Hydro-geomorphic response to the June 19-21, 2013 storm in Canmore and the Municipal District of Bighorn, Alberta

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ABSTRACT
In June of 2013, a series of damaging debris floods occurred in the Bow River Valley and adjacent areas. The town of Canmore and adjacent MD Bighorn were particularly affected by the event. Up to 270 mm of rain fell within 3 days leading to hundreds of debris flows and several damaging debris floods. The rainfall event is estimated as a return period between 250 and 750 years. The most costly damages were recorded on Cougar Creek fan, a 3.1 km^2 landform that is densely developed and crossed by Highway 1, Highway 1a and the Canadian Pacific Railway. An estimated sediment volume of 90,000 m^3 was transported to the fan reaches and more material was mobilized within the fan. This aggradation and associated erosion led to a one week closure of Highway 1 and a three day closure of the Canadian Pacific Railway, essentially paralyzing east-west traffic. In Exshaw, the storm triggered extensive debris floods on Jura, Heart and Exshaw Creeks, impacting the Hamlets of Exshaw and Lac des Arc. The event was recognized as constituting an intolerable risk and a series of studies were launched to understand hazard and risk in the affected area. This paper details the hydro-geomorphic response of the storm on Cougar, Exshaw and Jura Creeks.

RÉSUMÉ
En Juin 2013, une série d'inondations torrentielles dommageables s'est produite dans la vallée de la rivière Bow et les zones adjacentes. La ville de Canmore et MD adjacente Bighorn ont été particulièrement touchés par l'événement. Jusqu'à 270 mm de pluie sont tombés dans les 3 jours menant à des centaines de coulées de débris et plusieurs inondations de débris nuisibles. L'événement de précipitations est estimé à une période de retour de 250 et 750 ans. Les dommages les plus coûteuses ont été enregistrées sur le cône alluvial de Cougar Creek, d'un 3.2 km^2 cône alluvial qui est densément développée et traversé par le TransCanada Highway, Highway 1A et Canadian Pacific Railway. On estime à 90 000 m^3 ont été transportés vers le cône alluvial atteint en plus de matériel a été mobilisée dans le cône alluvial. Cela a conduit à une fermeture d'une semaine du TransCanada Highway et une fermeture de 3 jours de la Canadian Pacific Railway essentiellement paralysant le trafic est-ouest pendant presque une semaine. En Exshaw, la tempête a provoqué des inondations de Jura, Heart et Exshaw ruisseaux dans la ville d'Exshaw et Lac des Arc. Grotte Creek et petits ruisseaux adjacents inondés Highway 1A sur les deux côtés des communautés, leur couper l'accès à l'est et à l'ouest. L'événement a été reconnu comme constituant un risque intolérable et une série d'études ont été lancées pour comprendre dangers et des risques dans la zone touchée. Cet article détaille la réponse hydro-géomorphologique régionale de la pluie torrentielle pour les ruisseaux Cougar, Exshaw et Jura.

1 INTRODUCTION

The southwestern Alberta mountain front was affected by a high intensity/duration rainstorm between June 19 and 21, 2013. Direct runoff, coupled with meltwater released from rain-on-snow, caused sudden and prolonged high flows in the Bow, High, and Ghost Rivers and their tributaries originating in the Rocky Mountains. These flows resulted in high rates and volumes of sediment transport, bank erosion and avulsions on alluvial fans.

Almost all of the steep gradient tributaries to Bow River within the municipal boundary of the Town of Canmore and Hamlet of Exshaw were affected by the combined storm and snowmelt runoff, including Cougar Creek, Exshaw Creek and Jura Creek, the focus of this report. Major damage was sustained on Cougar Creek fan due to sediment deposition and bank erosion along the principal channel which is flanked by dense development Economic damages were in excess of $30,000,000 for emergency response and reconstruction of both public infrastructure and private property. This does not include costs associated with the closure of the Trans Canada Highway and the rail line, disruption to tourism and industry in Canmore, and the ongoing impact to displaced residents and businesses.

Most of the information in this paper is provided in greater detail in a series of reports by BGC Engineering Inc. (2013, 2014).

2 STUDY AREA

The study area is located in the Bow River Valley and encompasses two principal foci, namely Cougar Creek at the Town of Canmore and the Exshaw – Jura Creek fan complex at the Hamlet of Exshaw (Figure 1).

