The Johnsons Landing landslide of 2012, Kootenay Lake area, British Columbia

Peter Jordan
BC Ministry of Forests, Lands and Natural Resource Operations, Nelson, BC, Canada

ABSTRACT
On July 12, 2012, a large landslide occurred on the mountainside above Johnsons Landing, a small community in the West Kootenay region of British Columbia. Four houses were destroyed and two others damaged, and four people were killed in their homes. The investigation which followed addressed several aspects of the disaster, including emergency response, risk management, land use and zoning, hazard identification and warning, and landslide hazard monitoring. The landslide resulted from the sudden failure of an estimated 320,000 m^3 of glacial deposits. It travelled as a debris avalanche for 1.9 km at an average gradient of 16 degrees, at estimated speeds of up to 150 km/hr. A secondary debris flow travelled an additional 1 km to Kootenay Lake. As a first-time landslide in surficial material, the event was unusual due to its large size, exceptional mobility, and lack of an obvious cause. The landslide followed an exceptionally wet spring and early summer. The investigation found that the valley above the failure contained a complex of slow-moving or dormant bedrock failures, which may have caused deformation in the deep glacial deposits, gradually weakening them to the point of failure. A challenging question for landslide hazard studies is how such features can be mapped, and how to identify the few that might result in rapid failure.

RÉSUMÉ
Le 12 Juillet 2012, un important glissement de terrain s'est produit sur un versant de montagne en amont de Johnsons Landing, une petite communauté située dans la région de West Kootenay, en Colombie Britannique. Quatre maisons one été détruites et deux autres endommagées, et quatre personnes ont périe dans leurs maisons. L'enquête qui a suivi a porté sur plusieurs aspects du désastre, y compris les interventions d'urgence, la gestion des risques, l'utilisation du territoire, le zonage, l'identification et avertissement des dangers, et la surveillance des risques de glissement de terrain. Le glissement de terrain a été provoqué par une rupture soudaine de dépôts glaciaires d'un volume estimé à 320.000 mètres cube. L'avalanche de débris a parcourue une distance de 1,9 kilomètres, sur une pente moyenne de 16 degrés, à des vitesses estimées de plus de 150 km/h. Une coulée de débris secondaire a parcourue une distance supplémentaire d'un kilomètre jusqu`au lac Kootenay. Ce glissement de terrain qui a eu lieu en matériaux de surface pour la première fois est inhabituel en raison de sa grande ampleur, de la distance de parcours des débris exceptionnelle, et de l'absence de cause évidente. Le glissement de terrain a suivi un printemps humide et été hâtif. L'enquête a révélé que la vallée en amont de la catastrophe possédait un ensemble de ruptures du substrat rocheux en mouvement lent ou dormant qui pourrait avoir causé la déformation des dépôts glaciaires profonds en les affaiblissant progressivement au point de rupture. Une question difficile portant sur les études de risques de glissement de terrain est de déterminer comment cartographier de tels caractéristiques de terrains semblables, et comment identifier ceux qui ont la possibilité de déchaîner une rupture rapide.

1 INTRODUCTION

The Johnsons Landing landslide was, in terms of loss of life, the most devastating landslide incident to occur in western Canada since the 1980s. In British Columbia, about 100 people have been killed by landslides in the past century, most of them mine workers or travelers on highways. The event at Johnsons Landing was unusual in that people lost their lives in the supposed safety of their own homes, in an area which was previously not believed to be at risk from landslides. Two years after the landslide, the community is still traumatized by the event, and there are many unresolved questions about land use and acceptability of risk in mountainous areas, and the role of provincial and local governments in managing landslide risk.

Johnsons Landing is a small community located at the north end of Kootenay Lake, in a sparsely populated, mountainous area of southeastern British Columbia (Figure 1). On July 12, 2012, at 10:37 AM, a large landslide suddenly occurred, destroying four homes, damaging two others, and covering an area of about 20 ha with debris (Figure 2). Four residents were killed in their homes. As well as the loss of life and destruction of property, water supply, electricity, telephone, and road access to parts of the community were cut off for a year.

The estimated volume of the landslide is approximately 320,000 m^3. It originated as a sudden failure in a deep deposit of glacial till and colluvium at 1050-1250 m elevation, and is classified as a rapid debris avalanche (Hungr et al 2001). It descended the channel of Gar Creek, a steep narrow valley which occasionally carries small debris flows and snow avalanches. Some of the debris (170,000 m^3) travelled up and over a low ridge at a bend in the creek 1.5 km from the initiation area, and spread out approximately 250 m wide by 300m long with an average depth of 2.6 m on a terrace which was occupied by forest, cultivated land, and houses. A portion (less than 5%) of the debris continued flowing down the narrow creek channel as a debris flow, destroying the road crossing which accesses the community and inundating a portion of the alluvial fan of Gar Creek at 535 m elevation. Approximately 24 hours after the first landslide and debris flow, a second larger debris flow occurred, which originated from an area near the landslide source area and entrained loose landslide debris in the channel. It descended the full length of the Gar Creek channel, destroying an already damaged house on the fan. There were several near misses but no additional fatalities

The landslide occurred during dry sunny weather approximately a week after an unusually rainy period of early summer. The area most seriously affected, and where the fatalities occurred, was on a bench well above nearby stream channels, in an area believed by both residents and expert terrain mappers to be not at risk from landslides, flooding, or other hazards.

Figure 1. Map showing the location of Johnsons Landing at the north end of Kootenay Lake.

2 EMERGENCY RESPONSE AND FIELD INVESTIGATION

Response to the slide by the community was immediate, as emergency 911 calls were made within minutes of the event occurring. The first geotechnical personnel arrived by helicopter at 12:20 p.m. and began providing assessments of landslide hazard for the emergency search and rescue efforts. Initial and rapid geotechnical hazard site assessments were required as there are often secondary slides and flows following a first landslide event, and in fact a secondary debris flow occurred the following morning. Search and recovery operations continued during the following week, as well as temporary re-establishment of road access across the debris flow channel. During this time, geotechnical personnel were on the site each day, to monitor the unstable slide scarp and channel, set up lookouts, and provide continuing hazard assessments to the search teams.

An investigation began soon after the event, conducted for the local government (Regional District of Central Kootenay) but funded by the provincial government (Emergency Management BC). The study team consisted of a geotechnical engineering consultant (SNT Engineering Ltd.) and professional staff of the provincial government regional offices. The main objectives of the study were to investigate the causes of the landslide, analyse the hazard and risk of further landslides, and produce a map showing hazard zones. The study included runout modeling by UBC specialists (see section 5 below).

