# GONE LIKE A GHOST: THE GHOST GLACIER FAILURE AND SUBSEQUENT OUTBURST FLOOD, MT. EDITH CAVELL, JASPER NATIONAL PARK

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ABSTRACT: During the evening of August 9th or early morning of the 10th 2012 the Ghost Glacier fell from the North Face of Mount Edith Cavell in Jasper National Park. Approximately 125,000 cubic meters of ice fell close to a vertical kilometer onto a lower glacier and then a tarn which was full to overflowing with recent precipitation and the winter's snowmelt runoff. The resulting wind blast and water displacement caused extensive damage to the park's infrastructure within an area that receives high numbers of park visitors. After an extensive search and rescue response it was determined that, due to the timing of the event, nobody was missing or injured. The glacial lake outburst flood is representative of the hazards within a rapidly changing post glacial environment and presents challenging questions to risk managers in high visitor use areas such as the Canadian National Parks.

KEYWORDS: Complex avalanche, Rocky mountains, ablation.

## 1. MOUNT EDITH CAVELL

Mount Edith Cavell is located within Jasper National Park in the Canadian province of Alberta. The peak reaches an elevation of 3,363 m and at a distance of 21.8 km to the south of Jasper its north face is clearly visible from the townsite. The day use area is open during the summer months to the public many of whom are visitors to the area on vacation. To get to the area from Jasper, travel south on Highway 93 for 7.5 km, just past the park's south gate turn right onto Highway 93A. Follow 93A for 13 km, the Mt Edith Cavell road branches to the right just past the Astoria River and is 14 km long. Access by road to the area has been possible since the 1920's. The facilities and infrastructure of the area have been remodeled many times since those early days. The road ends in a parking area from which a trail system can be hiked to either the meadows at treeline or the Cavell Tarn below the north face of Mount Edith Cavell (Fig. 1). The area is one of the park's most popular destinations.

There are three noticeable glaciers on the north face of the Mount Edith Cavell; the Angel, Cavell and Ghost. The Angel Glacier is a hanging glacier flowing from a cirque below the peak and was formerly confluent with Cavell Glacier that occupies the area at the foot of the near vertical north face (Fig 1).

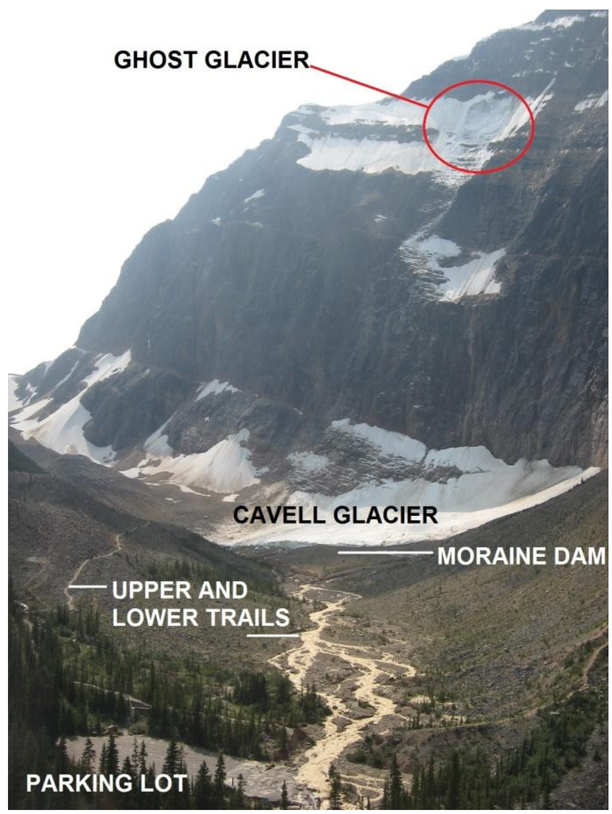


Fig. 1: The Mount Edith Cavell day use area. (Park Canada G.Lemke)

In the 1700s Cavell Glacier extended downvalley to the present parking lot. During the 20th century (See Luckman References) the glacier has receded upvalley and thinned, resulting, after 1960, in

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the formation of a proglacial lake into which Cavell Glacier now calves. The Ghost glacier is located high (2,800 m) on the mountain's north face. Photographic images taken in the early twentieth century show the glacier to be approximately twice the size of that prior to its release in August 2012. In the 1950's below the north face the pond which would become the Cavell tarn started to grow fed by the melting waters of the Cavell and Angel Glaciers. At the time of the Ghost Glacier failure it was over 38 m deep and close to 400 m in diameter.

