Fairmont Creek Debris Basins May 31, 2020 Flood Assessment

Final Report

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June 24, 2020
NHC Ref no. 3005607

FAIRMONT CREEK DEBRIS BASINS
MAY 31, 2020 FLOOD ASSESSMENT

FINAL REPORT

Prepared for:

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DISCLAIMER

CREDITS AND ACKNOWLEDGEMENTS

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- Brian Funke — Engineering Services Manager
- Kara Zandbergen — Engineering Technician

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- Peter Harding — Fairmont Resort Weather Station Access

The following NHC personnel participated in the study:

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EXECUTIVE SUMMARY

On May 31 2020 33 mm of rain fell at Fairmont Hot Springs following two days of extremely hot weather that led to substantial snowmelt in the upper watershed. The rain event, coupled with the preceding snowmelt, caused a large number of debris flows in the headwaters of Fairmont and Cold Spring Creek. As these events travelled downstream and the runoff increased the flows transitioned to debris floods. The debris floods filled the debris containment weirs constructed in 2018 on Fairmont Creek and the Fairmont Resort Dam on Cold Spring Creek. In both cases relatively little sediment passed beyond the debris containment weirs (Fairmont Creek) and dam (Cold Spring Creek) and as a result these structures can be credited with greatly reducing the amount of damage caused by the event. Without these structure the majority of the sediment would have arrived on the fan in the community where homes, condominiums and infrastructure are located.

The 6 hour duration rain event had a return interval of 10 years, using the Cranbrook Airport IDF as a proxy for the RDEK's Fairmont Ski Hill rain gauge. This does not consider antecedent conditions such as the snowmelt or flow of sediment. Based on a review of the capacity of the one stream crossing on Fairmont Creek that did not overtop the road, the flood event (downstream of the debris containment weirs) had a discharge on the order of 4 to 7 m^3/s corresponding with a 10 to 20 year return interval estimate. While a direct comparison to the 2012 event is difficult, the rainfall and snowmelt rates in the 2020 event were greater than the 2012 event.

On Fairmont Creek the upstream most two debris containment weirs constructed in 2018 were completely filled and the upstream most weir (weir #1) was buried by upwards of 3 meters of sediment. It is estimated that 15,000 m^3 of sediment was deposited in these two containment weirs (weir #1 & #2). In comparison the 2012 event was estimated to supply 65,000 m^3 of sediment to the fan. Downstream of the containment weirs the channel scoured due to a lack of sediment supply and the high flows. Upstream of weir #3, 10,000 m^3 of sediment was deposited, much of it mobilized downstream of weir #2. Downstream of weir # 3 the channel degraded and laterally migrated causing erosion to the berm separating the creek and hot spring intake huts. Had the channel cut through this berm the intake huts and the associated road would have been filled with sediment and water.

Over a 1.6 km long reach extending from the downstream limit of the 2018 construction to the Mountainside Golf Course the channel degraded and moved laterally attacking the banks of the creeks. The erosion washed away the road running along the creek at a number of locations and sediment was flushed down to the golf course. It is estimated that 8,000 m^3 of sediment were deposited on the golf course and in the golf course pond.

No gravel or larger sediment was transported beyond the sediment retention pond on the golf course; however, clearwater flooding did occur downstream. In particular the paved golf cart path running across the slope adjacent to the pond was overtopped and water flowed down the slope and between the condo buildings away from where the actual creek is located. Eventually the flow re-entered the creek. While flowing down slope away from the creek the water entrained soil and debris and transported this material further downslope. The creek downstream of the pond was not able to pass the flood in some areas and out of channel flooding occurred. This was exacerbated by two of the three culverts downstream of the pond having insufficient capacity to pass the flood event. Overall the area downstream of the pond sustained damage on account of the creek and culverts not being able to pass the clearwater flood. Had sediment coming from up the valley not been retained in the constructed debris containment weirs, the additional sediment that would have been deposited in the golf course community would have further reduced capacity and result in increased flooding and damages.

On Cold Spring Creek, the right embankment of the Fairmont Resort Dam was overtopped. As a result soil on the downstream side of the dam was partially eroded away. The culvert downstream of the dam was also overtopped and flood flows went over the road before returning into the creek.

At present the Fairmont Creek area is under an evacuation alert and this should stay in place until the following items are accomplished as outlined in greater detail in Section 4 of this report.

- Restore 5000 m^3 of storage capacity in weir # 2 by excavating material and have a plan to remove the remaining material within the next few weeks.
- Remove the sediment and debris that is directly in front of the culverts and reducing the capacity of the existing culverts.
- Remove 4000 m^3 of sediment from the golf course pond to restore 40 to 70% of storage capacity and have a plan to remove the remaining material within the next few weeks.
- Repair channel bank protection between Fairmont Creek and the hot water intake buildings to provide 1 meter of water depth along the stream channel from the downstream end of the 2018 construction work to the downstream culvert crossing.
- Have a plan in motion with a defined timeline to repair the channel bed downstream of weir # 2 to ensure the channel is not left in its current conditions throughout the summer and fall of 2020.

The Cold Spring Creek area is also under evacuation alert and this should stay in place until the following is addressed,

- Excavate sediment that was deposited in the Cold Spring Creek Fairmont Resort dam to restore 100 % of the storage capacity.

To enable the community to better manage flood events in the future the following items should be addressed:

- Replace road crossings with structures able to pass the 200 year flood event. At present most of the structures failed to pass the estimated 20 year storm. On account of climate change it is anticipated that extreme rainfall events will become more common in the future and flood volumes will on the whole increase.
- Improve Fairmont Creek channel capacity downstream of the golf course so the creek can contain future flood events. As part of this it may be necessary to come up with a vegetation and debris management program for landowners as well as account for the continued accumulation of limestone in the bottom of the channel over time.
- Consider the installation of additional sediment storage upstream of the golf course pond using a debris weir to reduce the likelihood of sediment being deposited in the golf course pond.
- Design and install additional grade control and bank stabilization structures along the 1.6 km reach of Fairmont Creek extending from the end of the 2018 construction work to the golf course. This should also include addressing the continuous growth of the limestone deposits at the hot springs discharge point that is directing the creek to the south and promoting bank erosion.
- Consider additional flood warning and flood management tools including in river water level sensors to indicate when debris weirs are getting full. In the golf course pond and the Cold Creek headpond water level sensors could also be used to estimate peak flows through the release structure and indicate when the structures are likely to overtop and have water flowing

over structures that were not designed to accommodate flood flows (e.g. golf cart road and dam abutments).

The May 31, 2020 clearwater flood event (downstream of the sediment weirs) has been estimated to have a peak flow on the order of the 10 to 20 year flood. The sediment delivery event had an estimated recurrence interval of 35 years and based on the occurrence of 2013 and 2020 event, as well as a revised analysis of the historic events, the 2012 event is estimated to have a recurrence interval of 165 years.

During the 2020 event the debris containment weirs constructed in 2018 and the golf course sediment retention ponds performed as intended and as a result the accumulation of sediment on the fan and through the community downstream was substantially reduced. The majority of the flooding that occurred was because the existing culverts and stream channel are not capable of passing the size of floods the watershed is expected to produce. On Cold Spring Creek the Fairmont Resort dam retained the sediment supplied from the watershed; however, the dam abutments were overtopped resulting in erosion and risked failure of the dam; as such improving the capacity to route water and any excess sediment past the dam is recommended.

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1 INTRODUCTION

On May 31, 2020 a large flood event in the East Kootenay's caused the debris basins constructed in 2018 on Fairmont Creek to fill and channel migration on the fan caused sediment to be deposited in the pond on the Fairmont Hot Springs Mountain Side Golf Course. Clearwater flows downstream of the pond exceeded the channel capacity and overbank flooding occurred through and downstream of the golf course. In addition, flooding occurred along Cold Spring Creek, the watershed north of Fairmont Creek. The Fairmont Resort Dam, on Cold Spring Creek upstream of the community, filled with sediment causing flow to spill over the spillway and right abutment.

To assess the risks associated with the filled sediment retainment structures on both creeks and flooding that occurred, Northwest Hydraulic Consultants Ltd. (NHC) conducted an overflight of with Brian Funke from the Regional District of East Kootenay (RDEK) on the evening of June 1, 2020. Subsequently, channel conditions along Fairmont Creek and Cold Spring Creek were examined on foot on June 1st and June 2nd with Brian Funke and Kara Zandbergen, respectively. Contractors started to clear sediment from both creeks on June 1st and continued after the site inspection.

1.1 Objectives

The purpose of this study and report is to support the RDEK in limiting the flood risk for the community of Fairmont Hot Springs, particularly to restore the effectiveness of the flood mitigation measures that existed prior to the May 31, 2020 event, and support the decision process in removal of the current flood evacuation alert.

The specific goals of this study and report are as follows:

- Provide an initially summary of the precipitation and climate conditions associated with the May 31 2020 event.
- Provide a high level review of the observations from the overflight of Fairmont Creek and Cold Spring Creek.
- Provide a brief description of channel changes observed, causes, and potential solutions along Fairmont Creek based on site observations.
- Identify next steps for high priority items on Fairmont Creek.
- Provide initial order of magnitude estimates of the volume of sediment stored in the sediment containment weirs.
- Briefly describe conditions on Cold Spring Creek.

The report is not a comprehensive review of Fairmont Creek or Cold Spring Creek and no attempt has been made to summarize all the existing reports or information about the watersheds. NHC's approach relies on interpretation and field observation based on the site photos and provides a general overview of the two watersheds and how they were impacted by the flood event.

