Chapter 8 Appendices

Tier I Fisheries Sensitive Watersheds (FSW) monitoring protocol rationale

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P.O. Box 9338, Stn Prov Govt
Victoria, BC, V8W 9M1

Prepared by

Marc Porter, Emily Snead, Simon Casley, Katherine Wieckowski
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, BC V6J 5C6

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Table of contents

List of Figures

List of Tables

1.0 Introduction

1.1 Background

In 2004, the government of British Columbia took steps towards protecting the social, ecological, and economic fisheries values in the province by putting into force the *Government Actions Regulations* (GAR). Under section 14 of the GAR, the Minister of Environment (MOE) is authorised to designate a watershed as a Fisheries Sensitive Watershed (FSW) that has both i) significant fish values and ii) watershed sensitivity. To qualify as a FSW, watersheds must meet two criteria: they must have significant fisheries values and watershed sensitivity. For a description of the process for designating a watershed as a FSW refer to Reese-Hansen and Parkinson (2006). Watersheds which have been designated as FSWs by the Minister require Forest Act agreement holders to establish results and strategies in their Forest Stewardship Plans consistent with the objective(s) set by the Minister. A FSW designation acknowledges the considerable benefits derived from British Columbia's fisheries resources and provides the legal framework that will require forest and range operators to undertake practices that maintain the natural watershed processes that conserve the ecological attributes necessary to protect and sustain fish and their habitat (Reese-Hansen and Parkinson 2006). To date, thirty-one FSWs have been designated by the MOE and over the course of the next several years there are plans to identify and designate additional watersheds throughout the province as FSWs (L. Reese-Hansen, BC Ministry of Environment, pers. comm.).

FSW designation has been undertaken for two reasons. First, designation is intended to conserve natural hydrological conditions, bed dynamics and channel integrity, as well as the quality, quantity, and timing of water flow. Second, designation is intended to prevent cumulative effects that would have adverse effects on fish habitat. Ultimately, the goal of FSW designation is to conserve fish habitat and the natural functions and processes required to maintain fish habitats now and in the future, while forest management activities proceed. Effectiveness monitoring is required to determine if FSW designation has achieved this goal.

MOE has been working with ESSA Technologies Ltd. to develop a comprehensive monitoring framework for FSWs along with supporting sampling design and GIS monitoring protocol. In 2008/2009, ESSA Technologies drafted a conceptual framework for monitoring FSWs (Wieckowski et al. 2008), as well as outlining a work plan to pilot the FSW monitoring framework (Pickard et al. 2009). In early 2009, ESSA drafted a framework for monitoring FSWs (Wieckowski et al. 2009) which was reviewed by the FSW working group during a workshop. A final version of the framework was released post workshop, and coupled with the work plan, constitutes the foundation for the current phase of work.

1.2 Report purpose

This purpose of this document is to provide the scientific rationale for the Tier 1 GIS-based FSW monitoring protocol (see Wieckowski et al. 2011). This document can be broken down into three sections. The first section of the document provides an overview of the province's Watershed Assessment Procedure (WAP) and provides much of the initial thinking and structure around the GIS protocol for FSWs. The intent of the FSW GIS protocol is to function as a coarse "WAP-lite" approach to determining watershed condition that can be applied broadly across the province's FSWs. The second section identifies the remote sensed indicators used in the protocol, the rationale behind selecting each of the indicators and their respective metrics, and the available agency data sources that can be used to inform each of the indicators. The last section summarizes recommendations and next steps necessary for implementation of the GIS protocol.

2.0 Overview of Watershed Assessment Procedure

2.1 Purpose

A fundamental role of forest hydrologists and geomorphologists throughout British Columbia is to assess forested watersheds with the intention of predicting and detecting changes over time. Among the many different methods to quantify these changes, a watershed assessment procedure (WAP) is a key step in the initial evaluation of an identified watershed. A WAP classifies net effects of past land-use and disturbance events (including forest fires, mass wasting, erosion, windthrow, etc.) and projects future effects of continued forest development and natural disturbance (Pike et al. 2007). In effect, a WAP evaluates a watershed's current functioning condition and its likely future state as a result of human and natural activities.

In 1999, the British Columbia watershed assessment procedure was redefined as, "…an analytical procedure to help forest managers understand the type and extent of current water-related problems that may exist in a watershed, and to recognize the possible hydrologic implications of proposed forestry-related development or restoration in that watershed" (BC MOF 2001). Water-related issues within a watershed are largely influenced by the cumulative effects of indicators including road density, riparian disturbance, stream crossing density, landslide occurrence, equivalent clear-cut area, surface erosion, etc. Results from a WAP can be used to guide watershed restoration activities in addition to providing planning and operational programs with integrated watershed information.

The purpose of a WAP is to provide watershed-level recommendations for forest development plans, based on an assessment of the potential for cumulative hydrological effects from past and future forest development (BC MOF 2001). Using the results from a WAP, forest managers can infer recommendations to mitigate or even prevent the impacts of forestry-related activities in a watershed. Indicators that highlight these impacts include the density of roads, logged slopes >60%, riparian logging, equivalent clear-cut area, and so on. A WAP combines each individual indicator to determine their cumulative effects so scientists can further understand the interactions between each indicator that ultimately effect watershed health (Sawyer and Mayhood 1998).

2.2 Indicator classes

A common challenge with any watershed assessment procedure is finding balance between addressing complex processes and conducting assessments in a timely, cost-effective manner (Pike et al. 2007). During a WAP, technical modules are applied which incorporate the use of GIS analysis, field work and professional judgment. A thorough compilation of existing and available remote sensing information is usually gathered to provide a detailed overview of a given watershed for a WAP. Examples of available datasets include recent aerial photographs, 1:20,000 TRIM topographic data, geologic and soils maps, aquatic features, forest cover maps, road features, zones dominated by snowpack, snowmelt, etc.

For Tier 1 FSW monitoring our focus is to develop a comparable but even more widely applicable and lower cost assessment approach (i.e. WAP-lite) based solely on easily obtainable GIS data; data that can be used to inform consistent assessments of the province's FSW watersheds on a regular repeat basis (Pickard *et al*. 2009).

The use of remote sensing data in watershed analysis can provide an efficient alternative to costly field-based data acquisition. Remote sensing can inform broad-scale monitoring of habitats at high spatial resolutions without causing habitat disturbance (Wieckowski *et al.* 2008). Remote sensed data can also be especially important for monitoring watersheds whose large size and/or rugged terrain would otherwise limit ground-based measurements and field studies. An increasing number of remote sensed datasets are becoming available for use, and are commonly projected into GIS software to allow for cost-efficient and long-term analysis of watershed environments. Numerous agencies in British Columbia currently assemble and use remote sensed datasets to map/quantify forest habitat and evaluate watershed conditions throughout the province (Wieckowski *et al.* 2008).

A watershed assessment procedure identifies potential hydrological impacts within a watershed, specifically the potential for: changes in peak flows, accelerated surface erosion, changes to riparian zones, and mass wasting events (Sawyer and Mayhood 1998). Combined, these hydrologic impacts represent the four indicator classes of a WAP which together influence water quality, quantity, and aquatic habitats. Indicator systems are developed to provide information to decision-makers and serve as proxy data to help indicate overall watershed health (Pike et al. 2007). Indicators are most useful when used as tools for monitoring watersheds as forest development continues over time (Gustavson and Brown 2002). Undesirable changes in these indicators suggest something did not proceed as planned, thus triggering an investigation into the changes of concern and producing remediation or mitigation strategies (Gustavson and Brown 2002). Quantitative metrics that allow evaluation of the status of these indicator classes have captured in previous WAP guideline documents (MOF 1995a, 1995b, 2001).

2.2.1. Peak Flow

The first of four main indicator classes involve specific metrics that influence changes in peak flow. The **peak flow index** is the maximum flow rate that occurs within a specified period of time, typically on an annual or event basis (BC MOF 2001). A peak flow hazard takes the estimated equivalent clear-cut area (ECA) and operational road networks within a watershed into account when describing potential risks for peak flow and channel changes. ECA and road density are the two primary factors considered because roads and cleared forests greatly increase peak flow rates during precipitation and melting events (BC MOF 2001). The peak flow index measures the overall sensitivity of a watershed basin to increases in peak flows, and higher flows result in an increase of erosive power by streams (Sawyer and Mayhood 1998).

The **equivalent clear-cut area (ECA)** is the second metric that effects changes in peak flow throughout a watershed and is used to inform the peak flow index. The ECA includes the area of land that has been harvested, cleared or burned, with consideration given to the silvicultural system, regeneration growth, and location within the watershed (BC MOF 2001). ECA explicitly relates to forest management as it is a direct response to operational forestry decisions respecting harvesting rate and location in watersheds (Gustavson and Brown 2002). I should be noted, however, that the ECA methodology produces an approximated outcome based on limited data (MOF 2001). The results should always be considered alongside other metrics and indicators when the impacts of timber harvesting within watersheds is evaluated (BC MOF 2001). Table A2.1 in MOF *(*2001*)* highlights the range of assumptions required for ECA calculations.

The hydrological recovery taken into account during an ECA calculation refers to the process by which regeneration restores the hydrology of an area back to pre-logging conditions (BC MOF

2001). Complete recovery involves numerous hydrological factors including the recovery of snow accumulation and melt characteristics, precipitation interception during storms, and the recovery of evapotranspiration. In British Columbia, the most crucial factor in hydrologic recovery incorporates snow accumulation and melting characteristics because peak flows throughout the province are typically generated by snowmelt and rain-on-snow conditions (BC MOF 2001). Table A2.2 in MOF (2001) shows snowpack recovery factors resulting from forest regeneration growth.

Road density above the H60 line is a third monitoring metric that influences peak flows. Defined as the elevation above which 60% of the watershed lies, the H60 line is considered to be a prime source for predicting major snowmelt peak flows in interior watersheds(MOF 1995b; 2001). Greater effects to peak flows are expected above the H60 line where road density is high because roads act as channels to rapidly transport melting snowpack downhill.

A fourth peak flow metric is **road density for the entire sub-basin** of a select watershed. Peak flows magnify as road density increases because roads act as surface drainage networks that increase runoff and drainage efficiency (MOF 2001). During heavy precipitation or melting events, roads increase flow concentrations into streams. For example, ditches intercept sub-surface and surface flows and roads reduce infiltration and transfer flows to the ditches, which then are rapidly transported to nearby stream channels (Gustavson and Brown 2002) Road density is a common metric which helps determine overall watershed health, and is a recurring metric throughout the three additional WAP indicator classes.

2.2.2. Surface Erosion

Surface erosion can negatively impact the overall health of a watershed by disturbing stream bank channels, and by increasing suspended sediment. Surface erosion typically degrades water quality, and often results in spawning habitat deterioration (Gustavson and Brown 2002). Increases in suspended sediment and turbidity in streams can pose health risks to many aquatic species and decrease net ecosystem productivity.

There are a number of WAP metrics that have been used for monitoring the risk of surface erosion. The first metric is **road density on erodible soils**. Soil erosion is a direct consequence of logging and road-building activity (Pickard *et al*. 2009). This metric requires an analysis of data on soil types throughout the watershed region. A qualified hydrologist or geologist must delineate soils susceptible to erosion. Susceptibility may also be influenced by road traffic, slope, and climatic patterns. Soil maps that accurately define erodible soils are currently only available at localized scales for a limited number of watersheds (but see future soil and surficial geology mapping products described in Appendix A)

A second metric to support the surface erosion indicator class incorporates the **density of stream crossings**. Road stream crossings represent a risk of local sediment and intercepted flow delivery, as well as a potential physical impediment to connectivity of fish populations (Gustavson and Brown 2002). A higher density of stream crossings is expected to result in greater negative impacts on the watershed.

Additional surface erosion metrics relate to the distribution of roads around streams, and roads situated on erodible soils. These are: the **density of roads <100m from a stream, density of roads on erodible soils** and the **density of roads on erodible soils <100m from a stream**. The latter metrics represents a greater threat to water quality, as erodible soils underlying poorly maintained roads will generate greater amounts of sediment. . Soil maps that accurately define erodible soils or unstable slopes are currently only available at localized scales for a limited number of watersheds. Extensive mapping of terrain stability and surface erosion potential within watersheds are, however, planned for the near future (see future soil and surficial geology mapping products described in Appendix A), and these should provide terrain stability and soil data from across the province that can be used to define these risk factors more accurately.

2.2.3. Riparian Buffer

A riparian assessment for a WAP determines the roles of riparian vegetation and wood debris in maintaining channel structure stability, and how these roles are affected by logging (BC MOF 2001). Riparian habitat is crucial for maintaining the integrity of stream channels, providing shade over the stream, supplying large woody debris, and preventing wind-throw related impacts that enhance disturbance and sediment delivery (Gustavson and Brown 2002). When riparian forests are cleared, bank cohesion and stability deteriorates. The linkage between channel stability and disturbance of riparian vegetation is determined by factors including channel slope, flow and composition of bank materials (Gustavson and Brown 2002). Changes in wood inputs and cover provided by riparian vegetation effect runoff timing, water temperature, toxin levels, sediment load, fish habitat availability, nutrient availability, micro climates and overall system productivity (Wieckowski *et al.* 2008). Multiple factors contribute to riparian condition and some include: water quality, watershed area, distribution and types of vegetation, access to freshwater and estuarine habitats, regulatory compliance, vegetation disturbance, form and structure, etc. (Stalberg *et al.* 2009.).

The riparian buffer indicator class contains four measuring metrics to calculate changes in riparian condition over time. WAP metrics are as follows: **density of roads < 100m from a stream**, **portion of streams that have been logged**, **portion of fish-bearing streams that have been logged**, and **riparian forest logged (%)**.

2.2.4. Mass Wasting

WAP metrics for assessment impacts of mass wasting events include: **density of landslides**, **density of roads on unstable slopes**, and **streambanks logged on slopes > 60%.** Landslide activity can greatly affect aquatic productivity and conditions within the entire watershed basin. Tracking the numbers of both landslides and slope failures act as surrogates for the degree of sediment delivery to streams (Gustavson and Brown 2002), recognizing that many local geomorphological factors, as well as distance from the receiving stream, will affect the actual sediment delivery of an individual mass wasting event (Sawyer and Mayhood 1998). Landslide frequency generally increases with expanded forest development due to road construction and skid trails. These activities often lead to road fill failures, drainage concentration, and diversion of runoff.

The assessment of landslide density within a watershed basin is typically conducted via the interpretation of high spatial resolution satellite or aerial imagery (Gustavson and Brown 2002). This imagery is very costly, and often covers small ranges. In order to monitor landslides, multiple series of satellite/aerial imagery – updated at frequent intervals – are required to support any change-detection strategies that quantify the density of landslides within a watershed. Provincial-wide coverage would require extensive funds and analysis. Identifying localized and small-scale mass wasting events is a difficult task when relying completely on remote sensing data; a more detailed field assessment of landslide density within a watershed may be required.

As described in Wieckowski *et al (2008).*, there are four categories of mass wasting power levels which are defined on the basis of the extent of forest disturbance. The first level *No Power* occurs in regions where no evidence can be found of geomorphic processes having occurred in the past 250 years. The second, *Low Power* level represents mass wasting events that do not have sufficient energy to uproot or break trees. These events typically deposit sediment around tree trunks, but are not visible from 1:20 000 aerial photographs. *High Power, Site Level* landslide events create narrow swaths less than 20m in width, through the forest floor. Again these events are not detectable in 1:20 000 aerial photographs. The greatest mass wasting events, *High Power, Stand Level*, create wide swaths (>20m) of moving debris throughout the forest. These massive events are visible on 1:20 000 aerial photographs.