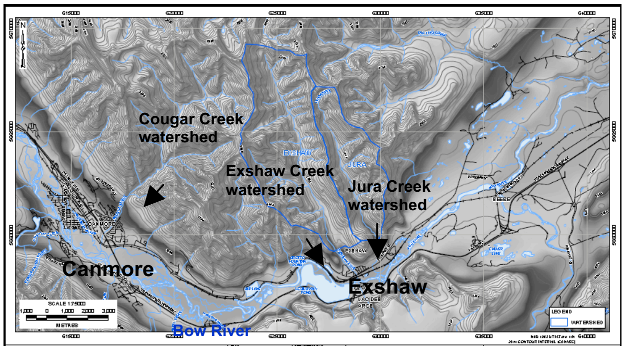

Figure 1. Study area.

3 HYDROCLIMATE

Hundreds of debris floods and debris flows occurred in the front ranges of the southern Canadian Rockies during the June 2013 flood. Such abundant sediment movement activity leads to the question of the storm's synoptics. This section summarizes the interplay of three low pressure cells responsible for the conveyance of warm air masses towards the southern Rocky Mountains.

3.1 Synoptic Weather Conditions

Three low pressure systems interacted to cause the heavy precipitation pattern in the Bow Valley. The resulting complex of storms incorporated large moisture supplies from air originating over the Pacific and Gulf of Mexico, and was able to move this humid air towards the east side of the Rockies. Winds with a significant easterly component pushed the humid air upslope leading to extensive cloud formation, precipitation and embedded thunderstorms. Moisture leaving the atmosphere as rain was replaced by a continual inflow of more humid air in the conveyer belt of winds from the south and east which enabled heavy rainfall for three consecutive days.

On 18 June 2013 an old extratropical cyclone was east of the Oregon coast with winds ahead of the low moving moist air from over the Pacific into southern Alberta (Figure 2). Warm temperatures prevailed over southern Alberta. A second, stronger low-pressure system existed over Utah and was moving northward.

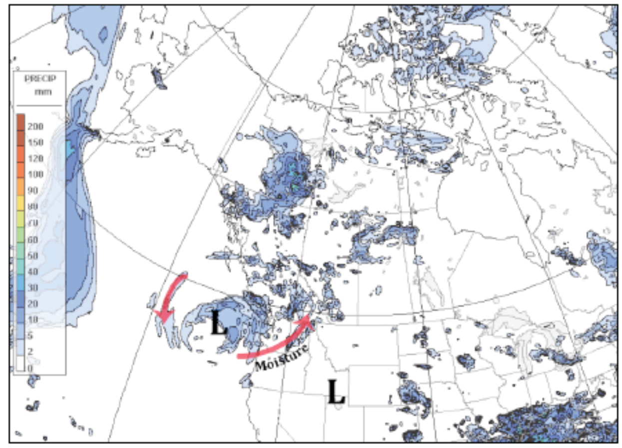

Figure 2. Map showing 24-hour accumulated precipitation (mm) valid at 5 am on June 18, 2013. "L" symbolizes low-pressure systems and red arrows show the prevailing direction of flow with moisture into southern Alberta.

On June 19, 2013, the old low pressure system from the Pacific was moving slowly eastward and continued to bring more moisture inland towards Alberta (Figure 3). The Utah low-pressure system was strengthening and moving northward now on the Idaho-Montana border, resulting in very warm moist air carried by increasing wind speeds towards southern Alberta. This warm and humid air originated from the Gulf of Mexico. The combined effect of these two lows was to create a conveyor belt of fast moving warm and humid air that was pushed towards the eastern slopes of the southern Albertan Rockies. These conditions led to heavy rain over southwestern Alberta.

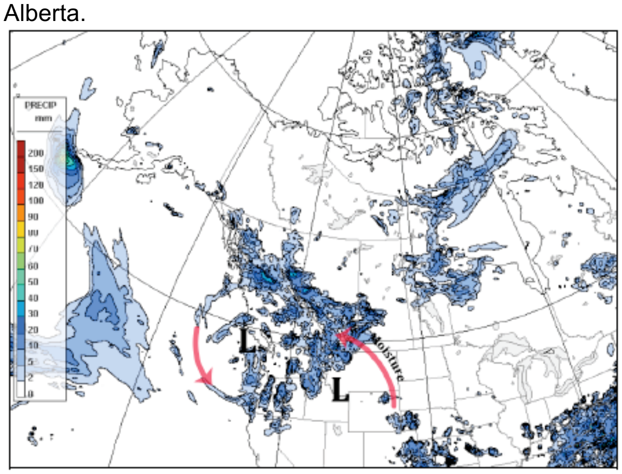

Figure 3. Figure 3. Similar to Figure 2, but for June 20, 2013.

