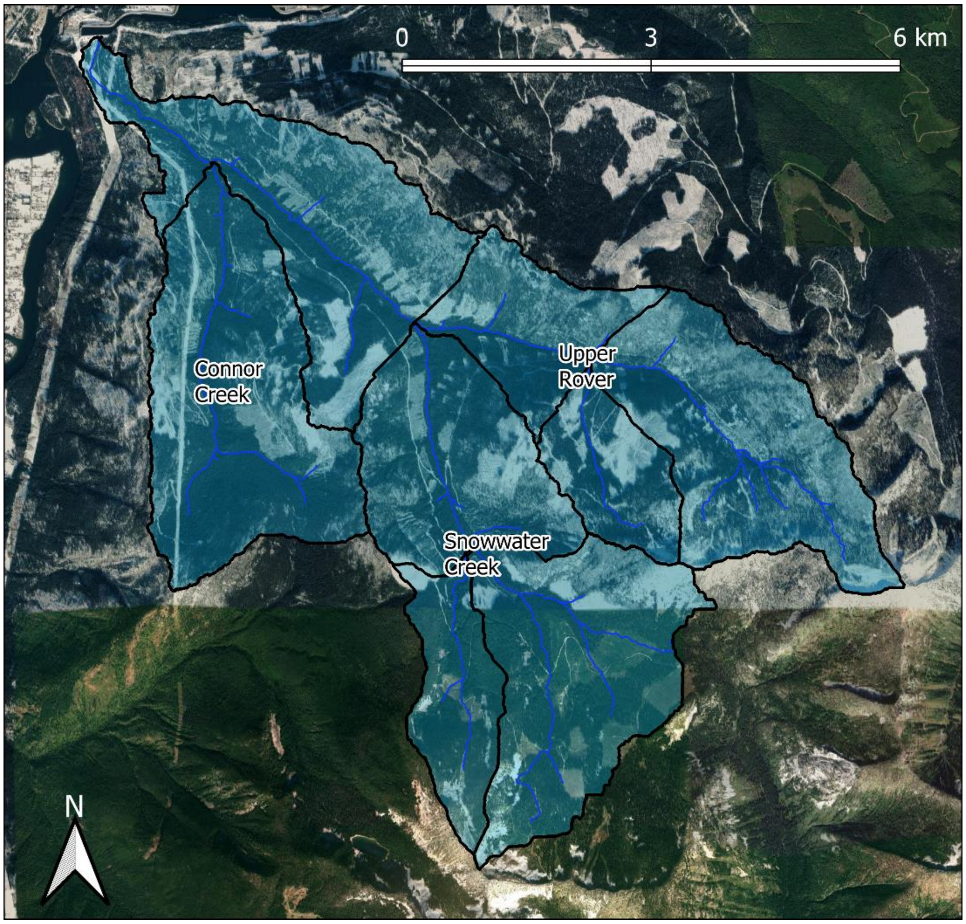
ROVER CREEK WATERSHED ASSESSMENT (2021)



Prepared for:
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INTRODUCTION

Troy Van Skiver, RPF, for Kalesnikoff Lumber Co. Ltd has retained Apex Geoscience Consultants Ltd (Apex) to undertake a watershed assessment on Rover Creek using a method consistent with the newly released Guidelines for Watershed Assessments (https://www.egbc.ca/getmedia/8742bd3b-14d0-47e2-b64d-9ee81c53a81f/EGBC-ABCFP-Watershed-Assessment-V1-0.pdf.aspx). In Rover Creek the values at risk are water quality at the intake reservoir and aquatic habitat in lower Rover Creek. For this assessment, the harmful events of concern are;

1. Changes in the frequency or magnitude of peak flows that could impact water quality or aquatic habitat,
2. Increases in sediment delivery above current levels and,
3. Changes to riparian function that could impact water quality or aquatic habitat.

METHODS

This assessment includes the analysis of the current equivalent clearcut area (ECA), a geospatial analysis of watershed physical characteristics of elevation, aspect and slope gradient distribution and a field review of the channels in Rover Creek to identify current conditions and information on past disturbance.

The ECA analysis and geospatial analysis has been undertaken by Apex Geoscience GIS specialist Cydne Potter GIT with input from Kim Green, PhD., PGeo. The field investigation of channels was undertaken by Kim Green, PhD., P.Geo. in October of 2020 during low flow conditions. The risk analysis was undertaken by Kim Green.

PHYSIOGRAPHY

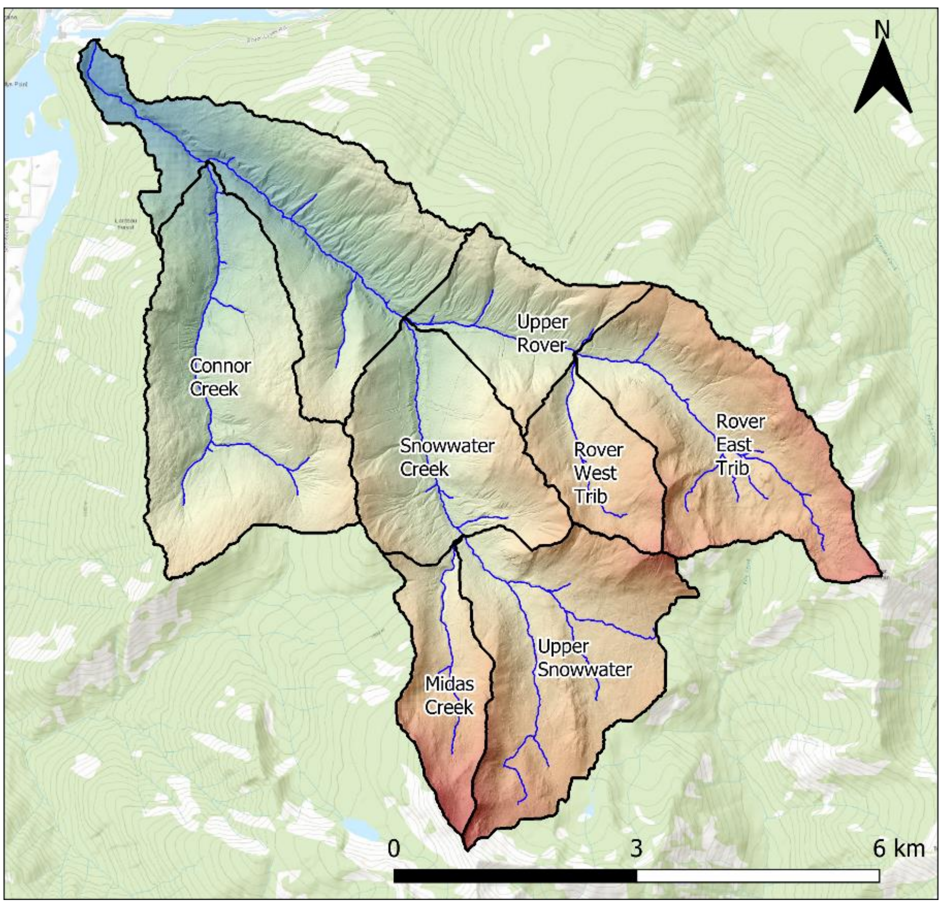

FIGURE 1. WATERSHED AND BASIN NAMES FOR ROVER CREEK USED IN THIS ASSESSMENT.

Rover Creek is a 4333-hectare watershed that ranges in elevation from 2244m at Mt. Conner to 526m at the confluence with Kootenay River. Rover Creek includes Connor Creek and Snowwater Creek tributaries. For this assessment Rover above Snowwater Creek is identified as Upper Rover.

The watershed is characterized by a large component of high elevation slopes. A hypsometric curve of Rover

Creek indicates the H60 elevation is at 1320 meters while the H20 elevation is just over 1720 meters.

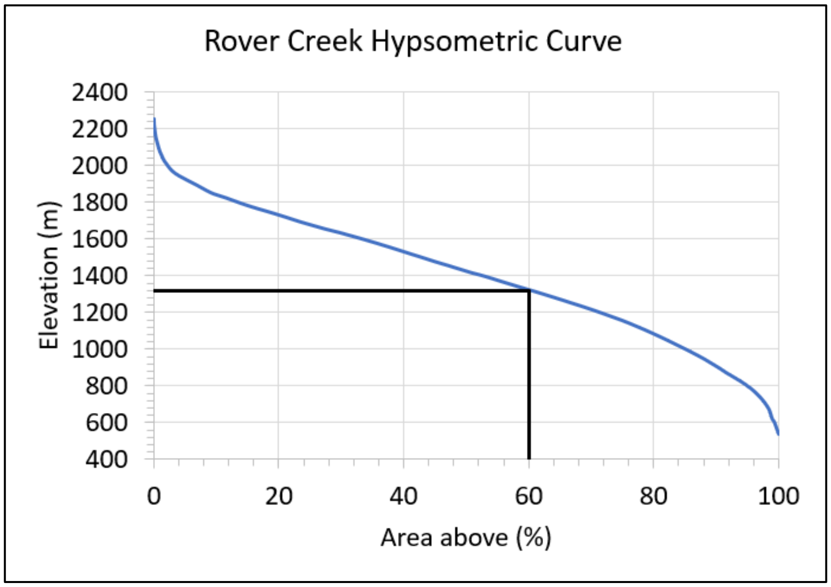

FIGURE 2. HYPSOMETRIC CURVE FOR ROVER CREEK INDICATES A LARGE COMPONENT OF HIGH ELEVATION SLOPES. THE H60 ELEVATION IS AT 1320 METERS.

GEOLOGY

Rover Creek is underlain by a variety of bedrock lithologies. The lower elevations are underlain by fine grained metamorphic sedimentary and volcanic tuffaceous rocks of the Ymir Group while upper elevations of Rover Creek are underlain by mafic volcanic and intrusive rocks of the Rossland Group. Coarsely crystalline granodiorites of the Bonnington Pluton underly upper Snowwater and Midas Creeks (Figure 3)

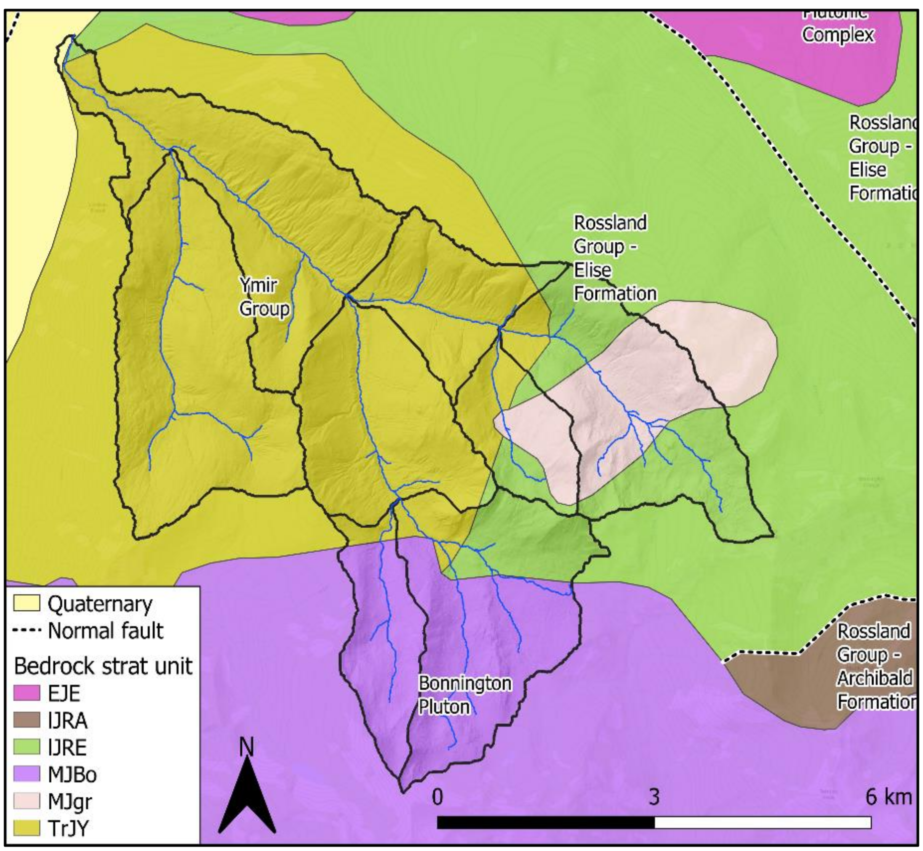

FIGURE 3. GEOLOGY OF THE ROVER CREEK AREA (IMAPBC)

The range of bedrock lithologies across Rover Creek results in differences in channel morphology. Channels underlain by coarse crystalline granodiorites contain angular cobbles and boulders while those underlain by finer grained meta-sedimentary rocks tend to have finer textured channel beds.

