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Re: Snow avalanche assessment of Cedar Boulevard landslide area, Sunshine Valley, B.C.

This is an assessment of potential snow avalanche issues at the site of a recent (May 26, 2011) debris slide that occurred on a steep slope above several houses located on Cedar Boulevard in the community of Sunshine Valley, which is about 18.5 km southeast of Hope, B.C.

Figure 1: view southwest showing the debris slide and homes along Cedar Boulevard. The Hope Princeton Highway is just visible at lower right. (Golder Associates photo, May 30, 2011).

The objectives of this assessment are to:

1. describe and quantify snow avalanche risk at this site with regard to roads, inhabited structures, and other infrastructure.

2. provide recommendations with regard to how the snow avalanche risk can be managed.

3. provide additional comments with regard to terrain and slope hazard issues that were noted during the field assessment.

With regard to this matter, the following comments are made:

1. The area of interest is located in a broad, U-shaped glacial valley, 2.7 km east of the Hope landslide, and the broad pass that marks the watershed boundary between the west-flowing Nicolum River, and the east-flowing Sumallo River.

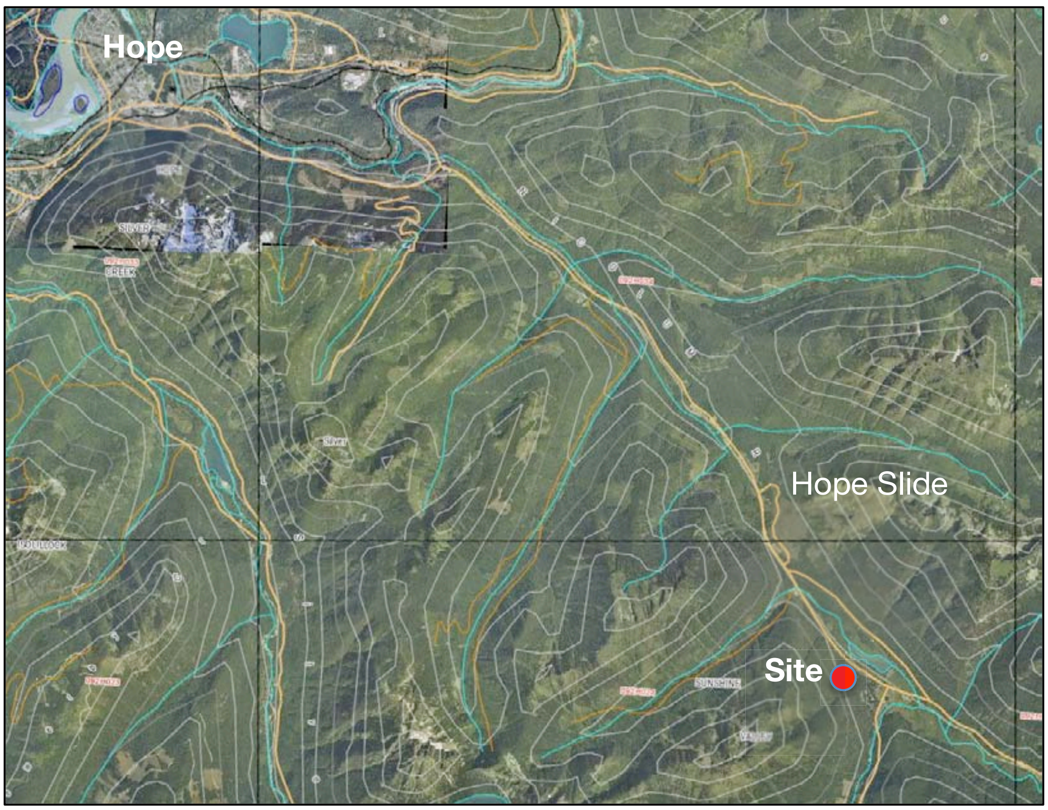

Figure 2: Overview map showing the site location in the Sumallo River valley (red dot; 18.5 km southeast of Hope, B.C.), and the general topography.

