Cumulative Effects Framework Silverton Creek, B.C.

Prepared for: The Slocan Lake Stewardship Society
By: Richard Johnson, Opus Petroleum Engineering
October 15, 2019

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Funding provided by: Columbia Basin Trust through the
Community Initiatives and Affected Areas Program,
Administered by the Regional District of Central Kootenay

Cover:
Sentinel-2 image of the Blacktail Mountain wildfire, Aug 18, 2018, with flames visible from 786 kilometres altitude. Image enhanced by author.

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Cumulative Effects Framework
Silverton Creek B.C

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1 Introduction

In 2017 the BC government published a document entitled "Interim Assessment Protocol for Aquatic Ecosystems in British Columbia". This protocol describes how to apply metrics, called "Benchmarks" to a watershed in a manner that creates consistency across watersheds in the province. Additionally one can periodically use the same metrics on one watershed to document changes in that watershed over time. In this report it will be referred to as the "*BC CEF Protocol*" for ease of writing. The document can be downloaded from the link supplied in the Bibliography.

This report uses that protocol on the watershed drained by Silverton Creek to provide a baseline going forward. It also shows how the "Total Land Disturbance" benchmark value changed as a result of the Blacktail Mountain wildfire of 2018. This demonstrates how the protocol can be used to track changes in a watershed over time.

The wildfire had a significant impact on the watershed and the on-going effects of that fire should be monitored as we move forward. As stated in the government report (Crookshanks, 2018) the hazard of flooding caused by snowmelt could impact the Village of Silverton and Highway 6 within the Village boundary.

This report also points out other problems that could occur as a result of the damage caused by that fire. The most significant are the debris slides that will occur. These will lower the quality of the water in the creek. They could also block the creek entirely creating a temporary dam. If that happens, water will build up behind that dam and eventually burst through the dam threatening the Village of Silverton with a flash flood.

Maina (2019) describes how there is greater snowpack in burned areas due to the lack of trees which hold up the snow and allow a large portion of it to sublimate. This leads to greater water runoff during the spring freshette, again causing erosion and slides.

This report does not address all of the indicators mentioned in the Cumulative Effects Framework but addresses the significant ones to indicate those that are most important and deserve further work. The portion of the Village of Silverton that falls within the Silverton Creek watershed has been left out of this study because it is small in comparison to the watershed itself and the study is designed to look at the main watershed upstream from the Village.

2 Conclusions

1. The following benchmarks for the Silverton Creek watershed are from the *BC CEF Protocols*:
    a. The *Road density* in the watershed is Low.
    b. The Road density less than 100 metres from creeks is High
    c. The Road density on unstable slopes is Low.
    d. The Stream crossing density is High
    e. The R*iparian disturbance* from wildfires alone is High.
        i. Before the 2018 Blacktail mountain wildfire it was Low.
    f. Peak flow index and Total Land Disturbance were not calculated
    g. There are no working Mines in the watershed.
    h. There are no *Permitted waste discharge* sites in the watershed.
    i. There are 4 *Downstream Water Rights Interests* shown in the Kootenay Boundary Water tool report, (Appendix D)
    j. There are no *Dams* in the watershed.

2. Using the "Rollup" system described in the *BC CEF Protocol* the Silverton Creek watershed rating is 0.54, which is designated as "Moderate".

3. Most of the benchmarks used to evaluate and quantify the state of a watershed using the *BC CEF Protocol* are easy to evaluate using a GIS mapping program such as the open source (free) QGIS. This gives an easy way to evaluate, quantify and compare the state of a watershed with other watersheds in the province and to show how the watershed is changing over time.

4. The Blacktail Mountain wildfire burned area can be expected to have debris flows in a manner similar to the Springer Creek fire area. Because the Blacktail Mountain fire is in an undeveloped area where no residences or highways are threatened, it will probably not receive much attention or restoration work from government agencies. This leaves it up to the local community to monitor and protect this natural asset, the Silverton Creek watershed.

3 Recommendations

1. Silverton Creek should be monitored for flow volume in real time by installing a water level monitoring system in the creek. This can alert the Village through a level alarm if the water flow drops precipitously indicating an upstream blockage.
2. Water quality monitoring should be continued on Silverton creek to document changes in the water quality which can indicate debris flows in the watershed.
3. The burned area should be monitored to document slides and their impact on the creek.
4. The burned area should be monitored to determine if re-growth is occurring and consider whether enhancements should be undertaken as part of the Village of Silverton's natural asset management program.
5. When LiDAR becomes available, it should be used to document and predict land movements in the watershed.
6. Studies using satellite radar have been used to predict land movements. The European Space Agency has two radar satellites, Sentinel 1A and 1B, that provide images about every three days at this latitude. The data is free. Canada has recently deployed an array of radar satellites that provide coverage of the entire country every day. These data could be helpful in predicting and monitoring land movement.

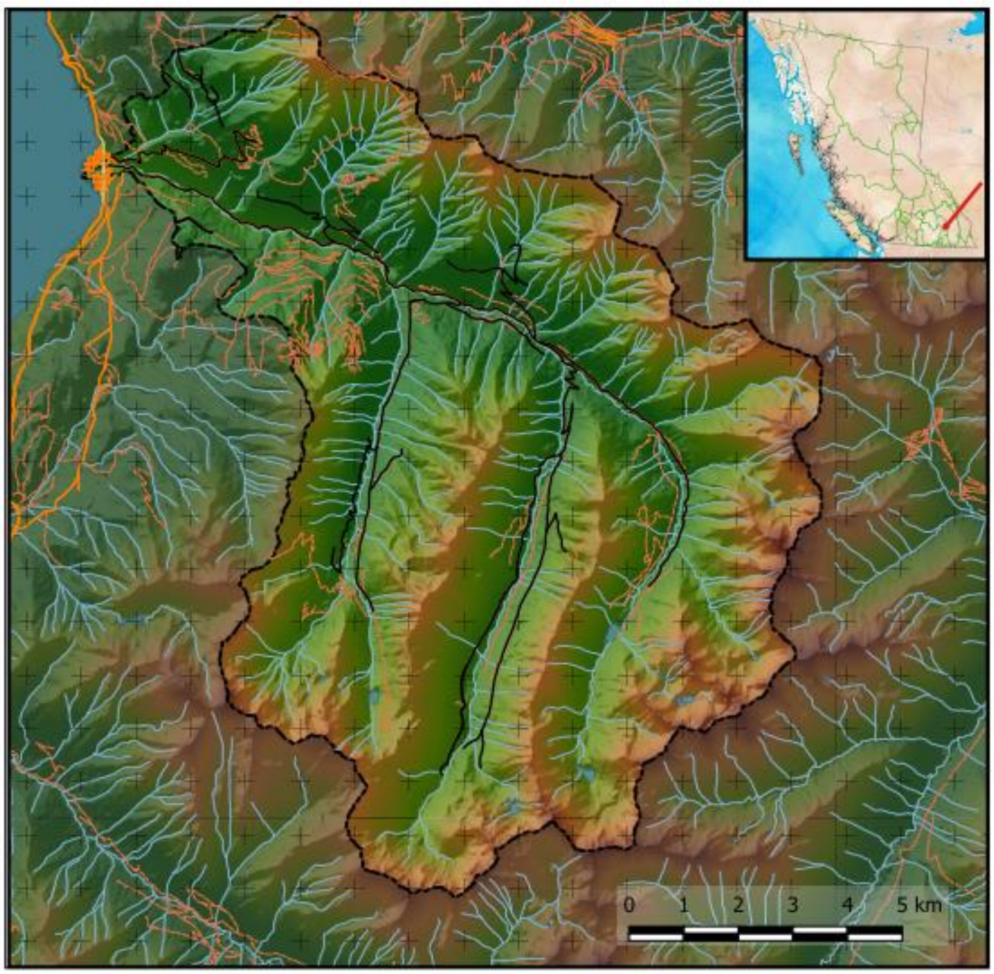
4 Discussion

The Silverton Creek watershed is located in the West Kootenay region of south eastern British Columbia. The map below shows the mountainous topography of the watershed. All inset maps in this report are taken from the larger sized maps that are included in Appendix A. The reader should consult the map in Appendix A to see greater detail.

This report calculates five of the six "benchmarks" following the procedure described in the *BC CEF Protocol.* The sixth is more complicated and has not been evaluated in this report.

The benchmarks have been rolled up into one value, as shown in the "Value Rollup" section of this report.

A separate section of this report has been written about the Blacktail Mountain wildfire because of its significant and long term impacts.



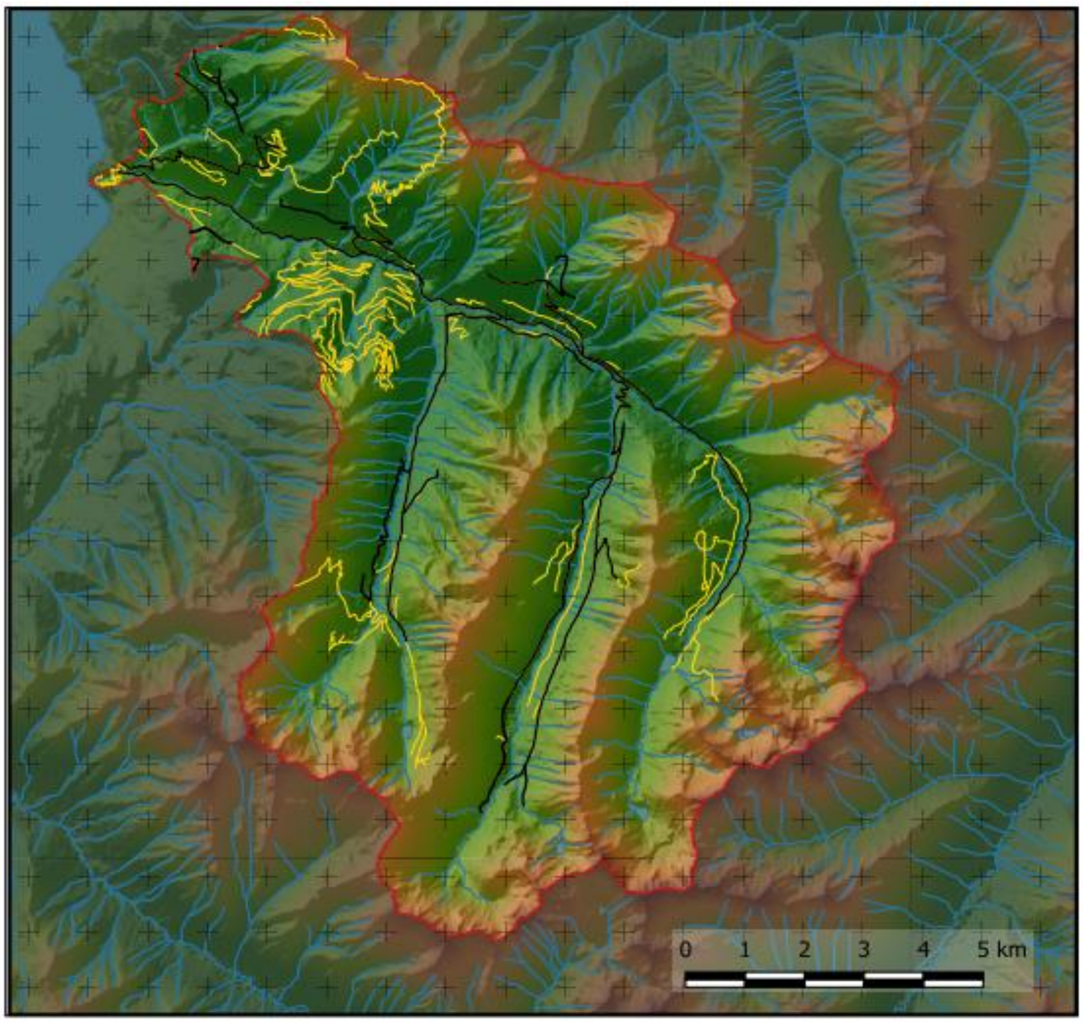
Silverton Creek Watershed Map 1

4.1 Road Density

The roads in the watershed are made up of two types, roads that are currently permitted (called "active roads" in this report) and roads that were built in the past but are not maintained or have been released from permit.

Map 2, inset below, shows the location of all of the roads on record in the BC provincial database (DataBC) within the Silverton Creek watershed. Those that are still active are shown in black the remainder in yellow.

The area of the Silverton Creek watershed is 121.8 square kilometres. Based upon the active road length (68 kilometres) the road density is 0.56 km/sq. km., "low" using the benchmarks listed in the *BC CEF Protocol,* which are:
<0.6 km./sq. km. – low; 0.6 to 1.2 km./sq.km. – moderate; >1.2 km./sq.km. – high.



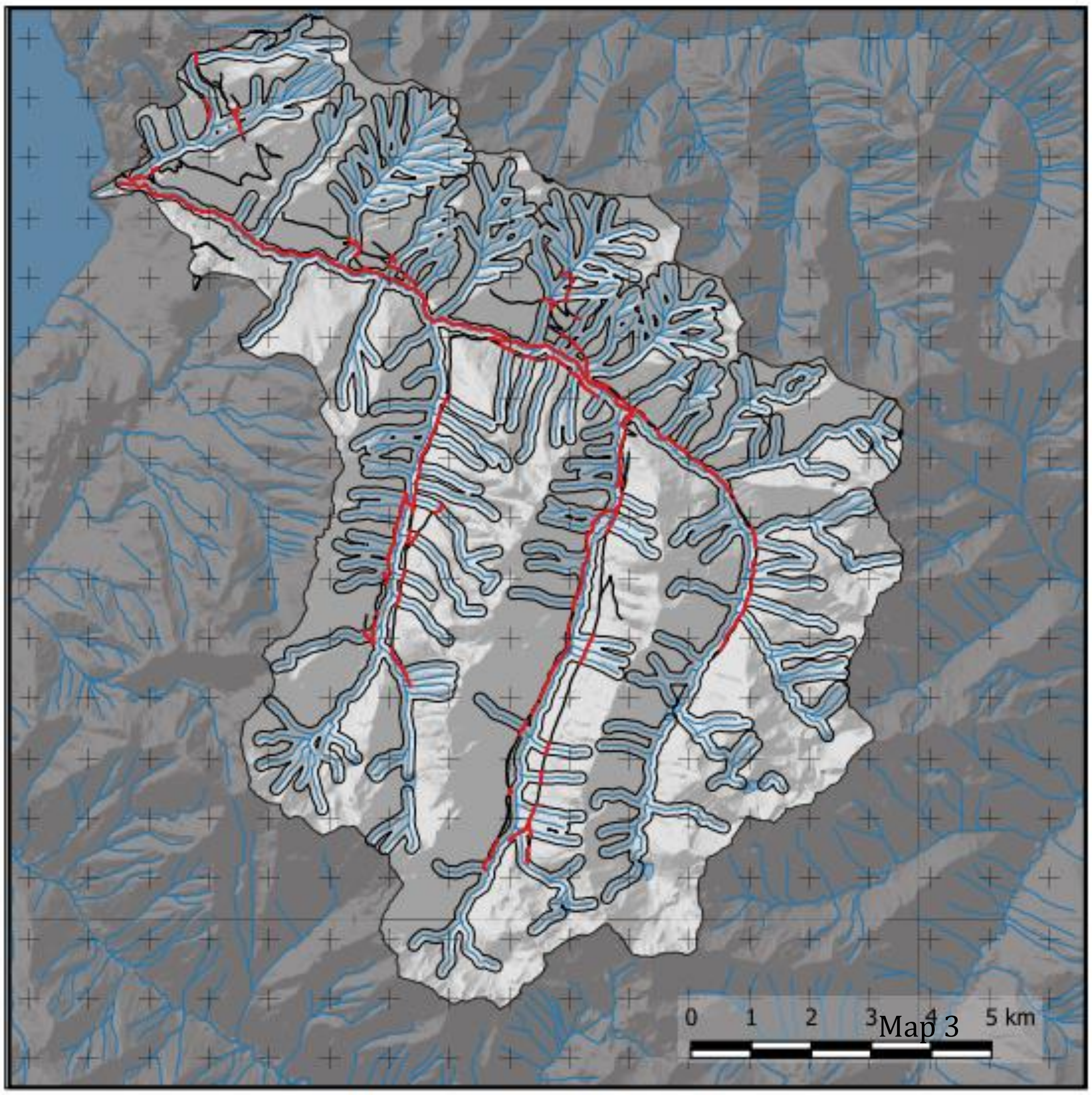
Silverton Creek Watershed
Active Road Density

Map 2

4.2 Road Density less than 100 m. from a stream

Roads that are near creeks and streams can impact the hydrology and water quality in the watershed. The *BC CEF Protocol* has a benchmark to address this called "Road density <= 100 m. from a stream (within 100 m. of a stream). The benchmarks are:
<0.08 km./sq. km. – low; 0.08 to 0..16 km./sq.km. – moderate; >0.16 km./sq.km. – high

The inset map below shows active roads in the Silverton Creek watershed together with the streams (showing the 100 metre buffer zone). The active roads that are within the 100 metre buffer are highlighted in red. The total length of the red segments is 36.6 kilometres, resulting in a value of 0.30 km per sq. km. This is in the "high" category, in the *BC CEF Protocol*.