Coarse grained colluvium and till overly the bedrock throughout much of the upper elevations of the watershed. Mid- and lower elevation slopes have blankets or veneers of silty basal till that is susceptible to landslides if water is diverted onto these steep slopes.

Slope Aspect

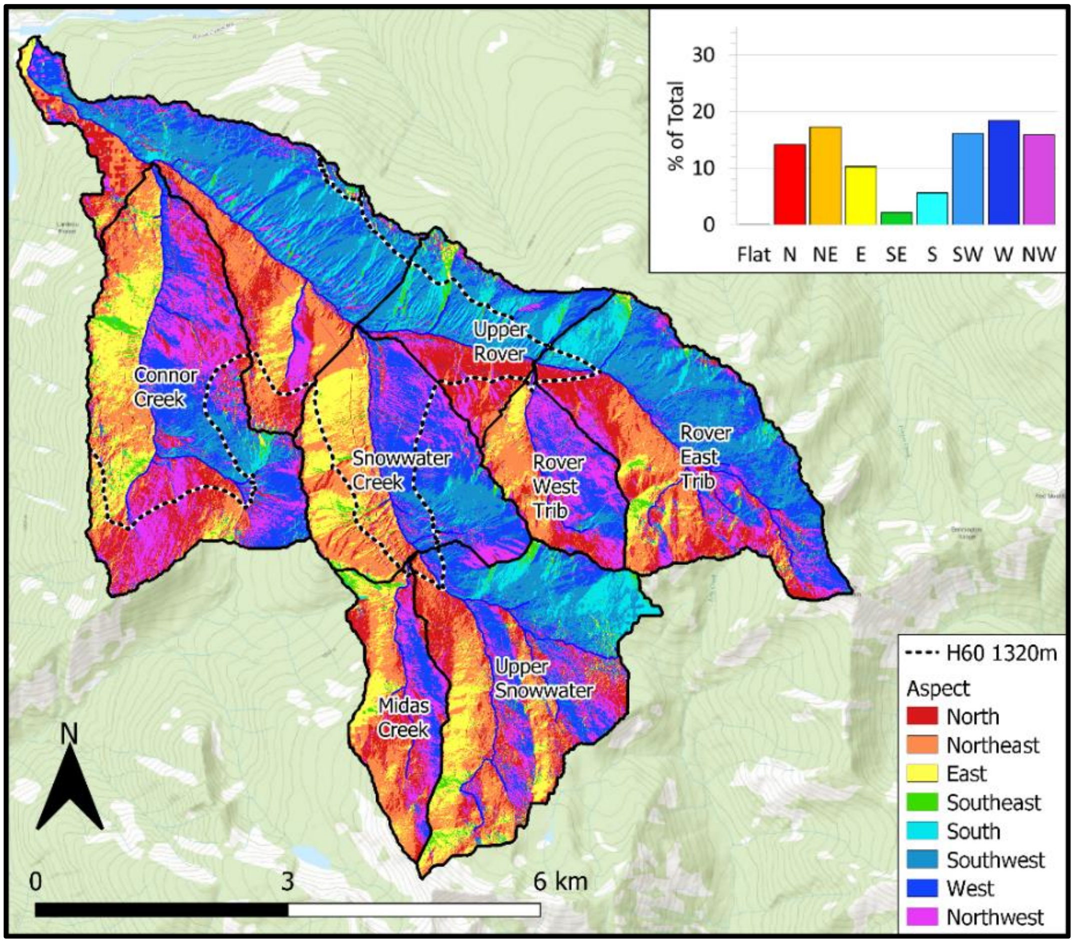

FIGURE 4. ASPECT DISTRIBUTION IN ROVER CREEK WITH THE H60 LINE.

The histogram of aspect distribution in Rover Creek (Figure 4) shows that slopes are southwest/west/northwest (shades of blue) and north/northeast/east (red, orange, yellow). Contrasting aspects result in differences in snowmelt timing from openings and juvenile stands situated across this range in aspects. Stands in Snowwater Creek that were monitored during the 2020 snowmelt period confirm that the southeast aspect open stand at 1500-meter elevation was snow free a full two weeks before the north aspect open stand at the same elevation. The contrasting aspects in Rover Creek are likely reducing the cumulative hydrological effects from the current level of disturbance.

Slope Gradient

Much of Rover Creek is classified as moderate to steep gradient with slope gradients exceeding 40%. The steepest gradient slopes occur on the valley sides along the main channels. The heights of land along ridgelines are generally gentler gradients leading to the occurrence of gentle-over-steep terrain in many parts of the watershed.

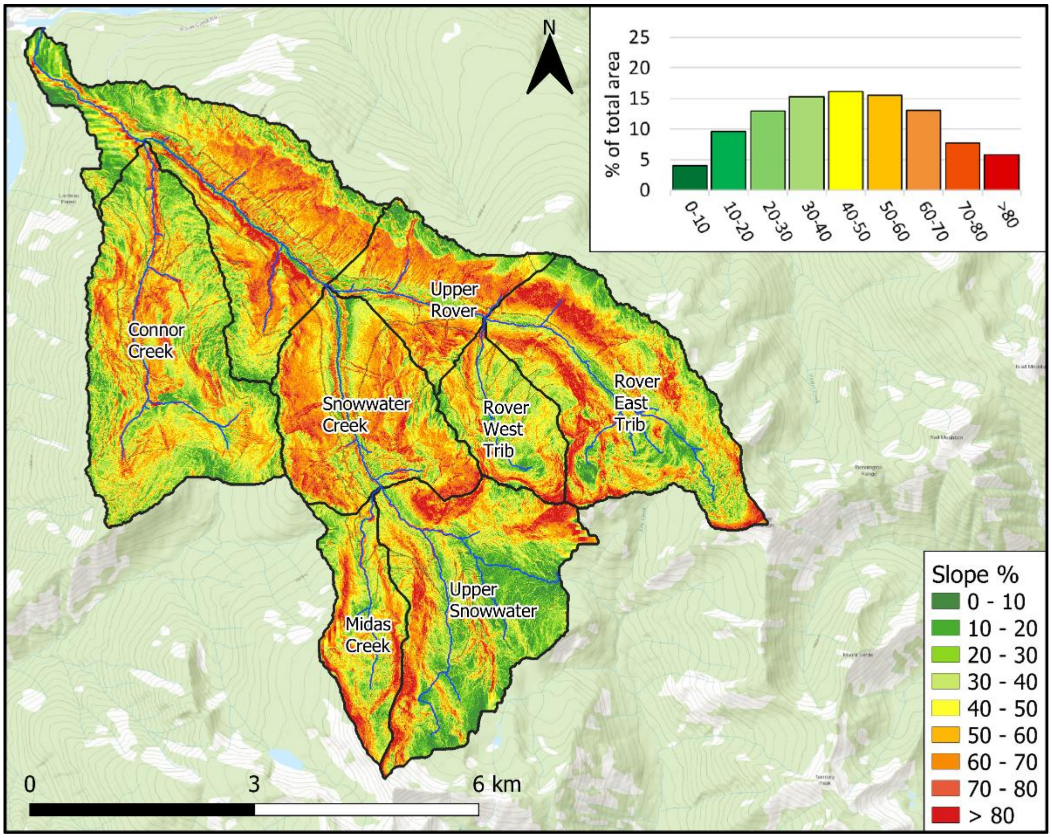

FIGURE 5. DISTRIBUTION OF SLOPE GRADIENT IN ROVER CREEK

Snowmelt sensitive zone

Discharge gauging on Rover Creek (Selkirk College study) indicates that an initial solar-radiation driven peak occurred between May 19th and May 21st 2020 followed by a large, rain-on-snow debris flood event on May 31st. A sentinel satellite photograph taken during early May (May 9, 2020, Figure 6) shows that the slopes below about 1350 meters on west, southwest and east slopes were snow free (red line) while snow was still present on north aspect slopes below about 1200 meters elevation (blue dashed line). The difference in snowmelt timing across aspects highlights that the H60 line in Rover Creek is only a rough estimate of the 'snow sensitive' zone in this watershed. In addition to delayed snowmelt on north aspect slopes, tight valleys in upper Snowwater, Midas and Upper Rover tributaries function to retain snow due to the influence of shading throughout the day in these areas.

