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FOREST AND RANGE EVALUATION PROGRAM

August 2020

WATERSHED ASSESSMENTS IN THE KOOTENAY-BOUNDARY REGION: Combining GIS and Ground-Based Methodology with Pour-Point Design

Prepared by:
Lisa Nordin, M.Sc., R.P.Bio.
Integrated Monitoring and Assessment, Resource Planning and Assessment Branch
B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development

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Boundary Creek. Photo credit: Kristie Steele

Science-based Monitoring and Evaluation

MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS
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FREP Forest & Range Evaluation Program
British Columbia

Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. This evaluation report represents one facet of this process. Based on monitoring data and analysis, the authors offer the following recommendations to those who develop and implement forest and range management policy, plans, and practices.

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Prepared by: Lisa Nordin, M.Sc., R.P.Bio
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EXECUTIVE SUMMARY

Since 2006, BC's Forest and Range Evaluation Program (FREP) has sampled over 11,000 post-harvest sites to assesses the effectiveness of forest and range practices in conserving resource values, including riparian/streams and water quality. To date, the focus has been on random sampling at recently harvested cutblocks. Riparian/stream conditions are evaluated at a reach scale and results are typically summarized by natural resource district.

In 2019, a pilot project was completed in the Kootenay-Boundary region to develop and test a methodology for evaluating riparian/stream condition at a watershed scale using targeted sampling. This project was initiated in response to interest among decision makers in having information on factors influencing the condition of specific watersheds of concern. Using this methodology, FREP researchers combined reach-scale ground assessments in a pour-point sample design with GIS estimates of riparian disturbance to result in an integrated ranking of condition. Results were supplemented with data from assessments of potential sediment delivery and habitat connectivity at road crossings. Treatment and reference watersheds within the Kettle River and Kootenay Lake drainage areas were sampled, where the majority of land disturbances in the treatment watersheds were due to logging and roads, and the reference watersheds were mainly undisturbed by human development.

Results

In the Kettle River drainage, the Boundary and Rock Creek treatment watersheds were found to be *not properly functioning*. The level of impairment was significantly higher in these two watersheds compared to all the others in the study, mainly due to a high amount of human-caused riparian disturbance. The reduced buffering capacity and resilience that results from an impaired riparian area means that these systems are presently in a sensitive state and may be easily affected and slow to recover from additional disturbance. Supplementary information gathered at road crossings indicates that sedimentation, livestock, and habitat connectivity for fish are also issues in the Boundary and Rock Creek watersheds. Attributes associated only with the stream channel identified flooding as one of the main causes of impacts in both treatment and reference watersheds in the Kettle River drainage, indicating that this area may be susceptible to naturally occurring high flow events.

In the Kootenay Lake drainage area, the Redfish treatment watershed was assessed to be in *properly functioning condition*, with results similar to several of the reference watersheds. Where indicators were impaired in Redfish, they were linked to road-related issues such as surface erosion and mass wasting using the riparian/stream evaluation. Similar issues were also observed at three road-crossing assessments in Redfish using the water quality assessment.

In addition to discussing the approach and findings, the report also presents recommendations for mitigating future detrimental effects in these watersheds.

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1.0 INTRODUCTION

The Forest and Range Evaluation Program (FREP) is a foundational element of the F*orest and Range Practices Act* (FRPA). FREP's overarching mandate is to promote the sustainable management of British Columbia's forest and range resources under FRPA by monitoring and evaluating the condition of FRPA resource values, including water and fish. FREP provides science-based data to inform resource managers, support decision-making, and enable the continuous improvement of forest and range stewardship in the province.

Major flooding in several of the watersheds in the Kootenay-Boundary region, along with associated concerns from the public over peak flows and water quality, prompted the desire for targeted FREP assessments to evaluate the functioning condition of these systems. Concurrently, there has been increasing interest from government and industry in developing options for applying existing FREP riparian assessments at a watershed scale. Presently, there is only one watershed sampling protocol within FREP, which was developed to assess fisheries sensitive watersheds (FSWs). The FSW design uses stratified random site selection derived from sections of a grid overlay of the drainage area (Pickard et al. 2014). The overall results subsequently roll up in an additive manner by large and small stream grouping to conclude on watershed condition. The FSW assessment includes conservative thresholds for the protection of fish and fish habitat that are applicable to areas where watershed sensitivity and important fish values could be at risk; however, the intensive sampling design requires substantial resources to complete. This often precludes the use of the FSW protocol for routine-level assessments, hence the desire to test a less intensive assessment methodology such as the one used in this study.

2.0 STUDY WATERSHEDS

Three treatment watersheds were chosen for sampling – two in the Kettle River drainage and one in the Kootenay Lake drainage – with additional reference basins in nearby areas for comparison. Selection of the treatment watersheds was made from a pool of basins that had ranked as moderate or high risk for the "water quantity" component in a 2017 cumulative effects assessment (using 2015 data layers), with additional consideration given to ground access and input from staff at the Selkirk Resource District. The Boundary and Rock Creek treatment watersheds are located within the Kettle River drainage system and the Redfish treatment watershed is located within the Kootenay Lake drainage system. Reference sampling took place in seven adjacent or neighboring watersheds where upstream development was limited. The Lynch and Sandner reference watersheds are mostly contained within Gladstone Park, and one of the Kokanee watersheds in the Kootenay drainage is contained within Kokanee Park (Figure 1). The watersheds and sub-catchment areas reported here are based only on the drainage area upstream of the sample locations and the areas may not exactly coincide with other published reports for these same watersheds. For example, although the Boundary and Redfish watersheds are mostly captured in their entirety, the Rock Creek watershed assessed in this study is comprised of a branch of the larger Rock Creek drainage and does not represent the entire Rock Creek watershed.

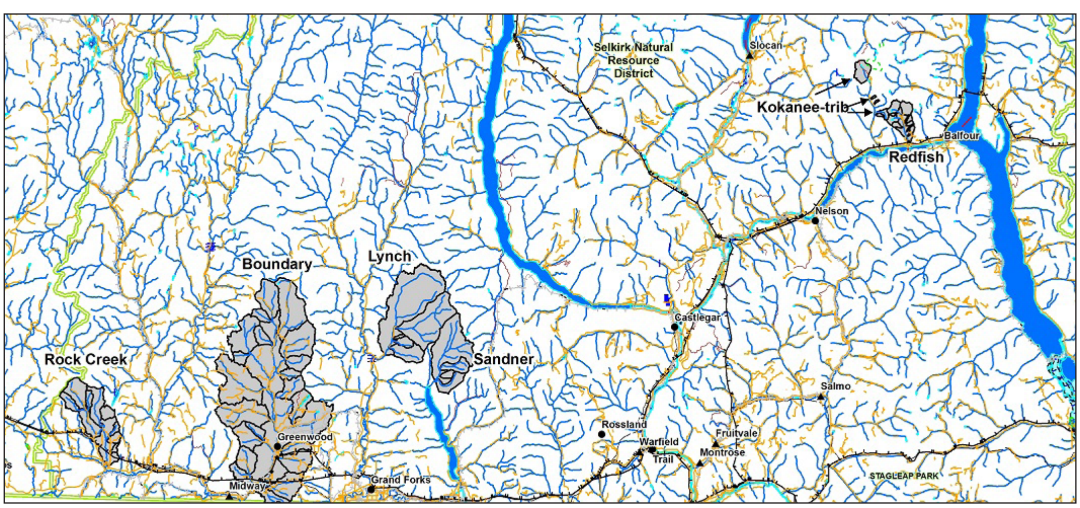

Figure 1. ***Locations of study watersheds (grey shading) within the Selkirk Resource District.***

3.0 SAMPLING DESIGN

Sampling sites were planned using a pour-point design that reflects systematic selection near the mouth of upstream sub-catchments within a watershed. Site selection of pour points is not limited to a specific sub-catchment size or stream order, and this variability allows for the unbiased evaluation of a watershed (Minnesota Pollution Control Agency 2019).

> Pour-point design distinguishes the condition of different sub-catchments that together contribute to the overall representation of watershed condition. Thirteen years of FREP data (2006-2018 inclusive) has shown that small (headwater) stream assessment results can be highly variable and tightly linked to localized effects, while those lower in the watershed are more reflective of cumulative upstream conditions. This can lead to an assortment of habitat and hydrological conditions across a watershed which can vary with upstream sub-catchment size, elevation, aspect, gradient, geology, stream order, stream magnitude, and morphology. Together, these variables can result in a range of responses to upstream development or "stressors" such as roads, forestry, agriculture, ranching, recreation, mining, oil and gas, and urbanization. Sampling this patchwork of sub-catchments that contribute to the overall functioning condition of a watershed allows for the identification of more sensitive areas for follow-up investigation or to target specific management and rehabilitation strategies.