In addition to quantifying the density of landslides within a watershed basin, two additional metrics contribute to landslide frequency. Both metrics – density of roads on unstable or potentially unstable terrain, and % stream banks logged on slopes >60% – contribute to mass wasting events, and are considered to be useful monitoring metrics in a WAP. Mapping of terrain stability is currently available only at localized scales for a limited number of watersheds (D. Filatow pers. comm). Several methodologies (B. C. Ministry of Forests 1995, Gustavson and Brown 2002, Sawyer and Mayhood 1998) however suggest that unstable terrain can be defined (as a default) as slopes greater than 60%. This has been used traditionally in BC (R. Guthrie pers. comm.) although with recognition that the potential impacts will be different on the coast vs. the interior. Until provincial scale terrain stability maps become available road densities on slopes >60% can represent a surrogate threshold in relation to landslide risk on unstable soils that can be evaluated across FSWs. Future efforts by the B.C. MOE (see future soil and surficial geology deliverables in Appendix A) are expected to provide extensive terrain stability maps that will significantly improve current methods to identify unstable slopes across the province.

As previously noted, logging of steep slopes greatly compromises the stability of ground surfaces within a watershed. The **percentage of stream banks logged on slopes >60%** reflects the potential for mass wasting events throughout a watershed. When timber is harvested on steep gradients peak flows increase, exacerbating surface erosion during heavy precipitation or snowmelt events. Removing vegetation on slopes >60% weakens surface and subsurface materials, resulting in increases to soil erosion susceptibility. Increased erosion along logged stream banks will result in high amounts of sediment deposition. Excessive sedimentation results in reduced survival of eggs and alevins, reduced physical complexity of river channels, loss of interstitial space for refuge, and reduced macroinvertebrate production (Gustavson and Brown 2002).

2.2.5. Additional Indicators for WAP Consideration

To compliment the four primary WAP indicator categories (Peak Flow, Surface Erosion, Riparian Buffer and Mass Wasting), there remain two additional monitoring indicators which could aid in the overall assessment of watershed health and productivity. The first involves a Low Flow Regime for the entire watershed, which measures the percent of area dominated by effective second growth forest. The FSW Monitoring Technical Working Group has begun exploring development of this metric for potential incorporation into FSW assessments. This metric would help to identify the hydrologic stability and maturity of any particular watershed, provided forest cutblock and land cover data is reliable and updated frequently. A second useful indicator involves habitat accessibility and connectivity throughout a watershed. This indicator determines whether fish have access to and movement throughout the range of their historical stream networks. In-stream impediments to fish movement can affect spawning behaviour and success, resulting in a reduction in habitat supply (Gustavson and Brown 2002). Quantifying impediments to fish habitat accessibility include determining the number of locations where fish are impeded, by type, and the amount, by type, of historical anadromous fish habitat that has been rendered inaccessible (Stalberg *et al*. 2009). Evaluating this broadly across a FSW would require combining a Tier 1-level inventory of all potential stream obstructions with assessments of fish passage success at a representative sample of sites (e.g. Tier II field-based monitoring) or a census of site if possible. In regards to completing a WAP, the interpretation of habitat connectivity also requires the ability to distinguish between natural and anthropogenic obstructions in order to accurately link forest development to watershed health.

2.3 Roll-up and risk categorization

WAP evaluations are implemented to improve forest practices, planning policies, adaptive management, and risk mitigation (Pike et al. 2007). The information provided helps to strengthen management of watershed regions, which influences aquatic productivity and health, water quality, and riparian status. When hazard indices exceed desirable values, the results of a WAP can inform scientific recommendations for action. While different monitoring metrics may be used by different agencies or in different regions all monitoring metrics used are generally standardized into values between 0 and 1, evaluated within each indicator category and then combined together to arrive at a cumulative hazard index score (Sawyer and Maywood 1998). The hazard indices are then interpreted in several pairwise matrices to assess the potential for environmental impact resulting from their interactions. Undesirable changes in hazard indices over time act as an "alarm signal," showing that something within the indicator class was not proceeding as anticipated or hoped (Gustavson and Brown 2002). This occurrence triggers water resource managers to investigate the changes within the specified watershed, and to mitigate/ resolve the adverse effects.

Results from this interpretation with medium or high-order indices are used to make recommendations for improvements to watershed management. A study conducted by Sawyer and Maywood (1998) identifies monitoring metrics with high and medium potential impacts on watersheds. Monitoring metrics with high potential impacts include road density within 100m of a stream, road density on erodible soils <100m from a stream, stream crossing density, portion of streams logged to the bank, and road density on erodible soils. Monitoring metrics that pose medium potential impact on a watershed include peak flow index, road density for the entire sub-basin, and portion of fish-bearing streams logged to the banks. By using GIS and the WAP procedure as a simple model with cost estimates, it is possible to estimate which combination of restoration approaches would provide maximum restoration at the lowest cost (Sawyer and Maywood 1998).

3.0 FSW indicators

3.1 Indicator selection process

In June and July of 2010, the FSW monitoring working group (FSW MWG) was convened to select indicators for monitoring FSW condition. During the meetings the working group noted that it would be prudent to develop an initial list of indicators and associated metrics/benchmarks that together as a group would reflect the properties of a healthy, properly functioning watershed (i.e., rather than just relying on one overriding indicator/benchmark). The following list of characteristics of natural, healthy watersheds was identified by the FSW MWG to guide indicator selection:

- Sediment production and transport at natural levels

    - Landslide rates similar to natural rate
    - Minimal stream crossings
    - Low road density
- ECA sufficiently low such that peak flows and timing do not exceed natural variability
- Natural low flow regimes
- Natural riparian and channel function
    - Intact riparian structure
    - Natural aquatic thermal conditions
    - Consistent short and long term LWD contributions
- Minimal cumulative risk of road related impacts
- Fish have unrestricted access to the watershed

In addition, the FSW MWG acknowledged the importance of selecting a suite of indicators for a particular FSW order that reflects why the watershed was designated fisheries sensitive in the first place.

Figure 1 illustrates the process used by the FSW MWG to structure discussions of potential indicators/metrics/benchmarks that capture the characteristics of healthy watersheds and which could be used by MOE for establishing a set of provincial default objectives.

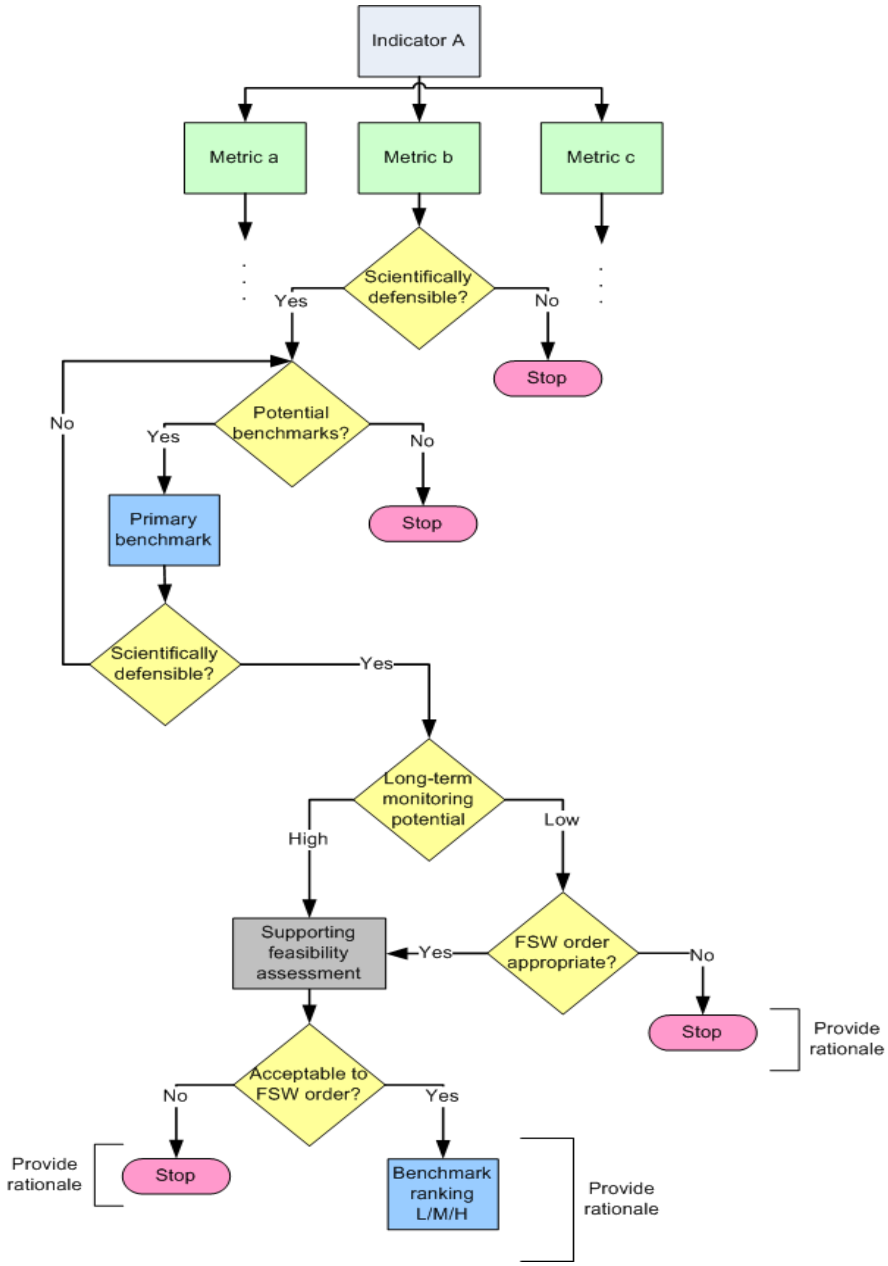

Figure 1 **Flow chart of FSW order indicator, metric, and benchmark vetting process.**

3.2 Indicator and metric rationale

A list of potential indicators and metrics/benchmarks for FSW monitoring (**Table 1**) was developed by the FSW MWG over the course of two workgroup meetings in June and July 2010. Summaries of agency data sources that could inform these metrics are provided in **Table 2** and **Table 3**. Practical assessments (i.e., contacts, data availability, data maintenance, cost, spatial extent/resolution, temporal extent/frequency of updates) are provided in Appendix A for each of these data sources. Benchmarks for each indicator identified by the MWG are intended to correspond to the minimal target characteristics of a healthy watershed. Approaching indicator selection in this manner helped to minimise the level of redundancy across indicators and potential indicator gaps. With regards to benchmarks, the FSW MWG chose to assign default benchmarks for each indicator in the absence of more complete data/inventory that would say otherwise. The intent is that licensees then have the option to collect the necessary information to support alternative benchmarks that are more specific, and more appropriate, to their management area. Similarly, as monitoring by MOE occurs over time, the default benchmarks can be validated and/or revised as required. Last, it is important to note that the list of indicators, metrics, and benchmarks in **Table 1** is currently being refined by the FSW MWG, and is expected to undergo further adjustments as we move forward with the development of protocols for calculating each indicator.

Table 1 Suite of potential indicators, metrics, and associated benchmarks for FSW monitoring.

Characteristics of a healthy watershed	Indicators	Metrics	Benchmark(s) for FSW objectives setting and monitoring	Supporting references
- Sediment production and transport at natural levels - Landslide rates similar to natural rate - Minimal stream crossings - Low road densities	Landslides	# of landslides	Landslides connected to stream channels not to exceed the natural rate For watershed as a whole, landslides not to exceed 3x the natural rate	Smith 2005 Guthrie and Millard (unpublished)
	Sediment	Sediment rating	- Maintain a below moderate rating (based on FREP criteria) for all sediment delivery points on fish bearing streams and direct tributaries to fish bearing streams - Maintain on average a below moderate rating (based on FREP criteria) for sediment delivery points across the entire watershed (derived from subsample)	Carson et al. 2009 (FREP)
	Roads	# of stream crossings	Density of stream crossings across the watershed to remain below the WAP-based moderate risk criteria (0.32/km^2 – interior watersheds; 0.8/km^2 – coastal watersheds)	MOF 1995a and 1995b
	Roads	Stream crossing condition	- Maintain a below moderate rating (FREP-based criteria) at all stream crossings on fish bearing streams and direct tributaries to fish bearing streams - Maintain on average a below moderate rating (based on FREP criteria) for stream crossings across the entire watershed (derived from subsample)	Tripp et al. 2009 (FREP)
	Roads	Road densities	Road densities on unstable slopes (i.e. slopes greater than 60%) to remain below the WAP-based moderate risk criteria (0.12 km/km^2)	MOF 1995a and 1995b
ECA sufficiently low such that peak flow and timing doesn't change relative to an amount for a watershed if it were not developed.	Vegetation cover	Equivalent clear cut area (ECA)	ECA not to exceed 20%	MOF 2001. Guthrie 2003
	Roads	Road densities	Road densities above H60 line to remain below the WAP-based moderate risk criteria (0.4 km/km2) (applicable to interior watersheds only)	MOF 1995a
Natural low flow regimes	Hydrologic stability/maturity	% of watershed with second	Net Equivalent Second Growth Area (ESGA) (forest stands 25-75 years) not to exceed 40% of forested area of watershed1	Jones and Post 2004 Perry 2007

[1] Net Equivalent Second Growth Area (net ESGA) = ESGA - ECA

Characteristics of a healthy watershed	Indicators	Metrics	Benchmark(s) for FSW objectives setting and monitoring	Supporting references
		growth forest		Derek Tripp, pers. comm.
Natural riparian and channel function • Intact riparian structure • Natural aquatic thermal conditions • Consistent short and long term LWD contributions	Riparian condition	% Riparian logged	Percentage of riparian forest logged upstream of POI (point of interest) not to exceed 25%	NOAA 1996 Nordin et al. 2008
	Riparian condition	Density of roads in riparian zone	Road densities within 100m of a stream to remain below the WAP-based moderate risk criteria (0.16 km/km^2)	MOF 1995a and 1995b
Minimal cumulative risk of road related impacts	Roads	Road density	Road densities across entire watershed to remain below the WAP-based moderate risk criteria (1.2 km/km^2)	MOF 1995a and 1995b
Fish have access to and movement throughout the range of their historical stream network	Aquatic connectivity	% accessible habitat	Maintain access to all potential fish habitat	Tripp et al. 2009 (FREP)
	Aquatic connectivity	Stream crossing condition	Maintain the pre-crossing width of the stream channel and the natural roughness of the stream channel bed on all new/restored crossings on fish streams	

3.3 Data sources

Table 2 Summary of available data sources

Data source	Organisation	Indicator
Digital Road Atlas (DRA)	GeoBC: LRDW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Vegetation Resource Index (VRI)	GeoBC: LRDW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting, Low Flow Regime
1:20 000 Freshwater Atlas: Stream Networks	GeoBC: LRDW	Surface Erosion, Riparian Buffer, Mass Wasting
Digital Elevation Model (DEM)	GeoBase	Peak Flow, Surface Erosion, Mass Wasting
Landsat	GeoBC: WMS	Mass Wasting
SPOT	GeoBC: WMS	Mass Wasting
Soil Landscapes of Canada	Agriculture and Agr-foods Canada	Peak Flow, Surface Erosion, Mass Wasting
Richard Thompson (research layer for fish habitat and fish passage obstructions	MOE	Surface Erosion, Riparian Buffer
RESULTS	GeoBC: LRDW	Surface Erosion, Riparian Buffer, Mass Wasting

