SARRANA CREEK RESTORATION

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ER 390 Final Project

Abstract

Sarrana Creek is in the Dunster Community Forest about 240 kilometres southwest of Prince George British Columbia. The forest surrounding the creek has been impacted by Mountain Pine Beetle mortality and recently the community forest decided to clear-cut portions of the dead pine. The initial site assessment showed that the creek channel was no longer flowing and instead five braided streams flowed. One side of the creek the area was supersaturated with water making timber harvest and tree regeneration impossible. The forest manager assumed that the hydrological regime shift was due to dead pine blowdown. To understand the hydrological characteristics of the site a biophysical inventory, soil pits, slope assessment, and geological assessment was performed. The results showed that pine was not the root cause of the hydrological regime shift was a previous rockslide on the site had created a complex network of drainage systems. In addition, it appears that the site is in a phreatic zone where surface water and groundwater meet. In response to the findings of the study, the community forest decided to leave the area alone and not actively pursue and restoration of the site. The manager did install two new culverts at the site to mitigate future erosion and damage from the complex drainage area. Finally, a policy of retaining larger buffers around riparian areas was implemented because of the findings of the study.

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Introduction

“We demand rigidly defined areas of doubt and uncertainty!” (Adams, 1979, 115)

This quote seeped in irony and satire encapsulates the challenges that British Columbia’s forests face for the future. Uncertainty abounds with cumulative factors such as climate change, increased wildfire intensity, diseases, pests, urban encroachment, biodiversity loss, and harvesting practices. All these factors combine to create a cauldron of bubbling uncertainty for forest management professionals. Unfortunately, in the face of uncertainty, the industry demands absolutes and understanding of complicated interlaced ecological systems and processes.

The mountain pine beetle (MPB; *Dendroctonus ponderosa)* will have lasting impacts on the landscape of western North America (see figure 1) (Teste, Lieffers and Landhäusser 2011). The current outbreak has led to extensive tree mortality in British Columbia and the western United States (Bone, et al. 2013). This tree mortality has altered hydrology and regeneration in the infected dead pine stands (Schnorbus 2011). The loss of canopy has shifted the moisture regimes of the soil. The root cause of this devastation is climate change. This is primarily caused by winter temperatures not exceeding a threshold to kill beetle larvae (Kurz, et al. 2008). Coupled with fire suppression and forestry practices that preserved a mature pine population, the MPB in 2006 went from an endemic outbreak to an epidemic. (Rex, Dubé and Foord 2013). Instead of the MPB working in conjunction with the pine trees removing the mature trees the epidemic population wiped out entire stands independent of age (Rex, Dubé and Foord 2013). The effects and ramifications of this epidemic continue to create challenges for forestry and watershed management.

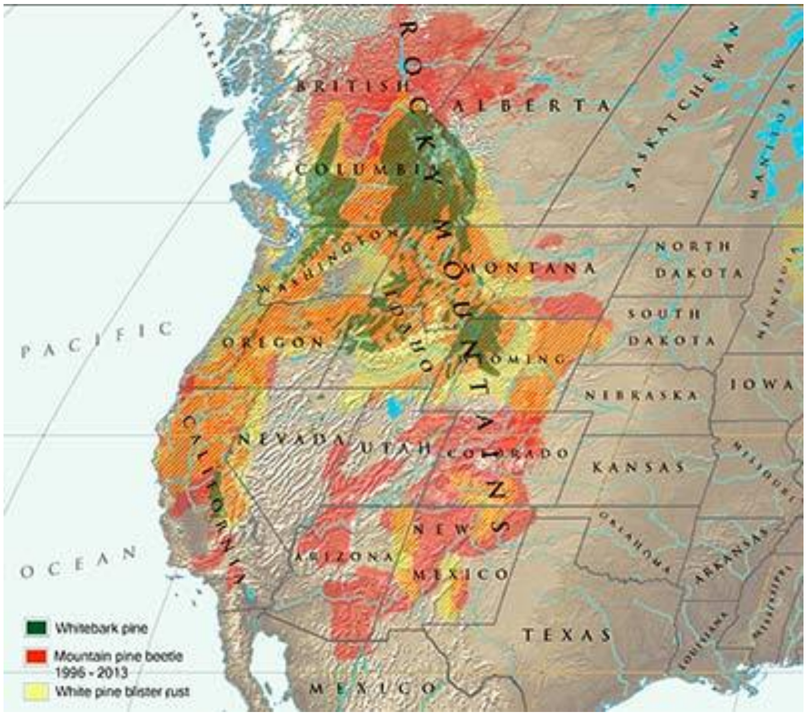

Figure 1 Map of MPB Outbreak in North America - Red Areas Indicate MPB Infestations (American forests.org)

The impact of the MPB on hydrology and regeneration are widespread and site-specific. Many factors contribute to these forest altercations. In the past, the MPB would only infect mature pine trees. Now with larger populations, the beetles infest all ages of pine (Schnorbus 2011). This causes large portions of the stand to be dead as opposed to the beetles only targeting the older trees, not leaving younger trees to contain to grow and benefit from natural thinning (Klutsch, et al. 2009). In addition, the practice of fire suppression makes it unlikely that these dead stands will benefit from a fire disturbance event (Taylor and Carroll 2003). Increased delivery of precipitation to the ground from the loss of canopy cover has caused an effect called “watering up”; where the ground is saturated with moisture that then deters natural regeneration (Rex, Dubé and Foord 2013) Pollen grain viability rates decline with each year after the pines are dead also contributing to poor regeneration (Teste, Lieffers and Landhäusser 2011). In addition, the populations of mycorrhizal fungi decline as well after an MPB attack, fungi are integral in nutrient uptake for trees (Treu, et al. 2014). Some studies have shown that seed banks have a low regeneration rate if not affected by a disturbance within the first three years of the outbreak (Teste et al., 2011). All these factors have contributed to low natural regeneration in dead MPB infected stands.

Figure 2 Photo of MPB infecting a Pine Tree (David Suzuki Foundation.org)

In response to the MPB epidemic, the B.C. government allowed the total annual allowable timber allowance to be raised, then adopted a strategy of clear-cutting to mimic natural disturbances in conjunction with a large-scale tree planting prescription (Rex, Dubé and Foord 2013). This policy brought about the largest log salvaging operation ever, eventually glutting the market and causing the price of pine to plummet (Abbott, Stennes and Cornelis van Kooten 2009). In many stands that were inaccessible because of the slope, economic feasibility or remoteness; dead stands have been left un-salvaged. These stands, experts say, may take up to thirty years before the hydrological regimes return to pre-epidemic conditions (Mikkelson, et al. 2013). Thus, for those communities that rely on timber as a source of income; these stands will not be economically viable for generations.

The Dunster Community Forest (DCF) which is located about 240 km southeast of Prince George B.C. (refer to figure #4). The DCF has been dealing with MPB-infected un-salvaged stands since its inception in 2006. The first approach was to take a holistic ecosystem approach to the problem where the natural successional processes were left alone (Theissen 2016). Quickly, the problems of the hydrological changes and the lack of natural regeneration of the lost pine were evident. It was then decided that this passive approach was not going to be conducive to the expectations of the tenure license (Theissen 2016). In 2015, a 20-hectare plot of dead pine was harvested using a clear-cut treatment and replanted immediately (Theissen 2016). This approach angered some residents and the government, because of the lack of visual absorption from the highway. In response to these concerns in 2016, the DCF began harvesting pine in smaller patch sizes and retaining dead pine stands as a visual absorption technique (Theissen 2016). One of the goals of the DCF is to maintain a sustainable forest economy for future generations (Theissen 2016).

Figure 3 Photo of Dead Pine in the DCF

Literature Review

Community forests

Community forests in British Columbia are operated in accordance with the tenure and its general applicability and are collectively referred to as the Community Forestry Initiative (CFI). As such, community forests are still subject to provincial regulations and the Province determines how many stems per hectare can be harvested, and the Community Forest Association (CFA) pays timber fees on harvested timber. The CFA is responsible for completing management plans, maintaining an inventory, reforestation, management of the water resources, recreation, and wildlife (Duinker, Matakala, Chege, & Bouthillier, 1994). The CFI framework allows community participants to be incorporated into forestry management based on common goals and principles. Some of these principles include that residents have access to the community forest, there is an opportunity for local participation in forestry-based decision making, and a mandate to protect and maintain a sustainable forest (Brendler & Carey, 1998). CFA's often have diverse stakeholders and participants coupled with varying topography this makes each entity unique.

Clear Cuts and Wildlife Implications

The word clearcutting has a largely negative connotation for the general public these days and has created a polemic divide on the subject. With one side believing that clearcutting is the symbol of what is wrong with the current forestry practices. And on the other hand, it is strongly defended by members of the forestry profession as an economically efficient and environmentally sound way of harvesting trees (Keenan & Kimmins, 1993). The definition of clear cut usually denotes the complete removal of under and overstory of the forest with the plan to replant, reseed, and regenerate the cleared area. For this paper, the definition will be associated with the degree of removal of the vegetation from the" forest of Influence". The Forest of Influence refers to the remaining forest surrounding a cut block and how it still impacts the cleared area. The adjacent remaining forests create edges and are conduits of nutrients, hydrology, determinants of available light, and wildlife habitats. Only when the cleared area reaches a size that most of its area is beyond the forest influence is it called a clear cut (Kimmins, 2011). This definition means that the minimum size that constitutes a clear cut varies with the height of the surrounding forest and is equal to an area greater than about four tree heights in diameter (Keenan & Kimmins, 1993).