The pour-point approach is termed "intensive watershed monitoring" in the United States, and has been in effect since 2006, beginning in the Snake River watershed. Since its introduction, sampling using this method has been completed in the Pomme de Terre, North Fork Crow, Le Sueur, Root, Little Fork, Sauk, Mississippi River-Red Wing, Tamarac, and the Upper Red River watersheds. Sampling methodologies using this design in the U.S. include those created for biological, water chemistry, and other contaminants for the purposes of water quality determinations. In this study, assessments of sample sites included ground-based FREP protocols, along with habitat connectivity evaluations and GIS-derived indices of riparian disturbance.

4.0 METHODOLOGY

4.1 *Sample Site Selection*

4.1.1 Riparian/stream assessment sites

Initial site selection was completed using the Freshwater Atlas 1:20 000 stream and watershed layers in ArcGIS along with other topographic reference layers. Once the main watershed of interest was identified, the lowest accessible point in the mainstem was determined for the first site. Upper sub-catchments flowing into the mainstem representing smaller drainage basins of varying stream orders were then located, moving upstream from the initial site. Sample sites representing these sub-catchments or "branches" were chosen ~100 m upstream of the confluence with the mainstem. The resulting number of sites and sub-catchments varies with the overall size and accessibility of the watershed. The objective was to compile an unconstrained mosaic of sub-catchment data that, when combined, characterized the entire watershed.

Not all pre-selected sample sites were field assessed. In several cases of first-order tributaries[1] to the mainstem, no stream was located. There is a known discrepancy between the number or length of streams in current spatial files and actual streams observed on the ground, with most interior drainages over-represented and most coastal drainages under-represented in the spatial files. There were two sites in the treatment watersheds and several in the reference watersheds that were found to be completely inaccessible due to geographic limitations (i.e., steep ravine) or privately-owned land. The locations of a few sites were adjusted slightly in the field by moving them upstream to allow for accessibility. The lack of roads in the reference catchments severely limited access to any sites in the upper portions of those watersheds, and thus reference sites in the Lynch and Sander watersheds were located mainly in the lower half of those watersheds. To supplement the reference group population, and have geographically representative comparisons for the Redfish watershed, five non-developed sub-catchments to Kokanee Creek were also sampled. The magnitude and complexity of the Kokanee Creek watershed is too high to compile these five spatially independent sub-catchments into a functional group, so these references were identified as independent watersheds. The final number and range of

[1] Stream order numbering follows a hierarchical approach starting at the headwaters and increasing as tributaries converge, as per Strahler, 1952.

sub-catchment areas sampled for each study watershed can be found in Table 1. An example of the sub-catchment sample basins within the Redfish treatment watershed is shown in Figure 2.

Table 1. Treatment and reference watersheds sampled.

Watershed	Total Area (km^2)	Watershed Order	# of Sampled Sub-catchments	Sub-catchment Size Range (km^2)
Treatment Watersheds				
Boundary	578.7	6	21	5.5 - 198.2
Rock Creek	88.9	5	10	1.4 - 22.6
Redfish	26.5	3	11	0.4 - 8.7
Reference Watersheds				
Lynch	174.1	5	5	1.0 - 97.3
Sandner	78.7	5	4	2.9 - 56.0
Kokanee Trib. 101	0.4	1	1	0.4
Kokanee Trib. 100	0.7	1	1	0.7
Kokanee Trib. 93	9.7	3	1	9.7
Kokanee Trib. 103	2.3	2	1	2.3
Kokanee Trib. 97	0.4	2	1	0.4

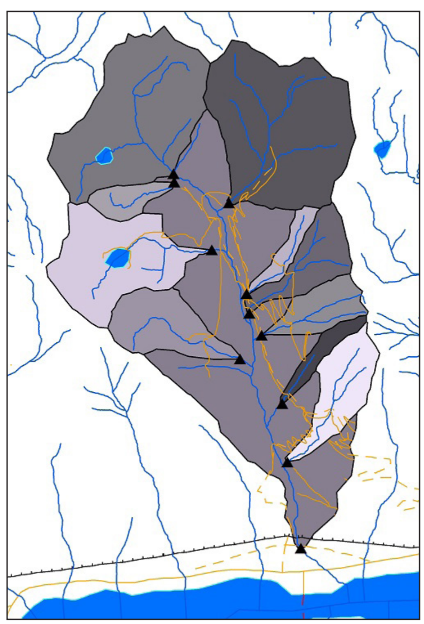

Figure 2. Sample sites (triangles) and associated sub-catchments within the Redfish watershed.

4.1.2 Water quality and habitat connectivity sites

Sites for water quality assessments (WQEE) were randomly chosen from a list of all accessible stream crossings in the sample watersheds that would be presumably crossed on the way to riparian sample reaches. The actual number and locations of the sample sites were dependent on access and the time spent in each watershed. Habitat connectivity assessments were planned at the WQEE sites, with the assumption that they would only be completed on fish streams with closed-bottomed culvert crossings. Ground confirmations of gradients greater than 20%, indicating a potential non-fish reach, and the presence of bridges or arches at the crossings rather than culverts precluded connectivity assessments at many of the potential sample sites. The final number of sampled sites for WQEE and habitat connectivity completed by watershed are provided in Table 2. Reference watersheds are not well represented because of their lack of roads.

Table 2. Number of water quality and habitat connectivity sample sites.

Watershed	WQ	Habitat Connectivity
Boundary	22	17
Rock Creek	15	3
Redfish	11	0
Lynch	5	1

4.2 *Field Assessments*

Field assessments followed established protocols developed for the Forest and Range Evaluation Program (FLNRORD 2019a). The Riparian Management Routine Effectiveness Evaluation (RMREE) protocol contains up to 120 measures, counts, or estimates associated with attributes of a stream and its adjacent riparian area to answer 15 main questions that reflect indicators of health or condition (Tripp et al. 2019).

The Water Quality Effectiveness Evaluation (WQEE) uses connectivity estimations in calculations with measured areas containing exposed fine sediment to approximate the potential of fine sediment to be transported to a stream at road crossings (Maloney et al. 2018). Sources of fine sediments may include roads, cut/fill slopes, ditch lines, landings, and mass wasting that are hydrologically connected to stream crossings. FREP effectiveness evaluations were developed to evaluate impacts from forest activities; where the primary impact on the water quality value is sedimentation, thus the WQEE does not test for other water-borne contaminants.

Habitat connectivity assessments were completed at a random selection of known or defaulted fish-bearing streams, and these mainly coincided with crossings where water quality assessments were also completed. The habitat connectivity methodology uses criteria outlined in the *Field Assessment for Determining Fish Passage Status of Closed Bottom Structures* (B.C. Ministry of Environment 2011) with the inclusion of blockages within a structure or stream channel located within the road right-of-way, as described in the RMREE protocol. The checklist used for the habitat connectivity assessments is provided in Appendix I.

4.3 *GIS-based Information*

GIS data was used to estimate riparian disturbance over the entire watershed as a more comprehensive proxy for riparian condition compared to field assessments where riparian attributes are representative at the scale of the sample reach. Using this approach provides a more robust indicator of riparian condition at the watershed scale.

There are six main indicator questions within the RMREE protocol that are reflective of riparian functioning condition, and these include attributes related to stand structure and function (windthrow, shade, large woody debris supply) and ground disturbance (bare soil, compaction, invasive plants). Most of the measurements taken to answer the main indicator questions are within 10 m of the stream and were developed to capture riparian response to adjacent logging. A 10 m assessment area is consistent with past FREP results that show significantly better results for small streams that had an intact 10 m buffer compared to those that did not (Nordin et al. 2017). In addition, many best practices for riparian management around small streams focus on retention within 10 m (BC Ministry of Forests 1995; Richardson et al. 2010; Rex et al. 2011;). Although it is recognized that there are studies identifying effective buffer widths at 30 m or larger, for the purpose of the watershed-level assessment described here, it was concluded that GIS-derived disturbance within 10 m would be used to evaluate watershed riparian condition to remain consistent with the current RMREE scoring system.

Disturbance was quantified using GIS spatial layers assembled by the provincial Cumulative Effects Aquatic Ecosystem GIS specialist (Sasha Lees) and includes all human-caused disturbance. A consolidated roads layer was also provided, which was merged with the disturbance layer. Any section of stream reach within 10 m of this integrated disturbance layer was identified as "disturbed." From these results, any section of stream that was within disturbance that was solely comprised of a forest stand harvested more than 20 years previously was modified by giving it a weighting of 0.33, which represents a partial recovery of riparian indicators. The specific value of 0.33 is an average that was calculated from the riparian results of a study conducted in the B.C. central interior at 70 sites associated with harvesting 20-30 years previously (see Table 1 in Nordin et al. 2009b). It also recognizes that despite 20 years of regrowth, two of the six RMREE riparian indicators are not likely to be fully recovered (Q12 – large woody debris supply; Q15 – riparian forest structure).