Silverton Creek Watershed
Active Roads within 100 metres of creeks

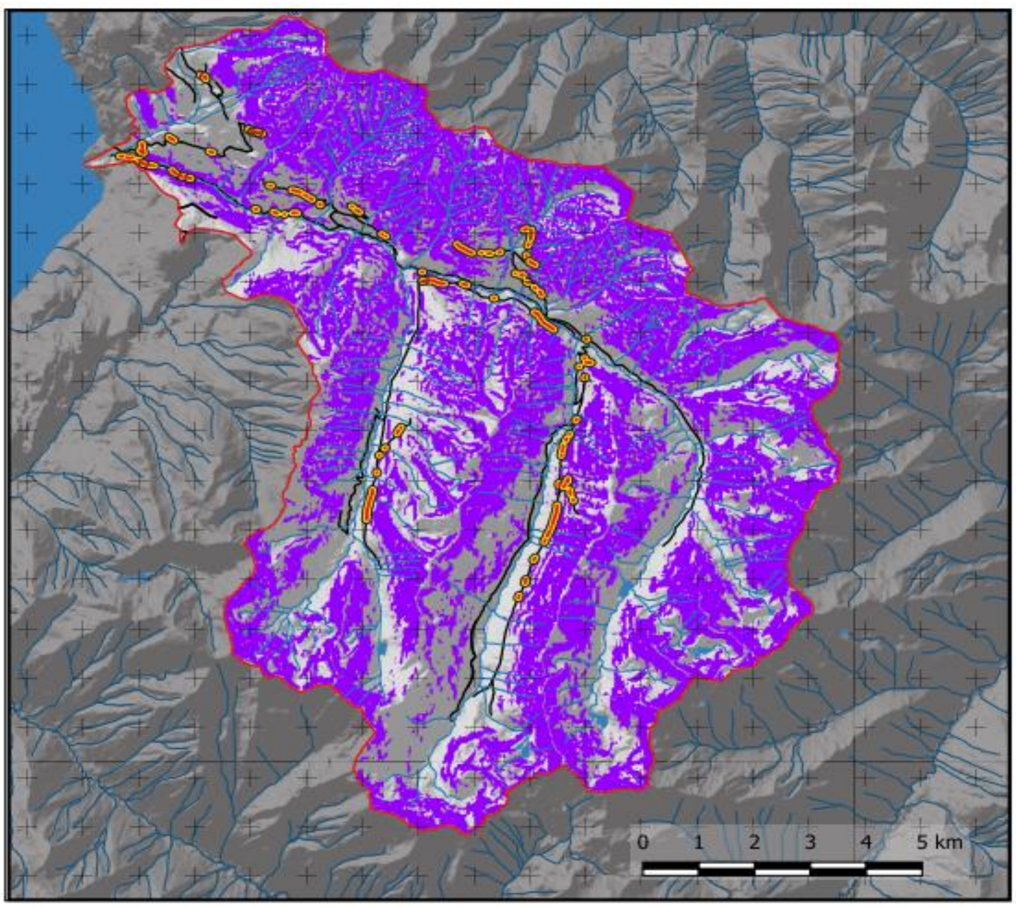
4.3 Road Density on unstable slopes

Roads on unstable slopes are another metric in Cumulative Effects mapping that is easy to calculate. The *BC CEF Protocol* defines unstable slopes as those slopes having a slope greater than 60% (31 degrees).

Map 4, clipped below, shows unstable slopes in lilac with those sections of active roads shown in red with a yellow outline.

Most roads in the Silverton Creek watershed were built along valley bottoms to get to logging sites. Once at the site the roads have to cross steeper slopes and some of these are defined as unstable using the definition above.

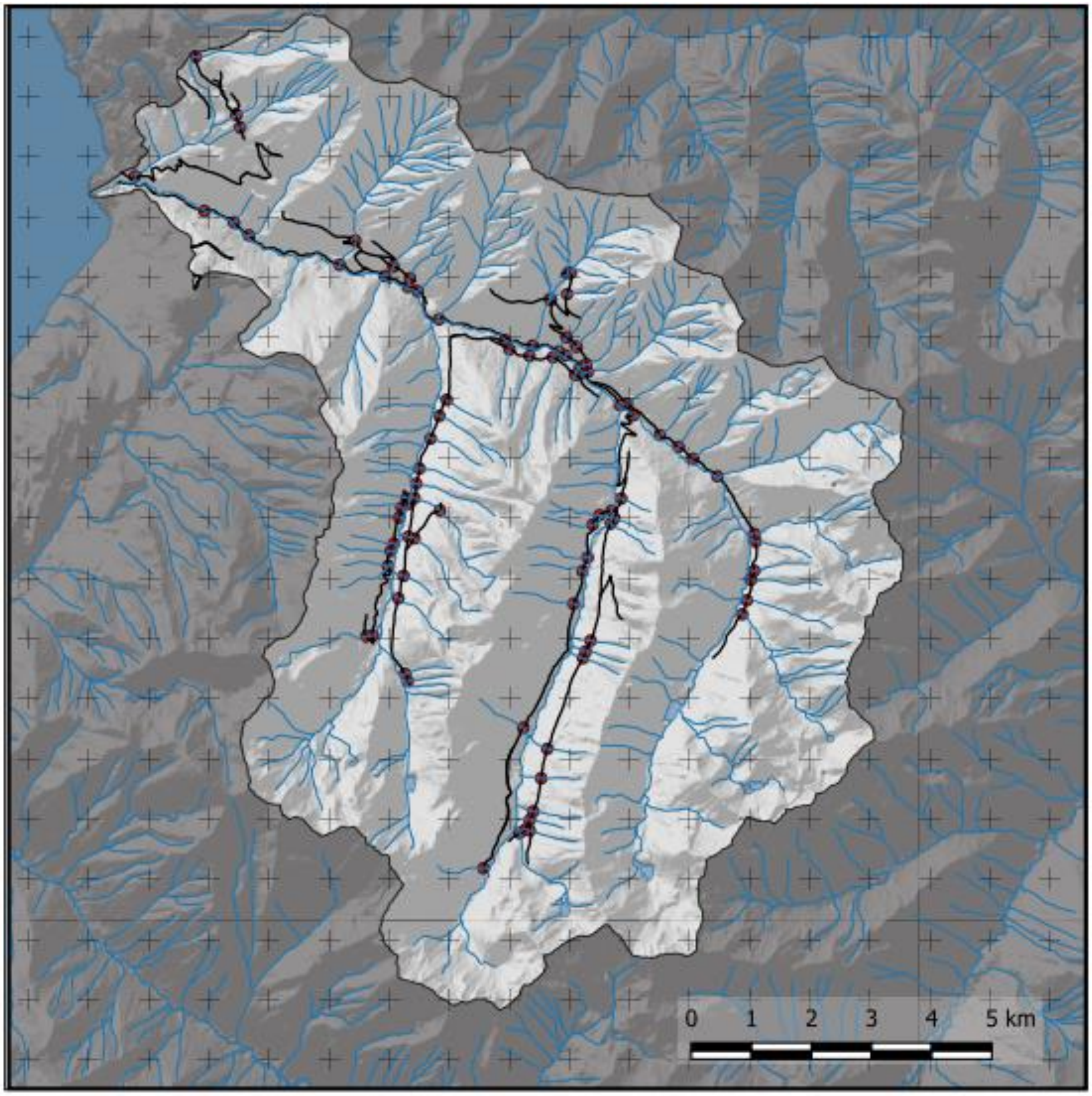
There are only 5 kilometres of roads on unstable slopes, yielding a value of 0.04 km./sq. km. Using the benchmark value shown in the BC CEF Protocol (shown below), the Silverton Creek watershed is “low”.
Benchmarks:
<0.06 km./sq. km. – low; 0.06 to 0.12 km./sq.km. – moderate; >0.12 km./sq.km. – high



Silverton Creek Watershed
Active Roads on Unstable Slopes

Map 4

4.4 Stream Crossing Density



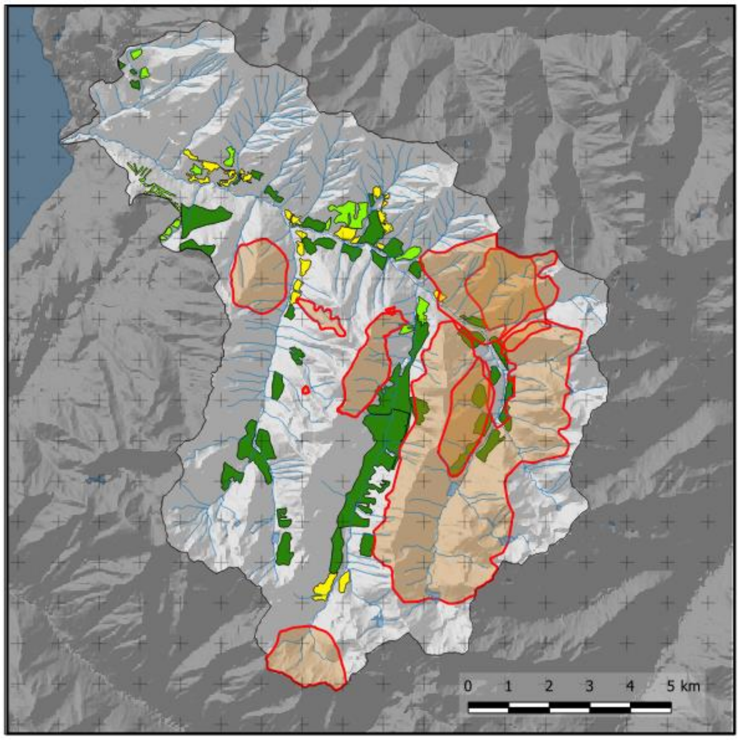
Silverton Creek Watershed
Stream Crossings of Active Roads

Map 5

The clip of Map 5 above shows the location of all places that an active road crosses a stream. The *BC CEF Protocol* has the following benchmarks for stream crossings in interior watersheds: <0.16/sq. km. – low; 0.16 to 0.32/sq.km. – moderate; >0.32/sq.km. – high

There are 68 kilometres of active roads in the Silverton Creek watershed. They cross streams 91 times; very "high" at 0.75 crossings per km.

4.5 Riparian Disturbance



Silverton Creek Watershed
Cut Blocks and Wildfires

Map 6

The *BC CEF Protocol* states the following: "Riparian related disturbance is defined as that occurring within 30 m. of a stream. Total Disturbance includes human disturbance since 1995 (rail, transmission, major rights of way, harvesting, mining, oil & gas, seismic, agriculture, and urban activity), historical logging (pre-1995), natural fire and insect disturbance."

There are no rail, transmission, major rights of way, harvesting, oil & gas, seismic, or agriculture that the author is aware of and the mining was before 1995. Urban activity would include the portion of the Village of Silverton that drains into the creek which has been specifically excluded from this report.

The map above shows the areas where there has been disturbance caused by wildfires fires and the location of cut blocks.

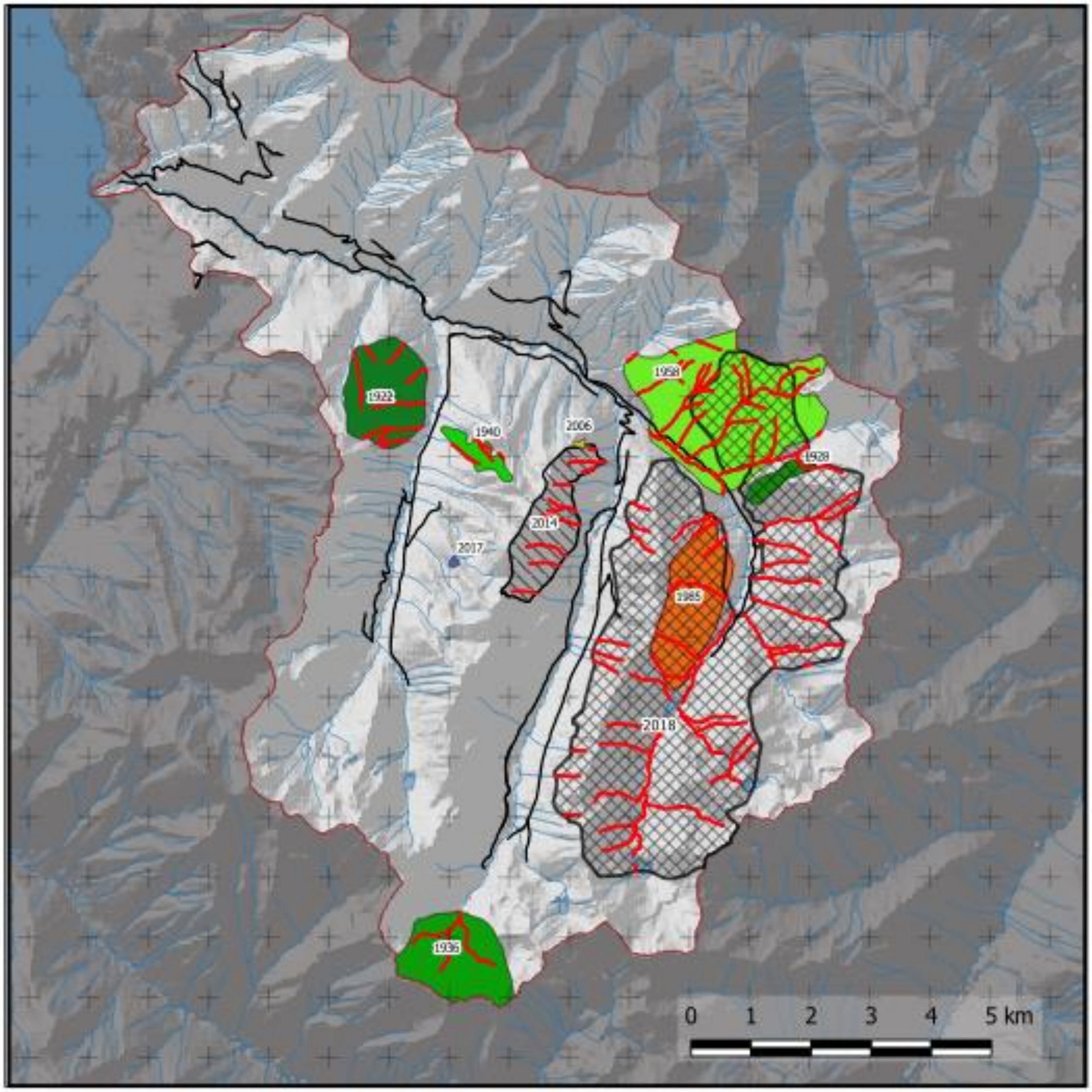
Timber harvesters have riparian disturbance rules that vary according to the stream conditions such as the width of the stream and whether it is fish bearing. Rather than try to determine which cut blocks came within 30 m of a stream, this report focuses on the wildfire disturbance only. If all of the cut blocks came within 30 m. of a stream it would add 14.5 kilometers to the total streams length.

The benchmark measure in the *BC CEF Protocol* is calculated by dividing the total length of streams with disturbed riparian area by the total length of all streams in the watershed.
The benchmarks are:
<0.10 km/km – low; 0.10 to 0.20 km/km – moderate; >0.20 km/km – high.

There are 269 kilometres if streams in the Silverton Creek watershed, excluding the Village itself. The total stream length within wildfire burned areas is 56.3 kilometres, after adjusting for riparian areas that have burned twice (portions of the 1958 and 1985 wildfire burn areas were burned again by the 2018 wildfire).

Thus, the Silverton Creek watershed is highly impacted by wildfires alone, being 0.21 km. per km. (56.3 km. /269 km.) without the disturbance caused by timber harvesting (cut blocks).

Prior to 2018 (the 2018 Blacktail Mountain fire is "square-hatched" on the map below), stream disturbance from wildfires alone was 13.0 km., giving a disturbance ratio of 0.05, rating "low". The Blacktail Mountain wildfire moved the Cumulative Effects benchmark to "high". This demonstrates how these benchmarks can be used to quantify changes in a watershed over time.



Map 7

Silverton Creek Watershed
Riparian Areas Disturbed by Wildfire

4.6 Other indicators

There are several other indicators that are described in the *BC CEF Protocol.* They are:

The '*Peak Flow Index*' is complicated and beyond the scope of this study. As stated in the protocol: "This is a preliminary risk categorization based upon the variable parameter ECA. This indicator assessment should be supported with localized watershed knowledge." (ECA is Equivalent Clear Cut Area.)

'*Total Land Disturbance*' is another category that requires custom development and is beyond the scope of this study.

'*Number of Mines'*: There are no active mines in the watershed.

There are no '*Permitted Waste Discharge*' locations that the author is aware of.

'*Water Withdrawals*' is a potential benchmark that is undefined in the *BC CEF Protocol.* Appendix D is a copy of a report that was generated by the Kootenay Boundary Water Tool. It shows water licenses (as of the date of the report) as well as numerous other factors. This tool is on-line and these reports can be generated by anyone, to update the information contained in them. The link to the Kootenay Boundary Water Tools is shown in the "Resources section of this report.

'Dams (#/watershed)' is 0 since there are no dams in this watershed.

4.7 Value Rollup

The *BC CEF Protocol* suggests using the following table to come to a single number to represent the total watershed condition. The author has coloured the groupings green for low, yellow for moderate and red for high to make interpretation easier.

Table 1. Indicator value score classification table. Values within a cell represent a range bounded by it and the number in the cell immediately to its right.