On 20 June 2013, the low-pressure system near the coast was weakening but still advecting moisture inland towards the former Utah low. The latter system was also weakening, but continued to transport subtropical moisture towards the Rockies. At the same time a surface low-pressure system developed in southern AB, which consolidated energy from the two former lows (marked by an X in Figure 4). During that time the very moist southeasterly to easterly flow across southern Alberta resulted in enhanced precipitation due to substantial orographic uplift. Thus heavy rain continued well into the 21st of June at which time the rain began to subside.

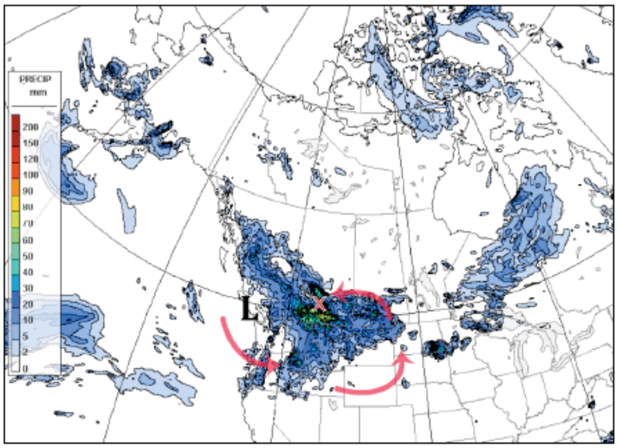

Figure 4. Synoptic Meteorology on June 20, 2013.

Bow River reached its highest recorded discharge at Banff with 439 m^3/s exceeding the previous instrumented record of 1923 (399 m^3/s).

3.2 Storm Rainfall

Some 9 million m^3 of rain (220 mm) fell on the 43 km^2 watershed of Cougar Creek over the course of 3 days. The event is the largest on record at the Kananaskis climate station (located about 20 km east-southeast of Canmore) for 1-day, 2-day and 3-day durations, with estimated return periods of 235-, 360-, and 750-years, respectively. The 1-day maximum rainfall at Kananaskis (157 mm) was 75% greater than the long-term average rainfall for the month of June. The return period of maximum rainfall intensity is estimated to range between 5 to 10 years, indicating that the storm intensity was not extremely rare for short duration rainfall, although it was extreme in terms of total volume and duration. Of interest is that the storm was much less severe in Banff, which is only located about 20 km to the northwest of Canmore.

3.3 Snowmelt Contribution

While snowpack is not monitored in the Cougar Creek watershed, it is monitored regionally at both the nearby Marmot Creek Research Basin, operated by the University of Saskatchewan, and at several locations further south managed by the Alberta provincial government. Over the flood event, an additional 90 mm snowmelt was observed by researchers at the University of Saskatchewan in the Marmot Basin.

Using the lowest regional provincially-operated snow pillow elevation with snow at the time of the storm event (2060 m), and assuming that the snowpack below 2060 m was minimal and non-contributory to runoff, it was estimated that 63% of the 41.9 km2 catchment could have been covered in snow immediately prior to the rainfall.

Two other data sources were also investigated to characterize the distribution of the Cougar Creek snowpack before, during, and after the June storm event: the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) and the model-based Snow Data Assimilation System (SNODAS). Unfortunately, there was too much cloud cover over the Cougar Creek watershed throughout June 2013 to utilize MODIS data for the present analysis. SNODAS parameter estimates suggest that roughly 7% of the Cougar Creek watershed had snow cover prior to the storm event (June 18), which ranged in thickness from approximately 14 to 123 cm. This is inconsistent with observations from the nearby Marmot Basin. Clow et al. (2012) indicate that SNODAS performs poorly in alpine areas due to the effects of terrain, vegetation and prevailing wind direction on the redistribution of snow by wind. Windward slopes experience snow scour and leeward slopes experience snow deposition. As the Cougar Creek watershed is on the leeward side of prevailing winds, it is possible that SNODAS under-predicted the snowpack here.

