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The August 1999 Debris Flow at Five Mile Creek, Banff, Alberta

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An intense but apparently highly localized rainstorm triggered a debris flow in Five Mile Creek basin in the Front Ranges of the Canadian Rockies on 4th August 1999. In comparison to debris flow activity observed historically along transportation corridors in the Canadian Cordillera, the event was a large one, and it caused major disruptions to traffic and telecommunications in the Banff-Lake Louise area. Channel aggradation which occurred during the debris flow appears to have increased the level of future hazard at this site, as well as having increased the potential for sediment transport by normal streamflow. This sediment transport is now having significant negative impacts on highway infrastructure and nearby wetlands, forcing Parks Canada to seek a mitigative approach that attempts to balance hazard management with ecological objectives. The occurrence of such a significant debris flow event in Five Mile Creek basin, which has little if any evidence of debris flow activity in the past several decades, underscores the potential for such events in other relatively inactive basins in the Front Ranges.

Introduction

A debris flow occurred in Five Mile Creek basin on 4th August 1999 closing the Trans Canada Highway, destroying telecommunication lines, and delivering sediment laden flow into the Vermilion wetlands. The basin shows little evidence of major debris flow activity in recent history and, therefore, this event raises concerns over future activity both within Five Mile Creek basin and within other similar basins throughout the Front Ranges of the Canadian Rockies. The objectives of this paper are to: i) describe the geomorphological characteristics of the Five Mile Creek basin; ii) report on the 1999 debris flow event; and iii) discuss some implications for future management of hazards on the fan, particularly as it is situated within a national park setting.

Site Description

Five Mile Creek basin is situated in Banff National Park, Alberta, 5 km west of the town of Banff, at approximately 51°11'N and 115°40'W (Fig. 1). The Trans Canada Highway, Highway 1A, and the Canadian Pacific (CP) Railway are routed across the fan of Five Mile Creek. The basin covers an area of 4.8 km^2, and ranges in elevation from 1490 m at the fan apex to 2780 m on Mount Cory.

The geology of Five Mile Creek basin is dominated by the Sawback Thrust fault, which bisects the basin along its NNW-SSE longitudinal axis (Price and Mountjoy 1972). The western slopes are composed of limestone and weaker shale strata, while the eastern slopes are formed of stronger dolomite and limestone. The less resistant shale and limestone of the western slopes are more susceptible to weathering and produce finer grained surficial material prone to erosion. The more resistant carbonate rocks of the eastern slopes, on the other hand, produce larger boulders that may be incorporated by debris flows via channel scouring and bank failure.

The slope gradients in the upper basin average 32°, while the gradient of the main channel averages 14° and 5° in the middle and lower reaches, respectively. The average gradient along the fan's axis is 4°, which is at the lower threshold for fans affected by debris flow activity in the Front Ranges (Jackson et al. 1987) and Cascade Mountains of British Columbia (de Scally et al. 2001). The basin ruggedness can be expressed by Melton's R:

$$R = H_b\ A_b^{-0.5} \tag{1}$$

where H_b is the relief and A_b the planimetric area of the basin, both values being measured above the depositional fan (Melton 1965). The R value for the Five Mile Creek basin is 0.61, which is well above the lower thresholds reported for debris flow basins in the Front Ranges (0.25-0.30) by Kostaschuk et al (1986) and Jackson et al (1987) and Cascade Mountains (0.38) by de Scally et al. (2001).