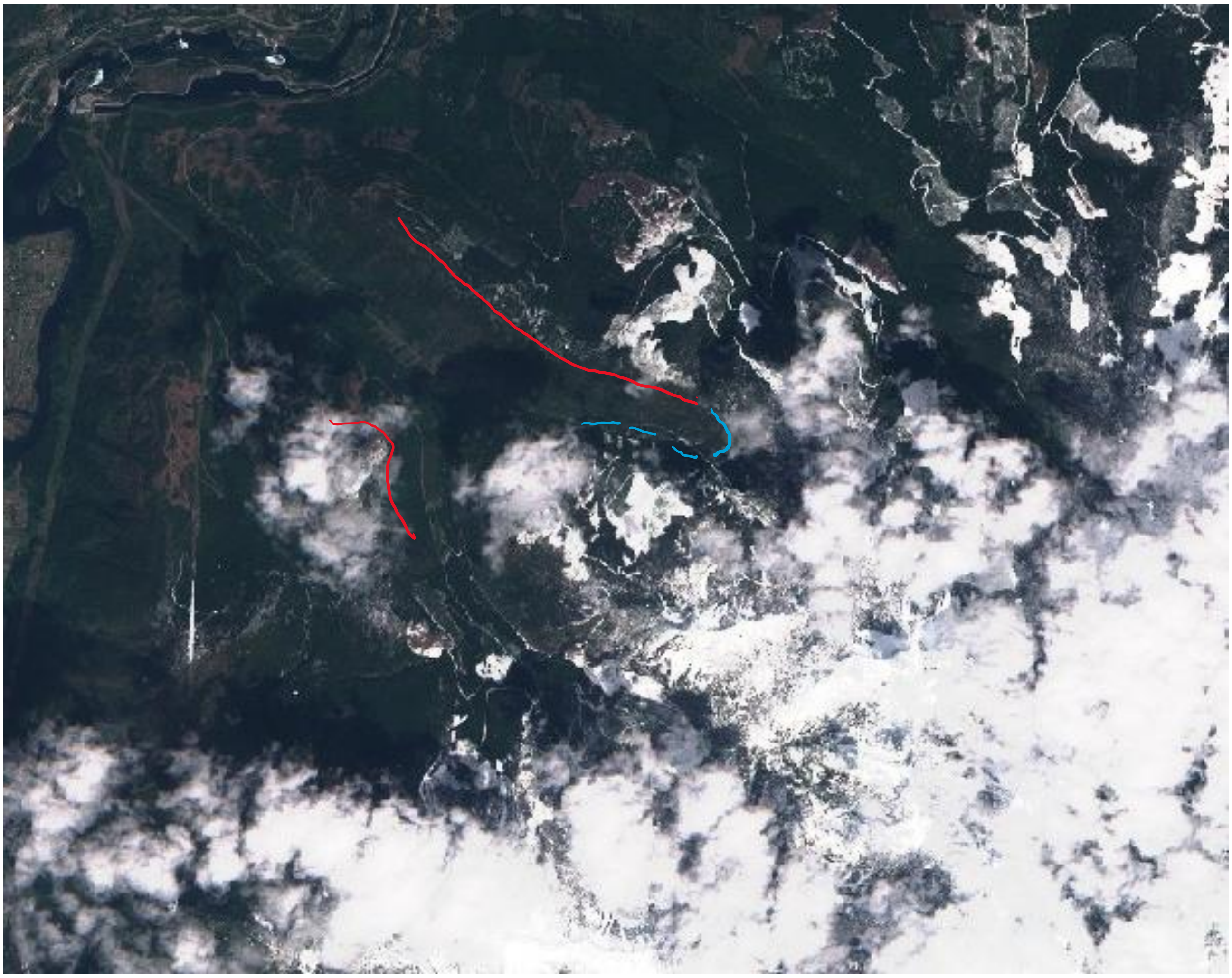

FIGURE 6. SENTINEL SATELLITE IMAGE FROM MAY 9TH 2020 IN ROVER CREEK. RED LINE CORRESPONDS TO APPROXIMATELY 1350 METERS WHILE BLUE LINE CORRESPONDS TO ABOUT 1150 METERS ON THE NORTH ASPECT SLOPES.

CURRENT FOREST DISTURBANCE

ECA ESTIMATION

Forest attributes of stand height and crown closure are used to estimate the equivalent clearcut area (ECA) of a regenerating stand compared to the clearcut condition. The information of stand height and canopy closure is estimated using data from the 2014 LiDAR provided by Kalesnikoff and the Province of BC's Vegetation Resource Inventory (2019). To understand the distribution of forest disturbance the ECA is determined for the Rover Creek, Connor Creek, Snowwater Creek and tributaries of Midas Creek and Upper Snowwater Creek, and Upper Rover as well as Rover West and Rover East tributaries (Figure 1).

The location and height of individual trees greater than 3 meters in height were identified from the 2014 LiDAR canopy height model. Growth projection curves developed from a detailed analysis of median stand height and age relationships derived from the 2014 LiDAR were used to project the 2014 LiDAR tree heights in Rover Creek to 2020 estimated heights. The watershed boundaries used for the ECA calculation were determined using the LiDAR derived digital elevation model (DEM) which was coarsened from a 1m to a 5m spatial resolution. The location of the watershed boundary assumes that surface runoff is not substantially diverted by roads that travers the watershed boundary. Some differences exist between the Provincial freshwater atlas boundary and the LiDAR-derived boundary. The LiDAR based boundary is more accurate and is used in this exercise for the estimation of ECA.

Hydrological Recovery

A study of hydrological recovery in West Kootenay stands has been under way in Rover Creek for the past two winters (2019 and 2020). This current study through Selkirk College Applied Research and Innovation Center utilizes mobile terrestrial LiDAR together with time lapse cameras and snow surveys to investigate differences in snow accumulation and snow melt across juvenile stands at a range of elevations and aspects. The preliminary outcomes of the Rover Creek study are consistent with other recent studies on the effect of cut blocks on snow accumulation and melt across different aspects which have determined that cut blocks on north and south aspects have very different effects on snow melt dynamics (Ellis et al., 2010). Cutblocks situated on north aspects tend to delay snowmelt while those on south aspects can advance snowmelt by several weeks compared to the forested stand. Preliminary results from the Rover Creek study confirms that snowmelt is substantially delayed in openings on north aspect slopes compared the mature stand and advanced on south and southeast aspect slopes relative to mature stands. However, the Rover Creek study also shows that elevation plays an important role in the extent of the changes in snow accumulation and melt processes. In addition, the Rover Creek study reveals that stands between about 3m and 5m height have very little influence on snow accumulation relative to the clear cut but elevated snowmelt rates compared to the clearcut condition.

The Rover Creek-based recovery curves are provided in Figure 7. These curves differ to some degree from the recovery curve produced by Winkler and Boon (2015) for Thomspon-Okanagan spruce – pine stands. In Rover Creek a stand located on north aspects in the ICH biogeoclimatic (BEC) zone is considered fully mature when it has a height of 27 meters and a LiDAR-derived canopy cover of 75% or greater while a stand located on south aspects in the ICH BEC zone in Rover is considered fully mature when it has reached a height of at least 22 meters and has a LiDAR-derived canopy cover of 55% or greater. A stand located in the ESSFwh BEC subzone is considered fully mature when it has reached a height of at least 20 meters and has a canopy cover of at least 45%. Locally, mature stands in the ESSFwm subzone in Rover creek are similar in height and canopy cover to mature stands in the ESSFwh subzone. Disturbed stands in the ESSFwm subzone in Rover Creek are located immediately adjacent to the ESSFwh subzone and are assigned recovery values based on mature stand characteristics in the ESSFwh subzone.

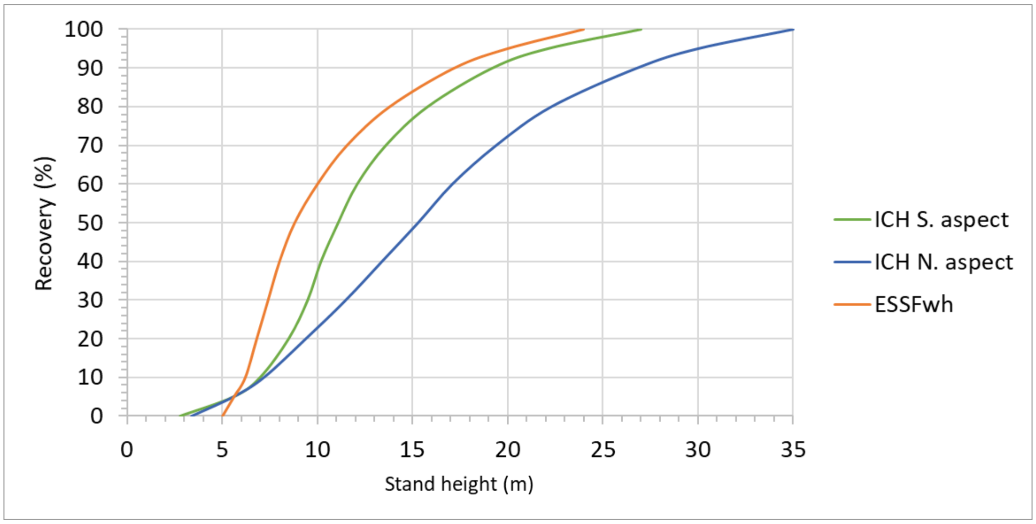

FIGURE 7
PRELIMINARY HYDROLOGICAL RECOVERY CURVES DEVELOPED FROM SNOW SURVEY DATA FROM SELKIRK COLLEGE STUDY.

The height and canopy closure characteristics of mature stands in Rover Creek were determined by undertaking a geospatial analysis of the LiDAR-derived canopy height model (CHM) for forest cover polygons in the VRI and determining the median, mean and mode values of tree-heights in each of the mature forest polygons located within each BEC subzone. For Rover Creek the median tree height value was considered most representative of the forest polygon and is used to establish a more accurate height of the regenerating stands. Canopy cover percentages for VRI polygons in Rover Creek were derived from the 2014 LiDAR. However, canopy cover may have changed significantly in the 6 years following the acquisition of the 2014 LiDAR, particularly in regenerating stands. LiDAR-derived canopy cover percentages were therefore compared against crown cover percentages listed in the 2019 VRI database and were further verified using recent Sentinel satellite imagery. Additionally, field survey data supplied by Kalesnikoff Lumber Co. Ltd. describing more recent measures of stand height, stem density, and tree species percentages were also considered.

TABLE 1. HYDROLOGICAL RECOVERY VALUES ASSIGNED TO STANDS IN ROVER CREEK

BEC Subzone	Stand height (m) of primary strata	LiDAR canopy cover (%)	Hydrological recovery (%)	BEC Subzone	Stand height (m) of primary strata	LiDAR canopy cover (%)	Hydrological recovery (%)	BEC Subzone	Stand height (m) of primary strata	LiDAR canopy cover (%)	Hydrological recovery (%)
ICH North Aspect	4 - 7	>15 - 25	10	ICH South Aspect	4 - 7	>15 - 20	10	ESSFwh	5 - 7	>15 - 20	10
	4 - 7	>25 - 35	20		4 - 7	>20 - 30	20		5 - 7	>20 - 30	20
	4 - 7	>35	30		4 - 7	>30	30		5 - 7	>30	30
	>7 - 12	>15 - 25	20		>7 - 10	>15 - 20	20		>7 - 10	>15 - 20	20
	>7 - 12	>25 - 35	30		>7 - 10	>20 - 30	30		>7 - 10	>20 - 30	30
	>7 - 12	>35	40		>7 - 10	>30	40		>7 - 10	>30	50
	>12 - 16	>15 - 25	30		>10 - 12	>15 - 20	30		>10	>15 - 20	30
	>12 - 16	>25 - 45	40		>10 - 12	>20 - 30	40		>10 to 14	>20 - 30	50
	>12 - 16	>45	50		>10 - 12	>30	50		>10 to 14	>30	70
	>16	>15 - 25	40		>12	>15 - 20	40		>14	>20 - 30	70
	>16	>25 - 45	50		>12	>20 - 35	50		>14	>30 - 45	80
	>16 - 20	>45	70		>12 - 16	>35 - 45	70		>14 - 17	>45	90
	>20 - 27	> 45 - 65	80		>16	> 35 - 45	80		>17 - 20	>45 - 55	90
	>20 - 27	>65 - 85	90		>16 - 22	>45 - 65	90		>17	>55	100
	>20 - 27	>85	100		>16 - 22	>65	100		>20	>45	100
	>27	>45 - <75	90		>22	>45 - <55	90				
	>27	≥75	100		>22	≥55	100				
	≤ 4 meters (and/or) <15%		0		≤ 4 meters (and/or) <15%		0				

RESULTS

Currently 1160 hectares or 27% of the 4333-hectare Rover Creek catchment is considered in a disturbed condition. When hydrological recovery is applied the current ECA for the watershed is estimated at 964 hectares or just under 23% of the total watershed area (Figure 7 and Table 2). The ECA above the H60 elevation of 1320 meters is estimated at 510 ha or about 12% of the watershed area.