The available snowpack and snowmelt data indicate that the 3-day rainfall estimate of 220 mm in the Cougar Creek watershed was augmented by snowmelt. While up to 63% of the watershed may have been covered in snow prior to the event, the available data suggest the additional contribution of snowmelt during the storm on the order of 10 to 30%.

4 GEOLOGICAL SETTING

4.1 Geology

The Canadian Rocky Mountains (CRM) are a fold and thrust belt, where thick units of more erosion resistant Paleozoic carbonates were folded and thrust progressively in a north-westerly direction over more friable Mesozoic sandstones and shales. Four main sequences of rocks can be characterized in the Canmore region.

The oldest unit at the base is part of the North American cratonic plate. The next unit is the Pre-Cambrian to Lower-Cambrian clastic and minor carbonate rock unit (~10 km thick) composed of weathered rock from the Canadian Shield (further east). The ~ 6.5 km thick middle carbonate unit (Middle-Cambrian to Upper Jurassic) consists of marine carbonates (limestone and dolostone) and shale. The upper unit (~ 5 km thick) is composed of a young Jurassic to Tertiary unit of sandstone, shale, conglomerate and coal.

Osborn *et al.* (2006) describe the final stages of the mountain building stage as being associated with differential erosion of various units. The softer Mesozoic rocks led to rounded mountain tops exposing the underlying Paleozoic and Proterozoic rocks that can support steeper and higher slopes. Most geologic units flanking Bow River valley are primarily composed of thick Carboniferous and Devonian successions. Most of the rock units are of Lower Carboniferous (Mississippian) origin with some representation of Upper Carboniferous (Pennsylvanian) and Devonian units.

Most of the rock formations are sedimentary (carbonates and siliciclastics) with minor metamorphic components (i.e. calcite). Geologic formations that are more resistant to erosion are more conducive to the formation of cliffs, while more recessive units tend form sloping ledges.

4.2 Engineering Geology

Thrust faults and folds in the region strike in a northwest to southeast direction. Two common joint sets can be differentiated: strike joints parallel to the orientation of bedding planes and dip joints that are perpendicular to bedding. Conjugate joints occur on rare occasions (Cruden and Hu, 1999). The main channel of Cougar Creek drainage is oriented approximately at a right angle to the main thrust fault belt. These conditions favour large scale instability in the watershed, primarily rockslides and rock avalanches. Large scale failures of this type can and have travelled into the valley bottom where they can dam Cougar Creek creating a sizable impoundment given the low overall creek channel gradient (5%). BGC (2014b) has documented at least twelve relic landslide dams along the mainstem channel of Cougar Creek.

4.3 Quaternary Geology

The Late Pleistocene and Holocene epochs of the Quaternary Period in the Canadian Rockies represent a period of changes in climate due to a transition from extensive glaciation to de-glaciation. During this period, the final stages of major glacial erosion and deposition occurred and the establishment of the present day Quaternary sedimentation in the Bow Valley was initiated.

Late Pleistocene glaciers reached their maximum extent in the Canadian Rockies around 16,500 years BP. During the Holocene minor periods of glacial advance alternated with glacial retreat restricted to the high elevation icefields and cirques (Reasoner *et al.,* 1994). Such advances provided sediments to the channel system and likely locally oversteepened some slopes. The lack of morainal deposits in the watershed can likely be explained by the high rates of geomorphic activity that eroded or obliterated evidence of Holocene glacial advances.

Tributary valleys were likely ice-free when there was still a sizable glacier in Bow Valley. This glacier would have created a dam against which ponding would have occurred in the principal tributary valleys. Particularly in low gradient valleys such as Cougar Creek, glaciolacustrine sediments suggest the development of glacially dammed lakes that may have persisted for many years or even centuries. Eventual drainage of these lakes and subsequent erosion has exposed thinly bedded lacustrine sediments in soil outcrops.

The early Holocene experienced a period of drought called the Hypsithermal that caused the lowering of lake levels, higher treelines and almost complete ablation of glaciers between 10,000 years BP and 9,400 years BP. According to studies in lake sediment cores, the glaciers did not re-establish until 6,800 years BP (Beierle, 1997; Beierle and Smith, 1998).

The term "Little Ice Age" is used to describe the late Holocene cooling time period beginning in approximately the 1200s and terminating in the mid-1800s with the present day warming trend. Summit Icefields, valley glaciers and cirques reached their Holocene maximum extent during this period of time (Luckman, 2000). There is little evidence of Little Ice Age moraines in the upper watershed of any of the study creeks where landslides and erosion may have removed such evidence.