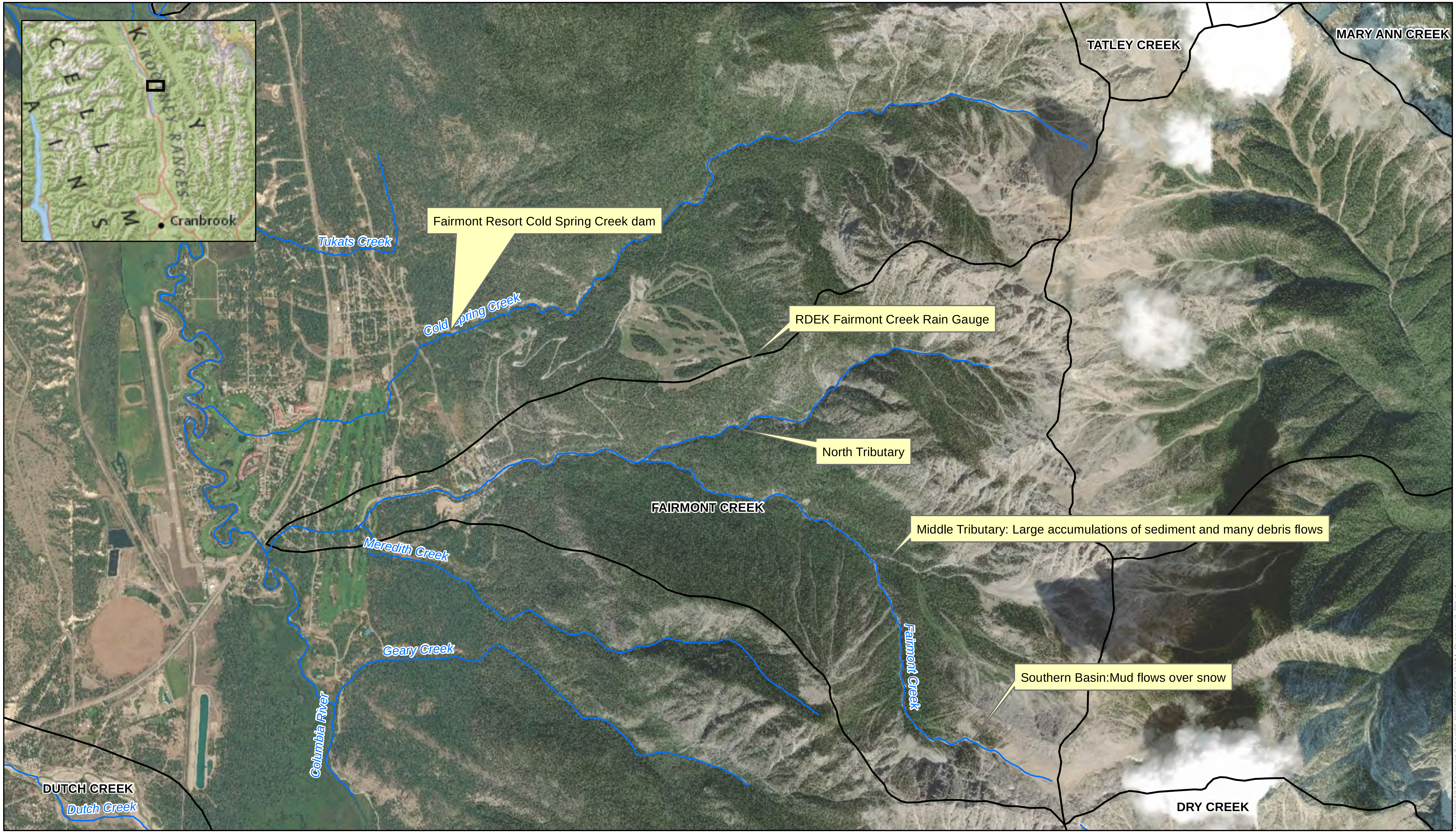
1.2 Terminology and Basin Overview

Map 1-1 shows the watersheds examined and identifies the key tributaries discussed in this report. As one moves from the mountain tops down to the toe of the two alluvial fans the channel slope is reduced dramatically and the processes that dominate the creek channel change in a predictable fashion from debris flows, to debris floods and then to clearwater floods. These three processes can be described as follows:

- Debris Flow: a debris flow is a fast moving flow of sediment and water that travels down channel. It contains a wide range of grain sizes and is a mass movement event. In essence it is a flow of sediment with water, rather than a flow of water that is moving sediment (debris flood).
- Debris Flood: a debris flood is a water driven flow that moves a lot of sediment and debris. The volume of sediment moved is often sufficient that the channel is rapidly evolving during the event scouring river banks and depositing extensive amounts of sediment and debris. Water velocities are similar to a clear water flow, but the channel is evolving sufficiently quickly that the inundation areas are constantly changing as sediment is deposited in one location and scoured in another.
- Clearwater Floods: Clearwater floods are controlled by water alone and the movement of sediment and debris does not cause extensive changes to the channel during the event. Debris may still cause minor modifications of the flow, but by-in-large the river flow is predictable and can be modelled without needing to account for potential changes in the elevation of the creek bed and how the creek will respond to changes in sediment supply.

In both Fairmont and Cold Spring Creek there were many signs that debris flows had occurred during the event in the headwaters and that the debris flows transitioned to debris floods before reaching the sediment containment weirs and Fairmont Resort Dam. Downstream of the debris containment weirs and dam flow was generally clearwater.

For Fairmont Creek the spatial arrangement of the key basins and areas of scour and sediment deposition are illustrated in Map 1-2. Note the overall region where the sediment containment occurs is referred to as the upstream and downstream basins while the actual rock constructed weirs are referred to as containment weir #1, #2 and #3.



Regional District of East Kootenay

nhc northwest hydraulic consultants

STREAM
WATERSHED

DATA SOURCES: BACKGROUND - ERSI WORLD IMAGERY

SCALE - 1:40,000
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Coordinate System: WGS 1984 WEB MERCATOR AUXILIARY SPHERE

Job: 3005607 | *Date: 17-JUN-2020*

MAY31 2020 FAIRMONT AND COLDSPRING CREEK FLOOD EVENT FIELD ASSESSMENT AND RESTORING DEBRIS CAPACITY RECOMMENDATIONS

Map 1-1 Overview of Fairmont and Cold Spring Creek Watersheds

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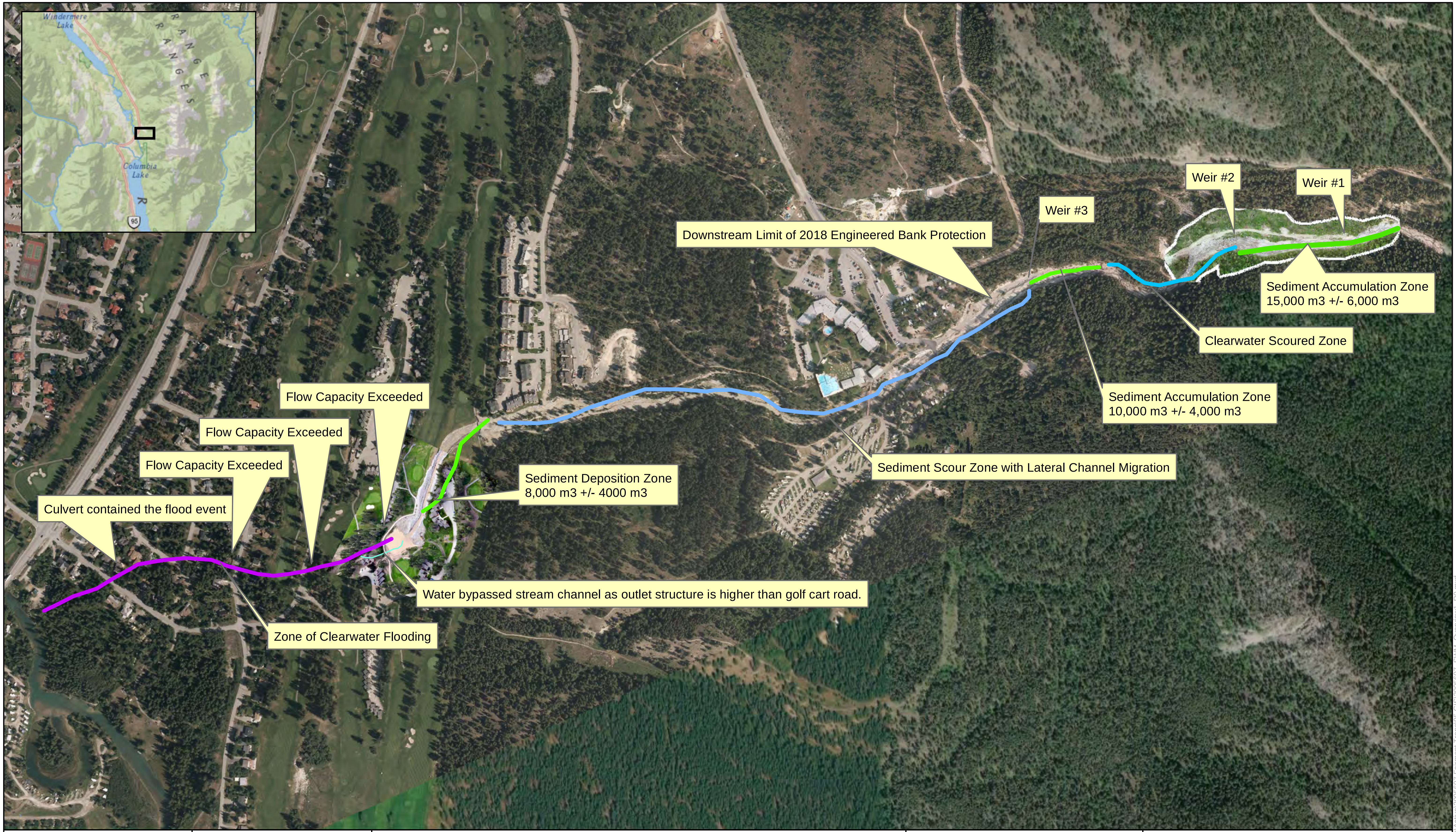

Regional District of East Kootenay

nhc northwest hydraulic consultants

DATA SOURCES:
BACKGROUND - ERSI WORLD IMAGERY;
2016-11-03 overview imagery from Airborne Imagery
Golf course pond from 2020-06-01 NHC overflight and roughly georeferenced
Barrier # 1 and # 2 from 2020-06-02 NHC UAV survey roughly geolocated.

SCALE - 1:10,000

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Coordinate System: WGS 1984 WEB MERCATOR AUXILIARY SPHERE

Job: 3005607 | Date: 11-JUN-2020

MAY31 2020 FAIRMONT AND COLDSPRING CREEK FLOOD EVENT FIELD ASSESSMENT AND RESTORING DEBRIS CAPACITY RECOMMENDATIONS

MAP 1-2 Overview of Fairmont Creek fan and debris accumulation zones

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1.3 Review of Design Flows and Sediment Volumes

The 200-year clearwater flood event for Fairmont Creek is specified in NHC (2017) as being 16.3 m^3/s, which includes an adjustment for climate change (Table 1-1). See NHC (2017) for a more comprehensive description of the event sizing and how this value was developed. Of note, KWL (2013) and Clarke & Golder (2013) refer to Crowther (1994)'s estimate of the 200-year instantaneous peak flow (2.9 m^3/s) as the clear water design flow for Fairmont Creek. As such the NHC 2017 report increased the 200 year design flood by 5.7 times. This is an exceptionally large change in the magnitude of the design event.

In comparison, the 2012 debris flood event design flow provided by Clarke & Golder (2013) had a peak flow of 165 m^3/s and total sediment and debris volume of 65,000 m^3. Table 1-1 summarizes the various flood flows and size of the design debris flood used for the 2018 design. These values continue to be used herein.

While the design event included an estimate that 65,000 m^3 of sediment could be deposited in the creek during a single event, on account of funding limitations, the debris containment weirs were constructed to contain between 15,000 and 17,010 m^3 of sediment in total (NHC, 2018).

Table 1.1 Design clearwater flood and debris flood Estimates for Fairmont Creek.

Design Event	Flow Estimates (m^3/s)
2-year peak flood	2.1
10-year peak flood	4.2
200-year peak clearwater flood adjusted to climate change	16.3
Debris flood (Clark and Golder, 2013)	165

2 EVENT CLIMATE AND HYDROLOGY

Fairmont Creek is a mountain stream that originates at the top of Fairmont Mountain, where the headwater elevation is over 2600 m above sea level (ASL). The entire watershed area is approximately 11 km^2, in which the headwater areas are alpine, and the mid and lower watersheds are mostly vegetated. The watershed is situated in the bowl of Fairmont Mountain; the channel slope transitions from over 35% in the upper watershed to 13% in the lower watershed along its 7 km reach.

On May 31, 2020, a debris flood event occurred within the Fairmont Creek watershed which caused damage to areas of the community of Fairmont Hot Springs. An analysis of available climate data was undertaken by NHC to characterize the event.

The event was caused by a strong low pressure cold front moving across the region that brought moderate to heavy rain, severe thunderstorms, and lower temperatures that followed unseasonably hot weather (Ashman, 2020). The Kootenay and southern Columbia basins saw 20 to 50 mm total precipitation with most of the rain occurring mid day on May 31st (Ashman, 2020).

Climate data from Fairmont Creek (RDEK funded gauge maintained by NHC), Redstreak (Parks Canada) and Morrissey Ridge (BCHydro funded maintained by NHC) climate stations were used to better understand the event at Fairmont and Cold Spring Creek. The Fairmont Creek station is located within the Fairmont watershed at an elevation of 1480 m with precipitation and temperature data available from 2016 onward (see Map 1-1). The station also has a snow depth sensor, but the station was snow free at the time of the event.