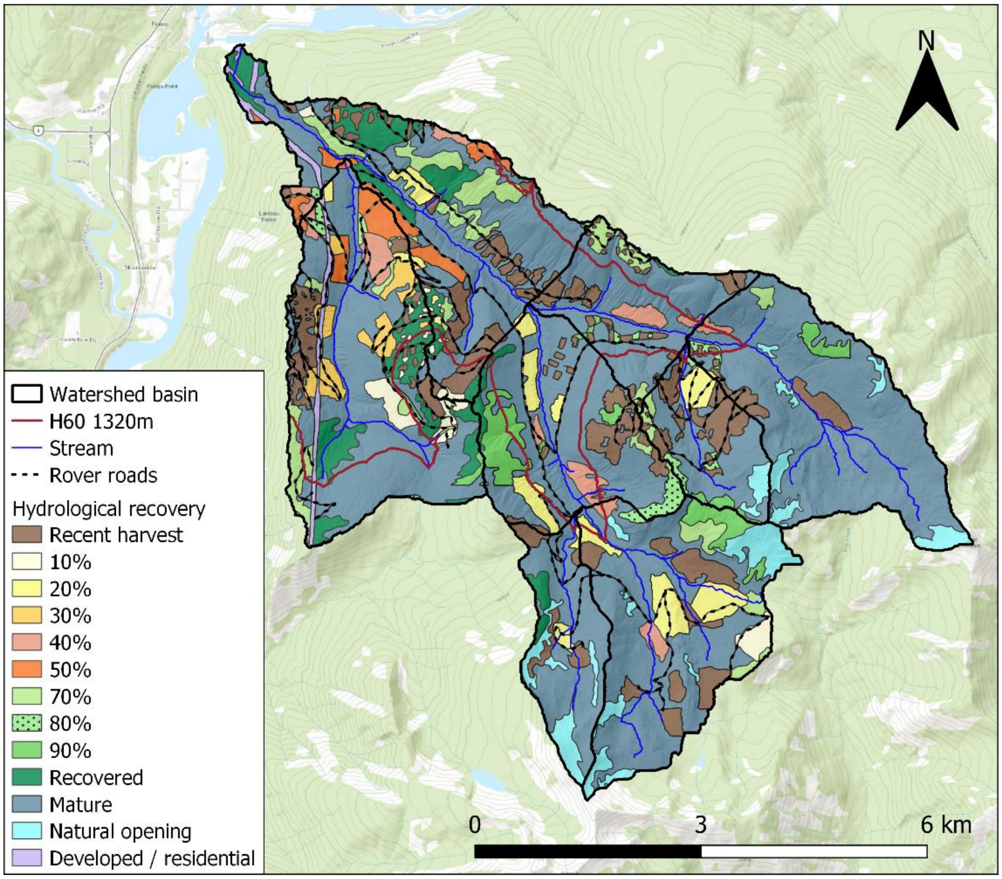

FIGURE 8. CURRENT ESTIMATED HYDROLOGICAL RECOVERY (%) OF CUT BLOCKS IN ROVER CREEK. THE H60 ELEVATION (1320M) IS SHOWN IN RED.

TABLE 2. CURRENT ECA IN ROVER CREEK AND SUBBASINS

Opening description	Applied recovery (%)	2020 Unrecovered area (ha)								
		Rover Creek	Rover Creek above H60	Connor Creek	Snowwater Creek	Upper Rover Creek	Midas Creek	Upper Snowwater	Upper Rover W Trib	Upper Rover E Trib
Total watershed area (ha)		**4333.0**	**2616.9**	**841.1**	**1499.8**	**1234.5**	**269.5**	**704.0**	**237.5**	**682.5**
Recent harvest	0%	469.5	304.9	58.6	165.8	144.0	28.8	81.9	61.0	38.2
Developed / residential	0%	44.3	4.7	25.9	0.0	0.0	0.0	0.0	0.0	0.0
Road openings	0%	52.9	17.2	17.0	12.0	7.6	2.2	4.2	3.8	0.7
Disturbed forest 10% recovered	10%	57.9	34.6	33.8	15.8	0.0	0.0	15.8	0.0	0.0
Disturbed forest 20% recovered	20%	131.0	87.8	5.3	94.6	15.9	7.4	53.0	15.0	1.0
Disturbed forest 30% recovered	30%	43.5	0.4	42.4	0.3	0.0	0.0	0.3	0.0	0.0
Disturbed forest 40% recovered	40%	58.8	12.9	14.7	21.7	14.8	0.0	9.3	0.0	3.4
Disturbed forest 50% recovered	50%	43.0	3.2	18.6	0.0	1.2	0.0	0.0	1.0	0.0
Disturbed forest 70% recovered	70%	56.7	27.3	13.1	9.8	10.5	0.0	8.5	2.1	1.9
Disturbed forest 80% recovered	80%	9.2	6.6	1.3	4.3	3.3	0.0	0.9	1.7	1.0
Disturbed forest 90% recovered	90%	11.8	10.3	0.9	8.4	2.5	0.0	3.0	0.8	1.5
Recovered	100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mature	100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural opening	100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total current ECA (ha)		978.5	509.8	231.4	332.6	199.8	38.4	177.0	85.4	47.7
Total current ECA (%)		**22.6**	**19.5**	**27.5**	**22.2**	**16.2**	**14.2**	**25.1**	**36.0**	**7.0**

The ECA in the individual tributaries range from 36% in upper Rover West to 7% in upper Rover East. Connor Creek and Upper Snowwater have ECAs exceeding 25% of their catchment areas. In most tributaries the existing development is distributed across aspects and elevations.

FIELD OBSERVATIONS

Road access allowed investigation of the channel of Rover Creek in several locations along its length from the upper headwaters of Snowwater and Upper Rover creeks to the reach of Rover Creek above the FSR 4 Km bridge (Figure 9). The channel was assessed in October 2020 during low flow conditions. Information on channel morphology, mobile bedload, riparian function, and historical disturbance events were noted during the field survey. Measurements of channel geometry and maximum mobile grainsize were collected at each of the field sites and is used to calculated bankfull flow and stream power to provide an understanding of the processes of sediment and water movement through the watershed. Figure 9 shows the location of the field sites from the 2020 field surveys.

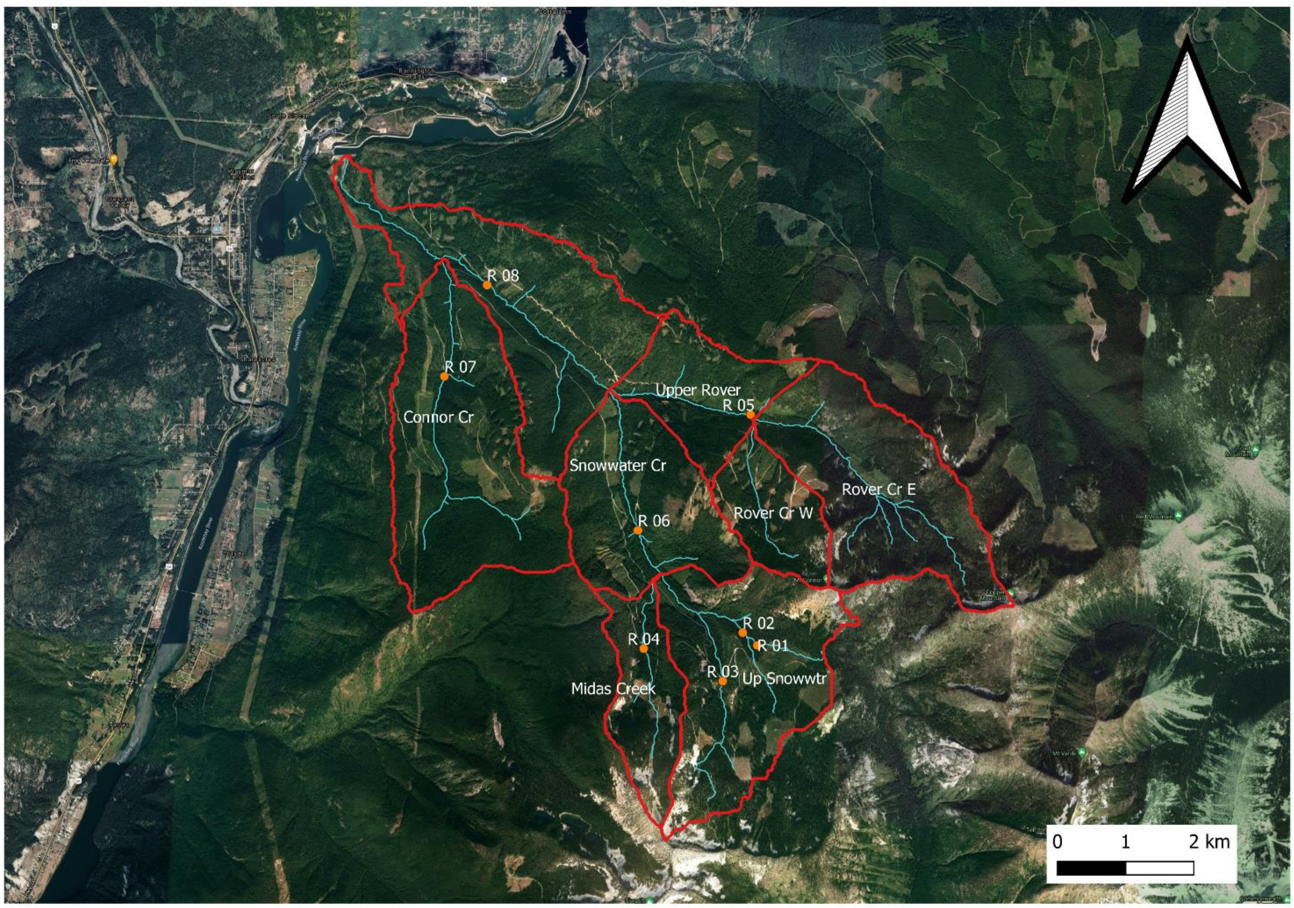

FIGURE 9. LOCATION OF FIELD SITES IN ROVER CREEK

SNOWWATER CREEK

The channel of Snowwater Creek was investigated at several sites from its headwaters to the reach above the confluence with Rover Creek (Figure 9). In the eastern headwaters (site R01), the channel has a gradient of 10% and is a mossy, angular boulder cascade colluvial channel with no indications of mobile sediment larger than gravel (<3cm). Some of the small woody debris (small branches and needles) was mobile this past freshet but woody debris larger than about 10 cm diameter has never moved (>200 yrs) and there are no indicators of larger flood events such as debris levees along this reach of the headwater channel. Riparian vegetation is hemlock, spruce and balsam up to 70cm diameter.

PHOTO 1. LOOKING UPSTREAM ON UPPER SNOWWATER CREEK AT SITE R01

However, evidence of recent channel disturbance related to this past year's flood was noted at site R02 (Photo 2). Here, the channel has a forced step morphology with a gradient of 7%, a bankfull width of 4m and angular cobbles to about 18 cm were mobile during the 2020 freshet. Large woody debris is present in the stream but was mobilized in the 2020 flood. Some fresh bank scour is also present but otherwise banks are overhanging and vegetated with herbaceous plants, moss and shrubs.

