Weather thresholds and Operational Safety Planning, Turbid Creek, Mount Cayley, Squamish River Valley, BC.

Submitted to:

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Introduction

Turbid Creek (Fig. 1), known locally as Mud Creek[1], drains the southwest slope of Mt Cayley, a Pleistocene stratovolcano located 50 km north of Squamish. The slopes of Mount Cayley have a well-documented history of landslide activity, and there is an extensive colluvial apron filling the Squamish Valley at the foot of the mountain (Fig. 2).

The Squamish mainline forest service road (FSR) crosses the debris apron and is frequently washed out at Turbid Creek (Fig. 3), presenting a hazard affecting road users and often leading to stranding of workers and tourists upstream of the washout. Further, washouts fill the road sump and/or damage or destroy the existing crossing requiring maintenance/reconstruction. Reconstruction puts road crews directly in the hazard zone for hours to weeks. Presently, during reconstruction there are no protocols in place for monitoring the hazard nor ensuring a safe work site once an event has taken place.

The purpose of this report is to characterise weather conditions that have resulted in landslide activity on the west side of Mount Cayley, and develop landslide warning criteria. A suite of measures are recommended that could be used to manage landslide risk before an event and during crossing reconstruction. This report recommends various risk management strategies; but the ultimate strategy will be determined by MoFLNRO.

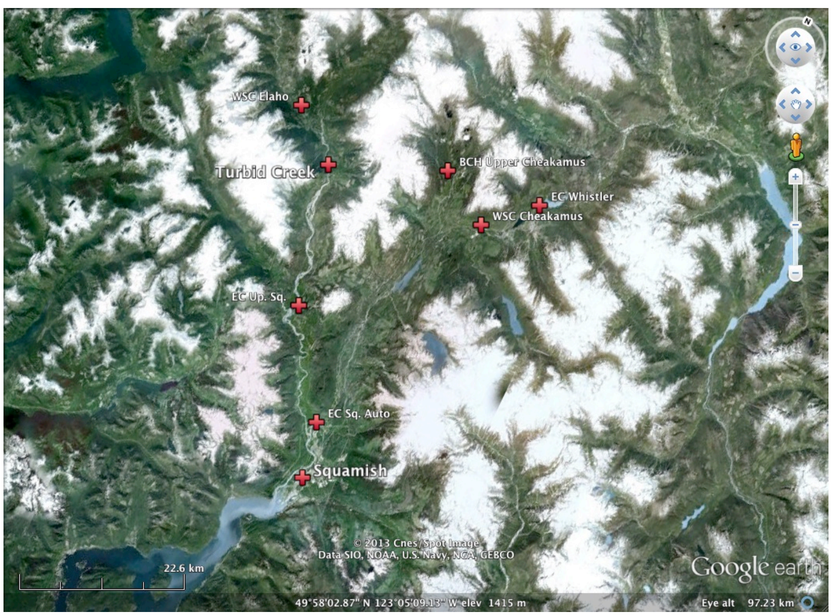

Figure 1. Location of Turbid Creek north of Squamish. Nearby climate stations and stream gauging stations are shown. EC, Environment Canada; BCH, BC Hydro; WSC, Water Survey Canada.

[1] In contrast to names on TRIM or NTS map bases, local useage as reflected on old Weldwood Empire Logging maps refers to Turbid Creek as Mud Creek, Shovelnose Creek as Turbid Creek and Shovelnose Creek is applied to the next drainage south. This report uses TRIM/NTS nomenclature as it is consistent with scientific literature.

Figure 2. View north up Squamish River to Mount Cayley. The river cutbank exposes a 14 m thick sequence of landslide materials deposited primarily by the 4800 year old landslide (Evans and Brooks 1991).

Figure 3. Washout at Turbid Creek in 1997. Exact date of occurrence unknown (from photos on file with Friele). Note this is a typical small, channelised event; it destroyed the crossing and filled Squamish River with debris, and may have briefly dammed the river.

Hazard & Risk Assessment

A hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (see Table 1). Consequence is a product of factors, including whether a given hazard will reach a site, whether elements at risk 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*. A *Partial Risk* is the probability of a given hazard affecting a site, otherwise known as the encounter probability.

Table 1. Qualitative hazard frequency categories (after MoE 1999).

Qualitative frequency	Annual return frequency	Comments
Very high	>1/20	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	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	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	The hazard is of uncertain significance.
Very low	<1/2500	The occurrence of the hazard is remote.