Table 3 List of indicators and their respective data

Indicator	Metric	Preferred data source	Rationale	Additional comments
Peak Flow	Peak Flow Index	Digital Road Atlas (DRA), Vegetation Resource Index (VRI), Digital Elevation Model (DEM) , FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	
	Equivalent Clear-Cut Area	Vegetation Resource Index (VRI), FSW Boundary Delineations	Attributes of VRI index allow for the calculation of regeneration growth for the ECA. Both sources are free and monitored by BC MOE.	
	Road Density for Entire Sub-Basin	Digital Road Atlas (DRA), Vegetation Resource Index (VRI), FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by BC MOE.	
	Road Density Above H60 Line	Digital Road Atlas (DRA), Digital Elevation Model (DEM), FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies. DRA is updated annually.	
	Road Density on Erodible Soils	Digital Road Atlas (DRA), Soil Landscapes of Canada, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	SLC V2.2 is best available source for determining surficial properties at this time. Look for future deliverables (Appendix A).
Surface Erosion	Road Density <100m from a Stream	Digital Road Atlas (DRA), 1:20 000 Freshwater Atlas: Stream Networks, FSW	Reliable and best available data sources for included monitoring metrics. Available free of	

Indicator	Metric	Preferred data source	Rationale	Additional comments
		Boundary Delineations	charge, and regulated by notable agencies.	
	Road Density on Erodible Soils <100m from a Stream	Digital Road Atlas (DRA), 1:20 000 Freshwater Atlas: Stream Networks, Soil Landscapes of Canada, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	SLC V2.2 is best available source for determining surficial properties at this time. Look for future deliverables (Appendix A).
	Density/ Number of Stream Crossings	Digital Road Atlas (DRA), 1:20 000 Freshwater Atlas: Stream Networks, Richard Thompson: MOE, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	
	Road Density for Entire Sub-Basin	Digital Road Atlas (DRA), Vegetation Resource Index (VRI) , FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	
	Roads on Unstable Slopes	Digital Road Atlas (DRA), Digital Elevation Model (DEM), Soil Landscapes of Canada, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	SLC V2.2 is best available source for determining surficial properties at this time. Look for future deliverables (Appendix A) for determining unstable slopes.
	Sediment Rating (FREP Criteria)	N/A		
	Stream Banks Logged on Slopes >60%	Vegetation Resource Index (VRI), 1:20 000 Freshwater Atlas: Stream Networks, Digital Elevation Model (DEM), RESULTS, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	
Riparian Buffer	Road Density <100m from a Stream	Digital Road Atlas (DRA), 1:20 000 Freshwater Atlas: Stream Networks, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	
	Portion of Streams Logged	Vegetation Resource Index (VRI), 1:20 000 Freshwater Atlas: Stream Networks, RESULTS, FSW Boundary Delineations	VRI and RESULTS databases are very reliable and updated frequently to provide data for cutblocks, all free of charge. The remaining sources are also reliable and the best available at this time. Also free of charge, and regulated by the BC MOE.	We assume that streams are protected by buffers. In some cases they are not, which should be noted. Cross-reference may be required on a case-by-case scenario of smaller stream reaches.
	Portion of Fish-Bearing Streams Logged	Vegetation Resource Index (VRI), 1:20 000 Freshwater Atlas: Stream Networks, Richard Thompson: MOE, RESULTS, FSW Boundary Delineations	Richard Thompson's research layer is available upon request, and is a valuable resource in determining fish-bearing streams. The remaining sources are also reliable and the best available at this time. Also free of charge, and regulated by the BC MOE.	We assume that fish-bearing streams are protected by buffers. In some cases they are not, which should be noted. Cross-reference may be required on a case-by-case scenario of smaller stream reaches.

Indicator	Metric	Preferred data source	Rationale	Additional comments
	Riparian Forest Logged (%)	Vegetation Resource Index (VRI), 1:20 000 Freshwater Atlas: Stream Networks, RESULTS, FSW Boundary Delineations	VRI and RESULTS databases are very reliable and updated frequently to provide data for cutblocks, all free of charge. The remaining sources are also reliable and the best available at this time. Also free of charge, and regulated by the BC MOE.	A buffer (minimum 100m) will need to be placed along all stream reaches in order to identify the riparian zone.
Mass Wasting	Density of Landslides in the Watershed	Landsat, SPOT, Landslides, Orthophotos, FSW Boundary Delineations	Orthophotos for purchase are most reliable for conducting change-detection in order to calculate landslide density. The free Landsat and SPOT data are the best available, but have unreliable temporal resolutions.	Future deliverables (Appendix A) may help determine landslide density or susceptibility based upon surficial geology and material. Orthophotos are costly.
	Density of Roads on Unstable/ Potentially Unstable Terrain	Digital Road Atlas (DRA), , Digital Elevation Model (DEM), Soil Landscapes of Canada, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies.	SLC V2.2 is best available source for determining surficial properties at this time. Look for future deliverables (Appendix A) for determining unstable slopes.
	Portion of Streambanks Logged on Slopes >60%	Vegetation Resource Index (VRI), 1:20 000 Freshwater Atlas: Stream Networks, Digital Elevation Model (DEM), RESULTS, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and regulated by notable agencies. Both VRI and RESULTS can yield information on recently logged regions.	
Low Flow Regime	Second Growth Forest (25-75 years)	Vegetation Resource Index (VRI), FSW Boundary Delineations	The VRI is a very reliable data source and is updated frequently. Attributes enable the identification of "Projected Age" which helps pin-point second growth forest.	
Cumulative Impacts	Stream Crossing Condition (FREP Criteria)	N/A		
	Accessible Habitat (%)			

4.0 Literature cited

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Tripp, D.B., P.J. Tschaplinski, S.A. Bird and D.L. Hogan. 2009. Protocol for Evaluating the Condition of Streams and Riparian Management Areas (Riparian Management Routine Effectiveness Evaluation). Forest and Range Evaluation Program, BC Min. For. Range and BC Min. Env., Victoria, BC. Available at: http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/Indicators-Riparian-Protocol-2009.pdf

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Appendix A – Practical Assessment Worksheets

Data Source: *Digital Road Atlas (DRA)*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Peak Flow	Peak Flow Index	
	Road Density for Entire Sub-Basin	
	Road Density Above the H60 Line	
	Road Density on Erodible Soils	
Surface Erosion	Road Density <100m from a Stream	
	Road Density on Erodible Soils <100m from a Stream	
	Density/Number of Stream Crossings	
	Roads on Unstable Slopes	
Riparian Buffer	Road Density <100m from a Stream	
Mass Wasting	Road Density on Unstable/Potentially Unstable Terrain	

Description of Data Source

Data Source:

Contact: Carol Ogborne, Team Lead – Base-Mapping: BCGOV ILMB Crown Registry and Geographic Base Branch (CRGB).
Telephone: 250-952-6557
Email: carol.ogborne@gov.bc.ca

References: GeoBC
Website: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=45674&recordSet=ISO19115

For information on the fully attributed and up-to-date DRA data, please visit:
http://ilmbwww.gov.bc.ca/bmgs/products/mapdata/digital_road_atlas_products.htm

Data Availability:
Available for public access.

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: Base Mapping and Cadastre Section (ILMB).

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Low.

Spatial extent/ resolution:
Full provincial coverage.

Temporal extent/ frequency:
Published on 11/15/2004, last revised on 05/01/2010.
This dataset is revised on an annual basis to provide a complete and accurate road networking database for the entire province of British Columbia.

Data Source: *Vegetation Resource Index (VRI)*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Peak Flow	Peak Flow Index	
	Equivalent Clear-Cut Area	
Surface Erosion	Stream Banks Logged on Slopes >60%	
Riparian Buffer	Portion of Streams Logged	Assuming stream buffers applied per Forest Practices Code (1995). Some may not be included; cross-check necessary in some cases.
	Portion of Fish-Bearing Streams Logged	Assuming stream buffers applied per Forest Practices Code (1995). Some may not be included; cross-check necessary in some cases.
	Riparian Forest Logged (%)	
Mass Wasting	Stream Banks Logged on Slopes >60%	
Low Flow Regime	Second Growth Forest (25-75 yrs)	

Description of Data Source

Data Source:

Contact: Tim Salkeld, BCGOV FOR Forest Analysis and Inventory Branch.
Telephone: 250 387-6736
Email: Tim.Salkeld@gov.bc.ca

References: GeoBC
Website:
https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47574&recordSet=ISO19115

http://www.for.gov.bc.ca/hts/vridata/standards/datadictionary/rpt_vri_datadict0505_draft1.0d.pdf
VRI Data Dictionary

https://apps.gov.bc.ca/int/ilmbrobread
ILMB Oracle Designer 10g CASE Repository

Data Availability:
Available for public access.

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: BCGOV FOR Forest Analysis and Inventory Branch. Ongoing resource status.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Medium to High because of large size of dataset and complexity of monitoring metrics.

Spatial extent/ resolution:
Full provincial coverage.

Temporal extent/ frequency:
Created on 10/15/2006, resource status is ongoing.
This dataset is revised on an annual basis to provide a complete and accurate VRI database for the entire province of British Columbia.

Data Source: *1:20,000 Freshwater Atlas: Stream Network*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Surface Erosion	Road Density <100m from a Stream	
	Road Density on Erodible Soils <100m from a Stream	
	Stream Banks Logged on Slopes >60%	
	Density/ Number of Stream Crossings	
Riparian Buffer	Portion of Streams Logged	Assuming stream buffers applied per Forest Practices Code (1995). Some may not be included; cross-check necessary in some cases.
	Portion of Fish-Bearing Streams Logged	Assuming stream buffers applied per Forest Practices Code (1995). Some may not be included; cross-check necessary in some cases.
	Riparian Forest Logged (%)	
Mass Wasting	Stream Banks Logged on Slopes >60%	

Description of Data Source

Data Source:

Contact: Malcolm Gray, Crown Registries and Geographic Base Branch (ILMB).
Telephone: 250 952-6573
Email: Malcolm.Gray@gov.bc.ca

References: GeoBC
Website:
https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50648&recordSet=ISO19115

https://apps.gov.bc.ca/int/ilmbrobread
ILMB Oracle Designer 10g CASE Repository

ftp://ftp.geobc.gov.bc.ca/pub/outgoing/FreshWaterAtlasDocuments/FWAv1.3-SDE.WarehouseModelSpecification.rev3.doc
GEOBC FTP site for Freshwater Atlas Documentation

ftp://ftp.geobc.gov.bc.ca/pub/outgoing/FreshWaterAtlasDocuments/FWARoutingDocumentation.doc
GEOBC FTP site for Freshwater Atlas Documentation

Data Availability:
Available for public access.

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: BCGOV ILMB Crown Registry and Geographic Base Branch (CRGB). Ongoing resource status.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Low to Medium.

Spatial extent/ resolution:
Full provincial coverage. 1:20 000 scale.

Temporal extent/ frequency:
Revised on 09/01/2008, next scheduled revision 12/15/2008, resource status is ongoing.
This dataset is revised on an “as needed” basis to provide a complete and accurate Stream Network database for the entire province of British Columbia.

Data Source: *Digital Elevation Model (DEM)*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Peak Flow	Road Density Above the H60 Line	
Surface Erosion	Stream Banks Logged on Slopes >60%	
	Roads on Unstable Slopes	
Mass Wasting	Stream Banks Logged on Slopes >60%	

Description of Data Source

Data Source:

Contact: GeoBase Technical Support.
Telephone: +01-819-564-4857 / 1-800-661-2638 (Canada and USA)
Fax: +01-819-564-5698
Email: SupportGeoBase@nrcan.gc.ca

References: GeoBase
Website:
http://geobase.ca/geobase/en/find.do?produit=cded

Data Availability:

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: Government of Canada, Natural Resources Canada, Earth Sciences Sector.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Medium, due to multiple data operations required for the above monitoring metrics.

Spatial extent/ resolution:
Full provincial coverage. Two available scales: 1:250 000 and 1:50 000.

Temporal extent/ frequency:
Published on 09/01/2000. Update period intervals: Unknown.

Data Source: *Free Landsat Data: Web Map Connection Service (WMS) and GeoBase*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Mass Wasting	Density of Landslides in the Watershed	These datasets may only be useful for reference. The temporal resolution is often unknown, or lies within a broad range of time, making change-detection strategies difficult and unreliable for landslide density calculation. See: "Orthophoto Imagery."

Description of Data Source

Data Sources:
Web Map Connection Service:
Contact: GeoBC InfoServ: Web Map Connection Service. Resources Information Standards Committee:
Email: RISCWeb@gov.bc.ca

References: GeoBC: GeoWeb BC Imagery WMS - wms_landsat
Website: http://openmaps.gov.bc.ca/imagex/ecw_wms.dll?wms_landsat?service=wms&request=getCapabilities

GeoBase:
Contact: GeoBase Technical Support.
Telephone: +01-819-564-4857 / 1-800-661-2638 (Canada and USA)
Fax: +01-819-564-5698
Email: SupportGeoBase@nrcan.gc.ca

References: GeoBase
Website: http://geobase.ca/geobase/en/data/imagery/landsat/index.html

Data Availability:
Available for public access.

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization for GeoBase: Government of Canada, Natural Resources Canada, Earth Sciences Sector.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Varies.

Spatial extent/ resolution:
Both WMS and GeoBase offer full provincial coverage.
WMS: Landsat data offers 30m resolution.
GeoBase: Landsat 7 data offers 1 panchromatic band (15m), 6 multispectral bands (30m) and 2 thermal infrared bands (60m).

Temporal extent/ frequency:
WMS: This dataset offers Orthophotography of British Columbia, including Landsat imagery. Exact dates of imagery are unknown, and update intervals are not specified.
GeoBase: Offers a complete set of cloud-free (less than 10%) Landsat 7 orthoimages covering the Canadian landmass using data from the Landsat 7 satellite. Landsat 7 images used to produce this data set were captured between 1999 and 2003. Imagery updates are unknown.

Data Source: *Free SPOT Data: Web Map Connection Service (WMS) and GeoBase*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Mass Wasting	Density of Landslides in the Watershed	These datasets may only be useful for reference. The temporal resolution is often unknown, or lies within a broad range of time, making change-detection strategies difficult and unreliable for landslide density calculation. See: "Orthophoto Imagery."

Description of Data Source

Data Source:

Web Map Connection Service:

Contact: GeoBC InfoServ: Web Map Connection Service. Resources Information Standards Committee:
Email: RISCWeb@gov.bc.ca

References: GeoBC: GeoWeb BC Imagery WMS - wms_spot15m,
Website:
http://openmaps.gov.bc.ca/imagex/ecw_wms.dll?wms_spot15m?request=getcapabilities&VERSION=1.1.1&REQUEST=GetCapabilities

GeoBase:

Contact: GeoBase Technical Support.
Telephone: +01-819-564-4857 / 1-800-661-2638 (Canada and USA)
Fax: +01-819-564-5698
Email: SupportGeoBase@nrcan.gc.ca

References: GeoBase
Website: http://geobase.ca/geobase/en/data/imagery/imr/index.html

Data Availability:

Available for public access.

Relative Cost:

Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization for GeoBase: Government of Canada, Natural Resources Canada, Earth Sciences Sector.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Varies.

Spatial extent/ resolution:

WMS: Current coverage is roughly 2/3 of province. 15m spatial resolution.
GeoBase: Full provincial coverage. 10m panchromatic spatial resolution and 20m multispectral spatial resolution.

Temporal extent/ frequency:

WMS: This dataset offers SPOT 15m satellite imagery of British Columbia. Exact dates of imagery are unknown, and update intervals are not specified.
GeoBase: Dataset offers a complete set of medium resolution orthoimagery based on SPOT 4 / 5 covering all of Canada south of the 81st parallel. The first SPOT images of this dataset were collected in 2005 and the imagery collection is scheduled to be complete in 2010. Imagery updates are unknown.

Data Source: *Orthophoto Imagery (for purchase)*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Mass Wasting	Density of Landslides in the Watershed	Although this is imagery has very high spatial resolution (1m) it is highly expensive ($500 each tile image), and does not provide full provincial coverage. However, this may be useful in identifying small-scale landslides.

