debris flow, and were recognised by Blunden in 1981 (this is also the source for one or more events in 2021). At two other sites, lineaments in bedrock were noted that were suspect potential instabilities (Figure 1).

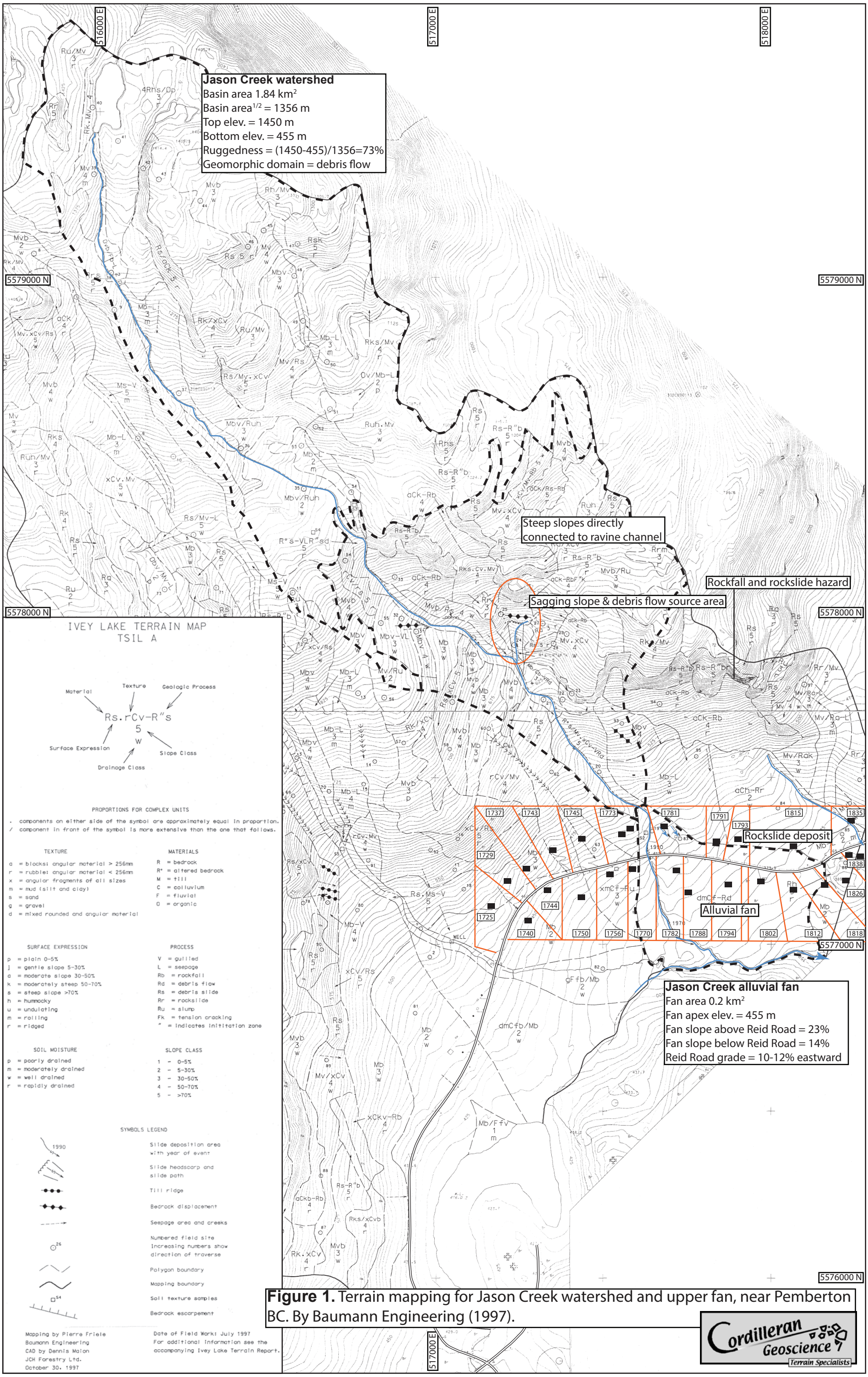


Figure 1. Terrain mapping for Jason Creek watershed and upper fan, near Pemberton BC. By Baumann Engineering (1997).

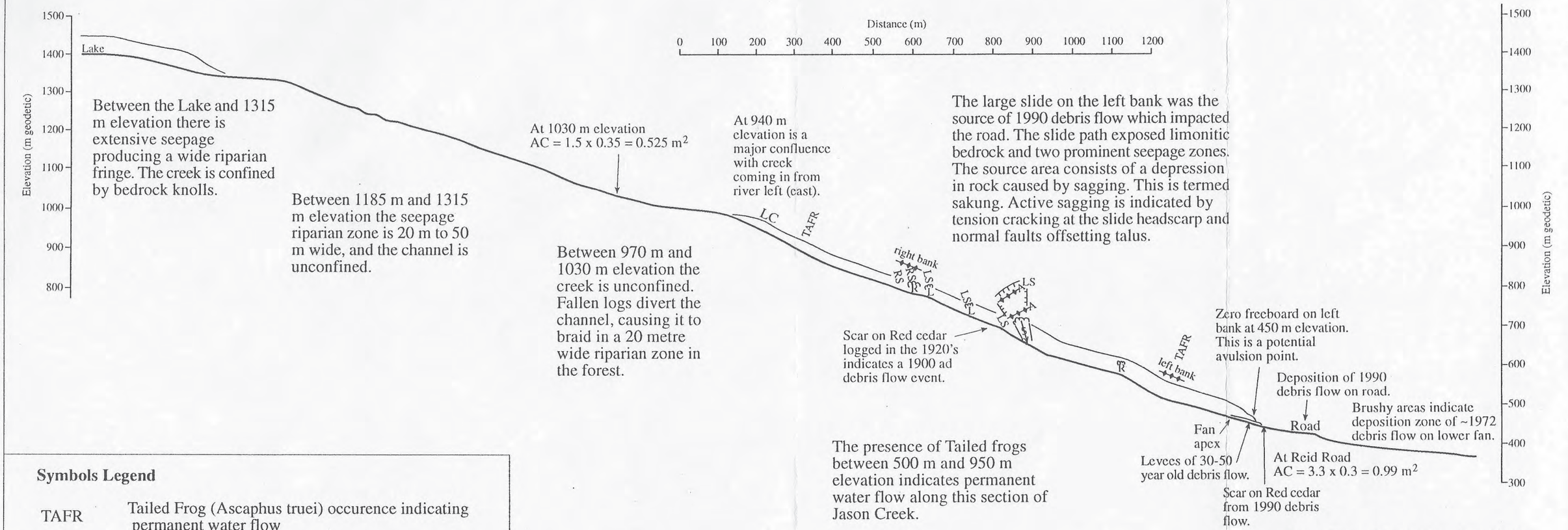
Cordilleran Geoscience
Terrain Specialists

Figure 2. Long profile of Jason Creek watershed and upper fan, near Pemberton BC. By Baumann Engineering (1997).

Cordilleran Geoscience
Terrain Specialists

Jason Creek Long Profile

Scale 1: 10 000; no vertical exaggeration.



The presence of Tailed frogs between 500 m and 950 m elevation indicates permanent water flow along this section of Jason Creek.

According to Forest Practices Code guidelines, the 1600 mm culvert on Reid Road is undersized for a Jason Creek 100-year flood.

Between 470 m and 970 m elevation the channel is steep and confined, incised 20 m to 40 m in bedrock. The bedrock is a shistose greenstone, which in places is highly altered to limonite. This bedrock is very friable contributing considerable rubble to the channel, resulting in a large volume of mobile bedload. Deep-seated instability in the bedrock is indicated by a number of offeset bedrock lineaments near the crests of the gully sidewalls. Historical evidence and the large size of the Jason Creek fan indicate debris flows are not uncommon along Jason Creek. Bedrock failures have likely caused the largest debris flows. Indeed, local greenstone is the predominant rock type found in fan sediment. Thus, there is a high risk of impact to structures located downstream on the Jason Creek fan.

Symbols Legend

TAFR	Tailed Frog (Ascaphus truei) occurence indicating permanent water flow
RC, LC	Tributary creeks; right and left banks respectively
RS, LS	Seeps; right and left banks respectively
R, L	Small slides; right and left banks respectively
	Large sidewall failure
A	Tension cracks in bedrock near crest of gully sidewall; inactive and active
AC = 1.35 m^2	Yearly active channel crossectional area

Figure 2
Ivey Lake Terrain Assessment

Jason Creek Longprofile and Gully Assessment

Baumann Engineering
September 5, 1997.

Cordilleran 2021 Observations

Watershed characteristics

The Jason Creek watershed rises from 455 m at the fan apex to 1450 m elevation just west of the headwater lake (Figure 1). The watershed area is 1.84 km^2 and overall has a basin steepness, or ruggedness, of 0.73 m/m (Table 1). Ruggedness values >0.6 m/m indicate that the watershed is prone to debris flow activity affecting the fan apex (Melton 1965; Millard et al 2006).

Table 1. Jason Creek above fan apex, watershed morphometrics and geomorphic domain.

Basin area	Basin area$^{1/2}$	Top elev.	Bottom elev.	Ruggedness	Geo domain
1.84 km^2	1356 m	1450 m	455 m	0.73 m/m	Debris flow

Ruggedness = (top elev. – bottom elev.)/basin area$^{1/2}$

The Jason Creek watershed has a convex long profile (Figure 2), with the lower half of the watershed below 1000 m elevation being much steeper than the upper half. These lower slopes are directly connected to the ravine sidewalls. Hence any instability in this lower slope area will enter the ravine and become conveyed to the fan apex. It is the ravine in this lower part of the watershed that was investigated December 1 & 12, 2021.