The investigation included acquisition of LIDAR imagery, which proved extremely useful for interpreting terrain features in this heavily forested area, and for preparing detailed maps for field work. Field work was conducted in September, when the site was deemed safe to work on. Following completion of analysis of field data and runout modeling, a report was prepared, which is available to the public (Nicol et al. 2013).

Figure 2. View of the landslide from the air, about 6 hours after it occurred. a – canyon with secondary debris flow; b – bend in channel and low ridge; c – bench where houses were destroyed.

Figure 3. Orthophoto showing Johnsons Landing and the July 12, 2012, landslide. See Figure 4 for interpretation of features. (Regional District of Central Kootenay orthophoto.)

3 LANDSLIDE CHARACTERISTICS AND PHYSICAL ENVIRONMENT

Figures 3 and 4 show the main features of the landslide, It consisted entirely of unconsolidated sediment (soil) of morainal, glaciofluvial, and colluvial origin. These deep glacial deposits form an irregular, gently-sloping (20-40%) terrace between 1100 and 1300 m elevation, in the middle part of the Gar Creek valley. The landslide appears to have originated in the southern part of the source area (location A on Figure 4), where the main scarp is about 10 to 15 m high. The landslide gained speed rapidly, and climbed about 30 m up the opposite valley wall (B). It then continued at high speed down the valley, climbing up the alternate valley walls three more times, with superelevations of 15 to 25 m. In the lower part of the valley, it straightened out (C), although still travelling at high speed with a depth of about 13 m.

At location D, there is a sharp right bend (about 70°) and widening in the valley, below which the creek enters a narrow canyon incised into the deep glaciofluvial and morainal deposits of the Johnsons Landing bench. At this location, most of the landslide debris climbed 10 to 25 m onto a ridge (E), with enough speed to overtop it, and then spread out onto the bench to the southwest, where the homes were located. Debris filled the bend area to a probable thickness of 5 to 10 m. From photos taken soon after the event, and from later ground observations, a possible temporary blockage of trees formed at the head of the canyon, and this may have helped to divert most of the subsequent debris over the ridge and onto the bench. The blockage then broke, sending a debris flow which contained a large proportion of trees down the canyon to the Gar Creek fan.

Most of the landslide volume originated from the immediate source area. Erosion and entrainment of debris along the Gar Creek valley appears to be limited to the loose soil at the rooting depth of the forest, which is typically under 1 m. It is estimated that about 10,000 m^3 of trees were included in the landslide. Many of these trees were deposited in the lower channel and on the fan by the first debris flow, and were carried into Kootenay Lake by the second debris flow.

From eyewitness descriptions and from superelevation, the landslide velocity down the channel is estimated at 90 to 120 km/h (25 to 33 m/s) with a reduced speed as it flowed onto the Johnsons Landing bench. Although the landslide was described by eyewitnesses as a single event which lasted less than a minute, there is some evidence from the deposits that it may have been a more complex event with several surges of debris, maybe only seconds apart. A substantial amount of debris was deposited in a wide part of the upper channel (F). Above the main scarp, a prominent feature is a large block of more-or-less intact glacial deposits (G) which dropped down about 20 m and then stopped. It may have been arrested by a bedrock outcrop (H) visible below the main scarp. During the search operations, there was concern that this block could fail; however, no further movement occurred. Within the source area, below the main scarp (I) a large area is covered with mostly intact trees with their root wads attached. This appears to be a result of a large block of debris which fell off the main scarp, and

