ASSESSMENT OF DEBRIS FLOW HAZARD AT FIVE MILE CREEK

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ABSTRACT
On August 4, 1999, a significant debris flow event occurred at Five Mile Creek near Banff, Alberta. The event is believed to have been triggered by a localized convective storm which was not captured by any of the surrounding weather stations. The paper gives a general overview of the recent work conducted to characterize the debris flow hazard at this site, focussing on a semi-quantitative assessment of the hazard level, defined as the probability of similar events happening again. Due to the limited availability of reliable data on past events, applying rigorous frequency analysis techniques was not possible, hence the probability of future occurrences was estimated from an analysis of recurrence intervals derived from historic records and geomorphic evidence.

RÉSUMÉ
Une importante coulée de débris se produisit le 4 Août 1999 au niveau du ruisseau Five Mile près de Banff en Alberta. On croit que cet évènement fut déclenché par un orage très local qui ne fut pas enregistré dans les stations météorologiques des alentours. Cet article donne une vue générale du récent travail qui a été fait dans le but de caractériser le hasard causé par la coulée de débris à cet endroit et en se concentrant sur une évaluation semi-quantitative du niveau de ce hasard. Ce hasard peut se définir comme la probabilité qui existe pour qu'un tel évènement puisse se produire à nouveau. Compte tenu de l'absence d'information de bonne qualité, sur des évènements similaires qui se seraient produits dans le passé, il n'a pas été possible d'appliquer des techniques rigoureuses d'analyse des fréquences. En conséquence la probabilité du déclenchement de futures coulées de débris a été estimée en analysant les intervalles de retour de tels évènements qui ont été derivés de données historiques et de l'évidence géomorphologique.

1. INTRODUCTION

Five Mile Creek is located on the north side of the Bow River Valley, and crosses the Trans-Canada Highway (Highway 1), 5 km west of Banff, Alberta, near the junction with Highway 1A, the Bow Valley Parkway.

Figure 1. Clearing the highway immediately after the August 1999 debris flow, (photo courtesy of Parks Canada).

A significant debris flow event occurred at this site on August 4, 1999, completely blocking the Trans-Canada Highway and cutting buried fibre-optic communications lines (Figure 1).

The event occurred at approximately 6:45pm, and covered approximately 200 m of the Trans-Canada Highway in debris that was several metres thick in places, resulting in total closure of the highway. Debris, including mud, trees and boulders several metres in diameter, plugged the highway culvert and flowed over the road, causing erosion of the shoulder above the culvert outlet. No injuries resulted from the flow, but there was substantial damage, including loss of the fibre-optic communications lines on the outside shoulder of the eastbound lanes, and loss of the pedestrian access to the Cory and Edith Pass trailheads from the Fireside day use area. Bouldery debris stopped short of the Canadian Pacific Railway mainline, though mud plugged the ditch and culvert, requiring some maintenance work.

It took approximately 20 hours to clear the two eastbound lanes so that the highway could be partially re-opened. It took approximately three weeks for the highway to be restored to normal operating conditions, requiring removal of approximately 40,000 m^3 of debris from the highway and another 15,000 m^3 from the downstream channel.

Subsequent to the 1999 debris flow event, during Spring and early Summer peak flows on Five Mile

Creek, significant quantities of granular debris have been transported and deposited in the creek channel, substantially plugging the culvert and channel downstream on each occasion. Prior to the 1999 event, clearing and maintenance of the culvert and channel was required only once every four or five years, however since the event, substantial maintenance resources have been required.

1.1 Site Description

Five Mile Creek drains southwards from the area around Cory Pass, across an alluvial-colluvial fan, and into the Bow River. The current creek channel runs along the eastern margin of the fan.

A day use picnic area and popular trailhead are located on the middle portion of the fan. The Trans-Canada Highway crosses the fan further downstream, with the Bow Valley Parkway junction on the western fan margin. The Canadian Pacific Railway mainline crosses the fan near the distal (far downstream) margin, 300 m downstream of the Trans-Canada Highway crossing.

The headwaters of Five Mile Creek are steep and rocky, with prominent snow avalanche tracks. The fan is within the Montane Forest zone of Banff National Park, and is dominated by White Spruce, with some Douglas Fir and Aspen. The watershed, as a whole, has less dense conifer growth than the watershed immediately to the east, probably due to less favourable surficial geology and more rugged terrain.