Between the fan apex at 455 m and 500 m elevation the channel has ~20-30% gradient with a valley flat ~20 m wide, with stored colluvium incised by a 12 m wide by 2-3 m deep trapezoidal channel (WPs 137-142). The Spider hoe cleared jams from this section of the channel. At 500 m elevation there is a break to a steeper (30-40% gradient), more steep-sided V-shaped channel, extending up to 575 m elevation. Through this reach (WPs 142-147) the sidewalls are undermined and unstable; there were two fresh bank slumps and several older bank slumps noted (Photo 66, 67, 70, 72). At one site (WPs 144, 145), three 4-6 m diameter boulders, the lowest partially supported by cedar tree (Photo 67), block the channel. This reach contains residual hazards that add to the total residual volume described below. From 575-655 m elevation the channel gradient breaks to 20-30% and the valley flat is up to 50 m wide (WP147). In this area the valley flat is filled 3-5 m deep with colluvium derived from degraded bedrock containing altered ripups (Photo 71).

The larger sagging slope instability extending from 655-800 m elevation and has an approximate plan area of 30,000 m^2 (Figure 1); assuming a potential failure thickness of 10 m, then a landslide volume of 300,000 m^3 is possible.

On December 1, 2021 there was a fresh landslide scar at the site of the 1990 debris flow source (Photos 4-7; Figures 1-3). Around the headscarp of the fresh scar there was unstable material bounded by gaping tension cracks (WPs 6-12); this unstable area was 50-75 m wide along its crest, by 15 m long downslope length, by 2-3 m thick, with a potential volume of 1500-3375 m^3. Between Dec 1 & Dec 12, 2021 the area had changed due to the debris flow 2200 hrs on Dec 1, with windthrow, and expansion headward ~5 m distance, defined by tension cracking with 1 m downdrop (Photos 73-76). The imminent failure volume is 1000-4000 m^3 (30-35 m wide by 15-25 m long by 2-5 m thick). This unstable area represented the greatest residual hazard.

Farther upstream, on the right (west) sidewall a smaller fresh slump was noted (Photo 7; WPs 21-22), with dimensions 10 m wide by 40 m long by 2-3 m thick, or 800-1200 m^3 in volume. This feature had not changed on Dec 12, 2021 (Photo 78), yet remains a residual hazard.

At several sites along the west sidewall there were bedrock lineaments and uphill facing (antislope) scarps (Photos 8, 9) suggestive of deep-seated bedrock instability in the sidewall (see WPs 3-5, 42; 41; 36-37, 23-25). Based on the width along the contour and sidewall length to the creek at these sites, and an assumed failure thickness of 5-10 m, then hypothetical debris flow volumes of 5000-50,000 m^3 are possible. On Dec 12, 2021, it was noted that the channel reach between 575-650 m elevation has a 50 m wide valley flat and is filled with colluvial blanket derived from altered bedrock (Photo 71, WP147). These deposits may reflect previous instability associated with these sidewall lineaments.

Flood frequency

A preliminary flood frequency analysis for Jason Creek at the fan apex was conducted using Pemberton Creek gauging data (1987-2018) and a proprietary scaling function based on a basin area-discharge relationship developed by the author (Table 2). This analysis suggests peak flows of 5.0 to 5.5 m^3/s for Q^{100} & Q^{200} floods, respectively.

Owing to high roughness and turbulent flow conditions, steep mountain streams (ie., step-pool morphologies) typically have peak flood velocities of ~2 m/s (Wilcox & Wohl 2007). Assuming a peak velocity of 2 m/s, the estimated peak discharge would require an opening size of about 2.5 m^2 to pass a clear water flood. Additional area would be required to accommodate sediment.

Table 2. Flood frequency analysis for Jason Creek (1.84 km^2), based on Pemberton Creek (32.4 km^2) gauge records (1987-2018) and scaling by basin size.

Return period (yrs)	Pemberton Creek Q^{peak} (m^3/s)	Jason Creek at apex Q^{peak} (m^3/s)	*Opening size (m^2)
2	19	1.9	1.0
10	32	3.3	1.6
50	43	4.5	2.2
100	48	5.0	2.5
200	53	5.5	2.7

*Assumes peak velocity of 2 m/s.

A method applied for culvert sizing in forestry operations in BC is the "Active Channel (AC) times three," where ACx3 is proportional to the 100-year flood (Beckers et al 2002). Baumann Engineering (1997) measured the active channel above Reid Road, reporting it to be 3.3 m wide by 0.3 m deep yielding an active channel (AC) area of 0.99 m^2 (Figure 2); thus, ACx3 on Jason Creek at the fan apex is ~3 m^2. This is in agreement with the opening size estimates reported in Table 2.

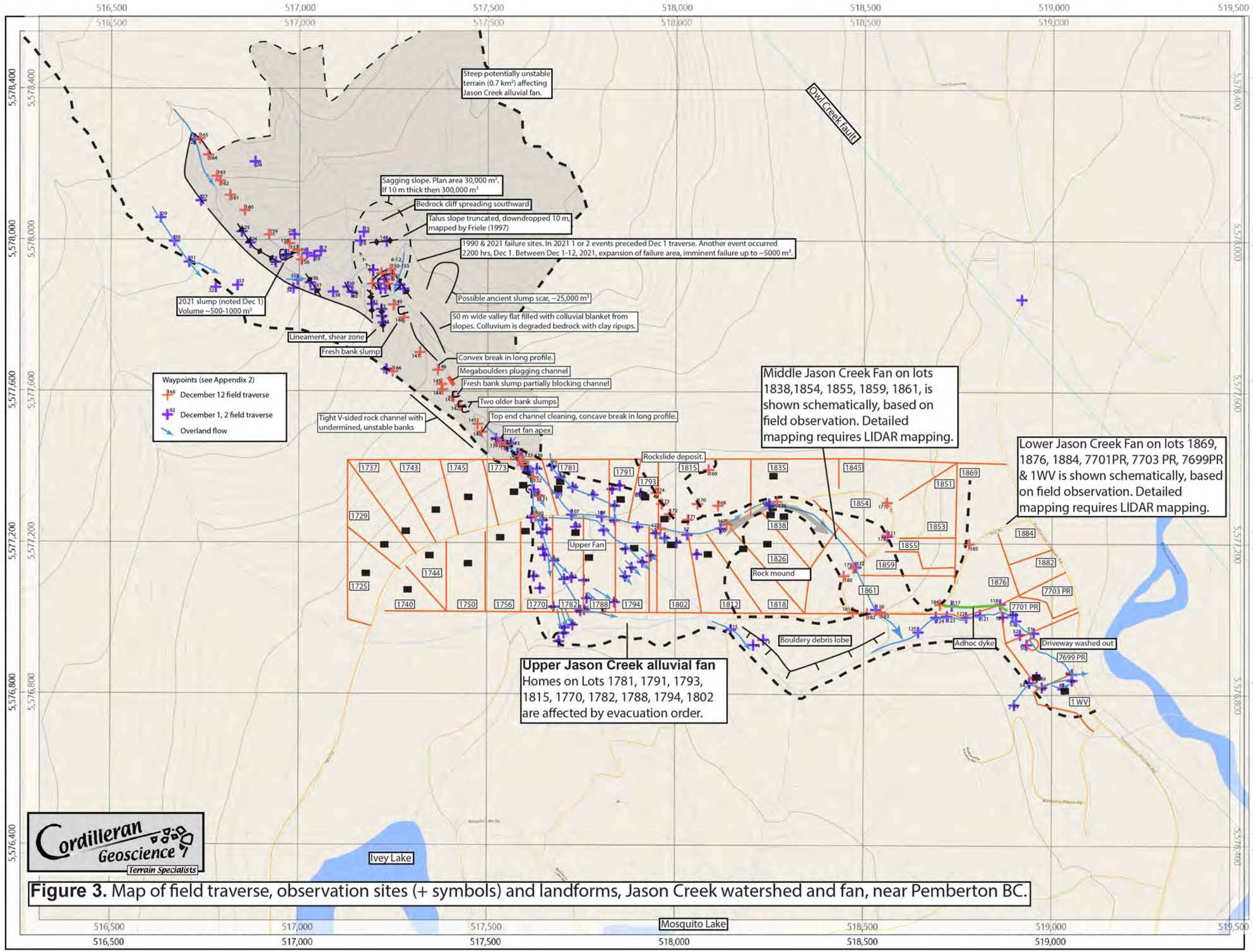


Figure 3. Map of field traverse, observation sites (+ symbols) and landforms, Jason Creek watershed and fan, near Pemberton BC.

Reid Road stream crossing structure
Jason Creek at Reid Road has been fitted with a 1600 mm metal culvert. This has an opening size of 2 m^2. A culvert's hydraulic function is optimal when 2/3 full or less; thus, a 1600 mm pipe provides an effective opening of 1.3 m^2. MoTI (2019; TAC manual, Table 1010.A) requires crossing structures to pass a 100-year to 200-year flow depending on road classification. Based on this assessment, a 1600 mm culvert is undersized for clear water floods on Jason Creek at the fan apex.

Alluvial fan areas
Below the fan apex at 455 m elevation, Jason Creek has deposited an irregularly shaped alluvial fan. The fan can be divided into three subareas: the upper fan, the middle fan, and the lower fan.