2. Cornelius Amelunxen (Canadian Avalanche Association Level III avalanche professional and a Full Guide with the Association of Canadian Mountain Guides) and Frank W Baumann, P.Eng. carried out a field assessment on Wednesday, June 8, 2011. The weather was cool and cloudy, but visibility and site conditions were good. The field assessment consisted of viewing the affected properties at the base of the slope, and then traversing the entire perimeter of the slide and taking measurements and recording observations at strategic points along the way.

3. The overall hillside at issue in this analysis is a relatively steep (27-32°), northeast-facing slope covered with old growth forest. Some of the trees, especially in the vicinity of the debris slide, are much older than others, possibly due to varying amounts of hillslope runoff and also the effects of past forest fires. The overall hillside rises from the valley floor at about 700 metres to near timberline at about 1600 metres elevation; however, the base of the slope is much steeper- about 38° on average; and locally, even steeper.

Figure 2: Google Earth image of the slide area at Sunshine Valley. The Hope Princeton Highway 3 is at the top of the photograph. The slide is about 225 metres long (slope distance) and varies from 16 m wide at the top, 35 m mid-slope, and 60 m at the bottom.

4. The top of the slide is located at decimal latitude/longitude 49.27908, -121.24644 and at approximately 840 metres elevation. The slide descended a vertical distance of 141 metres, over a horizontal distance of 177 metres (average 38.5° overall slope), and therefore was about 225 metres long (slope distance). The total slope area of the event is about 6500 m^2, and the original slide was about a metre deep on average, so involved a total of about 6500 m^3 of debris. In addition to debris, a large number of old growth trees were also removed during the event.

5. The debris slide removed most of the surficial and organic material down to an undulating bedrock surface, which consists of a relatively uniform and competent phyllite (metamorphic rock), which has foliation that generally dips into the slope at a shallow angle. The bedrock forms a smooth surface, which would not provide much anchorage for overlying snow; the surface roughness depth, or depth of snow at which snow avalanches could occur, would be less than 10 cm.

6. In order to assess the potential size of snow avalanches that might occur at this site now that the trees have been removed, an analysis of snow survey data was completed in order to establish the maximum depth of snow that would be expected at this site. In order to do this, data from manual snow survey station 3D01C, located at an elevation of 801 metres, and only about 3 km southwest of the study site, and from the Spuzzum Creek automated snow pillow station, 1D19P, located about 52 km northwest of the site, was used.

7. Station 3D01C is a snow survey station where manual measurements of snow depth and density are carried out at fixed times of the year; usually, on the first day of the month from February until June. In this case, about 18 to 20 years of data are available and indicate that the snowpack reaches its maximum depth between March 1 and April 1. In order to estimate the expected snow depth at various return periods, a Gumbel extreme value analysis of the 20 years of March 1 snow depth data was completed; the table below presents the results of this analysis.

Return Period (years)	Expected Value Snow depth cm
2	58
5	89
10	110
25	136
30	142
50	156
100	175
150	187
200	195
300	206
400	214
500	220

Table 1: Gumbel Extreme Value analysis of March 1 snow depth data for station 3D01C.

8. However, this information is based on data collected on March 1, which, according to nearby snow survey pillow data, does not represent the maximum snow depth that should be expected in any given year. In order to better estimate the maximum depth of snow that might be expected, data from snow pillow station 1D19P was used to provide a correction to the data from the manual snow survey station.