4.4 *Determining Functioning Condition*

4.4.1 Riparian/stream

The calculation of watershed condition involved a multi-step process (Nordin and Malkinson 2020), beginning with the extraction of the stream indicator values from the results of the RMREE riparian/stream assessment. Although the full assessment consists of 15 indicator questions, it is recognized that the six riparian indicators are only reflective of a small portion (100 m or 30 x channel width) of a drainage system, while the remaining stream indicators may also be reflective of upstream conditions. Studies have found increases in flow (Moore and Wondzell 2005; Winkler et al. 2017) and sediment regimes (Lewis et al. 2001; Gateuille et al. 2019) after logging or other development, and this can trigger impairment of stream indicators measured at downstream reaches (Nordin et al. 2009a). Therefore, for the extrapolation of RMREE data to a watershed scale, only the values representing the nine stream indicators were used from the ground assessments. The remaining six main indicator questions are related to the reach-level riparian vegetation and are not appropriate for extrapolation to a watershed scale. Instead, riparian disturbance is evaluated using GIS. The list of stream indicator questions and the associated attributes measured to assist in answering the questions are presented in Appendix II.

The stream indicator data was weighted according to the proportion of watershed represented by the sub-catchment area upstream of each sample site. All the adjusted proportional values were then added together to give a weighted stream score by watershed.

The amount of riparian disturbance within 10 m of a mapped streamline was then calculated as described in the GIS-based Information section above, and the total percentage of stream length disturbed (km stream disturbed/total stream km) was entered into a condition matrix that contained thresholds similar to other watershed assessments for hazard or risk associated with riparian disturbance (B.C. Ministry of Forests 1995b, 1999; FLNRORD 2019b). The resulting outcome represents the functioning condition for the entire watershed. A simplified matrix showing the relationship between the stream and riparian results with associated condition outcomes is presented in Table 3. Note that riparian disturbance is given a score from 0-5 in place of the ground-based six riparian indicators in the RMREE because since sampling began in 2006, there has never been a case where all six riparian indicators received a No answer at a single site, likely because of the complementary nature of the suite of indicators.

The integration of the stream and riparian indicators and subsequent appointment of a functioning condition using this methodology is equivalent to the scoring in the full-length RMREE reach-scale protocol with the total score similarly assigned one of the following four categories of condition (as per Tripp et al. 2019): *properly functioning condition (score 0-2)*; *functioning, but at risk (score 3-4)*; *functioning, but at high risk (score 5-6)*; and *not properly functioning (score >6)*. As with the full reach-scale RMREE protocol, an outcome of *properly functioning condition* or *functioning, but at risk* is considered good or "well managed", while the remaining two categories represent poor condition.

Table 3. Integration of ground-based stream data with GIS-derived riparian disturbance for the calculation of watershed condition. PFC = Properly Functioning Condition, FR = Functioning, but at Risk, FHR = Functioning, but at High Risk, NPF = Not Properly Functioning.

Weighted Stream Score		Percent Riparian disturbance (km/km) within 10 m of streams (Score)					
		< 0.12 (0)	0.12 <0.16 (1)	0.16-0.21 (2)	>0.21-0.25 (3)	>0.25-0.30 (4)	>0.30 (5)
Low	0	PFC	PFC	PFC	FR	FR	FHR
	>0-1	PFC	PFC	FR	FR	FHR	FHR
	>1-2	PFC	FR	FR	FHR	FHR	NPF
Mod	>2-3	FR	FR	FHR	FHR	NPF	NPF
	>3-4	FR	FHR	FHR	NPF	NPF	NPF
High	>4-5	FHR	FHR	NPF	NPF	NPF	NPF
	>5-6	FHR	NPF	NPF	NPF	NPF	NPF
Very High	>6-7	NPF	NPF	NPF	NPF	NPF	NPF
	>7-8	NPF	NPF	NPF	NPF	NPF	NPF
	>8-9	NPF	NPF	NPF	NPF	NPF	NPF

4.4.2 Sedimentation risk to water quality

The risk of sediment transfer from roads to streams was evaluated using the Water Quality Effectiveness Evaluation (WQEE) and results were utilized as supplementary data to help inform on the overall state of the watershed. The WQEE estimates the volume of sediment that may be potentially eroded from a road crossing over the course of a year and allows for the comparison of sites/road segments within a watershed or local area. The scoring of the eroded material is based on published literature (see Maloney et al. 2018), and the outcome categories are ranked according to the measured values at each site (Table 4).

Table 4. Values and associated categories of sediment generation used in the WQEE.

Total Volume of Fine Sediment generated at site (WQ Index)	Site Sediment Generation Potential Classes (based on consensus of field practitioners)	Associated General Level of Mangement of Site
<0.2 m^3	Very Low	Good
0.2-1 m^3	Low	
1-5 m^3	Moderate	
5-20 m^3	High	
>20 m^3	Very High	Poor

Scientific criteria for how cumulative impacts of sediment delivery (i.e., fine sediment, coarse sediment, and artificial drainage impacts on peak flow) affect the ecological function of watersheds is an area requiring more research. The current FREP Fisheries Sensitive Watershed Evaluation Procedure suggests a simple comparative approach to roll up site-scale evaluation of fine sediment delivery within a watershed into general classes of cumulative impact (Pickard et al. 2014). The benchmarks used in this study for each cumulative impact class are taken directly from provincial WQ data covering 7490 sites evaluated from 2008-2018, with a specific focus on the 433 sites sampled within the Selkirk Resource District (Table 5, derived from Maloney and Carson 2019). This approach enables us to understand how a watershed compares to other watersheds in the district and the province and provides useful information until more rigorous approaches are developed. However, the reader is reminded that these criteria are not grounded in scientific evidence of an ecological threshold, and any site given a moderate or higher ranking should be further investigated.

***Table 5.* Sites in each water quality category for data collected from 2008-2018.**

Unit	Very Low	Low	Moderate	High	Very High
Selkirk Resource District (N)	119	176	111	23	4
District %	27%	41%	26%	5%	1%
Province (N)	2011	3207	1847	364	61
Province %	27%	42%	25%	5%	1%

4.4.3 Habitat connectivity

The habitat connectivity assessments also provided supplementary information and were completed in fish-bearing reaches with fish passage requirements reflected in the measured attributes (Appendix I). In order to give detailed watershed-level conclusions regarding habitat connectivity, one would have to quantify the amount and quality of isolated fish habitat upstream of any barriers and consider the range, distribution, and habitat requirements of the species affected. There is some limited information given in this report as obtained from historical inventories, but no additional fish habitat assessments were conducted upstream of any of the identified barriers as part of this study. However, a fish stream with even one confirmed barrier should be considered impaired, as there have been regulations in place for fish passage since the Forest Practices Code was established in 1995. The scope of this study is to identify whether potential issues around habitat connectivity exist within the watersheds sampled, and any confirmed barriers can then be flagged for future investigation.

5.0 RESULTS

The following two tables allow for comparisons among all the study watersheds and will be used for reference in the subsequent sections that report out by specific watersheds. Two of the treatment watersheds were classed as *not properly functioning* after combining the stream and riparian assessment scoring as per Table 3, while one was found to be in *properly functioning condition* (Table 6). All the reference watersheds were ranked in the top two categories (*properly functioning condition* and *functioning, but at risk*), with three of the seven assessed to be *functioning, but at risk*.

***Table 6.* Riparian/stream watershed assessment results broken down by stream and riparian disturbance. PFC = properly functioning condition, FR = functioning, but at risk, FHR = functioning, but at high risk, NPF = not properly functioning.**

Watershed	Stream Score	Riparian Dist. %	Functioning Condition
Treatment Watersheds			
Boundary	3.2	31	NPF
Rock Creek	3.6	22	NPF
Redfish	1.6	11	PFC
Reference Watersheds			
Lynch	3.6	1	FR
Sandner	2.4	1	FR
Kokanee Trib. 101	0	0	PFC
Kokanee Trib. 100	0	0	PFC
Kokanee Trib. 93	3	3	FR
Kokanee Trib. 103	0	0	PFC
Kokanee Trib. 97	1	0	PFC

The proportion of water quality sites assessed in the *low* and *very low* risk categories ranged from 40-73% among all of the watersheds (Table 7). The lack of roads/crossings in six of the seven reference watersheds precluded assessments in these areas, with the assumption that there was no risk of sedimentation from roads in those basins. Although 60% of the crossings ranked as *moderate* or *high* in the Lynch watershed, this represents just three sites.