Upper fan
The upper fan, originally mapped by Baumann Engineering (1997; Figure 1), is a radially shaped typical fan landform. Its west edge is bounded by gentle terrain on the east side of Ivey Lake; the south side abuts rocky slopes climbing up to Mosquito Lake; the east side abuts a rock knoll; while the northeast edge abuts the morainal slopes and the prehistoric rockslide deposit (Figure 3). Jason Creek flows south across the fan to drain through a gap at 350 m elevation between the rock knoll and the Mosquito Creek slopes. This main channel then feeds directly to the lower fan area. On the east side of the fan, at 375 m elevation, Reid Road passes through a gap between the rock knoll and the rockslide deposits; if Jason Creek were to avulse eastward then it could flow through this gap, and it likely has done so in the past. This outlet feeds directly to the middle fan area.

This upper fan has an area of about 0.2 km^2. It has a concave long profile with 23% slope above Reid Road and 14% slope below Reid Road. This concave profile indicates preferential debris deposition at the fan apex. Fan materials consist of boulder-cobble gravel with a clay/silt/sand (ie, mud) matrix.

As noted by Baumann Engineering (1997) and Frontera (2021), there is a southeasterly trough east of the extant creek, that likely represents an abandonned channel. Given the low degree of channel incision on the fan, this channel, or any other course on the fan, could be occupied by the creek given an avulsion at the fan apex or at Reid Road.

As mapped December 12, 2021, the creek cleaning created a 170-200 m debris berm on the left bank above Reid Road (WPs130-137; Photos 61, 63, 64). The berm is not continuous, but is broken in several places, and there remains at least three avulsion points (WPs 132, 136, 137; Photo 64) where debris may avulse southeast directly affecting 1781 Reid Road.

Reid Road climbs up the fan from east to west, transverse across the contours, at an average gradient of 10-12%. This steep grade of the road, maintained through the Jason Creek crossing creates a situation where, given any blockage of the culvert, there is a high probability that the road will capture the creek and direct it easterly across the fan toward the gap and potentially affecting the middle fan.

Middle fan
This fan area is located between the lower fan apex at ~290 m elevation and ~350 m elevation, and is crossed by the climbing switchback on Reid Road (Figure 3). The fan is inset between higher rock-controlled terrain to the east and west. Due to low resolution topographic maps and lack of detailed field truthing, this fan area is not accurately mapped. It is crossed by a stream flowing directly off the hill above; and carries overland flow captured by Reid Road. As indicated above, it could be affected by Jason Creek flood and debris flow activity. The stream crossing this fan area joins Jason Creek just above the apex of the lower fan at 290 m elevation.

Lower Jason Creek fan
At ~290 m elevation Jason Creek emerges from a confined channel onto the valley bottom. Valley bottom sediments in this area consist of raised terrace gravels of the immediate post glacial Birkenhead River onlapped by Jason Creek fan. As with the middle fan, due to low resolution topographic maps and lack of detailed field truthing, this fan area is not accurately mapped. Average slope in this area is between 4-7%, indicating fluvial processes dominate.

Near the fan apex (WP124), tying into Reid Road (WP117) and extending downslope (WP119), and setback some distance from the left (east) streambank, there is an adhoc dike protecting lots 1876, 1882 & 1884 from overbank flooding (Figure 3). The left streambank through this reach has also been riprap armoured (WP 120). This bank protection ends at the house on 7701 Portage Road. Downstream of this point Jason Creek is incised between 4-6 m in adjacent deposits.

Damages resulting from the November 14 through December 1, 2021 storms
Jason Creek experienced two possibly three debris flow events (Photos 10, 11) resulting in partial stream avulsion at the apex above Reid Road (Photos 12, 13, 14), damage to the Reid Road crossing structure on Jason Creek (Photo 15), and overland flow flooding down Reid Road (Photos 16, 17) and affecting eight properties (Table 3). The damages were most extensive and severe on the upper fan area (Photos 18-23). No impacts were documented in the middle fan. On the lower fan, Jason Creek remained confined (Photos 24-32), but caused erosion where a driveway culvert became plugged forcing road overtopping and bank undermining (Photo 33). High flows ponding at the Portage Road and CN Rail culverts threatened those crossings (Photos 34-37).

Table 3. Summary of impacts noted by Cordilleran Geoscience December 2, 2021.

Property	Fan area	Impacts
1770 RR	Upper fan	Driveway access severed (Photo 43), bank erosion affecting domestic well (Photo 44), gravel splays and erosion in yard (Photos 18-19). House on hillslope above fan (Photo 43).
1773 RR	Upper fan	Property straddles fan apex. House is on west bank raised above creek. Small slump on toe of west bank. Debris flow, gravel splays and flooding on east side of property at fan apex (Photos 10-14). All creek cleaning activities occurred in this area, as will any future remedial action to protect other properties.
1781 RR	Upper fan	Avulsed debris slurry clipped the porch supports on the SE side of house (Photos 38, 39) – close call – and flowed down driveway to Reid Road. High flows from small creek behind shop (Photo 40).
1782 RR	Upper fan	House site unaffected. Extensive overland flow and erosion on lower half of property (Photos 20, 21).
1788 RR	Upper fan	House site unaffected. Overland flow across driveway & extensive overland flow and erosion on lower half of property affecting garlic patch (Photo 47) and dug pond (Photo 48).
1791 RR	Upper fan	Minor overland flow from small creek on 1781 RR intercepted by driveway and diverted back to Reid Road. Photo 41.
1793 RR	Upper fan	No impact noted. Photo 42.
1794 RR	Upper fan	Extensive overland flow through yard directly affecting house (Photos 49, 50).
1802 RR	Upper fan	Extensive overland flow through yard directly affecting house (Photo 51) and chicken house (Photo 52).
1812 RR	Upper fan	No impact noted (Photo 53).
1815 RR	Upper fan	No impact noted. Two towable tiny homes on fan area.
1818 RR	Upper fan	No impact noted. House raised on rock mound.
1854 RR	Middle fan	No impact noted.
1855 RR	Middle fan	No impact noted.
1859 RR	Middle fan	No impact noted.
1861 RR	Middle fan	No impact noted.
1869 RR	Lower fan	Protected by adhoc dike on 1876 Reid Road. No impacts.
1876 RR	Lower fan	Protected by adhoc dike on east property line. Minor bank erosion.
1882 RR	Lower fan	Protected by adhoc dike on 1876 Reid Road. No impacts.
1884 RR	Lower fan	Protected by adhoc dike on 1876 Reid Road. No impacts.
7701 PR	Lower fan	No impact noted. Photo 54.
7703 PR	Lower fan	No impact noted.
7699 PR	Lower fan	Driveway across creek (Photos 33, 56) to accessory building (Photo 57) washed out.
1 WV	Lower fan	Hillslope creek caused overland flow flooding. Culvert plugged (Photos 58, 59).

Hazard & Risk Assessment

Hazard & risk Concepts

A hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (see Table 4). Consequence (Table 5) is a product of factors, including whether a given hazard will reach a site, whether elements at risk (e.g., houses/people) will be present when the site is affected by the hazard, how vulnerable the elements at risk are to the hazard affecting the site, and the value of the elements at risk or the number of persons exposed. The product of the factors Hazard and Consequence equals Risk.

Table 4. Qualitative hazard frequency categories *affecting the building site*.

Qualitative frequency	Annual return frequency	Probability (% in 50 yrs)	Comments
Very high	>1:20	>90	Hazard is well within the lifetime of a person or typical structure. Clear fresh signs of hazard are present.
High	1:100 to 1:20	40-90	Hazard could happen within the lifetime of a person or structure. Events are identifiable from deposits and vegetation, but may not appear fresh.
Moderate	1:500 to 1:100	10-40	Hazard within a given lifetime is possible, but not likely. Signs of previous events may not be easily noted.
Low	1:2500 to 1:500	2-10	The hazard is of uncertain significance.
Very low	<1:2500	<2	The occurrence of the hazard is remote.

Table 5. Simplified consequence assessment.

Consequence	Description
Very High	Direct impact with extensive structural damage; loss of life & limb.
High	Direct or indirect impact with some potential for structural damage; loss of life & limb.
Moderate	Indirect debris impact. No structural damage but damage to houses and property.
Low	Minor property damage only.
Very Low	Virtually no damage.

No activity is free of risk, and the concept of safety embodies risk tolerance. In Canada and BC there is no legislated guidance for risk tolerance to geohazards, and the term “safe” has not been defined. In considering risk tolerance, an important concept is that risk of loss of life from natural hazards should not add substantially to those that one is typically subject to (e.g., driving, health, recreation, etc) combined. For reference, the risk of death and injury from driving in Canada is approximately 1:10,000 and 1:1000 per annum, respectively (Transport Canada 2011).

Hazard & Risk Evaluation Criteria

In British Columbia, the design flood level for normal hydrologic flood hazards is taken to be the 200-year return flood (WLAP 2004). The SLRD has no guidelines pertaining to landslide safety, and they require Qualified Professionals to recommend suitable criteria.

In lieu of the lack of hazard acceptability criteria adopted by the Squamish Lillooet Regional District, this study will refer to criteria adopted by the Fraser Valley Regional District (Cave 1993). The possible hazards affecting and the associated management responses are outlined in Table 6.

Table 6. Abridged hazard acceptability matrices for various hazards potentially affecting Jason Creek fan (after Cave 1993). For more details see original report.