Morrissey Ridge is located 115 km southeast of the Fairmont Creek station at an elevation of 1860 m. Precipitation, temperature, and snowpack data is available at Morrissey Ridge from 1986 to present day. The Redstreak gauge is located in Radium Hot Springs. A hypsometric curve of the Fairmont Creek watershed is shown in Figure 2.1, with the elevations of the Fairmont Creek and Morrissey Ridge climate stations indicated.

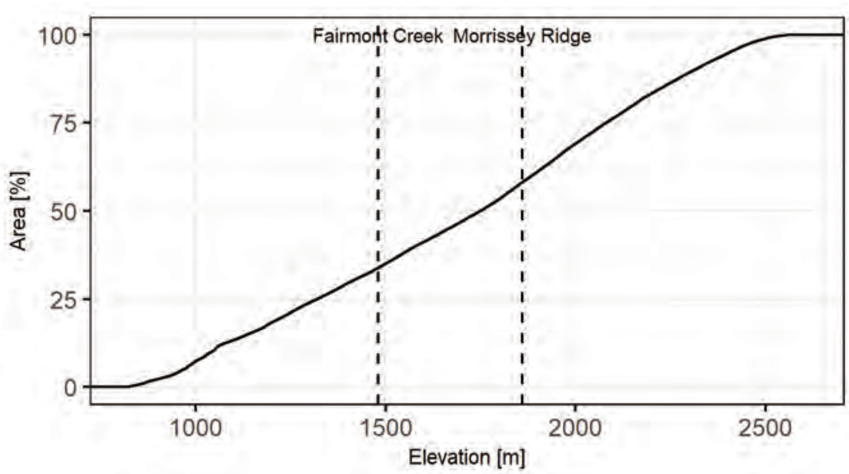

Figure 2.1 Hypsometric curve of the Fairmont Creek watershed. Elevations of the Fairmont Creek and Morrissey Ridge climate stations are indicated by vertical dashed lines.

2.1 Temperature

Temperature data is available at both Fairmont Creek and Morrissey Ridge. Figure 2.2 shows the mean daily temperature and associated daily minimums and maximums from May 25 to June 1, 2020.

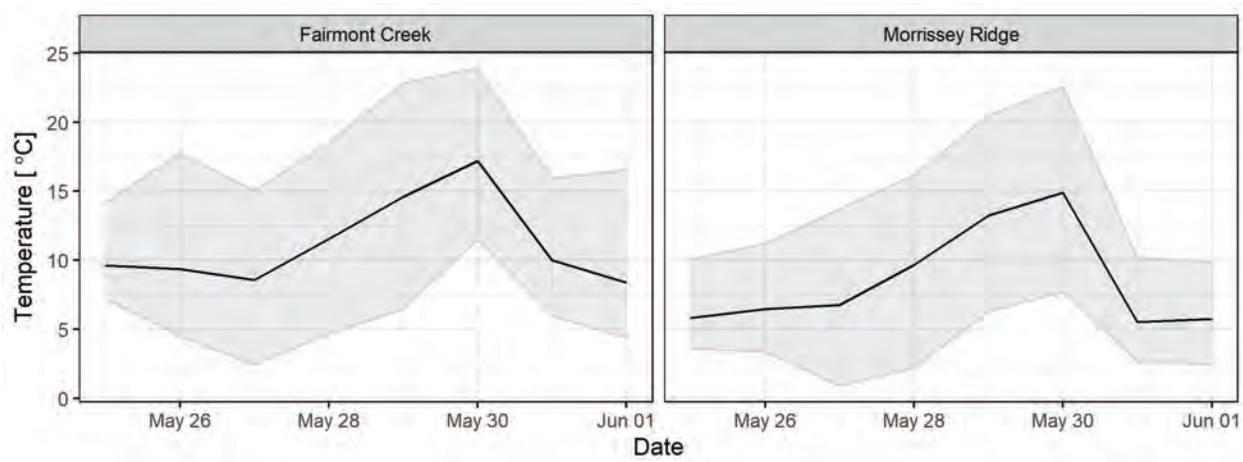

Figure 2.2 Daily mean temperatures (black line) and associated minimum and maximums (grey band) from May 25th to June 1st, 2020 for Fairmont Creek and Morrissey Ridge.

The daily temperature shows that daily means increased from 8°C to 17°C at Fairmont Creek with a similar warming trend seen at Morrissey Ridge. Daily highs were over 20°C on May 29th and May 30th.

2.2 Snow Water Equivalent

Snow water equivalent (SWE) measurements are available at Morrissey Ridge. Measured SWE over the period from May 25 to June 1, 2020 is shown in Figure 2.3, with the melt (SWE loss) over this period tabulated in Table 2-1.

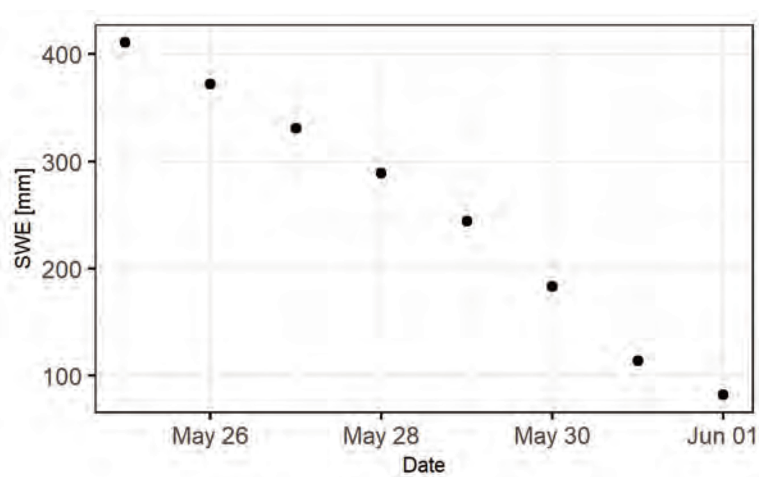

Figure 2.3 SWE values at Morrissey Ridge from May 25 to June 1, 2020.

Table 2.1 Daily snow water equivalent loss at Morrissey Ridge

Date	Snow Water Equivalent Loss [mm]
2020-05-26	42
2020-05-27	45
2020-05-28	41
2020-05-29	57
2020-05-30	58
2020-05-31	46

In the week prior to June 1st, there was sustained melt at Morrissey Ridge. Nearly 60 mm of melt occurred on both May 29th and May 30th. The two day cumulative melt during this period was 115 mm. These days with high melt correspond with the increase in temperature seen at Morrissey Ridge. Given the similar temperatures at Fairmont Creek it is expected that similar levels of melt would have occurred within the middle and upper Fairmont Creek watershed.

Historical SWE from Morrissey Ridge was analyzed to determine whether this level of melt over a one day and two day period was within the normal range. Boxplots showing the historical range of daily melt are shown in Figure 2.4. The lower and upper horizontal lines indicate the 25th and 75th percentile and the bold middle line indicates the mean. The one day melt values on May 30 and May 31, 2020 were in the 94th and 97th percentile for melt rates in the month of May. The two day melt total on May 31, 2020 was within the 96th percentile for two day melt totals in the month of May.

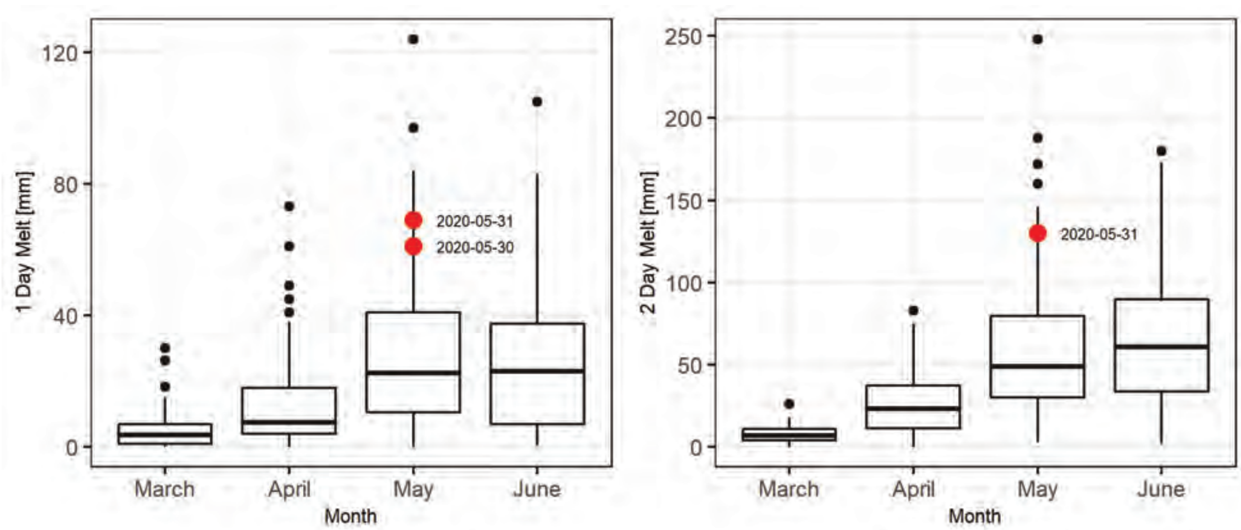

Figure 2.4 Range of one day and two day melt totals at Morrissey Ridge with melt on May 30th and May 31st indicated by red dots.

2.3 Precipitation

Precipitation measurements are available at Fairmont Creek, Redstreak and Morrissey Ridge (south of Fernie). Figure 2.5 shows the 24-hour cumulative precipitation received at each gauge between May 25th and June 1st.

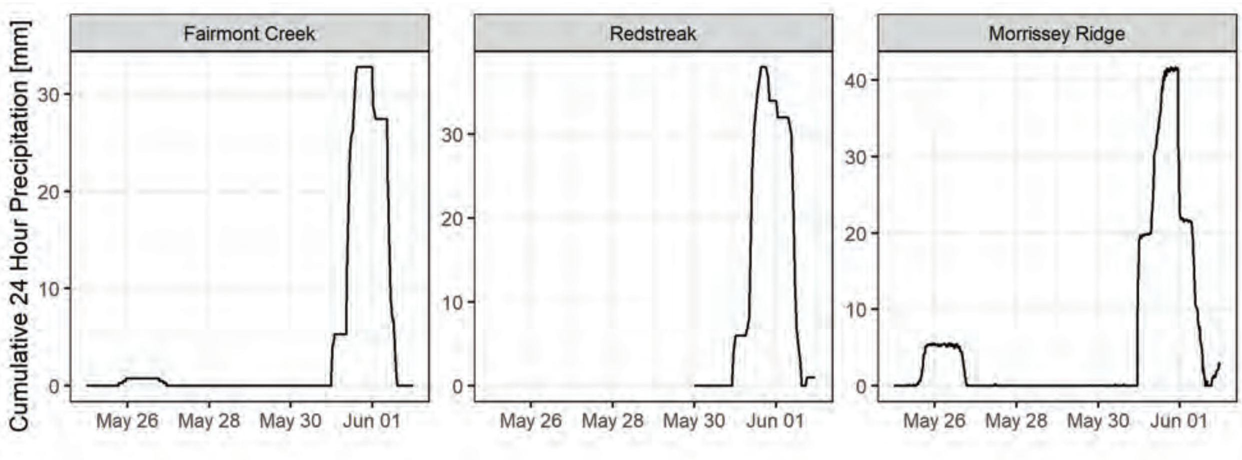

Figure 2.5 24 hour cumulative precipitation totals at Fairmont Creek and Morrissey Ridge

During this period, maximum precipitation at Fairmont Creek, Redstreak and Morrissey Ridge was 32.8, 38, and 41.7 mm respectively.