Clearcutting and road building have altered the structure and function of the forest by cutting the mature forest cover, increasing edge effect, and isolating remaining forest stands (R.F. & Csuti, 1994). Noss and Csuti (1994) suggest that patches initiated by natural disturbances are dissimilar from anthropogenic patches. This is because natural disturbances create patches without abrupt contrast and thus less edge effect between adjacent patches (Tinker, et al., 1998). The shape and size of the clear-cut patch impact biotic and abiotic components, through fragmentation and elimination of habitat for species that require late-successional forests (Lyon & Jensen, 1980). Many species find edges between the forest and the clear-cut optimum habitat, feeding in the clear-cut and then taking shelter in the trees. Larger vertebrates will move into the forest when heavy snow in the clear-cut impedes their movement and submerges their browse (Bunnell & Wind, 1999). The response of animal species to a disturbance like clear-cutting differs based upon their life history characteristics, habitat requirements, and interrelationships with forest species composition and structure (Bunnell & Wind, 1999).

Figure 4 Clear-cut with a feathered edge and seed retention trees

Patch size and shape

The size and shape of the clear-cut is the most important factor when considering the impact on the ecosystem processes and conditions. Hydrologic regime shifts in streamflow and water quality are determined by the size and shape of the clear-cut. The size and shape also govern the source of seed for re-establishment of understory species and local tree genotypes. In addition, large clear-cuts minimise the benefits of edge effects from the surrounding forest and limit the potential inoculum for many fungi and soil organisms (Keenan & Kimmins, 1993). In response to these ecological concerns forestry practices in British Columbia have adopted new techniques in clear-cut design and management. Some of these practices include retaining riparian zones, maintaining strips for wildlife conduits, feathered edges to mitigate blowdown, seed tree retention in groups, keeping patch size below 20ha, and creating shapes that mimic natural disturbance as opposed to squares or circles (Berkes & Colding, 2000). In addition, retaining snags and some live trees, and coarse woody debris can also ameliorate impacts on wildlife habitat (Keenan & Kimmins, 1993). Ultimately, when analyzing patch size dynamics, the umwelt of the species will determine the positive and negative factors of the clear-cut size and shape.

Large and Coarse woody debris in streams

The Mountain pine beetle is an integral fulcrum component in shaping lodgepole pine forest's composition, structure, and heterogeneity. Beetle-killed trees become an important habitat for invertebrates, insects, avian species, and small mammals (Bull, Parks, & Torgersen, 1997). Quantifying the downed woody debris associated with MPB events is difficult because of the variety of stand densities, wind patterns, slopes, aspects, and soil moisture regimes (Klutsch J. G., et al., 2009). These cumulative factors will influence the fall rate of mountain pine beetle-killed trees. It follows that downed woody debris accumulations would vary dependent upon site-specific conditions.

Large woody debris from fallen trees transferred to streams is an important source of nutrients for aquatic organisms. Fish habitat benefits from the woody debris creating pools, sinuosity, structure, and shade cover (Triska, 1984). The physical characteristics of the stream channel influence the movement of large woody debris. High streamflow may displace woody debris that are shorter than the width of the stream. Conversely, streamflow may deposit the debris in existing accumulations that are stabilized by stabilized woody debris (Lienkaemper & Swanson, 1987). The challenge for forest managers is how to balance the volume of wood in a stream for ecological benefits and not too much wood to impede proper functioning flow (Gippel, 1995).

The small stream initiative

The small stream initiative in the province of British Columbia is concerned about the amount of LWD and CWD entering small streams and the riparian buffers surrounding the streams. Small streams are critical to downstream reaches in terms of water, temperature control, pH balance, inorganic nutrients, plant material, and invertebrates. What happens on small headwater streams has a strong effect on the overall (cumulative effect) watershed condition (Nordin, 2017). The initiative defines the proper functioning of a stream based on criteria such as peak flow functioning, runoff filtration capability, ability to safely store and release water, maintain LWD supply, and provide shade to maintain stream temperature (Rex, Krauskopf, Maloney, & Tschaplinski, 2009). Due to the range of proper functioning assessment, each stream is monitored and assessed on a site-specific basis (Nordin, 2017). The initiative understands the fine line between natural woody debris and excess deposition of unstable wood that provide enough resistance to divert flow patterns. The initiative states that most excess woody debris in streams is from slash and logging practices where the riparian buffers are not large enough. Although there is no clear guideline on S6 streams the initiative recommends that riparian buffer should be as large as the size of the potential windthrow surrounding the small stream (Nordin, 2017).

Microrelief topography and hydrology

Surface microrelief topography in forests is an important component of slope hydrology. The soil surface in forests is formed by natural and human processes that create microtopographic irregularities (Frei & Fleckenstein, 2014). In forests, the soil surface is unevenly paired with pits and mounds formed by tree uprooting events. Uprooted trees often leave a root ball with embedded soil material creating the pit and mound irregularities (Valtera & Schaetzl, 2017). The size and dimensions of the pit and mound features are dependent on the dimensions of the uprooted tree and root. Trees that reach the soil through blow down events also contribute to micro topological soil dynamics (Valtera & Schaetzl, 2017). The hydrology of an area can be vastly altered by the pit and mounds created from fallen trees. The pits and windthrow can promote concentrated runoff or the opposite and stall runoff leaving pools and standing water (Valtera & Schaetzl, 2017). Continued accumulation of biomass decay and root balls have cumulative effects on the specific site's hydrological regime.

Geology of the study area

The study area is within the rocky mountain trench, this trench lies between the Rocky Mountains on the east and the Cariboo or Cassiar ranges to the west. This complex geology originates from when the Intermontane Superterrane continental plate shifted westwards and began colliding with island terranes 181 million years ago. These collisions with the North America plate squeezed and folded the Superterrane into the Columbia, Omineca, and Cassiar Mountain ranges (Cannings & Cannings, 1996). The Rocky Mountain trench lies about 100-150 kilometres west of the continental divide and this narrow sinuous belt of correlative rocks is referred to as the Upper Proterozoic. The Upper Proterozoic is about 9 kilometres thick and stretches for 4000 kilometres from Alaska to Mexico. The area in western Canada is known as the Upper Proterozoic Windermere Supergroup. The Windermere supergroup has been eroded from several glaciation events leaving undifferentiated; feldspathic sandstone and granule conglomerate, argillite, phyllite, schist, minor conglomerate, limestone and marble deposits (Mossop & Shetsen, 1994).

Mountain pine beetle and risk of fire

Pine bark beetles and fire are the most dominant disturbance force in western North America in the last thirty years. One study attempts to understand if each disturbance influences each other. Analyzing thirty years of data from the states of Washington and Oregon of fire and beetle affected sites (Nelson, Ciochina, & Bone, 2016). In a GIS framework, the two disturbances were overlaid to determine if there was a relationship between the beetle and then fire or fire and then a beetle outbreak. The results showed that the forests were more susceptible to beetle outbreaks after a fire event, but not conclusive with beetle infested forests being susceptible fire. One problem is comparing a first order disturbance to a second order disturbance and making assumptions of their interaction (Nelson, Ciochina, & Bone, 2016). This study illustrates the challenges of quantifying the landscape due to the large variability on the landscape scale.

Climate change and vegetation regime shifts in British Columbia

Climate change models such as the Coupled Global Model Version 1 and the Canadian Centre for Climate Modelling and Analysis demonstrate there will be a profound impact on British Columbia. One study examined past warm climates and present-day dominant tree species (Hebda, 1997). Expected outcomes of climate change include upslope and ecosystem migration of trees, a disappearance of forested areas in regions already dominated by dry climates. Northward migration of trees and a northward replacement of bioclimatic zones by modern novel ecosystems, and increased fire frequency. On the coast the Douglas Fir will expand in the Coastal Western Cedar zone, the Sitka Spruce a will play larger role as the Hemlock moves upslope. The Interior Steppe and Pine Savannahs will move upslope and northward displacing the Interior Douglas Fir Bioclimatic zone. The Subalpine Fir and Engelmann Spruce zones may merge and experience a higher fire frequency. The Central Interior may expect to expand the Steppe and Douglas Fir at the cost of Lodge Pole Pine. Further north White Spruce and Lodgepole Pine will be the predominant species whereas Black Spruce will be less abundant. In general, there will be increased fire frequency and vegetation regime shifts (Hebda, 1997).

Study Area

The Dunster Community Forest (DCF) is located approximately 240 kilometers south-east of Prince George, British Columbia. The DCF is in three bioclimatic zones the Interior Cedar Hemlock ICH (mm), Sub-Boreal Spruce (SBSdh), and Englemann-Spruce Sub-alpine fir (ESSfmm01).