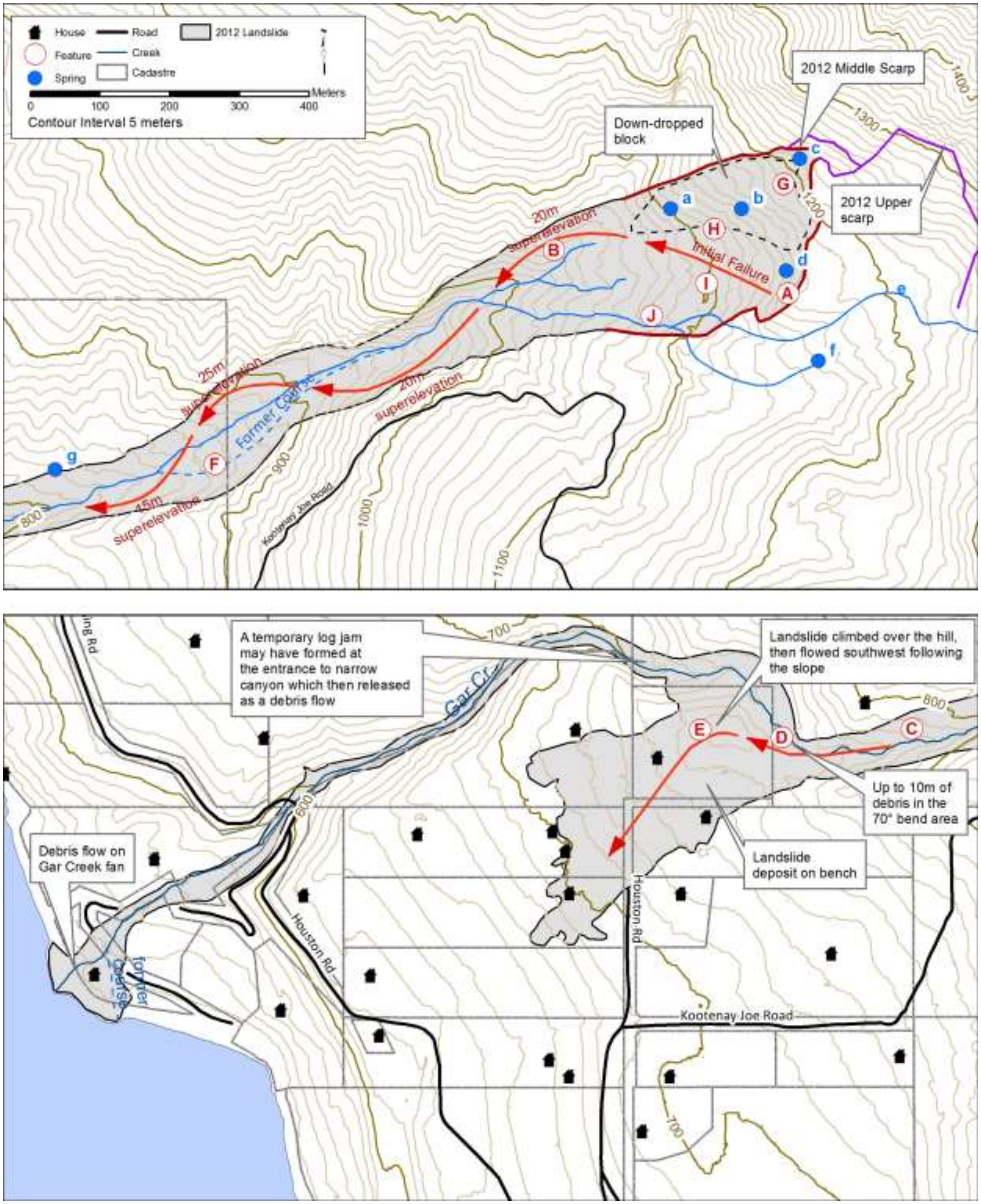

Figure 4. Map showing the features of the Johnsons Landing landslide. The top and bottom figures are the right (east) and left (west) parts of the map, respectively. Figure from the report (Nicol et al. 2013).

disintegrated on the slope below. This debris covers most of the area where the failure plane of the landslide might otherwise be observed. Significant water was observed at the landslide scarps a week after the event; in particular, seeping from the upper scarp located above the dropped block, and from several springs within the scarp area (H, I, J).

The landslide source area is heavily forested. Other than some selective horse logging 50 to 100 years ago, there has been no industrial development in the area. An old road built for fire fighting access is nearby, but has no apparent effect on the landslide.

The glacial deposits at the main scarp largely consist of till and glaciofluvial sediments of predominantly silty sand loam texture, with roughly 50% gravel (SM and GM). The loose to compact deposits show some weak stratification and do not appear to be over-consolidated, and they are non-cohesive and non-plastic. The sediments in the main scarp area are typical of kame deposits, which are mixed glacial till, glaciofluvial sand and gravel, and colluvial material, which typically form along valley sides and in tributary valleys alongside retreating glacial ice. The silty sand texture of the glacial sediments reflects the sedimentary rocks of the area (phyllite, schist, quartzite, and limestone), and is typical of soils of glacial origin in this region.

The surrounding area is mountainous, with a total relief of about 2500 m. The landforms and surficial deposits are a result of Pleistocene glaciations, and small glaciers remain on the higher peaks. The geology of most of the north Kootenay Lake area consists of weak metasedimentary rocks. Several large, ancient, bedrock landslides are found in the area, and there are a number of small, slow-moving failures in bedrock and in glacial deposits. Most landslides in the area appear to have moved little or not at all since early postglacial time.

Debris flows are the most common type of landslide in the region. Most of them are relatively small (less than 10,000 m^3), and they occur frequently in steep gullies or creek channels which are continually supplied with debris by rockfall, small debris slides, or snow avalanches. Many such channels have repeated debris flows with return periods of a few years to a few decades, which add to the accumulated volume of their alluvial fans. It is not uncommon for debris flows (and rarely, other types of landslides) to impact houses and infrastructure in the Kootenays and elsewhere in British Columbia. However, large landslides are very rare, and a rapid landslide of similar type and size to the Johnsons Landing landslide has not been recorded in the Kootenay Lake area in historic time.

4 LANDSLIDE TRIGGERING FACTORS AND POSSIBLE CAUSES

The spring and early summer of 2012 were exceptionally wet. The June 2012 rainfall set many records in the West Kootenays. It set not only a new record for the month of June, but a new record for precipitation for any month at four of the five local weather stations (one of which, Kaslo, has 105 years of record). The snowpack in the surrounding mountains was well above average (although not at record levels), and the spring snowpack was unusually late. The wet conditions in the spring of 2012 caused a number of landslides throughout the Kootenay region, some of which impacted houses, property, and roads.

Figure 5 shows two hydrologic measures which may provide an index of available water in the spring – early summer period. These are total May-July runoff for the most representative nearby streamflow gauge, Kaslo River, and the sum of May 1 snow water equivalent and May-July rainfall at nearby stations. Although arbitrary, these measures may provide a qualitative indication of valley-bottom groundwater levels in the area. The figure shows that using these indices, 2012 was amongst the wettest spring seasons since records began.

Previous hydrology and soil studies (Kutenai Nature Investigations Ltd. 1983; Salway 1983) indicate that Gar Creek responds slowly to snowmelt and rainfall events and peaks later in the summer than most streams in the region. There are several springs in the watershed, and it is speculated that karst aquifers in the mountains to the east and north may contribute to the streamflow. In the month preceding the landslide, residents observed that Gar Creek was flowing at higher levels that had been previously observed. In early July, there was no snow remaining in the watershed, and the weather was clear and hot. The continued high flow of the creek indicates either a delayed response to snowmelt, or possible contributions of snowmelt runoff through karst aquifers from adjacent higher watersheds. Numerous springs in the landslide source area indicate that high groundwater level was probably the main triggering factor.

The geotechnical factors which contributed to instability in the landslide source area are less certain. The return period of the high precipitation combined with the late snowmelt event may have been in the order of 500 years. If this is the case, similar hydrologic circumstances must have occurred often since deglaciation, but did not trigger a large landslide. Some other process must have occurred, which caused the stability to decrease over time.

During and immediately following deglaciation, there were probably numerous landslides and debris flows from the Gar Creek watershed, and for similar drainages throughout the region. These events were responsible in part for building the large valley-bottom kame terrace complexes, which include the Johnsons Landing bench. The available mapping and other evidence indicate that there has not been a large rapid landslide in the Gar Creek valley since early postglacial time.

Based on the LIDAR imagery and the field traverses, a complex of inactive or slow-moving bedrock failures was found to occupy most of the area of the south fork of Gar Creek, east of the landslide (Figure 6). Relatively inactive toppling deformation features were noted along with more recent transverse cracks. The age of these features is unknown, except that they are older than the age required for establishment of an old-growth forest and a mature soil profile (perhaps 1000 years). The most southwestern failure (Figure 7) is the most prominent, and it has no evidence of recent movement. Failures elsewhere in the valley appear to be much older, based on their more subdued topography on the LIDAR images.