PHOTO 2. LOOKING DOWNSTREAM AT SITE R02 ON UPPER SNOWWATER CREEK

Before this recent disturbance, the last channel forming flood causing channel avulsion and movement of large woody debris appears to be over 100 years old based the degree of decomposition of wood and age of riparian vegetation which includes mature hemlock and fir over 50 cm in diameter. The 2020 flood caused some of the older woody debris to break apart.

The western headwater of Snowwater Creek observed at site R03 has a notably different appearance than the eastern tributary observed at sites R01 and R02. In this reach the riparian vegetation has been logged and consists of smaller (to 40cm max) cedar and hemlock with small saplings less than 10cm along the channel banks. Old cut logs are in the channel and some are creating steps that are functioning to retain cobbles.

PHOTO 3. LOOKING UPSTREAM ON THE WESTERN TRIBUTARY OF UPPER SNOWWATER CREEK AT SITE R03.

The coarse cobble to boulder bedload in the channel appears bright and very mobile with little moss. Subangular boulders up to 35 cm were mobilized in the 2020 freshet. Here the boulders are primarily granitic in composition in contrast to metasediments and volcanic rocks in the eastern tributary. Some of the older woody debris in the channel appears to have entered after a burn. Channel banks are eroded and laid back.

MIDAS CREEK

PHOTO 4. LOOKING DOWNSTREAM AT MIDAS CREEK BELOW FSR

The channel of Midas Creek is a mossy, blocky colluvial channel with a gradient of 20% above the Rover FSR and a bankfull width of 2.3 meters. There is very old, large woody debris in the channel that has not recently moved although some movement of small woody debris (branches) is evident and cobbles up to about 20 cm were moved in the 2020 freshet.

Channel banks are overhanging and vegetated and the riparian vegetation consists of mature cedar, spruce, balsam fir and hemlock. Some gravel deposits from a past 10 to 20 year old flood event are evident but most of the lateral sediment deposits are mossy.

PHOTO 5. LOOKING UPSTREAM ON MIDAS CREEK AT FSR.

The vegetated lateral flood deposits can be seen on the right side of the channel of Midas Creek in photo 5.

Snowwater Creek mainstem channel above Rover Creek confluence

PHOTO 6. LOOKING UPSTREAM AT SITE R06 ON SNOWWATER CREEK ABOVE ROVER CREEK

Snowwater Creek at site R06 above the bridge has a cascade- boulder morphology with a gradient of 13% and a bankfull width averaging 5.4 meters. The granitic/gabbroic cobbles and boulders in the channel are generally bright, imbricated and subrounded suggesting they are moving during infrequent large flood events. Boulders larger than about 60cm are mossy suggesting they have not moved for several decades. Cobbles to about 16cm appear to be mobile annually but boulders up to 40 cm were mobile in 2020 flood.

Below the Snowwater Creek bridge the channel immediately downstream hosted a debris flood during the 2020 flood and all bedload including the largest boulders were mobilized (Photo 7). It appears that the slight constriction of the channel at the bridge caused flow velocity to increase enough to initiate a debris flood. It is not known how far downstream this debris flood continued but it is likely the turbidity from this event was carried down to the lower reaches of Rover Creek.

PHOTO 7. LOOKING DOWNSTREAM FROM BRIDGE OVER SNOWWATER CREEK AT SITE R-06. THE CHANNEL OF SNOWWATER CREEK HOSTED A DEBRIS FLOOD ALONG THIS PORTION OF THE CHANNEL IN 2020.

In addition to the recent debris flood deposit, a flood terrace containing broken LWD is present along the upper channel margins and appears several decades old (1974?).

Riparian vegetation consists of cedar and hemlock to about 40cm diameter. Channel banks, where not disturbed by the 2020 debris flood, are vegetated with alder shrubs and sapling conifers. Although there is some large woody debris in the channel, most is spanning or suspended above the channel. There is quite a bit of old large woody debris deposited on top of the old (1974?) flood deposit. This old LWD is mostly broken and rotting.

Upper Rover Creek

The lack of roads along upper Rover Creek limited access to this portion of the Rover Creek channel. The channel of upper Rover Creek was investigated at site R05 (Figure 9). At this site, the channel is substantially different from adjacent Snowwater Creek. It is smaller with a bankfull width of just over 4 meters and a gradient of over 15%. In addition, the channel is much darker and cobbles larger than about 30 cm are moss covered. The sediment bedload is generally finer textured with gravel and cobbles up to about 15 cm mobile annually.

There was recent bank scour/erosion related to the 2020 flood and some movement of LWD but no evidence of past large flood events. Some LWD is functioning in the channel but most is suspended above, and the large lag boulders present in this channel limits the ability of LWD to connect with the channel bed.

PHOTO 8. LOOKING UPSTREAM AT SITE R05 ON UPPER ROVER CREEK

ROVER CREEK BELOW SNOWWATER CREEK CONFLUENCE

The channel of Rover Creek was investigated upstream of the FSR bridge at 4 km. The channel has a step pool to forced step pool morphology. Rounded cobbles to 20 cm are mobile annually but boulders up to 50 cm were mobile in the 2020 flood. These 50 cm boulders are also forming steps in the channel of Rover Creek. The channel bed is bright and appears to have been fully mobile in 2020. An old flood deposit estimated at approximately 40 yrs old (~1974) is evident as a boulder level with alders, saplings and suspended LWD along upper channel banks. Channel banks were eroded in the 2020 flood.

PHOTO 9. LOOKING DOWNSTREAM AT ROVER CREEK ABOVE THE 4KM FSR BRIDGE

The riparian vegetation in this area is mixed cedar and hemlock to 60 cm diameter. There is some broken old LWD along channel banks and newer woody debris suspended above the channel but most of the functioning LWD appears to have been flushed out of the channel during the flood event that occurred approximately 40 years ago (1974?).

The channel of Rover Creek is locally confined by bedrock through this reach.

CONNOR CREEK

The channel of Connor Creek is very different in appearance from Snowwater or Rover Creek. Upstream from the Connor FSR it is small, with a bankfull width of just under 3 meters and a gradient of between 5 and 10 percent. Connor Creek has a forced woody debris step pool morphology and there is abundant, very old LWD functioning in the channel creating sediment-retaining steps. Much of the woody debris appears to have been functioning in Connor Creek for over a century.

PHOTO 10. LOOKING UPSTREAM ON CONNOR CREEK ABOVE CONNOR FSR

Generally, the mobile bedload of Connor Creek is limited to small cobbles and gravel less than 8 cm but cobbles up to about 16 cm were mobile during the 2020 flood. Banks are vegetated and overhanging but some recent scour is present. The riparian vegetation includes hemlock to 60 cm diameter.

HYDRAULIC GEOMETRY AND MOBILE GRAINSIZE

The relationship of flow cross-sectional area (bankfull width x average bankfull depth) to upstream watershed area (the area of the watershed draining to the survey site) provides information on the relative discharge from the various headwater basins in Rover Creek (Figure 10).

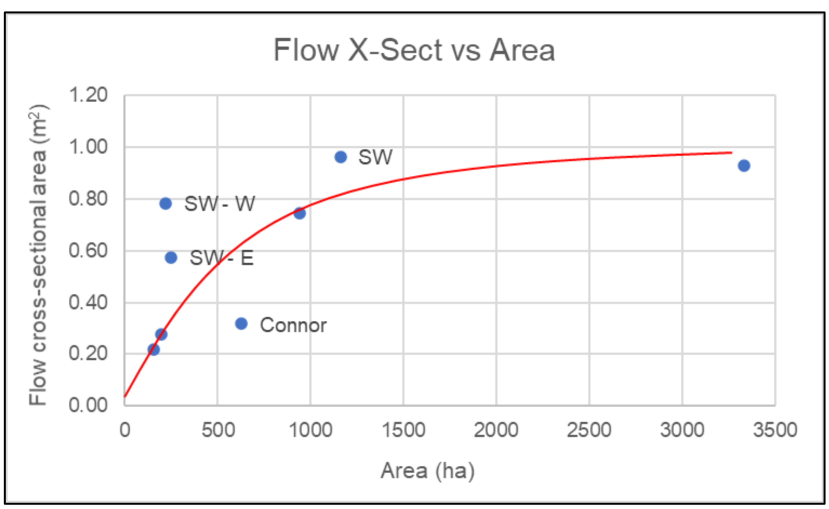

FIGURE 10. BANKFULL FLOW CROSS-SECTIONAL AREA TO WATERSHED AREA

The bankfull flow cross-sectional area of the Snowwater – West headwater channel (Site R03) is substantially larger in size than similar sized Snowwater East channel (R02). In addition, Snowwater Creek at site R06 (SW on Figure 10) sits above the overall trend of the graph. Conversely, Connor Creek lies below the trend for Rover Creek. This graph indicates that during average runoff years, Snowwater Creek is providing proportionally, more of the peak runoff in Rover Creek.

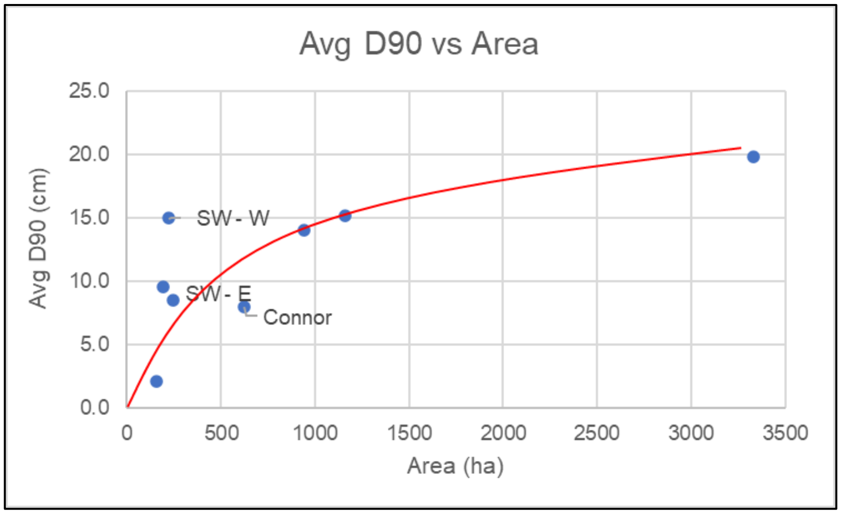

FIGURE 11. AVERAGE MAXIMUM MOBILE GRAINSIZE VERSUS WATERSHED AREA IN ROVER CREEK.

In addition to providing more of the annual peak flow the channel of Snowwater Creek (West) has a substantially larger mobile bedload than the general trend observed in Rover Creek (Figure 11). This graph also shows that the maximum mobile bedload in Connor Creek lies below the overall trend in Rover Creek.