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 landslides and associated phenomenon, 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 (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).

In British Columbia, terrain stability assessments (TSAs) in the forest sector typically present partial risk assessments, because the details of human (or other elements at risk) exposure to the hazard are generally not known in enough detail to conduct a meaningful total risk assessment site (Wise et al. 2004).

The report provides guidance to be used in a "model" for managing volcanic landslide risks facing public user groups and Ministry of Forests, Lands and Natural Resource Operations personnel, as per APEGBC & ABCFP (2008). Industrial user groups are encouraged to prepare their own terrain models and operational safety plans, as per WorkSafeBC, Occupational Health and Safety Regulation, Sections 4.1 and 4.2.

Consequences of Volcanic Landslide Impacts

The consequences of large volcanic landslides are extremely severe (Table 2). The documented landslides from Mt Cayley and affecting Squamish River have volumes ranging from Class 1 to Class 6; Class 7 landslides are possible but not confirmed.

Table 2. Consequences of volcanic landslides (after Jakob 2005).

Class	Volume (m^3)	Potential consequences[1]
1	$<10^2$	Very localized damage, known to have killed forestry workers in small gullies and damaged small buildings.
2	10^2-10^3	Bury cars, destroy small wooden buildings, break trees, block culverts, and damage heavy machinery.
3	10^3-10^4	Destroy larger buildings, damage concrete structures, damage roads and pipelines, and block creeks.
4	10^4-10^5	Destroy camps, destroy sections of infrastructure corridor, damage bridges and block creeks.
5	10^5-10^6	Destroy camps and forest up to 2km^2 in area, block creeks and small rivers.
6	10^6-10^7	Could obliterate valleys or fans up to several tens of km^2 in size, and dam large rivers with the potential for destructive outburst floods and hyperconcentrated flows. Example: Dusty Creek landslide 1963.
7	10^7-10^8	Could inundate large valleys up to 100 km^2 in size, and dam large rivers with the potential for destructive outburst floods and hyperconcentrated flows. Possible prehistoric events. Not well documented.
8	10^8-10^9	Vast and complete destruction over hundreds of km^2. No known events.

Volcanic Landslide Activity at Mount Cayley

Volcanic landslides are conditioned by many factors including slope relief, glacial oversteepening, debuttressing by glacier retreat, weak rock including structural controls and hydrothermal alteration, presence of groundwater seepage and time. Not all landslides are triggered in the same way: small debris flows may be caused by runoff mobilizing debris stored along channels, whereas large debris flows or rock avalanches may be derived from deep-seated slope failures (e.g., Clague & Souther 1982; Cruden & Lu 1992; Jakob and Friele 2009). Some landslides may occur without an apparent trigger, and others may be clearly triggered by phenomenon such as earthquake or intensive precipitation, or rapid snowmelt or both.

With respect to the more common smaller (<Class 4; Table 2) debris flows, a phenomenon observed at Meager Creek and Mount Cayley is that during long summer dry spells, as the edifice rock dries it becomes friable and ravels, with noticable rockfall occurring during dry periods, then with first rains of fall debris flows are often triggered in gully channels where debris collected. This is exactly what happened in 2012: the dry

spell was 2-3 months long, then in mid October the rains came; on Friday October 12, Jeff Fisher (Northwest Squamish Forestry) predicted a washout (Fisher, pers. comm.) and on Sunday October 14 the first of a series of washouts occurred.

Several large (Class 6 or Class 7; Table 2) prehistoric landslides at Mount Cayley have been directly dated by buried wood. The largest is the 4800 year old event that makes up the main body of the 14 m thick debris apron at the foot of the volcano (Fig. 2); other large events have been dated to 3200, 1100 and 500 years ago. These four events and 3-4 others between 1100 years ago and the historic period dammed the Squamish River forming a lake upstream that extended as far as the Elaho River confluence (Evans and Brooks 1991; Brooks and Hickin 1991). Smaller historic landslides have caused momentary impoundments, at least twice in the last 100-years (Clague and Souther 1983; Cruden & Lu 1992). The June 28 1984 event was described by Cruden and Lu (1992) as follows:

> "Approximately 3.2 million cubic metres of volcanics travelled 2.0 km down Avalanche Creek at velocities up to 35 m/s to dam the confluence of Avalanche and Turbid creeks. The breaking of the landslide dam caused an extremely fast debris flow. The velocity of the debris flow and associated wind gusts, up to 34 m/s, caused superelevations, hurled rocks and wood through the air, uprooted trees, and spattered mud 16 m up trees. The debris flow removed the logging road bridge and road approaches at the mouth of Turbid Creek, blocked the Squamish River during surges, and introduced huge quantities of sediment to the Squamish River."