Indicators	Score										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Road Density	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
Road Density near Streams	0	0.04	0.08	0.12	0.16	0.20	0.25	0.30	0.35	0.40	>0.45
Road Density on Unstable Slopes	0	0.03	0.06	0.09	0.12	0.15	0.20	0.25	0.30	0.35	>0.40
Stream Crossing Density (Coastal)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	>2.0
Stream Crossing Density (Interior)	0	0.08	0.16	0.24	0.32	0.40	0.50	0.60	0.70	0.80	>0.90
Riparian Disturbance	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	>0.30
Peak Flow Index	0	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	>0.60

Using Table 1 we get the following values indicating that the Silverton Creek watershed is considered "moderate" when the roll-up is calculated.

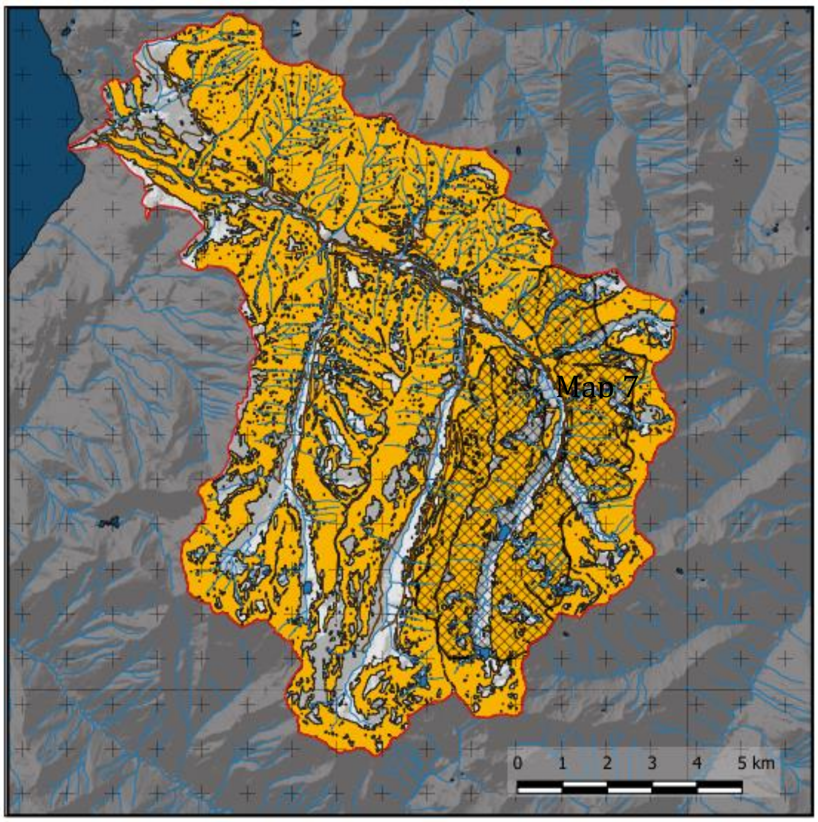
	Value	Category	Score
Road Density	0.56	low	0.2
Road Density near Streams	0.3	high	0.7
Road Density on Unstable Slopes	0.04	low	0.2
Stream Crossing Density	0.75	high	0.9
Riparian Disturbance	0.21	high	0.7
			2.7
Average			**0.54**

This excerpt is taken from the BC CEF Protocol and explains their procedure:

"The watershed unit value roll-up follows a similar procedure to that of the Watershed Assessment Procedure Guidebook (BC MOF 1999). Each raw, calculated indicator value is translated into a normalized score between 0 and 1 (Table 1). All values within the lowest classification receive a normalized score of 0 while the remainder of the calculated values are divided into equal interval classifications (from 0.1-1.0) with an identified upper value serving as the highest classification 1.0. Indicator values are assigned a score based on its corresponding interval. The classification represents the normalized score for the assessment unit indicator (Table 1). Each assessment watershed will therefore receive a single normalized score for each of the six benchmarked indicators assessed. Once indicator scores are calculated, the average of the six scores for each assessment watershed is calculated resulting in a single, comprehensive watershed score for each unit assessed. For coastal assessment watersheds, those that receive a value <0.3 are scored low, those that receive a value >0.7 are scored high while those in between are scored moderate. For interior assessment watersheds, those that receive a value <0.4 are scored low, those that receive a value >0.8 are scored high while those in between are scored moderate."

5 Wildfire and Debris Flow

On July 19, 2018 lightning struck Blacktail Mountain near the headwaters of Silverton Creek. The fire that it created moved north along the ridges on the east and west sides of the creek all the way to the divide that separates Silverton and Carpenter Creek to the north.. When the wildfire died, of natural causes, it had destroyed an estimated 2363 hectares of forest, using data from Sentinel-2 satellite images (Crookshanks, 2018). This is 19% of the area of the Silverton Creek watershed.



Silverton Creek Watershed Map 8
Slope Greater than 25 degrees and 2018 Wildfire

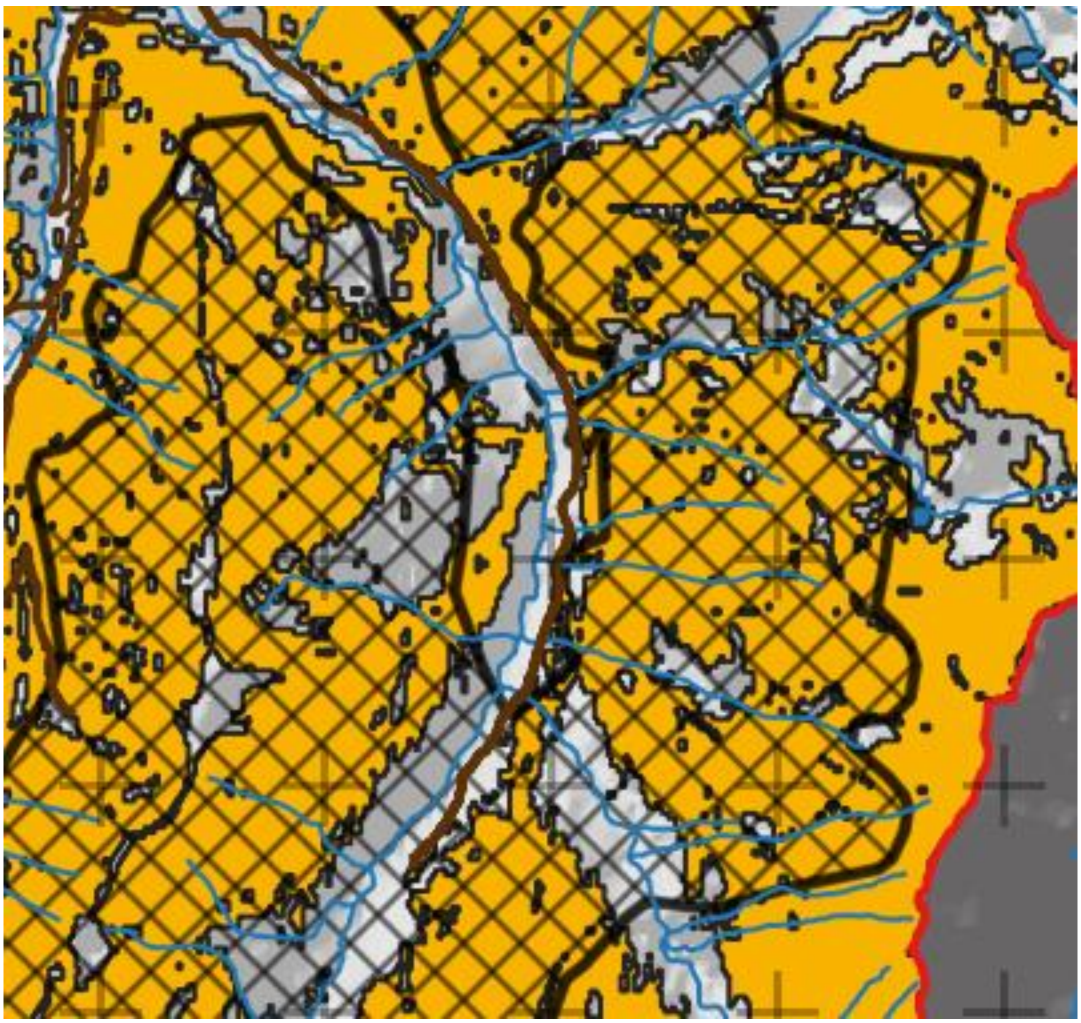
Much of the burned area was classified as severely burned from analysis of Sentinel-2 satellite data and ground truthing. Severe burns destroy all surface and subsurface organic matter and leave only altered sterile soil. With no root structure or tree canopy to influence rainfall and soil cohesion these severe burned areas are prone to debris flows which not only change the topography of the landscape but also can cause damming of creeks; changes in water quality and quantity; and threaten infrastructure and people.

The Springer Creek fire of 2011 can be used as an analog for what can be expected in the burned area in Silverton Creek. A report on the Springer Creek fire and a long term risk analysis is available from the Regional District of Central Kootenay (RDCK) website (Nichol, 2008). The bibliography at the end of this report has a link to that report.

The Blacktail Mountain wildfire burned area can be expected to have debris flows in a manner similar to the Springer Creek fire area. Because the Blacktail Mountain fire is in an undeveloped area where no residences or highways are threatened, it will probably not receive much attention or restoration work from government agencies. This leaves it up to the local community to monitor and protect this natural asset, the Silverton Creek watershed. Most of the threat from the burn can be expected as a result of debris flows.

As a general guideline, debris flow initiation occurs when soil saturation exceeds the ability of the soil to remain in place on a slope. Any slope of 25 degrees (47%) is a candidate for the initiation of a debris flow. Once initiated, transportation and erosion will continue to occur on slopes and gullies of 15 degrees (27%) or greater. Deposition usually begins once the gradient flattens to less than 10 degrees. (VanDine, 1996)

There are many other factors that influence debris flows and deposition (Chatwin, 1994; Highland, 2008) but the above are mentioned here to allow one to indicate where these debris flows may occur in the burned area of the Silverton creek watershed. Map 8, shows the burned area overlain on a map of the Silverton Creek watershed with the areas having a slope greater than 25 degrees shown in yellow-orange. An enlarged portion of Map 8 is shown below.



It is interesting to note that a study (Ferrell, 2019) done by a Selkirk College student, Karlie Ferrell, indicates the same areas and burn severities using Landsat 8 images rather than Sentinel-2 images as were used by Crookshanks (Crookshanks, 2018).

6 Resources

Govt. of BC video "CEF 101"

An introductory video on what the BC Cumulative Effects Framework is all about.
https://youtu.be/Zj6DKJuCQnE

Kootenay Boundary Water Tool

https://kwt.bcwatertool.ca/watershed

DataBC

https://data.gov.bc.ca/

Geogratis

http://geogratis.cgdi.gc.ca/

Rural District of Central Kootenay – wildfire reports

https://rdck.ca/EN/main/services/emergency-management/geotechnical-hazards.html

7 Bibliography

Chatwin, S., Howe, D.E. Schwab, J.W., 1994, "A Guide for the Management of Landslide-Prone Terrain in the Pacific Northwest, Second Edition", Research Program, Ministry of Forests (B.C.), Land Management Handbook Number 18.
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Crookshanks, S., 2018, "Post-Wildfire Natural Hazard Risk Analysis, Fire N51329, Blacktail Mountain", Ministry of Forests, Lands and Natural Resource Operations (FLNRO), Dec 10, 2018.
https://rdck.ca/assets/Services/Emergency~Management/Documents/Blacktail%20Fire%20-%20Wildfires%202018.pdf
(Appendix B to this report)

Ferrell, K., 2019, "Determining Burn Extent and Severity Using Vegetation Indices in Pre and Post Wild Fire Conditions", report prepared as a GIS 307 class project at Selkirk College, edited by R. H. Johnson. (Appendix C to this report)

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https://pubs.usgs.gov/circ/1325/

Appendix C to Highland report:
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https://rdck.ca/assets/Services/Emergency~Management/Documents/Debris%20Flow%20Control%20Structures%20for%20Forest%20Engineering.pdf

Appendix A
Maps

To the report entitled “Cumulative Effects Framework, Silverton, B.C., dated Oct 15, 2019”

Note:
All maps were produced using QGIS 3.8.1 Zanzibar
All map projections are EPSG: 26911, NAD83/UTM zone 11N
All maps are at a scale of 1:90,000
Vector and raster files used are available from the author upon request.

Appendix B
Report on Blacktail Mountain wildfire

To the report entitled "Cumulative Effects Framework, Silverton, B.C., dated Oct 15, 2019"

Crookshanks, S., 2018, "Post-Wildfire Natural Hazard Risk Analysis, Fire N51329, Blacktail Mountain", Ministry of Forests, Lands and Natural Resource Operations (FLNRO), Dec 10, 2018.

MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS,

POST-WILDFIRE RISK ANALYSIS – PRELIMINARY REPORT

NOTE: The results given on this form are preliminary in nature and are intended to be a warning of potential hazards and risks. It is not a final risk analysis and further work may alter the conclusions. Please contact the author for more information.

FIRE: Blacktail Mountain N51329	**FIRE YEAR: 2018**	**DATE OF REPORT:** 10 Dec, 2018

AUTHOR: Sarah Crookshanks

REPORT PREPARED FOR: District Manager, Southeast Fire Centre

FIRE SIZE, LOCATION, AND LAND STATUS: 2000 ha. Fire is located in the headwaters of Silverton Creek east of the Village of Silverton.

VALUES AT RISK: Village of Silverton, Highway 6

WATERSHEDS AFFECTED:	**TOTAL AREA**	**AREA BURNED**	**BURN SEVERITY (% of burned area)**
Silverton Creek	12180 ha	2000 ha (16%)	500 ha, 25% Low 930 ha, 47% Medium 570 ha, 29% High

SUMMARY OF HAZARDS AND RISKS[3]:	**HAZARD[1]**	**RISK[2]**
<u>Hazards</u>: The most significant hazard is flooding caused by snowmelt		
<u>Risks</u>:		
1. Risk of spring flooding impacting the Village of Silverton	M	L
2. Risk of spring flooding impacting Highway 6	M	L

1. Hazard = P(H), the probability of occurrence of a hazardous event
2. Risk = Partial risk P(HA) = P(H) × the probability of it reaching or affecting an element at risk
3. Rating definitions consistent with Land Management Handbook 69,Postwildfire Natural Hazards Risk Analysis in British Columbia (Province of British Columbia, 2015)

RECOMMENDATIONS:

1. The Village of Silverton should monitor water levels in Silverton Creek and their flood protection works during spring freshet. The Village of Silverton is also responsible for ensuring their flood protection works are well maintained.

2. The effects of the Blacktail Mountain fire on hydrological processes should be taken into account when planning future forest development (either salvage logging or the development of non-burned areas) in the Silverton Creek watershed.

POTENTIAL MITIGATION:

Flood protection works owned by the village are already in place on the Silverton Creek fan. No mitigation within the fire perimeter is recommended.

COMMENTS:

The impacts of the Blacktail Mountain fire on snowmelt-dominated peak flows will likely continue for several decades as the tree canopy is re-established within the fire perimeter.

The gradient of Silverton Creek is below the threshold for transport of debris flows and floods; therefore any landslides that may occur within the fire perimeter do not pose a hazard to infrastructure on the fan.

There is one domestic water licence on Silverton Creek in the name of Klondike Silver Corporation; based on the file information, it is unlikely that the licence is in use at this time.

SIGNATURE:
Original signed and sealed by Sarah Crookshanks, P.Geo.

ATTACHMENTS:
See attached memo and map for further details.

REVIEWED BY:
Original signed and sealed by Natasha Neumann, P.Ag.

Post-Wildfire Natural Hazards Risk Analysis, Fire N51329, Blacktail Mountain

Sarah Crookshanks, MFLNRO, December 10 2018

Introduction and methods

This memo provides additional information that is intended to supplement the initial preliminary report summary form (attached). The Blacktail Mountain fire burned approximately 2363 ha of land in the headwaters of Silverton Creek. The fire was initiated by lightning and was discovered on July 19, 2018. A natural hazards risk analysis of the fire was completed following the procedures outlined in Land Management Handbook 69 (Hope et al., 2015).

On August 30, 2018, an overview flight was completed by Sarah Crookshanks (MFLNRORD). The fire was still burning at the time, although the fire did not expand much through September. On October 10, 2018 a ground assessment of the fire was completed by Sarah Crookshanks and Natasha Neumann (MFLNRORD).

The burn severity mapping was provided by MFLNRORD Regional Operations based on Differenced Normalized Burn Ratio calculations using same year classification satellite imagery. The original classification under-reported the burn severity; therefore the burn severity classification break points were adjusted to better reflect field observations.

Burned area observations

The burn severity fire map in Figure 1 and the aerial photos of the fire (Figures 2 through 4) show that most of the burned area lies between 1600 and 2000 m on east and west facing aspects. The riparian zones along the valley bottoms for the most part remained unburned. Three burn severity plots were undertaken where access allowed. Soil burn severity was similar to the vegetation burn severity at all three sites.

The most significant post-wildfire hazard for Silverton Creek is flooding caused by snowmelt during the spring freshet. Approximately twenty percent of the Silverton Creek watershed burned, of which almost half is moderate or high burn severity. Approximately 27% of the Silverton Creek watershed above the H60 elevation (1650 m) was burned. The H60 elevation refers to the snowline elevation when the upper 60% of the basin area is still covered with snow. Vegetation removal in the area above the H60 elevation is generally understood to have a greater influence on peak flows due to changes in snow accumulation and snowmelt processes.

