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DEBRIS FLOW HAZARD AT FIVE MILE CREEK, BANFF, ALBERTA

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ABSTRACT

Five Mile Creek is located approximately 5 km west of Banff on the Trans-Canada Highway, on the north side of the Bow Valley. On August 4, 1999, a debris flow, triggered by an intense, localized convective storm, plugged the culvert carrying Five Mile Creek below the Trans-Canada Highway. Debris rapidly flowed over the highway, covering a 200 m long section with up to several metres of mud and bouldery debris. Traffic on the Trans-Canada was stopped for approximately 20 hours whilst two lanes were cleared. It took a further three weeks to restore normal service on the highway. This paper describes recent work conducted for Parks Canada to characterize the debris flow hazard on Five Mile Creek and to evaluate a range of solutions. The methodology of the investigation program is described and the results reviewed.

RÉSUMÉ

Le ruisseau Five Mile est situé le long de la route transcanadienne approximativement à 5 kilomètres à l'ouest de Banff du côté nord de la vallée de la rivière Bow. Le 4 août 1999, une coulée de débris, déclenchée par un sévère orage, avait bloqué les tuyaux d'écoulement du ruisseau Five Mile sous l'autoroute. Les débris avaient rapidement couvert la route sur une section plus de 200 mètres de long et plusieurs mètres d'épaisseur. La circulation fut immobilisée sur l'autoroute pendant plus de 20 heures. De plus, il a fallut trois semaines avant qu'une circulation normale ne fut rétablie. Cet article décrit le travail récent fait pour Parcs Canada par Thurber Engineering Ltd. pour déterminer les endroits possibles pour développement de coulées de débris le long du ruisseau Five Mile et pour évaluer une variété de solutions. L'article décrit aussi la méthodologie de l'étude et évalue les résultats.

1. INTRODUCTION

Five Mile Creek drains a portion of the north side of the Bow River Valley, and crosses the Trans Canada Highway 5 km west of Banff, Alberta, near the junction with Highway 1A, the Bow Valley Parkway. This investigation was prompted by a significant debris flow event that occurred on August 4, 1999, completely blocking the Trans-Canada Highway and cutting buried fibre-optic communications lines.

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 (Highway 1A) 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.

Figure 1 – Immediately after the August 1999 debris flow, clearing the Trans Canada Highway (photo courtesy of Parks Canada)

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. The forest 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.

1.1 Site History

The first significant man-made structure to be built in the Five Mile Creek area in recent times 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 fieldwork.

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.

1.2 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 are not 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 vary 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 1-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.

1.3 Geology

This portion of the Front Ranges is characterised 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 making it more susceptible to weathering and disintegration (van Steijn et. al. 1988).

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 alluvial fan.

1.4 Past Debris Flow Activity

In recent history, only two debris flow events have been noted on Five Mile Creek; an event that occurred during construction for the Trans-Canada Highway twinning in 1987, and the August 1999 event. The only other documented evidence found of previous debris flow events was the 1947 aerial photography, which shows evidence of a recent debris flow event crossing the Bow Valley Parkway at the east and west channels. Geomorphic and dendrochronological evidence for previous flows was found during fieldwork.

The 1999 debris flow event occurred on August 4, 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. Whereas prior to the 1999 event, clearing and maintenance of the culvert and channel was required only once every four or five years, since the event, substantial maintenance resources have been required every year.

1.5 Previous Work

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 has been done by de Scally (1999) on alluvial fans in the Banff National Park.

2. METHODOLOGY

The present assignment included a desk study, fieldwork and a hazard assessment. Once the nature and probable recurrence interval of the debris flow hazard was established, a series of possible solutions were examined.