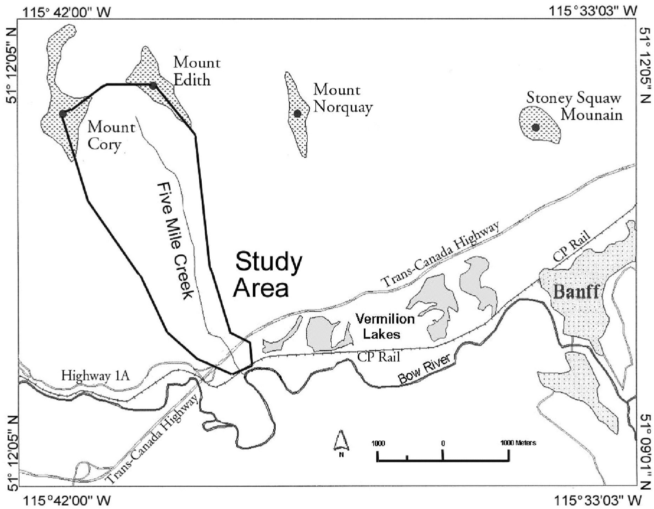

Figure 1: Location of Five Mile Creek basin in Banff National Park

The upper basin of Five Mile Creek is drained by four tributaries, three of which are incised into the finer grained colluvium of the northwest portion of the basin. Below the timberline, the main channel and the slopes are generally stable, with the exception of a few small scars indicative of landslide activity along east facing slopes. The lower channel currently flows along the northeastern margin of its depositional fan. A former channel, from which flow was diverted by the construction of a dyke at the fan apex, is still identifiable along the northwestern margin of the fan. The purpose of the diversion dyke might have been to direct flow away from the sections of the rail line and old highway (now Hwy. 1A) along the northwestern margin of the fan. The exact age of the dyke is unknown, but it is clearly visible on air photos dating back to 1947. The maximum age of small trees on the dyke, not accounting for an ecesis interval, suggests a construction date sometime in the 1930s (de Scally 1999).

The depositional fan of Five Mile Creek is probably a paraglacial fan; a term employed by Church and Ryder (1972) and Ryder (1971a, 1971b) to describe fans built rapidly by debris flows following deglaciation at the end of the Pleistocene. Roed and Wasylyk's (1973) observations of Mazama tephra (6600 yr. B.P.) near the top of fan deposits in basins adjacent to Five Mile Creek provides a minimum age for these paraglacial fans, and is supported by additional tephrochronological evidence collected by Kostaschuk (1980) and Kostaschuk et al. (1982) in the Bow Valley.

As is characteristic of paraglacial fans (Church and Ryder 1972 and Ryder 1971a, 1971b), most of the surface of the Five Mile Creek fan appears to have been unaffected by debris flows and streamflow in the recent past. The frequency and magnitude of recent debris flow activity in Five Mile Creek basin is largely unknown. Analysis of a series of air photographs dating from 1947 to 1993 shows no evidence of major debris flow activity, i.e. flows extending beyond the present channel. Debris flow lobes on the upper fan, which were created by an event(s) large enough to overflow the present channel, appear to be at least several decades old based on the degree of lichen and vegetation cover. A maximum tree age derived from tree ring analyses on 17 spruce trees growing on the deposits suggests that the lobes are at least 63 years old, and older if an ecesis interval is considered. It is therefore possible that the cessation of debris flow activity on the upper fan coincides with the construction of the diversion dyke.

The 4th August 1999 Debris Flow

The debris flow occurred at approximately 19:00 hours on 4th August 1999, burying the Trans Canada Highway and disrupting telecommunication lines between Banff and Lake Louise. It was triggered by an intense, localized rainstorm earlier the same afternoon. Although precipitation records from the nearby town of Banff indicate only 0.8 mm of rainfall between 00:00 and 19:00 hrs on 4th August, the storm was observed by two of the authors. A subsequent aerial survey on 13th August revealed the limited spatial extent of other smaller debris flows on the south end of the Sawback Range triggered by the same storm, further indicating the localized nature of the rainfall. Rainfall records from Banff, however, do suggest that antecedent soil moisture conditions may have played a role in the debris flow activity. The preceding month of July was the fourth wettest July since 1890, with 2.5 times the monthly average precipitation (Table 1). This role is not clear however, since only 7 mm of rain fell in the 16 days preceding 4th August.

Table 1 Monthly Precipitation Data for Banff Town Site, 1980 to 1994 and 1999

Precipitation (mm)	*May*	*June*	*July*
Minimum	10.7	14.6	2.0
Maximum	193.9	153.8	144.6
Mean	53.0	66.8	49.1
1999	29.9	31.1	126.6

Unpublished data, Meteorological Service of Canada

If the finer grained colluvium on the western slopes of Five Mile Creek basin were saturated, it would have been prone to debris flow initiation by the 4th August rainstorm. In fact, colluvium of this type has been identified as being ideal for debris flow initiation, especially when it becomes saturated (Owens 1973). The main initiation area of the debris flow does appear to have been the western portion of the basin drained by three tributary channels on Mounts Cory and Edith (Fig. 2). Significant scouring along these tributaries was observed immediately following the event, to the extent that little sediment remains for debris flows in the near future. In contrast, the 3.2 km long middle reach of Five Mile Creek above the fan experienced substantial aggradation of the channel bed, probably in the waning stages of the debris flow (see the middle oblique air photograph in Fig. 2).