Discussion of Field Observations

Information from the field observations and survey data indicate that not all tributaries are contributing equally to runoff in Rover Creek. Snowwater Creek West headwater basin appears to carry larger peak flows and transport larger and higher volumes of bedload than other tributaries of Rover Creek including Snowwater East tributary. Field observations also indicated that lower Snowwater Creek (at site R06) displays more frequent flood disturbance and, as well, was the primary source of discharge during the 2020 flood and the last (1974?) channel forming flood event that caused major disturbance in the Rover Creek channel through the lower reaches. In contrast, Connor Creek experiences lower peak discharge and, as well, transports minimal volumes, and smaller textured bedload compared to other tributaries of Rover Creek. There is no evidence of frequent past flood disturbance in either Connor Creek or upper Rover Creek above Snowwater Creek. Field observations identified recent flood disturbance in Snowwater Creek East (R02) that may be associated with recent clearcut logging in the catchment above this point. The speculation of harvesting related disturbance relates to the fact that there had been minimal historical flood disturbance in this channel (site R02) prior to the 2020 freshet and woody debris that had been stable in this channel for many decades was mobilized in the 2020 flood.

The differences in runoff and the frequency of floods in the tributary basins relates to differences in elevation and aspect distribution, slope gradient as well as bedrock geology. In Snowwater West headwater basin, high elevation, steep sided, north, east, and west aspect slopes and a broad, bowl-shaped valley contribute to the retention of snow in this basin into the late spring when it is prime for rapid melt during late spring rain-on-snow events. In contrast, Connor Creek is a low elevation watershed that has contrasting, northeast to east and west aspect slopes which contributes to lower amounts of snow accumulation and some degree of desynchronization of snowmelt between the two aspects. Desynchronization of melt is observed in upper Rover Creek in the Sentinel Satellite imagery from May 9, 2020 (Figure 6). This image shows that the snowline is roughly 150 meters higher on the south/southwest aspect slopes on the northeast side of upper Rover Creek compared to the northeast aspect slopes.

Risk Assessment

This risk assessment follows the guidance contained in the recently published document; Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Industry (EGBC – ABCPF Joint Practices Board, January 2020, downloaded from; https://www.egbc.ca/getmedia/8742bd3b-14d0-47e2-b64d-9ee81c53a81f/EGBC-ABCFP-Watershed-Assessment-V1-0.pdf.aspx). The values of concern in Rover Creek include water quality at the intake and aquatic habitat through the lower reaches of Rover Creek. For this assessment, the harmful events of concern are;

- Changes in the frequency or magnitude of peak flows that could impact water quality or aquatic habitat,
- Increased sediment delivery that could impact water quality or aquatic habitat and,
- Changes to riparian function that could impact water quality or aquatic habitat.

These harmful events are assessed relative to pre-forest development conditions in Rover Creek. The compounding effects of climate change are also considered in the assessment of harmful events.

Definition of Probability and Likelihood of an Event

The likelihood of an event that could cause harm to a Value is assigned a quantitative probability or qualitative likelihood according to the criteria in Table 2. For this assessment, the likelihood of an event is assessed for current conditions relative to an undisturbed watershed as well as the potential for incremental increases in the likelihood of the event associated with the potential future development.

TABLE 3. QUANTITATIVE AND QUALITATIVE LIKELIHOOD FOR A HARMFUL EVENT ADAPTED FROM LMH 61.

Probability of an Event Pe	Qualitative likelihood	Description
≥ 0.8	Very high	A noticeable change is certain to occur
0.6 to < 0.8	High	A noticeable change is likely
0.4 to <0.6	Moderate	A noticeable change is possible
0.2 to <0.4	Low	There is a small possibility of a change in the event but not noticeable
0 to < 0.2	Very Low	There is a very remote possibility of a change in the event occurring

Definition of Consequence to a Value at Risk

TABLE 4. EXAMPLE OF CONSEQUENCE FOR WATER QUALITY.

Consequence level	Physical effect Water Quality
Low	No impacts to water quality related to turbidity
Moderate	Noticeable increase in turbidity but manageable with existing infrastructure
High	Physical damage to water intake or prolonged turbidity event

TABLE 5. EXAMPLE OF CONSEQUENCE FOR AQUATIC HABITAT.

Consequence level	Physical effect Aquatic habitat
Low	Short term impacts to aquatic habitat
Moderate	Localized, long-term material adverse effects to aquatic habitat
High	Material adverse effect, extensive permanent destruction of habitat, degradation of habitat that is more than transitory

Due to the lack of information about the vulnerability of water quality and aquatic habitat in the lower reaches of Rover Creek this assessment is a partial Risk Assessment that considers only the likelihood of change in the harmful event given existing conditions relative to baseline undisturbed conditions.

Current conditions Partial Risk assessment

Changes in the frequency/magnitude of peak flows that could impact water quality and aquatic habitat through lower reaches of Rover Creek compared to undisturbed conditions

Forest disturbance can increase the frequency and magnitude of floods in snowmelt watersheds. No information is available regarding the current water quality in Rover Creek or on the vulnerability of aquatic habitat. The frequency/magnitude of the 'harmful' peak flow is dependent, in part, on the morphology of Rover Creek. Through the lower reaches Rover Creek channel alternates between bedrock confined and a boulder step to cascade morphology. Given the resilient nature of the channel, for this assessment an increase of more than 10% in the magnitude of floods across the range of return periods is considered a harmful change.

The current ECA in Rover Creek is estimated at just under 23% and openings in the forest cover are distributed across aspects and elevations with just over 60% of openings above the H60 elevation of 1320 meters and just under 28% below the H80 (1100m). In nearby Redfish Creek (23km^2) a study using a fully distributed hydrological model found that harvesting of just over 22% of the watershed area resulted in significant/detectable increases (≥10%) in the frequency and magnitude of floods when harvesting (~58% of openings) was concentrated in region between the H60 and H40 (Schnorbus and Alila, 2004). These increases in peak flow magnitude in Redfish Creek, across the full range of frequencies were larger when the level of harvest increased to over 30% and included areas above the H80 elevation (Schnorbus and Alila, 2004, Green and Alila, 2012). However, this same study determined that when harvesting focused on areas below the H80 or below the H60 the increases in peak flow magnitude were much smaller and statistically insignificant.

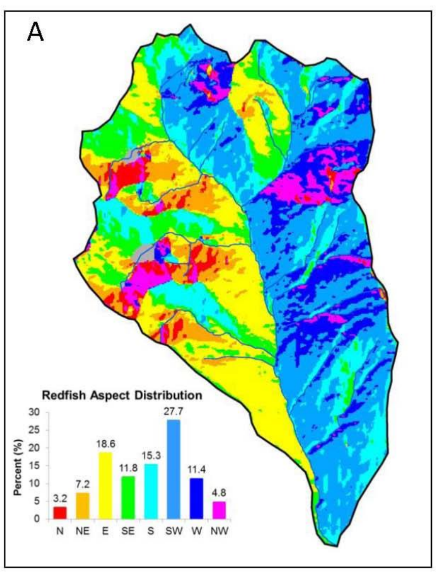

FIGURE 12. REDFISH CREEK ASPECT DISTRIBUTION

The increases in peak flows over a range of frequencies associated with harvesting mid and upper elevation forests in Redfish Creek are the result of synchronization of melt between mid/upper elevation openings and mid/lower elevation forests. Studies at the stand level by Ellis et al (2010) determined that openings on south aspect slopes tend to display greater alterations to the timing and rate of snow melt including advancing the melt by weeks in response to increased shortwave radiation compared to openings on north aspect slopes.

Rover Creek and Redfish Creek display substantial differences in physiography. Redfish Creek is roughly half the size of Rover Creek with steeper slopes that are predominantly south to southwest aspect (Figure 12) compared to the northeast/southwest contrasting slope aspects in Rover. Given these differences, and based on the study outcomes, it follows that Redfish Creek is likely to display greater increases in the advance and rate of runoff following harvesting on south/southwest aspect slopes than would occur in Rover Creek for similar levels unless the majority of harvest in Rover were situated on south/southwest aspect slopes – which it is not. In addition, the Redfish study shows that harvesting at lower elevation, in addition to mid and upper elevations, tends to reduce increases in peak flows through the desynchronization of snowmelt and the earlier melt of low elevation openings. Given this rational, and without model-supported information on runoff timing in Rover Creek, it is interpreted that the current 22.6% ECA, which is distributed above and below the H60 elevation represents a low likelihood for increasing the frequency/magnitude of peak flows to a level (>10%) that could affect water quality or aquatic habitat.

Increases in sediment delivery above undisturbed levels

Sediment enters stream channels episodically through bank failures, landslides and, through overbank floods (Return Period appx > 5 years) that fill the channel and mobilize the bedload and fine sediment stored in and along the channel banks. Forest harvesting can increase the occurrence of landslides through drainage concentration and diversion along forest roads and skid trails, and through increases in slope runoff above unstable slopes associated with forest openings.

Snowwater Creek below the Rover Creek FSR bridge hosted a debris flood in 2020 that likely mobilized a large volume of fine sediment. The debris flood appears to have been triggered by the constriction of the channel created by the bridge footings that increased flow velocity of the exceptionally high 2020 runoff on the downstream side sufficiently to initiate the debris flood. It is not known how far downstream this debris flood continued. The short-duration debris flood in the mainstem of Rover Creek that was observed in the vicinity of the 4km bridge on May 31, 2020 was the result of cumulative runoff from exceptionally high discharge related to the rain-on-snow and likely not directly related to the Snowwater Creek debris flood.

Besides the Snowwater debris flood, field observations did not identify any other active areas of increased sediment delivery associated with the existing forest roads. Channel disturbance from the 2020 flood/debris flood caused high levels of turbidity in Rover Creek through the lower reaches but observations of the channel made before the 2020 flood did not identify indicators that this section of channel was experiencing a higher frequency of overbanks floods related to the upstream level of harvest. Given the short-term nature of the debris flood disturbance at the Snowwater Creek (Rover Creek FSR bridge) the current likelihood of significant increases in sediment delivery associated with existing forest development is assessed as low.

Changes to Riparian Function that could impact water quality or aquatic habitat.

In Rover Creek, riparian vegetation functions in several ways to protect water quality and aquatic habitat. Large coniferous trees that enter the channel through the lower gradient reaches provide sediment storage sites that reduce the rate of bedload sediment transport. The root systems of large coniferous and deciduous trees provide armoring to channel banks and the forest floor to protect them from erosion during large overbank peak flow events. Finally, riparian vegetation moderates the delivery of runoff and the temperature of runoff from slopes to the stream channels through hyporheic flow. Logging activities that occurred in Rover Creek in the early to mid-1900's did not protect riparian vegetation and the old cut stumps from this early logging is evident along the lower valley sides and riparian areas in some locations of Rover Creek. Currently there are a few locations in Snowwater Creek where riparian vegetation has not been retained along smaller S5 and S6 channels (Bankfull width < 3 meters) in association with recent forest harvesting however, there are no locations along the lower reaches of Rover Creek below the confluences of Snowwater and upper Rover Creek tributaries where riparian vegetation has been disturbed by recent forest development activities. As a result, the likelihood for changes to riparian function that could impact water quality at the intake or aquatic habitat along the lower reaches is assessed as low.

Cumulative Effect of climate change on likelihood of harmful events

Downscaled global climate models for the Rover Creek area were investigated using the PCIC Climate Explorer tool (https://services.pacificclimate.org/pcex/app/#/data/climo/ce_files) .

Historical information indicates that the climate conditions leading to overbank floods such as occurred in 2020 include multiple days (>3 days) during May when the snowpack is ripe and there are long spring days when the temperature exceeds 20°C in Nelson BC, or when there is a combination of warm temperatures and a heavy precipitation event exceeding roughly 10mm between late April to May.