Description of Data Source

Data Source:

Contact 1: GeoBC Service.
Email: GeoBC.ServiceDesk@gov.bc.ca
Contact 2: Basemap Online Store Customer Support.
Email: BMOS@geobc.gov.bc.ca

References: GeoBC
Website:
http://archive.ilmb.gov.bc.ca/crgb/products/imagery/orthomosaic.htm

Data Availability:
Available upon purchase.

Relative Cost:
Data purchase / collection: $500.00 for each 20k digital orthophoto mosaic map sheet.
Incorporates up to 25 individual 20X compressed TRIM 20K map sheets that fall within a Quarter NTS letter block, 1m resolution (e.g., 82E/SW)

Data / indicator maintenance:

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: High Cost, especially at provincial scale.

Spatial extent/ resolution:
1m spatial resolution. Extent: Not fully provincial. Low provincial coverage of recent (less than 5 years old) orthophotos.

Temporal extent/ frequency:
Updated orthophotos for change-detection available upon purchase. Most available images for purchase range in age from 1995 to 2007.

Data Source: *Soil Landscapes of Canada (SLC) Version 2.2*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Peak Flow	Density of Roads on Erodible Soils	
Surface Erosion	Density of Roads on Erodible Soils <100m from a Stream	
	Roads on Unstable Slopes	
Mass Wasting	Density of Roads on Unstable or Potentially Unstable Terrain	

Description of Data Source

Data Source:

Contact: Agriculture and Agri-Food Canada, 1341 Baseline Road, Ottawa, Ontario K1A 0C5.
Telephone: 613-773-1000
Fax: 613-773-2772
TDD/TTY: 613-773-2600
Email: info@agr.gc.ca

References: Agriculture and Agri-Food Canada: Centre for Land and Biological Resources Research. 1996. Soil Landscapes of Canada, v.2.2, Research Branch, Agriculture and Agri-Food Canada. Ottawa.
Website: http://sis.agr.gc.ca/cansis/nsdb/slc/v2.2/intro.html

Data Availability:
Available for public access.

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Agriculture and Agri-Food Canada.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Medium to High, due to complexity of database files and shapefiles.

Spatial extent/ resolution:
Provincial coverage, dataset collaborated in 1996. Fairly low spatial resolution: SLC sample polygons are not well detailed.

Temporal extent/ frequency:
This dataset was revised in 2004, 2006, and 2007. Version 2.2 of the SLC database contains all relevant soils and surficial data for provincial-wide coverage.

Note: Limitation of Datasets: surficial composition percentages cannot be spatially assigned within a sample polygon. Example: polygon “X” contains 25% silt, 20% clay and 55% loam, but the exact distribution of these texture classes within the specified region is unknown.

Data Source: *Richard Thompson, BC Ministry of Environment*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Surface Erosion	Density/ Number of Stream Crossings	Database research layer based upon intersection with 1:20 000 Freshwater Stream Atlas. Not Available on the LRDW.
Riparian Buffer	Portion of Fish-Bearing Streams Logged	"Streamgradientreaches" layer in database contains fish habitat classifications for stream Reaches within the 1:20 000 Freshwater Stream Atlas stream network. Assuming stream buffers applied per Forest Practices Code (1995). Some may not be included; cross-check necessary in some cases.

Description of Data Source

Data Source:

Contact: Richard Thompson: Monitoring Unit Head, Ecosystems Protection and Assurance Branch. BC Ministry of Environment.
Telephone: (250) 356-5467
Email: Richard.Thompson@gov.bc.ca

References: N/A.

Data Availability:
Available upon request.

Relative Cost:
Data purchase / collection: Unknown.

Data / indicator maintenance: Richard Thompson: Ministry of the Environment.

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Medium, due to large size of dataset and complexity of monitoring metrics.

Spatial extent/ resolution:
Full provincial coverage. Data based upon the 1:20 000 Freshwater Atlas.

Temporal extent/ frequency:
Unknown. Information available upon request.

Data Source: *RESULTS Openings*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Surface Erosion	Stream banks Logged on Slopes >60%	
Riparian Buffer	Riparian Forest Logged (%)	
	Portion of Streams Logged	
	Portion of Fish-Bearing Streams Logged	
Mass Wasting	Portion of Stream banks Logged on Slopes >60%	

Description of Data Source

Data Source:

Contact: Caroline MacLeod: BCGOV FOR FS Division Forest Practices Branch
Telephone: 250 356-2094
Email: Caroline.MacLeod@gov.bc.ca

References: GeoBC: Ministry of Forests and Range Data Models
Website: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=52583&recordSet=ISO19115

Data Availability:

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: BCGOV FOR Forest Practices Branch

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Medium, due to large size of dataset and complexity of monitoring metrics.

Spatial extent/ resolution:
Full provincial coverage.

Temporal extent/ frequency:
Database created on 11/27/2003. Resource status is complete. Daily update cycle.

Data Source: *FSW Boundary Delineations*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
All	All	Layer will be used to delineate all FSW boundaries, which is essential to all aspects of the included monitoring metrics and indicators.

Description of Data Source

Data Source:

Contact #1: Byron Woods: Knowledge Management Branch (MOE)
Telephone: 250 387-5511
Email: Byron.Woods@gov.bc.ca

Contact #2: Lars Reese-Hansen: BCGOV ENV Ecosystems Branch
Telephone: 250 387-3980
Email: Lars.ReeseHansen@gov.bc.ca

References: GeoBC: LRDW
Website: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49678&recordSet=ISO19115

Data Availability:

Relative Cost:
Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: BCGOV ENV Ecosystems Branch (MOE)

Total cost: Low (1 week): Estimated Cost of Data Interpretation/ Extraction: Low to Medium, depending on complexity of metric calculation.

Spatial extent/ resolution:
This dataset includes approved legal boundaries for fisheries sensitive watersheds. Additional FSW's are updated and added frequently to expand the extent of coverage throughout British Columbia.

Temporal extent/ frequency:
Database created on 04/30/2007. Resource status is complete. Daily update cycle.

Data Source: *Future Soil & Surficial Geology Deliverables*

Summary table of indicators informed by the data source:

Indicator	Metric	Comments
Peak Flow	Road Density on Erodible Soils	New deliverables will enable the delineation of erodible surfaces and unstable terrain.
Surface Erosion	Road Density on Erodible Soils <100m from a Stream	
	Roads on Unstable Slopes	
Mass Wasting	Density of Landslides in the Watershed	
	Density of Roads on Unstable/ Potentially Unstable Terrain	

Description of Data Source

Data Source:

Contact: Deepa Filatow, Ministry of the Environment: Ecosystem Information Section.
Telephone: (250) 861-7675.
Email Deepa.Filatow@gov.bc.ca

References: N/A.

Data Availability:
Unknown, goal is to be publicly accessible. May be available upon request during early distribution.

Relative Cost:
Data purchase / collection: Free, open for public access.

Data / indicator maintenance: Unknown.

Total cost: Low (1 week): Unknown.

Spatial extent/ resolution:
Goal is to have full provincial coverage of British Columbia, using best-available datasets.

Temporal extent/ frequency:
Unknown.

Additional Information:
Objectives of new deliverables:
Create soils GIS products that will increase the use of BC soils information by:

- Creating a more user friendly provincial soils map both at the project boundary level (showing all available data) and at a detailed level (showing best available information for a subset of attributes).
- Housing BC soils data in a common data base from which other products and published maps can be derived.
- Identifying key soils attributes that are useful and commonly filled in the current soils data.
- Make BC soils information available to the public through a centralized distribution/access point using available web tools.

The ability to publish data to the LRDW, iMap and HaBC should be considered in the solutions.

Tier I Fisheries Sensitive Watersheds (FSW) monitoring protocol

Draft Version 2

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Prepared for:

British Columbia Ministry of Forests, Lands and Natural Resource Operations

and

British Columbia Ministry of Environment

P.O. Box 9338, Stn Prov Govt
Victoria, BC, V8W 9M1

Prepared by

Marc Porter, Emily Snead, Simon Casley, Katherine Wieckowski
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, BC V6J 5C6

December 20, 2011

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Table of Contents

1.0 Introduction

1.1 What is properly functioning condition?

Properly functioning condition is defined in the province's *Forests and Range Practices Act* (FRPA) as:

> *The ability of a stream, river, wetland, or lake and its riparian area to: 1) withstand normal peak flood events without experiencing accelerated soil loss, channel movement or bank movement, 2) filter runoff, and 3) store and safely release water.*

Properly functioning implies that the extent and rate of watershed disturbances are on average, small and within a watershed's natural range of variability; or large and beyond the rate of natural variability in no more than a small portion of the overall habitat. Properly functioning FSWs are expected to maintain a majority of streams that can withstand normal peak flood events without experiencing accelerated soil loss, channel movement or bank movement; can filter runoff and maintain water quality; can store and safely release water; can maintain aquatic habitat connectivity within the stream network and between the stream and adjacent riparian area; can maintain an adequate root network or large woody debris supply; and can provide shade and reduce bank microclimate change. Properly functioning FSWs should also be expected to maintain direct access to potential spawning and rearing habitats for all resident or anadromous fish populations.

1.2 How is functioning condition assessed?

Properly functioning condition of FSWs will be evaluated through a combination of monitoring undertaken using two distinct approaches. The first approach (referred to hereafter as Tier 1 and the subject of this document) incorporates monitoring based on remote-sensed or broad-scale inventory data available for all FSWs in regularly updated and easily available agency GIS layers. A second, more intense level of monitoring (referred to as Tier 2) incorporates field-based surveys that will be undertaken at a subset of FSWs. Tier 2 FSW monitoring is discussed in detail in Pickard et al. (2011a, b). Tier 1 monitoring of FSW condition will be based on an GIS-based indicator approach, similar to those used for the province's earlier standardized Watershed Assessment Procedures (WAP) (MOF 1995a, 1995b), but modified to accommodate use of more widely available provincial-scale GIS layers (i.e. a "WAP-lite" approach). The province's WAP has been defined as, "…an analytical procedure to help forest managers understand the type and extent of current water-related problems that may exist in a watershed, and to recognize the possible hydrologic implications of proposed forestry-related development or restoration in that watershed" (BC MOF 2001). Water-related issues within a watershed are largely influenced by the cumulative effects of a suite of indicators including road density, riparian disturbance, stream crossing density, landslide occurrence, equivalent clear-cut area, surface erosion, etc. The intent of the FSW Tier 1 "WAP-lite" monitoring will be to determine the status of these indicators so as to allow for a general assessment of a watershed's current functioning condition and its likely future state as a result of continuing human and natural activities (i.e., trends in watershed condition).

2.0 Components of FSW Tier 1 Monitoring

2.1 Describe the FSW

Before initiating Tier 1 monitoring assemble overview information relating to each FSW:

- define the boundaries of the FSW and any associated subunits of interest
- determine key issues in the FSW (fisheries, habitat sensitivities, forestry and other development pressures)
- identify the stakeholders in the FSW
- determine if a WAP has been undertaken previously in the watershed prior to FSW designation; if so, assemble historical data/reports for use as potential baseline for comparison
- determine if there are concurrent ongoing monitoring activities, localized mapping efforts that can support/supplement the standard Tier 1 monitoring approach that will be used across FSWs

2.2 Identify and assemble GIS data layers to inform assessment of the FSW

Primary GIS data layers that can inform FSW Tier 1 monitoring are available from the province's GeoBC online database (http://geobc.gov.bc.ca/) or the province's Land and Resource Data Warehouse (http://lrdw.ca/). These include the Digital Road Atlas, 1:20,000 Freshwater Atlas, Vegetation Resource Index, RESULTS Openings, and FSW boundary delineations. GeoBC also provides a web map connection service where Landsat, SPOT, and 1m Orthoimages can be uploaded into ArcMap.

Other useful data sources for GIS layers include the national GeoBase system (http://www.geobase.ca/geobase/en/index.html) that serves up a free Digital Elevation Model, and also provides both Landsat and SPOT satellite images (for a subset of locations and times). Should current and high spatial resolution imagery be needed, 1m Orthoimages are also available for purchase through GeoBC. The Soil Landscapes of Canada (SLC) data is available through the Agriculture and Agri-food Canada website (http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226522391901&lang=eng).

The province's stream research 1:20 000 GIS layers for: 1) fish passage and 2) fish habitat are available upon request from the MOE (see Appendix A in Wieckowski et al. 2011). New and more extensive provincial soil and surficial geology mapping are in the process of being developed by the MOE and should be available as GIS layers for FSW monitoring purposes in the near future (see Appendix A in Wiekowski et al. 2011).

Refer to Appendix A in Wieckowski et al. (2011) for more detailed descriptions and practical assessments of provincial and federal data sources that could inform FSW Tier 1 monitoring.

If more detailed resource mapping in GIS format is available for individual FSWs this local information may be used to supplement more generalized and poorer resolution provincial map layers available from agency data sources.

2.3 Indentify Tier 1 indicators and associated metrics

2.3.1 Indicator Category: Peak Flow

Metric: ***Peak Flow Index***

How is Peak Flow Index calculated?

The Peak Flow Index is calculated as a weighted measure of the proportion of the basin that has been clear-cut. For Interior Watershed Assessments (IWAP) the weighting depends on the fraction of clear-cutting in the upper 60% of the basin that is still snow-covered at the time that stream flows begin to rise in the spring (i.e. weighted ECA above and below the H_{60} line) (MOF 2011). For Coastal Watershed Assessments (CWAP) peak flow weighting depends on the fraction of clear-cutting in rain-dominated, transient snow, and snowpack zones (MOF 2011). In both the IWAP and CWAP, these elevations must be determined either by a hydrologist or by an agreeable default value.

To calculate peak flow, use a Digital Elevation Model raster (DEM) and clip to within the confines of the watershed in question. Determine the elevation cut-off's as described above. Use the Spatial Analyst tool in ArcGIS to manually re-classify the pixel values of the DEM based upon the elevation breaks determined. Once re-classified, convert the raster to features.

Now, use the VRI cutblocks from the Equivalent Clear-Cut Area (ECA) calculation, and clip the cutblocks to each elevation band from the DEM. Re-calculate the ECA in each individual elevational band of the DEM, and fill in either Form 1 (IWAP) or Form 2 (CWAP) of Ministry of Forests (2001).

To complete the Peak Flow Index calculation, *I* (IWAP) and/or *C* (CWAP) vertical variability weights will need to be determined either as default values, or by a hydrologist in a case-by-case scenario.

How are results interpreted?

Removal of forest vegetation typically results in increases in peak flow. Areas on slopes and high elevation with timber harvest have the greatest potential to experience increased peak flows. These increases result in surface erosion and sediment and debris transport into stream channels. These actions can disturb stream channels, block fish passage, degrade fish habitat, and reduce stream channel bed complexity.

Metric: ***Equivalent Clear-Cut Area (ECA)***

How is Equivalent Clear-Cut Area calculated?

The ECA calculation requires GIS-based datasets that determine the ages of logging cutblocks, tree heights in second growth, and elevation of the cutblocks within the watershed. Harvesting in higher elevated forests within watersheds has a greater effect on peak flows than harvests in lower elevations. The Forests Practices Code of British Columbia (1999) contains useful information for ECA calculations. Table A2.1 provides assumptions for ECA calculations and outlines factors relating to the type of forest disturbance. Table A2.2 shows snowpack recovery factors resulting from forest regeneration.

To calculate the ECA, use 1:20,000 forest cover maps (RESULTS and VRI) to isolate logged or disturbed forest areas. RESULTS and other logging data that may be available for the FSW can be combined with the VRI provided they contain stand height information, or where the forest age is accurately reflected in the VRI (PROJ_AGE_1), and therefore the VRI projected height can be used.