Four channel cross-sections were surveyed on the upper fan in May 2000 (Fig. 3), allowing for a determination of flow depths and cross-section areas at the peak of the 4th August debris flow (Table 2). Velocities *(V)* were then calculated using an equation based on the dilatant model with non-plastic grain-fluid dispersions (Bagnold 1954), which takes the following form for a wide channel (Hungr et al. 1984):

$$V = 0.67\, \xi\, S^{0.5}\, h^{1.5} \qquad (2)$$

where ξ is a dimensional coefficient inversely proportional to the volume concentration of solid particles in the debris, S is the channel gradient measured locally at each cross-section, and h is the maximum flow depth. Hungr et al. (1984) show a ξ value of 3.25 ($m^{-0.5}\, s^{-1}$) to work well for debris flows in British Columbia, so this was employed in the calculations. The resulting estimates of debris

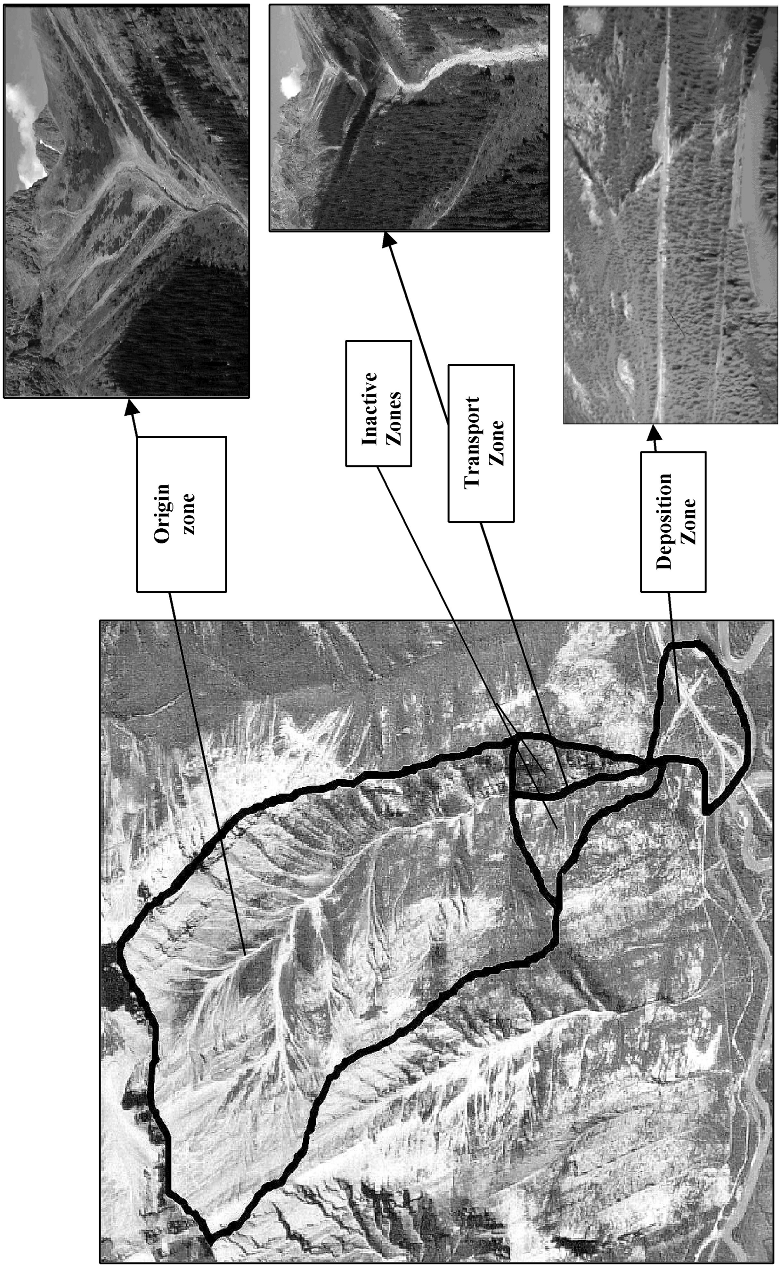

Figure 2: Debris flow origin, transport and deposition zones in the Five Mile Creek basin.