Table 7. Results for water quality assessments. Note that there were no crossings assessed in the Sandner or Kokanee reference watersheds.

Watershed (# sites)	% Very Low	% Low	% Moderate	% High	% Very High
Treatment Watersheds					
Boundary (22)	18	46	36	0	0
Rock Creek (15)	53	13	27	7	0
Redfish (11)	46	27	18	9	0
Reference Watersheds					
Lynch (5)	20	20	40	20	0

5.1 *Boundary Results*

5.1.1 Riparian/stream condition: not properly functioning

The Boundary Creek watershed was the largest in this study, with 21 sub-catchments sampled within the assessment polygon. Overall, the entire watershed was ranked as *not properly functioning* for the riparian/stream assessment, mainly because of the very high levels of human-caused *riparian* disturbance across the watershed (Table 6). Forestry was identified as the main development activity upstream in all but one of the sub-catchments, where agriculture was dominant, and there are more than 100 road crossings over streams in the watershed. The total proportion of the watershed affected by development was estimated by the assessors at 56% using aerial imagery and spatial layers.

At each site, general and specific causal factors related to impacts on *stream* channel indicator values were identified during the RMREE field assessments. Where the general causal factor could not be positively determined at the sample reach, "upstream factors" was selected. The proportion of indicator impacts was greatest in this category (Table 8), indicating that causes were most often related to unknown factors originating upstream. The specific indicators most affected by upstream factors were in-stream large woody debris processes, fish cover diversity, and fine sediments.

Table 8. Identified general causes of impacts to RMREE stream indicators.

Causal factors	# of affected sub-catchments (n=21)	% of total impacts
Upstream Factors (Unknown)	15	40
Natural Events	11	32
Roads	3	10
Other Impacts	2	8
Animal Disturbance	2	5
Logging	2	5

Where specific causes of impacts could be positively identified, the highest proportion of impacts to the stream indicators during the field assessments was attributed to flooding (Table 9). The indicators most frequently impaired by flooding were identified as in-stream large woody debris processes, stream bank stability, and connectivity (blockages).

Table 9. Top known specific causal factors impacting RMREE stream indicators.

Specific causes	% impacts where causal factor is known
Flooding	37
Mass Wasting	15
Livestock	12
Other (non-logging roads/trails)	10
Forestry road encroachment, running surface erosion	4

The 21 sub-catchments were each given a condition ranking based on their specific field-based stream indicator score and the GIS-derived percentage of riparian disturbance for the associated upstream drainage area. There was one sub-catchment that received a *properly functioning condition* ranking, but this drainage area only represented 1 % of the total assessed watershed, giving it low weight toward the total watershed ranking (Figure 3). Details on sub-catchment scoring is provided in Appendix III.

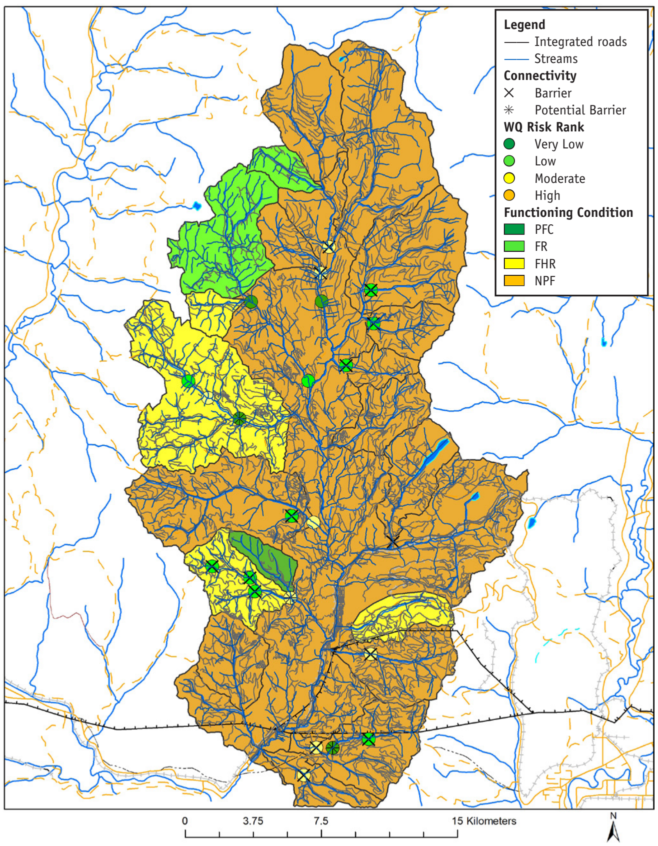

Figure 3. Map of Boundary sub-catchments with riparian/ stream, water quality, and habitat connectivity results.

5.1.2 Water quality and habitat connectivity

Water quality was measured at 22 stream crossings within the Boundary watershed. There were 17 known or defaulted fish streams at culverted sites that were assessed for habitat connectivity. Water quality results based solely on the amount of potential fine sediment that may be transported to streams varied (Figure 3), with 64% of the sites in the *very low* or *low* categories and 36% ranking as *moderate* (Table 10). Although there were not any results in the *high* or *very high* category, the proportion of sites in the *moderate* category is higher than the district and provincial benchmarks of 32% and 31%, respectively, for sites ranking *moderate* or higher (Table 4). There were six sites where it was noted that livestock were potentially compromising water quality by drinking, introducing fine sediments while crossing, and/ or defecating in the stream. All crossings assessed for habitat connectivity were determined to be a barrier or potential barrier, indicating that fish passage is limited in this watershed (Table 10; Figure 3). Twelve of these streams had previous habitat quality confirmations completed on them through the provincial fish passage program (B.C. Government 2019) and nine received an assessment of medium or high quality at or above the site. Provincial fish observation and distribution data obtained from the B.C. Data Catalogue (Data BC) shows the confirmed presence of rainbow and brook trout in the lower reaches of five of the catchments, suggesting that remediation work to restore fish passage at these crossings would benefit these populations.

Table 10. Water quality and fish habitat connectivity results for the Boundary watershed. Fish habitat data obtained from the Provincial Stream Crossing Inventory System (PSCIS).

Sample Site ID	Road Ref	FREP Rank	Livestock Issues Noted	Culvert Evaluation	Habitat Quality
1	Wallace 510	Low	No	Barrier	No Data
2	Wallace Creek FSR	Moderate	No		
3	Windfall Creek FSR	Very Low	Yes	Potential Barrier	Low
4	Windfall 800	Low	No		
5	Windfall 6800	Moderate	No		
6	Boundary Creek FSR	Moderate	No	Barrier	High
7	Deadwood 8800	Low	Yes	Barrier	Medium
8	Motherlode 800 0km	Low	Yes	Barrier	Medium
9	Motherlode 800 1km	Low	No	Barrier	Medium
10	Deadwood Road	Moderate	No	Potential Barrier	Medium
11	Sec. A	Moderate	No	Barrier	Medium
12	Gidon Creek Branch 1	Very Low	Yes	Potential Barrier	No Data
13	City of Paris Road	Low	No	Barrier	No Data
14	Norwegian Creek Rd	Moderate	Yes	Barrier	No Data
15	Norwegian Creek Rd	Moderate	No	Barrier	Medium
16	Boundary East FSR	Low	No	Barrier	High
17	Boundary East FSR	Low	No	Barrier	Low
18	Boundary East FSR	Low	Yes	Barrier	Low
19	Boundary Creek FSR	Moderate	No	Barrier	No Data
20	Macaroni Road	Very Low	No		
21	Boundary Creek FSR	Low	No		
22	Henderson Creek Rd	Very Low	No		
34	Res. Rd on Jewel Crk	Not eval for WQ	NA	Barrier	High

5.2 *Rock Creek Results*

5.2.1 Riparian/stream condition: not properly functioning

Although the Rock Creek watershed in this study is only a portion of the larger Rock Creek drainage system, the sampled sub-catchments provide a good representation of conditions within the designated assessment area. The study watershed consisting of 10 sub-catchments was ranked as *not properly functioning* overall for the riparian/stream component, with results just over the threshold in this category. The weighted *stream* indicator scores were slightly higher than those in the Boundary watershed, but *riparian* disturbance was lower (Table 6). Forestry was identified as the main type of development activity upstream in all but one of the sub-catchments, where roads were dominant. Like the Boundary watershed, there were more than 100 road crossings over streams in the Rock Creek watershed. The total proportion of watershed affected by development was estimated at 60% by the assessors using aerial imagery and spatial layers, though much of the harvesting was old.