Data available at a higher temporal scale at Fairmont Creek was compared to a regional intensity duration frequency (IDF) curve to determine the frequency of precipitation. Precipitation data from the Fairmont Creek station from May 25th to June 1st was compared to the Cranbrook IDF data, shown in Table 2-2. [1]

Table 2.2 Cranbrook airport IDF values and Fairmont maximum precipitation

Duration	Return Period						Fairmont maximum precipitation rates for event
	2	5	10	25	50	100	
5 min	3.8	6.3	8	10.1	11.6	13.2	1.5
10 min	5.7	8.6	10.5	13	14.8	16.6	2.8
15 min	6.8	10.1	12.3	15	17.1	19.1	3.8
30 min	8.1	11.8	14.3	17.4	19.8	22.1	6.6
1 hr	9.5	14	16.9	20.6	23.4	26.1	10.2
2 hr	12.2	16.8	19.8	23.5	26.4	29.2	17.3
6 hr	17.8	23.4	27.2	31.9	35.5	39	27.2
12 hr	21.2	28.1	32.7	38.4	42.7	47	27.4
24 hr	24.9	34	40	47.6	53.2	58.8	32.8

Based on the comparison, the amount of precipitation received at Fairmont was equivalent to a 10-year 6-hour storm at Cranbrook. Precipitation data is not available at the Cranbrook station during this period to compare total precipitation values to. The Cranbrook IDF curve was selected for comparison as it is the closest IDF curve to the Fairmont gauge, approximately 78 km away. The Cranbrook climate station is approximately 500 m lower than the Fairmont Creek station at an elevation of 940 m. Given the difference in elevation and location, there is uncertainty in using the IDF curve to classify the event. However, the historical record at Fairmont Creek is not long enough to generate site specific IDF curves.

[1] On June 2nd the rain gauge was cleaned, examined and validated by NHC and was found to be accurate to within 1% of the stated precipitation. A small amount of debris from the nozzle was removed.

When comparing the 24-hour precipitation total at Fairmont Creek to the available historical data at this location. The precipitation total of 32.8 mm on May 31, 2020 was slightly less than the maximum recorded value, which was 33.3 mm on September 18, 2019.

2.4 Event Analysis

On May 30 and May 31, 2020 temperatures within the Fairmont Creek watershed increased, causing two days of substantial melt. The amount of melt at Morrissey Ridge over the two day period was in the 97th percentile of all melt data measured in May. The temperature driven snowmelt would have been intensified by rainfall on May 31. The precipitation event was likely in the range of a 5 to 10-year storm.

The historical record at Morrissey Ridge, which starts in 1984, was examined to determine if other events with similar snowmelt and precipitation magnitudes have occurred in the past. Only one event was found, which occurred on June 11, 1991. The two day cumulative melt for the June 11, 1991 event was 106 mm after which 32.5 mm of precipitation fell in comparison to 115 mm of snowmelt followed by 42 mm of precipitation for the most recent event. The data suggest that this most recent event had exceptionally high snowmelt and precipitation trends at the Morrissey gauge.

Based on the analysis of available climate data, the event which led to the flooding in 2020 was substantial. Radiation driven melt on May 30th was followed by a rain on snow event on May 31st, resulting in the peak flows observed in the watershed.

While an accurate assessment of the peak flow discharge is not possible, we know that the two most upstream culvert crossings were not able to pass the flow. The initial crossing at Fairmont Resort Road is a 1200 mm (4') diameter culvert with roughly 2 m^3/s capacity (with minimal surcharging). In practice the culvert entrance is partially blocked and surcharging occurred. The road likely had about 0.3 m of water flowing over it (Photo 2-1), indicating flow was likely greater than 2 m^3/s.

The Columbia River Road crossing consists of a 1200 mm (4') and a 900 mm (3') diameter culvert. This crossing was overtopped during the flood event (Photo 2-2). The culvert outlet is perched with a free flowing drop. Given the condition of the culverts it is likely that this crossing could pass approximately 3 m^3/s. As such the flood flow is interpreted to be greater than 3 m^3/s.

The most downstream crossing at Fairmont Creek Road consists of two 1200 mm (4') diameter culverts. During the event this crossing experienced about 0.3 m of surcharging and did not overtop the road (Photo 2-3). This culvert has experienced a bit of debris blockage, but generally the entrance is reasonably clear and the flow through the culvert during the peak of the event has been estimated to be 4 to 7 m^3/s. This is a rough estimate, but it suggest the clear water flow was on the order of a 10 to 20 year flood event (4.2 m^3/s is estimated to be the 10 year flood event (Table 1-1)) and twice the historically estimated 200 year flood event (2.9 m^3/s; see Section 1.3). Modelling the geometry of the culverts and ideally calibrating the model with an observed flow would be required to refine these estimates.

An analysis of the peak flow on Cold Spring Creek was not completed; however, given its proximity to Fairmont Creek it likely experienced a flood with a similar return interval.

2.5 Comparison to 2012 Event

On July 15, 2012 convective storms triggered debris flows in the upper basin of Fairmont Creek that transitioned to debris floods in the lower basin and resulted in 65,000 m^3 of sediment being deposited on the golf course and downstream fan (Clarke Geoscience Ltd. and Golder Associates, 2013). Rain gauges in the region show a wide range precipitation rates on the 15th and the maximum daily precipitation rate at any of the rain gauges in the region was 26.4 mm two days before the event at Fort Steele (Clarke Geoscience Ltd. and Golder Associates, 2013). The day before the event the Cranbrook Airport experienced 23.4 mm of rain (Clarke Geoscience Ltd. and Golder Associates, 2013). There was not a rain gauge at Fairmont in 2012. In comparison to these regional numbers, the Fairmont Ski Hill experienced 32.8 mm in 24 hours on May 31, 2020.

During 2012 at Morrisey Ridge there was 21 mm of precipitation over 3 hours during the peak of the storm and a total of 35 mm over the duration of the 2012 event. In comparison, the total 2020 event precipitation was 41.7 mm and 3 hour precipitation totals were as high as 20 mm at Morrisey Ridge; however, in 2020 the 20 mm fell over a 75 minute period instead of over a 180 minute duration.

The report describing the 2012 event also notes that radar imagery showed peak rainfall intensities on the order of 8 mm/hr in the vicinity of the study area (Clarke Geoscience Ltd. and Golder Associates, 2013). The same rainfall intensity was observed in the 2020 radar images for May 31, 2020.

In regards to snowpack, Floe Lake at 2090 m elevation had 30 mm of SWE at the start of the 2012 event on July 15th and was snow free by the end of the event. In 2020 the same station had substantially more snow (SWE was 740 mm). Morrisey Ridge was snow free on June 19th, twenty six days before the debris flood event in 2012 while it had 132 mm of SWE at the start of the 2020 event. As such, while snowmelt was likely occurring in the Fairmont Creek during the 2012 event, the snow line would have been much higher in the basin and contributed far less to the overall runoff. It is roughly estimated that 40 to 50 % of the basin was snow covered during the 2020 event while 20-30 % of the basin would have been snow covered in 2012.

From a precipitation and snowmelt perspective, these data suggest the 2020 event was as large, or larger than the 2012 event. As will be explained in greater detail in the following sections, the total amount of sediment mobilized from upstream was estimated to be 20,000 m^3 in the 2020 event while it was estimated to be 65,000 m^3 in the 2012 event.

Photo 2.1 Upstream most 6’ diameter culvert under Fairmont Resort Road that was overtopped and the downstream flooded area during the event. Debris line and mud covered pavement are visible in the photo.

Photo 2.2 Columbia River Road crossing on Fairmont Creek that was overtopped during flood event.

Photo 2.3 Fairmont Creek Road culvert on Fairmont Creek. This road crossing was not overtopped and a debris line can be seen about 0.3 m above the culvert.

3 SITE OBSERVATIONS

Based on both the helicopter overflight and on the ground observations, as well as a brief review of historical photos from site a number of observations on both Fairmont and Cold Spring creek are possible. In both cases the observations are summarized starting at the top of the watershed and moving downstream. On account of COVID 19 observations were only possible from the back seat of the 407 helicopter which to some extent limited the ability to see and direct the flight; however, to the best of our knowledge, all the critical features in the watersheds were observed.

3.1 Fairmont Creek

The following subsections present the observations from the watershed upstream of the Fairmont Hot Springs Resort, the constructed debris containment structures at the resort, the reach between the structures and the golf course, the reach through the golf course, and finally the downstream most reach through the community.

3.1.1 Upper Watershed

Fairmont Creek contains three major tributaries upstream of the debris catch basins and all three tributaries are directly coupled to the downstream channel. During the May 31, 2020 rain event observations from the helicopter overflight suggest that all three tributaries experienced multiple debris flows and sediment flowed off the hillslopes into the main channel. In some cases the sediment flows started above the snow and ran out over and through snow deposits in the bottom of the valley. The middle tributary contains the largest deposits of sediment from the event and appears to have debris flows that moved the furthest down basin. Photo 3-1 through Photo 3-12 and the associated figure captions illustrate the features that were observed in the upper watershed. In general the sediment in the channel upstream of the basins is sand, gravel and cobble sized with only a few boulders. Given the channel gradient, even a modest amount of water flowing through the upstream creek channel will transport sediment downstream towards the basins. As such, the upstream portion of Fairmont Creek continues to be transport limited. In transport limited systems the movement of sediment is limited by how frequently flows capable of moving sediment occur. This is in contrast to supply limited conditions, which occurs if a channel becomes armoured and the movement of sediment is limited by how much sediment is supplied.

From an overall hazard perspective, during the overflight there were no signs of substantial landslide generated dams or the build up of sediments within the channel that could release in a rapid and unpredictable way. All indications are that additional runoff is required to bring more sediment and water down valley.

Photo 3.1 Sediment tracks and debris 300 m upstream of the ski hill water intake on the north tributary of Fairmont Creek. A debris flow deposit in the forest is visible in the top center of the image while extensive deposits of sediment in the two main channels are also visible.

Photo 3.2 Initiation and deposition zone of debris flow in north tributary watershed. Many similar features can be identified throughout the watershed.

Photo 3.3 View looking down north tributary. Relatively low gradient section of channel before incised canyon helps prevent debris flows from travelling further down valley.

Photo 3.4 Fairmont Creek middle tributary just upstream of confluence with southern main channel. Debris flow deposits fill the channel in some sections of the middle tributary.

Photo 3.5 Middle tributary approximately 700 m upstream of confluence with main channel. Debris flow deposit with no identifiable channel Indicates that mass movement processes dominated the transport of material in this region of the creek.

Photo 3.6 Debris flow over snow pack and then onto bedrock channel in southern most tributary of Fairmont Creek.

Photo 3.7 Debris flow sediments that travelled over snow in the southern most main channel of Fairmont creek

Photo 3.8 Hillslope raveling and shallow slope failures near the top of the southern most tributary of Fairmont Creek. Some of these failures appear to have transitioned to a debris flow or mud flow and travelled over the snow and down valley. Rapid snowmelt in days before the rain event would have helped saturate these soils.

Photo 3.9 Mud flow passing over snow in southern most basin of Fairmont Creek.

Photo 3.10 Fairmont Creek 1 km upstream of the upstream most debris containment weir and upstream of where the northern most tributary joins Fairmont Creek.