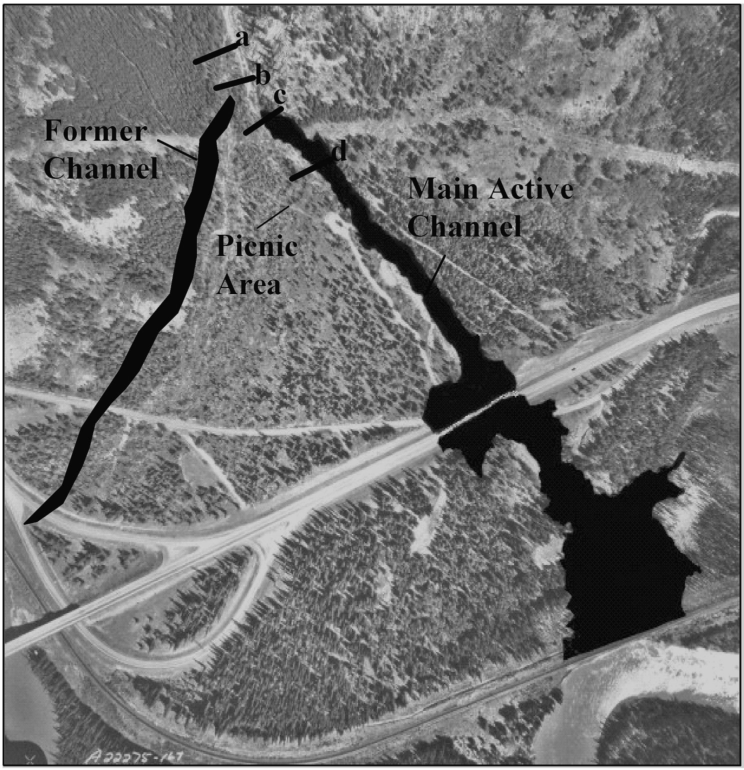

Figure 3: Deposit of the 4th August 1999 debris flow. The letters beside the deposit indicate the locations of the channel cross-sections in Figure 4.

flow velocity and discharge are shown in Table 2. The peak discharges at cross-sections (b) and (c) in Figure 4 and Table 2 are probably underestimated because of the significant infilling of the channel bed in the later stages of the event. The discharges at cross-sections (a) and (d) are judged to more accurately represent the true discharge, although the latter figure may be slightly overestimated because of probable scouring of the channel bed by streamflow following the event.

Table 2 Velocity and peak discharge estimates for the 4th August 1999 debris flow

Channel Cross section	Channel gradient (m)	Parameters at peak of debris flow			
		Depth (m^2)	Area $(m\ s^{-1})$	Velocity[1] $(m3\ s^{-1})$	Discharge
a	0.105	2.7	32	3.1	100
b	0.123	1.7	15	1.7	25
c	0.105	2.2	20	2.3	46
d	0.141	3.6	25	5.6	139

[1]Estimated using equation (2)

Approximately 10% of the debris flow overflowed into the former channel along the northwest side of the fan after the diversion dyke was destroyed by the flow (Fig. 3). The destruction of the dyke may have resulted from the constriction of the flow due to channel narrowing (Fig. 4b). Future overflows into the former channel are made even more probable due to aggradation in the main channel at this location during the waning stages of the debris flow, which has left the bed of the main active channel only 0.5 m lower than the former channel. The flow in the former channel extended approximately 500 m downstream of the dyke to Highway 1A. However, a log dam built by the debris flow about 200 m below the dyke prevented the transport of large rocks to the road. The finer material continued at relatively high velocities through this section, however, as is indicated by mud splashed onto trees up to heights of approximately one metre.