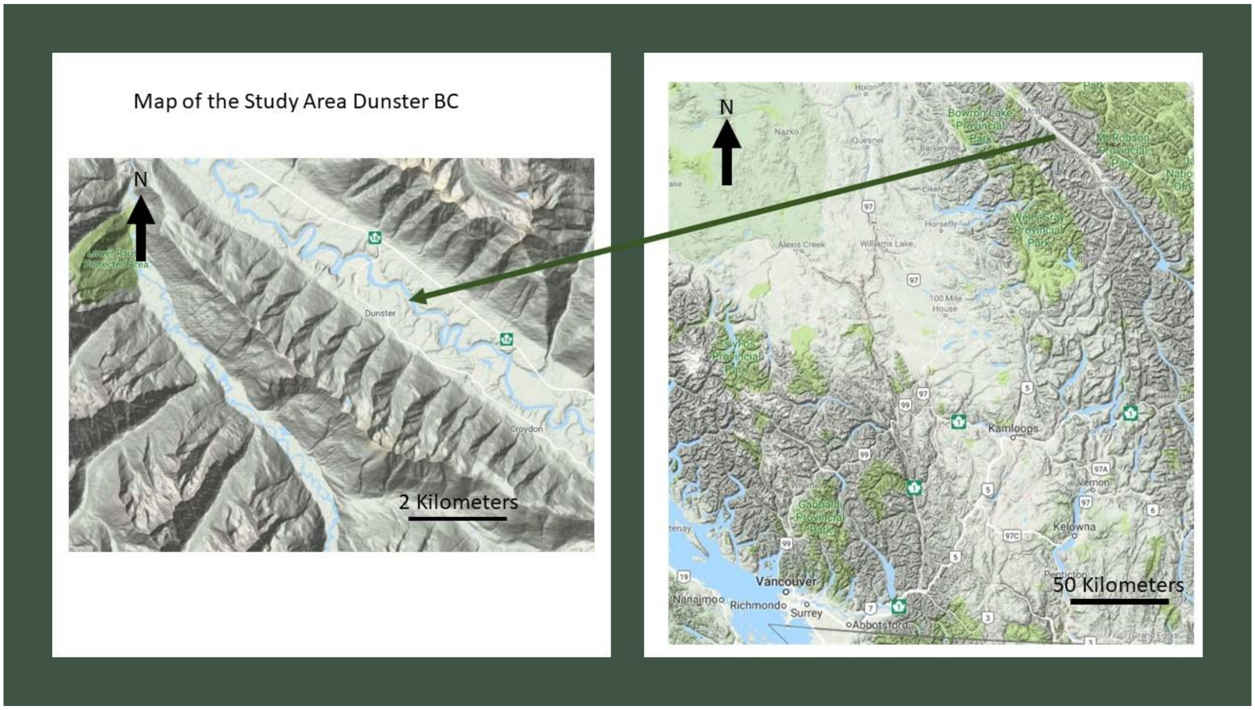

Figure 5 Study area in relation to the province of BC (google maps)

The Sarranna Creek study site is located 7 km southwest of Dunster, British Columbia (53°09’45.95N, 119°57’05.82W)(refer to figure 4). The site is located in-between 815-890 meters above sea level and in the Interior Cedar-Hemlock ICH (mm) bioclimatic zone (Meidinger, et al, 1988). This zone is in two separate parts of the province: the southeast and the northwest. The southeastern portion is situated on the lower slopes of the Rocky and Columbia mountain ranges. These forests are the most productive and have the highest diversity of tree species in the province. Abundant rain and heavy winter snows typify the ICH climatic zone. Warm summers and cool wet winters are caused by the primarily eastern weather flow. The slow melting snowpack keeps the soil moisture levels relatively high throughout the summer months (Meidinger & Pojar, 1999).

Table 1 Summary Climate Data for ICH (mm) (Meidinger, et al., 1988)

Seasonal Precipitation May- September (mm)		Annual Precipitation (mm)		Seasonal Mean temperature May- September (mm)		Annual Mean Temperature (°C)	
Mean	Range	Mean	Range	Mean	Range	Mean	Range
283	233-328	712	570-887	12.1	11.0-12.3	4.1	+2.1- +4.4

Table 2 Summary Soil and Site Data for ICH (mm) (Meidinger, et al., 1988)

Moisture Regime	Submesic- mesic
Nutrient Regime	Poor –Medium
Parent Material	(Glacio) Fluvial, Morainal
Soil Texture	Medium – Coarse

Vegetation

The forest’s of the ICH mm are dominated by the Western red Cedar *Thuja plicata*, Western Hemlock *Tsuga heterophylla*, Douglas Fir *Pseudotsuga menziessi*, White Spruce *Picea glauca*, and Black Spruce *Picea mariana.* Fire has had a major influence on vegetation development in the ICH. Seral (nonclimax) stands of Lodgepole Pine *Pinus contorta*, Trembling Aspen *Populus tremuloides*, Paper Birch *Betula papyrifera*, Subalpine fir *Albies lasiocarpa*, Red alder *Alnus rubra,* and Black Cottonwood *Populus balsamifera* often dominate at lower elevations. Even older stands, approaching climax, usually contain remnant individuals of shade-intolerant species that established after a fire (Meidinger & Pojar, 1999), (Banner, MacKenzie, Thomson, Pojar, & Trowbridge, 1993).

The shrub layer is dominated by False Azalea *Menziesia ferruginea* and White-Flowered Rhododendron *Rhododendron albiflorum*. Black Huckleberry *Vaccinium membranaceum*, Black Gooseberry *Ribes lacustre*, Highbush Cranberry *Viburnum edule*, Red Osier Dogwood *Cornus stolonifera*, Oval-leaved Blueberry *Vaccinium ovalifollium* are present in the understory and Devil’s Club *Oplopanax horridus* is found in the wetter areas (Meidinger et al., 1999).

The herb layer consists of Five-leaved bramble *Rubus pedatus,* One-leaved foamflower *Tiarella unifoliata,* One-sided wintergreen *Orthilia secunda, Bunchberry Cornus canadensis,* Sitka valerian *Valeriana sitchensis,* Prince's pine *Chimaphila umbellate,* Clasping twistedstalk *Streptopus amplexifolius, Oak fern Gymnocarpium dryopteris,* Spiny wood fern *Dryopteris assimillis,* and Lady fern *Arthyrium fillix-femina* (Meidinger et al., 1999).

The moss layer consists of Stiff club-moss *Lycopodium annotinum,*Red-stemmed feather moss *Pleurozium schreberi,* Knight's plume *Ptilium crista-castrensis,* Common leafy liverwort *Barbilophozia lycopodiodes,* Step moss *Hylocomium splendens,* Pipecleaner Moss *Rhytidiopsis robusta,* Short-Beaked Moss *Mnium thomsonii,* and Electrified Cat's Tail Moss *Rhytidiadelphus triquetrus* (Meidinger et al., 1999).

Site History

Figure 6 Shuswap people on the north side of the Fraser river at Tete jaune about 1910 (F.A. Talbot/Cassell & Co. Ltd. 1911)

The first European account of the Tete Jaune Cache area is conveyed in Dr. W.B. Cheadle's *Across Canada by land 1863,* where Cheadle remarks on a Shuswap village made of bark covered tents (refer to figure #5). He also remarked that the village site was plentiful in Salmon and berries making it a perfect summer village for winter preserving (Wheeler, 2008). Numerous early explorers, traders and ethnographic accounts clearly name the resident First Nations in this territory as 'Shuswap' (Secwepemc), confirming that the Simpcw, one of 17 Secwepemc bands, have rights to call this territory their homeland.

Several earlier attempts had been made to force northern Simpcw people out of the Fraser/Robson Trench region, which had been home to them for thousands of years. In August 1916 the government was successful in forcing their relocation (Simpcw, 2018). The Robson Valley is the ancestral and traditional hunting and gathering grounds of the Simpcw people.

In 1912 an event referred to as the "*Great fire*" roared through the Robson Valley from the east (Wheeler, 2008). This event left an ecological impact on the valley for the next 100 years. The fire on the Sarrana Creekside was not as intense as the earth-scorching effect the fire had on the north side of the Fraser river where until this day huge pockets of Black Cottonwoods are present without conifer regeneration. On the Sarrana Creekside Lodgepole pine regeneration dominated that side of the ridge (Theissen, 2018). The Lodgepole was left to grow for future harvesting, but in the 1990s the Lodgepole was attacked by the MPB and a decade later the stands were at epidemic proportions. In 2016, the DCF began harvesting pine in smaller patch sizes and retaining dead pine stands next to riparian areas and as a visual absorption technique (Theissen, 2018).

The Sarrana Creek study site is surrounded by tree mortality on each side and the flow has become multiple braids. The DCF does not know the cause of the braiding but blowdown is the prime suspect. At the time of the initial block layout, the manager was confused by the amount and width of the braiding. Thus, it was decided to leave a large riparian zone surrounding the old Sarrana Creek channel. After the block on the west side of the channel was logged there was noticeable surface water and general wetness adjacent to the creek. The DCF is unsure if the problem originates from blow down or some other hydrological regime shift (Theissen, 2018).

The manager of the DCF knows that blow down will be a future concern at these sites that have been impacted by the IBM. The purpose of this project is to research and assess the impact of the hydrological shift at this specific site. Then propose solutions and recommendations to restore the hydrological regime of this specific site. In addition, the report gives insight on solutions for future blow down events.

Methods

Table 3 List of equipment utilized for sampling at the Sarrana Creek site.