## 2. EVENT PRELUDE

The early summer of 2012 had been wet. This precipitation in combination with the melt water runoff from an exceptionally high snowfall winter had produced flooding in many areas of the park. During a severe convective storm on the night of August 7th, a few days prior to the Cavell event, ten landslides released from the rock slabs flanking Medicine Lake, 28 km east of Cavell. The largest of these swept a large section of pavement into the lake making the road impassable. Although likely, it is not known whether this storm also fell at Mount Edith Cavell, possibly contributing to the destabilization of Ghost Glacier. Images and video clips posted by the public on social media sites; Facebook and YouTube, showed glide cracks and relatively small releases occurring several days prior to the main release. These went unnoticed by park officials. There were no calls of concern from members of the public visiting the site.

### *2.1 The Glacier Falls*

During the night of August 9th or the early morning of August 10th approximately 60% of the Ghost Glacier released from the north face of Mount Edith Cavell (Fig. 2 and 3).The displaced ice fell approximately 1,000 m onto the Cavell Glacier (Fig. 4) and into the Cavell tarn (elevation 1,775 m), located approximately 600 m from the base of the north face, producing a glacial lake outburst flood (GLOF). The estimated volume of the displaced ice ranges considerably from a maximum 200,000 cubic meters to a minimum of 100,000 cubic meters. It is likely the volume was close to 125,000 cubic meters. The estimated average ice thickness of the failed glacier material was 20 m. The ice entered the tarn from the southeasterly edge of the Cavell Glacier displacing a huge volume of water and ice blocks across 170-180 m of the downvalley shoreline .

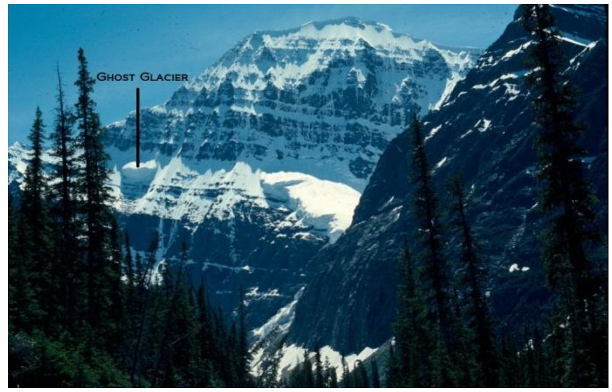


Fig. 2: The Ghost Glacier prior to August 10th 2012 (Parks Canada, Jasper Park archive)

Ice blocks of up to four and a half meters high, weighing approximately 60-80 mt, were lifted out of the tarn by the surge (Fig. 5). Warning signs, positioned at the shoreline, were blasted out to the side by the surge wave and/or air blast. The waters ran downhill over the moraine plug at the tarn outflow carrying ice blocks with it. The overflow from the tarn was carried down the former, now considerably enlarged, stream channel from the tarn and a second, new channel with a slightly lower ingress, was cut across the moraine dam approximately 50 m west of the former channel.

Fig. 3: The Ghost Glacier after it fell on August 10th (Park Canada G.Lemke)

The channels cutting across the flanks of the moraine dam were considerably enlarged, one up to 5 m deep and 30 m wide, by the exiting water. Massive blocks of glacier ice were carried into the larger channel (Fig. 6). The two overflow channels ran down the relatively steep face (ca. 9 degrees) before joining, about 205 m from the tarn. At this point the water fanned out over the outwash plain to a width of 75 m and a likely flow depth of 2 m.

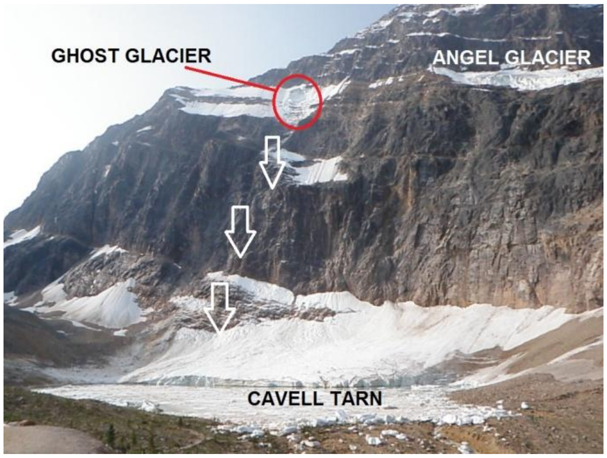


Fig. 4: The arrows show the trajectory of the ice-fall. (Parks Canada R.Wedgwood)