A list of historic debris flow activity at Turbid Creek (Table 3) has been compiled from various sources, notably from Jakob (1996) with more recent events provided by Jeff Fisher. The information on large prehistoric and historic events (i.e., 1963, 1984) was summarised by Evans and Savigny (1994).

Table 3. Documented landslides affecting Squamish mainline at Turbid Creek (see discussion). The trigger was assessed from analysis of local climate stations (Table 4).

Year	Date	Trigger	Volume (m^3)	Data Source
1963	July	..	5,000,000	Clague & Souther 1983
1967	..	..	..	Weldwood in Jakob 1996
1972	..	..	..	Weldwood in Jakob 1996
1978	..	..	..	Weldwood in Jakob 1996
1984	28-Jun	Rain	3,200,000	Jordan 1987; Cruden and Lu 1989
1984	08-Oct	Rain	500,000	Jordan 1987
1987	..	..	..	Weldwood in Jakob 1996
1991	..	..	..	Weldwood in Jakob 1996
1993	29-Jul	Rain	300,000	Jakob 1996, Pers. Obs.
1995	04-Aug	Heat	..	Jakob 1996
1997	..	..	..	Friele, Pers. Obs.
2005	08-Jul	Rain	10,000	Cordilleran 2005
2010	06-Aug	Heat	100,000	Jeff Fisher, Pers. comm.
2012	14-Oct	Rain	..	Jeff Fisher, Pers. comm.
2012	19-Oct	Rain	..	Jeff Fisher, Pers. comm.
2012	21-Oct	Rain	..	Jeff Fisher, Pers. comm.
2012	04-Nov	Rain	..	Jeff Fisher, Pers. comm.

Note that the list in Table 3 is not complete: Weldwood records may have not been comprehensive; Interfor (1995-2006) did not keep records; and Jeff Fisher has not provided details of all events since 1995. Never the less, over the 49 year record there have been 17 recorded events with an average of 1 every 2-3 years, but on some years there are multiple events, while the longest gap is 8-years (1997 to 2005). The 8-year gap is probably a fault of poor record keeping, so the real return period is likely 1-5 years, or very high (Table 1). The Turbid Creek channel is classified as a transport limited system (Jakob 1996), implying that debris supply is infinite and events may occur whenever climate conditions or other triggers allow. However, as with Mt. Garibaldi and other volcanoes, there are two landslide populations – smaller runoff generated and larger collapse generated.

As well as Turbid Creek, the other creeks draining the west slope of Mount Cayley may be considered debris flow prone. For example, Jakob (1996) reports that Terminal Creek has had an average debris flow recurrence interval of 1/11 per annum over the last 119 years, as deduced from historic records and dendrochronology. There is no record for Shovelnose Creek or the next creek south, but they are partially underlain by volcanic bedrock.

Climate Thresholds for Landslide Initiation

For background reference and comparison, at Mount Meager the climate triggers for volcanic landslide activity between 1975-2010 were compiled by Cordilleran (2012). During that period there were 7 landslides with known dates of occurrence. Landslides triggers were of three types: summer heatwave, late summer heat followed by rain, and fall rain. For these types the following thresholds observed:

- summer heat waves when the maximum daily temperature recorded at Pemberton airport was ≥20 ºC and the 6 day average maximum daily temperature was ≥25 ºC, or when the maximum daily temperature was ≥25ºC and the 6 day average maximum daily temperature was ≥ 20 ºC;
- late summer heat waves followed by rain when both the maximum daily temperature and the 6 day average maximum daily temperature were ≥ 20 ºC and the 24 hr rainfall was ≥ 20 mm; and
- fall rainstorms when the 24 hr rainfall was ≥ 25 mm and the 48 hr rainfall was ≥ 60 mm.

At Turbid Creek, landslides with known dates of occurrence (Table 3) happened in 1984 (2 events), 1993, 1995, 2005, 2010 and 2012 (4 events). In years with multiple events it is likely that the first event of the season provided ample sediment to the channel which then was progressively flushed by subsequent rain events. This observation points to the importance of post landslide assessment by a qualified professional to clear work site as safe, and ongoing weather monitoring during construction.