Handheld GPS Unit
Measuring Tape
I-Phone Camera
Logbook
Water
Shovel
Field Plant Guide Book
Compass

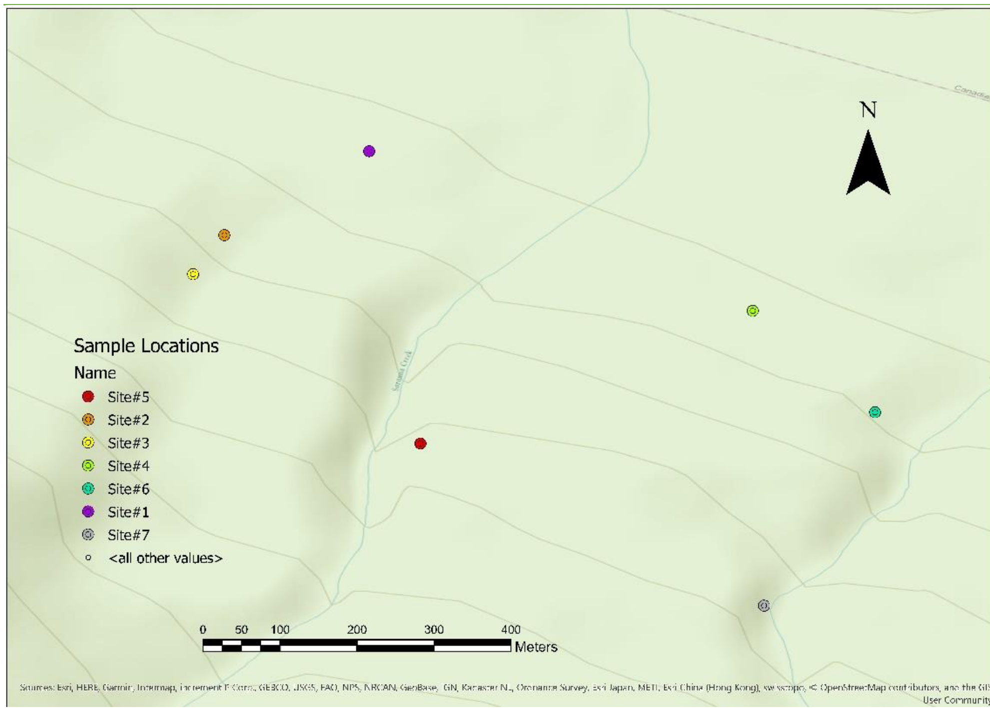

Figure 7 Map of the study using Sentinel-2 satellite imagery acquired on October 5/2018 (Google earth).

A site assessment of the blowdown area including a biophysical inventory, a hydrological assessment, wildlife risk assessment, and riparian considerations. A literature review will also be conducted focusing on blow down and hydrological regime shifts. After synthesizing the information and data a report will be delivered including recommendations for the restoration of the creek's hydrological regime. Finally, after reviewing the report the DCF will develop and implement an action plan on the site.

Seven sites were chosen at the varied elevations along the slope where the Sarrana creek used to flow in its channel. The sample areas have a 10-meter-long radius creating circular shaped survey sites. At each site, vegetation was noted at the shrub, herb and moss layers. In addition, percent canopy cover and coarse woody debris percent were recorded. The soil moisture regime and soil nutrient regime were calculated at the three sites as directed in the Land Management Handbook #25 (Field Manual for Describing Terrestrial Ecosystems). Then the slope position, drainage, soil texture, horizon thickness, humus form, root restricting area, and coarse fragment contents were performed by the field sampler.

The entire area was examined in the early spring and late summer where the changes in hydrological flow were noted. In the channel where the creek used to run an analysis of the geomorphology was conducted. A Thornthwaite-type Water Balance model was performed on the Dunster climate data to ascertain the soil evaporation and saturation conditions. Finally, a geological assessment of the ridge above the sample sites was performed to gain insight into the hydrological regime.

Figure 8 The complexity in structure and vegetation in the study area.

Results

Date:	August 11/2018	Time:	11:00AM-4:30PM	Temperature:	18°C
Coordinates:	53°09'44.96N 119°57'15.86W	Conditions: Wide Spread Smoke		Sampler:	Peter Blenman

The site had five different braids of water flowing about 50-metres west of the original drainage of Sarrana Creek. The source of the hydrological regime shift was not obvious though there are many cumulative blowdown events in the study area (refer to Figure 8). The main drainage has not been flowing since 2009 or earlier. The west side of the creek has saturated soils and evidence of watering up. This side has multiple layers of blowdown creating terraces and micromorphology that retains the water and impacts the vegetation regime. On the east side of the original creek channel, the soils are xeric, and the vegetation composition is different than the rest of the study area (refer to figure 7).

Figure 9 Evidence of recent blow down at the study site.

Site #1 is located on the west side of the creek on the edge of the cleared area and is wet. The tree layer has some spruce and hemlock and the shrub layers are dominated by thimbleberry, blueberry, and huckleberry (refer to table 4 and Figure 10). The site is very wet, and the moss layer is struggling while the wood tail is flourishing in the moist soils.

Table 4 Site #1 vegetation results

Cut block 1

Common Name	Latin Name
Black Spruce	*Picea mariana*
Western Hemlock	*Tsuga heterophylla*
Red Alder	*Alnus rubra*
Wood Horsetail	*Equisetum sylvaticum L.*
Fireweed	*Chamaenerion angustifolium*
Black Huckleberry	*Vaccinium membranaceum*
Thimbleberry	*Rubus parviflorus*
Sweet-Scented Bedstraw	*Galium triflorum*
Oak Fern	*Gymnocarpium dryopteris*
Knight's Plume	*Ptilium crista-castrensis*

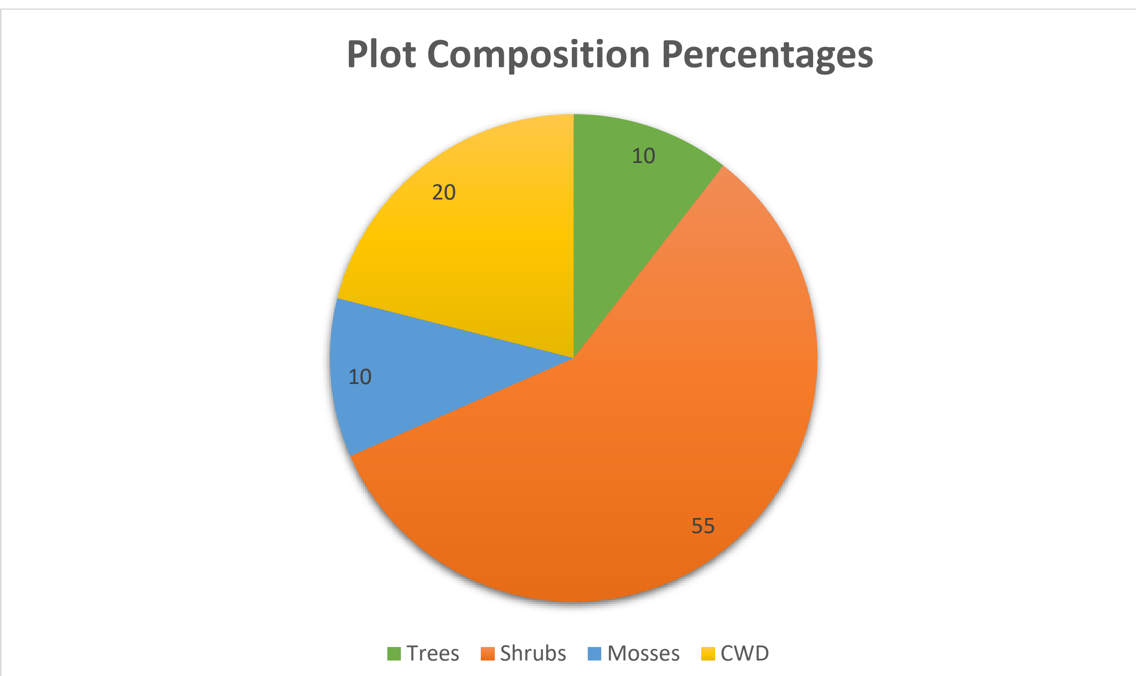

Figure 10 Composition percentage of sample site #1.

Site #2 is located upslope from sample #1 on the west side of the original creek channel (refer to Figure 7). The tree layer consists of cedar and spruce and the shrub layer has mostly thimbleberry, blueberry, and huckleberry (refer to table 5 and Figure 11). The site is wet with stiff club mass dominating the moss layer and larger shrubs growing such as highbush cranberry and saskatoons.

Table 5 Site #2 vegetation results.