The most common general causal factor related to the number of "No" answers in response to the RMREE *stream* indicator questions, signifying impacts to the indicators, was related to natural events (Table 11). The next most frequent causal factor was related to unknown factors originating upstream, indicating that the cause could not be ascertained at or near the sample reach. There were no impacts linked with logging at the sample reach, though it is possible that upstream logging or other development may have been contributing factors. The specific indicators most affected by both the natural and upstream factors were in-stream large woody debris processes, fine sediments, moss, connectivity (blockages), and channel bank stability.

Table 11. Identified general causes of impacts to RMREE stream indicators.

Causal factors	# of affected sub-catchments (n=10)	% of total impacts
Natural Events	7	41
Upstream Factors (Unknown)	7	33
Animal Disturbance	4	11
Roads	4	9
Other Impacts	2	6

Where specific causes of impacts could be identified, the highest proportion of impacts to the stream indicators in the assessments was attributed to flooding, with nearly half of the known indicator impacts affected by this factor (Table 12). Flooding was found to affect many of the stream indicators, with the most frequent being in-stream large woody debris processes, stream bank stability, and habitat connectivity.

Table 12. Top known specific causal factors impacting RMREE stream indicators.

Specific causes	% impacts where causal factor is known
Flooding	48
Forestry road encroachment, running surface erosion	15
Other (Mining, Recreation)	15
Livestock	12
Wildlife	6

The 10 sub-catchments were each given a condition ranking based on their specific field-based stream indicator score and the GIS-derived percentage of riparian disturbance for the associated upstream drainage area. There was one sub-catchment that received a *properly functioning condition* ranking, but this drainage area only represented 2.7% of the total assessed watershed, giving it low weight toward the total watershed ranking (Figure 4). Details on sub-catchment scoring are provided in Appendix III.

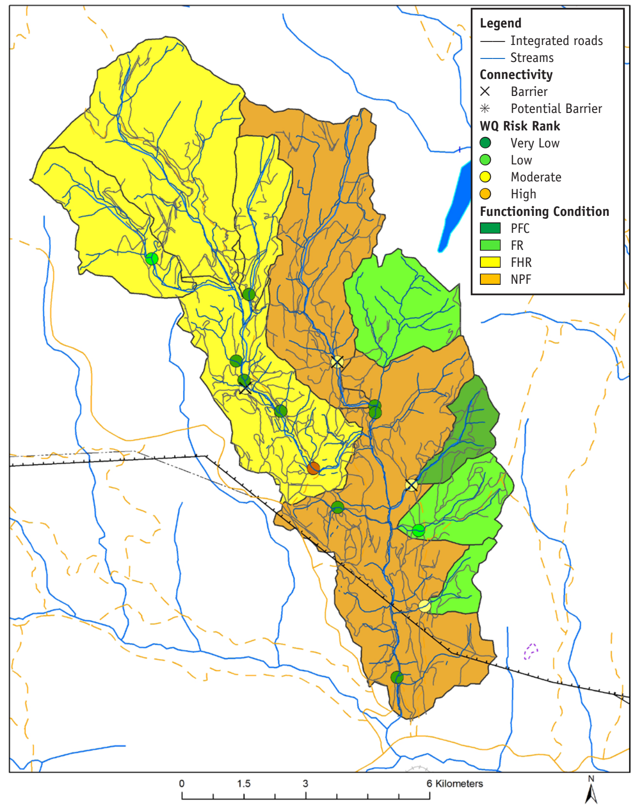

Figure 4. Map of Rock Creek sub-catchments with riparian/stream, water quality, and habitat connectivity results.

5.2.2 Water quality and habitat connectivity

Water quality was measured at 15 stream crossings within the Rock Creek watershed. There were three known or defaulted fish streams at culverted sites that were assessed for habitat connectivity. Water quality results based solely on the amount of potential fine sediment that may be transported to streams ranged from *very low* to *high* (Table 13), with 10 of the sites scoring in the *very low* or *low* categories. With four of the sites ranked as *moderate* and one site ranked as *high*, crossings in the Rock Creek watershed were slightly more at risk for transporting sediment to streams compared to other water quality sites in the district or province (Table 4). Eleven of the 15 sites were found to have livestock issues that could potentially contribute detrimental bacteria and other microorganisms to impair water quality. All three of the crossings assessed for habitat connectivity were determined to be barriers

(Table 13; Figure 4). Two of these streams had previous habitat quality confirmations completed through the provincial fish passage program and one received an assessment of medium quality above the site, while one was ranked low. Provincial fish data confirmed the presence of rainbow and brook trout in the Rock Creek mainstem. Further investigation into the benefits of restoring fish passage at the crossing with medium quality upstream habitat, including the identification of any additional downstream barriers, should be considered.

Table 13. Water quality and fish habitat connectivity results for the Rock Creek watershed. Fish habitat data obtained from the Provincial Stream Crossing Inventory System (PSCIS).

Sample Site ID	Road Reference	FREP Rank	Livestock Issues	Culvert Eval.	Habitat Quality
1	Stanhope FSR	Moderate	Yes	Barrier	Medium
2	Belchrome North spur	Very Low	Yes		
3	Wapiti FSR	Low	Yes		
4	Spur off BDBelchrome 2900	Very Low	Yes		
5	BDA91513BLK3SPUR1	Moderate	No	Barrier	No Data
6	Belchrome FSR	Very Low	Yes		
7	Private driveway	Very Low	No		
8	Fish Lake West Road	High	No		
9	BDMcDermid 1000	Very Low	Yes		
10	Old road south of Little Fish Lk	Very Low	Yes		
11	Old road south of Little Fish Lk	Very Low	No		
12	Little Fish FSR	Moderate	Yes	Barrier	Low
13	Little Fish FSR	Low	Yes		
14	Fish Lake Road	Moderate	Yes		
15	Canyon Road	Very Low	Yes		

5.3 *Redfish Results*

5.3.1 Riparian/stream condition: properly functioning

There were 11 sub-catchments sampled within the Redfish watershed located in the Kootenay Lake drainage area and together these delivered an overall ranking of *properly functioning condition*. The weighted *stream* indicator score for the Redfish watershed was 1.6 and total *riparian* disturbance was 11% (Table 6). Forestry was identified as the main development activity upstream, though more than half of the harvesting near streams was more than 20 years old, and there was very limited development in the northernmost basins. There was also a much lower road density network compared to the two treatment basins in the Kettle River drainage, with only 17 road crossings in the Redfish watershed. The total proportion of watershed affected by development was estimated at 12% by the assessors using aerial imagery and spatial layers.

At sub-catchments where *stream* indicators were impaired, the most common general causal factor was related to roads (Table 14). The specific indicators most affected by roads were channel bed integrity, moss, and fine sediments. The next most frequent causal factor was related to unknown events or activities upstream, indicating that the cause could not be ascertained at the sample reach. There were no impacts linked with logging at the sample reach, though it is possible that logging or other development upstream may have been contributing factors.

Table 14. Identified general causes of impacts to RMREE stream indicators.

Causal factors	# of affected sub-catchments (n=11)	% of total impacts
Roads	6	46
Upstream Factors (Unknown)	5	42
Natural Events	2	8
Other Impacts	1	4

Where specific causes of impacts could be identified (i.e., not labeled as "unknown upstream factors"), the highest proportion of impacts to the stream indicators in the assessments was attributed to road surface erosion, which affected more than half of the indicators (Table 15). Mass wasting resulting from roads was also a major factor and together these two factors were responsible for effects that were noted to the channel bed, moss, and fine sediment indicators.

Table 15. Top known specific causal factors impacting RMREE stream indicators.

Specific causes	% impacts where causal factor is known
Road running surface erosion	59
Mass wasting caused by roads	29
Wind	6
Other (Agriculture)	6

The 11 sub-catchments were each given a condition ranking based on their specific field-based stream indicator score and the GIS-derived percentage of riparian disturbance for the associated upstream drainage area. There were no sub-catchments ranked as *not properly functioning* and only two that were *functioning, but at high risk* (Figure 5). Four of the larger northernmost sub-catchments received a *properly functioning condition* ranking, which likely influenced the weighted watershed score and overall watershed condition despite the mainstem residual catchment assessment of *functioning, but at risk*. Details on the sub-catchment scoring is provided in Appendix III.