There are a number of climate stations in the vicinity of Turbid Creek. Readily available data comes from Environment Canada stations at Upper Squamish (1047672), Squamish Auto (at the airport- 71207) and Whistler (1048898) and the BC Hydro Upper Cheakamus station in Callaghan Valley. Rainfall often occurs in localised cells, especially in summer, so no single station can be representative of conditions at Mount Cayley. Moreover, there is a strong precipitation gradient as one moves inland, and this is reflected in the reduced mean annual precipitation between Squamish Auto (2200 mm) and Whistler (1230 mm). Since runoff integrates local rainfall, daily streamflow records for Elaho River near the mouth (08GA071) and Cheakamus River above Millar Creek (08GA072) were compiled to augment the climate data. Both the Upper Squamish and BCH stations are now discontinued, so only the Squamish Auto and Whistler stations are available for future reference.

Data compiled for assessment of climate triggers included maximum daily temperature and daily rainfall. A 5-day mean was calculated from maximum daily temperature, while 48 hour and 1-week antecedent precipitation was computed from the daily rainfall. The results are presented in Table 4. The results indicate that events in 1995 and 2010 were driven by heat (max daily T, 23-28 ^{0}C; 5-day mean of max daily T, 22-28 ^{0}C); in 1993 and 2005 events were caused by moderate rain (discounting Whistler: 24 hr, 16-38 mm; 48 hr, 33-38 mm); while 1984 and 2012 were caused by heavy rain (discounting Whistler: 24 hr, 30-75 mm; 48 hr, 57-165 mm).

Table 4. Climate data for landslides at Turbid Creek with known dates of occurrence. The only functioning and complete records are from Whistler and Squamish Auto.

	Temp (°C)		Precip (mm)			Temp (°C)		Precip (mm)		
Date	Daily max	5 day mean	24 hr	48 hr	1 wk	Daily max	5 day mean	24 hr	48 hr	1 wk
y-m-d	Upper Squamish (1047672)					Squamish Auto (71207)				
84-06-28	14	19	32	62	77	14	19	30	57	73
84-10-08	16	15	51	165	215	15	15	37	138	201
93-07-29	..	..	..	..	..	17	21	17	33	34
95-08-04	..	..	..	..	..	28	25	0	0	0
05-07-08	20	19	16	32	69	20	20	33	33	74
10-08-06	..	..	..	..	..	25	27	1	1	2
12-10-14	..	..	..	..	..	15	14	75	104	104
12-11-04	..	..	..	..	..	15	12	30	64	146
	Whistler (1048898)					BCH – Upper Cheakamus				
84-06-28	13	17	25	43	54	10	14	41	71	89
84-10-08	13	13	31	92	114	11	10	51	150	185
93-07-29	13	20	6	20	27	9	17	20	33	33
95-08-04	28	26	0	0	0	23	22	0	0	5
05-07-08	16	18	7	17	46	12	14	38	38	80
10-08-06	27	28	1	1	6	..	..	..	..	..
12-10-14	12	13	27	51	58	..	..	..	..	..
12-11-04	11	8	25	67	174	..	..	..	..	..

The charts below show the 3-week antecent conditions for a heat triggered landslide (August 6, 2010; Figure 4) and a rain triggered landslide (June 28 1984; Figure 5). Note that in Figure 4 it is evident that conditions that triggered the slide were exceeded in the previous 3-weeks without a landslide occuring.

Since there is no glacier within the Turbid Creek watershed it may be questioned why a heat wave could trigger a landslide. Firstly, there is a large icefield on the north side of the mountain, and secondly the rock is porous being made of of pyroclastics, lava flows and interbeds of till and colluvium. Thus, it is likely that ice melt on the glacier contributes to phreatic water, and a heat wave may result in high phreatic pore water pressures and seepage flow on the south side of the mountain.

As noted above, landslides are not automatically triggered whenever threshold conditions are met. Due to the incompleteness of the landslide record, and the lack of local climate data it is not feasible to assign probabilities of occurrence for landslides at Turbid Creek given these conditions. It is judged that these conditions establish the lower bound for landslide occurrence: below the threshold the landslide hazard is low, while above the landslide hazard is moderate or better.