Clip the VRI dataset to within the confines of the FSW polygon to isolate cutblocks within the watershed of interest. Extract all VRI polygons identified as having been logged/disturbed using the HRVSTDT and OPEN_IND fields. Dissolve the polygons based on OPEN_ID, HRVSTDT, and PROJ_HT_1 to identify unique openings for classification based on size. The next step is to classify the disturbed areas based on the assumptions presented in Table A2.1 of the WAP guidebook (MOF 2001). Using VRI and RESULTS, the clearcut area can only be adjusted based on size as there is no information on individual tree selection, strip cut width or utility corridors.

Next, classify the VRI cutblocks based on the snowpack recovery factors given in Table A2.2 (MOF 2001) using the projected tree heights (PROJ_HT_1). Heights may need to be extrapolated if reference material is not available or up to date. Now, determine the area of each cutblock in each of the VRI classes.

Use the following equation to calculate the growth recovery of each VRI cutblock height class:

$$ECA = A \cdot C\,(1 - R/100)$$

Where A is the original opening area, C is the proportion of the opening covered by functional regeneration (determined from Table A2.1), and R is the recovery factor determined by Table A2.2 (MOF 2001). Finally, add up the new recovery-weighted cutblock areas to arrive at a final ECA calculation for the watershed of interest.

Table A2.2 in MOF 2001.

Average height of the main canopy (m)	% Recovery
0 - <3	0
3 - <5	25
5 - <7	50
7 - <9	75
9 +	90

How are results interpreted?

The ECA calculation is used to estimate the Peak Flow Index, and is a valuable tool in combination with other FSW monitoring metrics to assess the impacts of timber harvesting on stream channels. Cutblocks that maintain a canopy are not weighted as heavily in an ECA calculation due to the abilities of the canopy to shade snowpack. Small openings within cutblocks tend to collect more snow over time, but melt rates are reduced by shade provided by forest canopies. In areas of higher elevation and gradient, the ECA holds a greater weight due to potential increases in peak flows. The scenario is reversed in lower elevations.

2.3.2 Indicator Category: Surface Erosion

Metric: ***Road density for entire sub-basin (km/km²)***

How is road density for entire sub-basin calculated?

Road density is defined as the total length of roads divided by the total watershed area (km/km2).

Upload the Digital Road Atlas and FSW Regions polygon data layers into ArcMap. Clip the roads within the confines of the FSW polygons. Within each FSW, determine the total length of all road segments and divide this length by the total area the FSW.

How are results interpreted?

High road densities within an FSW indicate a greater risk to fish habitat disturbance. Increases in road density may also lead to magnified surface erosion and landslide risk, with associated increases in stream turbidity and potential disruptions to aquatic functions.

Metric: ***Road density above the H60 line*** **(km/km²)**

How is road density above the H60 line calculated?

Our goal is to determine the density of roads located at an elevation above which 60% of the FSW area lies. To find the H60 Line, we will use the DEM. Clip the DEM within the confines of each FSW polygon region. Clip the Digital Road Atlas within the confines of the FSW polygon regions. Determine the elevation at which 60% of the FSW region lies, and divide the lengths of roads in this region by the area of the watershed above the H60 line.

How are results interpreted?

High road density above the H60 line has relatively greater implications for landslide and surface erosion activity than roads in the lower valleys.

Metric: ***Road density <100m from a stream (km/km²)***

How is road density <100m from a stream calculated?

This monitoring metric is calculated as the length of roads within 100m of a stream, divided by total area of a 100m road buffer.

To calculate this metric, first upload the 1:20,000 Freshwater Atlas and Digital Road atlas, and clip both layers within the confines of the FSW boundary. Place a 100m buffer (with the dissolve option enabled) around all stream networks. Create a new clipped layer that captures all road segments that intersect the 100m stream buffer, and calculate the total length of all these roads. Determine the total area of the 100m road buffers within the entire FSW, and divide the road segment length by the buffer area.

How are results interpreted?

Roads situated in close proximity to streams (<100m) can pose serious threats to stream channel stability. Road construction and maintenance can be very disruptive to streams, with frequent incidences of channel disturbance and point-source pollution. Roads within 100m of a stream also contribute to surface erosion and mass-transport of sediment. Increases in sediment deposition as a result of higher road density can have serious health implications to fish and their ecosystems.

Metric: ***Road density on erodible soils (km/km^2)***

How is road density on erodible soils calculated?

With the available data sources (Soil Landscapes of Canada (SLC)), we can only make general assumptions about surficial characteristics within a FSW region (unless more detailed local soil or terrain stability maps are available for a FSW). The data which describes surficial material type and percentages of cover within an EcoDistrict cannot be spatially represented in ArcGIS. Instead, each EcoDistrict polygon contains a number of attributes which list percentages of composition of multiple surficial materials. The exact locations of these materials within each EcoDistrict polygon are unknown. Future soil and surface geomorphology mapping planned by the MOE (Appendix A in Wieckowski et al. 2011) may solve this issue, as spatial references to real-time surface materials within the province will be made available for public use.

With the datasets that we do have, we can still render a general figure showing at-risk areas for surface erosion. To do so, acquire the SLC data along with the EcoDistricts shapefile data. Join the SLC Data to the EcoDistricts layer in ArcMap based upon the “ECODISTRIC” attribute. The EcoDistrict ID attribute is the only common field for you to project any of the SLC data. After the join, you will be able to find percentages of surface material for each EcoDistrict polygon. Note that the EcoDistrict polygons are drawn at a very large scale, so all conclusions from this step should be estimates only.

Next, clip the SLC/ EcoDistricts data layer to within the FSW Boundary layer. Consult a geologist who can determine which materials/ percentages of cover are indicative of potentially erodible soils and earth materials. Isolate those regions via a clip or selection, and then calculate the road density within those regions using the DRA Road Atlas.

How are results interpreted?

Higher road densities on erodible soils have major implications for FSW ecosystem health and productivity. An increase of surface erosion caused by roads results in increased turbidity, which can lower stream temperatures (lowers access to sunlight), clogs and scours fish lungs and gills, and decreases channel complexity. A high density of roads on erodible surfaces also influences small and large mass-wasting events, which also affects watershed ecosystem health.

Metric: ***Road Density on erodible soils <100m from a stream (km/km^2)***

How is road density on erodible soils <100m from a stream calculated?

As discussed earlier, delineating erodible soils is a challenge with the available datasets. In this monitoring metric, follow the initial GIS steps outlined for the metric “Roads on Erodible Soils” to define the areas of erodible soil. Next clip out those regions that are <100m from a stream. To do this, place a 100m buffer around all streams within the FSW polygon in question. Finally, clip the “Roads on Erodible Surfaces” layer to within the 100m buffer. Measure the total length of roads within this new region, and divide it by the area of the 100m buffers that lie on erodible soils.

How are results interpreted?

Areas of highly erodible soils with high road density (especially when within <100m from a stream network) pose increased risk of major disturbance to stream ecology through elevated fine sediment loads and associated turbidity.

Metric: ***Stream Crossing Density (no./km²)***

How is stream crossing density calculated?

There are two possible options for calculating stream crossing density. A fish habitat layer is maintained by MOE (contact: Richard Thompson) that includes stream crossing intersections (See Appendix A in Wieckowski et al 2011). Alternatively, a comparable layer can be developed by using the 1:20,000 Freshwater Atlas and Digital Road Atlas (and any supplementary road layers that may be available for the particular FSW). In this case, clip the 1:20,000 Freshwater Atlas and Digital Road Atlas within the FSW boundary.
Intersect the roads layer with the streams layer and return the resulting intersections as points.

To calculate the density of stream crossings simply divide the number of road-steam crossings on forest land in the FSW by the total area of the watershed.

How are results interpreted?
Stream crossings by roads represent risk of local sediment and intercepted flow delivery, as well as potential physical impediments to fish movements. In general the greater the density of road-stream crossings on forest land, the greater the risk to fish and their habitats.

Metric: ***Road Density on unstable slopes (km/km²)***

How is road density on unstable slopes calculated?

Available datasets limit the inferences we can make currently about unstable slopes in FSWs. As an interim default we will assume that all slopes >60% are unstable or potentially unstable. Using the DEM, isolate the areas within the FSW that are located on steep slopes >60%. To do this run a slop analysis and then perform a conditional operation on the resulting raster to only output those areas that represent slope of >60%. The result of this conditional operation can then be converted to a polygon file in order to facilitate further calculations. Once unstable slopes within the FSW are identified, calculate the road density within these selected regions.

Future deliverables from MOE (see Appendix A in Wieckowski et al. 2011) will provide detailed mapping of terrain stability characteristics within provincial watersheds. In the interim, estimates made with the available datasets (SLC) could provide some additional information for calculating this indicator, but only at a very coarse scale.

How are results interpreted?

Roads located on unstable slopes can be major contributors to surface erosion and increase risk of mass wasting events. A higher road density on unstable slopes generally indicates a greater risk to watershed health.

2.3.3 Indicator Category: Riparian Buffer

Metric: ***Portion of streams logged (km/km)***

How is portion of streams logged calculated?

Use the Vegetation Resource Inventory (VRI) to determine areas that have been logged recently. First, clip the VRI to within the confines of the FSW. Second, add the 1:20,000 Freshwater Atlas stream layer and clip to the FSW boundary. Next, isolate logged polygons in the VRI by running a “Select by Attributes” query to create a new layer where the projected age of polygons is 0, meaning it has been logged. Next, upload the RESULTS data layer and clip to within the FSW region polygons. With these two logged polygon layers, run a “Select by Location” query and determine where these VRI and RESULTS cutblocks intersect the stream networks. This query will yield cutblocks that intersect stream networks.

To calculate the portion of logged streams, divide the total length of streams intersecting cutblocks by the total length of streams within the FSW.

How are results interpreted?

As the portion of streams that are logged increases, so does the risk of surface erosion and mass-transport of sediment during heavy precipitation events. When forest vegetation is removed, stream channels are weakened due to the lack of root structures, and intensified surface erosion and mass-wasting are common outcomes.

Metric: ***Portion of fish-bearing streams logged (km/km)***

How is portion of fish-bearing streams calculated?

Follow the same steps as identified for calculating “Portion of streams logged”, but use only the identified fish reaches categorized in the province’s 1:20 000“StreamGradientReaches” layer (see Appendix A in Wieckowski et al. 2011) so that only the subset fish-bearing streams are targeted for the calculation.

How are results interpreted?

Consequences and implications of this metric may be of greater concern that the overall portion of streams logged as it represents potential impacts to the fish-bearing stream network in the FSW.

Metric: ***Riparian forest logged (%)***

How is indicator calculated?

In this GIS monitoring metric, we will use the Vegetation Resource Index (VRI), the RESULTS openings database, and the 1:20,000 Freshwater Stream Atlas to calculate the percentage of riparian forest logging within an FSW. Clip all three data layers to the FSW region polygons. To identify the riparian zone, place a 100m buffer around all stream reaches. Next, to completely isolate riparian logging, clip both the RESULTS and VRI layers to the 100m buffer. Calculate the area of logged riparian forest, and divide this area by the total area of the defined riparian forest in the FSW. This metric could be improved in the future by utilizing riparian models that could more precisely define stream riparian areas based on terrain differences defined by provincial DEMs. A riparian model of this type developed originally by the Nature Conservancy (TNC 2006) has been employed recently by BC Hydro to map variable width riparian zones for 1:20,000 streams across BC (S. Casley, pers.comm.).

How are results interpreted?

As the portion of streams that are logged increases, so does the risk of surface erosion and mass-transport of sediment during heavy precipitation events. Vegetation around the riparian zone helps to regulate the climate of the stream system by providing shade, channel complexity, channel stability, and protection from disturbance. When riparian vegetation is removed, stream channels are weakened due to the lack of root structures, and intensified surface erosion and mass-wasting are common outcomes.

2.3.4 Indicator Category: Mass Wasting

Metric: ***Stream banks logged on slopes >60% (km/km^2)***

How is stream banks logged on sloped >60% calculated?

Use the Digital Elevation Model (DEM) to isolate all areas with slopes >60% along the stream network. Then clip out the areas of cutblocks that intersect with these slopes.

To calculate density of stream banks logged on slopes >60%, divide the total length of streams within the region of >60% slope and cutblock intersection by the total area of >60% slope.

How are results interpreted?

Stream banks logged on steep slopes >60% have potential for significant generation of surface erosion and increased landslide potential, especially during heavy precipitation events. Vegetation on slopes intercepts precipitation and stabilizes surficial materials, and increased removal of vegetation on slopes will affect watershed health and productivity.

Metric: ***Density of landslides in the watershed (no./km)***

How is density of landslide in the watershed calculated?

Current available datasets do not provide provincial GIS coverages of landslide density within watersheds. There is free Landsat, SPOT, and Orthoimage data (see Appendix A In Wieckowski et al. 2011) available for public access, but should only be used for reference. This free data has unknown temporal frequencies, and only provides partial coverage of the province. To conduct a change-detection strategy for evaluating landslide occurrences within a watershed, you can purchase high resolution aerial imagery (see Appendix A in Wieckowski et al. 2011). Although this method produces fairly reliable results, it can be expensive to obtain the imagery needed. It is suggested that multiple parties purchase the aerial imagery and split costs to increase the overall cost-effectiveness of a change-detection method to monitor mass-wasting.

How are results interpreted?

Mass wasting events can are both beneficial and detrimental to FSWs. Landslides can transport woody debris into streams, adding to stream channel complexity which is favourable for spawning. Landslides can also harm fish-bearing stream networks by introducing large quantities of sediment, pollution, and passage blocks. Landslide density should be monitored closely and in conjunction with many of the indicators that focus on soil erosion, riparian logging, and unstable slopes.

Metric: ***Equivalent second growth area (ESGA)***

How is ESGA calculated?

Second growth forest implies an age of 25-75 years of forest regeneration age. To calculate this metric, use the Vegetation Resource Index (VRI). Clip the VRI to within the FSW region boundaries. Next, select (either manually in the attribute table, or in a query) all VRI polygons with “PROJ_AGE_1” (projected age) ranging from 25-75 years. Make a new layer, and divide the area of second growth forest by the total area of the FSW polygon to calculate a percentage of second growth forest. This total area of second growth is then partitioned out by incremental 5 year age category percentages to calculate the overall ESGA metric for the watershed. A preliminary approach to calculation of ESGS and net ESGA (currently under review by the FSW MTWG).is described in Appendix 1.

How are results interpreted?

This is a novel monitoring metric that has been proposed by Derek Tripp and is currently being reviewed by the FSW Monitoring Technical Working Group. The metric is based on the concept that extensive amounts of vigorously growing second growth forest in a watershed may cause significant long-term reductions in summer low flow. Review of the literature suggests that equivalent second growth area (ESGA) representing >40% of the watershed could have significant effects on summer low flow conditions.

2.3.5 Climate change indicators – *metrics still to be developed:*

After review of potential climate change monitoring indicators, a subset of indicators have been identified for potential incorporation into the Tier I FSW monitoring protocol. These indicators include remote sensed monitoring of the long term extent of snow/ice fields within FSWs. Snow field extent will have long term influences on water quality and availability, critical factors for maintaining aquatic habitat conditions that will need to be evaluated and assessed relative to the parallel effects of local land management actions on watershed condition. A further watershed risk indicator was also identified that uses a model (recently developed at UBC; D. Moore, pers.com.) to rate watershed susceptibility to the adverse hydrological impacts that could result from climate change. Incorporating these (or other) climate change related elements into the Tier I monitoring framework, determining related quantitative metrics that can be measured and tracked in this regard through remote sensed methods, and establishing defineable thresholds of concern are all elements still to be developed for the FSW monitoring Tier I protocol.