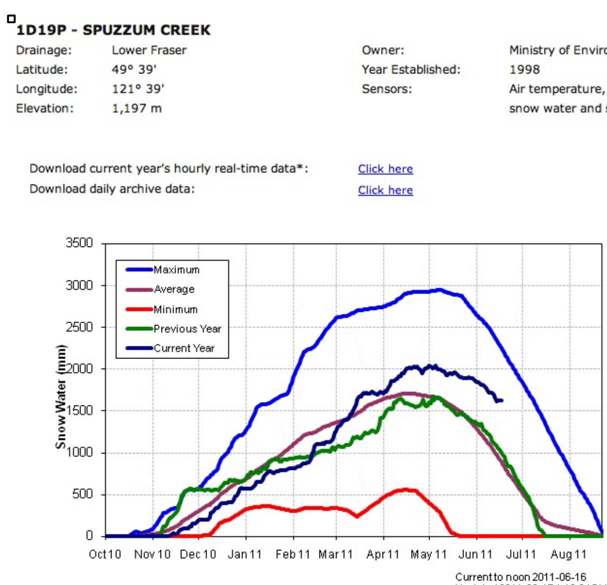

Figure 3: Snow pillow data from station 1D19P.

9. At Spuzzum Creek, the data suggests that, on average, the maximum snow depth is about 33% higher than as recorded on March 1. However, since station 1D19P is 400 metres higher in elevation, the snowpack peaks out in mid-April, several weeks later than would be expected at station 3D01C. Although it is difficult to accurately establish how much more snow would be expected to be present after March 1 when the snowpack peaks at station 3D01C, it is likely that values would be at least 25% higher than are reported in Table 1 above. If this correction is applied to data in Table 1, the maximum expected snow depths for various return periods at Sunshine Valley would be as follows:

Return Period (years)	Expected Value Snow depth cm	Adjusted Value Snow depth cm
2	58	72
5	89	112
10	110	138
25	136	171
30	142	177
50	156	195
100	175	219
150	187	233
200	195	243
300	206	257
400	214	267
500	220	275

Table 2: Adjusted maximum snow depths at Sunshine Valley for given return periods.

10. An Environment Canada weather station (1113581) is located at Hope Slide, about 3 km west of the study area, and has climate normal data that indicates that the maximum extreme snow depth over the 25 year period from 1971 to 2000 was about 164 cm. This depth would be generally consistent with the estimated 171 cm value given above.

11. There are no mandated standards for avalanche hazard acceptability in Canada; however, in the Guidelines for Snow Avalanche Risk Determination and Mapping in Canada (2002), the Canadian Avalanche Association recommends that a 300 year return period be used for snow avalanche hazard involving inhabited structures, and that a 100 year return period be used for snow avalanche hazard that affects highways. If these values are used, then according to Table 2, a 257 cm maximum snow depth should be used to define the hazard acceptability threshold for inhabited structures, and a 219 cm maximum snow depth should be used for potential impacts on Highway 3.

12. In 1993, Dr. Peter Cave, the then Building Inspector for the old Fraser Cheam Regional District (now the Fraser Valley Regional District) devised a set of risk matrices meant to guide the approvals process for proposed developments. For avalanche hazard, Dr. Cave proposed the following risk matrix:

Development	**Snow Avalanche Hazard**				
	1:30	1:30 to 1:100	1:100 to 1:500	1:500 to 1:10,000	<1:10,000
Minor Repair (< 25%)	5	4	4	4	1
Major Repair (> 25%)	5	4	4	4	1
Reconstruction	5	4	4	4	1
Extension	5	4	4	4	1
New Building	5	4	4	4	1
Subdivision (infill/extend)	5	5	5	4	1
Rezoning (for new community)	5	5	5	5	1

No.	**HAZARD-RELATED RESPONSES TO DEVELOPMENT APPROVAL APPLICATION**
1	Approval without condition relating to hazards.
2	Approval without siting conditions or protective works conditions, but with a covenant including “save harmless” conditions.
3	Approval, but with siting requirements to avoid the hazard, or with requirements for protective works to mitigate the hazard.
4	Approval, but with a covenant, including “save harmless” conditions as well as siting conditions, protective works, or both.
5	Not approvable

Table 3: Matrix that relates development approval to the scale of development and hazard.

According to this matrix, virtually any activity at this site that would trigger the need for a building permit would require snow avalanche activity to be mitigated using a combination of siting conditions and protective works, or both.

13. The potential avalanche slidepath at the study site was measured to be 225 metres long (slope distance) from the initiation point to the base of the slope, and was found to have a total area of about 6500 m^2. Using the above maximum depth values, the total amount of snow that could potentially accumulate on this slope would be about 14,200 m^3 for a 100 year return period, and 16,700 m^3 for a 300 year return period.