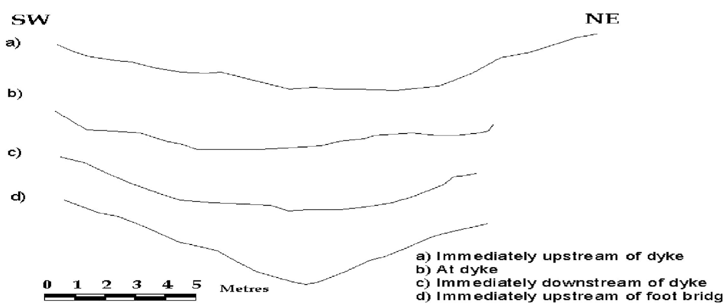

Figure 4: Channel cross-sections on the upper fan in May 2000. The cross-section locations are shown in Figure 3.

The main part of the debris flow travelled via the main active channel along the fan's northeast margin to the Trans Canada Highway, almost overflowing onto the fan surface at two locations. At a picnic site situated a short distance below the fan apex (see Fig. 3), a six-metre high wooden footbridge was dislodged and transported by the flow to the highway. The greatest disruption occurred at the highway, however, where an 8 m wide by 3.5 m high culvert was blocked with sediment allowing the debris flow to bury the highway (Figs. 5 and 6). The blockage was probably due in large part due to a boulder, reported by work crews to be "the size of a small car", that was lodged inside the culvert. The burial of the highway was gradual according to one eyewitness, probably accounting for the fact that no vehicles were trapped or damaged by the flow. Nonetheless, the Trans Canada Highway was closed for 20 hours, creating major traffic disruptions between Calgary and the British Columbia interior. The sediment deposits on the highway are estimated to have been up to 3 m in depth and covered the four lanes for a distance of 190 m. All four lanes were not reopened until late August.

Figure 5: Highway 1 closed by the debris flow, 5th August 1999. View is upstream from above the lower fan.

On the south side of the highway, the debris flow undercut a portion of the eastbound lanes, destroying buried telecommunication lines (Fig. 6). Immediately below the highway, the channel was

Figure 6: With the westbound lanes still buried by the debris flow deposit (top of photo) late on 5th August 1999, westbound traffic is being diverted via the eastbound lanes. The destroyed telecommunication line to Lake Louise is beneath the road edge where two individuals are standing.

filled to a depth of five metres by sediment. The debris flow continued another 280 m to the CP Rail line at the fan toe, with fines washing through culverts into the Bow River (Fig. 7). The low gradient along this reach (approximately 2°) indicates the fluidity of the flow below the highway. Nevertheless, boulders up to one metre in diameter, large logs, and concrete barriers from the highway were rafted as much as 260 m below the highway, where they were dammed up behind a stand of mature conifers. Two culverts used to direct water flow from Five Mile Creek under the CP Rail line into the Bow River were completely blocked by finer sediment. Immediately after the event Five Mile Creek was diverted by work crews into the Vermilion wetlands (upper left corner of Fig. 7), until the main channel was excavated.

The flow was of a relatively fine-grained nature, with particle size analyses of the deposits yielding measures of 32% and 57% (upper strata) for silts and clays above and below the highway, respectively (Table 3). The increase below the highway probably reflects the dam-like effect of the highway and the subsequent settling out of larger particles above the highway. The fine-grained nature of the flow helps to explain the significant mobility of this debris flow across the low-gradient fan, and supports the idea that

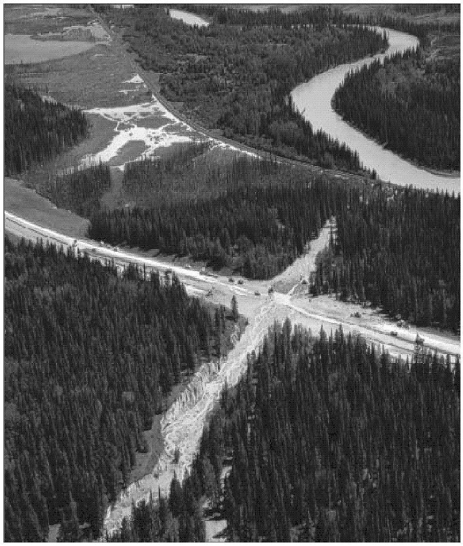

Figure 7: View east from above the upper fan on 5th August 1999, showing the debris flow deposit extending across Highway 1 to the CP Rail line adjacent to the Bow River. Five Mile Creek is being diverted into the Vermilion Lakes wetlands in the upper left of the photo.

the flow initiated in the finer colluvium of the northwestern portion of the upper basin. Larger clasts in the flow deposits were predominantly carbonates, which were probably incorporated into the flow via channel scouring.