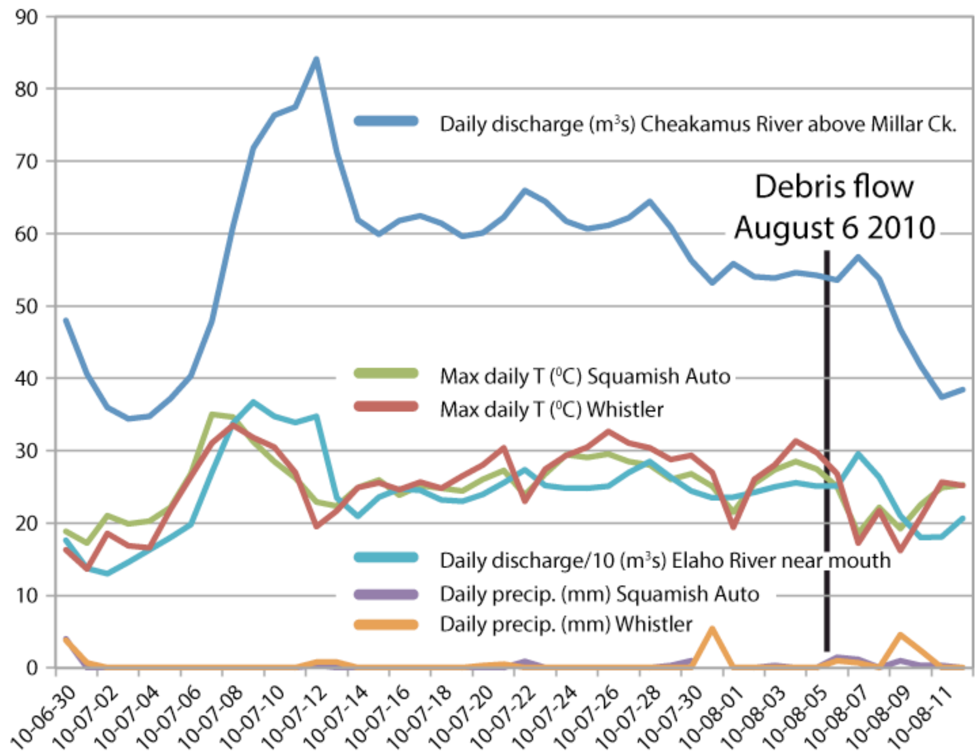

Figure 4. August 6, 2010 landslide – heat triggered. Climate and river flow data for 3-week period preceding landslide activity.

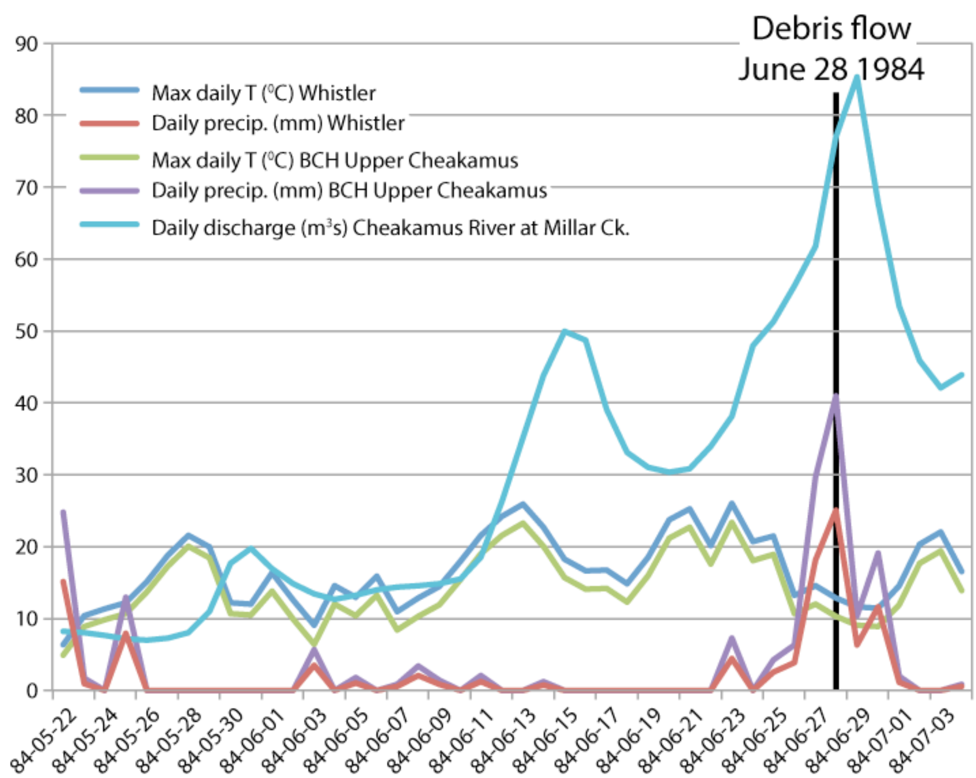

Figure 5. June 28 1984 landslide – rain triggered. Climate and river flow data for 3-week period preceding landslide activity.