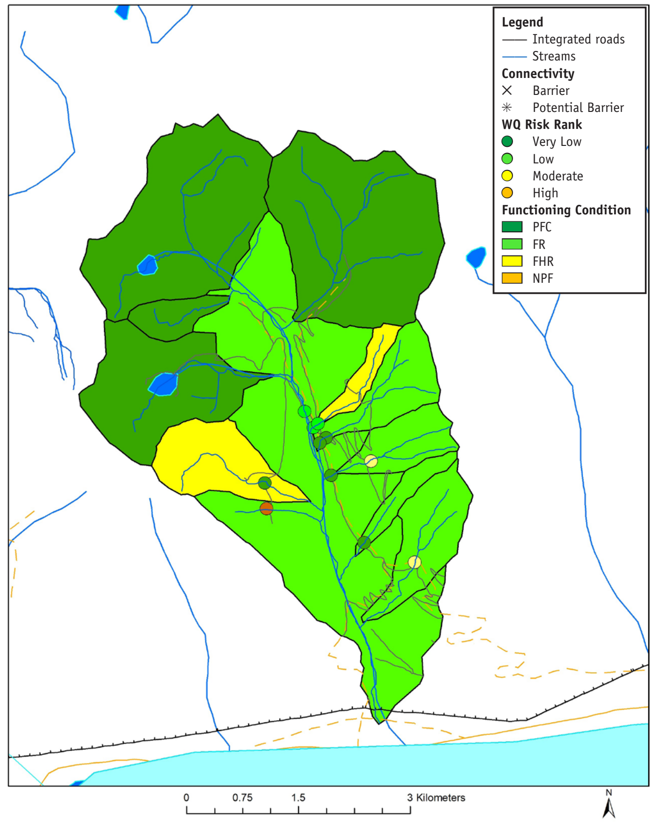

Figure 5. Map of Redfish sub-catchments with riparian/stream and water quality results.

5.3.2 Water quality and habitat connectivity

Water quality was measured at 11 stream crossings within the Redfish watershed. No habitat connectivity assessments were completed because all the streams where water quality assessments were completed were either too steep to be fish bearing or the crossing structure was a bridge or arch culvert, indicating fish passage was not an issue. Water quality results based solely on the amount of potential fine sediment that may be transported to streams ranged from *very low* to *high* (Table 16), with 73% of the sites scoring in the *very low* or *low* categories. Two sites ranked as *moderate*, which is below the benchmark for the district and the province for that category (Table 4). One of the sites was ranked as *high* because of mass wasting associated with the road right-of-way (Figure 6).

Figure 6. Redfish water quality site ranked as **high.**

Unlike the Boundary and Rock Creek watersheds, there were no livestock issues observed at the Redfish crossing sites (Table 16).

Table 16. Water quality results for the Redfish watershed.

Sample Site ID	Road Reference	WQ FREP Rank	Livestock Issues Noted
1	Redfish East FSR	Very Low	No
2	Redfish FSR	Very Low	No
3	Redfish FSR	Very Low	No
4	Redfish FSR	Very Low	No
5	Redfish FSR	Moderate	No
10	Redfish West FSR	High	No
11	Redfish West FSR	Very Low	No
12	Redfish FSR	Low	No
14	Redfish Southeast	Moderate	No
15	Redfish FSR	Low	No
16	Redfish North FSR	Low	No

Interestingly, the water quality ranking did not always correlate with downstream riparian results that identified roads as a causal factor. This could be because the assessment is only a snapshot in time and if a road is only occasionally used, the evaluation could miss the initial influx of sediment before weather amours the road surface. This means that it is possible that water quality results at a crossing could be ranked as low, but there could still be road sediments in the stream channel affecting form and function. Additionally, road sediments in a stream channel may be cumulative and representative of several road crossings upstream, where the water quality assessment only evaluates the potential fine sediment influx at a single crossing.

5.4 *Reference Watershed Results*

5.4.1 Riparian/stream condition

The seven reference watersheds were either *functioning, but at risk* or in *properly functioning condition* (Table 6). The lowest scores, indicating the fewest indicator impacts, were found in the smaller watersheds, suggesting that the stream channels in these drainages were not as disturbed. The larger watersheds exhibited *stream* values similar to those in the treatment watersheds. Although the stream scores in the larger reference watersheds were higher, the *riparian* disturbance was absent or very low, which resulted in better overall condition compared to the treatment watersheds. The top causal factor linked to stream indicators among all reference watersheds was identified as natural events, affecting indicators in nine of the sub-catchments (Table 17).

Table 17. Identified general causes of impacts to RMREE stream indicators.

Causal factors	# of affected sub-catchments (n= 14)	% of total impacts
Natural Events	9	59
Upstream Factors (Unknown)	6	27
Logging	1	7
Other Impacts (Not specified)	1	7

Where specific causes could be identified, the highest proportion of impacts to the stream indicators in the reference watershed assessments was attributed to flooding, with nearly half of the known indicator impacts affected by this factor (Table 18). The Lynch site, located lowest in the watershed (Site 40), was affected to a small extent by fires and logging, although the area represented by riparian harvesting was just 1.5%. It is possible that the overall Lynch watershed outcome could have been improved by sampling additional sub-catchments immediately above the harvest activity, but stream indicator results in a non-burned and non-harvested catchment located higher within the Lynch watershed (Site 41) were very similar to the site below the harvesting because of similar impacts from flooding effects. Details on sub-catchment results are provided in Appendix III.

Table 18. Top known specific causal factors impacting stream indicators.

Specific causes	% impacts where causal factor is known	Watershed affected
Flooding	45	Lynch, Sandner
Fire	20	Lynch
Low Retention (logging)	15	Lynch
High background sediment levels	10	Kokanee Trib.
Wind	5	Kokanee Trib.
Disease	5	Lynch

5.4.2 Water quality and habitat connectivity

Lynch was the only reference watershed that contained crossings for water quality and habitat connectivity assessments as there was some harvest activity in the lower portion of the basin. Three out of five of the water quality assessments were ranked *moderate* or *high* risk and the one culvert assessed was confirmed to be a barrier (Table 19). This barrier was located on a 2nd order tributary to the Lynch Creek mainstem. There were no historical habitat or fish data for this stream reach.

Table 19. Water quality and fish habitat connectivity results for the Lynch watershed.

Sample Site ID	Road Reference	WQ FREP Rank	Livestock Issues Noted	Culvert Eval.	Habitat Quality
1	Lynch 2600 FSR	Moderate	No		
2	BD Lynch 2657	Very Low	No	Barrier	No Data
3	Lynch Creek FSR	High	No		
4	Gladstone FSR	Low	No		
5	Gladstone FSR	Moderate	No		

5.5 *Differences Between Treatment and Reference Watersheds*

To identify differences between treatment and reference watersheds, the combined score representing ground-based and GIS data for all sub-catchments was entered into a weighted, by proportional area, analysis of variance (ANOVA). The overall weighted cumulative score for each watershed was not included in this analysis to avoid any effects from autocorrelation. Similarities were found between the *not properly functioning* Boundary and Rock Creek watersheds, and these were significantly different from all the other watersheds (Figure 7). Redfish was similar to four of the reference watersheds, but significantly different than Boundary and Rock Creek, indicating that the Redfish watershed is closer to a natural condition.

Three of the Kokanee reference watersheds located in the Kootenay Lake drainage were significantly different from six other watersheds, likely because these were single-sample catchments and both their stream and riparian impact scores were zero. The lack of impairment at these three Kokanee watersheds may be because they are small headwater drainages and lack transport potential. Like the upper sub-catchments of Redfish, they are higher elevation and undeveloped, which means water may be held in the snowpack longer and the risk of downstream flooding is less compared to catchments in the Kettle River drainage.

It should be noted that the similarities and differences shown in Figure 7 are based only on the integrated riparian/stream condition for the watersheds and do not consider the supplementary data reflecting potential effects from: limited habitat connectivity at stream crossings, livestock issues, or continued risk of sedimentation from roads. For example, even though Redfish results were not significantly different from several of the reference watersheds, three of the fourteen water quality sites scored as *moderate* or *high* risk (Table 16) and these problem crossings could be a continued source of sediment to downstream reaches that contribute to domestic water supply. These other factors should be considered when determining whether watersheds are impaired.

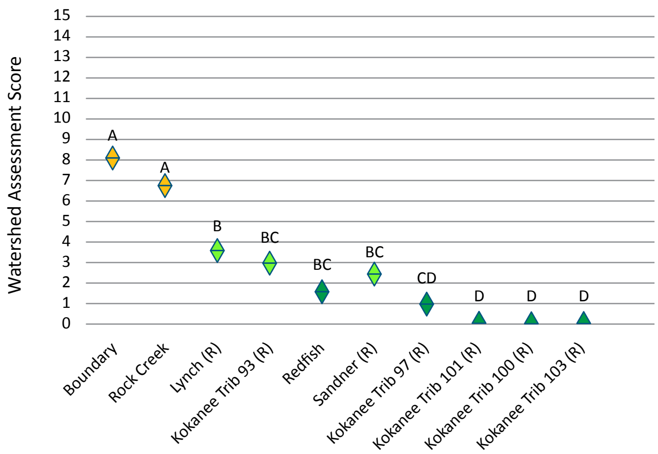

***Figure 7.* *Total watershed score reflecting level of impairment for treatment and reference (R) watersheds. Watersheds not connected by the same letter are significantly different. Dark green shading =* PFC*, light green =* FR*, orange =* NPF.**

One of the questions posed during the planning of the study was whether harvest-related activities had contributed to flooding and subsequently impaired functioning condition in the treatment basins. While it is not possible to separate upstream harvest-related effects from those that may be a result of other types of development, we investigated whether there are differences between treatment and reference watersheds using only the results from the stream-related indicators as these can be indicative of upstream activities (Nordin et al. 2009a).