2.4 Tier 1 assessment of functioning condition of FSW

Watershed assessment procedures applied in British Columbia have evolved over the years from threshold methods, to expert systems, to indicators, to professional judgment approaches (Chatwin 2001). Since 2004, legislation around watershed assessments is driven by the Forest and Range Practices Act (FRPA), where the decision to conduct watershed assessments is left to the discretion of the forest licensee. In most cases, watershed assessments in BC conducted under FRPA use professional assessment approaches, using 1999 WAP procedures (MOF 2001) as a general guide, modified to suit local conditions (Pike et al. 2007). Detailed professional assessment approaches are unlikely to be a viable option, however, for broad scale regularly repeated monitoring of watershed condition across multiple FSWs. For Tier 1 assessment of functioning condition in FSWs the intent is to you use a modified version of the combined indicator approach used in earlier provincial WAP procedures (MOF 1995a, b). These used point scores of measured watershed characteristics or land-use patterns to score the overall health or impacts of harvesting on watersheds (Chatwin 2001). Selected indicators represent proxies for watershed health. Tier 1 FSW monitoring will be similar to the Level 1 analysis developed for the 1995 IWAP/CWAP which used a GIS-based screening procedure based on indicators of watershed impact (health). As in the 1995 IWAP/CWAP procedures the Tier 1 FWS evaluation will be based on combined indicator scores for categories related to (1) peak flow, (2) sediment, (3) landslides, and (4) riparian condition. Condition scores for FSW monitored indicators/metrics will be based on the criteria for each metric indicated in IWAP/CWAP conversion tables (1995a, 1995b). Examples of the earlier IWAP/CWAP conversion tables are provided in Appendix 2. It will not be possible to capture all IWAP/CWAP metrics using the province-wide GIS coverages that will form the basis for FSW monitoring. As such, the appropriate roll-up of GIS-based indicators for Tier 1 assessments of watershed condition (i.e., not properly functioning, impaired, properly functioning) will need to be further developed through discussion with the FSW Monitoring Technical Working Group and refined/validated through ongoing pilot work in the Lakelse drainage and other watersheds.

Tier 2 FSW monitoring (described in Pickard et al. 2011) that will be undertaken in a subset of identified FSWs will be roughly comparable to IWAP/CWAP Level 3 evaluations, which were based on detailed field assessment of mass wasting, erosion, riparian condition and stream channel stability.

3.0 Next steps/recommendations

Continuing data assembly for the Lakelse pilot study will inform practical and analytical aspects of developing a broad-scale GIS-based program of Tier 1 monitoring across the province's FSWs. A full discussion of required steps to implement a FSW monitoring program at both the Tier 1 and Tier 2 level are described in the workplan outlined in Pickard et al. 2009. A key element for next steps will be continuing discussion with the FSW Monitoring Techical Working Group on alternative Tier 1 indicator rollup algorithms and weightings that could generate defensible overall assessments of FSW condition at a coarse scale.

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Appendix 1. Derivation of Net Equivalent Second Growth Area (Net ESGA) as a potential metric for describing maintenance of low flow regimes in FSWs

The possibility that second growth forests may cause significant long-term reductions in summer low flow should be considered. The term "hydrologic recovery" often used within the WAP procedure may not actually indicate "real recovery". Generally hydrologic recovery has been used to refer to only the first phase of recovery, when trees are starting to regenerate. This ends when the increase in water yield typically observed after harvesting drops back to pre-harvest levels. A second phase of recovery actually starts when evapotranspiration rates in the increasingly dense, vigorous second growth forest start to exceed the rate of a mature forest and pre-harvest low flows decline even further. At this time, Perry's thesis (Perry 2007) and a few other papers (e.g., Jones and Post 2004) indicate that there can be substantial (20-80%) decreases in summer low flow levels. It is not clear how long this second phase lasts, but it seems to be most evident in 35-50 year old Douglas Fir plantations. There are no longer term data available yet for paired watersheds to determine when full recovery actually occurs. This second phase of recovery may last until trees are harvested again, at which time the whole process would begin again.

The evidence for summer low flow deficits in second growth coniferous forests is pretty sound, though still maybe a little limited or not well known. Consequently we probably need a different metric for the effects of older second growth forests on stream summer low flows. We could term this ESGA for "Equivalent Second Growth Area". The data are limited, but the limited literature could support the beginning of a SG effect at 25 years, a maximum effect at 50 years, and "real" full recovery at 75 years. To calculate an ESGA we would then assume no effects on low flows ≤ at age 25, a 100% effect at age 50, then back down to no effects ≥ age 75, with an escalating/de-escalating (assumed) linear scale between 0 and 1 between 25 and 75 years **(Figure A1).**

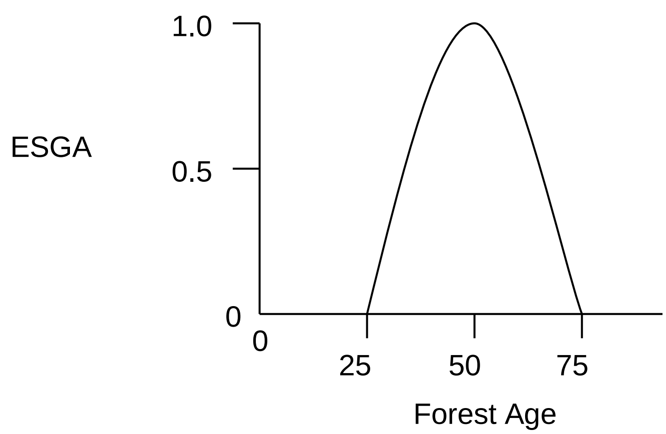

Figure A1. Suggested relationship between forest age and an equivalent second growth area (ESGA) metric for effects on watershed low flows. Shape of relationship is unknown so assumed linearly ascending annual ESGA scores from 0-1 between 25 and 50 years and linearly descending ESGA scores from 1-0 between 50 and 75 years.

This isn't intended to imply that there are no summer stream flow deficits where trees are younger then 25. Twenty five years is suggested based on a general sense of where the "crossover" might occur between increased annual flows and summer low flows. The data actually suggests the crossover from summer low flow increases due to clearcutting to summer low flow decreases due to regrowth occurs somewhere between 10-25 years, depending on tree species, snow pack, aspect. 25 years is suggested here with the thought that it might serve as a reasonable estimate of average tree age for 9+m tall trees, when there is 90+% recovery from peak flow effects due to clearcutting (see **Table A1**). This of course all varies by species and location.

Table A1. Hydrological recovery for fully stocked stands that reach a maximum crown closure of 50%–70%.

Average height of the main canopy (m)	% Recovery	Assumed Age (D. Tripp)
0 -<3	0	<5
3 – <5	25	6-10
5 – <7	50	11-15
7 – <9	75	16-20
9 +	90	21-25

None of the papers on second growth effects on summer low flows talk about tree height. It's always tree age, so it would take a bit to relate the two, but should be possible. A 10m tree on the coast is probably a lot younger than a 10m tree in the interior. For developing a metric we are assuming 100% recovery at age 25, requiring trees to grow steadily 0.4m a year. Not that unrealistic, but there is a lot of variability around the province. We could consult a silviculture expert for this, or go back to the literature and try and determine the tree heights of the second growth forests used in the analyses of low flow deficit effects.

Defining a particular ESGA threshold is difficult since most of studies have involved watersheds that were 100% logged. Detectable decreases in flow, however were still evident in watersheds that were 30% logged, but the effect was not as great**. A conservative "threshold" for ESGA in a FSW might therefore be 40% of the watershed.**

Interestingly, the effects of ESGA might be offset by the effects of ECA. It would perhaps be best to go further and develop a Net ESGA metric, discounting total ESGA by ECA since ECA could offset the impacts of ESGA on summer low flows. A calculation for this "net" affect would, for example, indicate that a % area for ESGA would be countered by an equal % of ECA, such that 50% ESGA – 20% ECA = 30% net ESGA). This would seem generally reasonable since clearcuts have been shown to increase summer low flows, suggesting that they would offset the effects of older second growth stands on decreased low flows in the same watershed. This "net" calculation would of course be based on a perhaps overly simplistic assumption that the effects of ECA vs. ESGA in a watershed are linear (i.e., % ECA equivalent to same % ESGA). As such we wouldn't predict any summer low flow deficits if ECA equaled ESGA.

Our low flow maintenance threshold for FSWs would therefore be: **Net ESGA not to exceed 40% of forested area of watershed.**

An example of the Net ESGA calculation (based on an escalating/de-escalating scale between 25 and 75 years for ESGA and incorporation of ECA) for a hypothetical watershed is shown below:

25% of the forest area is 50 years old, ESGA = 1 * 25% = 25%
50% of the forest is < 25 years old, ESGA = 0 * 50% = 0%
12.5% of the forest is 35 years old, ESGA = 0.4 * 12.5% = 5%
12.5% of the forest is 55 years old, ESGA = 0.8 * 12.5% = 10%

Therefore ESGA = 25% + 0% + 5% + 10% = 40%

But the watershed also has a calculated **ECA** of 25%. Therefore the Net ESGA for the watershed would = 25% + 0% + 5% + 10% - **25%** = **15%**

This watershed would consequently be considered to be safely below our defined Net ESGA threshold of 40%.

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Appendix 2. IWAP and CWAP Level 1 assessment conversion tables (Table A1 and A2) for scoring WAP indicator values.

Table A2. Interior watershed assessment conversion table (from MOF 1995a).

Impact category	Indicators	Score										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Peak flow	1. *peak flow index*	0	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	>0.60
	2. *road density above H_{60} line* (km/km^2)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	>1.0
	3. *road density for entire sub-basin* (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
	4. *roads on erosible soil* (km/km^2)	0	0.05	0.10	0.15	0.20	0.25	0.34	0.43	0.52	0.61	>0.7
Surface erosion	5. *roads < 100 m from a stream* (km/km^2)	0	0.04	0.08	0.12	0.16	0.20	0.25	0.30	0.35	0.40	>0.45
	6. *roads on erodible soils < 100 m from a stream* (no./km^2)	0	0.02	0.04	0.06	0.08	0.10	0.13	0.16	0.19	0.21	>0.24
	7. *no. of stream crossings* (no./km^2)	0	0.08	0.16	0.24	0.32	0.40	0.50	0.60	0.70	0.80	>0.90
	8. *road density for entire sub-basin* (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.72	1.94	2.16	2.38	>2.6
Riparian buffer	9. *portion of stream logged* (km/km^2)	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	>0.30
	10. *portion of fish-bearing stream logged* (km/km^2)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	>0.50
Mass wasting	11. *no of landslides* (no./km^2)	0	0.02	0.04	0.06	0.08	0.10	0.14	0.18	0.24	0.30	>0.4
	12. *roads on unstable slopes* (km/km^2)	0	0.03	0.06	0.09	0.12	0.15	0.20	0.25	0.30	0.35	>0.4
	13. *streambanks logged on slopes > 60%* (km/km^2)	0	0.03	0.06	0.09	0.12	0.15	0.20	0.25	0.30	0.35	>0.40

Table A2. Coastal watershed assessment conversion table (from MOF 1995b).

Impact category	Indicators	Score										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Peak flow	1. *peak flow index*	0	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	>0.60
	2. *road density* (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
Surface erosion	3. *road density* (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
	4. *road on erodible soil* (km/km^2)	0	0.05	0.10	0.15	0.20	0.25	0.35	0.45	0.55	0.65	>0.75
	5. *mainline road within 100 m of stream* (km/km^2)	0	0.04	0.08	0.12	0.16	0.20	0.25	0.30	0.35	0.40	>0.45
	6. *no. of stream crossings* (no/km^2)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	>2.0
Riparian buffer	7. *portion of stream logged* (km/km)	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	>0.30
	8. *portion of fish stream logged* (km/km)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	>0.50
	9. *mainstem logged* (km/km)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	>0.50
Mass wasting	10. *no. of landslides* (no./km^2)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	>2.0
	11. *no. of large landslides hitting mainstem*	0	0.4	0.8	1.2	1.6	2.0	2.6	3.2	3.8	4.4	>5.0
	12. *km of Class IV or V road* (km/km^2)	0	0.03	0.06	0.09	0.12	0.15	0.20	0.25	0.30	0.35	>0.40
	13. *ha of Class IV or V logged* (%)	0	1	2	3	4	5	6	7	8	9	>10
Headwaters	14. *km of stream logged >60%* (km/km)	0	0.15	0.30	0.45	0.60	0.75	0.85	0.95	1.05	1.15	>1.25
	15. *no. of stream crossings >60%* (no./km^2)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	>1.0

Tier II Fisheries Sensitive Watersheds (FSW) monitoring protocol rationale

Draft Version 2

December 2011

Prepared for:

British Columbia Ministry of Forests, Lands and Natural Resource Operations

and

British Columbia Ministry of Environment

P.O. Box 9338, Stn Prov Govt
Victoria, BC, V8W 9M1

Prepared by

Darcy Pickard, Marc Porter, Katherine Wieckowski, Simon Casley
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, BC V6J 5C6

Dec 20, 2011

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[1] (1) FREP Riparian Protocol, (2) FREP Water Quality Protocol, and (3) FREP/MOE Fish Passage protocol

Table of contents

List of Figures

List of Tables

1.0 Introduction

1.1 Background

In 2004, the government of British Columbia took steps towards protecting the social, ecological, and economic fisheries values in the province by putting into force the *Government Actions Regulations* (GAR). Under section 14 of the GAR, the Minister of Environment (MOE) is authorised to designate a watershed as a Fisheries Sensitive Watershed (FSW) that has both i) significant fish values and ii) watershed sensitivity. Watersheds which have been designated as FSWs by the Minister require Forest Act agreement holders to establish results and strategies in their Forest Stewardship Plans consistent with the objective(s) set by the Minister. For a description of the process for designating a watershed as a FSW refer to Reese-Hansen and Parkinson (2006). A FSW designation acknowledges the considerable benefits derived from British Columbia's fisheries resources and provides the legal framework that will require forest and range operators to undertake practices that maintain the natural watershed processes that conserve the ecological attributes necessary to protect and sustain fish and their habitat (Reese-Hansen and Parkinson 2006).

FSW designation has been undertaken to achieve two goals. First, designation is intended to conserve natural hydrological conditions, bed dynamics and channel integrity, as well as the quality, quantity, and timing of water flow. Second, designation is intended to prevent cumulative effects that would have adverse impacts on fish habitat. Effectiveness monitoring is required to determine if FSW designation has achieved these two goals. To this end , MOE has been working with ESSA Technologies Ltd. to build a conceptual framework (Wieckowski et al. 2008) for FSW monitoring that incorporates both remote-based and field-based surveys across multiple spatial scales (Wieckowski et al 2009; Pickard et al. 2009).

1.2 Report purpose

This purpose of this document is to provide the scientific rationale for the field-based FSW monitoring protocol proposed in Pickard et al. 2011. Here we provide a brief review of the specific indicators and sampling protocols that are to be used for FSW monitoring. We discuss in detail the sampling design alternatives and trade-offs that arose in developing the FSW monitoring protocol. We propose an approach for aggregating indicator data in order to make statements about watershed health. Finally, we describe the next steps required to implement and refine the FSW field-based monitoring protocol.