Existing Rainfall and Landslide Warning Criteria

Environment Canada

Environment Canada issues rainfall warnings when the 24hr rainfall is forecast to be ≥50mm and the 48hr rainfall ≥75mm (http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=D9553AB5-1#rainfall).

Chinook Business area

BCTS (2010) uses the criteria in Table 5 to determine wet weather safety shutdowns. The system includes work sheets for estimating snowmelt contributions. (http://www.for.gov.bc.ca/ftp/tch/external/!publish/EMS2/Supplements/Wet_Weather_Shutdown_Guidelines.pdf)

Table 5. BCTS wet weather safety shutdown guidelines (rainfall and snowmelt).

Zone	Shift end	24 hour	48 hour	72 hour
Very wet	50 mm	100 mm	150 mm	200 mm
Wet	45 mm	80 mm	130 mm	170 mm
Drier	30 mm	50 mm	80 mm	110 mm
Ustable road conditions upslope	10 mm	20 mm	30 mm	40 mm

The Mount Cayley area is in the CWH drier zone where 50 mm/24 hr and 80 mm/48 hr thresholds would be recommended for operational shutdown for normal (non-volcanic) operating areas. The slopes of Mount Cayley are considered unstable and the "unstable conditions upslope" are not unreasonable for work directly exposed to volcanic hazards.

Meager Creek Hotsprings

Baumann and EBA (1999) established the following climate criteria for closure of Meager Creek valley to recreational users:

- Average 6 day mean maximum daily temperature ≥25°C;
- 24 hour rainfall (actual or forecast) of 20mm/24 hour, in conjunction with 2 to 5 days of temperatures averaging ≥25°C.
- 24 hour rainfall ≥70mm/24 hour.

Lillooet River valley
Cordilleran (2012) provided a graduated warning system for an operational safety plan for volcanic hazards affecting Lillooet River Valley, as outlined in Table 6 below:

Table 6. Hazard levels for landslide activity at Mount Meager, after Cordilleran (2012). Note that a sustained summer drought will prime the system for a rainfall induced event.

	Max. daily temp. (ºC)		Rainfall (mm)	
Hazard Level	Daily max.	6 day av.	24 hr	48hr
Low	<25	..	..	..
Low	<20	<20	<20	<50
Moderate	≥25	..	..	..
Moderate	≥20	≥25	..	..
Moderate	..	..	≥20	≥50
Moderate	≥20	≥20	≥10	..
High	≥30	..	..	..
High	≥25	≥30	..	..
High	..	..	≥50	≥75
High	≥25	≥25	≥20	..
Extreme	≥35	..	..	..
Extreme	..	..	≥70	≥100

Existing Operational Safety Plans

The APEGBC & ABCFP (2008), Guidelines for Management of Terrain Stability in the Forest Sector encourages land users to develop terrain stability models to manage landslide risk affecting the environment and human safety.

Presently MoFLNRO nor industrial users operate under a safety plan for traversing/working in the vicinity of Mount Cayley. Aside from standard rainfall shutdown procedures (e.g., BCTS 2010), there is no alert/warning system, no protocol governing activities during high alert/warning, and no safety protocol for emergency repair works. Reporting of landslide events to MoFLNRO is simply linked to cost recovery for expenses incurred during reconstruction. No landslide record is kept, event records are archived with financial records (Jeff Fisher, pers. com.) and there is no simple recovery system.

Reconstruction following the 2012 events was described November 28, 2012 in an email from Jeff Fisher to Dave Southam. The first event occurred Oct 14 at about 9 am and filled the sump, plugged the tank-car culvert and destroyed the road. Emergency repair lasted till Oct 21 exposing one D-8 cat, one excavator and one rock truck for 7 days. The first few days were wet, with high creek levels, causing elevated hazard: a second event occurred Oct 19 at 3 am and a third Oct 21 at 6 am. Luckily, despite extended exposure during a high hazard period (e.g., high creek levels), no workers were affected. There was another event November 4 that destroyed the just-repaired crossing. Reconstruction lasted till Nov 16, exposing an excavator, a D-8 cat and a rock truck for 13 days. Jeff