1.2 Site History

The first significant man-made structure to be built in the Five Mile Creek area was the Canadian Pacific Railway, constructed in the Bow Valley in 1883. In 1885, Rocky Mountain Park was established and it consisted of 10 square miles around the Banff Hot Springs. Prior to 1930, there were few rules and little documentation concerning industrial activity in the Park, in particular mining and logging. There were a number of sawmills in the Bow Valley, including a site leased for a sawmill in 1918 located on the Bow River at Healy Creek, directly south of Five Mile Creek. Signs of logging on Five Mile Creek alluvial fan were found during field work. In 1911, the first road link from Calgary to Banff, the Banff Coach Road, was established, and work started on the Banff-Lake Louise road. In the 1950's, a berm was built at the fan apex to divert all creek flows into the east channel.

The Trans Canada Highway was completed in 1962, and was twinned through the Banff area in 1983. The Fireside picnic area and parking were established on the fan in the late 1970's.

1.3 Climate

The Five Mile Creek watershed is situated in the Montane Ecoregion, which is the warmest and driest area within Banff National Park. Based on Environment Canada Climate Normals for 1887-1990, Banff has an average precipitation of 468 mm/year. The greatest amount of precipitation accumulates from May to August, to an average of 220 mm of mostly rainfall. Precipitation records at Banff are 24-hour totals. The maximum observed 24-hour precipitation from 1887 to 1990 was 53.6 mm, giving an average intensity of 2.2 mm/hour.

Intensities for shorter duration storms have not been recorded at Banff, but have been estimated based on comparison with records at the Marmot Creek experimental basin, 40 km SE of Banff (Parks Canada 2000). In this region, for a 10-year return period storm, estimated intensities have varied from 2.5 mm/hour for a 24-hour duration, to between 7.5 mm/hour and 20 mm/hour, depending on elevation, for a one-hour duration event (deScally 1999).

June has the highest incidence of high-intensity rainfall (greater than 25 mm in a 24-hour period), coinciding with the spring snowmelt peak, often resulting in rain-on-snow runoff events. However, there is little data on short duration, convective rainfall associated with thunderstorms. Banff averages 11 days with thunderstorm activity per year.

1.4 Geology

This portion of the Front Ranges is characterized by sedimentary rocks stacked by thrust faults. NNW-SSE trending thrust faults define the valley sides. In addition, a number of undefined faults cross the valley. Rock mapped in the immediate area of Five Mile Creek includes siltstone, mudstone, shale, massive crystalline dolomite and limestone. The rock is locally highly fractured, with bands of rapidly alternating lithologies, which is noted in the literature as making it more susceptible to weathering and disintegration (Cullum-Kenyon et al., 2003).

The surficial geology of the area around Banff is largely the result of four Pleistocene glacial advances (Rutter, 1972). The first of these advances left a thick layer of till in the Bow valley. During glacial retreat, meltwater flows cut down through till and outwash, leaving terraces along the valley margins and re-working material in the valley floor. High sediment yields from creeks along the valley sides during immediate post-glacial time have resulted in construction of numerous alluvial-colluvial fans, including the Five Mile Creek fan.

1.5 Previous Studies

Several studies have been conducted on Five Mile Creek, including work by Couture and Evans (2000) in the aftermath of the 1999 debris flow event. Additional work was performed by de Scally (1999) on alluvial fans in the Banff National Park. Cullum-Kenyon et al. (2003), reported on the debris flow hazard characterization and the development of mitigative strategies at Five Mile Creek.

2. ASSESSMENT OF DEBRIS FLOW FREQUENCY

2.1 Historic Records

Historic records of past debris flow events at Five Mile Creek are limited to two debris flow events; an event that occurred during construction for the Trans-Canada Highway twinning in 1987, and the August 1999 event. This does not necessarily mean that few events occurred, as there was limited human activity in the area prior to 1920, and collective memory for geomorphic events is generally limited to no more than 20 years.

2.2 Air Photo Interpretation

A selection of stereo air photos covering the period 1947 to 1993 was obtained from the National Air Photo Library and examined for evidence of past debris flow activity and man-made changes to the fan.

Evidence of previous debris flow events was noted on the 1947 aerial photo. As illustrated on Figure 2, both the east and west channels are active and show evidence of recent debris flow activity. The west channel is diffuse, but clearly crosses the Banff Coach Road at approximately the same location where flow currently emerges onto the access road to the Fireside day use area. The east channel is not as well defined as on later photos, and appears to run west of its current location.

Figure 2 also shows fresh evidence of flow activity crossing the highway, but debris does not appear to have reached the Canadian Pacific Railway track. There is evidence for snow remaining in the middle reaches of the channel, and there are cones of debris in the channel, and locally on snow within the channel, originating from debris/snow avalanche chutes on the valley sides.