Discussion of post-wildfire flood hazard and risk

The Blacktail Mountain fire will increase the likelihood of earlier and possibly higher spring peak flows in Silverton Creek. Even though the proportion of burned area within the overall watershed is low, the potential for the synchronization of runoff is significant based on two factors: elevation and aspect. Assuming that the burned area (mostly located between 1600 and 2000 m) melts earlier, this runoff will combine with the snowmelt from forested land at lower elevations. In terms of aspect, the Silverton Creek watershed is mostly composed of south, east and west facing slopes. Since the fire mostly occurred on east and west facing aspects, the potentially earlier melt from the burned area will combine with the snowmelt from the south facing slopes. While synchronization will increase the likelihood of earlier and higher spring peak flows, the large basin size, wide elevation range and alpine areas may help to moderate the flood response potential in Silverton Creek.

Considering the factors discussed above, there is a moderate likelihood of increased spring flooding in Silverton due to the incremental hydrological effects of the Blacktail Mountain fire. This hazard of spring flooding is due to increased snow accumulation, more rapid snowmelt, spatially synchronized snowmelt, and higher groundwater levels in burned areas, and can persist for many years until revegetation occurs.

The Silverton Creek channel is incised on its fan and the likelihood of avulsion during a spring flood event is low. The Village and the highway contractor should monitor the channel on the fan during spring freshet. The formation of a log jam may cause higher streamflow velocities and exacerbate any bank erosion issues.

Historical disturbances, such as forest harvesting and other wildfires, also affect the frequency and magnitude of peak flows in Silverton Creek; however, the consideration of the cumulative impacts of all disturbances within the watershed is beyond the scope of this analysis. The effects of the Blacktail Mountain fire on hydrological processes should be taken into account when planning future forest development (either salvage logging or the development of non-burned areas) in the Silverton Creek watershed. Further hydrological assessment would be needed to confirm the extent of possible impacts.

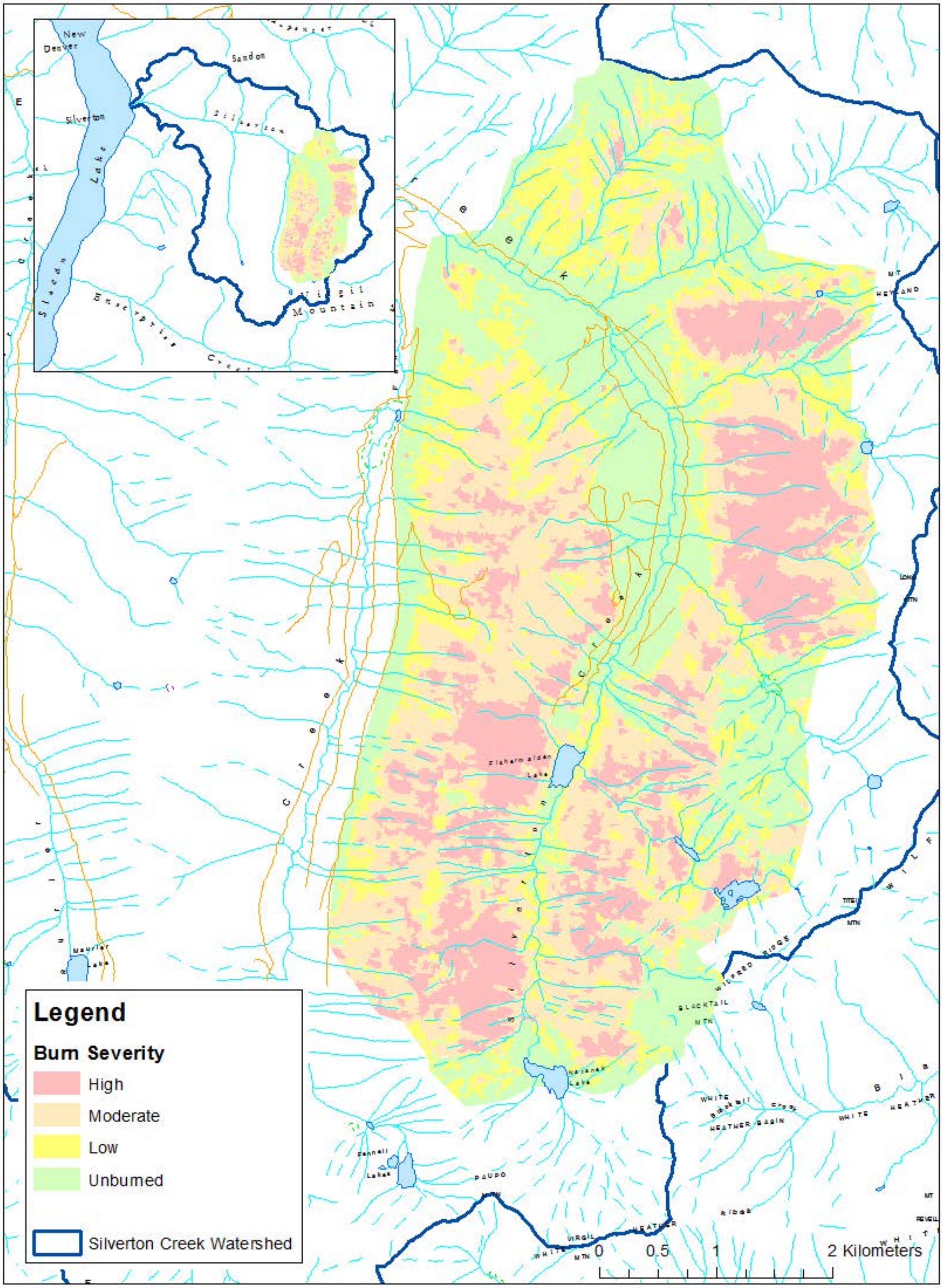

Figure 1. Burned area reflectance classification map of the Blacktail Mountain fire (N51329) showing estimated burn severity. Inset map shows the entire Silverton Creek watershed.

Figure 2. Looking north at the Blacktail Mountain fire from above Natanek Lake.

Figure 3. Looking east at the Blacktail Mountain fire within the Fennell Creek valley (tributary to Silverton Creek).

Figure 4. Looking south towards Nanatek lake.

Appendix C
Assessment of Blacktail Mountain wildfire

To the report entitled "Cumulative Effects Framework, Silverton, B.C., dated Oct 15, 2019"

Ferrell, K., 2019, "Determining Burn Extent and Severity Using Vegetation Indices in Pre and Post Wild Fire Conditions", report prepared as a GIS 307 class project at Selkirk College, edited by R. H. Johnson.

Determining Burn Extent and Severity Using Vegetation Indices in Pre and Post Wild Fire Conditions

Karli Ferrell

Advanced Diploma in GIS

GIS 307

March 9th, 2018

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Abstract
Several hundred million hectares of forest and other vegetation types are estimated to burn annually throughout the world, making forest fire the most dominant disturbance in forests. Remote sensing techniques have been identified as an effective tool for preventing and monitoring those forest fires. Focusing on the Blacktail Mountain fire, which started on July 19th, 2018, this study used three Landsat 8 images, and aimed to map the overall burned area by applying four vegetation indices; Normalized Difference Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index (MSAVI), Burn Area Index (BAI) and Normalized Burn Ratio (NBR). The burn severity was calculated by applying the Differenced Normalized Burn Ratio (dNBR), and fire prediction was attempted using Normalized Burn Ratio Thermal (NBRt). This study reveals the accuracy of the four indices in burn mapping, shows similar results between NDVI and NBR, and demonstrates that both are suitable for identifying and mapping burned areas. This study also concludes that dNBR can be a reliable tool in determining burn severity while paired with field data. Lastly, this study shows that when using NBRt on its own with minimal satellite images available, that it does not show significant results to assist in fire prediction. Challenges and limitations encountered when working with thermal bands are discussed. Further research is encouraged using satellite missions with a higher temporal resolution, as well as accompanied studies of other historical fires for a better understanding of fire characteristics on a larger scale.

1. Introduction

British Columbia, the most western Canadian Province, covers 95 million hectares of land. Forests cover close to 64% of that land, covering almost 60.3 million hectares (BC Forest Facts). BC forests are well known around the world for their ecological and wildlife value, picturesque beauty, and importance to recreation and tourism. Since the beginning of these forests, they have continuously changed as a result of wildfire. Wildfire is a frequent natural occurrence, and is a necessary event to encourage an ecological process which aids in rapid growth in young trees, early and abundant seed germination and the dispersal of seeds. It is also important for controlling age structures and creating ecological diversity. (Thuan Chu and Xulin Guo 2014). While on the other hand, forest fires can cause an extreme burden on our economic, environmental, and social livelihoods, and is one of the primary sources of large scale forest mortality across the world. In BC alone, by the end of the 2017 fiscal year, a total of 1,216,053 hectares was burned by wild fire, costing approximately $568 Million (Wildfire Averages).

To effectively manage these forest ecosystems, land managers and scientists require timely and comprehensive information on fire damage extent, and fire behavior. Better prediction of fire danger and fire detection has significant benefits for both economic and human safety values. (Leblon et al. 2012) This can be done with Remote Sensing, a technique that has been developing since the mid-1980's. A birds eye view offers a better advantage over the on the ground surveying with a global positioning system (GPS), which often fails to capture the patchiness of fires and large scale fire effects (Lentile et al. 2006). By acquiring images received by satellites orbiting the earth, this tool is able to address three different temporal fire-effect phases: pre-fire conditions, active fire characteristics and post-fire ecosystem responses in real-time. Vegetation information from remote sensed images is mainly interpreted by differences and changes of the green leaves from plants and canopy spectral characteristics by obtaining the electromagnetic wave reflectance information using passive sensors. The reflectance of light can change due to surface characteristics, temperature, and water content, therefor making this a valuable tool for assessing vegetation health over time. Vegetation Indices combining visible and NIR bands have improved the sensitivity of the detection of green vegetation. Each VI being used today has its own specific expression of green vegetation, its own suitability for specific uses, and some limiting factors (Xue and Su 2017).

The aim of this study was to discover the ideal VI for identifying and mapping the extent and severity of the burnt area left by the Blacktail Mountain Fire on pre and post fire images from the Landsat 8 Satellite Mission. This study focuses on two of the three fire effect phases, pre-fire, and active fire. As this fire occurred in 2018, there were no observations of vegetation regrowth post fire to assess the third fire effect phase.

This study also aimed to asses if detecting potential fire susceptible areas is reliable with Thermal Infrared Sensors. This sensor uses active sensors which measure the heat emitted from the ground to identify arid or drought stricken areas. Historically detection and monitoring of wildfires has relied on aircraft and satellites with visible and IR Bands. Advances in sensor platforms are revolutionizing the way we predict, detect and monitor wildfires. Sensor systems like Thermal Infrared are becoming more available and affordable with such instruments as the Landsat 8 Thermal Infrared Sensor (TIRS). As fires burn much hotter than the typical temperature of surfaces on the Earth, heat provides a strong signal for the prediction and detection of fire. While smoke can be a cue for detection, it can also obscure the visibility of the flame. Past studies have shown that TIR imaging has an advantage over NIR and SWIR sensors in this respect with its wavelengths ability to penetrate thick smoke and allow imaging of hotspots. Another advantage of TIR sensing for fire detection is that is can be performed both day and night, as it detects emitted energy rather than reflected energy from the sun (Allison et al. 2016).

The following research questions were answered during this study;

- examine the accuracy and suitability of NDVI, MSAVI, NBR, BAI in mapping burned areas compared to official data;
- identify the levels of severity within the burn perimeter using DNBR;
- asses if NBRT can reliably be used in fire detection.

2. Study Area

On July 19th 2018, a forest fire was detected on Blacktail Mountain in Kokanee Glacier Park, about 8 kilometers southeast of Silverton BC. This fire devastated 2,363 hectares (estimated), and left 19% of the watershed burned.

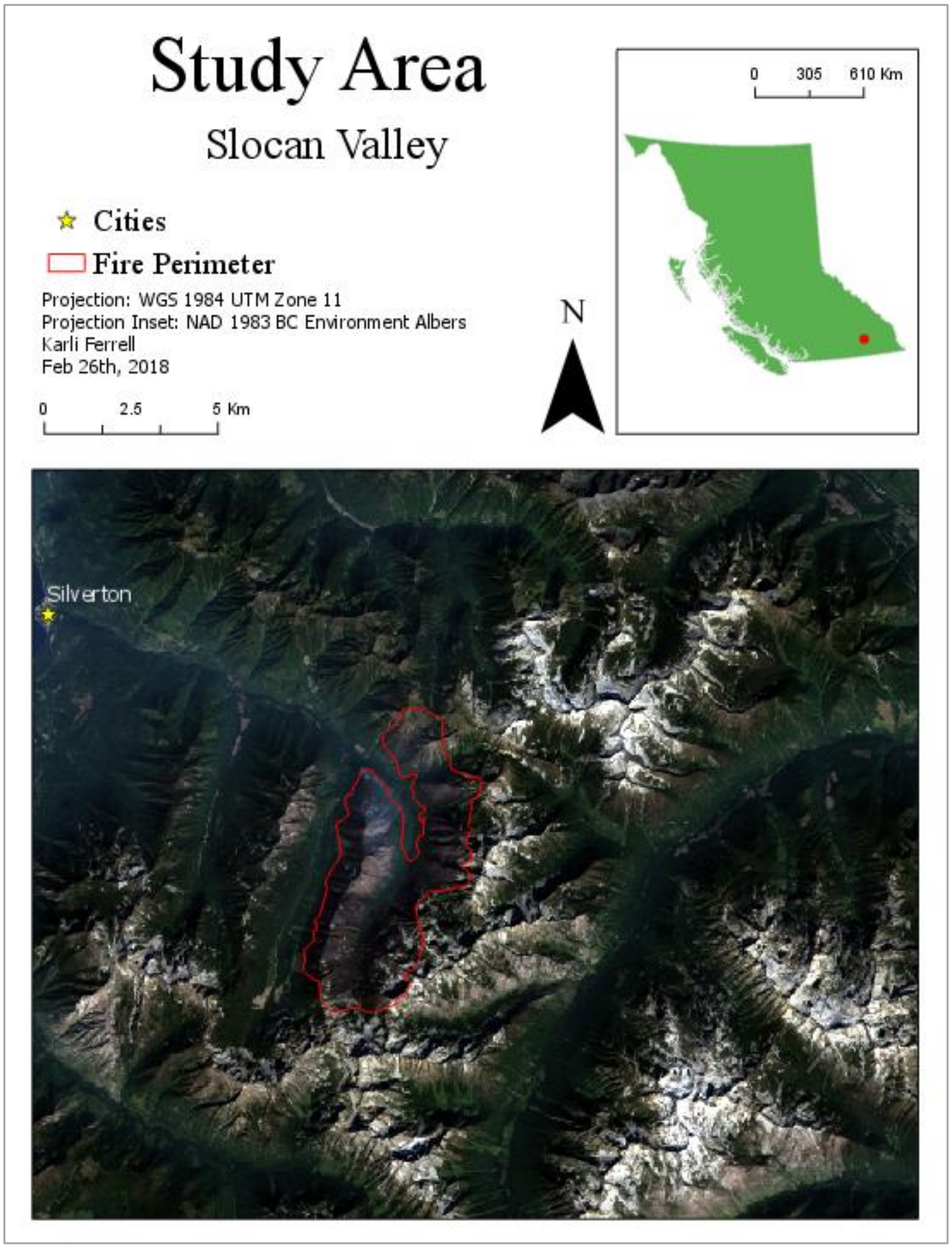


Figure 1 Blacktail Mountain in Kokanee Glacier Park

3. Client

Richard H. Johnson
Richard.slrc@gmail.com
250-358-2590

Richard is a Geological Engineer with over fifty years of experience in reservoir engineering, geology, economic evaluations, computer reservoir modelling, hydrogeology, and management. Richard is also the Managing Director at the Slocan Lake Research Centre (SLRC), a branch of Opus Petroleum focused on scientific research. The Slocan Lake Research Center (SLRC) is a non-political, non-government and non-profit agency devoting their efforts to environmental matters in the Slocan Lake Area.

This project will benefit the Village of Silverton with future forest fire management and resource planning. The contact for the Village of Silverton is Leah Main. She is a Silverton Councillor and RDCK Director.

4. Data Used

Landsat 8 is an American earth observation satellite launched on February 11th, 2013. This satellite has a 16 day repeat cycle, captures more than 700 scenes a day, and has produced over 1.3 million scenes available for download. This study used Landsat 8 imagery because of its repeated coverage, ease of access, and its use of Thermal Infrared Sensor instrument, which measures different intensities of the light as different surface temperatures (Landsat Missions).

Three images were acquired for the purpose of this study from the USGS Global Visualization Viewer (GloVis) website. Images were collected in 2017, one, a year prior to the fire, and one, 5 days prior to the fire, and one in 2018, immediately after the fire. The images a year prior and immediately after the fire were collected during the months of September (Sept 27th, 2017 and Sept 5th, 2018 respectively) to maintain consistency of environmental condition for accurate vegetation comparison. The image immediately prior to the fire was acquired on July 12th, 2018. Attention was taken to ensure images were cloud free, and with limited amounts of smoke post fire as to not interfere with analysis. Band information for these images can be found in Table 1. Highlighted bands are the ones used in the analysis for this study.