Fisher has not related what safety protocol were applied during the reconstruction work; MoFLNRO has no formal safety policy.
An example of a site specific operational safety plan for use at a specific crossing affected by a volcanic hazards is Cordilleran (2010a). Capricorn Creek was washed out in 1998 and 2009. In June/July 2010, Squamish Mills was reconstructing the crossing at Capricorn Creek to access Meager Valley for proposed logging. The OSP for work at the crossing site included tailored warning criteria, a graduated alert system, and various vigilance and closure levels (evacuate site/valley). Shutdown/evacuate valley response was in effect between July 24 to Aug 1 and operations ceased through the long weekend (July 30 to Aug 1). From Aug 2 to Aug 8 the alert decreased to "work with posted watchers, known/practiced escape routes and radio comunication between watchers and operators". During this time crews monitored the alert level, and were considering start-up under high vigilance when the Capricorn landslide occurred Aug 6, 2010 (Guthrie et al 2012).

When the Aug 6 2010 Capricoprn Creek landslide occurred, search and rescue entered the hazard area and began searching without having the site cleared as safe by a qualified professional. It is my understanding that post landslide assessments to characterise an event and potential residual hazards is not standard practice, but may occasionally be undertaken by a licensee or government agency. An example is a report by Cordilleran (2005) for Interfor documenting the July 2005 Turbid Creek event and providing risk mitigation measures for the reconstruction phase. This report is on file with the author, otherwise the record would be lost.

A post event landslide report was prepared for the Aug 6 2010 Capricorn Creek event (Cordilleran 2010b). That report was intended as a ministerial briefing document. A formal landslide recording system would be valuable for data to contribute to a warning system.

Landslide Risk Management

The following is a discussion of objectives and potential measures that could be applied to manage landslide risk at Mt Cayley. Specific strategies are not recommended because Cordilleran is not party to management considerations, such as relationship between the regulator (MoFLNRO) and licencees (Squamish Forestry, BCTS). MoFLNRO may use or direct licencees to comply with some or all of these strategies. Remember that landslide warning systems are inexact and fallible when based on so little available data (see Marquis 2001). Application of risk management measures reduces risk but does not gaurantee safety.

Guidance Documents

When working in areas potentially affected by Mt Cayley, industrial users should be required to operate under a "natural hazards operational safety plan" prepared and signed off by a qualified professional, consistent with the guidelines set out by APEGBC & ABCFP (2008) and WorksafeBC regulations.

Risk Management Plan Objectives
- Promote awareness and human safety.
- Any operational safety plan should be simple, practicable and credible to the general public and industrial users.

To function properly, access restrictions have to be respected by user groups. If the Squamish River FSR is closed too often, the public and industrial users will likely ignore the closures.

Authority
It is understood that under existing legislation, the MoFLNRO District Manager, or his designated officials have the authority to close FSR roads. Among other things, access may be restricted for the following reasons:
- Landslide hazard (debris flows, rock avalanches, etc.) is elevated due to hot weather, rainfall or both;

Climate Monitoring & Forecasting
Although developed for Lillooet River valley volcanic hazards, the hazard levels presented in Table 6 appear to be reasonable for application to Turbid Creek at Mount Cayley. This provides regional consistency. Forecasts for Turbid Creek should be monitored based on Squamish Auto, Whistler and any nearby MoFLNRO stations that may be operable at the time. Squamish Auto, or the nearest onsite station should be taken as representative for monitoring purposes.

Landslide Risk Management Measures
Landslide risk management may include some or all of the following measures:
- Climate monitoring and implementation of hazard warning system (Table 6);
- Signage at key locations (before Shovelnose Creek at 32.5 Mile and after Terminal Creek at 36.5 Mile) warning of the volcanic landslide hazard zone;
- Posting hazard levels on signs at key locations, on websites & radio, and in print media during periods of elevated hazard (Moderate and greater, Table 6);
- No stopping in the hazard area during periods of elevated hazard (Moderate and greater, Table 6);
- If work in the hazard area is required (e.g., emergency response), conduct work only when hazard is less than High (Table 6). If working under Moderate hazard, use dedicated vigilance personal in contact by radio with operators. Vigilance personal are to watch streamflow volume and colour and listen for landslide rumbling, and to alert operators if an event is detected. Once detected, evacuation time must be on the order of seconds, not minutes. Escape routes must be well-defined, free and clear and accessible to operators at all times.
- Controlling access at key locations (Terminal/Shovelnose creeks) during periods of High or Extreme hazard (Table 6).
- Traversing/working in the affected area (between FSR stations 32.5 Mile to 36.5 Mile) may resume once hazard levels have fallen below high and visible conditions (e.g., stream flow, colour) indicate no iminent events.