2.3 Precipitation Records

Anecdotal evidence suggests that the August 1999 debris flow was triggered by a localized convective storm. An eyewitness, traveling eastbound on the highway, reported having to pull-off the road because of heavy rain near Castle Junction (approximately 20 km to the west). This same eyewitness reported having seen the Fireside picnic area pedestrian bridge coming down the creek channel shortly thereafter (M. McIvor, personal communication).

Convective storms are characterized by short duration and high intensity. An analysis of daily rainfall totals at the Banff weather station for the period leading up and including August, 1999 indicated that the reported heavy convective storm was not captured by the Banff station (located 10 km east of Five Mile Creek). The total daily rainfall for the first three days of August, 1999 was small, with only 1.6 millimetres recorded on August 4.

Examination of monthly total precipitation over summer months indicated that the precipitation in July, 1999 was more than twice the average recorded for the period 1887-1990. Couture and Evans (2000) point out that this would mean that unconsolidated deposits on nearby mountain slopes would have been saturated when the thunderstorm event triggered the debris flow. However, it must be noted that there are 41 summer months with precipitation more than double the average in the period of record, indicating that in this case, the one-month antecedent precipitation is not a good indicator for debris-flow triggering events.

It was not possible to establish the return period for short (less than 24 hour) duration storm events due to the absence of hourly rainfall data. Likewise, examination of the historic precipitation record did not allow identification of a consistent pattern indicative of a triggering event.

2.4 Geomorphic Evidence

Distinctive flow lobes found on the fan below the Trans-Canada Highway, several metres above the elevation of the current channel, indicate at least two past episodes of debris flow activity. In several locations, a lobe of apparently younger debris can be found deposited over lobes of much older debris. Based on field experience and the appearance of the debris, the younger material was judged to be 20 to 50 years old, whereas the age of the older debris, noted to locally flow around trees, were assessed at 60 to 70 years, based on tree-ring counts.

An attempt was also made to identify past debris flow activity through the record of stress exhibited by trees (e.g., evidence of past mechanical damage through the appearance of eccentric growth rings). Evidence obtained through this dendrochronological study was not considered to be highly reliable, primarily due to the very limited number of trees felled for the study.

2.5 Frequency Assessment

Table 1 presents a qualitative assessment of the reliability of the evidence of past debris flow events. Higher reliability is assigned to well documented evidence, and the rank assigned to each event is a qualitative indication of the total reliability of the event with respect to the 1999 event.

Table 2 summarizes the debris flow frequency derived from Table 1. The return period (or recurrence interval) is defined as the frequency with which one would expect, on average, the occurrence of an event of a given critical magnitude (e.g., similar to the August 4, 1999 Five Mile Creek event).