Downscaled climate models for the RCP 8.5W/m^2 (worst-case) scenario suggest that total winter and spring precipitation is likely to increase but that daily temperatures during the winter months will also increase by several degrees (Figure 13). As a result, by roughly 2070 Rover Creek could have a substantially lower snowpack, and be substantially snow free at the lower elevations (below appx 1500m) reducing the occurrence of large snowmelt or rain-on-snow floods and the turbidity events associated with these floods. However, these same trends will increase the likelihood of rain-on-snow peak flows and changes in the timing of runoff and duration of low flows. Due to the lack of discharge gauging in Rover Creek it is not clear the extent of the advancement of peak flows that may be occurring with climate change. In nearby long-term gauged Anderson Creek since gauging began in the late 1940's peak flows have advanced by, on average, 6 days but this is in part associated with a large area of beetle killed forest in the upper elevations. Although Anderson Creek is a lower elevation watershed than Rover Creek some of the earlier peaks in Rover could experience similar shifts or, more likely there will be more peak events earlier in the spring. However, the annual maximum peak flows, which are driven by high elevation snowmelt are unlikely to shift in timing assuming solar-radiation driven snowmelt remains the primary driver of annual maximum peak flows.

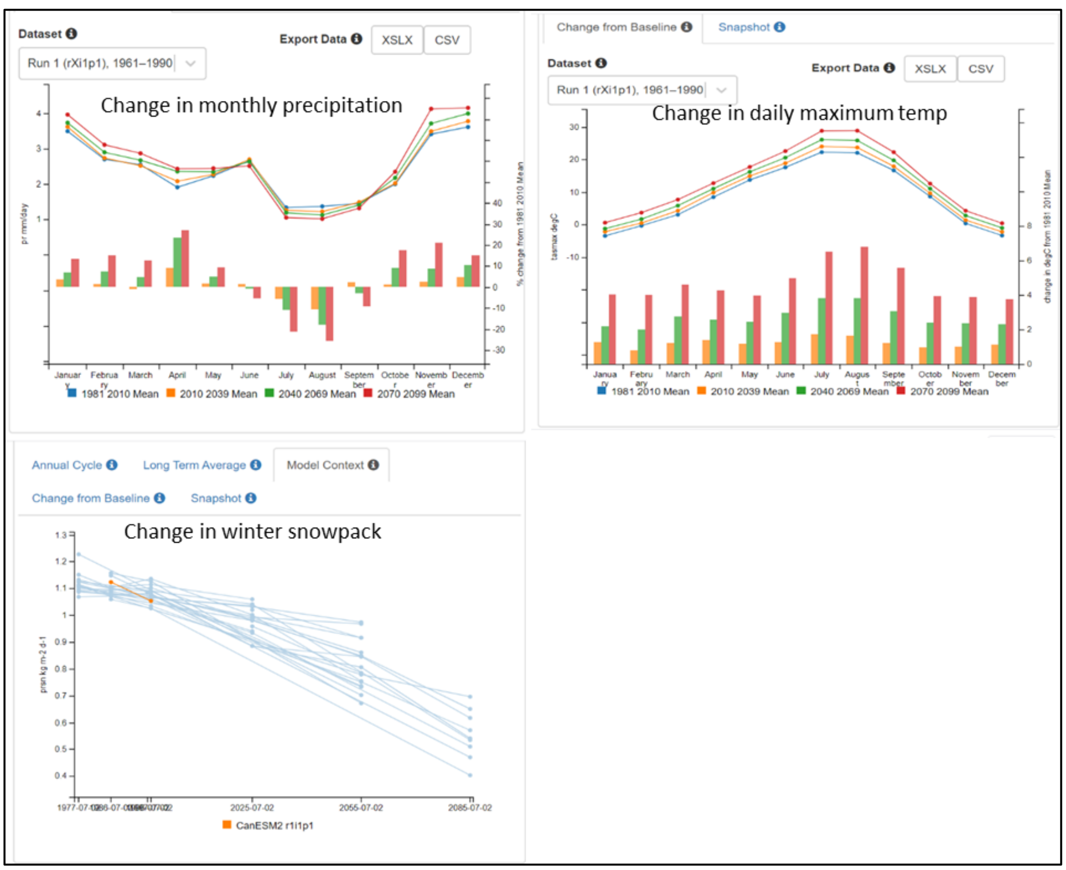

FIGURE 13. TRENDS IN MONTHLY TEMPERATURE, MEAN DAILY MAXIMUM TEMPERATURES AND WINTER SNOWPACK FOR THE ROVER CREEK AREA FROM PCIC CLIMATE EXPLORER TOOL.

Future Forest Development/Disturbance

Changes in the frequency/magnitude of peak flows that could impact water quality and aquatic habitat through lower reaches of Rover Creek

Besides the Redfish Creek study there are no other local studies available on which to base a recommended upper limit to harvesting to limit the potential for changes in flood frequency/magnitude in lower Rover Creek. Field observations indicate that Snowwater Creek is contributing relatively higher runoff to Rover Creek compared to other tributary channels but field observations and satellite imagery also indicated the May 31st 2020 flood was driven by rain-on-snow from both Snowwater Creek and upper Rover Creek. Satellite imagery (https://apps.sentinel-hub.com/sentinel-playground) from both 2020 and 2021 indicates that Connor Creek is mostly snow free by the time Rover Creek is peaking in mid-May. While harvesting has the potential to alter the frequency and magnitude of flooding in Connor Creek, these alterations to flows in Connor Creek are unlikely to influence the frequency/magnitude of later peak flows in lower Rover Creek.

Based on the Redfish Creek study, it is interpreted that forest development/disturbance that increases the volume and accelerates the timing of runoff cumulatively in these two headwater tributaries will increase the likelihood of impacts to water quality and aquatic habitat through the lower reaches of Rover Creek. To this end, a more detailed investigation has been undertaken to determine the current ECAs across elevations for existing development in Snowwater Creek and upper Rover Creek.

The hypsometric curves for Snowwater and upper Rover Creek are nearly identical with the H60 elevation in Snowwater Creek at 1540 meters and at 1560 meters in upper Rover Creek (Figure 14). For this more detailed analysis and as in Redfish Creek, the existing development in both headwater basins is considered with respect to their H80, H60 and H40 elevations (Figure 15, and Tables 6 and 7). However, because there is also forest development above the H40 elevation in Rover Creek, two 'upper forest' areas are included. Upper forest 1 is the H60 to H40 zone and upper forest 2 is the full area above the H60 elevation.

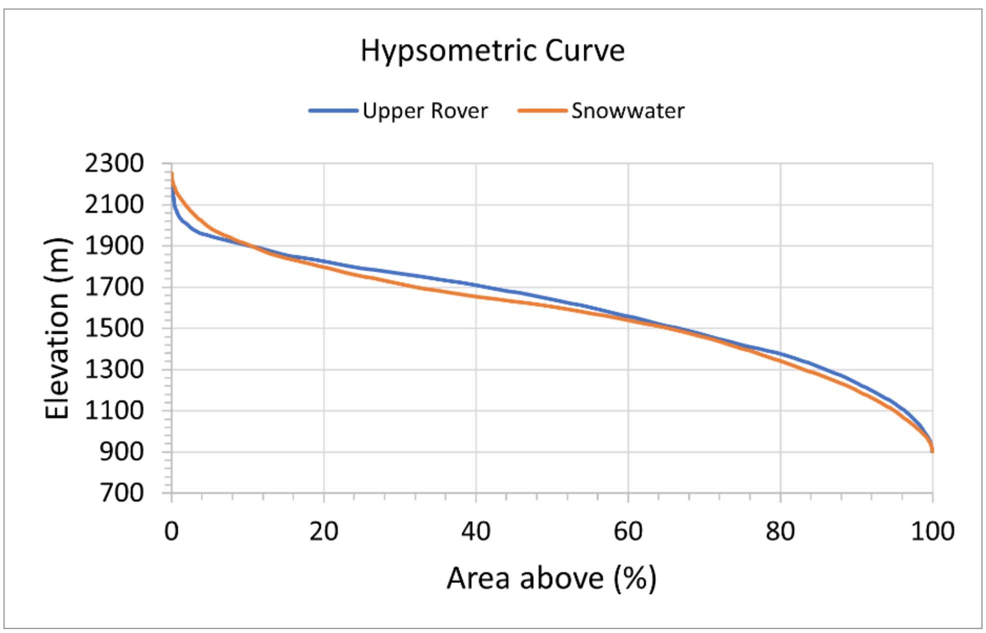

FIGURE 14. HYPSOMETRIC CURVE FOR SNOWWATER AND UPPER ROVER CREEKS

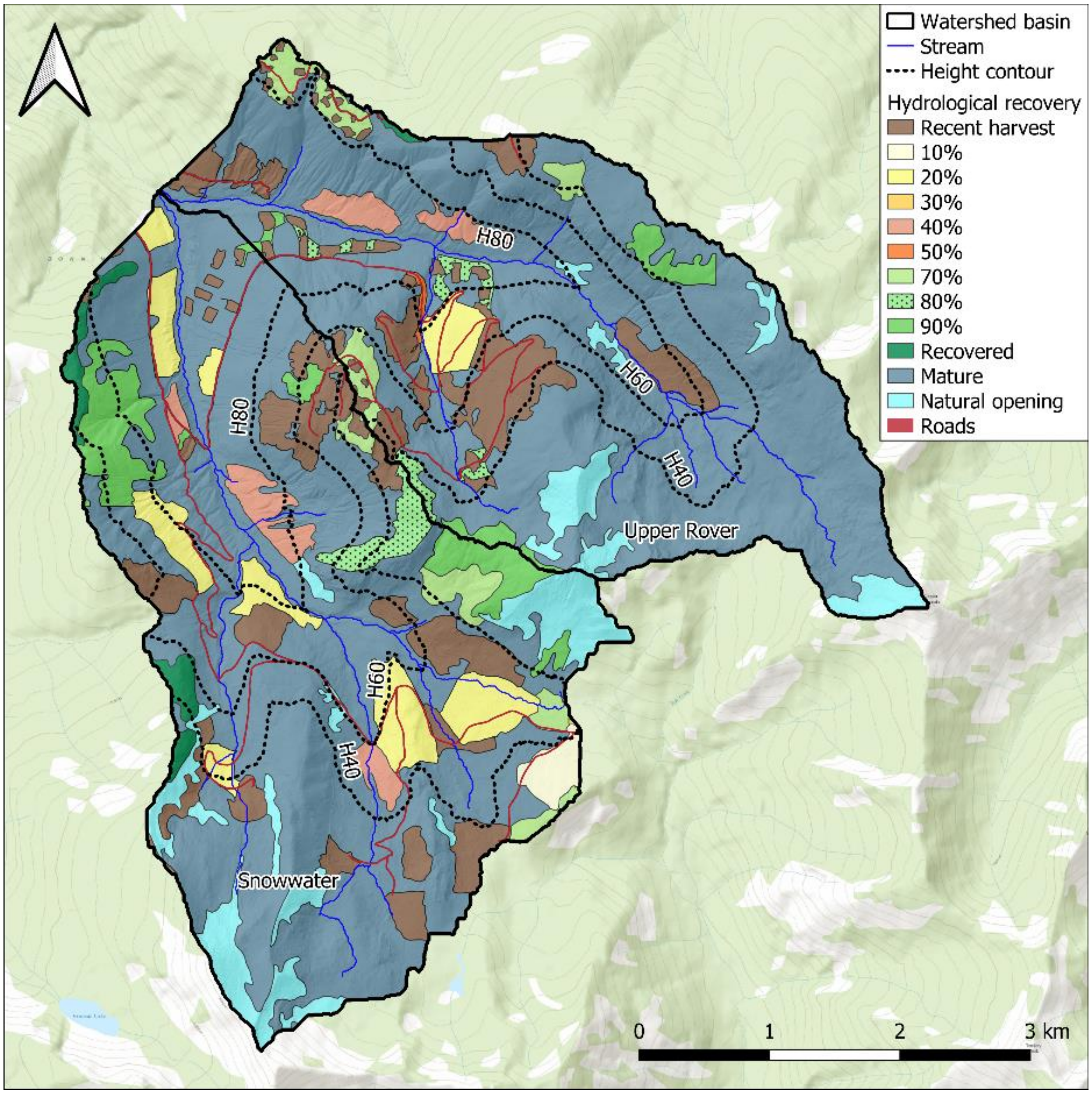

FIGURE 15. DISTRIBUTION OF CURRENT OPENINGS WITH RESPECT TO THE H80, H60 AND H40 ELEVATIONS.