Common Name	Latin Name
Western Red Cedar	*Thuja plicata*
Black Spruce	*Picea mariana*
Saskatoon	*Amelanchier alnifolia*
Red Alder	*Alnus rubra*
High bush Cranberry	*Viburnum edule*
Bunch Berry	*Cornus canadensis*
Devil's Club	*Oplopanax horridus*
Oval-Leaved Blueberry	*Vaccinium ovalifollium*
Black Huckleberry	*Vaccinium membranaceum*
Thimble berry	*Rubus parviflorus*
Queens Cup	*Clintonia uniflora*
Red stemmed feather Moss	*Pleurozium schreberi*
Oak Fern	*Gymnocarpium dryopteris*

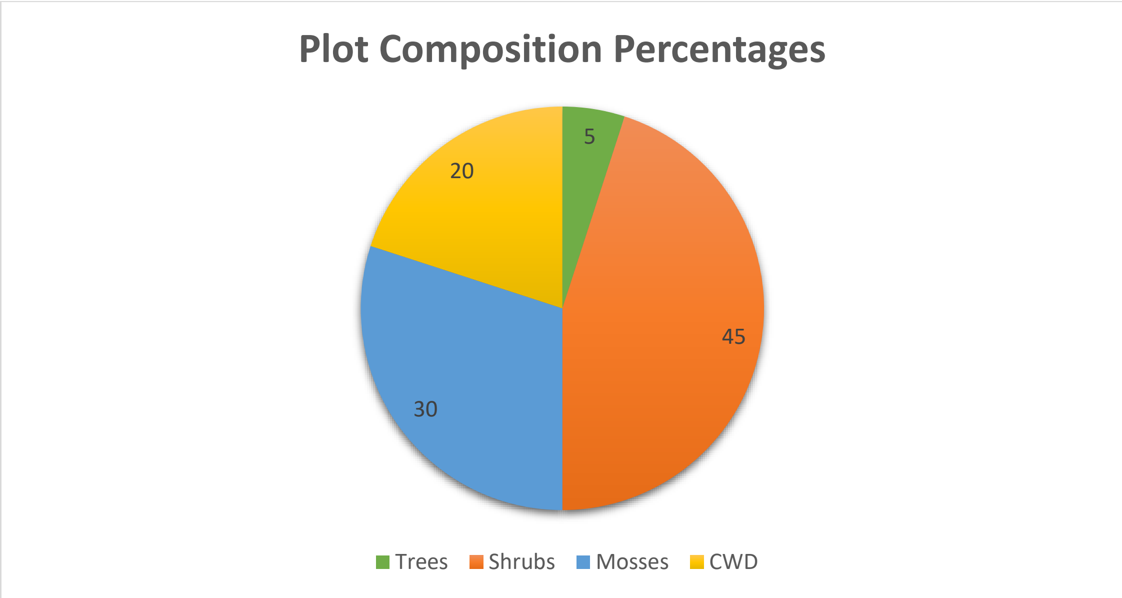

Figure 11 Composition percentage of sample site #2.

Site #3 is in the riparian area and is surrounded by trees such as cedar, spruce, pine, and hemlock (refer to table 6 and Figure 12). The site has large boulders and rocks underneath layers of blowdown the dominant species is devils club. The site also has interspersed thimbleberry and blueberry like Figure 8.

Table 6 Vegetation results from Site #3.

Common Name	Latin Name
Black Spruce	*Picea mariana*
Lodgepole Pine	*Pinus contorta*
Western Red Cedar	*Thuja plicata*
Western Hemlock	*Tsuga heterophylla*
Devil's Club	*Oplopanax horridus*
Thimble Berry	*Rubus parviflorus*
Oval-Leaved Blueberry	*Vaccinium ovalifollium*
Oak Fern	*Gymnocarpium dryopteris*
Red stemmed Feather Moss	*Pleurozium schreberi*
Knight's Plume Moss	*Ptilium crista-castrensis*

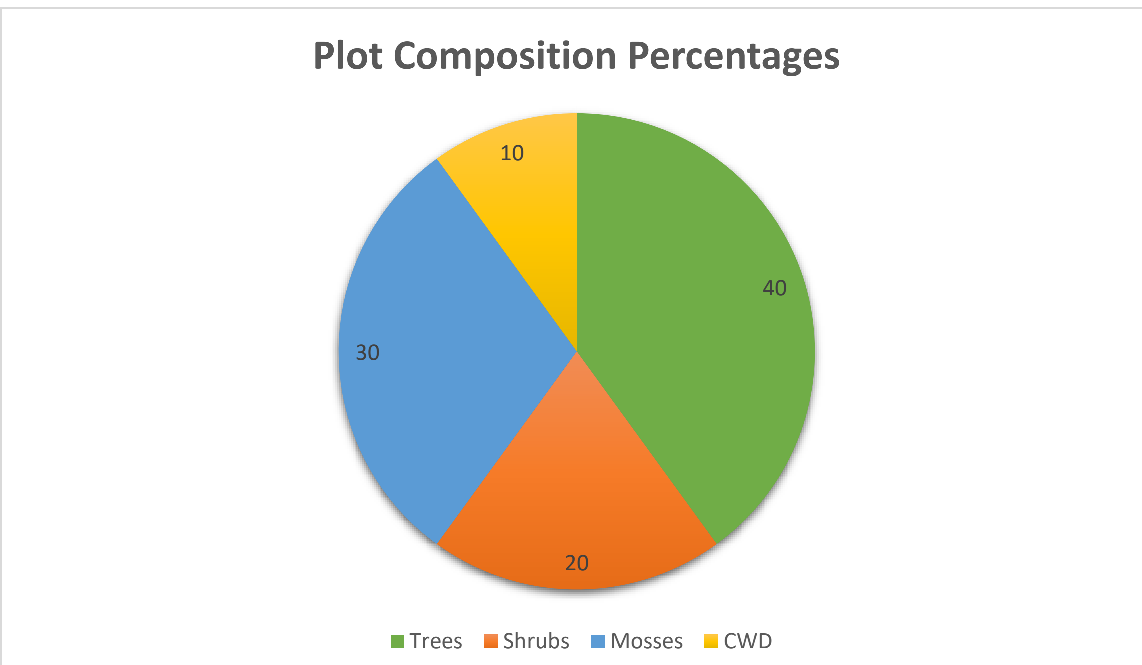

Figure 12 Composition percentages of Site #3.

Site #4 is also in the riparian area, but has slightly less canopy cover dominated by cedar, Douglas fir and spruce (refer to Table 7 and Figure 13). The site has less shrubs and is saturated with water allowing lots of wood tail and oak fern to flourish.

Table 7 Vegetation results from Site #4.

Common Name	Latin Name
Western Red Cedar	*Thuja plicata*
Douglas Fir	*Pseudotsuga menziessii*
Black Spruce	*Picea mariana*
Paper Birch	*Betula papyrifera*
Red Alder	*Alnus rubra*
Wood Horsetail	*Equisetum sylvaticum* L.
Oval-Leaved Blueberry	*Vaccinium ovalifollium*
False Box	*Paxistima myrsinites*
Clasping Twisted Stalk	*Streptopus amplexifolius*
Queen's Cup	*Clintonia uniflora*
Oak Fern	*Gymnocarpium dryopteris*
Stiff Club Moss	*Lycopodium annotinum*
Red Stemmed Feather Moss	*Pleurozium schreberi*

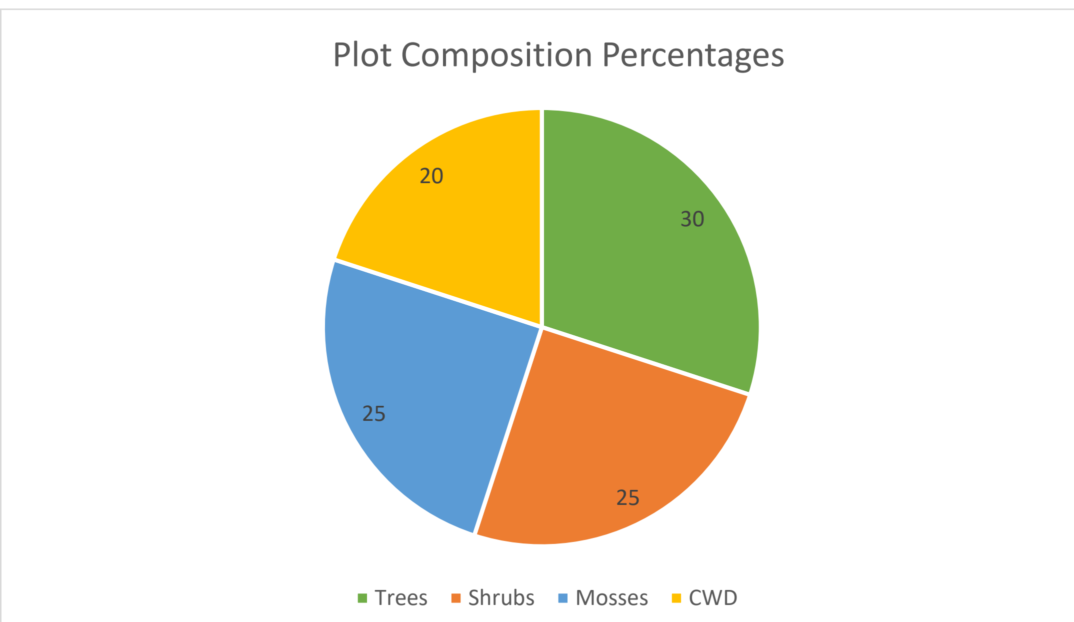

Figure 13 Composition percentages for Site #4.

Site #5 is in the riparian zone east of the original creek channel and only has deciduous forest cover such as cottonwoods and birch (refer to table 8 and figure 14). The site is also wet with devil's club and wood tails flourishing in wet, well drained soils. The alder and azalea were the dominant shrubs with less beery species being present than the other plots.