14. When considering potential avalanche release, one must consider the size and angle of the avalanche starting zone, and also the configuration of any particularly steep or unusual masses of snow within the starting zone where an avalanche is more likely to start (the so-called trigger point or zones). In this case, the starting zone was found to be 23 metres long, 16 metres wide, and therefore could have up to about 1000 m^3 of snow resting on a 38° slope. The starting zone is relatively uniform, so no discrete trigger points are present; however, since the slopes below the starting zone are relatively steep, an avalanche that started at the top of the slope is likely to mobilize or entrain all of the snow present on the slope below.

15. Avalanche occurrence is directly related to slope angle. According to Tremper (2001), the following relationship applies:

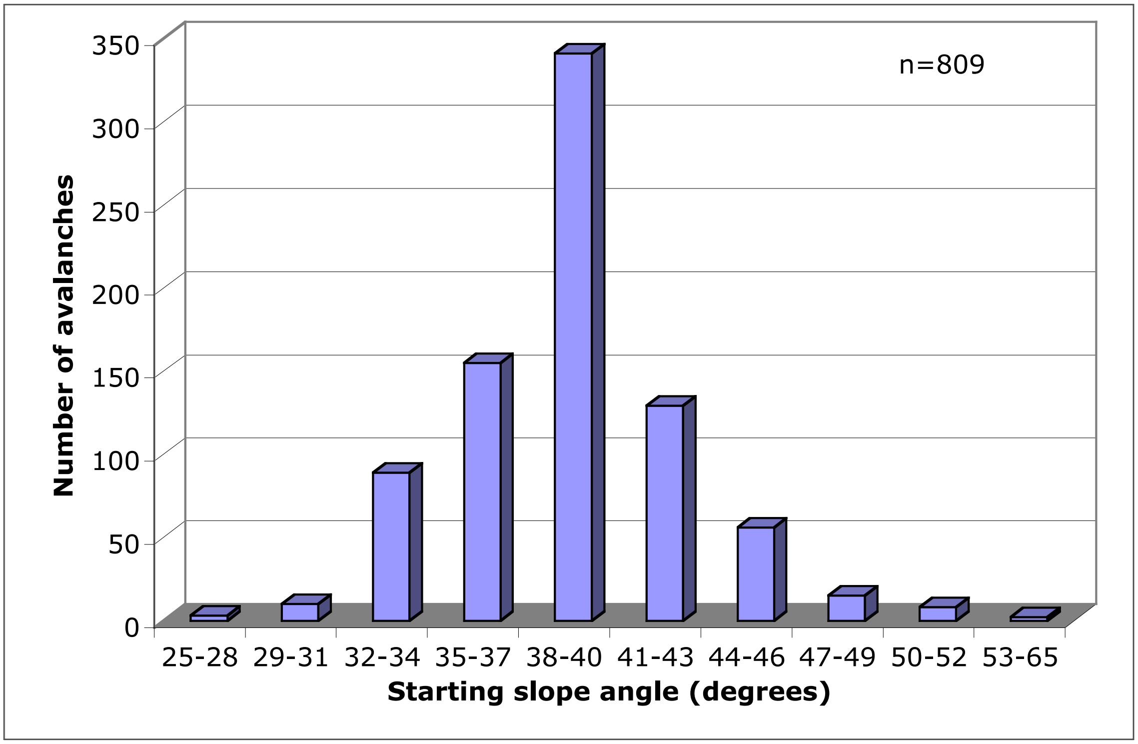

Figure 4: Frequency of avalanche occurrence relative to slope angle.

The graph indicates that avalanches are most likely to start on slopes of between 38 and 40°; on steeper slopes, snow tends to slough off as it accumulates, and on lower angled slopes, there is less of a vector force component down the slope to initiate a release. As noted above, in this case, the starting zone has a 38° slope angle, and therefore has the highest probability of initiating an avalanche.