5 HYDROGEOMORPHIC RESPONSE

Unlike in Calgary and High River, the Town of Canmore, was not flooded by Bow River. However, numerous tributary creeks produced debris floods or debris flows transporting on the order of several hundred thousand cubic metres of debris from their respective watersheds onto adjacent alluvial fans and the Bow River floodplain. In this paper, we discuss the events and hydro-geomorphic response of the June 2013 storm for Cougar, Exshaw and Jura Creeks. It is hoped that this description provides insight into the hazards and risks of alluvial fans in the Canadian Rocky Mountains, which in turn will hopefully lead to a systematic fan hazard and risk evaluation strategy in Alberta.

5.1 Cougar Creek

The most damaging flow was on Cougar Creek where approximately 90,000 m^3 of debris were deposited (BGC, 2014b).

5.1.1 Watershed

Cougar Creek fan has an area of 3.1 km^2 and is unlike most fans in the Canadian Rocky Mountains in that it is very densely developed, including 1417 residential homes; a number of lodges/resorts between Highway 1 and Highway 1A; a light industrial area in the southeast corner of the fan; one elementary school (Elizabeth Rummel); a heliport (Alpine Helicopter); numerous roads including a crossing of the creek at Elk Run Boulevard; Highways 1 and 1A; the Canadian Pacific (CP) Rail line; various municipal infrastructure (telecommunication lines, sewers, etc.); and powerlines (Figure 5).

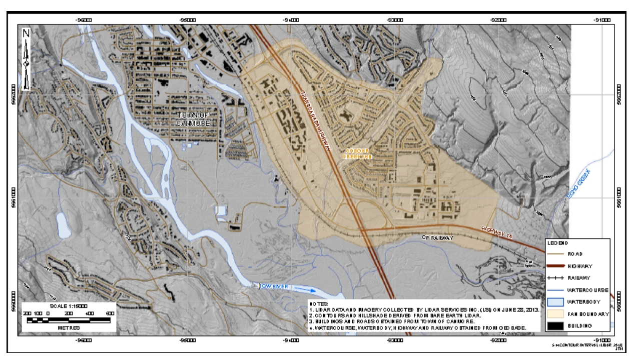

Figure 5. LiDAR-generated shaded relief image of Cougar Creek fan and Infrastructure.

Table 1 provides some morphometric information of Cougar Creek channel and watershed.

Table 1. Morphometric characteristics of the Cougar Creek watershed.

Characteristic	Value
Watershed area[1] (km^2)	43.5
Fan area (km^2)	3.1
Maximum elevation (m)	2820
Minimum elevation[2] (m)	1404
Mean elevation (m)	2150
Average gradient mainstem (%)[3]	5.5
Average gradient on fan (%)	4.2

1 As measured to the fan apex.
2 As observed at the fan apex.
3 For a distance of 3 km upstream of the fan apex.

5.1.2 June 2013 Event

The June 2013 storm event led to extensive aggradation along Cougar Creek both upstream of the fan apex and on the fan reaches, which was accompanied by lateral instability on the fan as the channel lost confinement. Comparison of 2009 and 2013 LiDAR surveys indicates that local aggradation and erosion of up to 8 m and 5 m occurred. The channel aggradation allowed the streamflow to overtop the confines of the previously confined channel which led to flood waters eroding banks past property lines, undermining buildings foundations and destroying the support of decks and supported balconies (Figure 6). The peak flow of the debris flood appeared to have exceeded at least three to four times the estimated 100-year return period flood of 16 m^3/s (AMEC, 2003). The flood event was unusual in that high flows were sustained for a period of several days.

Figure 6. Aerial view of Cougar Creek fan following the June 2013 flood.

Due to significant effort by the Town of Canmore and its consultants and contractors, no creek avulsion occurred near the fan apex at a culvert crossing of Elk Run Boulevard. Here the 9.5 m wide, elliptical culvert sustained damage, but survived thanks to continuous excavation of debris during the event which threatened to block the culvert. An avulsion at this location would have led to significantly more damage to buildings and infrastructure than was observed.

5.1.3 Damages

The damages incurred along the creek corridor during the 2013 debris flood were severe.