	Hazard Categories (per annum) and Management Responses				
Mtn. stream erosion/avulsion	>1:10	1:10-1:100	1:100-1:200	1:200-1:500	<1:500
Major repair (>25%)	5	4	2	1	1
New building	5	5	4	2	1
Subdivision	5	5	5	4	1
Debris flood	>1:50	1:50-1:200	1:200-1:500	1:500-1:10,000	<1:10,000
Major repair (>25%)	4	4	1	1	1
New building	4	4	3	1	1
Subdivision	5	5	4	2	1
Debris flow	>1/50	1/50-1/200	1/200-1/500	1/500-1/10,000	<1/10000
Major repair (>25%)	5	4	2	1	1
New building	5	5	4	3	1
Subdivision	5	5	5	4	1
Catastrophic landslide	>1/200	1/200-1/500	1/500-1/1000	1/1000-1/10000	<1/10000
Major repair (>25%)	5	5	2	1	1
New building	5	5	5	1	1
Subdivision	5	5	5	5	1

1 - Approval without conditions relating to hazards.
2 - Approval without siting conditions or protective works conditions, but with a registered covenant against title.
3 - Approval, but with siting requirements to avoid the hazard, or with requirements for protective works to mitigate the hazard.
4 - Approval as (3) above, but with a registered covenant against title as well as siting conditions, protective works, or both
5 - Not approvable.

Hazard assessment

The upper Jason Creek fan is vulnerable to typical alluvial fan hazards including overland flow flooding and erosion arising from channel avulsion; water floods with high sediment concentration, or debris floods; debris flow and possibly catastrophic landslide. The type and intensity of these processes diminish downslope. The middle and lower fan areas are likely only vulnerable to overland flow and debris flooding.

Considering recent and previous (Baumann Engineering 1997) observations, small debris flows on the order of 100s m^3 to 5000 m^3 volume occur on average every 25-years on upper Jason Creek fan. Medium-sized debris flows, from 5000-50,000 m^3 likely have a moderate to low frequency, or ±1/500-years. Large landslides ranging from 50,000-300,000 m^3 are conceivable, but with very low (<1/2500-years) frequency.

Based on these preliminary judgements, a Frequency-Magnitude model can be developed for example purposes (Figure 4). Two end-member frequency-magnitude pairs are plotted on a Log-Log chart: a 1/25-year event with 1000 m^3 volume and a 1/5000-year event with 100,000 m^3 volume. A straight line between is assumed. The 1/500-year event volume can then be interpolated as ~13,000 m^3; with uncertainty, this may vary from 10,000-25,000 m^3. A 1/100-year event is estimated to have a volume of ~3000 m^3.

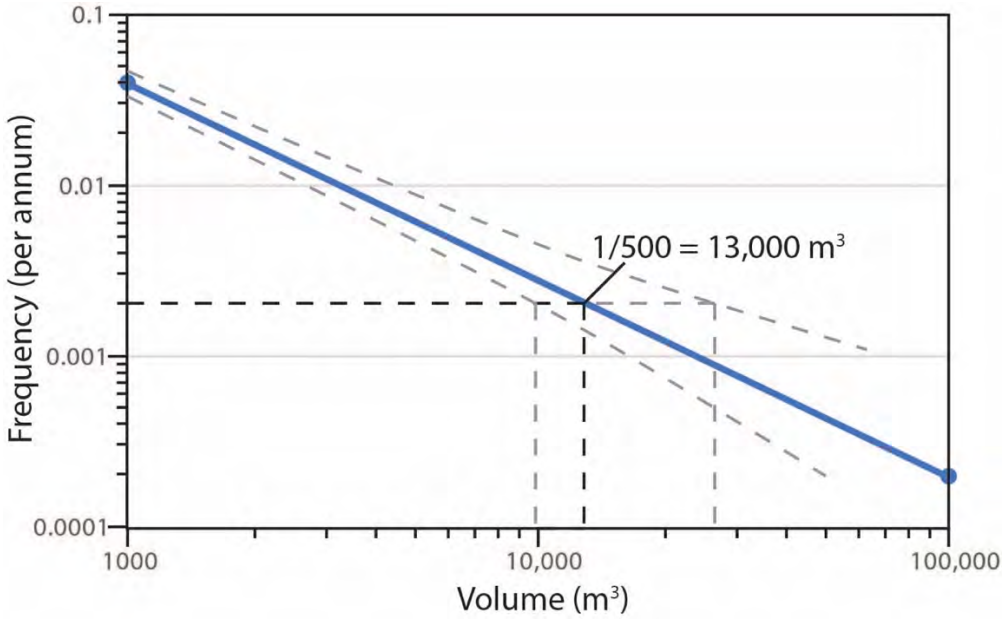


Figure 4. Hypothetical F-M diagram for debris flow affecting upper Jason Creek fan. Volumes are based on estimates from field observation of likely failure scenarios; the frequency for small events is based on historical record; while the frequency-magnitude of larger events is uncertain, as reflected by the widening confidence bands.

As has been recently demonstrated, High frequency (Table 4) debris flow events may have direct impact at the fan apex at or above Reid Road, and may trigger secondary effects like avulsion, overland flooding, debris flooding and erosion within areas lower on the fan.

Based on expert judgement, Moderate frequency (Table 4) debris flow, with volumes ranging up to ~25,000 m^3, will have direct impact at sites on the upper fan below Reid Road, and all lots on the upper fan are considered to be potentially vulnerable to direct or secondary impacts. These events may result in secondary impacts on the middle and lower fan.

Residential Development on Alluvial Fans in BC

Professional guidance documents delimit the standard of care for legislated flood and landslide risk assessment in BC (EGBC 2010, 2012).

WLAP (2004) provides provincial guidance for construction on alluvial fans, as cited below:

- Where possible, development of alluvial fans should be discouraged, and the land should be retained in non-intensive uses such as parks, open-space recreation, and agricultural uses.

- Where a study of the flooding hazard is not available and the hazard is considered significant, an assessment of the land by a suitably qualified professional should be required.
- Development should be discouraged in areas where local knowledge, experience or studies indicate concern that there may be a debris flow hazard.

Consent to develop may be granted by an approving officer:
- Where there is no alternative land available, and
- Where an area of an alluvial fan can be shown to be stable because of hydraulic, physical and/or geological conditions.

This approval should be subject to hazard management and flood proofing requirements determined on a site-specific basis. Such requirements may include but are not limited to:
- Development density regulations,
- The identification of the safe building site(s),
- Building elevation and foundation design requirements,
- The construction of on-site and/or off-site protective works, and
- Land use regulations to prevent the alteration of the terrain and features such as landfills, excavations and the construction of new roads and utilities that would alter the hazard rating for the land.

If consent to develop on an alluvial fan is granted:
- The setback should be determined in accordance with [riprarian areas regulation].
- Where the hazard is low, the building should be elevated a minimum of 1.0 metres above the general elevation of the surrounding ground on concrete foundation and protected from scour.

Emergency Repairs on Reid Road

One of the first tenets of emergency response is to ensure hazards are clear before entry. Between November 16-25, 2021 Capilano Highways conducted emergency repair works at Jason Creek, including sending a spider hoe several hundred metres up the ravine channel to clear debris. This work was done without first examining the source of the debris flow event in the headwaters to ensure no residual hazards existed. The examination of the headwater was not complete till 1500 hrs on December 1, when significant residual hazards were reported.

Another tool to improve safety when working in a high hazard setting is the use of spotters. At Jason Creek, work was conducted in the high hazard area without benefit of a spotter to warn the operator(s) of a potential landslide recurrence. The ravine is a confined space and it is not possible to exit rapidly in a machine or on foot. Advance warning is critical in this context.

At about 1230 hrs, December 1, 2021 Cordilleran arrived and immediately requested that a spotter be placed upstream a good distance to provide ample warning for the operator who was conducting cleanup at the crossing. The spotter and operator were required to be in radio contact so that if required, rapid egress could be affected. Later that day Shannon Payne (MoTI) visited the site and discovered that a spotter was not present. Similarly, on December 2, 2021, Friele encountered the machine operator clearing debris at the crossing, and again with no spotter.

Conclusions

- The Jason Creek watershed is prone to landslide activity, and debris flow and other processes such as debris flooding, overland flow and erosion periodically affect the upper Jason Creek fan.
- These observations were reported by Blunden (1981) and described again by Baumann Engineering (1997). Blunden's (1981) report was provided to MoTI as part of the subdivision approval process. Somehow his observations were not taken into consideration and embodied into constraints on development, such as restrictive covenant, siting constraints or protective measures. Baumann Engineering's (1997) report was provided to the local MoF for guidance to support proposed logging of the watershed area. No logging has occurred. As such, the findings regarding potential threats to life safety were not passed on to, or otherwise noted by, SLRD (ie., as part of a referral process).
- Subdivision of the upper Jason Creek fan area, development of Reid Road, and the construction of homes have all occurred without regard to terrain hazards affecting the upper fan.
- Reid Road climbs steeply up the fan, crossing Jason Creek before levelling out above Ivey Lake. This creates a situation whereby Reid Road may capture and redirect the creek southeasterly down the fan. Wilford et al (2005) makes the following comments: where "roads climb to stream crossings, if drainage structures become plugged, water runs down roads and ditches, creating erosional problems. When hydrogeomorphic events encounter a climbing road, the result is generally a re-directing of the event away from the channel, increasing the disturbed zone on a fan. Design road profiles to drop to stream crossings or avoid the fan altogether with a crossing at or above the apex. If roads must climb to the stream crossing, design features to allow water and sediment to cross the road: robust ditchblocks and over-sized cross-drains; armoured rolling dips; outslope road with no ditchline." Reid Road is the epitome of a poorly designed road on a fan.
- The Jason Creek culverts at Reid Road (1600 mm), 7699 Portage Road (<1600 mm), and Portage Road (~1400 mm) appear to be undersized for clear water and hydrogeomorphic peak flood events. At Reid Road, culvert blockage and failure may result in loss of road access and channel avulsion leading to direct damages on private properties. At 7699 Portage Road, the road grade dips through the crossing (a good measure), and failure of the culvert will only lead to temporary loss of driveway access to an accessory building. Potential washout of Portage Road has an obvious severe consequence for transportation. The CN rail crossing at Reid Road appeared to become almost overwhelmed during the event, but the December 12, 2021 inspection revealed four culverts ranging in size from ~1000-1200 mm. As it was close to overtopping this crossing should also be reviewed to ensure adequate sizing.
- The upper fan of Jason Creek is vulnerable to High (>1/100 year) to Moderate (1/100-1/500 year)(Table 4) debris flow hazard, with estimated volumes ranging up to 25,000 m^3. These events may be highly destructive to existing development, resulting in severe property damage and the potential for injury and loss of life. Referring to the Cave criteria (Table 6), development in this area should be (or rather "have been") highly constrained, with management responses ranging from "Not approvable" to "Approvable with conditions" including siting conditions, protective works and covenant registered against title.