Fig. 5: A large glacial ice blocks washed onto the moraine dam. (Parks Canada R.Wedgwood)

Downvalley a terminal moraine, dating from the1860s, constricted the flow of the water adjacent to the parking lot, 1,020 m from the tarn. Surge marks on nearby trees and rocks indicate the water was at least 1.6 m deep here. The relatively narrow creek channel through the 4 m high moraine wall was widened to 40 m by the surging water. Just below the moraine the floodwaters excavated the material from below the pavement in the parking area (1,170 m) causing the asphalt to fold and sag over the larger rocks below (Fig.7).

Fig. 6: Glacial ice blocks deposited in an enlarged downstream channel. (Parks Canada R.Wedgwood)


Fig. 7: Collapsed pavement in the parking area (Parks Canada R.Wedgwood)

One of the four outhouses was undermined and toppled over, while the nearby picnic area between the road and creek was buried by rocks and gravel (Fig. 8). Part of the flow was diverted into the lower quarter of the parking area and down the area access road for approximately 100 m. Some of the quartzite boulders pushed onto the road measured 1 m x 0.75 m x 0.25 m. In the outwash downstream of the parking area a maximum water depth of 1.6 m was estimated from the mud drape against a large standing snag (Fig. 9).

Fig. 8: A picnic tables partially covered by rocks carried by the surging waters. (Parks Canada M.Eder)

Close by the picnic area, the water excavated a new channel ca 2-5 m wide that exposed buried tree stumps.  Radiocarbon dates from these trunks indicated that they probably grew on a former outwash surface and were buried by outwash from the glacier during 1700s and 1860s Little Ice Age advances.  Continuing towards Cavell Lake the water depths appeared to decrease as they spread across the valley width spanning a distance of 154 m. The total extent of the downstream damage was significant. This included:

- Removal of trees
- Drainage channel erosion
- Signage destruction
- Lower hiking trail destruction
- Destruction of pavement at the entrance end of the parking lot and a section of the road
- Destruction of an outhouse and excavation of the septic tank pit. Large boulders (40 cm by 40 cm by 50 cm) and tonnes of gravel pushed onto the road below the parking area for approximately 100 m.
- The complete and partial burial of metal and wooden picnic tables in the lower picnic area under tons of gravel and boulders

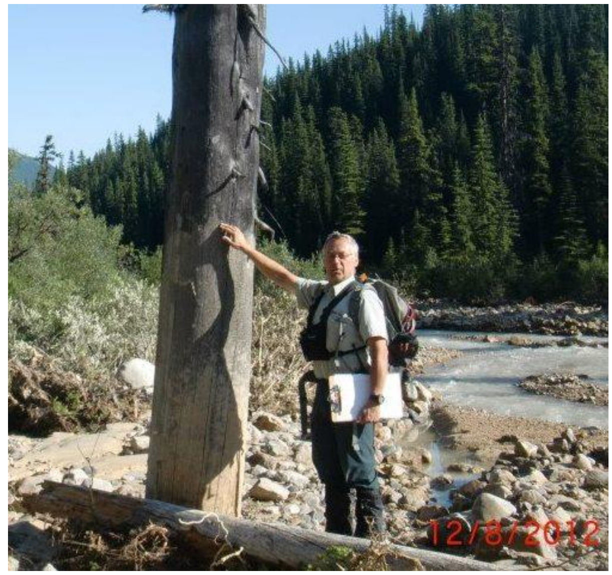


Fig. 9: Water surge marks left on a snag (Parks Canada R.Wedgwood)

### *2.2 The First Encounter*

The first people to encounter the aftermath of the outburst flood were three alpine climbers. They report that at approximately 04:00 AM while driving up the Cavell road their passage was blocked by a river flowing down the road. They reported the temperature being cool at an estimated $10^{0}$ C and hearing a loud booming over the roar of the water which sounded like thunder. Parking a little further away from the water front they continued on to the climbing route on the east ridge of Mount Edith Cavell. At 08:21 AM a tourist driving up to the Edith Cavell day use area reported a “mud slide” blocking the road just above the Edith Cavell International Hostel. The report was made with a cell phone from the junction of 93A and the access road to the day use area. Initially the magnitude and the nature of the event was not realised and highway crews were sent to clear the road debris. More information arrived at 08:50 AM when a Parks biologist arrived at the site and reported, “lots of water and debris” across the road.  By 09:22 AM park staff were on site and it was apparent that a significant event had taken place which warranted further investigation. The access gate was closed at the Cavell road junction with 93A, and it did not reopen to public motorised access until late June 2013.