The desk study included:

- A review of debris flow processes, focussing on characteristics of the Five Mile Creek events.
- A literature review to identify mitigative strategies adopted at sites with similar debris flow problems.
- A review of policies and regulations to identify areas that impact the range of mitigation options available, and how these options are implemented.
- A synthesis of the construction and maintenance history of built assets in the general area.
- A review of historic air photos covering the Five Mile Creek area to provide information on geomorphic processes and the occurrence of past debris flow events.
- A review of climate and meteorological data available from Environment Canada.
- An estimate of creek flood flows, based on regional hydrometeorological data.

In addition to reviewing published information, interviews were conducted with various stakeholders over the course of the study.

Fieldwork consisted of field reconnaissance visits, a helicopter flyover and detailed field mapping. Observations and photographs obtained during the helicopter flyover were used to identify priority areas for field checking. Detailed mapping of the creek and fan area was then conducted to evaluate the amount of sediment available for transport, and to provide input into the hazard assessment. Distance along the creek was determined using a hip chain, with station 0+000 set as the upstream end of the Canadian Pacific Railway culvert at the end of the east channel. The creek was divided into a number of reaches, based on differences in channel gradient and character. A number of elements were recorded for each reach, including:

- average channel and sideslope gradient,
- average depth and width of the channel,
- estimated quantity of sediment available for transport within the channel and the range of sediment size, and
- evidence of levées, super-elevation of debris, springs, bank erosion or landslides.

Additional fieldwork was conducted across the fan to provide further information on the character and frequency of past debris flows. Past debris flow lobes were noted on several portions of the fan. Observing whether trees protrude through the lobes, or if the debris has flowed around the base of the tree, allows estimation of the relative age of the lobes, and that of past debris flow events.

A qualitative assessment of hazard was performed using a simplified version of the Gully Assessment Procedure of the B.C. Forest Practices Code (BC Ministry of Forests 2001). The potential for debris flow initiation was established from parameters determined during the field mapping of the creek.

The probability of occurrence of future debris flow events was estimated from the frequency of past debris flow activity, determined through historic records and geomorphic evidence, and using procedures described by Morgan et al. (1992). This approach assumes that debris flows are true random events and that the frequency of future events will be similar to the frequency of past events.

A detailed review of climate records was also carried out, to investigate the occurrence of weather patterns similar to those which preceded the August 1999 debris flow event.

3. OBSERVATIONS

The upper reaches of the watershed are characterised by sediment inputs from avalanche tracks and tributary creeks. Creek gradient ranges from 10º to 17º within the mapped reaches (Figure 2).

There is no clear evidence for an initiation point for the 1999 debris flow. Levées occur throughout the upper reaches of the watershed, though some are likely the result of avalanche activity. A rock-controlled constriction near the upper mapped portion of the creek retains a significant quantity of sediment, representing a potential initiation point. However, there is evidence for debris flow activity immediately upstream of this area. It is thought likely that high creek flows and debris floods from tributary creeks combined to gradually form a debris flow in the upper reaches as additional sediment was added to the flow.

Figure 2 – Upper reaches of the watershed.

The middle reaches of the creek are characterised by scour of the creek bed and incorporation of additional debris from the channel sides. Creek gradient is between 6º and 12º.

Prominent bouldery levées occur locally along the channel. Particularly on outside creek bends, there has been erosion and undercutting of the creek banks, resulting in landslides in many cases (Figure 3). Several major landslide scarps occur through this section, though most appear to be older slides that have contributed minor sediment during the recent debris flow event.

From chainage 1+900 to 2+000, significant quantities of water issue from the creek bed and banks. Above this point, during the fieldwork, the creek was essentially dry. The springs appear to issue from bedrock. It is thought likely that the addition of water at this point significantly increased debris mobility and erosive power.

Immediately below the fan apex, the channel narrows, steepens and becomes deeper. The creek is constrained on the left bank by rock. Considerable creek bed erosion appears to have occurred through this section.

Figure 3 – Middle reaches of the watershed. Note how the rock promontory has been stripped clean. Bouldery levée and damage to tree to the left of the picture.