To compare watersheds equally, natural influences on variability were first identified using the attributes measured in completing field assessments for the reference sub-catchments only. There are between 36-41 stream attributes measured to answer sub-indicator questions within the RMREE protocol, depending on channel morphology (Tripp et al, 2019). These attributes and the rationale for their inclusion in the assessment can be found in Appendix II. The sub-indicator responses are used to help answer the main indicator questions – including this data in the analysis was considered useful in determining any underlying natural variation. A stepwise regression identified gradient and stream order as significant covariates in the responses to the sub-indicator questions, meaning that indicator data linearly increases or decreases with changes in stream order and channel gradient. These variables were included in a generalized linear model (GLM) to remove the effect of natural variation and produce adjusted means for the stream scores for the main indicators by which the watersheds could be compared equally. A one-way ANOVA using the adjusted stream scores in a weighted design by sub-catchment proportional area revealed that the Redfish watershed was not significantly different than one of the nearby Kokanee reference watersheds or from Sandner, a reference watershed in the Kettle River drainage system. Boundary and Rock Creek were similar to one another but were also not significantly different from both nearby reference watersheds, Lynch and Sander. Boundary was also similar to one of the Kokanee Creek reference watersheds. These results suggest there is overlapping variability in the stream indicator results among watersheds that prevents the determination that human development has caused flooding in treatment watersheds.

The similarity in the stream indicator results between treatment and reference watersheds makes it difficult to conclude the extent at which upstream development has contributed to impacts to stream channels. This is likely because surface flows have been high enough in the reference watersheds to affect the indicators that are used in part to determine functioning condition. Therefore, any flooding over and above those naturally occurring high flows would not have been picked up by the assessment. The sub-indicator data used to answer the main indicator questions for stream channel integrity were tested in linear regressions and there were three that were significantly related to both the total percentage of upstream development in the watershed and the percent disturbance within 10 m of the stream. Positive relationships were identified between the percentage of upstream development and: 1) recent LWD accumulations in the channel; and 2) bank disturbance, meaning LWD accumulations and bank disturbance increase with upstream development. A negative relationship was identified between upstream development and the abundance of moss. However, the strength of all correlations were weak (r^2 = 0.15-0.2), mainly because there was high variability in the data where upstream development was low or absent. These findings indicate that, while there are linear relationships between increasing upstream development and impairment of specific stream indicator attributes, flooding in both the treatment and reference reaches have confounded the results and prevented any conclusive determinations of cause and effect or magnitude of human-caused impacts.

6.0 DISCUSSION AND RECOMMENDATIONS

The Boundary and Rock Creek treatment watersheds were assessed to be *not properly functioning* using a routine-level watershed evaluation. This assessment was based on a pour-point design for sample site selection and used a weighted scoring system with field and GIS information to derive a condition ranking similar to the reach-level RMREE protocol in use since 2006. The third treatment watershed in this study, Redfish, was assessed to be in *properly functioning condition*. Three of the reference watersheds received a ranking of *functioning, but at risk*, while the remaining four reference watersheds were found to be in *properly functioning condition*. The reference watersheds receiving the top condition ranking were also the smallest and located in the Kokanee Creek drainage, which is relatively higher in elevation compared to the other watersheds where flow regimes are likely different. The *properly functioning* upper catchments of Redfish are in similarly higher elevations and these areas have also received limited disturbance, which could have resulted in a more regulated release of water during snowmelt. This may explain in part why Redfish results were better than several of the basins in the Kettle River drainage where elevations are lower, and disturbance is much higher. Where causal factors could be positively linked to indicator impacts, flooding was the most frequently identified cause in both treatment and reference watersheds located in the Kettle River drainage area.

There were significant differences in the overall condition scores given to the Boundary and Rock Creek watersheds compared to all other watersheds, and these differences can be attributed mainly to human-caused riparian disturbance. The differences in stream indicator values alone between treatment and reference watersheds were more difficult to ascertain, even after the effect of natural variability was removed. This may be because after specific thresholds for main indicator impairment are crossed, the indicator is assigned a "No" response rather than a continuous variable, so streams that have different levels of disturbance over and above threshold values display similar results.

The high proportion of riparian disturbance in the Boundary and Rock Creek watersheds was a significant factor in their *not properly functioning* outcomes. Upstream factors and flooding were identified as main causal factors related to stream indicator impairment. Though it is uncertain as to exactly how much influence logging and roads have had on the magnitude of recent flood events in the watersheds examined in this study, the high level of riparian harvesting in the Boundary and Rock Creek watersheds suggest that there is a reduced buffering capacity in these systems to facilitate the regulation of surface water flows.

These results are especially important considering the lower portions of these basins had been identified as *high* risk during planning with respect to the water quantity component of a cumulative effects assessment, which included disturbance metrics such as cutblocks and roads (FLNRORD 2019b). Increases in the timing, magnitude and frequency of peak flows after harvesting are well known (Green and Alila 2012; Schnorbus and Alila 2013; Winkler et al. 2017) and additional development activities within watersheds with existing high levels of disturbance and lowered stream resilience, such as in Boundary and Rock Creek, should be carefully reviewed by a hydrologist to quantify risk. Harvesting or other clearing activities should not only incorporate machine-free zones and riparian buffers around all water features, but also include mitigation measures to reduce the connectivity of surface water runoff from roads to streams. Careful planning, development, and maintenance of any bare/compacted soil features, such as roads, ditch lines, landings, and cut/fill slopes, should be implemented with the objective of minimizing overland flow and sediment transfer to stream channels. Upgrading old roads rather than constructing new ones, and deactivating and rehabilitating any crossings no longer in use would also be beneficial.

Although the Redfish watershed was in better condition overall, the lower portion was more at risk compared to the headwater catchments, with the most common causal factor linked to roads. This is consistent with a long-term sediment monitoring project that found the bedrock geology in Redfish contributes to a higher transfer of surface water runoff from roads to streams compared to a groundwater-driven watershed, making Redfish more sensitive to increases in water turbidity (Jordan 2006). Implementing the same practices as described for the Boundary and Rock Creek drainages for roads and avoiding steep or otherwise unstable ground for the construction of any new roads is recommended. Grass seeding of exposed cut slopes or other ground that may be hydrologically connected, and inserting cross drainages or ditch blocks where appropriate, are examples of methods to reduce the transfer of sediment to streams. Road maintenance should include strategies such as crowning and berm breaks to dissipate road surface runoff. Limiting new harvesting and roads in the higher elevations should also be considered to avoid any potential increases in peak flows and transfer of suspended sediment to downstream reaches.

Investigating existing problem areas identified in the supplementary water quality and fish habitat connectivity results is also recommended to improve function not otherwise accounted for in the riparian/stream evaluation. Ease of access could be assessed at stream crossings where cattle were observed to evaluate the efficacy of implementing range barriers or cattle guards. Establishing low-risk watering sites combined with attractants and stable ford crossings may be additional considerations to minimize the impacts from cattle. Crossings that ranked moderate or higher for the potential transfer of fine sediments during the water quality assessments could also be critically reviewed to identify potential improvement strategies, along with those crossings where culverts are a barrier to upstream fish passage. Implementing solutions for these and any other known problem areas would result in an immediate benefit to the overall functioning condition of these watersheds.

APPENDIX I. RAPID ASSESSSMENT FOR BARRIER DETERMINATION – CLOSED BOTTOM STRUCTURES

To evaluate closed bottom structures (pipe culverts) only.

* SWR = Stream Width Ratio is calculated as natural channel width/culvert diameter.