- Given the observed instability at the 650-700 m elevation, which was observed to increase in size between December 1-12, 2021, the hazard of a landslide up to 4000 m^3 affecting the Jason Creek upper fan area is judged to be "imminent."
- The home at 1781 Reid Road is situated on the fan apex above Reid Road and is in a High hazard location. At about 0430 hrs, December 1, 2021, this building experienced a "close call" being just clipped by a muddy debris slurry (Photos 38, 39). Given the potential avulsion sites along the fan apex above, and without protective works, this site is not safe to occupy. The remaining homes on the upper fan, with their main floors at grade, are also not resilient to hydrogeomorphic impacts.
- Hazard threat varies with weather and runoff conditions (increasing with snowmelt freshet, periods of high antecedent moisture and/or heavy rain during fall & early winter). For sites with unstable areas upslope, potential rainfall/runoff triggering thresholds are as low as 1-2 yr rainfall events. On this basis it is not deemed practicable to keep residents on permanent alert, invoking evacuation whenever wet periods are forecast.
- Areas on the middle and lower portions of Jason Creek fan are likely only vulnerable to secondary impacts such as avulsion, debris flooding, overland flow and erosion.
- An adhoc setback dike exists on 1876 Reid Road (Photos 25, 26). It is not known if this was built following an engineered design, to a designated flood level, or if other hydrogeomorphic processes were considered. Given the bank armouring, the dike crest height above the creek, and its setback condition it appears more than enough protection for regular clear water flooding on the main channel of Jason Creek. However, should a significant hydrogeomorphic event become directed down Reid Road to the middle fan, then the apex of this dike could be bypassed and areas on the landside could be affected by flood waters and debris flowing down Reid Road.
- WLAP (2004) provides provincial guidance for proposed residential development on fans. Generally, it is discouraged, but where the hazard can be shown to be Low (<1/500-year; Table 4), then a minimum standard is to raise the main floor 1-m above finished grade on a concrete foundation. All of the existing residential structures observed on the Jason Creek fan (Photos 39-42, 45, 46, 49-51, 53-55, 57), aside from that at #1 Walkerville (Photo 58), were built with the main floor at grade, and as a result are highly vulnerable to damages arising from hydrogeomorphic impacts. The home at #1 Walkerville is raised above grade on a concrete foundation and is resilient to overland flow flooding.
- Emergency repairs on Jason Creek at Reid Road were conducted without first ensuring that no residual hazards threatened the site. While a helicopter review was conducted, aerial review is often not sufficient to see through a mature conifer canopy. Historic reports indicated hazards likely existed. In retrospect, it is known that they did, as demonstrated by subsequent hydrogeomorphic events on December 1 at 0430 hrs and 2200 hrs. Further, the work was conducted without benefit of a safety spotter in direct communication with the operator. The absence of a spotter was noted even subsequent to the request for one. These actions put the excavator operator in harm's way.

Recommendations

- More detailed geotechnical assessment is required to more precisely characterise the Frequency-Magnitude model for landslide and associated alluvial fan hazards affecting Jason

Creek fan (upper, middle & lower). With a detailed understanding of how frequent and how big these events may be, then judgements can be made about how best to remediate the flood and landslide risks.

- The types of tasks required to conduct this work include collection of high-resolution LIDAR and Ortho mapping of the Jason Creek watershed and fan areas, detailed field work including the use of dendrochronology to age landslide scars on trees, test-pitting, stratigraphic analysis of fan sediments, radiocarbon dating of buried soil layers, and empirical or numerical modeling of various debris flow volumes and rheologies.
- Remedial measures to consider include educating landowners of the hazards and risks, implementation of warning systems, expropriation, and the construction of catchment basins, deflection berms and/or stream channelization.
- Until more detailed analysis can be conducted, hazard and risk refined, and remedial measures enacted, the homes on lots 1781, 1791, 1793, 1815, 1782, 1788, 1794 & 1802 Reid Road must remain on evacuation order.
- The crossing structure on Jason Creek at Reid Road needs to be sized properly to accommodate 100-200 year flood and debris flow events; while the crossing structures at Portage Road and CN Rail tracks need to be sized to accommodate 100-200 year flood and sediment loading.
- Capilano Highways should review and update procedures for work in high hazard areas.

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Caveat

This report is part of a rapid assessment conducted during a local emergency. Conclusions and recommendations are based on experience and expert judgement. The conclusions and recommendations convey serious implications for residents, property owners and other affected parties. Prompt action should be taken to verify and refine conclusions, to ensure public safety and just outcomes for all.

Closure

This report was prepared for use by Squamish Lillooet Regional District, including distribution as required for purposes for which the report was commissioned. The report cannot be distributed to other third parties without prior written consent by Cordilleran Geoscience. The work has been carried out in accordance with generally accepted geoscience practice. Judgment has been applied in developing the conclusions stated herein. No other warranty is made, either expressed or implied to our clients, third parties, and any regulatory agencies affected by the conclusions.

Original sealed

Pierre Friele, P.Geo.
Senior Geoscientist

Appendix 1. Annotated photos (see Figure 3 for WP locations).

Landform overview

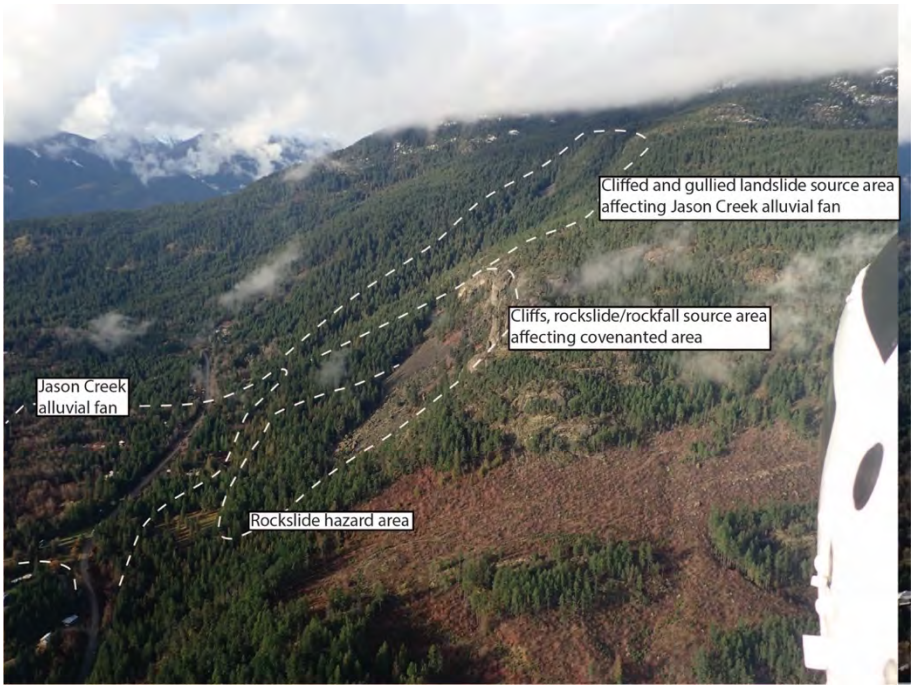

Photo 1. View west over Ivey Lake watershed delineating hazard areas discussed in report.

Photo 2. View southwest over cliffs to rockslide hazard area affecting lots 1791, 1793, 1815 & 1835 Reid Road.

Landslide hazard source areas

Photo 3. WPs 6-12. View straight down on sagging slope above the 1990 & 2021 failure sites. On center right (north) is bedrock cliff sagging and spreading to the left. On the center left (south) is a small opening with creek visible, and that is the slide area. In the center is a talus opening. The talus is normally faulted, with a 10 m drop on the south side.

Photo 4. WPs 6-12. 1990 & 2021 failure site. Note cream to orange altered bedrock. Clayey and soft.