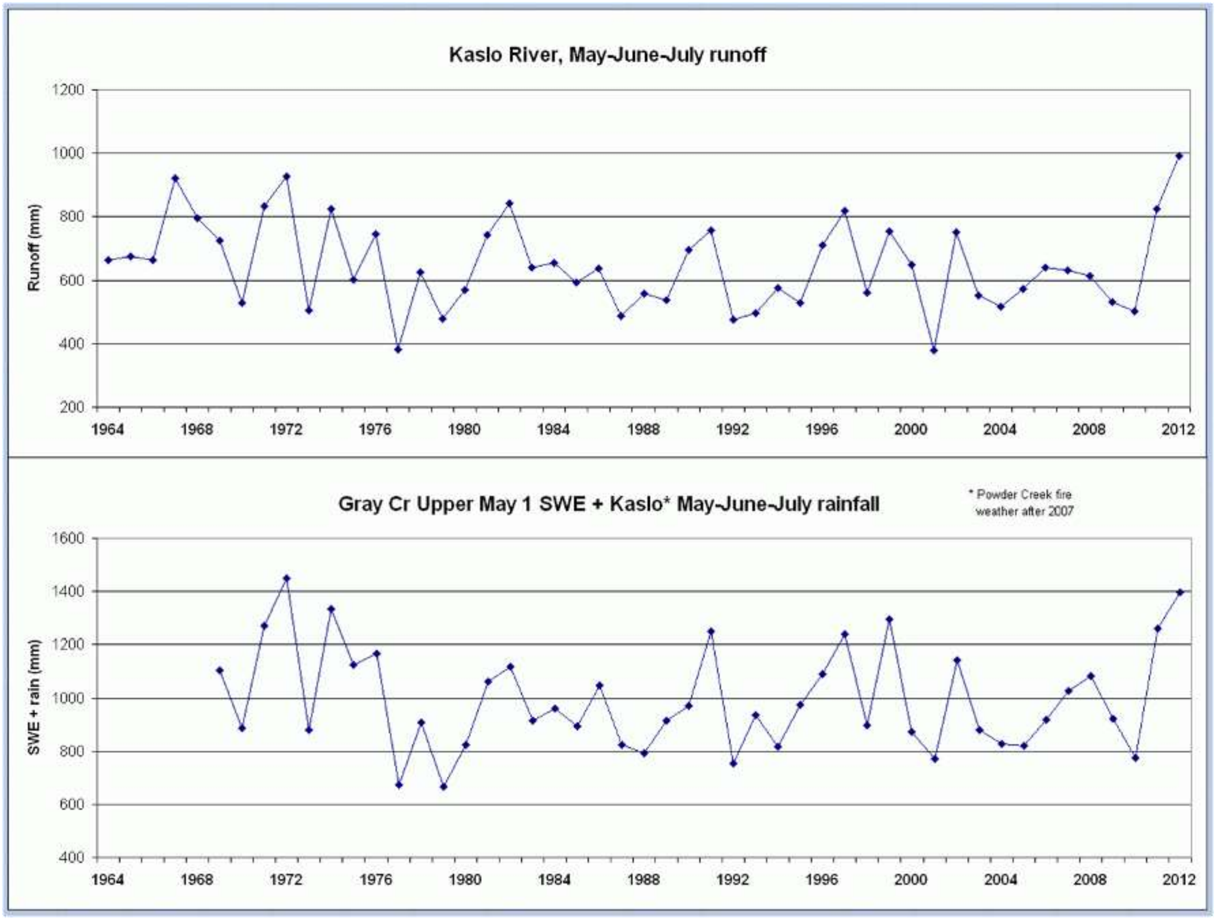

Figure 5. Graphs illustrating runoff and precipitation for the May-July spring freshet period, 1964-2012. The lower graph is an index consisting of snow water equivalent (SWE) plus rainfall for the period, for representative stations.

It is unlikely that any part of the bedrock complex ever failed rapidly, as no rock avalanche debris has been observed further down the Gar Creek valley.

The continual movement of material may have resulted in the establishment of new subsurface drainage paths or blocked previous drainage paths. It is possible that movement at the toe of the bedrock failure complex placed stress on, and probably deformed the thick glacial deposits in which the failure occurred. This deformation could have reduced the strength of these deposits by creating small fractures, causing dilation of the sediment in some places, and may have contributed to the brittle failure of the thick glacial deposits. We hypothesize that this is the most feasible mechanism that contributed to the landslide.

Eyewitness accounts indicated that there was unusual activity in Gar Creek in the week preceding the landslide. High turbidity was observed four or five days before the event, although this is a common occurrence during snowmelt in many streams in the region. Two days before the landslide, very high turbidity and sediment load was observed, as well as local changes in stream course and fluctuations in flow. The community water intake was damaged. One day before (July 11), small debris flows were observed, as well as deposition of gravel and logs, bank erosion, and extreme turbidity. These changes in the creek prompted residents to try to contact local soils experts and government officials by e-mail on July 11; however, the messages were not received until after the landslide had occurred.

These observations suggest that some form of slow progressive failure preceded the landslide event by up to a week. No observations were made during this time in the source area, which is of difficult access, and apparently no-one suspected that the changes in the creek were indicative of an imminent large landslide. From eyewitness accounts of the event, it is apparent that most of the landslide volume failed suddenly and rapidly.

5 HAZARD AND RISK ASSESSMENT

The greatest concern of residents and local government authorities was the possibility of further activity of the landslide scarp, or of future landslides originating in the unstable area. Therefore, an objective of the investigation was to map the potential hazard area, and to analyse the risk of possible landslides, including runout and potential deposit areas.