Attribute	Measurement	Category Score	Field Score
Embedded	Continuous and embedded > 30cm or 20% of pipe diam.	0	
	Continuous, but <30cm or 20% pipe diam.	5	
	Discontinuous or not embedded	10	
Outlet Drop (perch)	< 15 cm	0	
	15-30 cm	5	
	>30 cm	10	
Culvert Slope	<1%	0	
	1-3%	5	
	>3%	10	
SWR *	<1.0	0	
	1.0-1.3	3	
	>1.3	6	
Culvert Length	<15m	0	
	15-30m	3	
	>30m	6	
Total Field Score			

Barrier Determination

Total Field Score	Determination
0-14	Passable
15-19	Potential Barrier
20+	Barrier

Record additional observations regarding potential blockages[1] in stream within culvert and road right-of-way

____

[1] For fish streams, consider debris or sediment accumulations a blockage if the height of the obstruction is more than twice the channel depth immediately below it. For all streams, if recent sediment or debris deposits are preventing more than 2/3 of the flow (at bankfull depth) from remaining in the channel, consider it a blockage (i.e., flow is or will be forced above or around the obstruction; look for signs of erosion if flows are low).

APPENDIX II. RMREE STREAM INDICATORS AND MEASURED ATTRIBUTES

Question #1 • Is the channel bed undisturbed?

Disturbance, such as aggradation or degradation, can simplify a stream channel and reduce productive fish habitat. Impacts from logging can cause either too much sediment (i.e., from eroding roads, collapsing banks) or too little (concentrated in traps caused by log jams or inappropriately sized culverts). Either situation will result in a less complex morphology characterized by a reduction in pools and a more uniform channel depth. Attributes that may lead to a failure for this indicator question include increases in mid-channel bars, sediment wedges, multiple channels, or a lack of lateral bars.

Question #2 • Are the channel banks intact?

Forest harvesting can alter the amount and type of vegetation on stream banks, thereby reducing resistance to fluvial erosion. Disturbed banks contribute fine and/or coarse sediments to the stream. Fine sediments fill in void spaces between gravels and affect invertebrate diversity and fish spawning potential. Coarser sediments cause channel aggradation and can lead to a reduction of pools and possible dewatering. Eroded banks can result in a wider and shallower stream that is more susceptible to warming. Attributes that may lead to a failure for this indicator question include excessive bank disturbance, the absence of deep-rooted vegetation, the lack of stable undercut banks, and recently upturned root wads.

Question #3 • Are channel LWD processes undisturbed?

LWD in the stream channel not only provides fish habitat, but also regulates sediment transfer and controls alluvial channel morphology. Impacts from harvesting can be gauged by examining the type, abundance, and position of LWD accumulations. Attributes that may lead to a failure for this indicator question include abundant recently deposited LWD, excessive accumulations that span the channel, parallel LWD in the stream, and removal of LWD by equipment or weather events.

Question #4 • Is the channel morphology intact?

Pools and riffles are important components of productive fish streams. The reduction of pools or riffles caused by harvesting activities will lead to diminished fish habitat. Attributes that may lead to a failure for this indicator question include lack of pools, absence of deep pools (double the riffle depth), and sediment texture homogeneity.

Question #5 • Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?

In-channel debris can contribute to log jams and excessive build-up of sediments that can be a barrier to the movement of water, nutrients and organic matter downstream, and fish in both directions, thereby affecting habitat for aquatic and semi-aquatic species both at the reach scale and downstream. Attributes that may lead to a failure for this indicator question include the presence of recent blockages, downcutting, crossing structure-related accumulations, dewatering, and channel diversion.

Question #6 • Does the stream support a good diversity of fish cover attributes?

Fish cover diversity is indicative of an undisturbed stream with a well-developed riparian area. Although actual amounts of the cover can vary, it is rare for a properly functioning system to have less than five different types of cover. Attributes that may lead to a failure for this indicator question include a lack of diversity in the following types of fish cover: deep pools, boulders, organic material, undercut banks, aquatic vegetation, overhanging vegetation, and a stable mineral substrate with void spaces.

Question #7 • Does the amount of moss present in shallow areas of the channel indicate a stable and productive system?

The relative abundance of a healthy growth of moss can be linked to fish and invertebrate productivity. The presence of moss in vigorous condition indicates moderate flows, clean water, a stable streambed of adequately sized substrate, sufficient shading and nutrient levels. If any of these qualities are altered, the abundance or health of moss will decline. Attributes that may lead to a failure for this indicator question include absence or poor condition of moss.

Question #8 • Has the introduction of sand or fine inorganic sediments been minimized?

Fine-textured sediment can impact spawning and rearing habitat for fish by filling in the spaces between gravels and blanketing the substrate. Invertebrate habitat will also be affected and sensitive species (those with external gills) will be limited. Attributes that may lead to a failure for this indicator question include abundance of fine sediment particles, single large areas of recently deposited (soft) sediment, substrate embeddedness, and the absence of sensitive invertebrates.

Question #9 • Does the stream support a diversity of aquatic invertebrates?

Invertebrates are sensitive to sand, silt, toxic compounds, and pollutants, and are good indicators of a healthy stream with clean water. The number of invertebrates is not as important as the diversity of species because of the implication that a larger community requires a wider range of stable environmental conditions. When clearing or other development causes large fluctuations in flow, water temperature or turbidity, species numbers will decline until only those that can adapt persist. Attributes that may lead to a failure for this indicator question include low numbers of sensitive invertebrate species, major invertebrate groups, insects, and total invertebrate species.

APPENDIX III. SUB-CATCHMENT RESULTS BY WATERSHED

Watershed Condition: PFC = Properly Functioning Condition; FR = Functioning, but at Risk; FHR = Functioning, but at High Risk; NPF = Not Properly Functioning.

Sample	Watershed	Catchment Area (km^2)	Stream Score	% Riparian Disturbance	Watershed Condition
18	Boundary	10.5	1	0.369	FHR
19	Boundary	38.2	2	0.315	NPF
22	Boundary	6.1	2	0.448	NPF
32	Boundary	15.7	0	0.325	FHR
21	Boundary	13.9	4	0.255	NPF
28	Boundary	27.6	1	0.195	FR
23	Boundary	10.6	2	0.439	NPF
27	Boundary	7.7	3	0.329	NPF
26	Boundary	6.0	1	0.176	FR
30	Boundary	53.2	1	0.400	FHR
29	Boundary	5.5	1	0.352	FHR
39	Boundary	22.5	5	0.259	NPF
24	Boundary	32.3	4	0.342	NPF
16	Boundary	22.8	2	0.404	NPF
17	Boundary	19.9	2	0.317	NPF
34	Boundary	15.7	3	0.286	NPF
25	Boundary	42.5	3	0.283	NPF
35	Boundary	9.4	2	0.384	NPF
38	Boundary	14.7	4	0.360	NPF
31	Boundary	5.8	1	0.110	PFC
36	Boundary	198.2	5	0.274	NPF
101	Kootenay_sub	0.4	0.0	0.000	PFC
100	Kootenay_sub	0.7	0.0	0.000	PFC
93	Kootenay_sub	9.7	3.0	0.028	FR
103	Kootenay_sub	2.3	0.0	0.000	PFC
97	Kootenay_sub	0.4	1.0	0.000	PFC
41	Lynch	55.1	4.0	0.000	FR
42	Lynch	1.0	2.0	0.000	PFC
70	Lynch	15.6	1.0	0.029	PFC
71	Lynch	5.1	1.0	0.000	PFC
40	Lynch	97.3	4.0	0.015	FR
4	Redfish	1.1	1.0	0.203	FR
5	Redfish	0.4	3.0	0.243	FHR
7	Redfish	2.7	1.0	0.136	PFC
8	Redfish	0.5	2.0	0.055	PFC
1	Redfish	1.3	4.0	0.016	FR
3	Redfish	0.9	2.0	0.139	FR
11	Redfish	1.5	2.0	0.265	FHR
15	Redfish	8.7	2.0	0.180	FR
6	Redfish	4.7	0.0	0.057	PFC
9	Redfish	4.3	2.0	0.000	PFC

Sample	Watershed	Catchment Area (km^2)	Stream Score	% Riparian Disturbance	Watershed Condition
2	Redfish	0.4	4.0	0.081	FR
60	Rock Crk	22.6	4.0	0.224	NPF
67	Rock Crk	16.0	5.0	0.138	FHR
68	Rock Crk	6.5	4.0	0.193	FHR
58	Rock Crk	1.4	3.0	0.042	FR
59	Rock Crk	3.9	3.0	0.153	FR
62	Rock Crk	2.4	1.0	0.092	PFC
65	Rock Crk	14.6	4.0	0.243	NPF
64	Rock Crk	5.5	1.0	0.203	FR
66	Rock Crk	4.1	4.0	0.172	FHR
69	Rock Crk	11.9	2.0	0.281	FHR
106	Sandner	10.3	5.0	0.000	FHR
105	Sandner	56.0	2.0	0.010	PFC
107	Sandner	2.9	2.0	0.000	PFC
108	Sandner	9.5	2.0	0.000	PFC

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