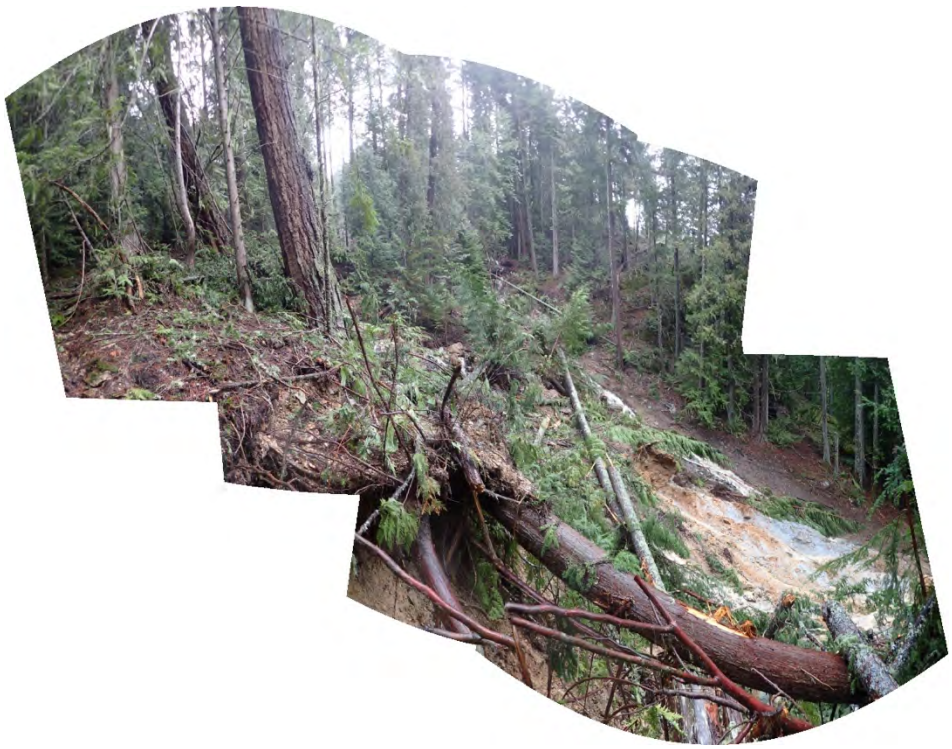

Photo 5. WPs 6-12. Right side failure area, view east. Note back-leaning Douglas fir marking an unstable area around the fresh headscarp (ie. hangfire).

Photo 6. WPs 6-12. Left side failure area view south and east. Note torn ground (tension cracks) leading right (east) from creek marking an unstable area around fresh headscarp (ie. hangfire).

Photo 7. WPs 21-22. Jason Creek, right bank slump in altered bedrock with seepage at headscarp.

Photo 8. WPs 3-5. Uphill facing or "antislope scarp" on Jason Creek right bank near 1990 & 2021 failure area. These features indicate potential deep-seated instability in the bedrock.

Photo 9. WP23. Uphill facing or “antislope scarp” on Jason Creek right bank near WPs 21-22 creek sidewall slump.

Jason Creek immediately above Reid Road at fan apex

Photo 10. December 1, 2021 debris flow on Jason Creek. View downstream showing muddy trimlines defining an area 12 m wide by 3 m deep; channel bottom about 4-5 m wide. Using a “Spider” excavator, this area was cleared of debris jams between the November 15 and November 30 washout events.

Photo 11. December 1, 2021 debris flow on Jason Creek. View upstream showing muddy trimlines and coarse bouldery debris. Using a "Spider" excavator, this area was cleared of debris jams between the November 15 and November 30 washout events.

Photo 12. WP71. View upstream showing muddy slurry overflow onto east side of fan at apex. Main channel is to the left (west).

Photo 13. WP71. View downstream showing muddy slurry overflow onto east side of fan at apex. The bright spot in the center trees with slight blue/green colour to left is the house at 1781 Reid Road.

Photo 14. WP78. View downstream across debris deposition on left (east) bank just above Reid Road. Creek is bright area on right. Material consists of muddy cobble (0.12-0.25 m dia) to fine (0.25-0.5 m dia) boulder gravel with occasional metre-sized boulders.

Impact on Reid Road

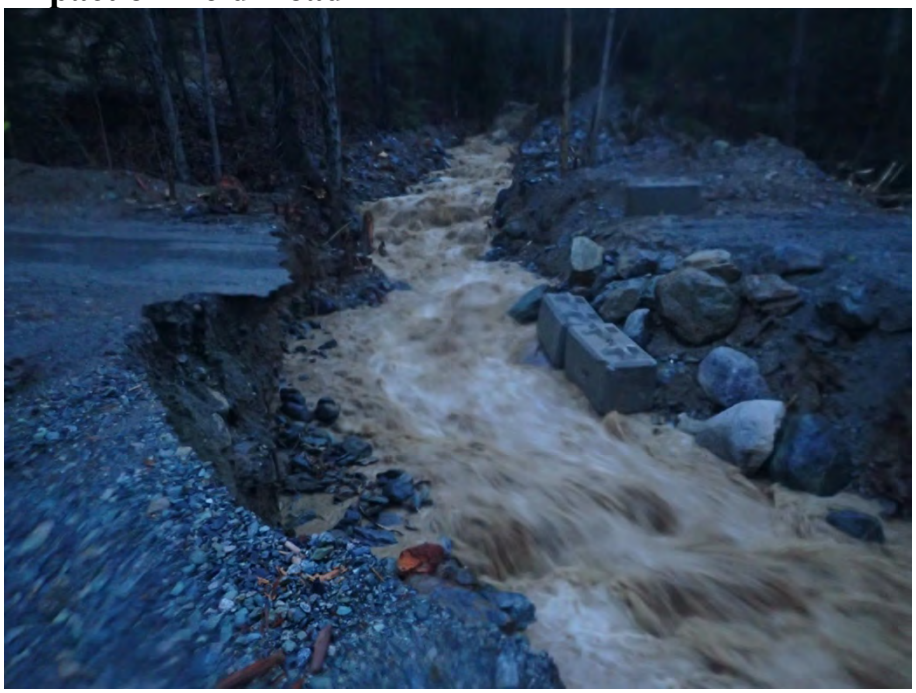

Photo 15. WP43. View upstream to Jason Creek at Reid Road, December 1, 2021 at 4 pm. Note that channel upstream has been recently cleared by the "Spider" hoe.

Photo 16. WP62. View up (east) along south side Reid Road, eroded shoulder. On north side at this point overflow from hillslope tributary (WPs 67-70) follows 1791 Reid Road driveway to join Reid Road.

Photo 17. WP60. View up (east) along north side Reid Road, eroded shoulder. At this point on south side of road (WP59), water avulsed from shoulder toward house at 1802 Reid Road.

Jason Creek fan below Reid Road

Photo 18. WP105. View upstream along Jason Creek in 10 m wide channel, incised 2 m into fan surface.

Photo 19. WPs 81, 104. View downstream, treehouse on left. Unconfined debris deposition area, Jason Creek spreads over 20 m width.

Photo 20. WP103. Head of nickpoint erosion. View upstream, treehouse on right.

Photo 21. WP103. View downstream. Major channel erosion, 6 m by 2 m deep, trees down left and right.

Photo 22. WP102. View upstream to incised overflow channel. Deposition from this overflow channel affected garlic patch (WP101) and pond (WP91) at 1788 Reid Road.

Photo 23. WP92. Multiple braided channels in woods.

Middle Jason Creek

Photo 24. WP15. Jason Creek in bedrock ravine.

Lower Jason Creek

Photo 25. WP117. View downslope along adhoc dike on west side of 1876 Reid Road. Creek on right (east) in the trees. Dike ties into Reid Road near lower fan apex.

Photo 26. WP119. View upslope along adhoc dike on west side of 1876 Reid Road. Creek on left (east) in the trees. Dike ends at uphill side of house at 7701 Portage Road.

Photo 27. WP125. Footbridge just above lower fan apex. Minor bank erosion.

Photo 28. WP122. View upstream. Creek incised 1-2 m. Left bank erosion.

Photo 29. WP121. Channel confined by adhoc dike. Flood surge on left bank.

Photo 30. WP120. View upstream along Jason Creek, channel 3-5 m wide, incised 2 m. Note riprap bank on river left (right side photo).

Photo 31. WP120. View downstream along Jason Creek, channel 2-3 m wide, incised 2 m. Note riprap bank on river left (left side photo).

Photo 32. WP52. View upstream to log footbridge over Jason Creek, 7701 Portage Road.

Photo 33. WP50. 7699 Portage Road. Creek is incised 4 m into fan surface. Internal access road crosses through incised channel; culvert plugged with wood, road overtopped causing bank erosion and undermining of trees.

Photo 34. WP46. View upstream along Jason Creek from Portage Road.

Photo 35. WP46. Erosion of Portage Road shoulder on upstream (north) side.

Photo 36. WP46. Erosion of Portage Road shoulder on upstream (north) side.

Photo 37. WP46. Jason Creek ponding on uphill side of CN Rail tracks. Highwater wracklines show rail line was almost overtopped.

Impact on residential Lots

Upper Reid Road

Photo 38. 1781 Reid Road. Porch supports at southwest corner of house clipped by debris slurry.

Photo 39. 1781 Reid Road. Porch supports at southwest corner of house clipped by debris slurry.

Photo 40. 1781 Reid Road. Shop with small creek immediately upslope. This creek is usually just a seepage.

Photo 41. 1791 Reid Road. Slope left to right. Small residential building dug into fan and not on permanent foundation. Not resilient to flood water or debris.

Photo 42. 1793 Reid Road. Collection of buildings; main floor at house at grade and accessory buildings not on permanent foundations. Not resilient to flood water or debris.

Photo 43. 1770 Reid Road. House on slope above fan, and somewhat shielded from hydrogeomorphic events by right bank (west) gully sidewall, since trimmed down by Reid Road. Property driveway access severed by washout.

Photo 44. 1770 Reid Road, WP106. View upstream to road. Domestic water well is close to west side of creek and was threatened by erosion. Owner placed adhoc armour to protect well.

Photo 45. 1782 Reid Road. House. Main floor at grade; not resilient to flood water or debris. House escaped impact because slight throughcut in fan by Reid Road directed overflow eastwards down road.

Photo 46. 1788 Reid Road. House. Main floor at grade; not resilient to flood water or debris. House escaped impact because slight throughcut in fan by Reid Road directed overflow eastwards down road.

Photo 47. 1788 Reid Road. Garlic patch partially damaged by overland flooding.

Photo 48. 1788 Reid Road. Dug pond filled in with sediment by overland flooding.