Above Elk Run Boulevard, aggradation and channel widening resulted in the creek eroding a section of road and the backyards of a number of homes. An outdoor hockey rink on the left bank of the creek at Elk Run Boulevard was also completely destroyed (Figure 7). A major concern during the flood was Elk Run Boulevard becoming outflanked, resulting in the creek overtopping the road and potentially heading into the subdivision. Emergency crews were present throughout the storm at the road crossing to keep the culvert inlet as free of debris and sediment as possible and to minimize the amount of outflanking that did occur (major erosion occurred behind both concrete wingwalls). Existing riprap on either bank was completely destroyed during the flood, presumably due to initial undermining followed by channel aggradation.

Figure 7. Upstream view of Cougar Creek from Elk Run Boulevard during the June 2013 flood.

Between Elk Run Boulevard and Highway 1, the creek also significantly widened. Damages to homes were severe in this reach (Figure 8). Walking paths on either side of the creek were completely eroded and a pedestrian bridge was outflanked on either bank, although it was not washed away. Riprap placed on the banks and in the channel during 2012 was completely destroyed, initial undermining followed by channel aggradation.

Figure 8. Damage to homes along left (east) bank of Cougar Creek between Elk Run Boulevard and Highway 1.

Additional major damage was recorded at Highway 1, where the blocked culverts resulted in flows avulsing over the highway and down the median to the east (Figure 9). These overflows resulted in portions of the highway being undermined and collapsing. Further downstream, the box culverts at Highway 1A and CP Rail were also blocked by sediment and debris, the latter of which was out of commission for approximately three days until it was repaired.

Figure 9. Lower Cougar Creek fan during July 19, 2013 flood. Photo: Alpine Helicopters.

5.1.4 Debris Floods

The June 2103 flood event on Cougar Creek is best described as a debris flood. A debris flood can be defined as: "a very rapid surging flow of water heavily charged with debris in a steep channel" (Hungr et al., 2001). Debris floods typically occur on creeks with channel gradients between 3 and 30%. The term "debris flood" is similar to the term "hyperconcentrated flow", defined by Pierson (2005) on the basis of sediment concentration as "a type of two-phase, non-Newtonian flow of sediment and water that operates between normal streamflow (water flow) and debris flow (or mudflow)". Transitions from water flow to debris flood / hyperconcentrated flow and vice versa occur at minimum volumetric sediment concentrations of 3 to 10%.

A detailed hazard assessment of Cougar Creek (BGC, 2014b) indicates that significant sediment movement in the watershed derives from two distinct data populations.

- The first population is interpreted as debris floods where sediment concentrations (bedload and suspended sediment) increase in response to extreme rainfall and elevated bank erosion rates. Given the low channel gradient (~5%) along Cougar Creek, sediment entrainment is largely through the tractive forces of water, rather than mass channel bed mobilization as can be observed on steeper channels.
- The second data population is interpreted to consist of debris floods triggered by hillslope processes (debris flows, slumps, ravels) feeding sediment to the main channel as well as landslide dam outbreak floods from either tributary debris-flows or rock slides of variable size.

Although the June 2013 debris flood was unusual, a 1947 air photograph of the fan illustrates that the Cougar Creek fan has historically been a very active landform (Figure 10).

Figure 10. Cougar Creek current buildings and lot lines superimposed on a 1947 air photograph.

5.2 Municipal District of Bighorn

Similarly destructive debris floods and some debris flows occurred at the Municipal District (MD) of Bighorn. Here, in particular Exshaw, Jura, Heart and Grotto Creeks, witnessed significant debris floods that blocked the only access (Highway 1A) and the Canadian Pacific Railway Line in several locations to the east and west of the Hamlet of Exshaw. This event isolated the hamlet and all business activity ceased for several days.

Jura Creek and Exshaw Creek are south flowing tributaries that discharge into Bow River at the Hamlet of Exshaw (Figure 11). Similar to Cougar Creek, both creeks were impacted by debris floods during the June 2013 rainstorm, with major volumes of sediment transported to their respective alluvial fans.