16. Typical snow densities range from less than 100 kg/m^3 for light powder snow to a maximum of about 700 kg/m^3 for rain-saturated snow. Since the study site is located near the Coast, where wet snow is more common, a maximum density of about 600 kg/m^3 can be used for planning purposes. If these densities are applied to the volume calculations given above, the maximum avalanche snow mass that could be expected to fall in this area is about 8,500 tonnes for a 100 year return period, and 10,000 tonnes for a 300 year return period.

17. Avalanche size in Canada is described as per the attributes given in the following table:

Size	Description	Typical Mass	Typical Path Length	Typical Impact Pressures
1	Relatively harmless to people.	<10 tonnes	10 m	1 kPa
2	Could bury, injure or kill a person.	10^2 tonnes	100 m	10 kPa
3	Could bury a car, destroy a small building, or break a few trees.	10^3 tonnes	1000 m	100 kPa
4	Could destroy a large truck, several buildings, or a forest with an area up to 4 hectares.	10^4 tonnes	2000 m	500 kPa
5	Largest snow avalanches known. Could destroy a village or a 40 ha forest.	10^5 tonnes	3000 m	1000 kPa

Table 3: Canadian Snow Avalanche Size Classification (Weir, 2002).

Based on snow mass, the table indicates that up to Size 4 avalanches could be generated at this site. Although the slide path is not as long as suggested in this table, and therefore the impact pressures would likely be less than indicated, the sheer mass of avalanche snow that could be released could easily crush a building.

18. Although a detailed analysis of avalanche runout is beyond the scope of this report, it nevertheless is apparent that any houses located at the base of the slope would be destroyed if a full depth avalanche occurred. Since the surface roughness depth is very low (10 cm), and the underlying rock surface relatively smooth, the probability of a full depth release in any given season would be high; that is, very likely to occur. If the avalanche deposits at the base of the slope are assumed to form a half-cone, then the volume of the half cone would be: $Volume = \frac{1}{6} \times \pi \times r^2 \times h$ where r is the radius of the cone, and h is the height of the cone. If a 30° angle is assumed for the slope of the cone, then the height, h = r x tan 30, or r x 0.58 and the formula for the volume of the half-cone can be re-written as $Volume = \frac{1}{6} \times \pi \times r^3 \times 0.58$. Since the volume is known for a 100 year return period (14,200 m^3), the formula can now be re-written to find the radius of the cone: radius = $\sqrt[3]{10.3 \times V/\pi}$ or radius = $\sqrt[3]{3.29 \times V}$ = $\sqrt[3]{3.29 \times V}$ = 36 metres.

This suggests that a full depth, slow moving wet snow avalanche with a 100 year return period is likely to create a cone-shaped deposit of snow that would extend at least 36 metres beyond the base of the slope. By comparison, the edge of Cedar Boulevard is about 40 metres from the base of the slope and the edge of Highway 3 is about 60 metres from the base of the slope. Note that this calculation assumes that there is no excess travel of snow beyond the base of the deposition zone- this would be the case for a slow-moving, wet snow avalanche.

19. Maximum runout can also be estimated by measuring the runout angle, or the angle between the top of the starting zone and the object in harm's way. In this case, the runout angle to the edge of Highway 3 is about 30°. According to Weir (2002), the British Columbia Ministry of Highways assumes that avalanche slidepaths with more than a 25° runout angle to the edge of a road could potentially reach the highway at unacceptable frequencies.

20. Finally, runout can also be estimated using the Norwegian Geotechnical Institute (NGI) method. This is done by first establishing where the so-called beta point is located; or the point on a slidepath where the slope angle drops to less than 10°, and then measuring the horizontal distance from the beta point to the top of the starting zone. McClung (1989) found that in the Coast Range mountains, the ratio between the horizontal distance from the beta point to the top of the starting zone and the horizontal distance from the beta point out to the edge of the deposit is about 0.159 for mean runout, and 0.56 for maximum runout. At Sunshine Valley, the beta point is located at the base of the slope, and the horizontal distance from the beta point to the top of the starting zone is about 177 metres, so the distance from the base of the slope out to the maximum limit of snow deposition is predicted to be 177 m x 0.56 or 99 metres. The mean runout would be 177 m x 0.159 or 28 metres.