Photo 49. 1794 Reid Road. House dug into fan on uphill side. Main floor at grade; not resilient to flood water or debris. Overland flow affected house. Residents were evacuated between 10pm and midnight December 1, 2021.

Photo 50. 1794 Reid Road. Overland flow ran down east side of house through yard. Residents were evacuated between 10pm and midnight December 1, 2021.

Photo 51. 1802 Reid Road. House with main floor at grade; not resilient to flood water or debris. Overland flow affected house.

Photo 52. 1802 Reid Road. Chicken coop affected by overland flow.

Photo 53. 1812 Reid Road. Although on Jason Creek fan, the house and lot were not directly affected by recent events. Main floor at grade; not resilient to flood water or debris.

Lower Jason Creek residential area

Photo 54. 7701 Portage Road. Main floor at grade, with half basement on downslope side. Not resilient to flood water.

Photo 55. 7699 Portage Road. Main floor on grade. Not resilient to flood water.

Photo 56. 7699 Portage Road. Culvert plugged causing overtopping and washout of internal access road to accessory building. Associated bank erosion undermined immature cedar on left bank.

Photo 57. 7699 Portage Road. Accessory building. Main floor on grade. Not resilient to flood water.

Photo 58. 1 Walkerville. House raised 60 cm on reinforced concrete foundation. Only house noted in entire area to be so constructed. House is resilient to floodwater. Note overland flow from side creek.

Photo 59. 1 Walkerville. Side creek that caused flooding in yard.

Channel Assessment Dec 12, 2021


Photo 60. WP130. Repaired Jason Creek culvert outfall and driveway access 1770 Reid Road.

Photo 61. WP131. Top end constructed boulder berm on left bank. Extends down to Reid Road. Trapezoid: 12 m crest to crest, 3 m wide creek flat, 3 m deep.

Photo 62. WP132. View upstream to short step in channel. Bank slump on north sidewall.

Photo 63. WP133-135. Left bank constructed Berm. Trapezoid, 11.5 m crest to crest, 5 m base, 2-2.5 m deep.

Photo 64. WP137. Constructed berm ends, not tied into bank. Debris flow can go around south side to 1781 Reid Road.

Photo 65. WP139. View upstream. Inset fan apex, 2 m tall erosional nick point in channel exposes colluvial fill. Note debris piled on banks by Spider Hoe.

Photo 66. WP143. View downstream to right bank. 10 by 10 by 2-3 thick, bank slump partially blocking channel.

Photo 67. WPs 144-145. View upstream. Three large 4-6 m dia boulders block channel. Partially supported by shattered cedar stem. Upper boulders partially buried by debris sloughed from south sidewall.

Photo 68. WPs 144-145. Altered ripups in colluvium.

Photo 69. WPs 144-145. Altered ripups in colluvium.

Photo 70. WP145. View downstream to fresh right bank 15 m wide slump. Altered bedrock, seepage.

Photo 71. WP147. Colluvium composed of degraded bedrock. Exposed on right bank. In this reach valley flat is the ~50 m wide and filled with sidewall slump colluvium 3-5 m thick.

Photo 72. WP148. View upstream. Fresh slump/slide on right bank, 15 m wide, still 90% residual. Reach break to steep ravine upstream.

Photo 73. WP151. View east across crest of main active failure area. Changed since Dec 1, with new extension of tension cracking and settlement some 5 m headward.

Photo 74. WP151. Altered materials exposed in fresh scarps.

Photo 75. WP152. View west across fresh downdropped blocks.

Photo 76. WP154. Right side of major since Dec 1 slump area, fresh tension cracking and settlement across 30-35 m wide convex slope crest, 5 m offset, 15-25 m slope length, 2-5 m thickness, or 1000-4000 m^3.

Photo 77. WP155. Mine adit.

Photo 78. WP158. View of slump noted Dec 1 slump. No change noted. Residual hazard.

Appendix 2. Raw field waypoint observations

Title	Northing	Easting	Description
1	5577341	517623	Undercut right bank, new slump and tension crack, incipient slump, 100-200 m^3.
2	5577468	517540	Apex old channel, left bank failure 10 m tall by 5 m wide. Debris flow mud trimline 2-3 m deep.
3	5577659	517231	Ridge parallel to creek sidewall joins hillslope.
4	5577799	517219	Scarp crest, Rs.rCv, 85% for 50 m to creek, confined channel.
5	5577817	517218	Lineament shear zone, forms shark fin of rock.
6	5577871	517276	East fork tributary.
7	5577871	517215	Between main and east fork trib, 25 m wide failure, same site as 1990.
8	5577884	517209	Dry draw rock gully, uphill at 330 azimuth (// Owl Creek fault).
9	5577896	517225	Right side crest of slab, 25 m wide by 15 m long by 2-3 thick
10	5577907	517246	Left edge failing area, 1 m down drop, 10 m downslope length, 2-3 m thick, point on east tributary at convex break from 70-90% down to 10-20% up. Creek flowing now but rarely does.
11	5577871	517228	Unstable volume, 500-1000 m^3 plus 10-20 mature conifer
12	5577881	517266	Shear in left sidewall crest, 130-150 azimuth (// Owl Creek fault), rock fins possible topple.
13	5577921	517196	Shear zone talus flat, whole zone is being down-dropped, talus slope truncated 10 m vert
14	5577996	517231	Convex break in talus, -85%, +50% to base of cliff 50 m slope distance up.
15	5578021	517170	Creek running clear, goes underground at talus flat to emerge in headscarp at 2 m depth
16	5577998	517161	Crest of scarp down to previous creek, -110% Rs, +40%, Cbf incised from previous
17	5577970	517056	Spring
18	5577958	517039	Right bank failure, log crossing.
19	5577965	517020	10 m wide inset 10 m above creek
20	5578014	516987	Till or talus ridge perpendicular to contour, -60-70%, +40%, lows either side are talus below bluffs
21	5577960	516965	Spring left side headscarp
22	5577957	516962	As previous, slump 10m by 10m by 2-3m displaced downslope 10 m, altered Gambier Group clayey cream orange.
23	5577941	516937	Toe of inset 3 m downdrop, creek on unstable side
24	5577992	516870	Ncd in lineament parallel with break to sidewall
25	5578022	516847	Lineament merges into canyon slope
26	5578207	516882	Cliffs and talus
27	5578103	516738	Sidewall crest
28	5578265	516721	Jason Creek. Crest of incised gully, -70-90% Rs.rCv-VRsud, +15-30%, approximate snow line.
29	5578058	516632	Creek unconfined braided over 15 m on forest floor.
30	5577996	516668	Creek

31	5577941	516707	Creek splits into two (ie, upside down V).
32	5577874	516778	Spring +40%, -10-15%
33	5577880	516836	Ponding on flats
34	5577872	516984	Ncd in swale just above sidewall crest
35	5577894	516995	Trib creek 1 m wide
36	5577887	517029	Sidewall crest, tension crack in bedrock, back-leaning trees.
37	5577868	517042	Bedrock tension crack from WP36 extends to here, 10 cm wide gape, 4 m thick potentially unstable slab, 50 m down to creek.
38	5577863	517090	To left (east) of WP terrain is gullied unstable.
39	5577876	517129	Crest eroding slope 15-20 m above river, 2 m vertical undercut at sidewall crest
40	5577862	517140	End previous
41	5577831	517194	10 m cliff, gaping tension crack at crest in 1-4 m, possible topple 10 m tall by 1-4 m thick by 10-20 m long
42	5577781	517223	10 m wide flat 10-20 m long, down-dropped 5 m on creekside, 30-50 m above river, similar to lineament noted on way up, two times volume
43	5577266	517617	Right side road breach
44	5577846	518918	Owl creek running clear
45	5576839	519053	1 Walkerville. Small creek overland through yard.
46	5576855	519054	Portage Road. Jason creek culvert undermined, eating to road shoulder.
47	5576816	519030	1 Walkerville. House raised 60 cm on concrete foundation.
48	5576820	518973	1 Walkerville. Culvert overwhelmed, recent bank hardening.
49	5576847	518960	7699 Portage Road. Building at grade.
50	5576933	518933	7699 Portage Road. Culvert plugged with wood, road in dip, overtopped, trees down, creek incised 4 m.
51	5576963	518952	7699 Portage Road. Houses at grade.
52	5576959	518915	7701 Portage Road. Log bridge, good clearance.
53	5576996	518905	7701 Portage Road. House with basement left bank creek.
54	5576832	518940	Creek
55	5576773	518900	Creek
56	5577300	518250	Creek, in ravine between hill and mound
57	5577222	518031	Water from Jason running down left side road
58	5577201	518003	1802 Reid Road. Small Creek.
59	5577213	517971	1802 Reid Road. Overflow from road affecting house floor at grade, no lift, new house. Not resilient to flood or debris.
60	5577226	517947	1802 Reid Road. Eroded right side of road, overflow to house below
61	5577242	517900	1794 driveway
62	5577260	517839	1791 Reid Road. Left side road eroded, overflow trib in from lot to left
63	5577298	517838	Overflow intercepted by driveway
64	5577331	517908	1793 Reid Road. Complex of mobile buildings on log foundation, house at grade or dug in. Not resilient to flood or debris.
65	5577352	517852	1791 Reid Road. Fan edge.