2.0 Field-Based Indicators and Protocols

In order to promote greater harmonization of monitoring approaches across the province and to leverage past efforts, field-based data inputs into the decisions for the FSW monitoring program will be a combination of performance measures collected using existing Forest and Range Evaluation Program (FREP) and BC MOE protocols. These are rapid assessment protocols that have been developed for evaluating the condition of streams and riparian areas (Tripp et al 2009), assessing water quality (Carson et al. 2009) and determining impairments to fish passage (BC MOE 2009). Rapid assessment protocols are cost effective assessments that use semi-quantitative methods to quickly collect, compile, analyze, and interpret environmental indicator data to facilitate management decisions (Barbour et al. 1999). The indicators used by FREP were selected by a multi-agency and multi-disciplinary team of scientists and technical specialists that evaluated a large number of potential indicators assembled from a thorough review of scientific and technical resource management literature. Criteria used for indicator selection included foundation in reliable scientific data; relevance and responsiveness to forestry practices, particularly riparian management and road systems; broad geographic coverage; and capability to measure changes in ecological processes and conditions (Tschaplinski and Brownie 2010). FREP's Riparian Protocol utilizes a suite of over 50 indicators, allowing comprehensive assessment of both biological and physical components of stream/riparian ecosystems. The FSW monitoring initiative will benefit from incorporating the data collection methodologies already established under FREP and MOE by: 1) achieving efficiencies in cost of program development and personnel training; 2) establishing data compatibility across sites that are monitored under different programs; and 3) allowing for potential comparisons between FSWs and non-FSWs across the province.

3.0 Monitoring Design

3.1 General overview of alternatives

A review of alternative design options for FSW monitoring is provided in Wieckowski et al. (2008) and should be referred to for a more in-depth discussion. In essence, there are six approaches that could be considered for the design of FSW monitoring: 1) descriptive surveys, 2) observational surveys, 3) analytical surveys, 4) impact surveys, 5) control-impact surveys, and 6) designed experiments. The strength of inference increases across these study designs (from descriptive studies at the low end to designed experiments at the high end), but requires increasing amounts of investigator control to achieve. **Figure 1** illustrates the relationship between the degree of control and the strength of inference possible for an array of study designs. Choosing the right monitoring design requires careful consideration of the: study objectives, the degree of control required, the desired level of inference, the effect size of interest, and the tradeoffs surrounding issues of cost and feasibility of the various approaches. As the prime objective for the FSW monitoring program will be to determine whether or not designating a watershed as a FSW is an effective management action, the study design should provide evidence of causation as well as a strong level of inference. The monitoring program therefore needs to be as close to a designed experiment as possible. In addition, the observed watersheds should be selected randomly so that inferences to the population of all watersheds can be made. While the initial FSW pilot work will initially be a simple descriptive study (i.e,, indicator information collected will only be relevant to the particular watershed sampled) the longer term intent will be to build a monitoring program built on an analytical survey approach or potentially a replicated 'Before After Control Impact' (BACI) design (see Wieckowski et al 2008), where random sampling of FSWs and non-FSWs will allow inferences to be made across FSWs as a class of management action.
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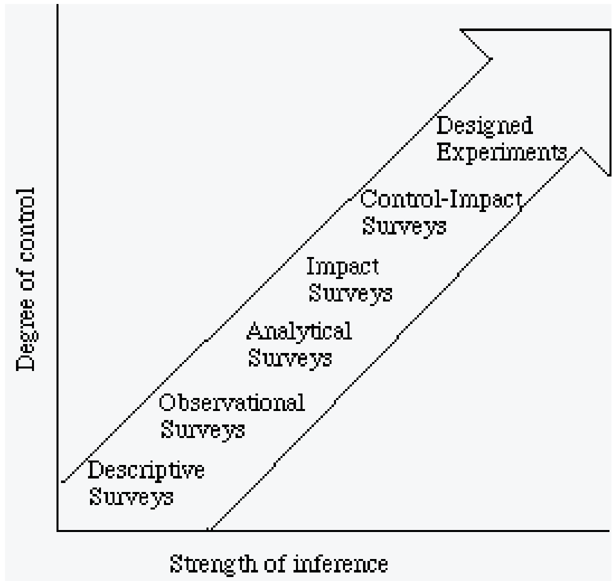

Figure 1. Relationship between degree of control, strength of inference (and ability to determine causation), and type of study design (modified from Schwarz 2006).

3.2 Description of target population

The *target population* can be defined in several ways: 1) the complete collection of individuals to be studied (Lohr 1999); 2) the population about which information is wanted (Cochran 1977); and 3) the complete set of units about which we want to make inferences (Elzinga et al 2001). Regardless of definition, in order to make inferences about the entire target population, all individuals within the target population must have some chance of being selected in the sample. For FSW monitoring the initial target population will be all legally designated FSWs, with watershed boundaries as delineated by the province's 1:20,000 Freshwater Atlas GIS. This is a target population that is likely to change over time as more FSWs are designated within BC. Eventually the target population for monitoring could expand to encompass all 1:20,000 defined watersheds in BC, albeit with a focus on FSWs. This approach would allow for a comparison of trends in habitat condition in FSWs vs. non-FSW watersheds.

3.3 Temporal considerations

A thorough review of options for the timing and frequency of FSW monitoring efforts is provided in Wieckowski et al. (2008). The appropriate sampling frequency of FSW indicators both within and between years will be dictated by the objectives of the monitoring program, the ecology of the system and the characteristics of the target population.

Within years: As habitat conditions within FSWs will vary seasonally (e.g., temperature, stream flow, vegetation cover, etc.) it will be important to be consistent with the timing of sampling and reporting of indicator metrics. Optimal timing could relate to critical periods in the ecology of the watershed, key components of forest management actions or logistical issues around sampling. The FREP protocols for riparian and water quality monitoring as well as the MOE Fish Passage protocols that in combination will be used for FSW Tier 2 monitoring already incorporate these factors into their guidance documents (Tripp et al. 2009; Carson et al. 2009, MOE 2009) and suggest that the optimal period for sampling is between late spring, when all snow has left sampling areas and mid autumn, before the snow returns. The actual months when these conditions apply will vary regionally.

Between years: Sampling that spans multiple years will be important for assessing any change in the status of FSWs over time. A variety of repeat sampling designs (potentially incorporating a mix of both permanent (long term) and temporary sample sites) could be developed for FSW monitoring, and will be explored as part of the Lakelse pilot work in 2011. The specific frequency of return visits and the sample sizes required to evaluate long term status and trends will ultimately depend on factors such as the monitoring objectives, the properties of the sample design, and the sensitivity of the indicators monitored (e.g., signal to noise ratio – Kaufman et al.1999).

3.4 Sampling frame

The *sampling population* or *sampling frame* is the collection of all possible sampling units that might have been chosen in a sample, or can alternatively be described as the population from which the sample was taken (Lohr 1999). For FSW monitoring the sampling frame will be represented by the complete network of stream reaches present within FSWs (the target population) as defined by the province's 1:20,000 Freshwater Atlas stream hydrology GIS layer. This sample frame will be likely be restricted for monitoring purposes to the smaller subset of stream reaches found below the tree line in each FSW (i.e., the vegetation zones in which forest harvesting could occur).

3.5 Stratification options

A thorough discussion of the potential benefits of incorporating sampling stratification into the design for FSW monitoring is provided in Wieckowski et al. (2008).Stratification is a tool which can be applied to any sampling design. In a stratified random design the sampling frame can be divided into a variety non-overlapping groups (strata) based on some characteristic such as habitat type, stream size, etc. A random sample is then chosen from each of the strata. Stratification may result in a more efficient design when there is less variability within strata than between strata (Cochran 1977; Lohr 1999). Stratification may also be useful if estimates for individual strata are desired as well as for the entire population and sampling intensities can be weighted for particular strata of interest. Some level of stratification generally results in large gains in precision, especially when the response variable of interest is closely related to the strata (Cochran 1977). However, more strata are not necessarily better. The optimal number of strata will depend on the rate at which the precision of the estimate improves as the number of strata increases, as well as how the cost of the survey changes as the number of strata increases. Cochran (1977) provides a detailed example of one method that can be used to calculate the optimal number of strata by simply considering the tradeoff between cost and precision as the number of strata increase. This can provide the information needed to find a practical balance without the need for completing rigorous calculations.

Various potential stratifications for FSW sampling have been considered based on distinct factors that could influence watershed condition and the habitat response to FSW management actions. The intitial list of FSW stratifications to be explored in the Lakesle pilot study in 2011 are:

STRATA:

1) **Logging influence** (as defined by RESULTS and VRI layers, and supplemented by satellite imagery interpretation):
    a. Never cut
    b. Within cutblock and within 1 km downslope influence of cutblock – **recent cut** (≥1995) (including fringing 50m buffer area around perimeter of cutblock)
    c. Within cutblock and within 1 km downslope influence of cutblock – **older cut** (pre-1995) (including fringing 50m buffer area around perimeter of cutblock)

2) **Fish habitat criteria for stream reaches** (as defined by MOE Fish Passage layer)
    a. Non-Fish habitat
    b. Fish habitat – Stream Order (1st and 2nd)
    c. Fish habitat – Stream Order (≥ 3rd)

3) **Proximity to road (as defined by DRA, FTEN and supporting local DKM road layer)**
    a. Close (≤ 100m)
    b. Far (> 100m)

Table 1 provides a summary of some of the readily available GIS data layers that can be used for developing selected sampling strata for FSWs.

Table 1. Summary of available GIS-based data layers to inform the FSW sample frame and potential sampling strata.

Data layer	Data Source	Sample Frame
1:20 000 Freshwater Atlas: Stream Hydrology	GeoBC: LRDW	Stream reaches
1:20 000 Freshwater Atlas: Lakes	GeoBC: LRDW	Stream reaches
		Strata
Digital Road Atlas (DRA)	GeoBC: LRDW	Roads
Forest Tenure Roads (FTN)	GeoBC: LRDW	Roads
DKM roads	Regional Forest District	Roads
Vegetation Resource Index (VRI)	GeoBC: LRDW	Cutblocks, cutblock influence
RESULTS	GeoBC: LRDW	Cutblocks, cutblock influence
Digital Elevation Model (DEM)	GeoBase	Cutblock influence
Landsat	GeoBC: WMS	Cutblocks
Fish habitat classifications (research layer)	Richard Thompson (MOE)	Fish Habitat

Fish passage obstructions (research layer)	Richard Thompson (MOE)	Fish barriers
Biogeoclimatic zones (BEC)	GeoBC: LRDW	Tree line and vegetation types

3.6 Selection of sites

There are two probabilistic sampling designs that are most commonly used and form the basic building blocks of most sampling designs: simple random sampling and systematic random sampling. Simple random sampling refers to the situation where a random sample of all sampling units within the sampling frame is selected (e.g., drawing numbers from a hat). Systematic random sampling refers to the situation where sampling units are selected at regular intervals using a randomly selected starting point. There are multiple variations of these basic designs that have been developed to address particular situations. For monitoring of indicators within FSWs we are proposing the use of a generalized random-tessellation stratified (GRTS) design for selection of sample sites. The selection of points would incorporate within-watershed strata of importance (e.g., stream order, cut-blocks, etc.). GRTS is a recent approach that draws on the strengths of each of the basic sample designs. GRTS designs are spatially-balanced probabilistic surveys developed by the U.S. Environmental Protection Agency (EPA) under their Environmental Monitoring and Assessment Program specifically for use in sampling natural resources (Stevens & Olsen 2004). A detailed review of possible sampling approaches and a rationale for recommending GRTS for FSW monitoring is provided in Wieckowski et al. (2008).

Creating and implementing a GRTS design can be more complex than more commonly used simple random or systematic random sampling, as the estimate and variance calculations are complicated and hand computations are not really feasible. It can also difficult to generate a spatially explicit sampling frame for a large geographic scale; however, GIS technology has made this possible and now relatively straightforward. The actual generation of sampling frames depends on the study objectives, target populations, and the extent to which the digital coverage reflects the target population (as it would with any design). The selection of a GRTS sample and the computations have been automated to a great extent. Software packages required to create GRTS designs include psurvey.design (free for download from the U.S. Environmental Protection Agency (EPA) Aquatic Resources Monitoring website (http://www.epa.gov/nheerl/arm/designing/design_intro.htm), R statistical package and ArcGIS).

3.7 Sample size

The appropriate number of sites to sample within FSWs for effective monitoring of indicator status within and across FSW sampling strata is not known at this stage. Wieckowski et al (2008) describes some of the issues around sample size that need to be considered in regard to specifying tolerable limits on potential decision errors. Developing sample size calculations for FSW monitoring will require:

- estimates of variability of monitored indicators within and between sampling strata
- the desired level of accuracy/precision with which to address monitoring questions (i.e., how specific do our answers to these questions need to be and what amount of uncertainty (error) are we are willing to accept around these answers?)
- cost of sampling
- the time and cost of moving between sampling sites

- the significance test of interest (i.e., the difference between two groups or a significant trend over time)
- knowledge about the distribution of the data of interest

Pilot work in the Lakesle drainage in 2011 will help determine the cost and logistical aspects of sampling across a watershed, and will be used to develop initial estimates of variability within and between watershed sample units (reaches/strata). Within the Lakelse study area we will be undertaking sampling at a minimum of 4 sample sites per defined strata (if possible), while endeavouring to undertake sampling at the maximum number of sites possible (in the time available) in order to develop the best estimates possible of sample unit variability. While 3 sites would typically be a sufficient minimum sample to generate an average, use of the GRTS design (for which spatial balance is based on a four level quadrat recursive partitioning (Steven and Olsen 2004)) suggests that at least 4 sites should be sampled to maintain the required design assumptions.

4.0 Roll-up to categorize watershed condition

While each of the three field-monitoring protocols that will be used for Tier 2 monitoring have their own methods for rolling up their indicator results into final scores for a site, it is not yet clear how the results from all three should be rolled up for combined assessments of watershed condition in a FSW. There exist a range of different possibilities for how indicator scores could be rolled up to this scale; refer to Appendix B in Wieckowski et al. (2008) for a discussion on alternative roll up approaches and a summary of different strategies that have been used by a variety of agency monitoring programs. There is no simple or unique solution to determine how to aggregate this information to the watershed scale. Each indicator metric could be reported and analyzed independently or through multivariate techniques. Alternatively, each metric could be compared against a pre-defined threshold and a continuous or binary score recorded. The data from each site (i.e., stream reach) could be combined into a single 'site condition' score and an average score across sites in the watershed could be reported. The site level metrics could also be averaged across the watershed and then a 'watershed condition' score generated at the watershed level based on the average performance of the metrics. An appropriate roll-up approach for assessing condition of FSWs at the Tier 2 scale will be developed over the course of 2012 through continued discussion with the FSW Monitoring Technical Working Group.

5.0 Next steps/recommendations

It is critical that pilot work be undertaken in the Lakesle and other drainages (as possible) in order to assess all practical aspects of developing a field-based Tier 2 monitoring program across multiple FSWs (i.e., cost, logistics, appropriateness of protocols in the field). Pilot data collection and analysis will also be needed to inform appropriate sample sizes for indicator monitoring and to assess the potential benefits and potential draw backs of incorporating various strata into the sample design. Existing datasets from prior agency monitoring should be assembled and used to supplement/support analyses from the Lakesle FSW pilot work (e.g. FREP riparian inventories from throughout the province could be used for developing estimates of sample unit variability; census of fish passage conditions at culverts in the Lakelse drainage could be used to assess possible biases in alternative designs being considered (Pickard et al. 2011) for selecting sites for fish passage and water quality sampling. A full discussion of required steps to implement a FSW monitoring program are described in the workplan outlined in Pickard et al. 2009.

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Tier II Field-based Fisheries Sensitive Watersheds (FSW) monitoring protocol

Draft Version 2

December 2011

Prepared for:

British Columbia Ministry of Forests, Lands and Natural Resource Operations

and

British Columbia Ministry of Environment

P.O. Box 9338, Stn Prov Govt
Victoria, BC, V8W 9M1

Prepared by

Darcy Pickard, Marc Porter, Katherine Wieckowski, Simon Casley
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, BC V6J 5C6

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[1] (1) FREP Riparian Protocol, (2) FREP Water Quality Protocol, and (3) FREP/MOE Fish Passage protocol

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 What is properly functioning condition?