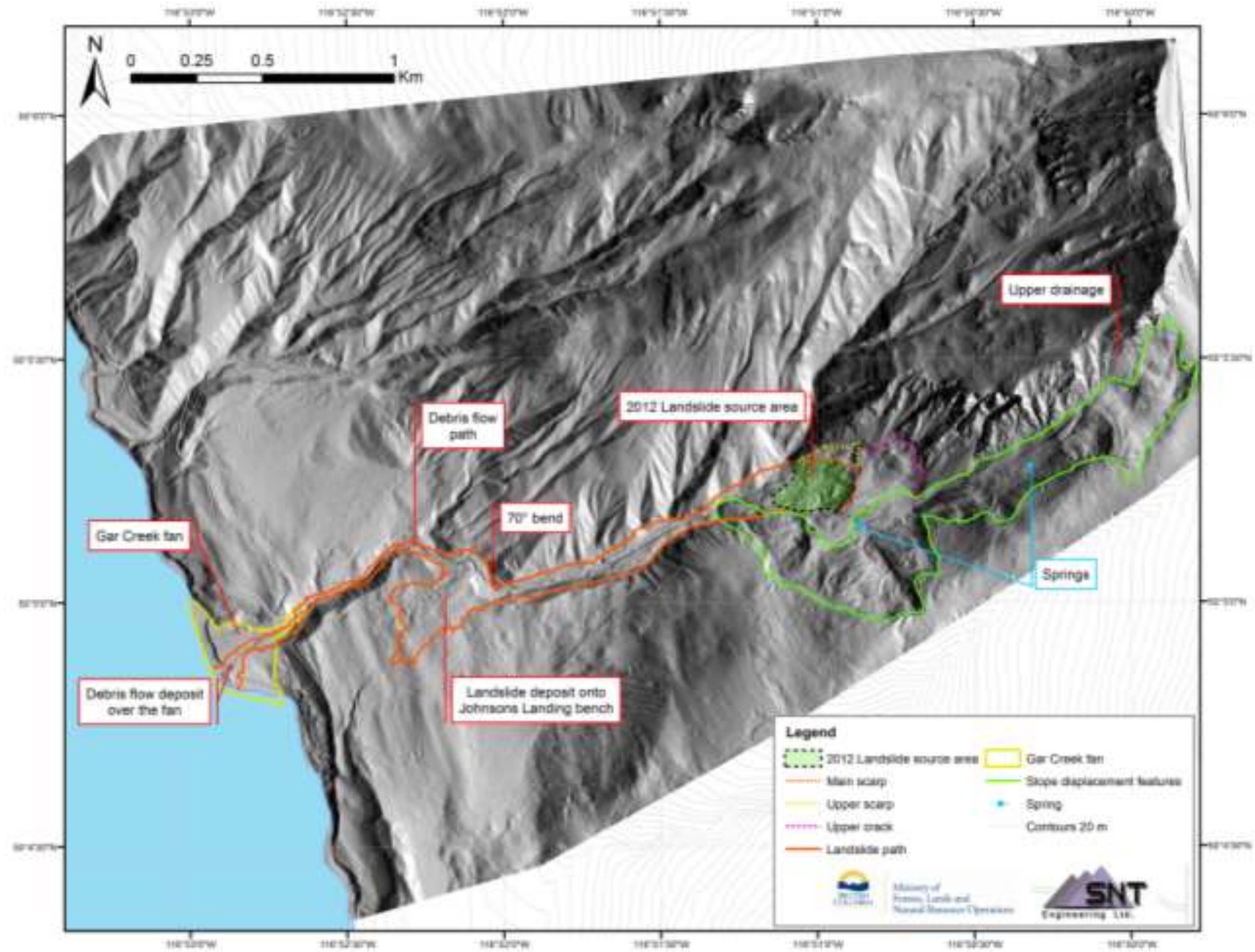

Figure 6. LIDAR image of the Johnsons Landing landslide and adjacent area. The dashed purple line shows the upper crack bounding the potential future landslide, and the green line outlines the area of displaced bedrock in the upper Gar Creek valley. Figure from the report (Nicol et al. 2013).

5.1 Hazard analysis

LIDAR imagery and field traverses in the failure area identified a continuous crack, approximately 400 m long and 200 m above the main scarp, with visible displacements of up to 4 m. The surface area bounded by the crack and the main scarp below is about 6.4 hectares. The depth to bedrock is unknown and the average depth of a potential failure surface is uncertain. However, lower and upper bounds of the potential volume can be estimated by assuming it varies from 1 to 5 m at the crack, to 8 to 12 m at the main scarp.

Topographic cross-sections and limit equilibrium analysis were used to estimate the pore water pressures that could result in failure of various parts of the potentially unstable volume. Corresponding return periods were assigned by judgment and consensus amongst the four authors of the report (Table 1). These return periods (or annual likelihoods of occurrence) are subjective probabilities and are very approximate. They may be revised, if future observations in the potential source area provide information on ground movement.

5.2 Runout and risk analysis

To estimate the potential run-out distances and deposit thickness for these potential events, landslide runout modeling was done by the Department of Earth and Ocean Sciences at the University of British Columbia. Two landslide run-out models were utilized, DAN-W and DAN-3D (Hungr 1995; McDougall and Hungr 2004; Hungr & McDougall 2009). The inputs to the model include basal shear resistance parameters that can only be determined through empirical means. To determine these parameters a back analysis of the landslide event was undertaken. This back analysis provided the calibrated parameters used for the forward analysis. Both DAN-W and DAN-3D were used in order to exploit the strengths and weaknesses of both models. DAN-W was able to simulate the July 12th, 2012, debris avalanche with minimal assumptions. The drawback in using DAN-W is that it is a two-dimensional model and cannot produce a three-dimensional deposit shape.

Table 1. Estimates of future landslide magnitude and probability.

Likelihood of Landslide Occurrence per year	Landslide Magnitude (m^3)	Description
0.01 (1:100)	100,000	Failure of dropped block and adjacent oversteepened upper scarp
0.001 (1:1000)	300,000	This is the estimated volume represented by failure of the dropped block and retrogression of the upper scarp, with a groundwater level slightly higher than in 2012. This volume is similar to the 2012 event.
0.0001 (1:10,000)	500,000	Representative of failure of most of the potentially unstable volume, which would require substantially higher pore water pressures than the 1:1000 case.
0.00001 (1:100,000)	900,000	This represents the failure of the maximum feasible estimate of the potentially unstable volume under extremely unlikely pore water pressure conditions.

It was noted that DAN-3D had difficulties in reproducing the overtopping of the channel at the bend of Gar Creek. This is likely due to a combination of two factors. It is hypothesized that a channel obstruction composed of timber at the flow front developed during the debris avalanche, which caused most of the debris to be diverted onto the bench. Also, DAN-3D explicitly neglects lateral shear strength, and it is likely that significant lateral shear stresses developed when the flow reached the sharp bend. With the inclusion of a channel obstruction it was possible to achieve reasonable results using DAN-3D; however both the volume and geometry of this obstruction are assumed parameters. The DAN-W back analysis determined that there are two sets of parameters that are able to reproduce the bulk characteristics of the July 12th landslide. One set of parameters uses only one rheology to model the channel and debris field, an approach consistent with past analyses undertaken with DAN-W. The other set of parameters uses two flow rheologies, one to simulate the channel and another to simulate the debris field where basal resistance was expected to be higher due to the fact that it is mostly forested. Both sets of parameters were able to reproduce the run-out, duration, velocities and debris field volume observed during the event.