66	5577343	517831	1791 Reid Road. Building dug in and at grade no foundation. Not resilient to flood or debris.
67	5577327	517780	1781 Reid Road. Creek, shallowly confined.
68	5577346	517727	1781 Reid Road. Propane tank, 50 cm freeboard.
69	5577373	517693	1781 Reid Road. Creek off hill behind shop, no freeboard.
70	5577403	517671	1781 Reid Road. Edge of fan, creek flowing off hill, never flows more than trickle, but for now.
71	5577396	517632	1773 Reid Road. Debris track with overflow directed to house at 1781 Reid Road.
72	5577436	517580	Jason Creek fan apex, at big rock in channel.
73	5577462	517562	Creek off left sidewall
74	5577475	517523	Excavated debris plug
75	5577455	517553	-Rd Cross section, 12 m crest to crest, 3 m deep, banks 4 HD: 3 VD, slope 20-25%
76	5577394	517608	1773 Reid Road. Big jam, creek higher than track through 1781 Reid Road, wedge flat extends 40 m upstream, plug 20 m Downstream, 10 m wide, 10 m thick. Urgent removal.
77	5577332	517684	1781 Reid Road. Debris slurry from WP71 clipped house corner.
78	5577324	517636	1773 Reid Road. Deposition zone, overflow left main flow to culvert, no freeboard.
79	5577259	517646	1770 Reid Road. Avulsion track, creek left.
80	5577236	517658	1770 Reid Road. Small berm, deflected creek right, away from yard.
81	5577167	517653	1770 Reid Road. Fan deposition area below road, creek through tree house.
82	5577112	517624	1782 Reid Road. Approx right edge fan, spring
83	5577080	517641	1770 Reid Road. Dug pond.
84	5577031	517677	1782 Reid Road. Ncd.
85	5576976	517706	Overflow
86	5576962	517704	As previous
87	5576940	517691	Ivey Lake creek running clear
88	5576983	517727	Two overflow ck join
89	5577021	517748	1782 Reid Road. Overflow rejoins Jason Creek on right.
90	5577024	517758	1788 Reid Road. Left bank erosion, 1.5 m tall bank
91	5577054	517765	1788 Reid Road. Level area, pond now debris filled by event.
92	5577030	517807	1788 Reid Road. Multiple braided channels in woods
93	5577043	517838	1788 Reid Road. Dry overflow.
94	5577112	517866	1794 Reid Road. Dry overflow.
95	5577135	517883	1794 Reid Road. Dry overflow.
96	5577149	517912	1794 Reid Road. Dry overflow.
97	5577166	517935	1802 Reid Road. Dry Overflow, chickens
98	5577170	518057	1812 Reid Road. Log house at grade.
99	5577184	517867	1794 dug in built at grade, water and mud all around in middle of night

100	5577233	517810	1788 Reid Road. Avulsion across drive toward previous house
101	5577101	517757	1788 Reid Road. Garlic patch, jrbservices@gmail.com
102	5577108	517724	1782 Reid Road. Overflow.
103	5577104	517704	1782 Reid Road. Major channel erosion, 6 m by 2 m deep, trees down left and right, nick point, no freeboard 10 m upstream.
104	5577153	517677	1770 Reid Road. Just below tree house creek unconfined spreads over 20 m wide area.
105	5577183	517648	1770 Reid Road. Creek in 10 m wide channel incised 2 m.
106	5577226	517644	1780 Reid Road. On creek below road right bank. Owner conducted adhoc bank armouring to protect well site.
107	5577274	517724	Water from WP77 to here, then follows north side Reid Road.
108	5577269	517804	Driveway 1781 Reid Rd
109	5577238	518119	1818 Reid Road. On rock mound above fan hazard.
110	5577304	518248	1838 Reid Road. Home raised on rock mound above fan hazard.
111	5577219	518562	1854 Reid Road on north; 1855 Reid Road on left; both on fan.
112	5577137	518479	Creek
113	5576945	518234	Bouldery cone
114	5576931	518207	Left bank scarp, creek incised
115	5576971	518147	Middle Jason Creek, incised in deep ravine.
116	5577025	518532	Creek crosses road left to right
117	5577036	518734	1876 Reid Road. Start adhoc dike
118	5577040	518862	7701 Portage Road. Gate
119	5577012	518896	7701 Portage Road. End adhoc dike at house, main floor on grade, with basement.
120	5577006	518870	Lower Jason Creek, 3-5 m wide, incised 2 m.
121	5577012	518809	Lower Jason Creek. Flood surge overbank left.
122	5577005	518772	Lower Jason Creek. Left bank erosion.
123	5577007	518721	Lower Jason Creek. Iron pin.
124	5577005	518692	Lower Jason Creek. Apex lower fan.
125	5576965	518645	Lower Jason Creek. Footbridge.
126	5577430	517580	Big rock at left bank apex, from here down left bank bermed
127	5577401	517602	1773 Reid Road. Long prime convex break, +15% to big rock, -30% over convex break. Break may predate recent events. Break is not bedrock controlled
128	5577387	517609	1773 Reid Road. Right bank slump (WP1) now armoured at base.
129	5577242	517735	1782 Reid Road. Pic of house.
			December 12, 2021 Channel assessment
130	5577270	517627	Jason crossing completed
131	5577324	517638	Top end boulder berm left bank, trapezoid: 12 m crest to crest, 3 m flat base, 3 m deep.
132	5577373	517621	Potential avulsion point, 120 degrees to 1781 RR, trapezoid, 11 m crest to crest, 3 m at base, 2 m deep

133	5577400	517605	Top step, start debris berm LB
134	5577406	517592	Berm left bank. Trapezoid: 11.5 m crest to crest, 5 m flat base, 2-2.5 m deep.
135	5577413	517594	Top of 2.5 m tall berm, transition to smaller volume berm
136	5577414	517595	Smaller volume berm, Dec 1 avulsion site, same geometry as previous
137	5577429	517583	Top end berm not tied into bank, potential avulsion point, left apex still higher up.
138	5577459	517548	Near inset fan apex. Trapezoid: 8 m crest to crest, 4 m wide at base, 2.5 m deep, on left bank, flat 15 m wide, toe of right bank altered gambier group
139	5577466	517532	Inset fan apex, erosional nick point in channel
140	5577493	517484	Top end of spider work, levees both side, valley flat 15-30 m inset channel with narrow terraces
141	5577514	517473	Left bank erosion
142	5577563	517427	Steep sided rock gully 30 m deep, 9 m crest to crest, 30% channel gradient 100% sloping sidewalls, 2 right bank slumps
143	5577586	517409	10 by 10 by 2-3 thick, bank slump partially blocking channel
144	5577606	517380	Three megaboulders (4-6 m dia) forming jam. Partially held up by wood.
145	5577620	517377	Top of boulder jam, right bank rotten seeping failure scar 15 m wide, left bank slumped on top of boulders
146	5577657	517368	Convex top end nasty ravine, -40%, +30%
147	5577704	517320	~50 m wide valley flat filled with sidewall slump colluvium 3-5 m thick, creek incised, right bank photo.
148	5577795	517277	Possible old rock slump scar left bank 50 m wide by 30-50 m tall. On right bank opposite and up 20 m, fresh slump/slide 15 m wide, still 90% residual. Reach break to steep ravine.
149	5577829	517250	Toe of slide at confluence
150	5577884	517234	Start residual hazard left bank tension cracks.
151	5577906	517249	Left crest failure area, changed since Dec 1, but still 50% residual volume, 25 m wide by 25 m long by 1.5 m thick
152	5577922	517242	Right side of fresh (since Dec 1) slump, 20 m wide by 5 m thick offset from crest by 2-5 m thick, incipient failure.
153	5577906	517231	Fresh crown, 1 m downdrop, -70%, +10% in inset flat area behind crest.
154	5577912	517217	Right side of major since Dec 1 slump area, fresh tension cracks and settlement across 30-35 m wide convex slope crest, 5 m offset, 15-25 m slope length, 2-5 m thickness, or 1000-4000 m^3.
155	5577885	517193	Mine adit.
156	5577948	517005	10 m wide by 15 m long slide right bank, noted as old Dec 1.
157	5577973	516995	Tree throw from slump noted Dec 1, no change at site
158	5577991	516974	Shots of Dec 1 slump 35 m opposite here, convex break from steep ravine to lb bench
159	5578014	516919	Old blocks cry debris levee inset colluvium, -+40%
160	5578078	516854	Left edge talus opening at toe, just inside trees
161	5578119	516815	Creek on rock cascade, +60%, -70%, scattered cool vial blocks, left bank talus right bank rCv up to bluffs 15 m up

162	5578156	516789	Right bank erosion 5 m by 5 m
163	5578169	516780	Altered bedrock in channel
164	5578225	516757	30 m deep V-sided ravine +55%, -45%, confluence two ravines
165	5578268	516734	Crest of ridge between two ravine, convex break, -70-90%, +25%
166	5577653	517248	Intersect fresh human tracks (PK Read), trail, goes to main failure site.
167	5577250	518135	Ditch flow forced onto road by gentle toe of slope distal to rock slide
168	5577299	518112	Fan edge
169	5577394	518087	10 m block
170	5577304	518058	10 m rockfall block
171	5577262	518033	Rockslide at edge of fan
172	5577276	517984	Trib creek at rockslide block
173	5577304	517963	Creek Upstream side of rockslide
174	5577333	517948	Trib creek edge of fan, up edge rock slide
175	5577238	517960	1815 Reid two tiny home trailers, both on fan
176	5577310	518269	Driveway to lot upside of road, house ok
177	5577308	518561	Hillslope meets flats on west
178	5577222	518561	1858 driveway, fan hazard boundary crosses road
179	5577135	518473	Creek crosses road, inset in fan gravels
180	5577114	518446	Road becomes right bank of fan area
181	5577018	518470	Lose right confinement join Jason main
182	5577014	518508	Actual creek crossing, previous marked too low
183	5577018	518545	East side road confines fan
184	5577038	518702	Any flood confined on road will bypass start of adhoc dike
185	5577199	518779	East hillside veers from road