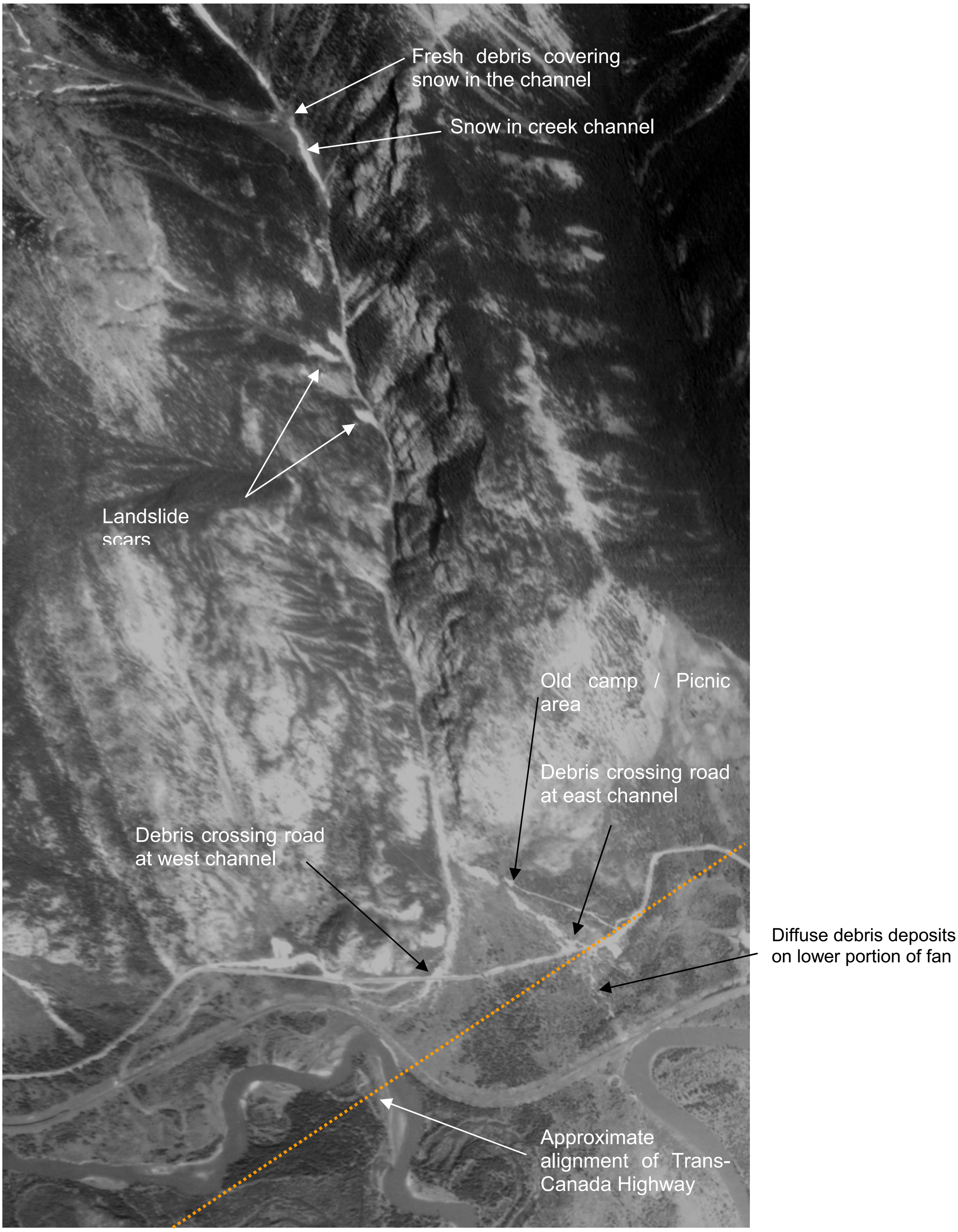

Figure 2 – 1947 Air Photo of the Five Mile Creek Area (portion of A10932 – 204 © Natural Resources Canada – National Airphoto Library)

Table 1 – Qualitative assessment of reliability of data for debris flow events

Year of Event	Records	Geomorphic	Dendrochronology	Overall
1999	High	High		High
1987	Medium	Medium		Medium
1942 – 1947	High	Medium		High
1932 – 1935			Low	Medium
1893 – 1896	↑ Banff Coach Road constructed	↑ Limit of reliability for subtle geomorphic evidence	Low	Low
1888			Low	Low
1879	↑ CPR constructed		Low	Low
1867			Low	Low

Table 2 – Summary of debris flow frequency for Medium to Large Magnitude Events

Reliability	No. of Events	Period	Return Period (yrs)
High to Medium	2 - 4	1932 - 2001	17 - 35
All events	8	1845 - 2001	20

Table 3 – Summary of potential events and anticipated magnitude

Year of Event	**Records**	**Geomorphic**	**Dendrochronology**
1999	Large	Large or Medium	-
1987	Small	Large or Medium	-
1942 – 1947	Large or Medium	Large or Medium	-
1932 – 1935	-		Unknown
1893 – 1896	↑ Banff Coach Road constructed	↑ Limit of reliability for subtle geomorphic evidence	Unknown
1888			Unknown
1879	↑ CPR constructed		Unknown
1867			Unknown

It is noted that there is some uncertainty in the correlation of events prior to 1999 from records and geomorphic evidence – in particular, it is not clear whether the younger debris lobes are the result of an event in the 1980's or an earlier event. These uncertainties are included in the assessment presented in Table 2.

It is also noted that with the exception of the August 1999 event, it has not been possible to quantitatively determine the magnitude/volume of past debris flows.

The magnitude of past events, as summarized in Table 3, was estimated qualitatively, based on comparison with the August 1999 event, assessment of air photos, geomorphic evidence, and some judgement.