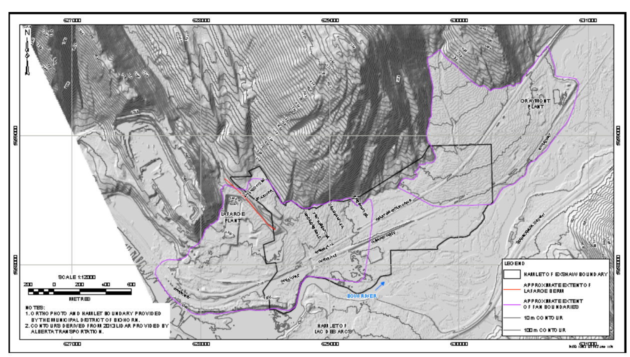

Figure 11. Exshaw and Jura Creek LiDAR-based topography and fan outlines.

5.2.1 Exshaw Creek

Exshaw Creek has a watershed area of approximately 31 km^2, and elevations range between 1300 m and 2820 m. The fan of Exshaw Creek covers an area of approximately 1 km^2 and is bordered by steeply rising mountains to the north, and Bow River to the south. On its eastern margin, Exshaw Creek fan interfingers with Jura Creek fan. Most of the hamlet's residents live on the east side of Exshaw Creek, with only a few residential properties located on the west side immediately adjacent to Highway 1A. A majority of the west fan area is occupied by the Lafarge cement plant which is protected from Exshaw Creek by a berm that is up to 10 m high and extends from the fan apex to just below the cement plant, a distance of about 500 m. An industrial area is also located near the fan margin between the CP Railway and the Bow River.

From the fan apex at elevation 1340 m, Exshaw Creek flows for about 800 m before reaching the bridge crossings of Highway 1A, the CP Railway, and a secondary road (Figure 12). Just downstream of this final bridge, Exshaw Creek discharges into Bow River. The Hamlet of Lac des Arcs is located directly opposite of Exshaw on the fan of Heart Creek, on the south side of Bow River.

Figure 12. Exshaw Creek looking upstream with Bow River in the lower left hand corner. The industrial complex on the left in mid fan is Lafarge cement. The Hamlet of Exshaw is mostly on the right (east side) of the fan.

About 700 m upstream of the fan apex, an approximately 8 m high dam is located on Exshaw Creek. This dam was constructed around 1906 and was originally used to supply fresh water to the plant and hamlet residents. The dam no longer functions as a reservoir, as it is completely filled with sediment.

5.2.2 Jura Creek

Jura Creek is located to the immediate east of Exshaw Creek, and has a watershed area of approximately 14.6 km^2. Elevations in the Jura Creek watershed range between 1290 m and 2385 m.

The fan of Jura Creek has an area of about 0.8 km^2 and is generally undeveloped. Exceptions are a lime and limestone plant operated by Graymont and located on the fan's distal margin to the east; the east end of the Exshaw Industrial Area; and the linear corridors of Highway 1A and the CP railway. The distal east end of the Exshaw Creek fan and the distal west end of the Jura Creek coalesce at the east end of the residential development in the Hamlet of Exshaw.

From the fan apex at elevation 1345 m, the creek flows for about 1 km down to Highway 1A (Figure 13). Prior to the June 2013 flood, streamflows used to be conveyed under the highway through a 2.2 m diameter culvert. This culvert was destroyed by the June 2013 debris flood. The CP Railway is located a further 230 m downstream, below which Jura Creek discharges into a side channel of Bow River.

Figure 13. Jura Creek fan with a re-excavated channel through the centre of the fan and the avulsion path to the left (west). Highway 1A in the foreground. July 2013.

5.2.3 Watershed Conditions

The watersheds of both Exshaw Creek and Jura Creek were severely impacted by the June 2013 flood: the mainstem channels and their tributaries showed evidence of extensive channel disturbance. Several tributaries experienced either hyperconcentrated flows (debris floods) or debris flows during the June 2013 flood, contributing sediment to the mainstem channel of both creeks, which had a braided channel planform for a significant portion of its length.

Both creeks are incised into a thick unit of presumably late Pleistocene sediments (Figure 14 and 15). These sediments are very unstable and provide a quasi-unlimited supply of sediment during flood events. The implication is that a repeat hydroclimatic event of similar magnitude to 2013 storm (or larger) will result in similar or larger sediment movements with similar or more severe flood consequences, and potential risks to personal safety.

Figure 14. Upper watershed of Jura Creek showing a very active floodplain approximately one month after the June 2013 debris flood.

Figure 15. Upstream view of Exshaw Creek in mid reaches. The channel is incised into a thick sequence of unstable late Pleistocene sediments. July 2013.