Table 8 Vegetation results for Site #5

Common Name	Latin Name
Black Cottonwood	*Populus balsamifera*
Paper Birch	*Betula papyrifera*
Red Alder	*Alnus rubra*
False Azalea	*Menziesia ferruginea*
False Box	*Paxistima myrsinites*
Wood Horsetail	*Equisetum sylvaticum* L.
Thimble Berry	*Rubus parviflorus*
Oak fern	*Gymnocarpium dryopteris*
Fireweed	*Chamaenerion angustifolium*
Devil's Club	*Oplopanax horridus*
Bunch Berry	*Cornus canadensis*
Pearly Everlasting	*Anaphalis margaritacea*
Clasping Twisted Stalk	*Streptopus amplexifolius*
Raspberry	*Rubus occidentalis*
Red stemmed Feather Moss	*Pleurozium schreberi*

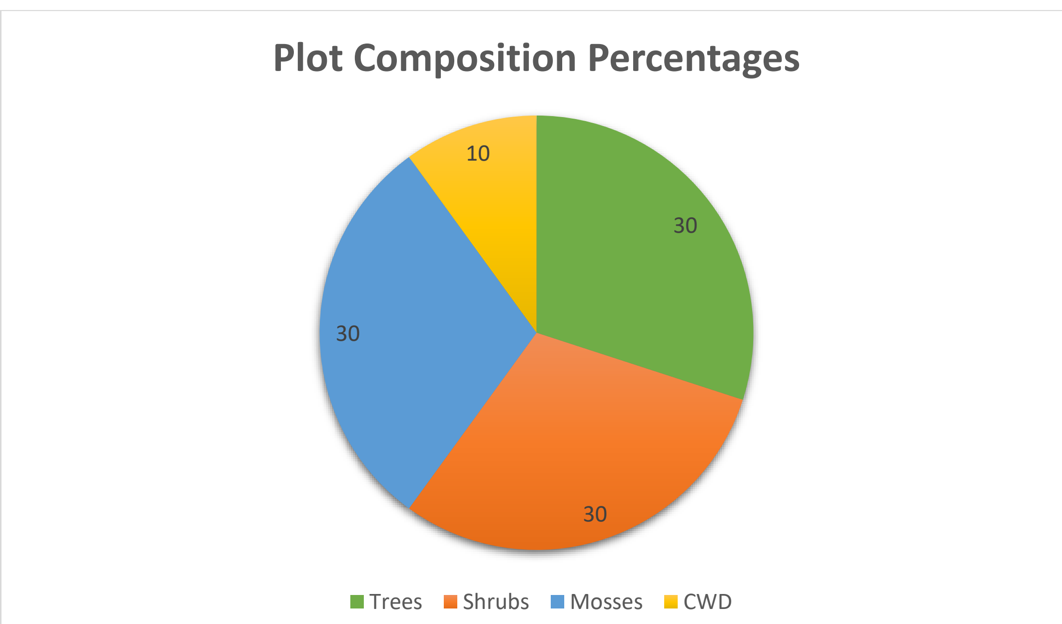

Figure 14 Composition Percentages for Site #5.

Site # 6 is located on an old skid trail that has evolved into one of the stream braids there are no trees in the plot (refer to Table 9 and Figure 15). The site is also wet with devil's club and wood tail growing in the wet areas. In the drier areas the thimbleberry, and blueberries are present.

Table 9 Vegetation results for Site #6.

Common Name	Latin Name
Thimbleberry	*Rubus parviflorus*
Bunch Berry	*Cornus canadensis*
Wood Horsetail	*Equisetum sylvaticum* L.
Devil's Club	*Oplopanax horridus*
Oak Fern	*Gymnocarpium dryopteris*
Clasping Twisted Stalk	*Streptopus amplexifolius*
Sweet-Scented Bedstraw	*Galium triflorum*
Red Stemmed Feather Moss	*Pleurozium schreberi*

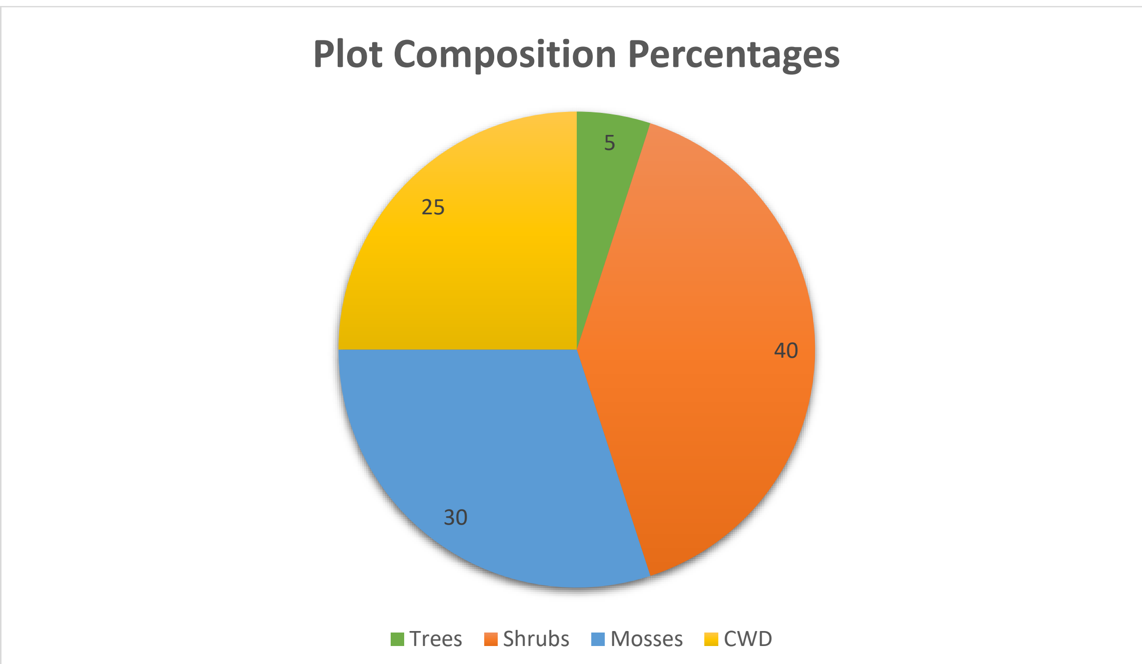

Figure 15 Composition percentages for Site #6.

Site #6 is located on the east side of the original channel and has extremely dry soil profile with only dead pine on the site (refer to table 10 and Figure 16). The shrub layer is dominated by huckleberry, blueberry, and bunchberry. The moss layer is so dry that is brown and shrivelled up.

Table 10 Vegetation results for Site #7.

Common Name	Latin Name
Lodgepole Pine Dead	*Pinus contorta*
Black Spruce	*Picea mariana*
Black Huckleberry	*Vaccinium membranaceum*
False Azalea	*Menziesia ferruginea*
Oval-Leaved Blueberry	*Vaccinium ovalifollium*
Bunch Berry	*Cornus canadensis*
Red Stemmed feather Moss	*Pleurozium schreberi*

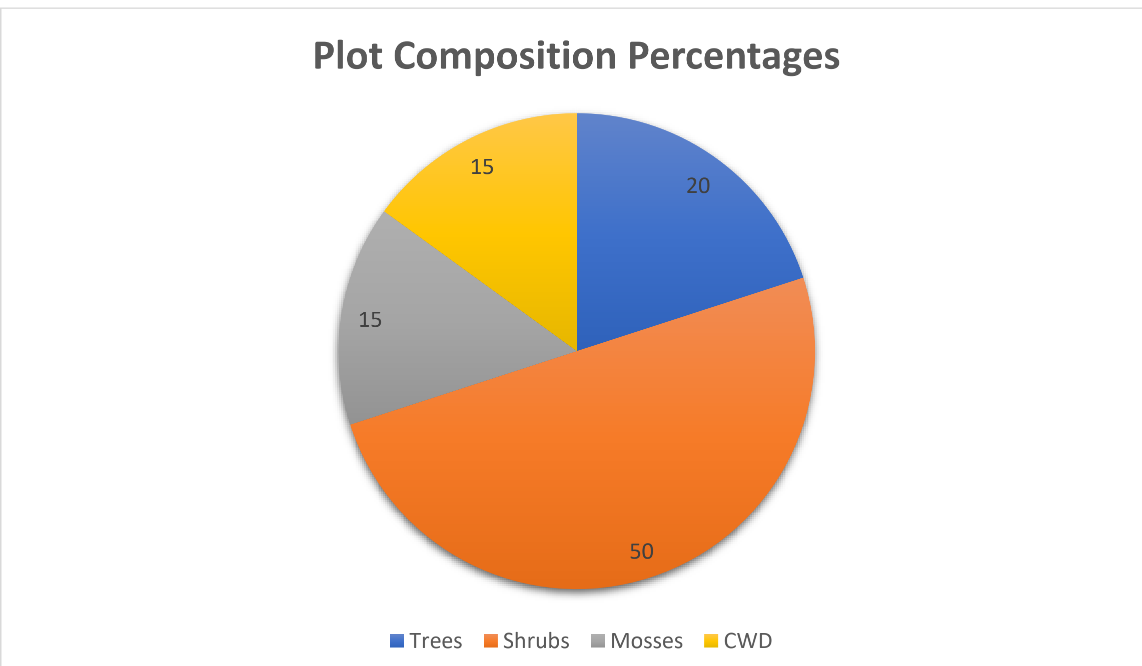

Figure 16 Composition percentages for Site #7.

Soil Pits

Figure 17 Soil pit sample and slope site assessment locations (Google earth).

Slope and Slide assessment

At all the sites assessed for slope stability and there was evidence of a previous landslide. In addition, all the sites were wet and had vegetation growing on the slopes. The soil texture at all the sites was mostly silt and clay, and there was no evidence of creep even with the steepness of the slopes (refer to Table 11 and Figure 17). The ditch at the bottom of the sample site was full of coarse woody debris and small woody debris from local fire wood gathering and overland saturated flow.

Table 11 Slope characteristics of the five sample sites at Sarrana creek.