Table 3 Particle size analysis of the debris flow deposit

Sample site	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
Above highway	6	26	22	46
Below highway (lower strata)	2	10	26	62
Below highway (upper strata)	18	39	43	0

The debris flow deposits on the fan were mapped immediately following the event using a GPS unit with sub-metre resolution. The areal measurements were combined with depth measurements along 48 cross-sections, which were based on field observations, such as the height of debris deposits on vegetation, identification of the original channel bed, and eye-witness accounts. The estimated volume of the flow is 52,400 m^3, which is in close agreement with the volumetric estimates of 50,000 m^3 and 45,000 m^3 by Public Works Canada and the Geological Survey of Canada, respectively (see Couture and Evans 1999). In comparison, a 1989 debris flow at West Wilson Creek in the northern part of Banff National Park was estimated to have a volume of 38,400 m^3, with the maximum volume of historic debris flows from this basin being 62,700 m^3 (Podor 1992). Estimates of debris flow volume along the east shore of Howe Sound in the southern Coast Mountains of British Columbia range between 15,000 and 62,500 m^3 (Church and Hungr, 1990), while the maximum for recent debris flows in the Cascade Mountains is 60,000 m^3 (Thurber Consultants Ltd. 1985). Therefore, in comparison at least to relatively recent events along transportation corridors in the Canadian Cordillera, the Five Mile Creek debris flow of 1999 was a relatively large event.

Insights and Implications of the 4th August Debris Flow

On the basis of its low gradient and lack of recent activity, the Five Mile Creek fan appears to have a lower likelihood of experiencing large debris flows compared to many other basins studied in the Front Ranges of the Canadian Rockies (Kostaschuk et al. 1986; Jackson 1987; Jackson et al. 1987; de Scally 1999). The 4th August debris flow, however, underscores the fact that large events can occur even in marginally suitable basins where the frequency of modern debris flow activity is low. A key factor controlling the frequency may be the frequency of sufficiently intense rainfalls, perhaps in conjunction with antecedent moisture conditions in the basin. While debris flows in such circumstances may be rare, they may also be of a high magnitude given that the basin has time to accumulate large amounts of colluvium between events. This contrasts with the higher frequency of debris flow activity in basins where glacier cover can provide large quantities of meltwater for debris flow triggering, such as Cathedral Crags in Yoho National Park (Rowbotham 1984) and West Wilson Creek in Banff National Park (Podor 1992).

The August 1999 event also demonstrates that, with sufficiently high clay content of sediment and water input, channellized debris flows can travel a significant distance even on low-gradient fans, in this case where the average gradient along the fan axis approximates the lower threshold (4°) for debris flow fans in the region. The debris flow travelled approximately one kilometre over an average channel gradient of 5° and did not terminate until a gradient of 2° was reached. In comparison, Hungr et al. (1984) report debris flows from basins underlain by both volcanic and crystalline rocks in British Columbia where deposition began at channel gradients of 8 to 12°. Although the grain size distributions for the flows in this previous study are unknown, it is noteworthy that the deposition angles from the Five Mile event were much lower.

The August 1999 debris flow resulted in changes to Five Mile Creek which have significant implications for future hazard management on the fan. First, since much of the lower and especially middle reaches of the channel experienced deposition rather than scouring by the debris flow, the probability of a future debris flow event has not been reduced nearly as much as would otherwise be the case. The surficial geology of the area suggests that much of Five Mile Creek basin above the fan is a "bedrock-dominated" (Bovis and Dagg 1987) or "weathering-limited" (Jakob 1996) type basin. Rutter's (1972) map for example characterizes even the lower part of the basin as "bedrock exposed at the surface or thinly veneered by drift and colluvium". In such basins, the removal of sediment by a debris flow would normally decrease the probability of another event until mass wasting and fluvial processes replenish the supply of sediment in the channel. Such removal of sediment appears to have not happened during the August 1999 event, except in the high elevation tributary channels.