Post Landslide Crossing Maintenance/Reconstruction

- A post landslide channel assessment (e.g., Cordilleran 2005) should be conducted to ascertain the location of the landslide initiation zone and whether there are signs of residual instability (tension cracks, etc) and/or excess volumes of debris stored along the channel and threatening the reconstruction work area.
- Post-landslide crossing maintenance/reconstruction should not proceed as long as hazard levels remain High (Table 6).
- Post-landslide crossing maintenance/reconstruction should not proceed until the work site has been deemed safe by a qualified professional.

Landslide Recording System

- Post-landslide channel and residual risk assessments should be archived in a specific file created for this purpose. In future, data could be analysed to improve operation safety planning.

References

APEGBC & ABCFP, 2008. Guidelines for Management of Terrain Stability in the Forest Sector. APEGBC, Burnaby, BC.

Baumann, F.W., Friele, P.A. and Jakob, M. 1999. Meager Creek geologic hazards assessment and risk management. For B.C. Ministry of Forests, Squamish Forest District.

Brooks, G.R. & Hickin, E.J. 1991. Debris avalanche impoundments of Squamish River, Mount Cayley area, southwestern British Columbia. Canadian Journal of Earth Sciences, 28: 1375-1385.

Brooks, G.R. & Hickin, E.J., 1995. The origin of a tephra-like bed near Mount Cayley volcano, southwestern British Columbia, Canada. Canadian Journal of Earth Sciences, 32: 2040-2045.

Clague, J.J., and Souther, J.G. 1982. The Dusty Creek landslide on Mount Cayley, British Columbia. Canadian Journal of Earth Sciences, 19: 524-539.

Cordilleran Geoscience 2005. July 8 2005 debris torrent on Mud Creek, 33.5 Mile Squamish River, near Squamish. Report for International Forest Products.

Cordilleran Geoscience 2010a. The August 6, 2010 Capricorn Creek Landslide, Meager Creek valley, southwestern British Columbia: Description, emergency response, infrastructure damage and future hazards. For BC Ministry of Environment, Victoria, BC.

Cordilleran Geoscience 2010b. Operational Shutdown Criteria, Capricorn Creek crossing reconstruction. Report to Stirling Angus, RPF, JCH Forestry Ltd., Squamish, BC.

Cordilleran Geoscience 2012. Volcanic Landslide Risk Management, Lillooet River Valley, BC: Start of north and south FSRs to Meager Confluence, Meager Creek and Upper Lillooet River. Report to Squamish District. Ministry of Forests, Lands and Natural Resource Operations

Cruden, D.M.; and Lu, Z-Y., 1992. The rockslide and debris flow from Mount Cayley, B.C., in June 1984. Canadian Geotechnical Journal, 29(4): 614-626.

Evans, S.G., and Brooks, G.R. 1991. Prehistoric debris avalanches from Mount Cayley volcano, British Columbia. Canadian Journal of Earth Sciences, 28: 1365 – 1374.

Evans, S.G. and Savigny, K.W. 1994. Landslides in the Vancouver-Fraser Valley-Whistler region; in Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia. (eds) J.W.H. Monger; Geological Survey of Canada, Bulletin 481, p251-286.
Jakob, M., 1996. Morphometric and Geotechnical Controls of Debris Flow Frequency and Magnitude in Southwestern British Columbia. UBC, PhD Thesis.
Jakob, M., 2005. A size classification for debris flows. Engineering Geology, 79: 151-161.
Jakob, M., and Friele, P.A., 2009. Frequency and magnitude of debris flows on Cheekye River, British Columbia. Geomorphology, 114: 382–395.
Jordan, P., 1994. Debris Flows in the Southern Coast Mountains, British Columbia: Dynamic Behaviour and Physical Properties. UBC, PhD Thesis.
Marquis, P., 2001. How Practical are Precipitation Shutdown Guidelines? Streamline, 5(4):13-16.
Transport Canada, 2011- http://www.tc.gc.ca/eng/roadsafety/tp-tp3322-2007-1039.htm#t12
Wise, M.P., G.D. Moore, and D.F. VanDine (editors). 2004. Landslide risk case studies in forest development, planning and operation. BC Ministry of Forests, Research Branch, Victoria, BC. Land Management Handbook Number 56.

Closure

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If you questions please call.

Sincerely,

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