### *2.3 The Alarm Is Sounded*

With a large area that needed rapid searching a helicopter was dispatched from the town of Valemount, located 83 km to the west in British Columbia. An incident command post was established as rescue teams hastened to respond. Of immediate concern was the whereabouts of the occupants of the three vehicles parked close to but not in the debris on the road. These belonged to three alpine climbers who had arrived at the site at 04:00 AM to climb the east ridge of Mount Edith Cavell. None had thought to report the event. With the access to the area being restricted, calls from the public and local tour companies rapidly started arriving at the information and dispatch centres. The Parks Visitor Experience manager and the Media Relations officer were notified so information could be released to the public, business community and media outlets. The area was searched for missing or injured people with ground teams and, starting at 11:39 AM, with an airborne helicopter team.

By 14:40 PM the search and rescue team felt confident that nobody had been involved in the event and the helicopter returned to Valemount. The climbers were accounted for and all the other persons in the area, except one, had been asleep at the hostel at the time of the event. The hostel staff who had spent the night at the hostel, located 1.8 km from the parking area trailhead, reported that they may have heard a loud noise between 01:30-02:30 AM. A photographer who had spent the night in his car below the hostel reported, in a conversation with the author, that he had not heard anything all night.

### *2.4 Site Assessment*

With public safety concerns under control, and access to the area restricted, the site was visited on August 11th and 12th to measure and record the character and destructive nature of the event. The field work focused from the tarn and downvalley for 1.2 km (Fig. 10).

Later that summer both Drs. Brian Luckman and Colin Laroque visited the site to survey and research the event. Given the unusual nature of the event in a high visitation area Parks Canada decided to restrict the access to the area until a comprehensive risk assessment had taken place. As the summer progressed the road was opened to non-motorised transport up to the Cavell International Hostel. Restricted activity permits were issued to tour operators in the Tonquin Valley allowing them to use the road for motorised access to the trailhead at the hostel. The day use area accessing the meadows and tarn remained closed to the public.

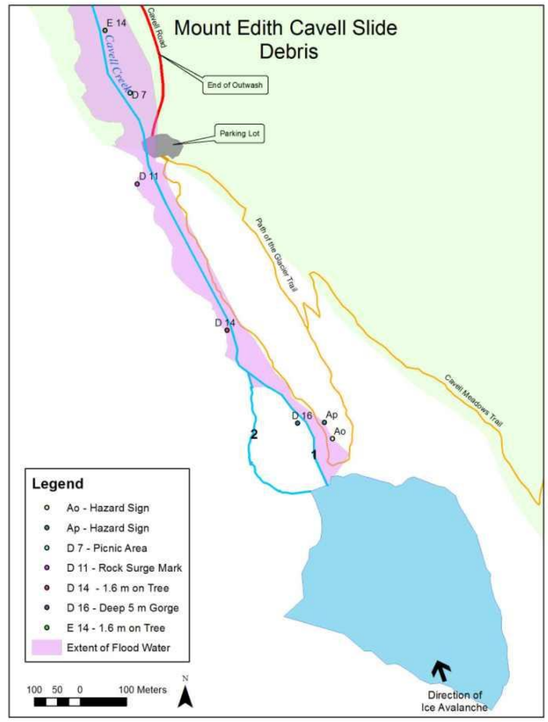


Fig. 10: The survey area composite map.

### *2.5 Cavell Tarn*

Historical photographic images, dating from the early twentieth century, show the Cavell Glacier fully occupying the location of today's tarn. A pond at the snout of the Cavell Glacier started to become a regular seasonal occurrence in the 1960s. The tarn has developed and grown over the past fifty years as the glacier has receded. This process will likely continue. Several field trips were made to the tarn in October 2012 to survey its depth, surface area and position. By this time the surface of the tarn was frozen 1-2 inches thick. Holes were chipped and depth measurement were taken with a weighted line at fifty meter intervals along two crossing transect (Fig.11). The periphery of the tarn was walked and crawled with a GPS in hand. The most westerly tarn-glacier interface was not walked due to icefall and avalanche danger. This location is shown in Figure 11 with red cross-hatching. The position of this interface was mapped using distance measurements, taken by range finder, from GPS locations. The high mountains surrounding the tarn often produced inaccurate GPS values. As several field trips were made, erroneous loci were replaced with those that were more representative of field observations.