Figure 4 – Overview of middle and lower portions of the watershed and the west channel on the fan. Note how the west channel becomes diffuse as it crosses the Fireside day use area access road (bottom of picture).

Further downstream, the channel gradient reduces, the width increases significantly, and the depth decreases. Significant deposition of sediment has occurred through this reach. At the pedestrian bridge, the channel becomes constricted, and there is evidence that debris backed-up and overflowed the main channel.

Downstream of the pedestrian bridge, the channel gradient becomes locally steeper towards the highway culvert, with local channel scour (Figure 5). There has also been significant local bank erosion. The channel is highly incised through this reach.

Figure 5 – East channel during the freshet in June 2002, immediately above the Trans Canada Highway culvert (photo courtesy of Highwood Environmental Management).

Figure 6 – East channel below the highway culvert in September 2001.

Immediately above the highway culvert, there are outcrops of glacially scoured bedrock that constrain the elevation of the channel base. Bedrock is also locally exposed in the left bank of the creek channel near the fan apex, and several prominent exposures occur along the west fan margin. Bedrock outcrops on the western fan margin represent constraints on the extent of debris flow activity on the fan.

Downstream of the culvert, the creek runs through a roughly 1 m wide artificial channel with a 1º - 2º gradient. Gravel from previous channel clearing operations has been piled-up along the channel sides (Figure 6). Beyond this reach the channel opens out across the lower portion of the fan. There is significant deposition of gravel, cobbles and boulders through the trees at this point, and as a result, a large number of trees are showing distress. The limit of the main lobes of debris is approximately 70 m upstream of the Canadian Pacific Railway culvert (Figure 7).

Figure 7 – Lower portion of the east channel towards the Bow River. The channel has been cleaned several times.

4. DEBRIS FLOW HAZARD

4.1 Hazard Recognition

The first step in a rigorous assessment of debris flow hazard is determining if the hazard exists. It is clear that there has been a debris flow hazard on Five Mile Creek in the past, but this does not necessarily mean that a debris flow hazard currently exists. In order to determine the current debris flow hazard, it is necessary to assess whether pre-conditions for further debris flow events exist, and if further triggering events could occur.

Pre-conditions for a debris flow event include an adequate supply of sediment, and the means to initiate a debris flow. Sediment supply was assessed through detailed mapping of the creek channel. It was estimated, at the time of the mapping, that between 30,000 m^3 and 40,000 m^3 of sediment was readily available within the immediate channel, not including contributions from channel scour or lateral erosion. Further sediment inputs are likely from avalanche chutes and landslides along the channel.

Assessing the potential for initiation of a debris flow event is dependent on the mechanism of debris flow initiation. Debris flows can be initiated through three broad mechanisms:

- A landslide in the gully sides or headwall enters or blocks the gully and subsequently transforms into a debris flow,
- A landslide occurring on the valley sides enters the gully and transforms into a debris flow, or
- Increasing creek flow entrains progressively more bed material, eventually transforming into a debris flow (Tognacca and Bezzola, 1997).

Debris flow initiation by landslides can be semi-quantitatively assessed through mapping the stability of the terrain surrounding the creek channel. In its simplest form, this uses slope angle and slope material type, combined with observation of past instability to assess whether a landslide is likely to occur. This broad approach is taken by the B.C. Gully Assessment Procedure, and adapted for use in this project. The 'sidewall failure potential' shows that most reaches above the fan have a high potential for failure. However, none of the landslides identified along the creek are thought to have been the primary triggers for the 1999 debris flow. As a result, an assessment of initiation potential based on landslide occurrence alone might be misleading.

Assessment of initiation potential for debris flows triggered by increasing creek flow is difficult as this process is poorly understood. The 'water transport potential' adapted from the BC Gully Assessment Procedure is considered to give an indication of debris flow initiation. Most reaches above the fan have a moderate or high water transport potential. This, combined with field observations, is considered an indication of high debris flow initiation potential.