Photo 3.11 Fairmont Creek 450 m upstream of upstream most debris containment weir. This is downstream of the confluence with the northern most tributary. Most up-valley zipline is visible in image.

Photo 3.12 Fairmont Creek 300 m upstream of the upstream most debris containment weir. 2nd upstream most zipline is visible in the image.

3.1.2 Debris Containment Weirs

In 2018 three debris containment weirs were constructed over a kilometer long section of Fairmont Creek extending from the Fairmont Hot Springs Hot water collection buildings upstream. The construction was split into two areas with the area just upstream of the hot springs intake buildings including a large protected bank on the north side of the creek and a single debris containment weir (weir # 3). Upstream of this weir a confined channel leads to a second wider section of valley where the two other weirs are located. The estimated volume of sediment the weirs can store based on the design memo are summarized in Table 3-1. Table 3-2 provides a summary of the estimated sediment accumulate (and scour) in the respective portions of the channel. Downstream of weir 3 some scour occurred but it has not been quantified as the scour was relatively small in the immediate area.

Prior to the rain event on May 31 2020 sediment was already moving in the watershed due to the snowmelt and an earlier, smaller rainfall event. Kara Zandbergen conducted a site visit on May 28th and noticed that weir # 1 was already full. During the site visit on June 1st and 2nd it was not possible to see any signs of weir # 1 as it was buried by a few meters of sediment (see Photo 3-13 and Photo 3-14).

Photo 3-14 includes both a photo from 2019 when the containment weirs were nearly empty and a photo after the May 31 2020 event that illustrates weir # 2 is completely full. It is estimated that 20,000 (+/- 6,000) m^3 of sediment is stored in weir # 1 and # 2 combined. In comparison it was estimated that these two weirs may only store 6,200 m^3 of sediment (NHC, 2019). The reason for the discrepancy in storage volume is largely due to the sediment being stored upstream of the weir at an angle of 9.25 % for the first few hundred meters and steeping to 14% at the top of the storage zone. The estimate provided in NHC (2019) conservatively only considered sediment storage below the invert of the weirs in the 'dead storage' zone. The amount of sediment storage above the invert in the 'live storage' zone depends on the ratio of water to sediment when the flood is occurring as well as the grain size of the sediment. The observed deposition angles are relatively steep and reflect the high sediment supply of Fairmont Creek.

Photo 3-15 illustrates that some sediment and debris overtopped containment weir # 2; however, it does not appear that substantial amounts of sediment or debris passed over the weir. If a substantial amount of sediment and debris had passed over the weir it is likely that the riprap in the foreground of Photo 3-15 would be filled with sediment.

Photo 3-16 provides a before and after comparison of the creek channel downstream of weir # 2 and illustrates that degradation of the channel has occurred. For most the flood event it is estimated that this reach experienced 'clearwater scour' as no sediment would have been transported over the weir. As a result of the clearwater scour the bed degraded approximately 2 meters and vertical sandy banks were exposed. Restoring the grade of this section of the creek is a priority and discussed in Section 5.2 of this report.

Further downstream the creek is confined and generally experienced small to moderate amounts of scour and bank retreat. The large sediment deposits adjacent to the channel from the 2012 event were not activated during the May 2020 event (Photo 3-18). Throughout this reach the grade of the channel is constrained by the bedrock that outcrops in the canyon (Photo 3-19). While the lack of sediment supply due to the upstream sediment containment weirs promoted degradation and sediment entrainment throughout this reach, this is a better outcome overall than having no containment weirs and all the sediment stored in the upstream containment weirs flushed through this reach and downstream.

Based on the site observations the majority of the sediment scoured downstream of weir # 2 was deposited upstream of weir # 3 (Photo 3-20 and Photo 3-22). It is estimated that 5,000 (+/- 3,000) m^3 of sediment are deposited upstream of weir # 3. Sediment was deposited upstream of weir # 3 at an angle of 6 % (+/- 1%). Unlike weir # 2 the toe of weir # 3 did not experience as extensive scour despite the clearwater flows (Photo 3-23); nevertheless, about 1 meter of sediment was scoured along the channel downstream to the point where the right bank riprap placement ended in 2018. The 2018 riprap did not have flow along the toe of the placed material except at the downstream end of the material. The flood did not affect the condition of the riprap.

Table 3.1 Storage volume estimates provided in NHC (2019) based on dead storage only.

Location	Estimated Capacity (m^3)
Upstream Basin	
U/S of Weir No. 1	1,800
D/S of Weir No. 1	4,400
D/S of Weir No. 2	700
Downstream Basin	
U/S of Weir No. 3	10,000
D/S of Weir No. 3	4,400
Total	**16,700**

Table 3.2 Storage volume estimates for 2020 event.

Location	Estimated Capacity (m^3)
Upstream Basin	
U/S of Weir No. 2	20,000
D/S of Weir No. 2	-1,000
Downstream Basin	
U/S of Weir No. 3	5,000
Total	**24,000**

Photo 3.13 Fairmont Creek filled with sediment. Flow is from top of image to bottom. Upstream most containment weir (weir # 1) is under a few meters of sediment and located in bottom portion of the image. Downstream most zipline is visible in the image.

Photo 3.14 2019-09-17 (left) and 2020-06-01 (right) photos of containment weir # 1 and # 2. 2019 photo taken looking downstream while 2020 taken looking upstream. Arrows link containment weirs.

Photo 3.15 Sediment and debris that overtopped weir # 2 during the May 31, 2020 event.

Photo 3.16 Top photo indicates the area downstream of the second debris containment weir in 2019, viewed looking downstream. The bottom photo shows the same area after then 2020 event looking upstream. The arrow links the common weir.

Photo 3.17 Incised stream channel at downstream limit of containment weir # 2. This section of channel needs grade control added and the banks protected to prevent additional channel migration and sediment removal.

Photo 3.18 Fairmont Creek downstream of containment weir # 2. Horizontally aligned logs are place on top of 2012 sediment deposition and illustrate that the May 2020 event only activated a fraction of the channel in this area.

Photo 3.19 Bedrock constricted and bedrock grade controlled portion of Fairmont Creek between weir # 2 and weir # 3. Small slope failures from most recent event are visible, as well as perched terraces from 2012 event.

Photo 3.20 Sediment containment weir # 3 on September 17 2019 (top) and June 1 2020 (bottom). Flow from bottom of image to the top. Blue pipe is located in area where sediment accumulated upstream of weir.

Photo 3.21 Sediment and debris that has passed overtop of weir # 3 is illustrated in foreground while scoured bed downstream of weir # 3 is also visible.

Photo 3.22 June 1 2020 helicopter photo of containment weir # 3 filled with sediment as well as degraded channel adjacent to hot spring intake buildings. The excavator working in the channel had just started to access the channel and repair the eroded bank upstream and to the left of where it is positioned in the image.

Photo 3.23 Downstream toe of containment weir # 3 showing limited scour after May 2020 event.

Photo 3.24 Degraded channel downstream of containment weir # 3 upstream of end of 2018 riprap placement. Hot spring intake buildings are over the berm to the right of the image.

3.1.3 Hot Springs Water Intake to Fairmont Golf Course

Between the downstream limit of the 2018 construction work and the golf course is a 1.6 km reach of channel that experienced erosion and channel migration. These processes resulted in additional sediment being mobilized in this reach and transported downstream. For the most part this reach has not been extensively engineered and a lot of the bank protection appears to be ad-hoc or missing all together. There were many locations where the channel migrated laterally and eroded sediment, as such a complete description of all the problem areas is beyond the scope of this memo. This memo provides a discussion of the key locations along the reach, in reality, the entire reach should be stabilized and protected to reduce downstream sediment supply and damage to infrastructure along the reach.

Immediately downstream of the 2018 bank protection the creek eroded the left terrace and then attacked and eroded much of the berm separating the creek from the hot water intake huts that are located much lower in elevation than the channel at this location (Photo 3-25). Largely due to luck the channel did not migrate all the way through the berm and fill the hot water intake huts with water and sediment. Further downstream, but still upstream of the upstream most culvert there are a few other locations were the placed rock failed and the flow eroded the berm, but none of these attacked the bank to the same extent (e.g. Photo 3-27).

The upstream most 1800 mm (6') diameter culvert was not able to pass the entire flood flow and the creek overtopped the road (Photo 3-28). Based on the areal extent of the mud on the road, the water depths during the flood were likely on the order of 0.3 m, but this is very difficult to assess as sediment may have also been on the road. The capacity of the intake of this culvert appears to be significantly constrained. The water flowing off the road and back into the creek likely caused the erosion of the downstream creek bank that is visible in Photo 3-29.

Further downstream sections of stream bank were eroded and added material to the system. This included two sections of road that contained the golf course irrigation supply line that is now suspended in the air. At the upstream most site of erosion the continued accumulation of limestone at the hot spring release location on river right likely contributed to the erosion of the left bank (Photo 3-30).

In general the channel degraded and lateral migration through this reach and is responsible for the sediment that was deposited on the golf course and in the golf course pond downstream. Relatively little sediment would have moved through the reach from the upstream culvert. To reduce the accumulation of sediment in the downstream reach the channel needs additional grade control structures and the banks protected to limit lateral bank migration.

Photo 3.25 Bank erosion adjacent to hot springs intake huts immediately downstream of the downstream limit of the 2018 riprap placement as seen on the evening of June 1, 2020.

Photo 3.26 Evening of June 1, 2020 photo of eroded berm after initial re-alignment of channel by the excavator in the preceding hour. The small amount of remaining bank that separated the creek from the hot springs intake building is visible on image right and was about 1 m tall and 1.5 m wide.

Photo 3.27 Upstream most 4' culvert viewed looking downstream. Creek overtopped road and debris line is visible crossing roadway on a diagonal.

Photo 3.28 Four foot diameter culvert and road that was overtopped.

Photo 3.29 Bank erosion downstream of upstream most 4' culvert.

Photo 3.30 Fairmont Hot Springs pools and mineral rich water discharge point (light colored uniform textured deposit). Golf course irrigation pipe can be seen hanging in the air where the roadway has been eroded.

3.1.4 Golf Course and Downstream Debris Containment Pond

Sediment mobilized in the reach immediately upstream of the golf course was transported by the flood and deposited on the golf course and in the golf course pond. Map 3-1 illustrates the extent of sediment infilling along this reach. The channel upstream of the golf course successfully contained the sediment that was mobilized, transporting it to the pond. It is estimated that about 8,000 m^3 of sediment was deposited in this pond and along the channel upstream; however, this estimate is rough as the thickness of the deposit is difficult to judge without a survey. Nevertheless, it is clear that the pond and channel functioned as intended as it captured sediment in a manner that prevented the stream from avulsing to a different route down the fan.

Regional District of East Kootenay

nhc northwest hydraulic consultants

POND INFILL

DATA SOURCES:
2016-11-03 imagery from NHC project 3002097 unknown source
2020-06-01 imagery from NHC overflight and roughly georeferenced

SCALE - 1:1,500

0 15 30 60 m

N

Coordinate System: WGS 1984 WEB MERCATOR AUXILIARY SPHERE

Job: 3005607 | *Date: 11-JUN-2020*

MAY31 2020 FAIRMONT AND COLDSPRING CREEK FLOOD EVENT FIELD ASSESSMENT AND RESTORING DEBRIS CAPACITY RECOMMENDATIONS

Map 3-1 Golf course pond imagery from Nov 3 2016 and June 1 2020 showing changes in sediment accumulation due to the 2020 flood event.