The back analysis conducted using DAN-3D determined that only a two-rheology set of parameters could reasonably reproduce the bulk landslide characteristics of the July 12th, 2012, event. This back analysis did not predict that any material would deposit in the upper channel; however, using an assumed channel blockage, the back analyzed volume deposited on the Johnsons Landing bench was relatively close to the measured volume. The duration, velocities and 3-D debris deposit shape of the event were well predicted. Figure 8 shows the DAN-3D deposit shapes for the back analysis and several forward analysis scenarios.

The runout analyses show that a future landslide of similar magnitude to the 2012 landslide will travel further due to the lack of trees in the channel and on the bench, and therefore a lower basal friction. An uncertainty in the modeled runout is the assumption that a channel obstruction formed at the entrance to the canyon. Without an obstruction, the model predicts that most of the debris should run down the canyon to the fan. The likelihood of another channel obstruction is less than during the 2012 event due to fact that there will be fewer and/or smaller trees incorporated into a future landslide (at least for the next several hundred years).

There are no official standards for acceptable or tolerable risk thresholds in British Columbia. Based on criteria used in British Columbia (Cave 1992; BGC Engineering Inc. 2007) and elsewhere (Hong Kong Geotechnical Engineering Office 1998; Australian Geomechanics Society 2000), for the purposes of this investigation, a map was prepared showing the area that could potentially be inundated by a landslide with an annual probability of 1:100 to 1:1000 as “high hazard”, and 1:1000 to 1:10,000 as “moderate hazard”. The map (Figure 9) also shows the area that could be potentially affected by debris flows which have higher probability and could occur without a future large debris avalanche.

5.3 Monitoring

A recommendation of the report was that a simple landslide monitoring program be established. In late 2012, the investigators placed stakes at several locations on the upper crack, and measured the displacement during 2013. These observations showed movement on the crack ranging from near zero to about 30 cm. Such movement could simply be a result of settling of the displaced soil, or it could indicate progressive movement of the potentially unstable volume. Repeated photography from the ground and from the air showed no significant changes at the landslide scarp, other than minor sloughing and erosion. Rainfall in June 2013 was again well above average, although not as high as the record rainfall of 2012.

Based on the limited monitoring to date, no further conclusions can be made about the stability of the potentially unstable area, or about the estimated return periods used in the hazard analysis.

More advanced monitoring methods such as the installation of geotechnical instrumentation are not feasible at this site due to lack of road access, the high cost of such systems compared to the value of the properties at risk, and jurisdictional issues.

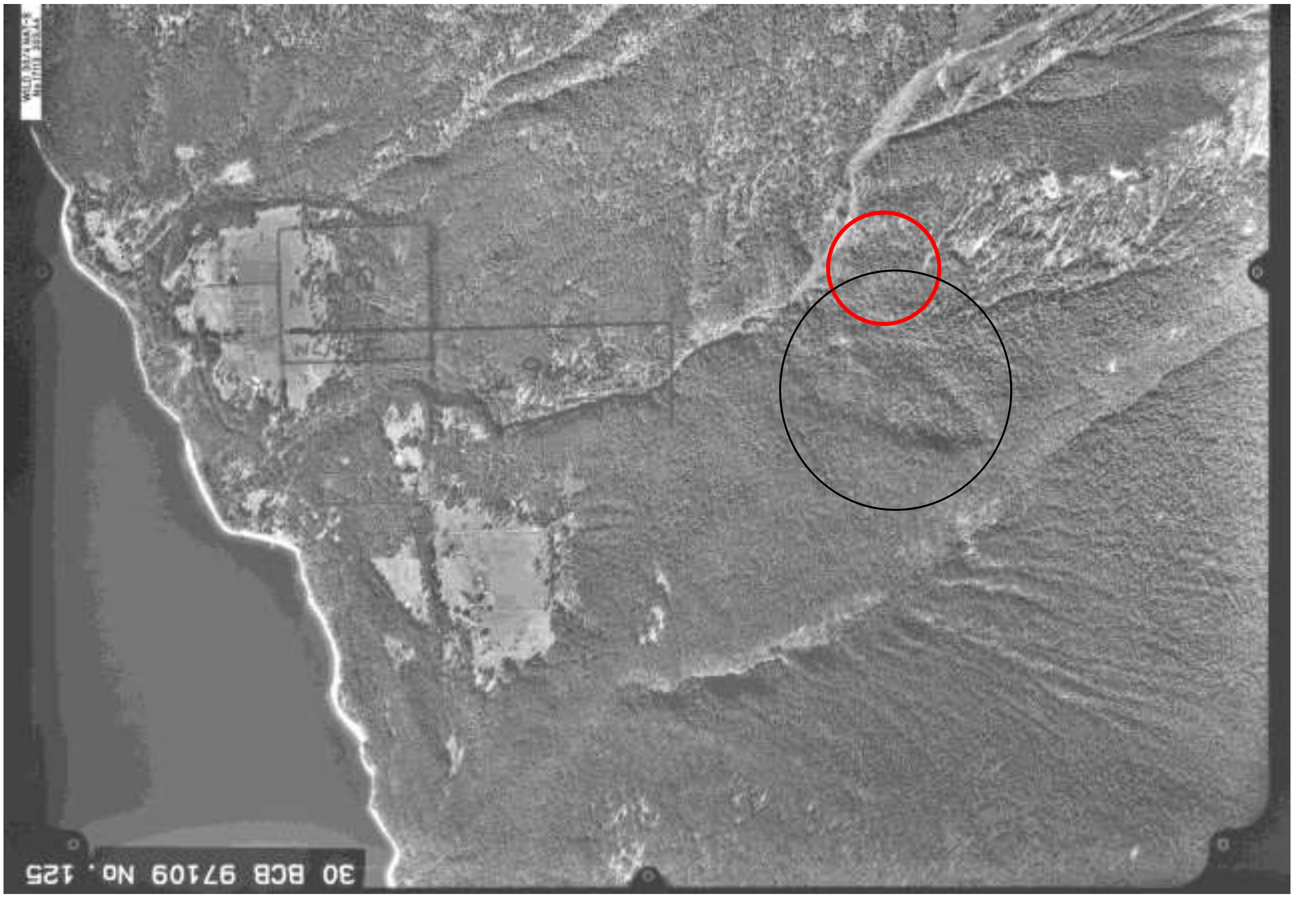

Figure 7. Pre-landslide air photo of the Johnsons Landing area. Red circle shows the location of the 2012 landslide source area. Black circle locates the ancient bedrock landslide feature, part of the area of displaced bedrock in the Gar Creek valley. Compare with Figure 3, which shows the area on the bench inundated by the landslide.