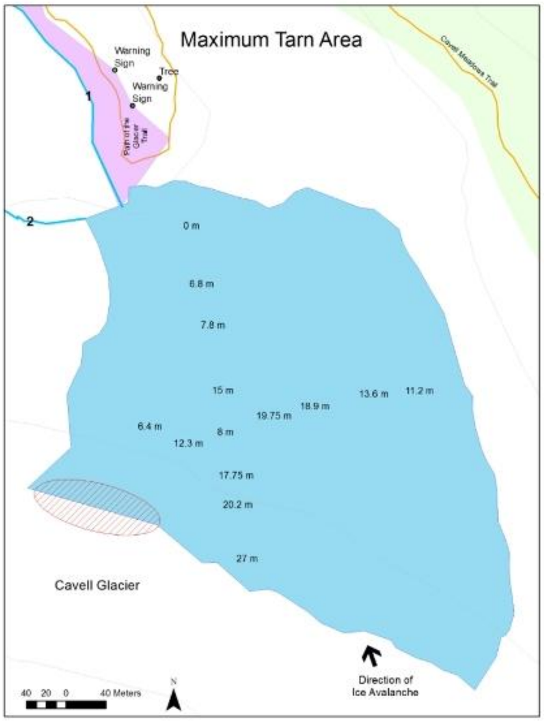


Fig. 11: Cavell tarn showing the maximum tarn area and the depth measurements taken from the ice cover in October 2012. The primary (1) and secondary (2) drainage channels are shown in blue (top of map) and the pink polygon shows the area flooded by the overflow.

Over the course of the field trips the tarn drained noticeably. This could be inferred by the melt line on the ice cliffs of the Cavell glacier and the relative distance to the surface of the tarn (Fig. 12), the high water line on the shoreline and relative position of the tarn surface and the sagging surface ice of the tarn ice. In the late winter, an avalanche forecasting field team, noted that the tarn appeared fully drained. The snow covered ice surface sagged noticeably (Fig. 13). The lowest point (deep spot) lay close to where the bathymetric survey had placed the deepest part of the tarn three months earlier. The greatest recorded water depth was 27 m, measured 46 m from the ice cliff of the Cavell Glacier. During the time of the bathymetric survey it was calculated that the water levels had dropped between 5 m (minimum drop), and 11.8 m (maximum drop) since the GLOF. This variance is due to difficulties in interpreting where the high water mark was along different sections of the shoreline.


Fig. 12: The drop in water level of Cavell tarn between August 10th and early October 2012. (Parks Canada R.Wedgwood)

The depth of the tarn at the time of the GLOF is estimate to be between 32 m – 38 m at the deepest location measured in October. With the winter melt and heavy rains in July and early August the tarn was filled to close to maximum capacity in August 2012. During this time the surface area of the tarn was calculated to be 15.6 hectares. Its north south dimension was close to 410 m and its east west dimension 408 m. The periphery of the tarn is calculated at 1,680 m. The data collected was used by BGC Engineering during their risk assessment.

### 2.6 Risk Assessment

On November 8th BGC Engineering Inc, sent a field team of Allen Jones (PEng, Dynamic Avalanche Consulting Ltd) and Pete Quinn (PEng, BGC), to conduct a site inspection. Over the previous week 30 cm of snow had fallen and on the evening of November 6th a further 10 cm fell in Jasper townsite. With snow depths between 20 cm – 60 cm anticipated along the closed Cavell day use road the author and the team accessed the site by helicopter. The conditions were not ideal for field work with deep snow drifts which made it problematic to travel and observe the geology of the area. Throughout the day size 1 and 2 loose snow avalanches ran down the sides of Mount Sorrow (2,972 m), an adjacent peak. The cloud ceiling prevented aerial photography at or above the Angel Glacier and the location of the former Ghost Glacier was obscured for the entire day. Despite these setbacks the team felt that sufficient information had been collected to supplement existing data. In March 2013 the final draft of the risk assessment report was submitted (see Qinn References).