4.2 Triggering Events

Anecdotal evidence suggests that the August 1999 debris flow event was triggered by a localised convective storm. An eyewitness, travelling eastbound on Highway 1A, reports having to pull-off the road because of very heavy rain near Castle Junction. (M.McIvor, pers.comm.). Unfortunately, the August 4, 1999 event was not captured by the Banff weather station.

A detailed analysis of daily precipitation records at Banff was undertaken. It was not possible to directly estimate the return period of the convective storm that is thought to have triggered the August 1999 event. Furthermore, analysis of the daily precipitation records at Banff has not identified a consistent pattern indicative of a debris flow-triggering event. This suggests that either:

- There are a number of possible meteorological conditions that might trigger a debris flow event in the Five Mile Creek watershed, and/or
- The rainfall records at Banff do not adequately represent conditions at Five Mile Creek.

Previous studies have identified a number of meteorological conditions under which debris flows can be triggered (Church and Miles 1987):

- Locally concentrated rainfall with high antecedent moisture but no snowmelt,
- Widespread moderate rainfall and snowmelt,
- Heavy rain onto thawing ground with little snowmelt,
- Low return-period rain, or rain on snow, or snowmelt.

All of these scenarios are possible in the Five Mile Creek watershed at different times of the year.

4.3 Past Debris Flow Frequency

A detailed review of evidence for past debris flow activity was undertaken, including historic records, geomorphic evidence and a limited dendrochronological study. Between two and four events were identified with what is considered moderate to high reliability between 1932 and 2001, giving an average return period of between 17 and 35 years. A total of eight possible events were identified from 1845 to 2001, giving an average return period of 20 years.

There is some evidence to suggest that the occurrence of potential triggering factors has varied in the past:

- There is a marked cluster of years with greater than average precipitation from 1897 to 1905.
- Logging and fires in the watershed ceased in 1910.

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, variations in precipitation or other climate changes over time, and the occurrence of fire.

5. RISK REDUCTION CONCEPTS

The hazard assessment suggested that the risk of future debris flow events was sufficiently high that some protective measures would be required. Risk reduction strategies are complicated by the fact that there is already significant infrastructure on the fan, and any measures taken could not increase the risk to any component. Risk reduction measures are also constrained by environmental concerns. Some measures that might otherwise have been considered, cannot be contemplated in a National Parks environment.

A review of risk reduction measures was undertaken. Risk reduction strategies fall into one of two broad categories; Preventative measures seek to reduce the likelihood that a debris flow will be triggered, while Control measures are designed to reduce or constrain debris flow damage (Figure 8).

In addition to the debris flow hazard to infrastructure on the fan, the other main objective was to reduce or eliminate the need for channel maintenance on the lower fan resulting from gravel transport and deposition (Figure 9).

A series of measures were discussed, and concept designs produced and costed. The main options considered included:

- Replacement of the Trans Canada Highway culvert with a clear span bridge,
- Construction of a debris basin on the upper portion of the fan, and
- Construction of a terminal berm.

The conceptual designs were evaluated based on cost, effectiveness and minimisation of disruption to the fan environment. An environmental impact assessment was conducted on each of the conceptual options. Elements of particular concern included:

- Impacts on groundwater and surface water flows and quality, particularly with respect to backchannel areas of the Bow River at the far end of the west channel, and the Vermillion Wetlands, downstream of the east channel.
- Impacts on vegetation and wildlife, both in the short-term during construction, and in the long-term. This area is an important movement corridor for large carnivores, and is considered prime habitat for ungulates.
- Heritage resources, recreational use and aesthetics, both during construction, and in the long-term.
- Public safety and infrastructure protection.

Figure 9 – East channel downstream of the highway culvert in September 2002. Note the large quantity of gravel in the channel compared with Figure 6.