Table 1. Spectral and spatial information for Landsat 8

Band	Spectral Resolution (micrometer)	Spatial Resolution
Operational Land Imager (OLI)		
Band 1 –Coastal aerosol	0.43 – 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 - Near Infrared (NIR)	0.85 – 0.88	30
Band 6 – SWIR 1	1.57 – 1.65	30
Band 7 – SWIR 2	2.11 – 2.29	30

Band 8 – Panchromatic	0.50 - 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30
Thermal Infrared Sensor (TIRS)		
Band 10 – Thermal Infrared (TIRS) 1	10.60 – 11.19	100
Band 11 – Thermal Infrared (TIRS)2	11.50 - 12.51	100

5. Methods

Two Vegetation Indices, Normalized Difference Vegetation Index (NDVI), and Modified Soil Adjusted Vegetation Index (MSAVI) as well as and two Burn Indices, Burn Area Index (BAI), Normalized Burn Ratio (NBR), were used to test their suitability and limitations for burn mapping. In addition to measuring burned area, Pre and Post NBR images are used to understand the degree of post-fire environmental change. Differenced Normalized Burn Ratio (DNBR) was used to detect the severity of burn scars left within the study area. Normalized Burn Ratio Thermal (NBRT) was used on an image acquired 5 days before the fire occurred to quantify emitted heat from the ground surface.

Prior to mapping the burned areas, satellite images were pre-processed. In ENVI version 5.3, radiometric calibration and dark object subtraction were completed after sub-setting the images to the study area. The Indices, based on the RED, NIR, and SWIR bands, were calculated for mapping the burned area in this study.

- Normalized Difference Vegetation Index (NDVI) – is a widely used SI and is related to the amount of green vegetation making use of the relatively high reflection of vegetation in the NIR spectral region wavelengths , and absorption of radiation by chlorophyll in the red spectral region (Schepers et al. 2014):

NDVI = (NIR-RED) / (NIR+RED)

- Modified Soil Adjusted Vegetation index (MSAVI) – specifically designed for burned land application, a modified version of SAVI, MSAVI reduces soil noise and increases the dynamic range of the vegetation signal (Burn Indices Tutorial):

MSAVI = 2NIR + 1 - Sqrt (2NIR + 1) ^ 2 - 8 (NIR - RED) / 2

- Normalized Burn Ratio (NBR) – Similar to NDVI, except that is uses NIR and SWIR wavelengths. Widely used for burn severity assessments, provides good discriminatory power between burned and unburned areas (Schepers et al. 2014):

NBR = (NIR- SWIR) / (NIR+SWIR)

- Burn Area Index (BAI) – specifically designed to detect and enhance the charcoal signal post fire. This SI using red and NIR reflectance values to calculate the spectral distance from each pixel to a reference spectral point to which burned pixels converge. Brighter pixels indicate burned areas (Burn Indices Tutorial):

BAI = 1 / (0.1- RED) ^2 + (0.06 – NIR) ^2

In order to determine the accuracy of these four indices, a shape file was created in ENVI outlining the burn perimeter produced by each Index respectively. Shapefiles were created subjectively based on visual interpretation using the grey scale color contrast between pixels in the images. These shapefiles were compared to the official perimeter shape file released by the Province of BC, Wildfire Service. The area was calculated by clipping the Indices shape files from the official shape file in ArcGIS Pro. For separability of burned forest from unburned forest, random ROI's were plotted for histograms representing the spectral indices for all four indices.

Following the corrections, and SI burn area mapping, the dNBR was then applied to the study area to identify the levels of severity within the burn perimeter.

- Differenced Normalized Burn Ratio (dNBR) - Becoming the standard SI methodology to assess burn severity, dNBR is used by differencing the post and pre-fire index images. Differenced images are best measured using data collected immediately before the fire and then immediately after the fire to reduce reflectance from vegetation regrowth (Work with the Difference Normalized Burn Index).

dNBR = PrefireNBR – PostfireNBR

Finally, thermal bands were calibrated to brightness temperatures, and stacked with the multi-temporal bands. The Normalized Burn Ratio Thermal was then applied to July 12th image to quantify if any area showed signs of drought or increased ground temperature before the fire struck on July 19th, 2018.

- Normalized Burn Ratio Thermal (NBRT) - Uses the thermal band to enhance the NBR. The addition of the thermal band, allows the detection of heat for fire prediction, and analysis even in images with thick smoke.

NBRT = (NIR – SWIR (TIR/1000))/(NIR + SWIR (TIR/1000))

Both dNBR and NBRT final images were the classified to determine area coverage within the official polygon of each burn severity category and to produce final maps.

Methods Work Flow Diagram

Figure 2 Work Flow Diagram

6. Results and Discussion

Using Fig. 3 for analysis, it can be seen in all the images that a grey scale is used for its values with darker colors representing burn scars, and lighter colors representing healthy vegetation, with the exception of BAI which symbolized the burn scar with white. Using visual analysis on the images along with analysis of the spectral signatures (Fig 4) from the four indices using histograms, it is clear that NBR has the best separability between mean burn and mean unburned area values. NDVI also has substantial mean value separability, while MSAVI and specifically BAI have significant overlapping spectral signatures.

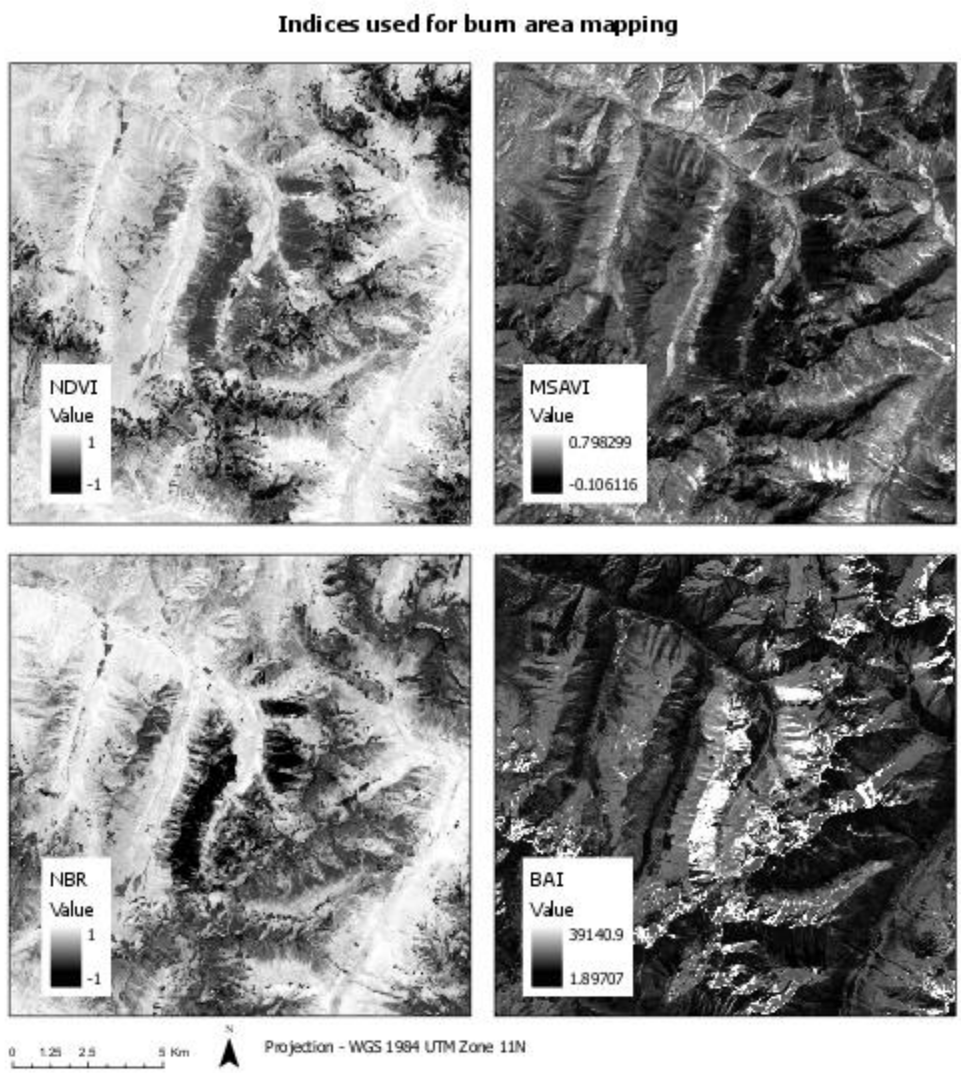
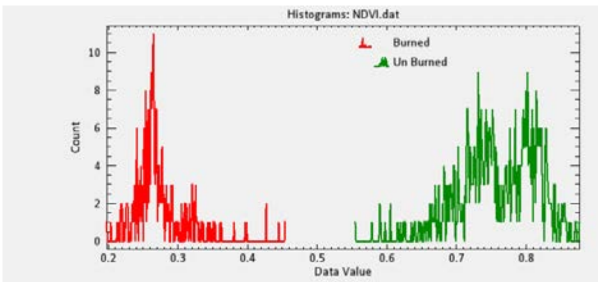
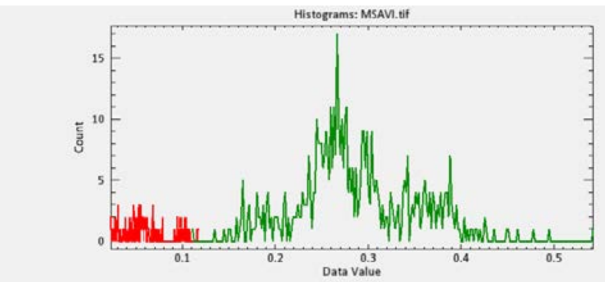


Figure 3 Compared Indices for Burn Mapping

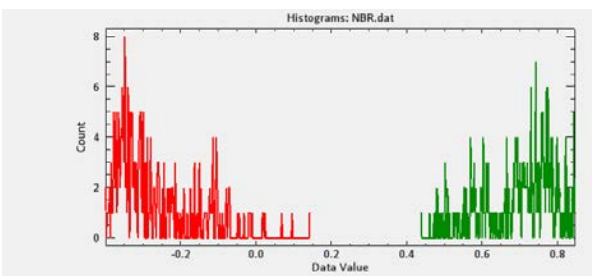
Histograms show the distribution of pixel values with the images (a) NDVI, (b) MSAVI, (c) NBR, and (d) BAI. The actual threshold values to identify burned areas differ from one index to another, since each index has a different sensitivity. Fig. 4 shows the differential sensitivities of the indices to burned and unburned areas. They are largely discernible from each other in NDVI and NBR, less so in MSAVI, and the least discernible in BAI.



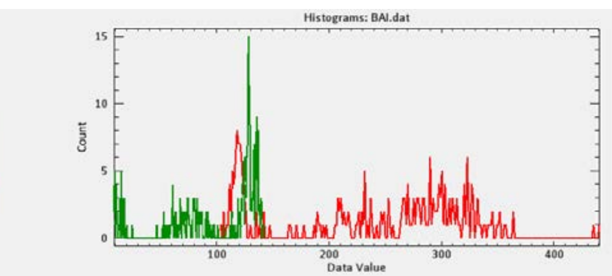
(a)



(b)



(c)



(d)

Figure 4 Indices Histogram Comparison

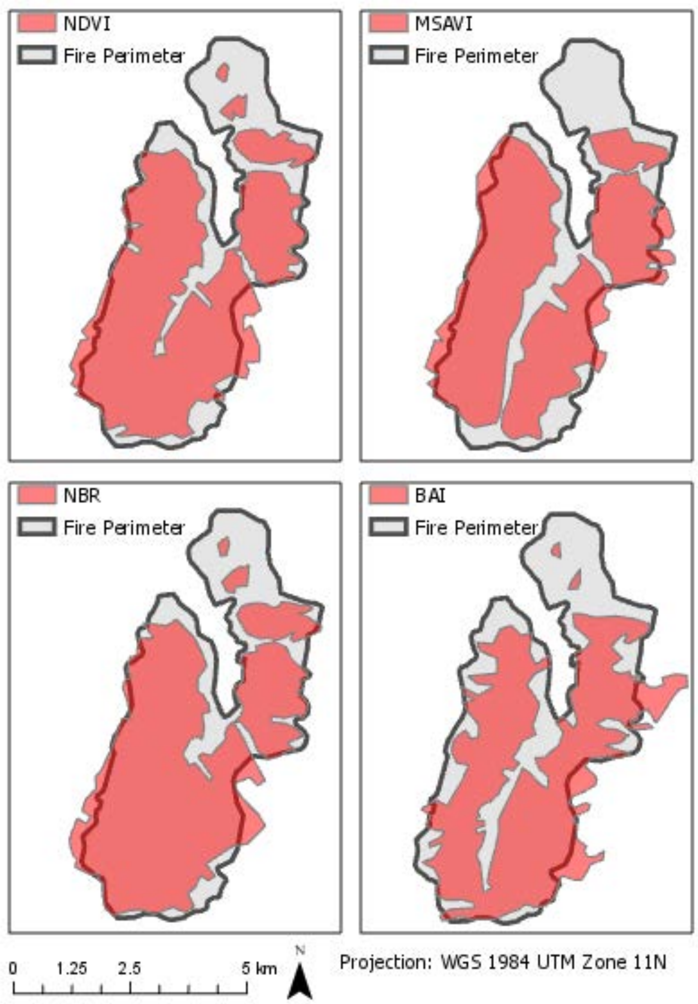


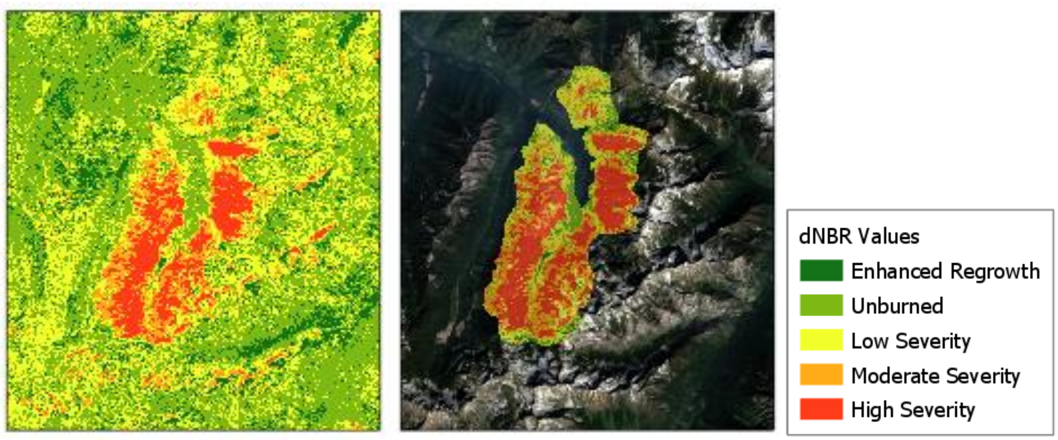
Figure 5 Polygons of VI's compared to official fire perimeter shapefile

In Fig 5 the shape files created from each Indices are compared to the official fire perimeter released by BC Fire Service. Table 2 calculates the difference in area burned compared to the shape file, total area inside the perimeter and total area outside the perimeter. NBR and NDVI performed well, both showing considerably more accuracy than MSAVI and BAI for both fire area interpreted inside the official fire perimeter and fire area interpreted outside the perimeter. The results from BAI unexpectedly provided the poorest performance. BAI showed the least discrimination of burned areas with rock.

Table 2. Area of Indices coverage compared to official perimeter

Burned Area in Ha				
	NDVI	**MSAVI**	**NBR**	**BAI**
Total Burned Area	1807.4	1765.9	1878.7	1628.1
Inside the Official Perimeter	1673.3	1564.1	1739.9	1469.9
Outside the Official Perimeter	134.1	201.8	138.8	158.2
Official Burned Area	2361.5	2361.5	2361.5	2361.5

By performing the dNBR, Fig 6 (a) demonstrates the level of severity from the burn scar. There is a clear distinction between areas of high severity burn and lower severity. Higher dNBR values represent a higher indication that the pixels in the image are “burned”. For increased accuracy it is suggested that dNBR results are supported by a field assessment, as dNBR values can vary by scene. However as these figures show, dNBR can provide a useful initial interpretation. This can provide valuable indication on exact locations where land managers should focus their reclamation efforts (Normalized Burn Ratio). Fig 6 (b) shows the different levels of burn severity clipped to the official perimeter, overlaid on the post-fire Landsat 8 image.



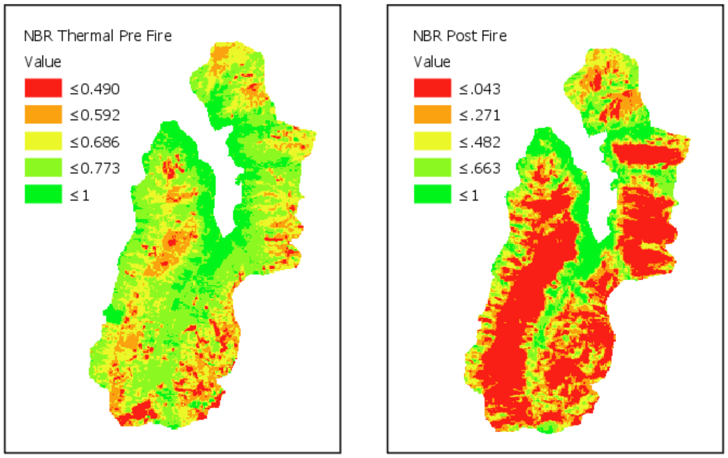
(a) *(b)*

Figure 6 Burn Severity Map

Table 3. Burn Severity Classification

Burn Area Severity Classification			
Severity Level	dNBR range	Area (ha)	Percentage
Enhanced Regrowth	< -0.1	37.2	1.6
Unburned	-0.1 to + 0.1	265.4	11.2
Low Severity	+ 0.1 to + 0.27	561.4	23.8
Moderate Severity	+0.27 to + 0.66	643.0	27.2
High Severity	>0.66	854.5	36.2

Fig. 7 (a) shows the heat response from the pre-fire image and Fig. 7 (b) shows the heat response from the post fire image. I expected to see more correlation between the two images, such as a response from low moisture level and arid drought conditions. The red values in the NBRT images, when visually interpreted in the original true color image, mostly represent heat reflected from rock. Table 4 does not show any pattern or consistency between the value changes. Therefor the answer to this research question is unknown and further research using other historical fire data for comparison is necessary to make a conclusion.