TABLE 6. UPPER ROVER ECA BY ELEVATION

Opening description	**Applied recovery (%)**	**2020 ECA (ha)**				
		Upper Rover	**Lower Forest (<1380m)**	**Middle Forest (1380m - 1560m)**	**Upper Forest 1 (1560m - 1710m)**	**Upper Forest 2 (above 1560m)**
Total watershed area (ha)		**1234.5**	**251.5**	**244.6**	**246.1**	**738.5**
Recent harvest	0%	144.0	31.7	41.8	58.9	70.5
Developed / residential	0%	0.0	0.0	0.0	0.0	0.0
Road openings	0%	7.6	2.0	2.8	2.7	2.7
Disturbed forest 10% recovered	10%	0.0	0.0	0.0	0.0	0.0
Disturbed forest 20% recovered	20%	15.9	0.7	15.3	0.0	0.0
Disturbed forest 30% recovered	30%	0.0	0.0	0.0	0.0	0.0
Disturbed forest 40% recovered	40%	14.8	14.7	0.1	0.0	0.0
Disturbed forest 50% recovered	50%	1.2	1.0	0.3	0.0	0.0
Disturbed forest 70% recovered	70%	10.5	0.2	5.2	3.5	5.1
Disturbed forest 80% recovered	80%	3.3	1.7	0.1	0.5	1.5
Disturbed forest 90% recovered	90%	2.5	0.2	0.0	0.0	2.3
Recovered	100%	0.0	0.0	0.0	0.0	0.0
Mature	100%	0.0	0.0	0.0	0.0	0.0
Natural opening	100%	0.0	0.0	0.0	0.0	0.0
Total current ECA (ha)		**199.8**	**52.2**	**65.5**	**65.7**	**82.2**
Total current ECA (%)		**16.2**	**20.7**	**26.8**	**26.7**	**11.1**

TABLE 7. SNOWWATER ECA BY ELEVATION

Opening description	Applied recovery (%)	2020 ECA (ha)				
		Snowwater Creek	**Lower Forest (<1340m)**	**Middle Forest (1340m - 1540m)**	**Upper Forest 1 (1540m - 1660m)**	**Upper Forest 2 (above 1540m)**
Total watershed area (ha)		**1499.8**	**299.2**	**301.4**	**315.9**	**899.5**
Recent harvest	0%	165.8	8.2	41.3	53.7	116.4
Developed / residential	0%	0.0	0.0	0.0	0.0	0.0
Road openings	0%	12.0	4.7	2.0	3.4	5.3
Disturbed forest 10% recovered	10%	15.8	0.0	0.0	0.5	15.8
Disturbed forest 20% recovered	20%	94.6	26.8	22.0	44.4	45.8
Disturbed forest 30% recovered	30%	0.3	0.0	0.0	0.3	0.3
Disturbed forest 40% recovered	40%	21.7	13.0	2.6	6.1	6.1
Disturbed forest 50% recovered	50%	0.0	0.0	0.0	0.0	0.0
Disturbed forest 70% recovered	70%	9.8	0.0	0.0	2.5	9.8
Disturbed forest 80% recovered	80%	4.3	0.0	0.3	1.0	4.0
Disturbed forest 90% recovered	90%	8.4	1.5	3.0	0.9	3.9
Recovered	100%	0.0	0.0	0.0	0.0	0.0
Mature	100%	0.0	0.0	0.0	0.0	0.0
Natural opening	100%	0.0	0.0	0.0	0.0	0.0
Total current ECA (ha)		**332.6**	**54.2**	**71.2**	**112.8**	**207.3**
Total current ECA (%)		**22.2**	**18.1**	**23.6**	**35.7**	**23.0**

Currently, in upper Rover Creek the ECA of the ‘lower forest’ is 4%, the ECA of the middle forest is 5% and the ECA of the upper forest is 5% (7% above H60) of the upper Rover watershed area. In Snowwater Creek the ECA for the lower forest is 4%, the middle forest ECA is 5% and the upper forest ECA is just under 8% (14% above H60) of the watershed (Snowwater Cr). Based on the Redfish modeling study the upper Rover Creek distribution is similar to the 1/3U harvest scenario, while the Snowwater Creek harvesting distribution is similar to the 2/3U scenario. Based on the Redfish Creek scenarios these current levels of disturbance result in a low likelihood of increasing the frequency/magnitude of floods in upper Rover Creek but a moderate likelihood in Snowwater Creek.

The influence of increasing the level of forest disturbance in Snowwater Creek and upper Rover Creek on the frequency/magnitude of floods is complex. The Redfish 1/3A scenario where harvesting in the lower forest area is 6% has a relatively lower impact on the magnitude of floods over the range of frequencies relative to the 1/3U scenario where harvesting in the lower forest is just over 5%. This response suggests that that harvesting in the lower elevation band is reducing the impacts on the hydrograph through desynchronization of runoff between lower and upper elevations. However, the aspect distribution of slopes in upper Rover and Snowwater creeks is very different from that in Redfish Creek. Forest openings on lower and mid elevation north aspect slopes (N, NW and NE) are likely to synchronize rather than desynchronize runoff with the upper elevations.

In upper Rover Creek, if proposed development includes openings on north aspect low or mid elevation slopes a more conservative ECA should be adopted in which the ECA is managed to 5% or less of lower and mid elevation areas that could potentially synchronize with runoff from higher elevation forested areas. Otherwise, an ECA of less than 7% in these regions should not substantially increase the current likelihood of altering flood frequency/magnitude. In addition, harvesting above the H60 should also be managed to less than 7% ECA – especially give the exiting moderate level of harvest above the H60 in Snowwater Creek.

With a current ECA of just under 14% above the H60 elevation in Snowwater Creek, additional harvesting above the H60 will result in a high likelihood of altering the frequency/magnitude of floods in this tributary. However, harvesting of lower elevation east, west or south aspect slopes in lower and mid elevation bands to below 7% threshold is unlikely to compound the existing moderate likelihood.

This estimate is based only on an approximate understanding of the influence of forest harvesting on desynchronization/synchronization of runoff based on the Redfish modeling outcomes. Development of a hydrological model for Rover Creek would provide a more informed understanding of the level of harvest that could be sustained in these upper basins without influencing flood frequency/magnitude in lower Rover Creek.

Increases in sediment delivery above undisturbed levels

Increases in sediment delivery can occur through an increase in the frequency of overbank floods that entrain fine sediment and organic material from channel banks and adjacent forest floor or by the increase in bank failures and landslides. Changes in the frequency of overbank floods could occur in Connor Creek if the level of harvest increases beyond the current 28% ECA. Connor Creek discharges directly into lower Rover Creek and likely begins to peak while flows are still relatively low in Rover Creek which could increase turbidity in this lower section of Rover Creek. The current low likelihood of increasing sediment delivery associated with instability from roads and blocks will not increase with future development if measures are taken to identify and mitigate for increased runoff due to roads and blocks on the steep slopes above Rover Creek. Harvesting and roadbuilding above steep terrain should be subject to detailed terrain stability assessments. Measures to mitigate increases in risk associated with landslides are contained within Detailed Terrain Stability or Landslide Risk Assessments (DTSFA or LRA) undertaken by qualified professionals.

Changes to Riparian Function that could impact water quality or aquatic habitat

The current low likelihood to water quantity and aquatic habitat on Rover Creek associated with riparian function will not change with future harvest if measures are implemented to protect riparian function along perennial water courses.

Considerations for Future Forest Harvesting in Rover Creek to limit increases in Risk

As indicated in the discussion above, the current level of development, estimated at just under 23% ECA, represents a low likelihood for increasing the frequency/magnitude of peak flows and sediment delivery and riparian function to the elements at risk in the lower reaches of Rover Creek. Some additional harvesting could be undertaken in upper Rover and Snowwater creeks but care is needed to ensure additional openings do not result in synchronization with runoff from the higher elevation areas that are contributing to peak flows. Development of a hydrological model to explore the cumulative effects of harvesting scenarios and future climate change on the frequency and magnitude of floods in Rover Creek would be beneficial for forest management and harvest planning.

Development in Connor Creek is not likely to influence the magnitude/frequency of floods in Rover Creek however, increases in the frequency of overbank floods in Connor Creek will contribute turbidity to the lower reaches of Rover Creek.

Despite this assessment of risk to elements in the lower reaches of Rover Creek, channel disturbance indicators in upper East Snowwater Creek tributary are potentially related to recent clearcut harvesting in this headwater basin but this local disturbance does not translate to a cumulative impact in the lower reaches of Rover Creek. Consequently, while cumulative impacts may not currently exist to elements at risk in the lower reaches of Rover Creek, local impacts from past development have been noted, including changes in the frequency and magnitude of floods (East Snowwater) and riparian disturbance (West Snowwater). To avoid increasing the risk of harmful events in the lower reaches of Rover Creek, forest management should focus on limiting impacts at the scale of the tributaries and, as well, considering how the tributaries contribute cumulatively to discharge and sediment delivery to the lower reaches of Rover Creek.

Currently the ECA in Connor Creek exceeds this threshold and may already be experiencing some increases in flood frequency/magnitude. Given its low elevation, there is a high likelihood of changes in peak flow magnitude and frequency in Connor Creek given additional harvesting, particularly if the openings are situated above its H60 elevation.

LIMITATIONS

The accuracy of information provided in this assessment report is dependent on the accuracy of the data the analyses are based on. The LiDAR data for Rover Creek is old and of poor quality so there is likely to be uncertainty of at least 5% in the ECA analysis. The field observations are made using a strategic survey system that is meant to cover a range of sites over different scales and across elevations and aspects. The road network in Rover Creek limited access to much of upper Rover Creek above Snowwater Creek as well as lower Rover Creek below the 4km bridge so there may be some channel disturbance present that was not noted during this assessment.

Submitted by:

Kim Green, P.Geo., PhD

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