Factors	Site 1	Site 2	Site 3	Site 4	Site 5
Slope Shape	Convex	Concave	Concave	Convex	Convex
Slope Angle	35	41	21	32	45
Material Type	Fluvial/ Glaciofluvial	Fluvial/ Glaciofluvial	Fluvial/ Glaciofluvial	Fluvial/ Glaciofluvial	Fluvial/ Glaciofluvial
Texture (% Clay, silt, Sand)	30,50,20	25,55,20	25,55,20	30,50,20	20,50,30
Coarse Fragment Shape	Angular	Angular	Angular	Angular	Angular
Overburden Depth(m)	0.45	0.32	0.85	0.63	0.88
Evidence of Landslides	Y	Y	Y	Y	Y
Gully Erosion	Y	Y	Y	Y	Y
Bedrock Location	Buried	Buried	Buried	Buried	Buried
Wet soil (Y/N)	Y	Y	Y	Y	N
Vegetation(Y/N)	Y	Y	Y	Y	Y

Site series Form

The soils on the east side of the creek were saturated and pools of water are present. The only dry site was on the west side of the creek and was draining well and exhibited dry soil characteristics (refer to Table 12 and Figure 17)). The soils were a mixture of regosol and organic soil types suggesting a young soil profile. The aspect of the site faces north leaving the study site in the shade of its own mountain ridge for much of day.

Table 12 Soil characteristics of the sample sites at Sarrana creek.

Factors	Site 1	Site 2	Site 3	Site 4	Site 5
Aspect	36°N	38°N	31°N	32°N	28°N
Elevation (m)	855	881	808	838	932
Slope angle	35	41	21	32	45
Soil Moisture Regime	Hygric	Hygric	Hygric	Subxeric	Xeric
Soil Nutrient Regime	Medium	Medium	High	Medium	Low
Meso-slope position	Mid	Mid	Mid	Mid	Mid
Mineral Soil Drainage	Imperfectly	Imperfectly	Imperfectly	Imperfectly	Well
Mineral Soil Texture	Loamy	Loamy	Loamy	Loamy	Loamy
Surface Horizon Depth (cm)	45	41	80	65	32
Humus Form	Mor	Mor	Mor	Mor	Mor
Root Restricting Layer (cm)	16	12	20	18	14
Coarse Fragment Content	<40%	<30%	<40%	<30%	<20%
BGC Zone	ICHmm	ICHmm	ICHmm	ICHmm	ICHmm
Structural Stage	1	1	5	1	1
Crown Closure (%)	0	0	85	32	0

Thornthwaite-type Water Balance model

Thornthwaite-type Water Balance model (MS Excel Workbook) was used to calculate the water-balance calculations. Table 13 is a completed water-balance spreadsheet for Dunster, BC, at 52.5°N latitude, the annual values are calculated by summing the monthly values (refer to figure #18). The annual precipitation and water input are equal to mm (refer to figure #18), this must be equal (Dingman, 2002). The snow pack has a medium accumulation of 56mm in January and melts by the beginning of March. ET=PET for the months when W>PET is January – April and, September-October (refer to Figure #18). Soil-water storage is recharged by rain and is at capacity for only March and April, (refer to Figure#18). It declines in the period from April to August because PET>P and further evaporation are contributed by water from soil storage. The average monthly "water surplus" is calculated by W-ET-ΔSOIL which is 246mm (refer to Table #18).

Table 13 Thornthwaite-type Water Balance model for the Dunster region (Environment Canada).

			MONTHLY WATER BALANCE DATA										
			Temperatures in C, water-balance terms in mm.										
Month:	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Year**
=================	====	====	====	====	====	====	====	====	====	====	====	====	====
P	55.7	34.4	38.8	33.9	40.5	58.1	62.1	54.3	53	62.3	58.1	58.6	610
T	-7.7	-4.2	0.16	5.69	10.1	13.5	15.4	14.8	10.5	5.07	-2.2	-6.9	4.52
F	0.00	0.00	0.03	0.95	1.00	1.00	1.00	1.00	1.00	0.85	0.00	0.00	
RAIN	0	0	1	32	41	58	62	54	53	53	0	0	354
SNOW	56	34	38	2	0	0	0	0	0	10	58	59	256
PACK	198	232	227	4	0	0	0	0	0	2	68	128	
MELT	0	0	57	224	4	0	0	0	0	9	0	0	294
INPUT (W_m)	0	0	70	263	61	76	80	47	54	68	0	0	720
PET	0	0	24	42	63	83	90	78	52	30	0	0	462
W_m - PET	0	0	44	221	-5	-13	-22	-40	-2	37	0	0	
SOIL	82	82	100	100	96	84	68	45	44	82	82	82	
DSOIL	0	0	18	0	-4	-11	-17	-22	-1	37	0	0	
ET	0	0	26	42	66	88	97	69	55	30	0	0	473
SURP=W-ET-DSOIL	0	0	25	221	0	0	0	0	0	0	0	0	246
DEFIC=PET-ET	0	0	0	0	0	1	5	18	1	0	0	0	26

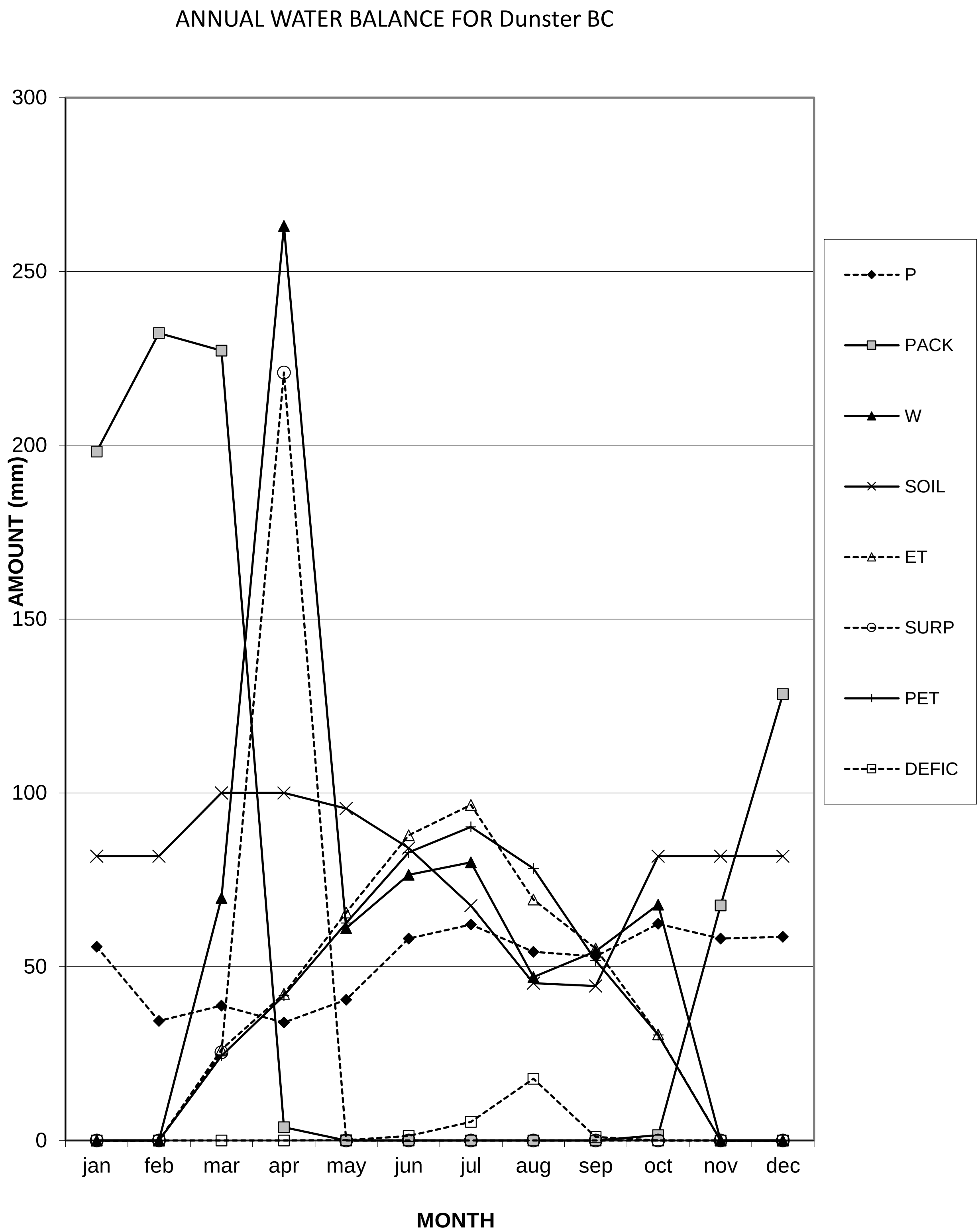

Figure 18 Thornthwaite-type Water Balance model chart for Dunster BC.

Geological Composition of the Ridge

Table 14 Geological ridge assessment above the study site.

Date:	August 14/2018	Time:	9:00AM-3:30PM	Temperature:	14°C
Coordinates:	53°09'44.96N 119°57'15.86W	**Conditions:** Wide Spread Smoke		**Sampler:**	Peter Blenman

The assessment was conducted on the ridge above the sample sites by driving up to about 1200 metres and then walking on the spine. The top of the ridge resembled a tor with blocks cleaving to either side of the ridge and falling down the slopes. The ridge here is the front range of the Cariboo Mountains and thus the sedimentary rock is thrust vertically upright creating the block shape (refer to Figure 19). The placement of this rock allows for water to seep, flow, and be held in the rock. The mass wasting mechanism of freeze and thaw hydrofracturing impacts the structural integrity of the slope (Bierman & Montgomery, 2013). Above the Sarrana creek drainage, there is evidence of cleaving of the ridge that had contributed to previous landslides.