(a) *(b)*

Figure 7 NBRT Map

Table 4.

Pre Fire Thermal Images compared to Post Fire NBR			
	NBR Thermal Pre Fire Area (ha)	NBR Post Fire Area (ha)	Total (%) change between pre and post fire images
Red	114.3	969.9	Up 88.2
Orange	323.1	420.4	Up 23.1
Yellow	612.3	376.9	Down 38.4
Light Green	920.88	318.9	Down 65.4
Green	389.5	274.0	Down 29.7

7. Conclusions

Remote Sensing has proven to be an effective and timely tool in wildfire management and for studying wildfire behavior. Using Indices on these remotely sensed images continues to improve and advance, but as mentioned above they all have their own suitability for specific uses, and some limiting factors. Each VI may provide better or worse results dependent on forest type, study area size, and sensor type. This study only covered one fire covering just over 2000 hectares, spanning similar forest cover type. Results from this study may be biased to this specific area and the fire behavior in that event. Normalized Burn Ratio and Normalized Difference Vegetation Index proved to be considerably more effective indices for mapping this fire specifically. Differenced Normalized Burn Ratio was also effective on this fire, showing clear distinction between areas of high a low burn severity. However with the low temporal resolution, this study was unable to achieve a comprehensive conclusion to answer whether Thermal bands can be used to predict if an area is susceptible to fire hazard or not. Without a larger scale study with further research it cannot be reliably used for fire detection.

Studying fire in all three fire stages is necessary to continue our understanding of fire behavior, however sending out field staff can be often unsafe, inefficient, and inaccessible. The use of VI's in burn mapping and severity mapping is fast, affordable and safe. It can be done at any stage of a fire, and can be applied to any geographic location through the expansive coverage of modern satellite missions.

8. Limitations

One of the main limitations of this study is the temporal resolution of the satellite mission Landsat 8. An increased image acquired cycle would have made analysis of the thermal bands possibly more constructive. As it was very cloudy during this study period, it also minimized my availability of images. The cloud coverage was too severe, and while the heats emitted energy can penetrate smoke, it is unable to penetrate cloud similarly to the passive sensors. I would have liked to study how well the thermal bands provided image analysis through thick smoke, however no images were found on smoke filled days.

9. Further Research and Recommendations

The best way to validate the results from the fire severity map would be to confirm actual conditions on the ground. Aerial surveys and field work should be considered once this area is snow free. I would also recommend continued monitoring of this this area yearly, using the successful Indices mentioned earlier in this report. This will provide an excellent visual analysis on how well the vegetation is recovering. I would also recommend doing more research, once Lidar Data is available for this region, as it is beneficial in providing tree canopy and regeneration heights, which is a valuable aid in estimating timber value.

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Appendix D
Silverton Creek Watershed Report

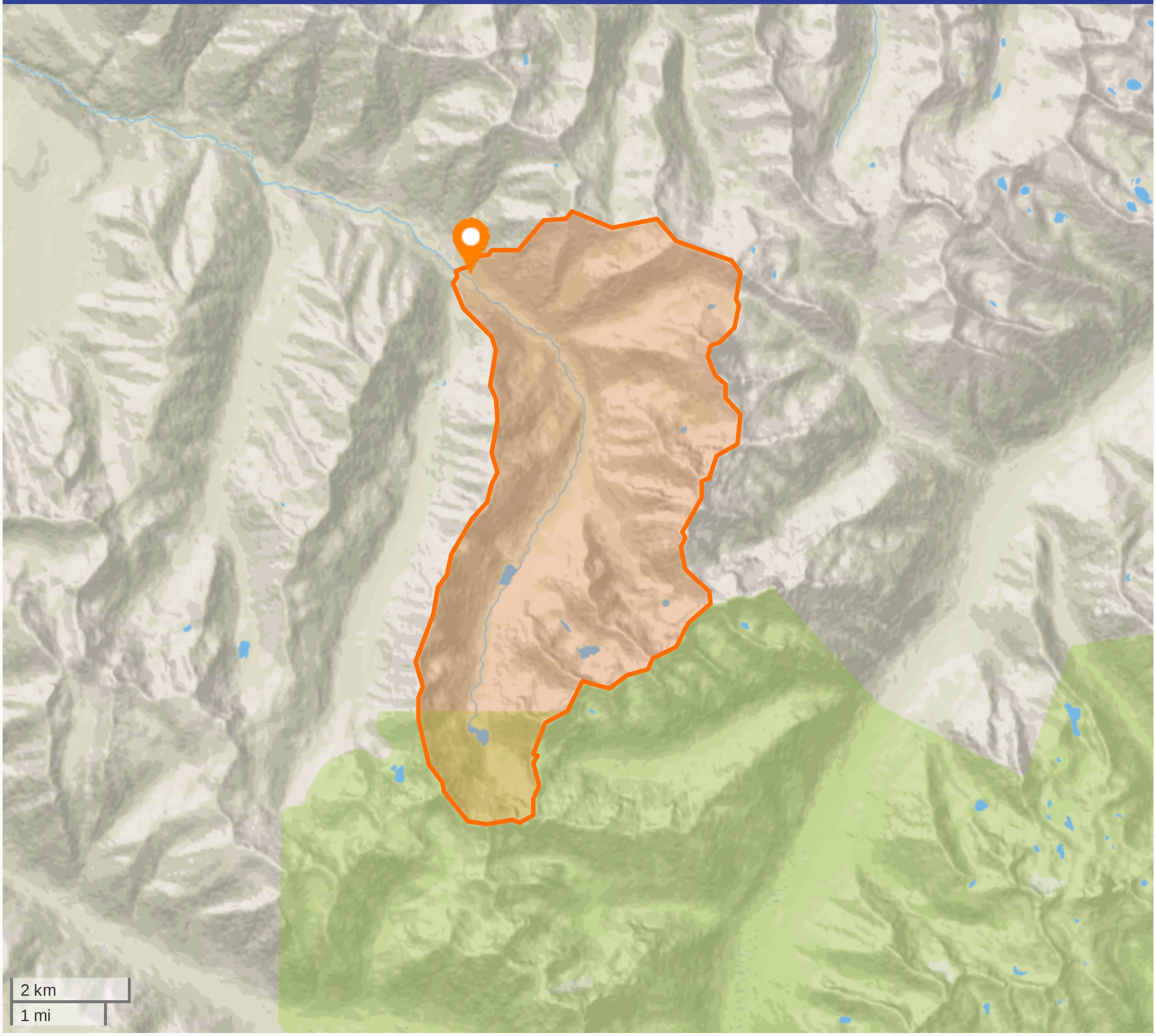
To the report entitled "Cumulative Effects Framework, Silverton, B.C., dated Oct 15, 2019"

Report from the "Kootenay Boundary Water Tool"

Silverton Creek

- Silverton Creek
- Slocan River
- Kootenay River
- Columbia River
- Pacific Ocean

Watershed Report
July 14, 2019
WFI: 9262241



Coordinates
49.91929, -117.23508

Watershed area
34 km²

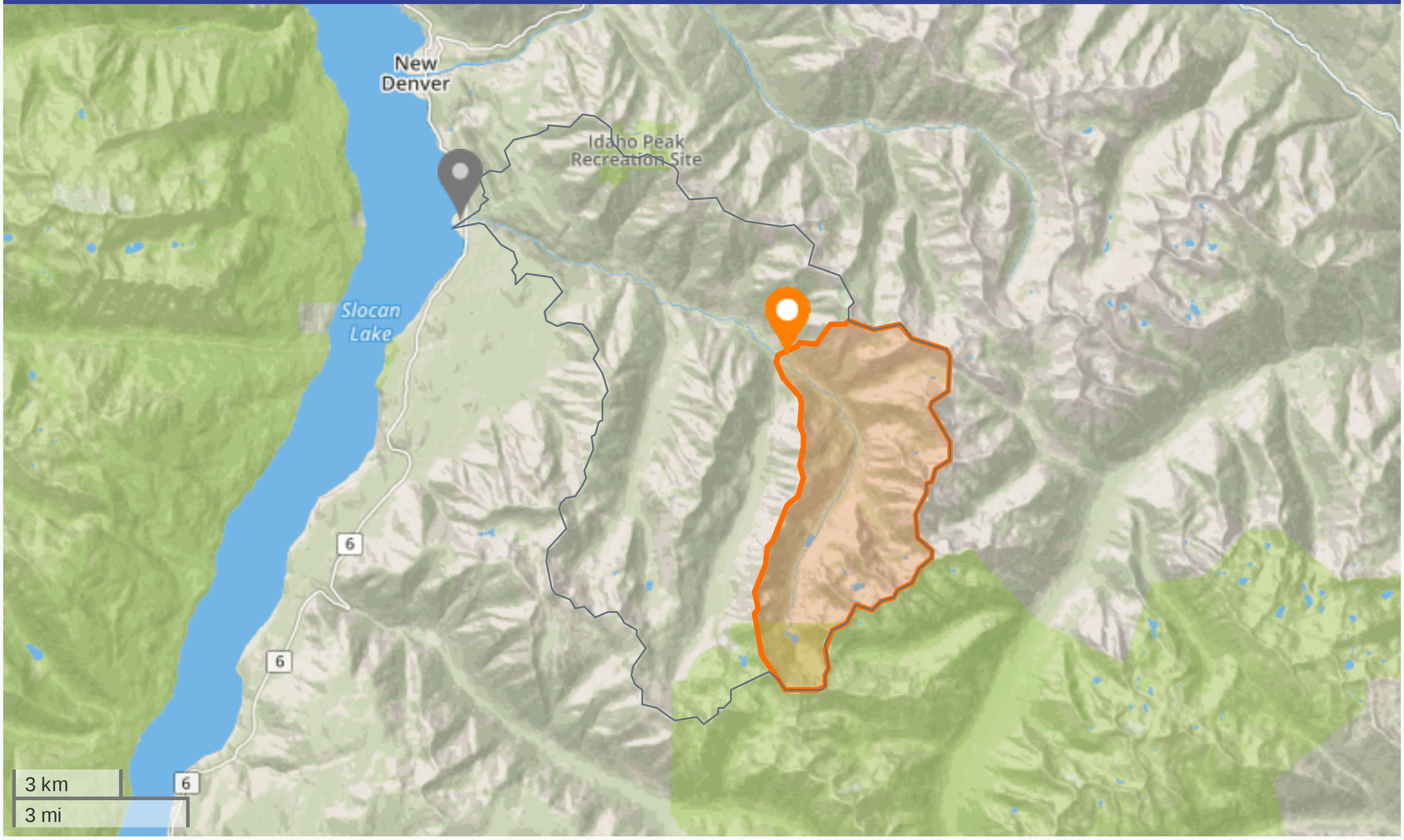
Watershed elevation
1,304 - 1,976 - 2,502 m
(min - mean - max)

British Columbia | Ministry of Forests, Lands, Natural Resource Operations and Rural Development

KOOTENAY BOUNDARY WATER TOOL

Hydrology - Annual

The map shows the query (orange) and downstream (grey) watersheds. The table below provides an overview of the hydrology and existing authorized water allocations under the *Water Sustainability Act* within these watersheds.



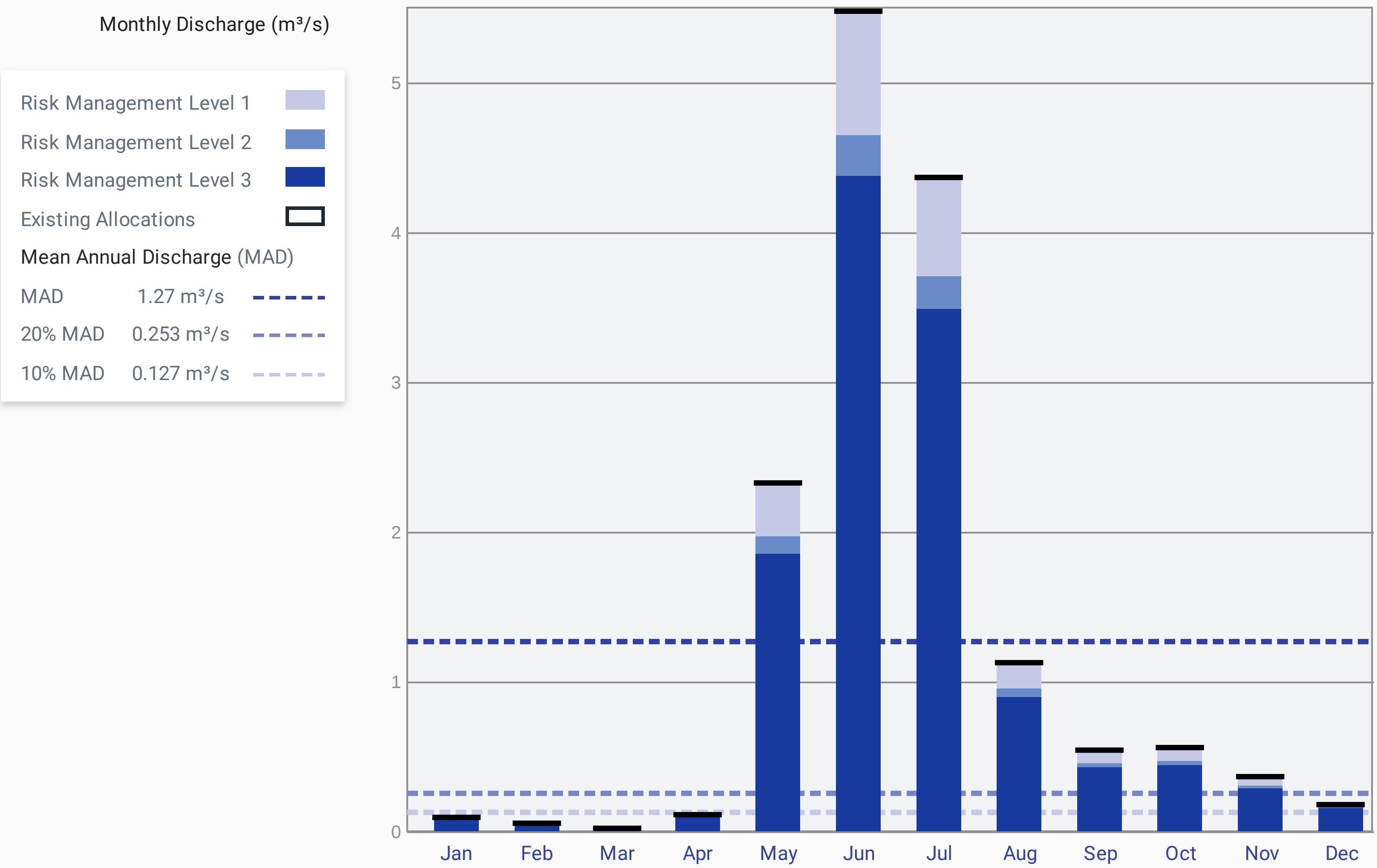
	Query Watershed	Downstream Watershed
Area (km²)	33.8	122
Mean Annual Discharge (m³/s)	1.27	3.79
Allocations (m³/s)	0	0.059
Allocations (%)	0	1.6
Reserves & Restrictions	Present*	Present*
Annual Runoff (m³/yr)	39,974,397	119,649,015
Current Total Allocations (m³/yr) (Water licence & Short Term Use Approvals)	0	1,873,231
Seasonal Flow Sensitivity**	Winter	Winter

The downstream watershed is defined at the location where the queried drainage meets with another drainage of comparable size. For information further downstream, please generate an additional report at a location of interest. Predictions for small watersheds (generally smaller than 50 sq. km.) may be less accurate due to the lack of hydrometric data available for watersheds of this size.
* For more information on water reserves or restrictions present in the watershed, please visit the links below or contact FrontCounter BC.
Water Reservations: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-reservations
Water Restrictions: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-allocation-restrictions
FrontCounter BC: www.frontcounterbc.ca **Email:** FrontCounterBC@gov.bc.ca **Toll Free**: 1-877-855-3222 **Outside North America:** ++1-778-372-0729
**Ptolemy, R. Environmental Flow Protection in British Columbia. Presentation to 2015 IFC Panel, April 29, 2015.