The major aggradation in the section of channel situated on the fan (Fig. 4a-c) has also resulted in an increased potential for avulsion or overflow during a future flood or debris flow. The potential is greatest at the site of the destroyed dyke (Fig. 4b), and therefore, the debris flow hazard may have increased at Highway 1A and the CP Rail line at the west margin of the fan, and at the picnic area on the fan itself. As discussed below however, a decision may soon be made to permanently re-route Five Mile Creek to its former channel along the fan's northwest margin.

The large amounts of sediment remaining in the channel of Five Mile Creek are presently also contributing to increased sediment loads in the stream, necessitating more frequent excavation of the channel and culverts at Highway 1 and the CP Rail line on the fan's east side. During the May 2000 freshet, the 3.3 m of clearance in the culvert under the highway was completely filled by sediment over a three week period. Again in June 2001, the culvert was filled in a matter of days by sediment transported during rain generated high flows. These flows necessitated an emergency re-routing of Five Mile Creek into its former channel along the fan's northwest margin. And, by the summer of 2002, with the culvert under the highway almost completely plugged again by course sediment, a major re-excavation of the channel was undertaken. Along the toe of the fan, streamflow in the following years has also transported sediment (including gravel and cobble sized material) through two small culverts under the CP Rail line into the Bow River. In order to protect the Trans Canada Highway, relieve the Vermilion wetlands of excessive sediment input (Fig. 1 and 7), and work toward the ecological goals associated with restoring more natural sediment transport processes on alluvial fans in Banff National Park (Canadian Heritage 1997; de Scally 1999), Parks Canada is, at the time of writing, considering the permanent re-location of Five Mile Creek to its northwest channel. In this case a debris straining structure would probably be constructed above Highway 1A along the northwestern channel to arrest debris flows, while allowing gravel and cobble sized sediment to make it through culverts under the CP Rail line to the Bow River (S. Cullum-Kenyon, pers. comm. 2001). The delivery of coarse sediment into the Bow River by tributaries such as Five Mile Creek is seen by Parks Canada as an important component of restoring and maintaining gravel bars in trunk streams (Canadian Heritage 1997; de Scally 1999). The current debate over management of debris flow hazards at Five Mile Creek is therefore made more interesting by the need to balance such hazard management against ecological objectives in a national park setting.

Conclusions

The debris flow of 4th August 1999 at Five Mile Creek was a relatively large event in comparison to others observed along transportation corridors in the Canadian Cordillera. Furthermore, the event has not alleviated the risk of further events in the near future as much as might be expected, due to aggradation in the middle and lower reaches of the channel. In addition to ensuring a sediment supply for future debris flows, the aggradation has increased the probabilities of overflow onto the fan surface, avulsion, and reoccupation of the former channel during future debris flows or floods. As a result, the nature of the hazard on the fan has been altered. A further problem is created by the fact that much of this sediment can be mobilized by even relatively modest streamflow, leading to blockage of culverts under Highway 1 and CP Rail line. Parks Canada is presently considering options for addressing this problem which would also allow it to partially meet the objective of restoring more natural sediment transport processes on alluvial fans, as outlined in the management plan for the park.

The August 1999 event is noteworthy in other respects. It occurred in a basin which appears not to have produced debris flows for several decades. Moreover, the fan of the basin has an average gradient that is at the lower threshold for debris flow fans in the Front Ranges, yet the debris flow managed to travel a large distance. The August 1999 event therefore raises the possibility of other large debris flows occurring in other basins in the Front Ranges which are currently not considered to be at risk. It also underscores the idea that even forested paraglacial fans can produce infrequent but large debris flows. The fact that the rainstorm which triggered the August 1999 event was not recorded by the nearby Banff meteorological station highlights the difficulty of estimating the magnitude and recurrence interval of localized storms capable of triggering debris flows in such basins.

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