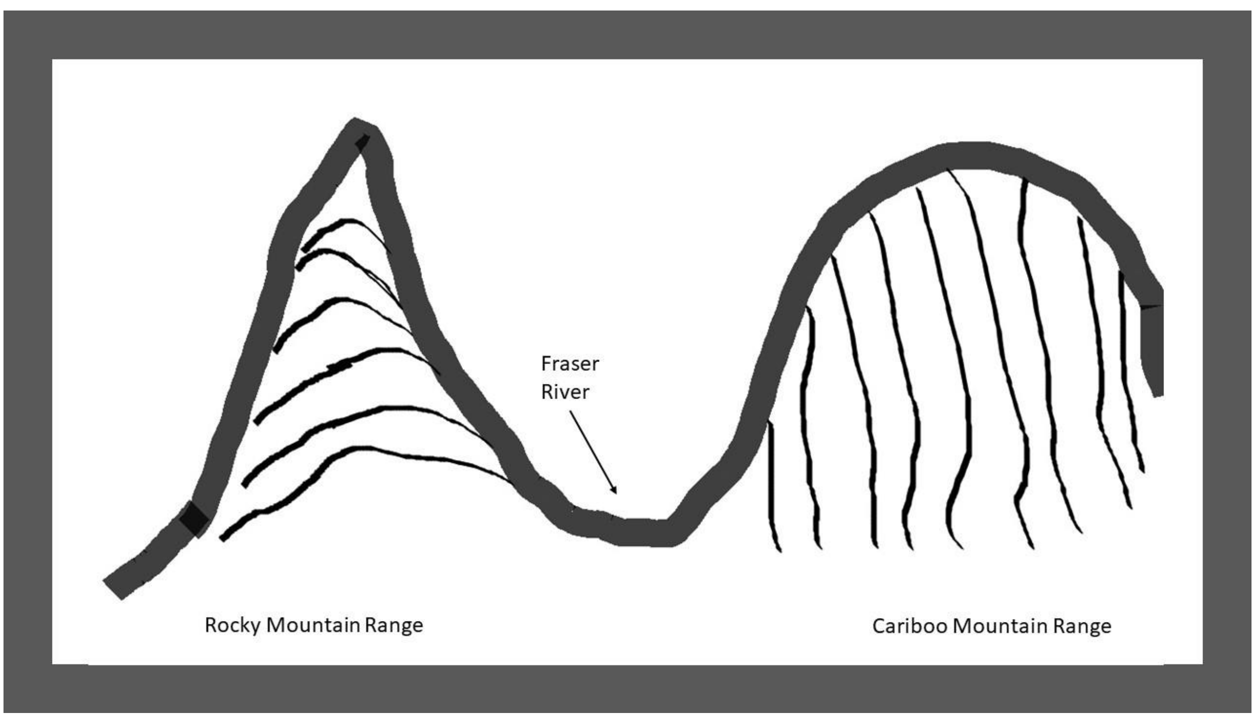

Figure 19 Drawing representation of the rock structure of both mountain ranges at the study site.

Discussion

Summary

There are many cumulative factors impacting the hydrological regime of Sarrana Creek such as blowdown, rockslide debris, timber harvesting, aspect, and geology. An area about 400 metres long between the Sarrana Creek and the drainage east are now a network of braids and subterranean hydrology (refer to figure 7). One area on the west side of the Sarrana Creek is very wet and wetland vegetation is thriving. Blowdown from the previous MPB outbreak is not the primary cause of Sarrana Creek's hydrological regime shift. In fact, the hydrology at the site is most prominently impacted by fallen boulders and rocks from a previous rockslide. The 400-metre riparian zone that was left by the DCF surrounding Sarrana Creek was the correct decision. The ditch adjacent to the road below the site area is now collecting water for the whole 400-metre stretch and to ensure the continued stability of the roadway culvert installation and ditch cleaning will have to be implemented.

Wetland area

The area adjacent to the west side of the old creek channel is seeping water and conifer regeneration is non-existent. The wet area is about 10 metres higher than the old creek channel. Thus, the old creek channel is not the root of the extra water on the site. The 400-metre stretch of area has saturated soils, subterranean water flow, and new channels of overland flow from blowdown and anthropogenic trail building. The site also has downed logs that are creating micromorphological that is creating pools and terraced wetlands (refer to Figure 20). Sites 2 and 3 on the westside have Devil's Club present indicating subsurface water flow as the club likes to have it's roots wet but not continuously submerged in water (refer to Tables 5 and 6) (Kranabetter & Shaw, 2003). The Devil's Club is also an indicator of areas prone to seepage and wetness. The forest manager commented that one of the braids of Sarrana Creek that empties into the ditch runs clear all year around (Theissen, 2018). This suggests that the groundwater and surface flow are intertwined in this area being an influent and effluent region for groundwater recharge and discharge (refer to Figure 21) (Bierman & Montgomery, 2013).

Figure 20 Wetland area with bulrush growing in the saturated soil.

Figure 21 Stream outlet that runs clear all year around.

Riparian Area

The riparian east of the old creek channel is a network of small streams and under ground water flows. There is no evidence that blowdown is responsible for the creek's new hydrological regime. The water runs through this area below in rocks and boulders strewn through the area from a previous rock/landslide (refer to Table 11). It also appears that the area has a history of wetness and braided flow with rich organic soil layers and moderate draining soil profiles (refer to table 12). A major problem in the region is that because there is no formal channel flow, tracks made from timber harvesting have become new streams (refer to Figure 22). Above this area, the soils are dry and show no evidence of the soil saturation in the riparian area (refer to Figure 7). The vegetation sampled site 8 and 9 also have Devil's Club present suggesting similar hydrology to the wetland area west of the creek bed. This area is draining better and the ditch along the road below is collecting the 400-metre swath of water flow.

Figure 22 Old skid trail now a new steam braid on the east side of Sarrana Creek.

Recommendations

Wetland Area

The restoration of the area west of the Sarrana Creek would involve the removal of fallen logs that were left after harvesting and MPB mortality blowdown and regeneration of tree species. At this point in time, the area is too wet for such a restoration endeavour and a couple of years the hydrology may become more xeric. The results of the Thorn Waite model showed that the soil in the region is subject to evaporation of water from the soil (refer to Figure 18). If the DCF is set on growing trees on this site in the future the site needs to be drier that could be accomplished by planting water-loving trees such as willows. In my opinion the area should be left alone because the hydrology in this region is unpredictable and uncertain. In addition, the wildlife in the area is thriving in these sites due to the biodiversity and large swath of forest between the cut blocks.

Figure 23 Sentinel-2 image showing the sample sites and the wetland area (Google Earth).

Table 15 Wetland restoration budget

Treatment	Cost
2400 stems per hectare	$2000.00
Labour	12 hours X $25.00=$300.00
Total	$2300.00

Roadway and culvert installation

The area between the two creek channels in Figure 24 along the logging road needs timber removal and a couple of culvert installations. The water is now running as sheet flow over the roadway this is because the ditches are full of large and coarse woody debris with no culverts to handle the sporadic flow in this region. The first step would be removing the wood from the existing ditch. Then excavating the ditch to be about 0.75 meters deep and 1.66 meters wide. At the two original creek channels, two culverts would be installed with a diameter of 0.5 meters. The road and terrain are already graded naturally for the two culverts to collect water for about 175 meters in each direction (refer to Figure 24).

Figure 24 Sentinel-2 image showing the sample sites and the culvert installation area (Google Earth).

Table 16 Budget for two culverts installation.

Treatment	Cost
Culvert	2 X 260.00=$520.00
Excavator	6 hours X 160.00=$960.00
Excavator Transport	$900.00
Labour	6 X $50.00=$300.00
Total	$2680.00

Additional Restoration Outcomes

Shortly after consultation with the DCF about the Sarrana Creek recommendations the wetland area, it was decided to leave the area alone and not pursue an active restoration to the site allowing a passive restoration approach. Within two days of the consultation, the two culverts were installed in the proposed locations and the ditch was cleared of woody debris. In response to the community's lack of knowledge about the importance of not leaving wood in the ditches adjacent to the logging roads. A poster was created illustrating how ineffective the ditches are when full of discarded wood from firewood collection. In addition, the DCF posted on their website forum an ultimatum that if the ditches continued to be full of discarded woody debris that the logging roads would be closed to the public for firewood collection. Finally, a policy of retaining larger riparian buffers was implemented in the DCF. The manager is thoughtful of how the wildlife utilizes these areas and the uncertainty of the hydrological regimes in the area warrant the larger buffer size.

Conclusion

The Sarrana Creek region is a complex network of braided streams and geology that created an area of uncertainty in the DCF. After closer examination, it was evident that the hydrological regime shift was not due to blowdown as first assumed but cumulative factors over centuries of geological, hydrological, and natural processes. The DCF choose to leave the area as is and mitigate future damage to their road system as opposed to a full-scale restoration of the site. The DCF sees the importance of leaving the site as a learning tool and the importance that wider riparian areas have wildlife populations. In the future, the DCF has implemented a policy to ensure larger riparian zones in their forest harvesting practices. This embracement of uncertainty has been the real lesson taught from this hydrological regime shift. Hopefully, future generations will also learn how complicated and dynamic natural processes are to deal with from a land management perspective.

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