Hydrology - Monthly

Silverton Creek

The chart and table show information on modeled hydrology and existing allocations in the query watershed. This location is shown with an orange marker and watershed outline in the map on page 2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% of MAD	6.9%	3.8%	1.1%	8.3%	183.5%	431.6%	343.9%	88.1%	42.4%	43.7%	28.3%	13.6%
Flow Sensitivity	High	High	High	High	Low	Low	Low	Low	Low	Low	Low	Mod
Existing Allocations (m³/s)	0	0	0	0	0	0	0	0	0	0	0	0
Mean Monthly Discharge (m³/s)	0.087	0.048	0.014	0.105	2.32	5.47	4.36	1.12	0.536	0.553	0.359	0.172
Potential Allocation (m³/s, Risk Mgmt 1)	0	0	0	0	0.349	0.82	0.653	0.167	0.08	0.083	0.054	0
Potential Allocation (m³/s, Risk Mgmt 2)	0.004	0.002	0.001	0.005	0.465	1.093	0.871	0.223	0.107	0.111	0.072	0.017
Potential Allocation (m³/s, Risk Mgmt 3)	>0.004	>0.002	>0.001	>0.005	>0.465	>1.093	>0.871	>0.223	>0.107	>0.111	>0.072	>0.017

Notes

The watershed at this location is 33.81 km² in size. Monthly and annual mean flow estimates are known to be less reliable in watersheds of this size due to increased inter-annual and seasonal variability, imprecise watershed delineation, and lack of hydrometric data available in the region for watersheds of this size. Generally, the capability of small watersheds to provide reliable flows is lower than for larger watersheds.

Methods: Monthly discharge estimates have been generated from a hydrologic model. Existing allocation volumes have been summarized from government water licence and short term approval databases. Potential allocations are determined using criteria established in the Province of BC Environmental Flow Needs (EFN) Policy. Risk management levels have been calculated assuming the presence of fish. If the source can be classified as non-fish bearing, this may affect risk management levels. For more information on the EFN policy: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-policies/environmental-flow-needs

Risk Management Levels: The Province of BC Environmental Flow Needs Policy establishes risk management levels to be used in the evaluation of applications for water rights. Risk Management Levels and associated Risk Management Measures are discussed on page 5 of this report.

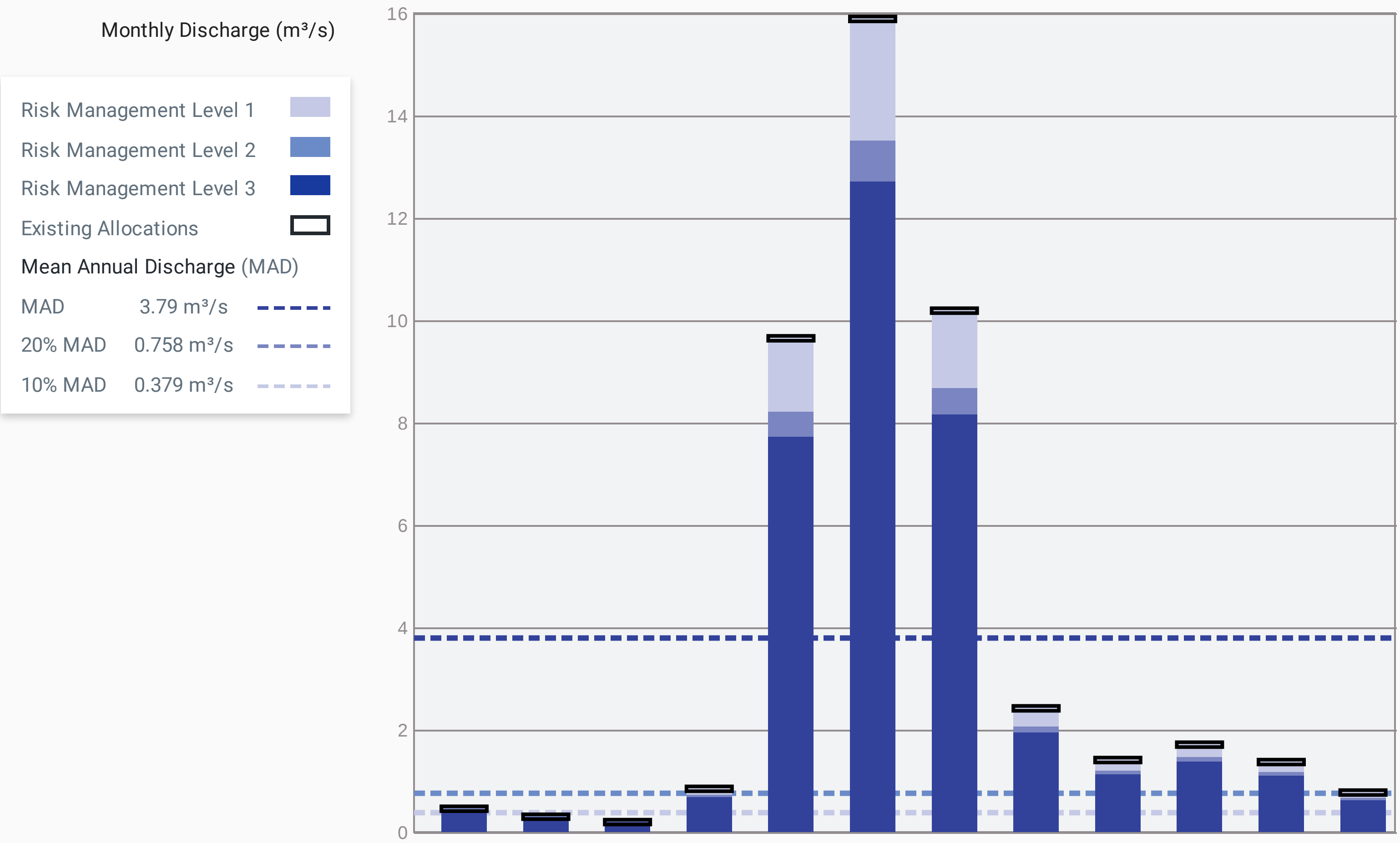
Accuracy: The query watershed is within the Kootenay Boundary Region. The hydrologic modeling study conducted in this region employed a water balance approach to estimate runoff in ungauged basins. The model used 143 watersheds with hydrometric gauges, and included detailed information on watershed climate, evapotranspiration, topography, vegetation and land cover. The model was calibrated using stream flow measurements from the Water Survey of Canada, and validated using a leave-one-out cross validation. Error metrics calculated for the entire model domain are: Mean error = 4.3%, Median Error = 0.3%, Mean Absolute Error = 14.8%, Watersheds within +/- 20% = 79%.

Allocations: Existing allocation volumes are determined from digital databases and include BC Water Sustainability Act licences and short term approvals. These represent a maximum amount of water authorized, not actual use. In many cases, licences may have additional terms and conditions to those represented in the digital version which are not represented. This may result in existing allocation volumes being presented as larger than are actually approved, either in total (on an annual basis) or for individual months. On subsequent pages of this report, information on each licence occurring in the watershed is provided, along with links to scanned copies of complete water licence information. For more information on specific areas of concern, please contact Water Stewardship Staff via FrontCounter BC. Contact information for FrontCounter BC is provided on page 2 of this report.

Hydrology - Monthly

Silverton Creek

The chart and table show information on modeled hydrology and existing allocations in the **downstream watershed**, where the subject drainage meets with another drainage of comparable size. This location is shown with a grey marker and watershed outline in the map on page 2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% of MAD	12.3%	8.2%	5.5%	22.6%	254.7%	420.0%	268.5%	64.0%	37.5%	45.2%	36.3%	20.7%
Flow Sensitivity	Mod	High	High	Low	Low	Low	Low	Low	Low	Low	Low	Low
Existing Allocations (m³/s)	0.059	0.059	0.059	0.059	0.06	0.06	0.06	0.06	0.06	0.059	0.059	0.059
Mean Monthly Discharge (m³/s)	0.468	0.312	0.207	0.857	9.66	15.9	10.2	2.43	1.42	1.72	1.38	0.784
Potential Allocation (m³/s, Risk Mgmt 1)	0	0	0	0.069	1.39	2.33	1.47	0.304	0.154	0.198	0.147	0.058
Potential Allocation (m³/s, Risk Mgmt 2)	0	0	0	0.112	1.872	3.125	1.976	0.426	0.225	0.284	0.216	0.098
Potential Allocation (m³/s, Risk Mgmt 3)	>0	>0	>0	>0.112	>1.872	>3.125	>1.976	>0.426	>0.225	>0.284	>0.216	>0.098

Notes

Methods: Monthly discharge estimates have been generated from a hydrologic model. Existing allocation volumes have been summarized from government water licence and short term approval databases. Potential allocations are determined using criteria established in the Province of BC Environmental Flow Needs (EFN) Policy. Risk management levels have been calculated assuming the presence of fish. If the source can be classified as non-fish bearing, this may affect risk management levels. For more information on the EFN policy: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-policies/environmental-flow-needs

Risk Management Levels: The Province of BC Environmental Flow Needs Policy establishes risk management levels to be used in the evaluation of applications for water rights. Risk Management Levels and associated Risk Management Measures are discussed on page 5 of this report.

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Allocations: Existing allocation volumes are determined from digital databases and include BC Water Sustainability Act licences and short term approvals. These represent a maximum amount of water authorized, not actual use. In many cases, licences may have additional terms and conditions to those represented in the digital version which are not represented. This may result in existing allocation volumes being presented as larger than are actually approved, either in total (on an annual basis) or for individual months. On subsequent pages of this report, information on each licence occurring in the watershed is provided, along with links to scanned copies of complete water licence information. For more information on specific areas of concern, please contact Water Stewardship Staff via FrontCounter BC. Contact information for FrontCounter BC is provided on page 2 of this report.

Risk Management Levels and Measures

Guide to interpreting potential allocation amounts in each environmental flow needs risk level as defined in the Province of BC Environmental Flow Needs Policy.

Water volumes presented as "Potential Allocations" within this report are determined in consideration of the Province of BC Environmental Flow Needs Policy. Within the Policy, risk management measures are suggested to assess or mitigate potential effects of withdrawals from a stream, and provide an ecosystem perspective on environmental flow needs. The measures are associated with risk levels 1, 2, and 3 and are intended to guide where more caution may be needed in reviewing an application or making a decision.

Where there are known species or habitat sensitivities, more detailed, site-specific studies may be required. Where detailed assessments or studies exist, they will supersede policy recommendations.

Risk management levels, for assessing new applications to withdraw water, are determined for each month using the relationship of mean monthly flows to the mean annual discharge, and also using a stream size threshold based on mean annual flows. The calculations presented within this report assume all streams are fish-bearing. Where no water is indicated as available under a risk level, the stream may be very flow sensitive during that time, or the stream may have existing allocations in excess of the relevant threshold.

Inter-annual hydrologic variability may affect the amount of water available in a given year. The impact of this variability on water allocations should be considered separately from the information presented in this report.

The following risk management measures may be appropriate for consideration before a decision is made, could be completed by regional staff to inform a decision, or could be a condition of the licence or approval.

Risk management measures may differ for short-term approvals vs. licences and may vary in relation to withdrawal amounts.

Risk Management Level 1

Measures to assess or mitigate potential effects on low sensitivity flow periods:

1. Assess veracity of information and ensure appropriate methods are used (Resources Information Standards Committee)
2. Consider downstream users and species/habitats

Risk Management Level 2

Measures to assess or mitigate potential effects on moderate sensitivity flow periods:

In addition to Level 1 measures:

1. Establish adequate baseline hydrological data before withdrawals
2. Prepare reconnaissance-level fish and fish habitat impact assessment (e.g., Section 4.1.10.1 in Lewis et al. 2004)
3. Issue seasonal licence, or restrictions during low flow periods
4. Development of off-stream storage
5. Inclusion of a daily maximum or inst. withdrawal e.g., greater consideration of instantaneous demand over averages
6. Limit pump intake size
7. Monitor and report water use during higher risk flow periods (e.g., install flow gauge)
8. Monitor low flows and limit withdrawals when flows drop below a certain level
9. Ministry staff to conduct audit of basin use/beneficial use review
10. Refuse application to withdraw water

Risk Management Level 3

Measures to assess or mitigate potential effects on height sensitivity flow periods:

In addition to Level 2 measures:

1. Issue limited licence term, allowing for review and potential adjustment (e.g., 5 years)
2. Prepare detailed habitat assessment (e.g., Lewis et al. 2004; Hatfield et al. 2007)

References

Hatfield, T., A. Lewis, and S. Babakaiff. 2007. Guidelines for the collection and analysis of fish and fish habitat data for the purpose of assessing impacts from small hydropower projects in British Columbia.

Lewis, A., T. Hatfield, B. Chilibeck, and C. Roberts. 2004. Assessment methods for aquatic habitat and instream flow characteristics in support of applications to dam, divert, or extract water from streams in British Columbia. Prepared for Ministry of Water, Land & Air Protection and Ministry of Sustainable Resource Management.

A. Lewis. 2002. Rationale for Multiple British Columbia Instream Flow Standards to Maintain Ecosystem Function and Biodiversity. Draft for Agency Review. Prepared for Ministry of Water, Land and Air Protection and Ministry of Sustainable Resource Management.

Resources Information Standards Committee: https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resource-standards-and-guidance/inventory-standards

Water Policies, including Environmental Flow Needs: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-policies

Allocations

Existing allocations in the watershed summarized by purpose and source.

Water rights in British Columbia are administered under the *Water Sustainability Act*. The existing water allocations in the watershed are summarized by water source, type, and whether the purpose is consumptive or not. On the following pages, each individual water right is listed with information on the specific water source and quantity, ordered by seniority.

Annual Volume	Consumptive Surface Water (m³)	Non-consumptive Surface Water (m³)	Consumptive Groundwater (m³)	Non-consumptive Groundwater (m³)
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

Agriculture
Commercial
Industrial
Municipal
Oil & Gas
Power
Other

Downstream Water Rights Interests

Current licences, active applications, and short term use approvals on or near the main stem of the waterbody, downstream within the water management basin.

BC Water Sustainability Act - Water Interests - 3 Licences, 407,025 m³ Total Annual Volume

Licensee	Number	POD	Priority Date ↓	Expiry Date	Quantity	Flag
PRIVATE INDIVIDUAL NAME Domestic from Levar Creek	F005836 File # 0242225	PD27972	2/4/1898		4.55 m³/day	M
PRIVATE INDIVIDUAL NAME Domestic from Levar Creek	F005836 File # 0242225	PD27974	2/4/1898		4.55 m³/day	M, N
Klondike Silver Corp (76987) Domestic from Silverton Creek	F005056 File # 0242224	PD27963	7/19/1899		9.09 m³/day	T
PRIVATE INDIVIDUAL NAME Power: Residential from Levar Creek	C108365 File # 4003034	PD27972	7/11/1994		max rate: 0.013 m³/second	T

Water Licence Flag Description
D: Multiple PODs for PUC/qty at each are known/PODs on different sources
M: Max licenced demand for purpose/multiple PODs/qty at each POD unknown
P: Multiple PODs for PUC/qty at each are known/PODs on same source
T: Total demand one POD

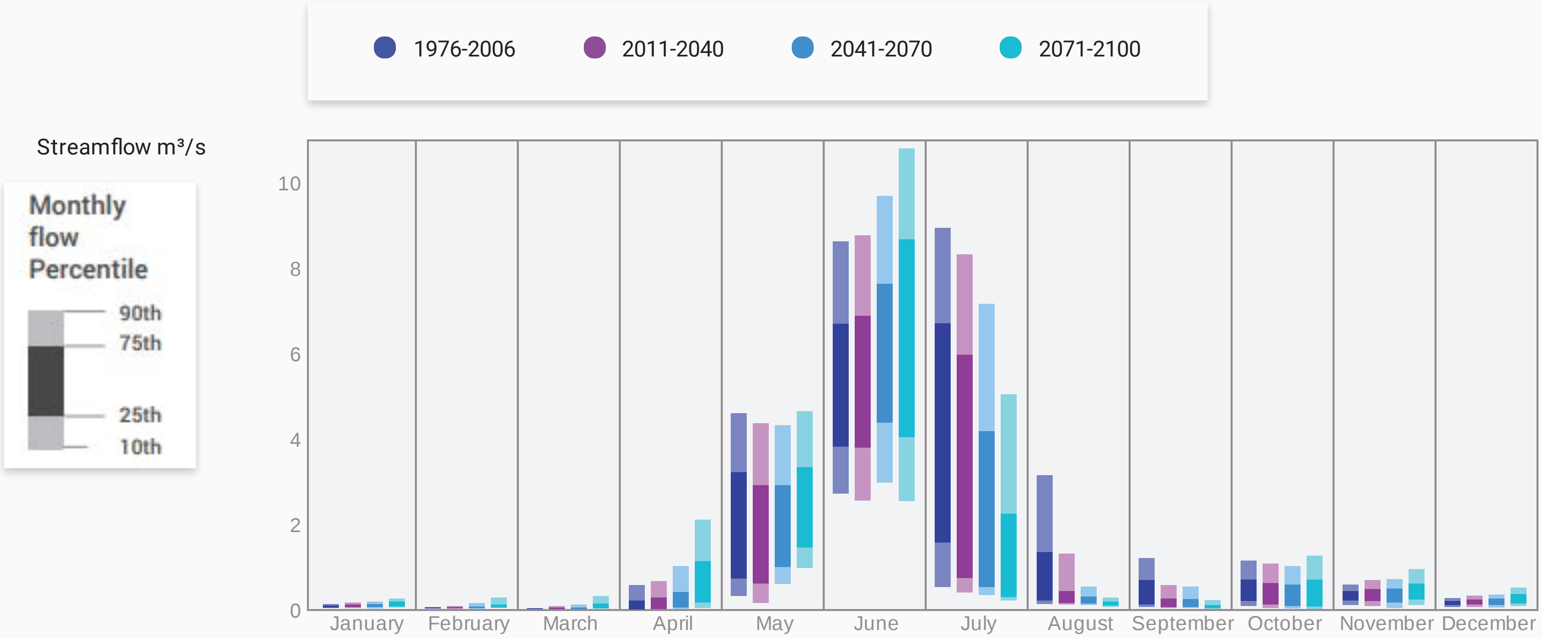
Other
N: Licence volumes not used in calculations
R: Rediversion

For more information on water licences:
Water Licence Query Tool: http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input
Water Rights Databases: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-licences-approvals/water-rights-databases

Current and Future Hydrologic Variability

Modeled hydrologic variability and future characteristics derived from process based hydrology models from Pacific Climate Impacts Consortium (PCIC)[1] and the University of Colorado (UC)[2]

The chart and table below summarize the daily output of Variable Infiltration Capacity (VIC) hydrology models to describe potential past and future hydrologic variability in the watershed. Values should be used as estimations only. If the chart and table below have only 1976-2006 values, the data is from UC. If there are future predictions, the data is from PCIC.