Fig. 13: Cavell Tarn with the presumed deepest spot marked by a red circle. The black lines show the two axes along which depths were measured in October 2012. (Parks Canada R.Wedgwood)

### 2.7 The Cost

Prior to the GLOF a high use trail led from the parking lot, located one kilometer downstream, to the tarn shoreline. At the terminus two cautionary signs were positioned warning the public of icefall danger from the Angel Glacier (Figure 14). On a busy day in August upwards of 100 people may, at any given moment, be hiking the lower trail between the tarn and parking area. It was extremely fortunate that the event happened during the night when there was nobody present.

The event's aftermath occupied a significant amount of park resources. Ten Resource Conservation staff members participated in the search on August 10th. Other park staff involvement included: Highways with road clearing, Park Wardens with closures, External Relations with website and business communications and Visitor Experience gathering information for local messaging. Although most of the emergency response costs to parks occurred on the 10th activity did continued until the 16th. During this period Resource Conservation staff involvement amounted to 112 hr of regular time and 25 hr of overtime. Resource conservation overtime costs came to $1,469. The helicopter search costs amounted to $6,863.55 and the incidental search costs, for meals, were $283.49. No estimations have been made as to the revenue loss or disruption caused to local tour operators, the hostel or the vacationing public. The costs of the risk assessment and the trail redevelopment are not recorded in this report.


Fig. 14: The Angel Glacier located to the West of the tarn also threatens the tarn and those hiking below it. (Parks Canada R.Wedgwood)

### 2.8 Post Script

In June 2013, with the implementation of risk treatment measures underway, the road to the day use area was opened to the motoring public. The lower trail to the tarn, which had been damaged by the GLOF, was abandoned. Warning signs were strategically placed to inform the public of the dangers associated with entering that area. The lower picnic area was also abandoned, although the partially buried tables remain visible and in place. The lower end of the parking lot and the section of the road where the pavement had been damaged remained unpaved but well graded and smooth. A new trail section and picnic area was under construction above the parking area. Visitor Experience (VE) provided a “roaming interpreter” throughout the summer to interact with the public and monitor the glacier activity. On August 10th, exactly a year after the GLOF, he observed large chunks of serac ice falling from the lower quarter of the Angel Glacier snout. Associated with the icefall was an increase in water flowing down the cliff face into the tarn. None of the ice reached the tarn. A Resource Conservation specialist responded to the site. A group of young adults who had ignored the warning signs, and were at the tarn shore edge, were led to safer ground. The water level of the tarn was approximately three meters lower than the previous year at the time of the GLOF. As a precaution, a Resource Conservation specialist with avalanche training, remained in the area with the VE interpreter to monitor the glacier activity and tarn water level until 8:00 PM. At the end of the day no ice avalanches had occurred of sufficient size to reach the tarn and the water level had not risen significantly.

During the evening of August 15th 2014 an intense rain event occurred as reported by climbers returning from Mount Edith Cavell. Images from a stationary camera near the mountain recorded this event. The following morning at 08:00 AM a member of the public reported the road being impassable as it was covered in rock, mud and water. Images from the camera, established for long term monitoring, showed large volumes of water coming from the Angel Glacier and the north face of Mount Edith Cavell. There were indications of small landslides and icefalls from the Angel Glacier. It is thought that water broke through a restriction in the west drainage channel and picked up additional material from the banks. As in 2012 approximately 100 meters of road was impacted as the water slowed and the debris deposited (Fig.15). No park visitors were in the area at the time. In the immediate aftermath of this event access to the area was restricted.

Fig.15: A debris flow August 2014 (R.Wedgwood).

## 3. CONCLUSIONS

The complex nature of the hazards near Mount Edith Cavell along with the high numbers of visitors it receives makes the site an interesting case study in risk management. The variety of activities which draw visitors to the area is made more complex by the visitor's varied risk perceptions and tolerances. Given these broad variables there is a heightened need to carefully select the most effective risk communication and risk treatment tools. Early warning indications of reoccurring similar events would include high water levels in the tarn, an increasing frequency of small icefall events, rapidly expanding crevasses or bergschrunds and intense rainfall events. There may be a role for social media site postings to aid in early warning notification .The value of historical documentation, high resolution digital mapping data and access to powerful geomatic analysis tools such as GIS cannot be overstated. In a national park context it has raised the question as to what lengths are we willing to alter the natural landscape in our most treasured locations in order to reduce the magnitude and consequence of low frequency yet highly destructive events. Future infrastructure development will benefit from the knowledge and the warning that this type of event is possible and may be on the increase with predictions of climate change.

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