3.1.5 Downstream Reach (Golf Course and Downstream Housing Development)

Downstream of the golf course pond the flood was essentially a clearwater flood. The largest extent of flooding was caused by the paved golf cart path being lower than the top of the outlet structure and as result water flooded over the golf cart path and down between the buildings instead if through the outlet structure (Photo 3-31). In addition, the next two culverts downstream of the golf course pond (Photo 3-32 and Photo 2-2 respectively) were not able to pass the flood and water flowed over the road and through a number of properties. The channel does not have adequate capacity for the flood event, and flows went overbank in some locations.

It is likely the channel segments could not contain the flows for the following reasons:

1. The channels are too small to contain the flood flows assuming the channels were design to pass the historic 200 year estimated flood flow.
2. The channel bed has aggraded over time due to the accumulation of limestone from the hot water springs located up river.
3. The establishment of vegetation and debris along the channel promoted woody debris dams blocking water flow through the reach.

Photo 3.31 Golf course sediment containment pond and area downstream that experienced clearwater flooding. Flood waters went overtop of the paved golf course road.

Photo 3.32 Culvert that was overwhelmed during the flood event that is located 250 m downstream of the golf course pond on road providing access to Fairmont Mountainside Vacation Villas.

Photo 3.33 Lower Fairmont Creek illustrating a section of channel that experience over bank flooding leading into a forested portion of the reach.

Photo 3.34 Lower Fairmont Creek in a section of channel with a very narrow channel bed and lots of established vegetation.

Photo 3.35 Aerial image of Fairmont Creek downstream of golf course sediment containment pond. Roadway in image center and top of image were overtopped during the event.

3.2 Cold Spring Creek

Overall Cold Spring Creek is similarly characterized to Fairmont Creek, however, it has smaller watershed area and downstream fan (Map 1-1). Debris flows are common in the upper watershed and the slopes are generally well coupled to the creek channel. Mid-watershed the creek channel appears to be somewhat more incised and landslides associated with channel downcutting are more common.

3.2.1 Upper Watershed

The upper portion of Cold Spring Creek contains two primary basins that supply sediment, with the northern, larger basin producing the majority of the sediment. A large debris flow gully 5.7 km upstream from the dam (Photo 3-36) is a substantial source of sediment fed by rock fall, rock avalanches and debris flows that originate further up the slope in two distinct gully systems (Photo 3-37). These sediments are washed downstream as debris flows that transition to debris floods (Photo 3-38). This sediment and water continues to move downstream and has caused localized bank erosion and a few relatively small landslides (e.g. Photo 3-39). At this time there appears to be no large landslides in the lower basin that could block the channel entirely. As the channel approaches the Fairmont Resort dam shown on Map 1-1 the sediment and water is flowing both through the channel and through the adjacent forest and the sediment deposits are clearly thick and extensive (Photo 3-40 and Photo 3-41).

Much like Fairmont Creek the supply of sediment in Cold Spring Creek is nearly limitless as the movement of sediment is largely controlled by the creeks ability to move the sediment, rather than the overall supply of sediment to the channel.

Photo 3.36 Major debris flow system on Cold Spring Creek located 5.7 km upstream from the dam can be seen on image right. The toe of the deposit has been scoured by river flows.

Photo 3.37 Upslope debris flow channels that merged and then enter Cold Spring Creek at the location shown in Photo 3-36.

Photo 3.38 Cold Spring Creek 4 km upstream from dam. Extensive deposits of freshly mobilized sediment are visible.

Photo 3.39 Two small landslides on south side of creek 1.5 km upstream of the dam. An old road appears to cut across the top of these slides.

Photo 3.40 Cold Spring Creek 2.2 km upstream of the dam. Thick deposits of alluvial sediment can be seen filling the valley.

Photo 3.41 Cold Spring Creek 300 m upstream of the dam.

3.2.2 Fairmont Resort Dam

Following the May 31st event, the Fairmont Resort dam on Cold Spring Creek was completely filled with sediment. The grade of deposited sediment had an angle of 8.5% +/- 1%. Some sediment moved past the dam and downstream during the event. On the downstream side of the dam the banks of the creek and a portion of the embankment fill of the dam was eroded; right abutment (Photo 3-43). Erosion on the downstream side of the dam is concerning as it could include material that is part of the structural support of the dam. Sediment build up in the forebay of the dam raised the bed elevation sufficiently that water was flowing over the dam's abutments rather than through the spillway. On the whole the erosion does not appear sufficient to cause the dam to be in immediate risk; however, priority repairs are suggested in Section 5.5 of this report. Due to the potential consequence of failure, repairs of the dam should be designed and overseen by a qualified professional (e.g. geotechnical engineer) and likely requires notification to the provincial Dam Safety Officer.

Photo 3.42 Sediment deposited in dam on Cold Spring Creek.

Photo 3.43 Downstream face of dam showing path of water to right side of spillway and resulting scour.

Photo 3.44 View looking downstream into dam headpond which has become filled with sediment. Note the presence of a abutment on river left at the crest of the dam but no evidence of a abutment on river right as the creek bed has aggraded and is above the abutment wall.

3.2.3 Downstream Crossings and Channel

A short distance downstream of the dam the stream crosses Fairmont Resort Road through a culvert that appears undersized, shown in Photo 3-45. During the flood event the road was overtopped; the culvert entrance was cleaned out before the photo was taken. There are no signs of extensive sediment accumulation through this reach; however, rocks could be heard moving through the culvert at the time the photo was taken. Cold Spring Creek downstream of this culvert was not evaluated during the site inspection.

Photo 3.45 Cold Spring Creek crossing under Fairmont Resort Road downstream of Fairmont Resort dam.

4 SEDIMENT DELIVERY RECURRANCE INTERVAL FOR THE 2020 EVENT

In order to estimate the recurrence interval of the 2020 event, NHC reviewed historic records of debris flow and/or debris flood events. In doing so we have grouped both types of events as it is difficult to distinguish processes on the fan and separate out the events. Together debris flow and debris flood events are referred to as sediment delivery events herein.

Sediment delivery events were based on the test pits excavated into the fan and described in Clark Geoscience and Golder Associates (2013) and the 2013 (Clarke Geoscience Ltd., 2015) and 2020 events that occurred following the excavation of the pits. The resulting dataset was analyzed by applying threshold-exceedence plotting positions following the approach outlined in Appendix 5 of England et al. (2019). To do this, it was necessary to estimate both volumes of historical events and detection thresholds describing the smallest event that would be expected to be in the debris delivery event inventory for various historical periods.

Test pits described by Clark Geoscience and Golder Associates (2013) show evidence of at least one large debris flow event prior to 1900 and one or two overlying debris delivery events based on the presence of discrete massive deposits separated by soil horizons. Due to relatively low sampling intensity across the surface of the fan, it is possible that these pits did not intersect deposits of other debris flow events. Based on evidence in the pits, we assume one debris delivery event that was comparable to—or greater than—the 2012 event occurred sometime between 1800 and 1900 (with sensitivity tests to evaluate possible bracketing periods of 1600-1900 and 1850-1900) and that two events with magnitude similar to or less than the 2020 event occurred between 1900 and 1950. The lower bound perception threshold for events prior to 1900 is assumed to be 50,000 m^3 and the perception threshold for events between 1900 and 1950 is assumed to be 15,000 m^3, based on the assumption that volumes less than this may not have left any discernable deposits intersecting the test pits. Perception thresholds of 5,000 m^3 and 1,000 m^3 are assumed for the periods from 1950-2000 and 2000-2020, respectively. Volume estimates for the complete set of historic events are shown in Table 6. These are rough approximations based on narrative descriptions of the events and comparison to select events with better known volumes (in particular the 1984, 2012, 2013, and 2020 events).

Table 4.1: Approximate volumes used for magnitude-frequency analysis

Date	Volume (m3)	Volume lower bound	Volume upper bound
unknown, pre 1900	100,000	50,000	200,000
between 1900 and 1950	15,000	5,000	25,000
between 1900 and 1950	20,000	5,000	25,000
1952-1964	5,000	2,500	7,500
1984	10,000	5,000	15,000
2006-2007	3,000	1,000	10,000
2012	65,000	60,000	70,000
2013	6,000	4,800	7,200
2020	20,000	15,000	30,000

Results of this analysis are shown in Figure 4.2. The 2020 event was approximately a 35 yr recurrence interval event. This result is sensitive to the assumption of the magnitudes of the two events between 1900 and 1950, if one or both these events were actually larger than the 2020 event, then its recurrence interval would be calculated as 29 or 25 years, respectively.

These results also provide context for the rough assumption provided by Clark Geoscience and Golder Associates (Clarke Geoscience Ltd. and Golder Associates, 2013) that the 2012 event represented a 500 yr recurrence interval design event for the system. Using the approach provided here, and the two events since 2012, the estimated recurrence interval for the 2012 event is 165 years. This result is sensitive to two assumptions: the first is weather the large pre-1900 event was larger or smaller than the 2012 event and the second is the beginning date for the earliest perception period. Depending on the particular assumptions made, the possible range of recurrence intervals for this event is estimated to be between 130 and 630 years, as illustrated in Table 7.

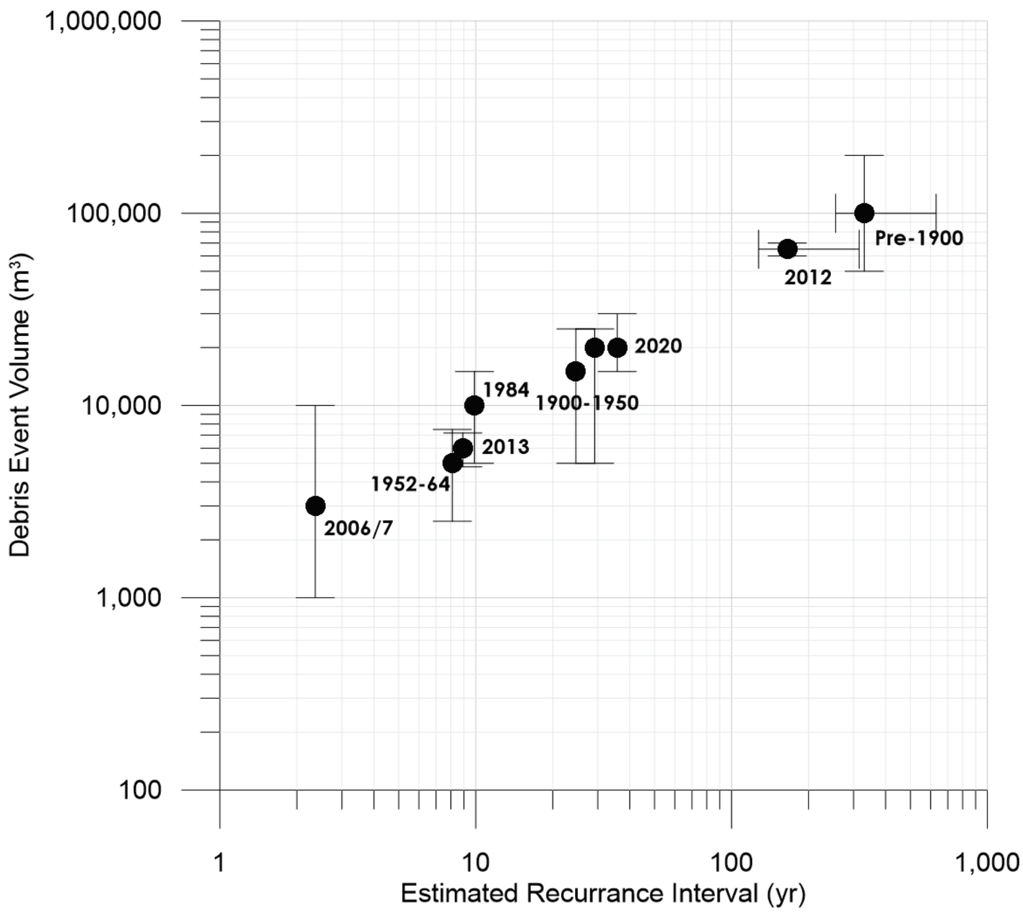

Figure 4.1: Magnitude-frequency plot for debris delivery events to the fan apex.