Parks Canada has decided to proceed with the terminal berm concept. This option entails construction of a diversion berm at the fan apex, which would allow normal creek flows to continue along the east channel, while diverting floods and debris flows into the west channel.

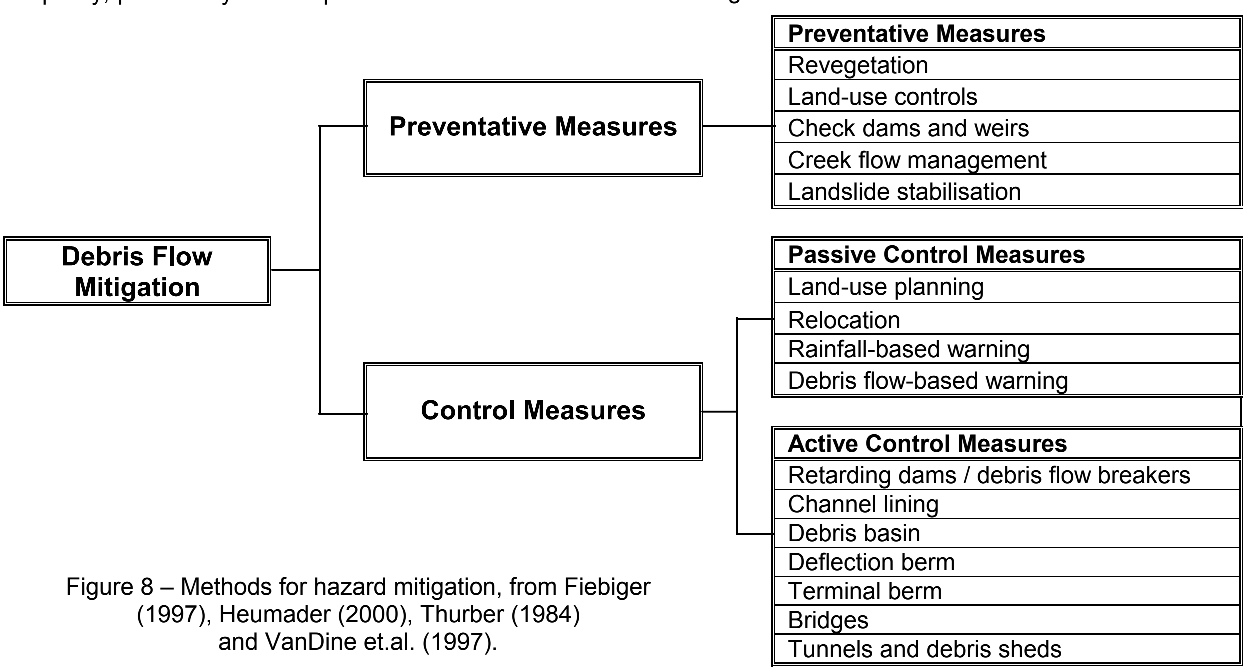

Figure 8 – Methods for hazard mitigation, from Fiebiger (1997), Heumader (2000), Thurber (1984) and VanDine et.al. (1997).

Debris flows would be allowed to spread out over a portion of the natural fan, constrained by a terminal berm, constructed along the Fireside day use area access road.

6. DISCUSSION

This study raises a number of important issues in assessing, communicating and reducing risk from natural hazards:

- Going from an “engineering judgement” approach to a more rigorous risk assessment is difficult and time-consuming. Even with good historic records and climate data, assessing debris flow frequency requires considerable judgement.
- Communicating risk effectively to a non-technical audience is challenging. Different people perceive risk in different ways, depending on their background. Comparing risk of everyday occurrences to probability of occurrence of natural hazards may not always be useful, depending on which examples you choose.
- Balancing public safety and infrastructure protection, environmental concerns and limited operating budgets is challenging. It should be noted that there are many natural hazards that impact the major transportation corridors through the Canadian Rockies.

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