3. ASSESSMENT OF PROBABILITY OF OCCURRENCE

3.1 Background

The probability of occurrence of debris flow events over a number of years can be estimated from the frequency of past events using the approach described by Morgan et al. (1992). In this approach, the individual events are assumed to be independent and the annual probability of occurrence A (or return period R) remains constant from year to year, hence the probability of X occurrences of a debris flow exceeding a certain magnitude in N years can be represented by a binomial distribution:

$$P(X) = {}_{N}C_{X}\, A^{X}\, (1 - A)^{(N-X)} \qquad [1]$$

It follows that the exceedance probability $P(X \geq 1)$, i.e. the probability that at least one significant event (e.g., medium or high magnitude in the case of Five Mile Creek) will occur over a period of N years can be expressed by :

$$P(X \geq 1) = 1 - P(X = 0) = 1 - (1 - A)^{N} \qquad [2]$$

It is also noted that the annual probability of occurrence A is the reciprocal of the return period R:

$$A = 1 / R \qquad [3]$$

An estimated return period can then be translated into estimated probability of occurrence over a specified period, using Equation 2.

3.2 Application to Five Mile Creek

Using the return periods noted in Table 2, the estimated annual probability of occurrence of a debris flow event likely to impact the Trans-Canada Highway is between 3% and 6%. Table 4 summarizes the estimated probability of occurrence of a similar or larger debris flow event for different time periods, determined using the approach described above.

Table 4 – Probability of occurrence of a debris flow similar to or larger than the 1999 event over a specified period

Period (years)	Probability
1	3% - 6%
5	15% - 25%
10	25% - 45%
20	45% - 70%
50	75% - 95%

3.3 Discussion

It is noted that this is not a rigorous analysis, but rather an estimate of probability, based on an incomplete dataset. The estimate assumes that the events are random, and that the annual probability of occurrence does not change with time.

Changes in the frequency of occurrence of debris flow events are possible in the future. Such changes might be caused by changes in the character of the creek channel or watershed (e.g., due to fire), variations in precipitation or other climate changes over time.

It is also noted that the probability for the number of events that can occur during a specified number of years can also be calculated assuming a Poisson distribution, as opposed to the binomial distribution used herein (e.g., Benjamin and Cornell, 1970; Crovelli, 2000; McClung, 1999). Crovelli (2000) noted that adopting the binomial model can overestimate the exceedance probabilities for relatively short mean return periods ('a few years'), and short periods of time. Application of both approaches to the Five Mile Creek data set produced estimates of the probability of occurrence over periods of 1 to 50 years which were identical for all practical purposes.

4. CONCLUDING REMARKS

This work was performed by Thurber Engineering for Parks Canada (Thurber, 2002). Tasks performed as part of this work in addition to those described herein included a detailed mapping of the creek channel, aimed at determining the availability of sediment supply as a pre-condition for initiation of a debris flow, and an unbiased review of various mitigative options, for consideration by Parks Canada. An assessment of the potential for further debris flows in the creek, including an estimate of the probability of future events, was required for the decision making process.

It is recognized that a natural hazard such as a debris flow is deterministic in nature, i.e. it is caused by various physical conditions and triggering mechanisms, such as availability of sediments and heavy precipitation. However, because of uncertainties regarding these natural conditions and mechanisms, probability models such as that described above are sometimes required for engineering analyses. Randomness and a fixed annual probability of occurrence are assumptions of the probability models, not of the natural events.

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6. REFERENCES

Benjamin, J.R., and Cornell, C.A., 1970. Probability, statistics and decision for civil engineers. McGraw-Hill, Inc., New York, 684 p.

Crovelli, R.A. 2000. Probability models for estimation of number and costs of landslides. U.S. Geological Survey Open-File Report 00-249.

Couture, R., and Evans, S.G. 2000. Five Mile Creek Debris Flow. Geological Survey of Canada Open File #3876.

Cullum-Kenyon, S., Heinz, H.K., Sobkowicz, J.C., VanDine, D., and Kerr, D. 2003. Debris flow hazard at Five Mile Creek, Banff, Alberta. Proceedings Geohazards '03, Edmonton, pp. 327-334

de Scally, F. 1999. Alteration and restoration of alluvial fan processes in the Lower Bow Valley, Banff National Park. Unpublished Report to Parks Canada.

McClung, D.M. 1999. The encounter probability for mountain slope hazards. Canadian Geotechnical Journal, 36: 1195-1196.

Morgan, G.C., Rawlings, G.E. and Sobkowicz, J.C. 1992. Evaluating total risk to communities from large debris flows. Proceedings, Geohazards '92, Vancouver, pp. 225 – 236.

Rutter, N.W. 1972. Geomorphology and multiple glaciation in the area of Banff, Alberta. Geological Survey of Canada Bulletin 206.

Thurber Engineering 2002. Five Mile Creek alluvial fan study, Banff National Park, Alberta. Unpublished report to Parks Canada.