Table 4.2: Possible range of recurrence interval estimates for the 2012 event depending on assumptions made in the magnitude-frequency analysis.

		Relative Rank of 2012 event	
		Largest	2nd Largest
Beginning of perception period	1600	630	315
	1800	330	165
	1850	255	130

5 PRIORITY REPAIRS

At present the Fairmont Creek area is under an evacuation alert and this should stay in place until the following items are accomplished as outlined in greater detail below.

- Restore 5000 m^3 of storage capacity in containment weir # 2 by excavating material and have a plan to remove the remaining material within the next few weeks.
- Remove the sediment and debris that is directly in front of the culverts and reducing the capacity of the existing culverts.
- Remove 4000 m^3 of sediment from the golf course pond to restore 40 to 70% of storage capacity.
- Repair channel bank protection between creek and hot water intake buildings to provide 1 meter of water depth along the stream channel from the end of the 2018 construction work to the culvert crossing.
- Have a plan in motion with a defined timeline to repair the channel bed downstream of weir # 2 to ensure the channel is not left in its current conditions throughout the summer and fall of 2020

The Cold Spring Creek area is also under evacuation alert and this should stay in place until the following is addressed,

- Excavate sediment that was deposited in the headpond upstream of the Fairmont Resort dam on Cold Spring Creek to restore 100 % of the storage capacity.

5.1 Remove Accumulated Sediment in Debris Containment Weirs

The three debris containment weirs constructed in 2018 managed to store a total of 25,000 m^3 of sediment during the May 2020 flood event and are now full. The initial design was for them to store 20,000 m^3; however, once they were built it was estimated they may only store 11,300 m^3 upstream of containment weir # 3 (Table 3-1). The weirs stored more than twice the amount of sediment originally estimated as the deposition of sediment upstream of the weirs was initially based on a low gradient slope[2], while the actual deposition angle varied between 9 and 14 %. In comparison to the 20,000 m^3 of

[2] Note the storage volumes provided in Table 3-1 are still applicable for the ability of the structures to store water as water storage would occur at an essentially horizontal water surface slope. As such the structures do not qualify as dams as they are both less than 7.5 m tall and store less than 10,000 m^3 of water (Ministry of Forests, Lands, and Natural Resource Operations, 2016).

material that came into the reach during the May 2020 event, the design event based on the 2012 event is 65,000 m^3.

To handle additional high flow events and recover the functionality of the containment weirs all three weirs need to be completely emptied as soon as possible. With the weirs as they are, there is very little sediment storage capacity within the system upstream of the first culvert and it is likely that any flood event capable of mobilizing the bed will overwhelm the culvert, take out the road to the campground, and cause flooding far worse than observed during the May 2020 event.

At the completion of sediment removal it is recommended that an RTK UAV survey or UAV survey with RTK ground control points be conducted to better confirm the topography of the containment weirs when they do not have sediment in them.

A UAV survey without ground control was completed for weir # 1 and # 2 and could be used to provide a better estimate of the volume of material in the weir should that be desired. The volume of material removed may also be determined through a count of trucks and volume of trucks leaving the site.

Like the upstream weirs, the golf course pond functioned as purposed and stored approximately 8000 m^3 of sediment, preventing a channel avulsion. The accumulated sediment needs to be removed to the full extent possible to restore the functionality of the pond as a sediment capture basin.

5.2 Repair Channel Bed Downstream of Weir # 2

As illustrated in Photo 3-16 and Photo 3-17 the channel bed downstream of the second debris containment weir degraded approximately 2 meters during the event. The channel in this region has a slope of about 8 % and is capable of degrading more given the relatively steep slope, reduced supply of sediment once the basin upstream is excavated and the fine grain size of the creek bed. To prevent the channel from degrading further and potentially threaten weir # 2, a relatively small weir should be built near the downstream limit of the placed rock as sketched in Figure 5.1 Furthermore the apron of rock at the downstream toe of weir # 2 should be supplemented with coarse rock.

The conceptual design includes a rock weir to support the existing debris containment weir and should raise the creek bed approximately two meters so it is slightly above the toe of the riprap on the north side of the creek. The rock can likely be sourced from the top meter of rock placed along the right (north) bank protection as illustrated in Figure 5.1. This rock can be used as it is unlikely the creek channel will reach this elevation, based on the current channel grade, unless a very substantial debris flood occurs and fills the entire valley with sediment. The design should ensure the channel cannot go down the roadway where the existing rocks prevent vehicle access.

Based on an initial review of the UAV survey NHC conducted on June 2nd, 2020, the proposed weir repair should be relatively easy to design and capable of passing both the design clearwater and debris flood. Once constructed this structure will provide a one time storage volume of approximately 1000 m^3 between weir # 2 and the proposed weir (weir # 2.5). This is a one time storage volume as the material should not be excavated in the future.

Additional rocks that are available in the channel and along the top of the bank on the left (south) side of the channel should be place across the channel bed and along the left (south) bank at the toe of the weir to prevent the channel from migrating south or degrading the channel further (see bottom panel of Figure 5.1).

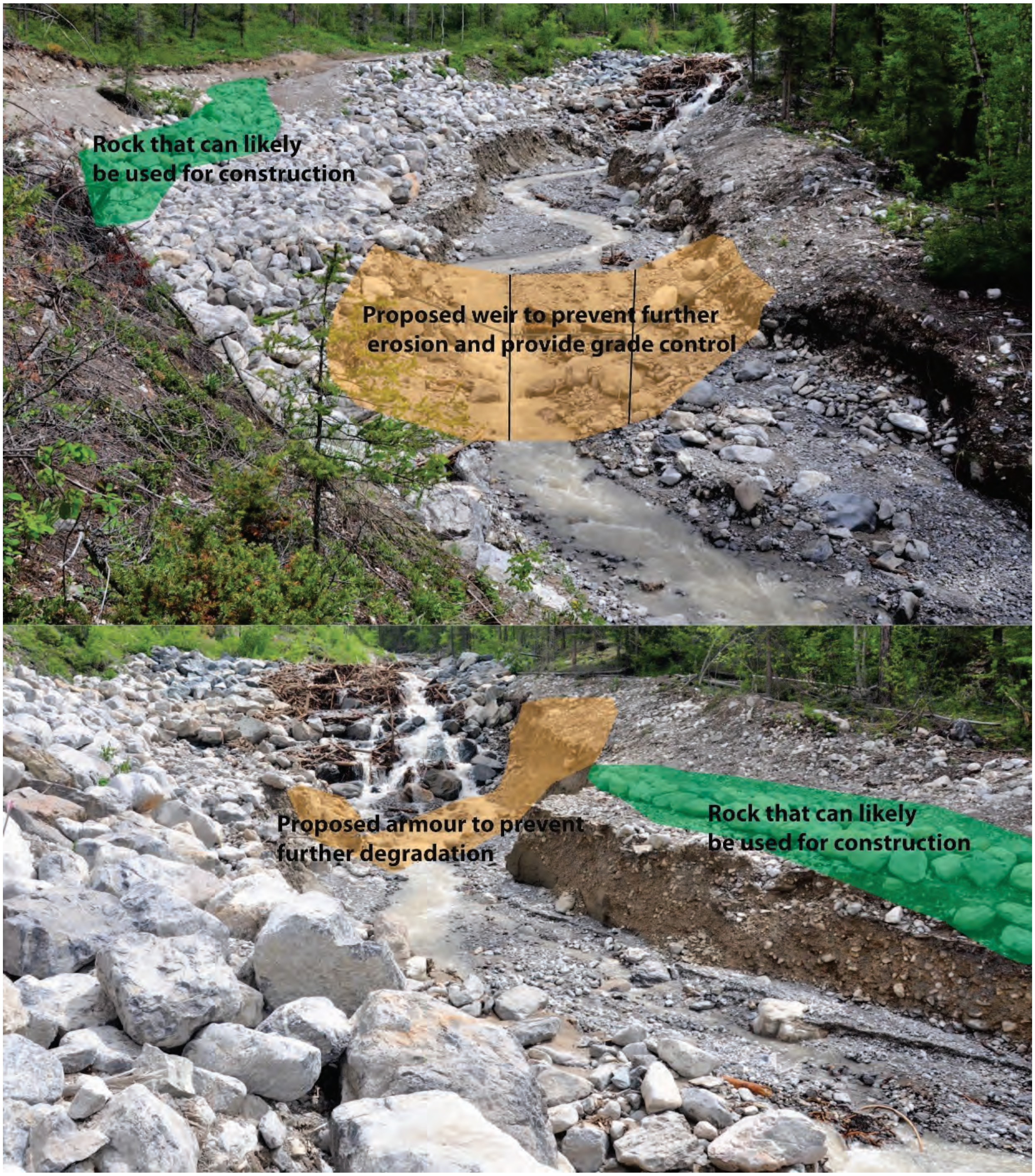

Figure 5.1 Proposed location of grade control repair using a rock weir; view upstream towards weir #2.

5.3 Repair Channel Bank Protection Separating Fairmont Creek from Hot Springs Intake

The RDEK recognized the immediate risk of channel migration adjacent to the hot springs water intake huts and had a contractor redirect the creek away from the eroded berm on the evening of June 1st. Subsequently the toe of the creek downstream of weir #3 was protected with more suitable material and bank partially raised. This bank needs to be rebuilt up to the elevation of the pre-existing berm and grade control weirs need to be installed along the length of the channel to limit the degradation of the channel and lateral migration of the channel into the southern terrace. The most important grade control structure is the one at the upstream end of the channel where the downstream limit of the 2018 construction work is. At this location the stream bed has degraded approximately a meter (see Photo 5-1) and the channel needs to have a rock weir installed across the channel to prevent headcutting and further erosion extending upstream. This weir can only be installed once the berm separating the creek from the hot water intake huts is reconstructed and protected with bank protection as the channel as of the evening of June 2, 2020 did not have sufficient freeboard to allow rock to be placed in the creek.

Photo 5-2 shows a section of the berm where the existing rock needs to be repositioned at an appropriate bank angle (e.g. 2:1 slope) and tightly placed so that it provides adequate bank protection (that is placed interlocking each stone to construct a stable rock structure with minimum voids).

Photo 5.1 Partially repaired channel adjacent to hot spring intake on evening of June 2 2020.

Photo 5.2 Section of berm upstream of first culvert along Fairmont Creek that experienced bank erosion and needs the bank protection rebuilt to prevent the creek from eroding through the berm and flowing down the hot spring intake access road.

5.4 Restore Culvert Capacity

Throughout both Fairmont Creek and Cold Spring Creek the existing culverts are under sized and debris management is critical. Until such time that the culverts can be replaced it is important to retain as much capacity as possible by removing sediment and debris that builds up in front of the culverts and breaking up any limestone deposits that may have partially filled the culverts and reduce their capacity. During the site inspection it was difficult to assess the degree to which limestone had accumulated in the culverts, but some of the residences noted this was an issue. As flows recede this should be evaluated and means of restoring the full capacity of the culverts implemented.