6 DISCUSSION AND CONCLUSIONS

The report made several recommendations, including:

- Notify local residents of the estimated hazard and risk.
- Restrict further land development or building in the areas identified as having a moderate, high, or very high hazard unless subsequent geotechnical investigations are conducted that supports the development, recommends protective works, and/or reduces the assessed hazard.
- Establish communication plans and protocols to update residents and visitors of local conditions during periods of potential increased landslide hazard.
- Establish a watershed plan for resource management and development on crown land within the Gar Creek watershed.

Some general recommendations were also made that are applicable elsewhere in British Columbia, including: increase public awareness of when and how to report signs of unusual creek activity and slope instability; improve the availability of landslide hazard maps and reports to regulatory bodies, qualified professionals, property owners and the public; and establish uniform and consistent landslide risk tolerance/acceptability criteria for assessment of landslide risk relating to land development, building permitting, and existing residences.

As a result of the Johnsons Landing landslide, and several other less severe landslide events in 2012, the British Columbia government established an internal committee to review landslide hazard management. The committee is beginning to address several of the general recommendations mentioned above, including improving the extent and accessibility of landslide hazard mapping, and addressing the lack of provincial standards for acceptable or tolerable risk.

The Johnsons Landing area was covered by detailed terrain mapping, which was proven by our field work to be quite accurate. It did not indicate any unstable or potentially unstable terrain features of concern in the area. It did note the presence of some of the inactive bedrock failure features above the landslide area. However, such failures are very common in the Kootenay Lake area, as in most mountainous regions. It is unlikely that any commonly used hazard mapping technology would have identified this site as being subject to a large, first-time landslide. A significant problem in geologic

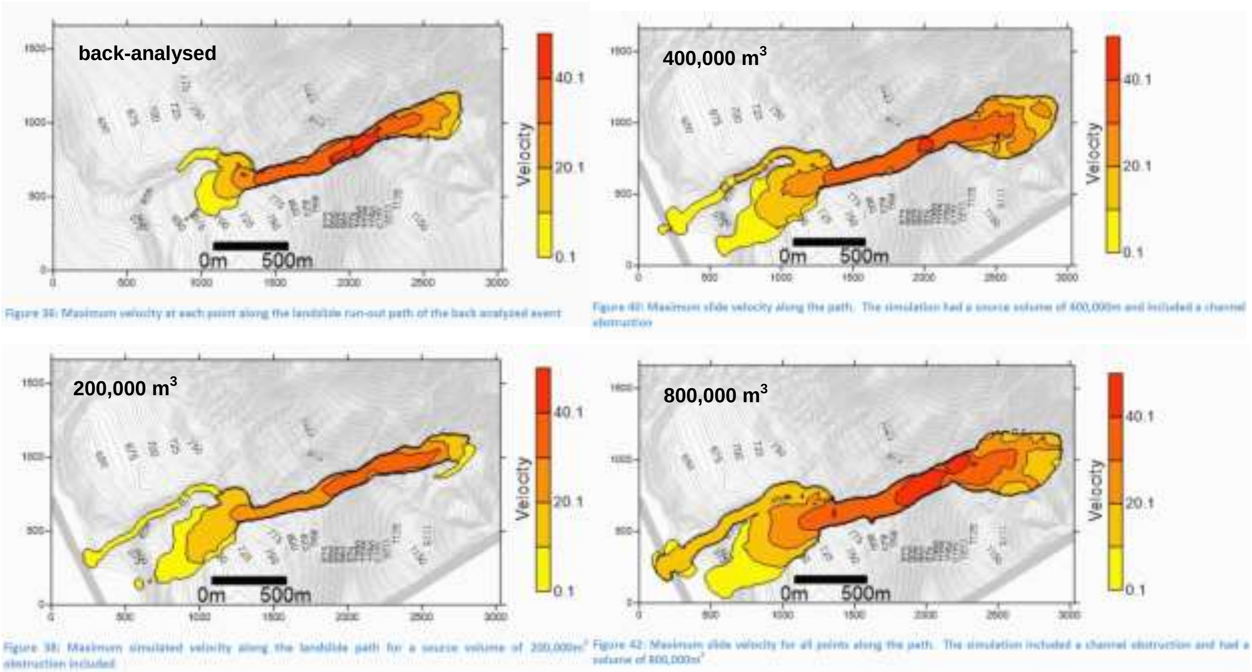

Figure 8. Examples of output from the DAN-3D runout analysis. The upper left map shows the back-analysed extent and velocity; the other three maps show the forward analysis for three potential future landslide magnitudes.

hazard mapping and assessment is how to identify the very small proportion of inactive or slow-moving slope instability features which have the potential to fail rapidly.

A fundamental problem in all aspects of landslide hazard management in British Columbia is the poorly defined division of responsibilities between the provincial government, local governments, and private landowners. As a result of changes to provincial legislation a decade ago, natural hazards are the responsibility of local governments. However, for many or most natural hazards in mountainous regions, the hazard originates on Crown land at higher elevations, and affects private land in the valley bottoms. Local governments have limited or no jurisdiction over this Crown land, and limited resources and funding to undertake mapping or investigations. This especially applies to the sparsely populated unincorporated areas outside cities and towns (which in British Columbia are under the jurisdiction of Regional Districts).

At Johnsons Landing, almost two years after the 2012 landslide, little progress has been made to resolve the problems facing the community. An evacuation order issued by the Regional District remains in place, despite the absence of any indication of a short-term risk from further large landslides. Residents and landowners in the mapped hazard areas face uncertainty about the future allowable use of their properties, yet neither level of government has offered to compensate landowners or buy the affected properties. (However, a provincial disaster assistance program provided some funding to the most directly affected residents.) Monitoring of the landslide area is being done unofficially by the author, with volunteer help from colleagues and local residents. Neither level of government will commit to long-term monitoring, citing the usual excuses of lack of jurisdiction, limited staff and funds, and fear of liability.

The Johnsons Landing landslide, although a rare and tragic incident, illustrates some of the natural hazard management problems presented by high magnitude, low probability events. It is especially relevant to the large areas of Canada which have an established, but low-density, population in areas which are potentially at risk from a variety of natural hazards, some of them unsuspected.