5.2.4 Event Chronosequence and Damages

On Wednesday June 19, both creeks were dry in mid-afternoon. At about 5:00 PM, flows were noted in Jura Creek. As the Highway 1A culvert at Jura Creek was known to be problematic during flow events due to sedimentation, MD of Bighorn staff began mobilization efforts to ensure excavators were on stand-by. Two excavators started work at Highway 1A later that evening. As flows continued to rise, an additional excavator and a bulldozer were mobilized to Jura Creek at around 9:30 PM.

Flows continued to increase through the night and at about midnight Jura Creek partially avulsed upstream of Highway 1A on the right (west) bank. At the same time, the heavy equipment was unable to keep the highway culvert free of sediment. As a result, Jura Creek was flowing both over Highway 1A, along the highway ditch on the north side, and along the upstream avulsion path (Figure 12). The diverted water pooled at a low-lying area located at the east end of the residential development in the Hamlet of Exshaw. Water pooled to a depth of about 1.3 m and the homes in this area were under water for about one week after the flood event.

A local state of emergency was called early in the morning of Thursday, June 20 and a decision was made at 2 AM to excavate a channel through Highway 1A at the culvert location to minimize the amount of water avulsing to the west toward Exshaw.

Later that morning, Exshaw Creek became the focus of attention due to rising floodwaters. Problems along this watercourse started near the fan apex where a pedestrian bridge was undermined and swept downstream. Creek overflows then started to descend into residential areas on the east side of the creek, again near the fan apex.

About this time the bridge at Highway 1A had become blocked with debris and a second flow avulsion developed on the left (east) bank of Exshaw Creek (Figure 16). These overflows were conveyed along the upslope ditch of Highway 1A toward the already inundated low-lying area, further aggravating flooding there.

Figure 16. Downstream view of the Highway 1A bridge spanning Exshaw Creek. July 2013.

High flows continued unabated through Thursday, June 20 and by the afternoon concerns were raised that the Highway 1A bridge abutments were in danger of being compromised. Limestone riprap was then mobilized from the Lafarge quarry to shore up the bridge abutments and also a section of the right bank where ongoing erosion was threatening the local firehall.

According to Reeve Dene Cooper, 150 of the hamlet's 200 residential homes sustained some degree of damage during the flood event. These damages included sewer back-ups, as the hamlet's pumps were damaged by the flooding. Flood damages were greatest in the low-lying area where overflows from both creeks coalesced and ponded, with drainage intercepted and redirected by the Highway 1A road embankment.

The high sediment volumes mobilized in Exshaw Creek also resulted in a secondary fan forming at the confluence with Bow River. Reeve Dene Cooper noted that the fan temporarily extended about two-thirds of the way across the river at the peak of the flood event, resulting in Bow River flows being diverted along the right (south) bank which led to significant bank erosion of the Heart Creek fan (Figure 17). One home in Lac des Arcs was severely undermined by the bank erosion. Review aerial imagery indicates that approximately 15 m of bank erosion occurred at this location during the flood event.

Figure 17. Aerial view of the confluence of Exshaw Creek with the Bow River. Deposition at the mouth of Exshaw Creek concentrated flows along the right bank of the Bow River, resulting in bank erosion and undermining of one home (circled in red). All homes of Lac des Arcs are located on Heart Creek fan.

By the afternoon of Saturday June 22, flows in both creeks had returned to normal levels for the season.

6 CONCLUSIONS

A very heavy rainfall event with up to 270 mm precipitation occurred over a period of three days in mid June of 2013. This amount is roughly half of the mean annual rainfall, as measured at the Kananaskis climate station located some 20 km east of Canmore. The return period of this storm is likely in the hundreds of years and was exacerbated by snowmelt contribution in the order of 10 and 30%. This rainfall event led to damaging debris floods on Cougar Creek, Exshaw Creek and Jura Creek.

Of these creeks, Cougar Creek is particularly dangerous because debris floods are generated by at least two processes. One is bedload mobilization by exceedance of a critical discharge as a function of the intensity and duration of a rainstorm, which at times can combine with snowmelt (e.g. the June 2013 event). The other debris-flood generator is a landslide (debris flow or rock slide/rock avalanche) dam outbreak flood of which there is ample evidence along the main channel of Cougar Creek. In particular a high landslide dam close to the fan apex could result in peak flow rates far exceeding those by rainfall-generated floods and debris floods.

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