5.5 Cold Spring Dam Evaluation

The slope on the downstream side of the Cold Spring Creek dam should be repaired with suitable material under the direction of a qualified professional to ensure the structural integrity of the dam has not been compromised. It is expected that the regional Dam Safety Officer should be notified of the damage and the repair.

Furthermore, it appears that the capacity of the structure is not adequate for sediment storage and likely also for flow conveyance. It is recommended that the dam be further reviewed and updated if necessary. Potentially, the updates could include the invert of the spillway being lowered to increase capacity, the adjacent embankments raised to increase capacity, or embankment improved to allow for safe overflow. The appropriate design value is dependent on the consequence classification of the dam; and therefore should be done with consultation with the Dam Safety Officer.

As part of this analysis the ability to utilize existing Fairmont Resort dam as a sediment retention basin should be reviewed. The dam clearly functioned successfully as a debris retainment basin, but it likely was not designed for this purpose. The inadvertent use of the structure as a sediment retainment basin should be reviewed in the context of the most recent event. This review should also be conducted in the context that the RDEK is moving ahead with the design and construction of a new upstream sediment retainment structure on Cold Spring Creek.

6 RECOMMENDED IMPROVEMENTS

The following items will enable Fairmont Creek and Cold Spring Creek to experience floods similar in magnitude to the May 31 flood with a reduction in damage to property and infrastructure.

6.1 Replace Crossings so They Can Pass the Updated Flood Flows

All but one of the stream crossings along Fairmont Creek and the one crossing that was examined on Cold Spring Creek were over topped during the flood event. The one crossing that was not overtopped was surcharged to a water depth of approximately 30 cm. In practice, all of these crossings need to be enlarged and replaced to accommodate the predicted 200 year flood flow.

The rectangular outlet structure on the golf course sediment collection pond also needs to be evaluated and potentially upgraded to pass the design flow without flooding the golf cart road. We understand that there was 30 to 35 cm of limestone deposited at the bottom of the rectangular structure raising the invert of the structure during the May 31 event (Photo 6.4 and Photo 6.5). This should was subsequently removed (Photo 6.6); however, we anticipate this structure will still only pass about 4 m^3/s and should be enlarge to accommodate the design flow. A maintenance plan for this structure to ensure the invert is not allowed to progressively increase is also required. Furthermore, the elevation of the low point of the paved golf course road should be compared to the low cord of the bridge over the outlet structure to assess if the golf cart road could be raised without water reaching the low cord of the bridge. Ideally all the flood flows would be able to pass under then low cord of outlet structure. It needs to be recognized that even if this happens, debris may block the outlet or restrict flow and water flowing over the golf cart track may be possible. The relative risks of having water flowing over the golf cart track through the condo developments needs to be compared to the risk of directing all the water down the creek channel. It may be worthwhile raising the golf cart path to ensure the flooding is limited to the general location of Fairmont Creek.

During the design phase of the culvert replacement work, the continuous precipitation of limestone rock on the bottom of the channel and in the culverts should be considered as part of the design and the crossings should be sized and designed to accommodate ongoing reduction in channel dimensions that will occur as the limestone deposits grow.

Photo 6.1 Eroded soils downslope from golf cart road that was overtopped when water levels in the golf course pond sediment trap were raised.

Photo 6.2 Current outlet of golf course pond and 4 meter tall cascading channel that leads into Fairmont Creek. It appears that a sill is currently blocking water passage below the boardwalk on the right side of the image.

Photo 6.3 Downstream end of channel at pond outlet following flood event. Photo provided by contractor removing sediment from pond.

Photo 6.4 Upstream end of channel leaving golf course pond following May 2020 flood event. Photo provided by contractor excavating sediment.

Photo 6.5 Channel draining golf course pond after accumulated sediment had been removed by contractor. Photo by Kara Zandbergen.

6.2 Improve Channel Capacity Downstream of the Golf Course

Downstream of the golf course sediment retention pond flooding occurred because the channel did not have the capacity to contain the flood flows. The channel may be undersized for the following reasons:

- Historical flood hydrology suggested the 200 year event was much smaller (2.9 m^3/s)
- The channel has infilled with limestone on account of the hot springs water being released into the creek
- The channel has been reduced in size as debris and vegetation has established along the river banks

To accommodate the anticipated flood flows the channel needs to be given a wider area to flow and the banks need to be raised. Furthermore, a means of managing vegetation encroachment and debris accumulation in the channel needs to be implemented. As part of this, residents and land owners along the channel are likely going to have to modify their properties to accept and maintain a portion of the floodway in order to accommodate the flood flows that are going to occur in Fairmont Creek. On account of the ongoing accumulation of limestone in the channel and the long term maintenance challenges associated with infrastructure, channelizing flood flows into engineered conduits is not advised.

Photo 6.6 Fairmont Creek immediately downstream of golf course sediment retainment pond.

6.3 Provide Additional Sediment Storage Upstream of Golf Course Pond

During the site inspection it was recognized that containing the sediment that is eroded out of Fairmont Creek between the hot springs and the golf course would reduce the risk of flood and avulsion to the downstream homes along the creek. A site that was identified as having tall stable bedrock banks and potentially sufficient room for downstream scour protection is illustrated in Figure 6.1. The structure could possibly be a weir similar in form to the ones upstream.

Figure 6.1 Potential location of additional debris catchment weir upstream of golf course sediment retention pond.

6.4 Improve Grade Controls and Bank Protection along Fairmont Creek

Fairmont Creek experienced extensive erosion and channel migration between the downstream end of the 2018 construction work and the golf course (see purple area identified on Map 1-2). In practice this channel would benefit from bank protection works and grade control structures being installed along the entire 1.6 km. High priority work should include grade control structures space relatively uniformly along the length of the reach to limit channel incision. Furthermore bank protection work at key locations should be conducted to limit the lateral migration of the channel. Key locations include:

- tall banks that can add a disproportionate amount of sediment,
- sections of channel with a sharp curvature,
- or in areas with more sensitive infrastructure.

See Photo 6-4 through Photo 6-8 for examples of the erosion that is occurring along the middle portion of Fairmont Creek. The goal of the work should be to reduce the total amount of sediment entrained and moved to the downstream reaches.

As part of this work the limestone deposits from the hot springs should be broken up, especially the upstream most one and the channel path restored. At present the upstream most limestone deposit and to a lesser extend the downstream deposit, are helping deflect the creek to the left (south) bank. As the creek is deflected it has eroded the road embankment and resulted in the irrigation line for the golf course being suspended in the air at two locations (e.g. Photo 6-7).

Photo 6.7 Middle portion of Fairmont Creek that would benefit from both bank protection and grade control structures.

Photo 6.8 Section of access road that was washed out and exposed irrigation waterline.

Photo 6.9 Limestone deposit in historic channel that has now directed flow south and eroded the bank.

Photo 6.10 One of two extended suspended section of golf course irrigation waterline.

Photo 6.11 Limestone sediment accumulation on right bank (image left) of the creek and eroding bank on left bank of the creek with exposed irrigation water line.

6.5 Enhance Flood Warning and Flood Management System

To provide a better understanding of the status of the floods in Fairmont and Cold Spring Creek and other nearby watersheds the following action items could be taken:

- Provide a common Decision Support System (DSS) to review all the nearby real time precipitation and water level, stream discharge data as well as incorporate BCRFC flow forecasts and Environment Canada precipitation forecasts (e.g. Figure 6.2).
- Install stilling wells in the upstream side of the Fairmont Creek sediment containment weirs using rigid perforated pipe. The pipe would need to be wrapped in geotextile cloth and then buried in the bank with riprap. Once installed a pressure transducer could be put in the debris containment weirs and used to trigger high water level alarms to indicate that a debris flood has raised the water level upstream of the weir. A system like this is installed in Fitzsimmons Creek and when a pre-determined stage is exceeded a LED light is turned on and camera images are sent out every 10 minutes to the municipality.
- Install a water level sensor in the golf course pond and develop a high flow rating curve based on the concrete outflow structure to improve flood hydrology. This sensor would also be configured to trigger an alarm so that operators could be notified and they could evaluate opening the low level outlet in the pond to potentially help prevent the pond from over-topping the golf cart pathway.

- Install a water level sensor just upstream of the spillway on the Cold Spring Creek to better understand the flood hydrology of Cold Spring Creek and when and if the structure may be overtopped. This could also be used to develop alarm threshold for when significant quantities of sediment are expected to start to be mobilize and improve the redesign of the culvert crossings down channel.
- Initiate an annual maintenance program to ensure the rain gauge on the ski hill is operating correctly and passing validation tests.

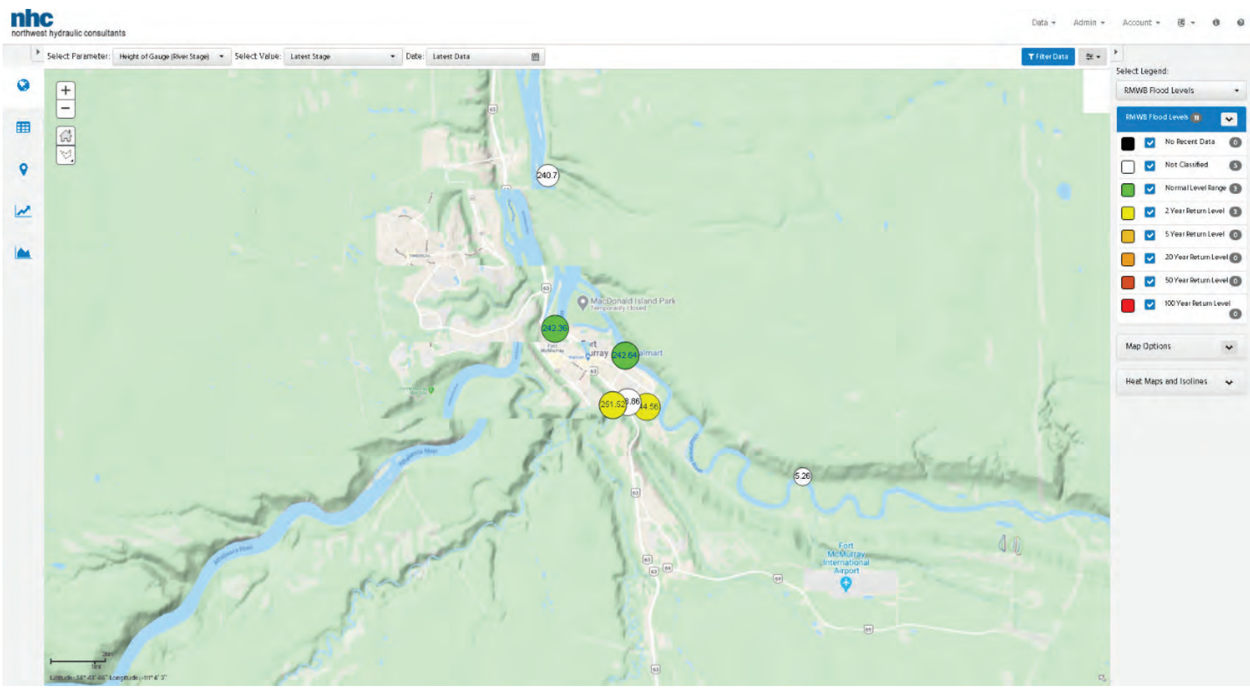

Figure 6.2 Screen shot of the decision support system that Fort McMurray (Regional Municipality of Wood Buffalo) uses to manage their ice jam and rain fall flood monitoring system. NHC maintains the system for RMWB. Yellow dots indicate stations in flood stage while green dots indicate stations in normal range. White dots do not have flood stage defined.

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