ACKNOWLEDGEMENTS

Doug Nicol, Dwain Boyer, and Daryn Yonin conducted the landslide investigation and wrote the report, along with the present author. The runout analysis and modeling were done by Oldrich Hungr, Jordan Aaron, and Giacomo Marinelli. Marc Deschenes, Tim Giles, and Will Burt assisted with field work and mapping. Residents of Johnsons Landing, especially Bob Yetter, Roger Atkins, Osa Thatcher, Richard and Angele Ortega, and Gerry Rogers, provided valuable local observations and logistical support, and assisted with monitoring.

REFERENCES

Australian Geomechanics Society. 2000. Landslide risk management concepts and guidelines. Sub-committee on landslide risk management, *Australian Geomechanics*, March 2000, pp. 49–92.

BGC Engineering Inc. 2007. *Berkley Landslide Risk Management*, report prepared for District of North Vancouver, available at http://www.dnv.org/article.asp?a=3696.

Cave, P.W. 1992. Hazard acceptability thresholds for development approvals by local government. In *Geological hazards in British Columbia*, BC Geological Survey Branch, Open File 1992-15: 15-26.

Hong Kong Geotechnical Engineering Office. 1998. Landslides and Boulder Falls from Natural Terrain: Interim Risk Guidelines. *GEO Report No 75*, Geotechnical Engineering Office, the Government of Hong Kong Special Administrative Region, 183 p.

Hungr, O. 1995. A model for the runout analysis of rapid flow slides, debris flows, and avalanches, *Canadian Geotechnical Journal*, 32: 610–623.

Hungr, O. and McDougall, S. 2009. Two numerical models for landslide dynamic analysis, *Computers & Geosciences*, 35: 978-992.

Kutenai Nature Investigations Ltd. 1983. *Resource Inventory of Argenta and Johnsons Landing Watersheds*, report prepared for BC Ministry of Forests, Nelson, British Columbia.

McDougall, S. and Hungr, O. 2004. A model for the analysis of rapid landslide motion across three-dimensional terrain, *Canadian Geotechnical Journal*, 41: 1084-1097.

Nicol, D., Jordan, P., Boyer, D. and Yonin, D. 2013. *Johnsons Landing Landslide Hazard and Risk Assessment*, report prepared for Regional District of Central Kootenay, May 16th, 2013, available at http://www.rdck.ca/EN/main/services/emergency-management/johnsons-landing.html.

Salway, A. 1983. *Hydrology of the Argenta Slope*, report prepared for the BC Ministry of Forests, Nelson, British Columbia.

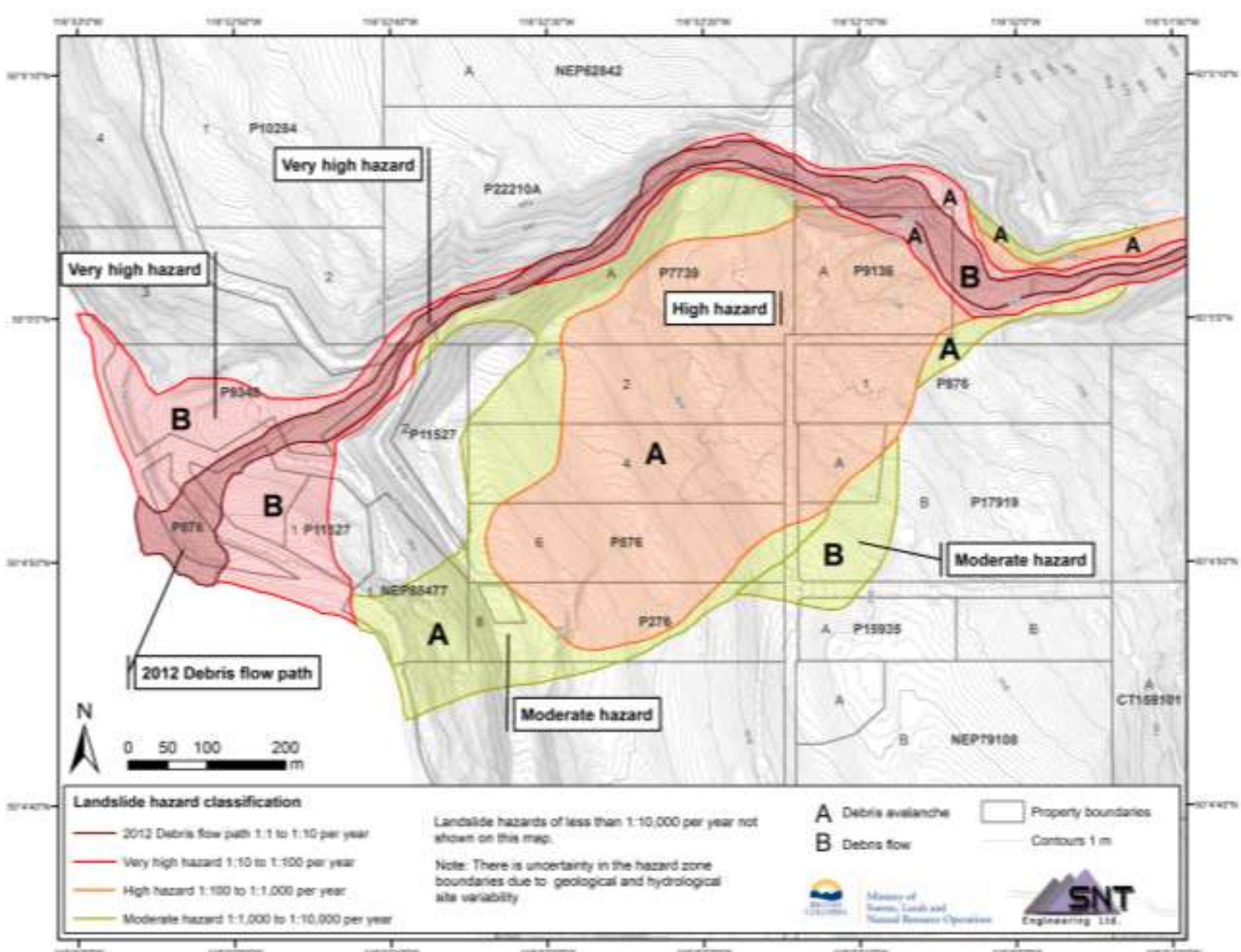

Figure 9. Map showing hazard zones derived from the runout analysis. Figure from the report (Nicol et al. 2013).