Conclusions

1. The May 26, 2011 debris slide that impacted houses at 15191, 15201, 15211 and 15221 Cedar Boulevard in the Sunshine Valley Community, 18.5 km southeast of Hope, B.C. removed most of the trees that would anchor snow on this slope, and exposed a relatively smooth and steep bedrock surface, which therefore has created a new snow avalanche slidepath.

2. Based on nearby snow survey data, this new 6500 m^2 slidepath resting on a 38.5° slope could generate avalanches that might have volumes of up to 14,200 m^3 at return periods of 100 years, and up to 16,700 m^3 at return periods of 300 years. If a maximum snow density of 600 kg/m^3 is used, these avalanches could involve 8,500 tonnes of snow at a 100 year return period, and 10,000 tonnes of snow at a 300 year return period.

3. Since the mass of snow that could be triggered on this slope at return periods of 300 years, is up to about 10,000 tonnes, a Size 3-4 avalanche (on a scale of up to 5) could occur. Such an event would destroy a building, and likely kill anyone caught in its path.

4. Although there are no legislated hazard acceptability standards for avalanches, there is a well-established precedent for adopting a 300 year return period for inhabited structures, and a 100 year return period for impacts on highways.

5. Avalanches generated on this slope could flow out to at least 36 metres beyond the base of the slope, and possibly even go as far as Highway 3, which is 60 metres from the base of the slope.

6. The cul de sac turnaround area at the west end of Cedar Boulevard would be threatened by avalanches, especially if the houses and debris present there were removed. This poses a risk to the travelling public, and especially to snow plow crews who would likely be working at the height of a storm, and therefore when the hazard is highest.

7. The powerline along Cedar Boulevard may be exposed to snow avalanche hazard, and may need to be relocated farther north, or the towers may need to be protected.

8. Avalanche fencing or other snow retaining structures, mid-slope benches, or earthworks could be used to reduce the avalanche hazard at this location- but the costs are likely to be prohibitive. The design of such structures is beyond the scope of this report, and would require additional assessment and detailed design work.

Recommendations:

1. Since there is a high likelihood that destructive avalanches will occur on this slope at return periods that, according to the Canadian Avalanche Association and other expert advisors, would be considered unacceptable, no new houses should be built at the base of the slope below the area that slid on May 25, 2011 unless protective works or retention structures are first installed.

2. Existing houses below the debris slide should not be occupied during periods of the year when there is a possibility of snow avalanche activity. Generally, this would be from late November until the middle of May, or when there is more than about a half metre of snow present on the ground.

3. As per current WorkSafe BC regulations, an avalanche safety management plan should be prepared to ensure that highway and subdivision workers are adequately protected from the threat of snow avalanche activity when working in this area.

4. The cul de sac at the end of Cedar Boulevard should either be moved to a safer location farther to the east, or should be marked with avalanche danger signs, and closed off when there is more than about a half metre of snow on the slopes above.

5. The powerline located on Cedar Boulevard should ideally be moved farther north, or the poles should be protected from impact by installing a protective or deflection structure on their uphill-facing side; however, the design of such structures is beyond the scope of this report.

References:

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Tremper, Bruce. 2001. Staying Alive in Avalanche Terrain. Mountaineer Books.

An Understanding:

The conclusions of this report are based on the currently available data and may need to be modified if additional information becomes available. It must be stressed that terrain analysis, hazard assessment and the evaluation of slope and hydrologic hazards is an inexact science and that any development in mountainous terrain is subject to some degree of geologic or hydrologic risk. This means that the absolute safety or stability of any proposed development cannot be guaranteed and that users of this report must accept a certain degree of risk if they carry out such development plans. If questions remain, additional specialist advice or a second opinion should be obtained.

Yours truly,

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