Period	Percentile	January	February	March	April	May	June	July	August	September	October	November	December
1976-2006	90th	0.13	0.07	0.04	0.58	4.6	8.6	8.9	3.2	1.2	1.2	0.59	0.28
	75th	0.11	0.06	0.03	0.22	3.2	6.7	6.7	1.4	0.71	0.71	0.45	0.22
	50th	0.08	0.05	0.03	0.07	1.7	5.1	3.6	0.46	0.32	0.4	0.32	0.16
	25th	0.06	0.04	0.02	0.02	0.74	3.8	1.6	0.22	0.13	0.21	0.22	0.12
	10th	0.05	0.03	0.02	0.02	0.33	2.7	0.54	0.14	0.08	0.1	0.12	0.08
2011-2040	90th	0.17	0.09	0.09	0.67	4.4	8.8	8.3	1.3	0.58	1.1	0.7	0.34
	75th	0.13	0.07	0.06	0.29	2.9	6.9	6	0.45	0.28	0.64	0.49	0.25
	50th	0.11	0.06	0.04	0.14	1.8	5.7	3.4	0.34	0.19	0.4	0.38	0.2
	25th	0.07	0.05	0.03	0.03	0.62	3.8	0.75	0.17	0.08	0.13	0.21	0.13
	10th	0.05	0.03	0.02	0.02	0.17	2.6	0.42	0.13	0.05	0.05	0.1	0.08
2041-2070	90th	0.2	0.16	0.13	1	4.3	9.7	7.2	0.54	0.54	1	0.73	0.37
	75th	0.15	0.09	0.06	0.42	2.9	7.6	4.2	0.32	0.25	0.6	0.51	0.28
	50th	0.12	0.08	0.07	0.29	2.5	6.1	2.7	0.26	0.14	0.39	0.41	0.23
	25th	0.07	0.04	0.03	0.06	1	4.4	0.54	0.16	0.07	0.1	0.18	0.12
	10th	0.04	0.03	0.02	0.03	0.61	3	0.35	0.12	0.05	0.04	0.05	0.06
2071-2100	90th	0.27	0.29	0.33	2.1	4.7	11	5.1	0.29	0.23	1.3	0.95	0.52
	75th	0.2	0.13	0.15	1.1	3.4	8.7	2.3	0.2	0.12	0.71	0.62	0.37
	50th	0.18	0.14	0.18	0.68	3.2	7.1	1.3	0.19	0.11	0.44	0.55	0.33
	25th	0.09	0.06	0.04	0.18	1.5	4.1	0.3	0.1	0.05	0.08	0.25	0.15
	10th	0.06	0.05	0.03	0.05	0.99	2.6	0.22	0.08	0.03	0.03	0.12	0.1

For the historical period, the hydrologic models are driven by gridded datasets generated from historical weather station data. The years 1976-2006 were selected as the most recent 30 year period with historical data available. Calculated percentiles for this historical time period are based on the sample of daily predictions for each month over this time period. These percentiles have been scaled using the hydrology estimates on page 3, but have not been adjusted for regulation and thus represent unimpeded flow conditions. For future time periods, the hydrologic models are driven by gridded Global Circulation Models (GCMs) - CGCM3 A2 Run 1, GFDL 2.1 A2 Run 1, HadCM A2 Run 1. Calculated percentiles for the future time periods show the highest 90th and 75th percentiles from the three GCMs. The 50th percentile is the average of the 50th percentile from the three GCMs. The 25th and 10th percentiles are the lowest 25th and 10th percentiles from the three GCMs. Change between historical and future time periods were calculated using the GCM outputs and scaled using the hydrology estimates on page 3, but have not been adjusted for regulation.

Please note that future estimates of hydrologic variability are only available in the area covered by PCIC's hydrology modeling, the University of Colorado project did not forecast future hydrologic conditions.

References

1: Pacific Climate Impacts Consortium, University of Victoria, (Jan. 2014). Gridded Hydrologic Model Output. Downloaded from https://data.pacificclimate.org/portal/hydro_model_out/map/ on 2018-01-15.

2: Livneh, Ben; Bohn, Theodore J.; Pierce, David W.; Muñoz-Arriola, Francisco; Nijssen, Bart; Vose, Russell; Cayan, Daniel R.; Brekke, Levi (2015). A spatially comprehensive, hydrologic model-based data set for Mexico, the U.S., and southern Canada, 1950-2013. NOAA National Centers for Environmental Information. Dataset. doi:10.7289/V5QZ27ZG [2018-02-02]

Land Cover and Topography

Characteristics of the query watershed. For more information on watershed characterization in British Columbia please refer to Pike and Wilford (2013).

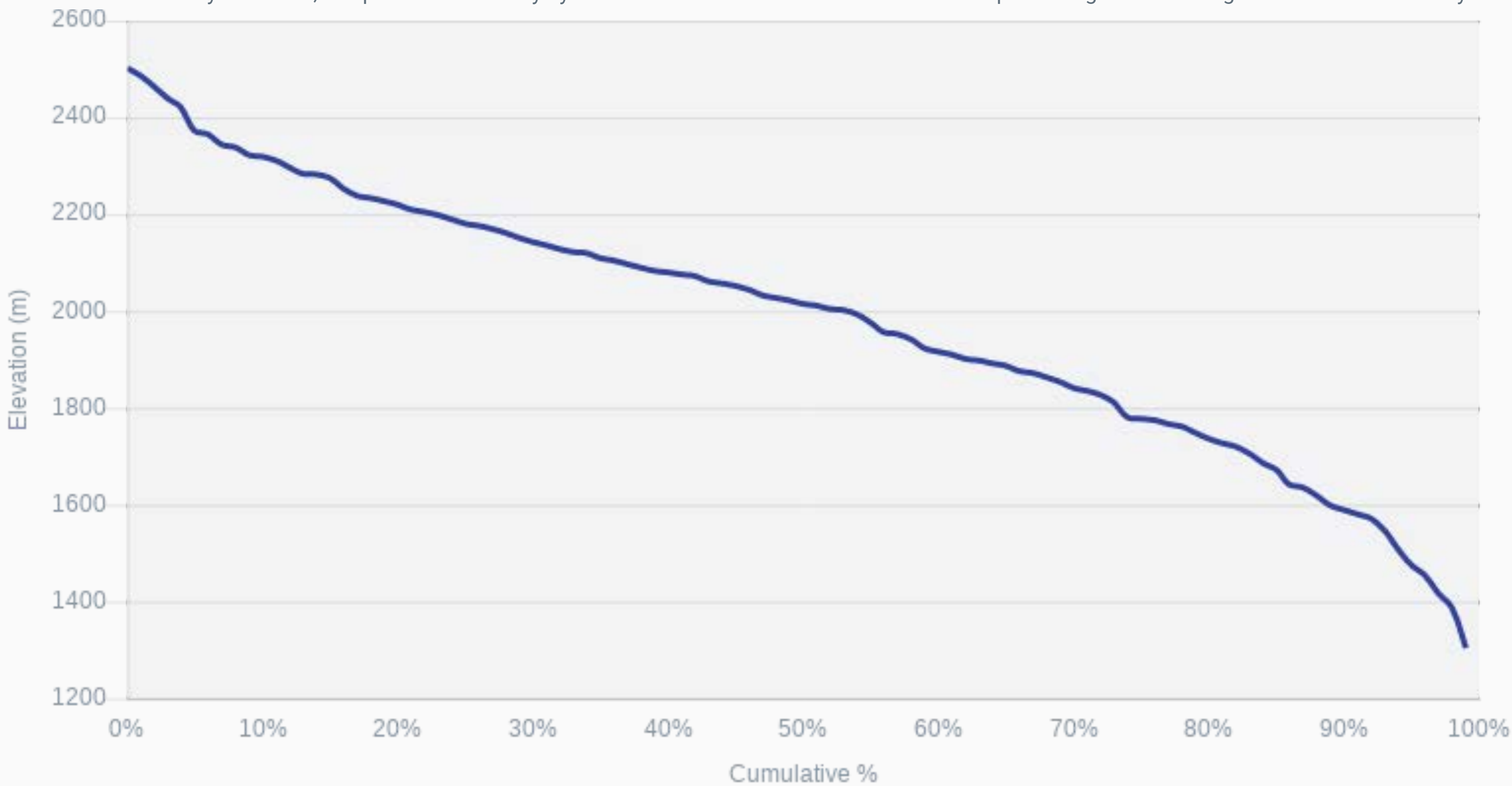
Land Cover

The land cover characteristics chart illustrates the composition of vegetation and land cover types in the query watershed. These land cover components are incorporated in the hydrologic model, to represent the variations in evapotranspiration rates amongst the classes.

Class	Percent	Area
Barren	4.2%	1.42 km²
Coniferous	81.8%	27.7 km²
Deciduous	0.0%	0 km²
Developed	0.0%	0 km²
Grassland	0.0%	0 km²
Herb	0.0%	0 km²
Mixed	0.0%	0 km²
Shrub	14.0%	4.72 km²
Snow	0.0%	0 km²
Water	0.0%	0 km²
Wetland	0.0%	0 km²

Topography

Elevation of the query watershed influences hydrology in a number of ways. The amount, and state of precipitation (as rain or snow) is influenced by elevation substantially. Likewise, temperatures will vary by elevation in value and also direction of temperature gradient throughout the course of the year.



Reference:
Pike, R.G. and D.J. Wilford. 2013. Desktop watershed characterization methods for British Columbia. Prov. B.C., Victoria, B.C. Tech. Rep. 079. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr079.htm.

Climate

Historic normal conditions and predicted future change.

The climate of the query watershed has been characterized using ClimateWNA (Wang 2012). Charts are presented below displaying the reference time period **1981-2010** as well as three illustrative future climate change scenarios for the period 2041-2070 that have been selected to estimate a wide range of potential future change in the query watershed (Cannon, 2015).

Scenario A illustrates the **ACCESS1-0-r1** global climate model (GCM), Scenario B shows the **CanESM2-r1 GCM** and Scenario C shows the **CNRM-CM5-r1 GCM**. All climate change scenarios presented are from representative concentration pathway (RCP) 8.5. These three climate models and concentration pathway were chosen to illustrate the widest spread in projected future climate for smaller subsets of the full CMIP5 ensemble, over most of Western North America.

Historic and future climate change information has been provided to assist in understanding potential changes in the basin as temperature and precipitation are intricately related to stream flow. For example, snowpack levels affect many aspects of water resources, from instream flows for fish to community water supplies to soil moisture, groundwater, and aquifer recharge. Climate studies generally indicate a trend of rising air temperatures for all seasons across BC while precipitation trends vary by season and region (Pike *et al*. 2008, Rodenhuis *et al*. 2007). Local responses to changing precipitation and temperature will differ due to BC's inherent hydrological diversity as well as varying climate trends. These charts are intended as a quick glance starting point to basin climate change assessment.

1981-2010:

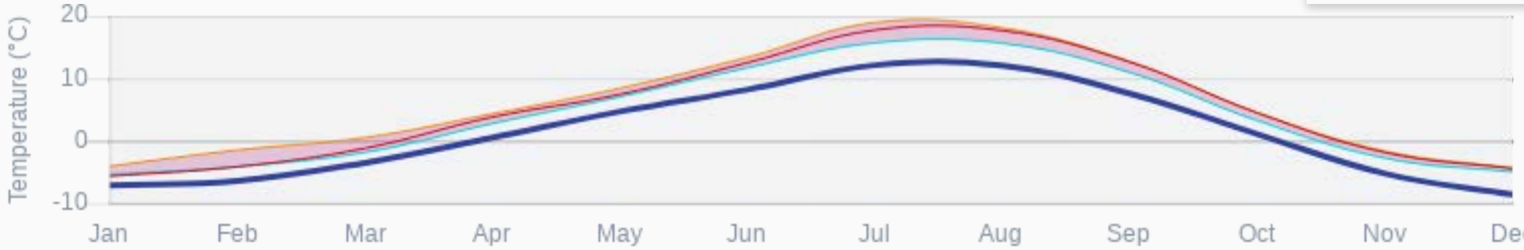
2040-2071

Scenario A:

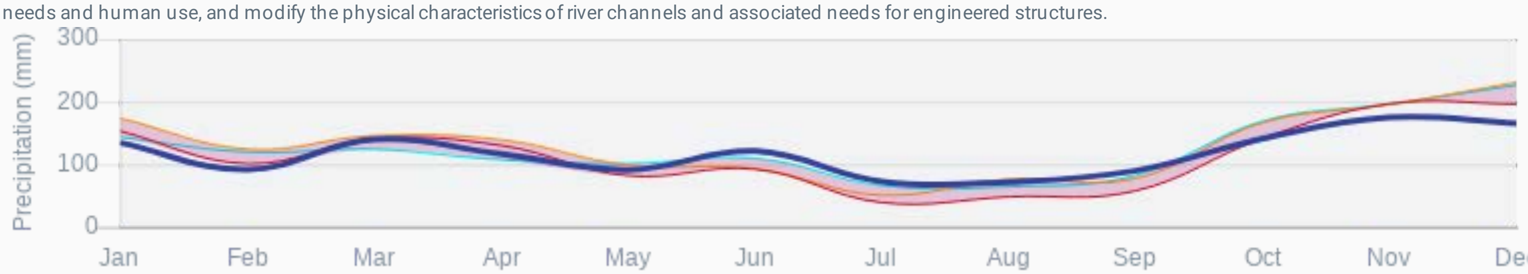
Scenario B:

Scenario C:

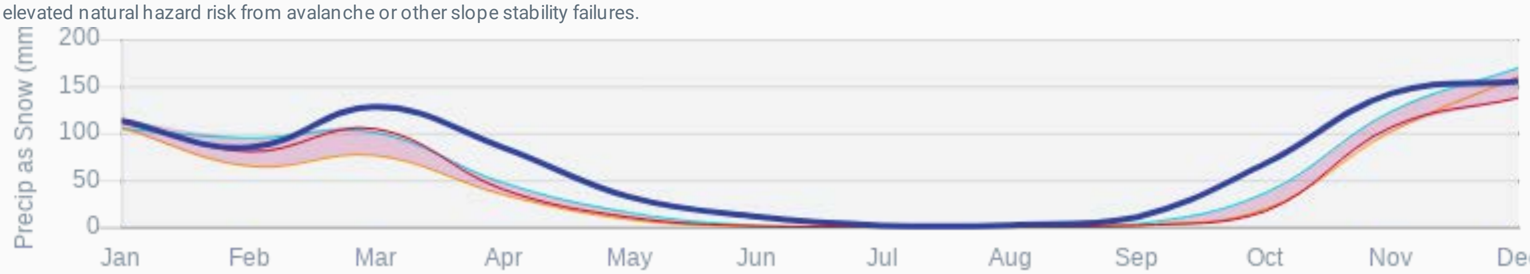
Temperature Monthly temperatures are presented as averages of the monthly mean temperature for the query basin as a whole. Projected changes in temperature may affect the hydrology in the watershed by influencing the time of freeze and thaw, evapotranspiration rates, form of precipitation, and vegetation composition, among other factors.



Precipitation The precipitation in the query watershed is shown as an average unit precipitation for the watershed. Changes in precipitation timing and amount may affect the hydrology in the watershed by influencing the timing and magnitude of peak and low flow conditions. These changes may affect availability of water for environmental flow needs and human use, and modify the physical characteristics of river channels and associated needs for engineered structures.



Precipitation as snow Precipitation as snow in the query watershed is presented as an average unit precipitation for the query basin as a whole. Changes in the amount of precipitation as snow may affect winter snowpack volumes and associated melt related hydrology in the spring. An increase in rain-on-snow events may be associated with elevated natural hazard risk from avalanche or other slope stability failures.



References

Cannon, A.J., 2015. Selecting GCM Scenarios that Span the Range of Changes in a Multimodel Ensemble: Application to CMIP5 Climate Extremes Indices. Journal of Climate, 28(3): 1260-1267. doi:10.1175/jcli-d-14-00636.1

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock, and A.T. Werner. 2008. Climate Change and Watershed Hydrology: Part I - Recent and Projected Changes in British Columbia. Streamline, Watershed Management Bulletin 1(2) 8-13. https://www.pacificclimate.org/sites/default/files/publications/Pike.StreamlineHydrologyPartI.Apr2008.pdf

Rodenhuis, D., K.E. Bennett, A.T.werner, T.Q. Murdock, and D. Bronaugh. 2007. Hydro-Climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium. https://www.pacificclimate.org/sites/default/files/publications/Rodenhuis.ClimateOverview.Mar2009.pdf

Wang, T., Hamann, A., Spittlehouse, D., and Murdock, T.Q. 2012. ClimateWNA – High-resolution spatial climate data for western North America. Journal of Applied Meteorology and Climatology 61: 16-29.