Consistent with the Forest Practices Code's and FREP's definition of **properly functioning condition** FSW's considered to be properly functioning are not necessarily pristine watersheds lacking human or natural disturbance. Rather, properly functioning implies that the extent and rate of such disturbances are on average, small and within a watershed's natural range of variability; or large and beyond the rate of natural variability in no more than a small portion of the overall habitat. Properly functioning FSWs are expected to maintain a majority of streams that can withstand normal peak flood events without experiencing accelerated soil loss, channel movement or bank movement; can filter runoff and maintain water quality; can store and safely release water; can maintain aquatic habitat connectivity within the stream network and between the stream and adjacent riparian area; can maintain an adequate root network or large woody debris supply; and can provide shade and reduce bank microclimate change. Properly functioning FSWs should also maintain direct access to potential spawning and rearing habitats for all resident or anadromous fish populations with well designed, installed and maintained culverts and other structures on stream-intersecting resource roads that provide for adequate fish passage.

2.0 Monitoring Design

Developing a monitoring design for FSWs requires careful consideration of the resource to be sampled (*target population*), what will be measured (*indicators*), how they will be measured (*response design*), where they will be sampled (*sample design*), how frequently they will be sampled (*time selection*), and how measurements will be summarized (*population estimation*) (Theobold et al. 2007).

2.1 Target population and sampling frame

The target population for the monitoring program is all designated FSWs in the province. This is a target population that is likely to change over time as more FSWs are legally designated within BC. The general sample frame for FSW monitoring will be based on the population of stream reaches in naturally forested areas within these FSW watersheds. This whole-watershed FSW sample frame differs from that used for standard FREP Riparian and Water Quality monitoring, which have sample frames that are restricted to stream reaches found within cutblocks or immediately adjacent to cutblocks (within 2 RMA widths). More specifically, the actual sample frame for FSW monitoring will be an electronic (1:20K scale) representation of those streams on a GIS (the province's Freshwater Atlas stream network layer). There is likely to be some lack of correspondence between the tangible, physical population of stream reaches and this defined sample frame. Two potential sources of non-correspondence are incomplete coverage (there are streams in the landscape that don't have corresponding mapped depictions in the 1:20K sample frame) and over-coverage (there may be stream traces indicated in the sample frame that do not correspond to flowing streams in the field) (Stevens 2002). These mismatches in the sample frame will be identified in the field and adjusted for as possible in the final selection of sample sites.

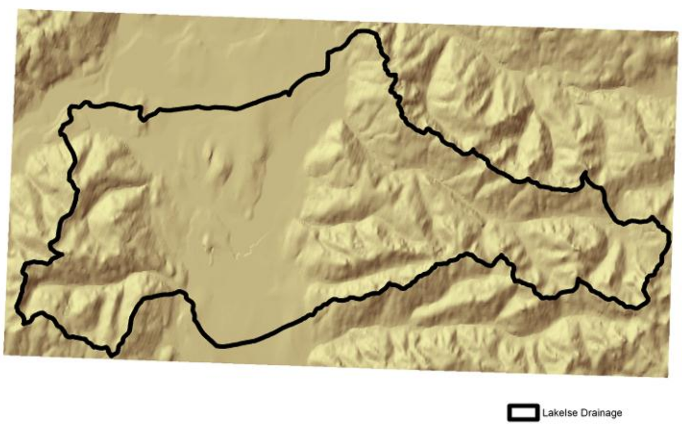
The sampling frame for FSWs can be split into a number of distinct categories (i.e., the population of stream reaches can be organized into separate "strata" of interest). Each pre-defined stratum can then be sampled as an independent subgroup, out of which individual elements can be randomly selected.

Stratification can provide the ability to draw inferences about specific subgroups that may be lost in more a more generalized random sample and can generate more efficient statistical estimates in cases where the variability between the defined strata is greater than variability within the strata. GIS layers available for the province that have been developed from remote sensed data and inventory databases provide a variety of options for stratifying sampling within FSWs. ***Figure 1*** presents an example (for the Lakesle pilot area) of the process of GIS development for the FSW sample frame and potential stratifications that could be used to adjust the sample frame. For initial FSW pilot work we are intending to explore the value of stratifications based on road proximity, fish habitat type, cutblocks and downslope cutblock influence. ICTRT (Interior Columbia Basin Technical Recovery Team). 2005. *Interior Columbia Basin TRT: viability criteria for application to Interior Columbia Basin Salmonid ESUs*. Draft. July, 2005. *URL* www.nwfsc.noaa.gov/trt/col_docs/viabilityupdatememo.pdf

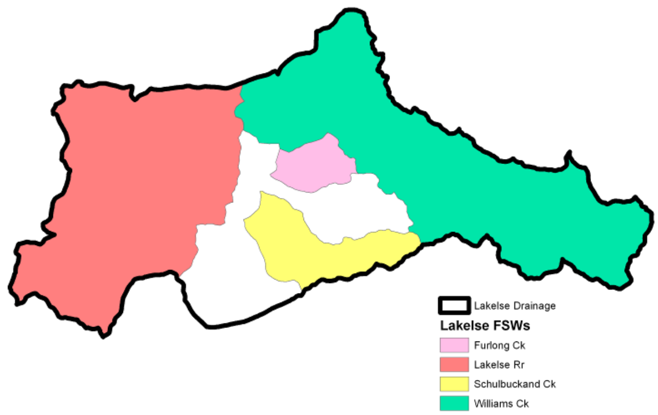
Appendix 1 provides detailed instructions for the ArcGIS processing of agency GIS layers required to produce suggested spatial filters and stratifications for FSW monitoring.

It should be noted that there are, however, some potential drawbacks to using stratified sampling in FSWs. First, identifying strata and implementing such an approach will increase the cost and complexity of sample selection, as well as leading to increased complexity of population estimates. Also for designs with a large number of strata, or those with a specified minimum sample size per group, stratified sampling will likely require a larger number of samples than in a more generalized approach, thereby increasing field effort and costs. In general, some level of stratification is almost always helpful, more strata may not always be necessary.

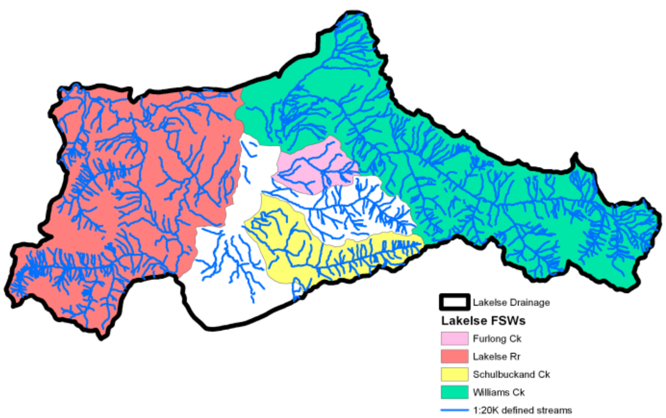
1) Delineation of drainage basin selected for development of a FSW monitoring design (Lakelse drainage presented here as an example)



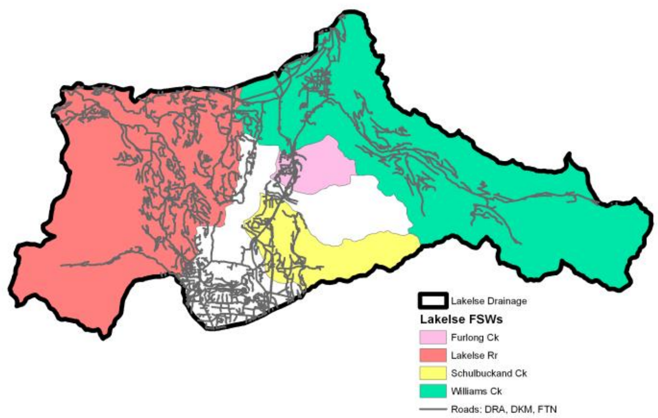
2) Delineation of FSWs within the larger drainage (example: Lakelse drainage)



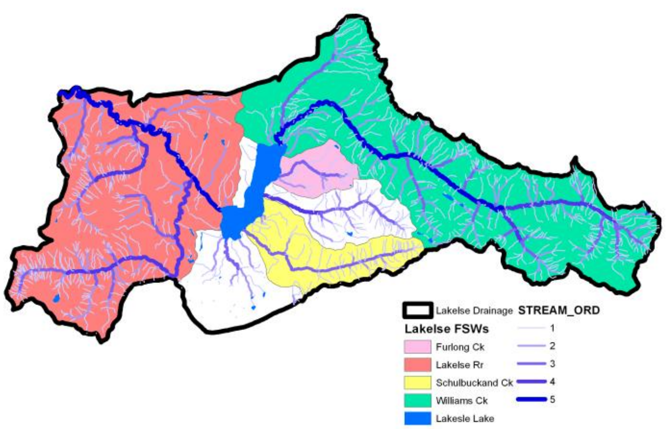
3) Delineation of 1:20K stream network that will provide basis of FSW sampling frame



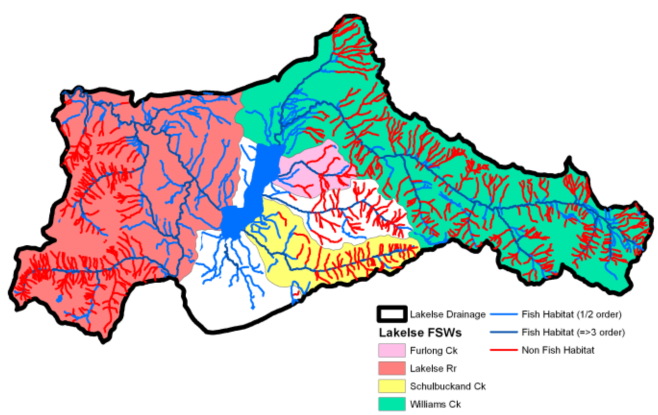
4) Delineation of roads to be used as a potential sampling strata within the FSWs



5) Delineation of 1:20K defined stream orders to be used as a potential sampling strata within the FSWs



6) Delineation of fish habitat/stream order classifications to be used as a potential sampling strata within the FSWs



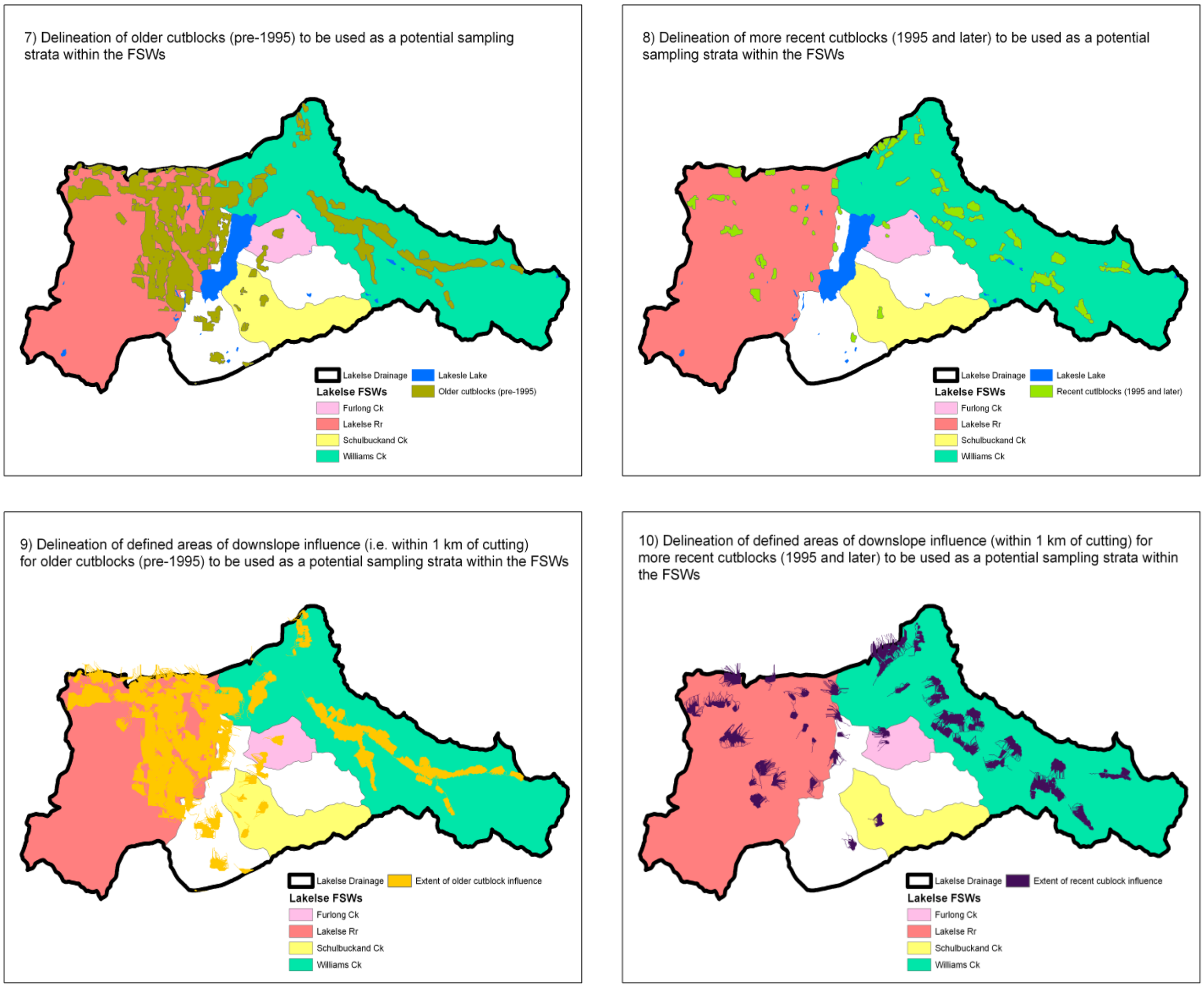


Figure 1. Mapped depictions of spatial layers used for developing a FSW sampling frame and some example sampling stratifications.

2.2 How to select sites?

In the Office

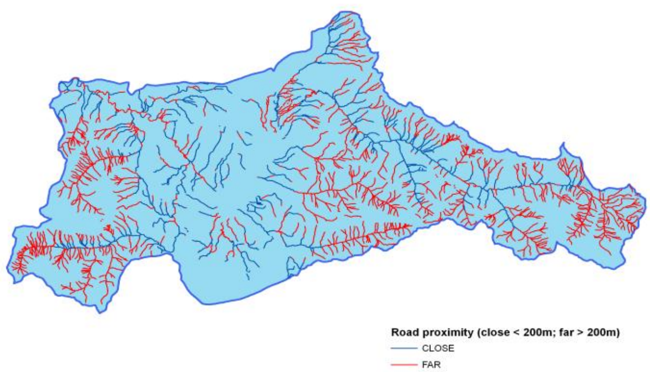
Development of a long-term monitoring plan for FSWs requires development of an efficient sampling design that can provide statistical rigor yet is flexible to inevitable logistical or practical constraints during field data collection. For FSW monitoring we propose use of the Generalized Random Tessellation Stratified (GRTS) sampling algorithm developed by the U.S. Environmental Protection

Agency (EPA). GRTS is a spatially balanced, randomized sampling design based on a hierarchical, random tessellation of the study area, incorporates unequal inclusion probabilities and can be applied to points (e.g. individual sites), lines (e.g. stream reaches), or polygons (e.g. lake areas). It was developed specifically for sampling natural resources (e.g., Stevens 1997; Stevens and Olsen 2000; Herlihy et al. 2000) and is available from the EPA as a free library for R statistical software and can be implemented in ArcGIS (using ESRI software ArcGIS v9).

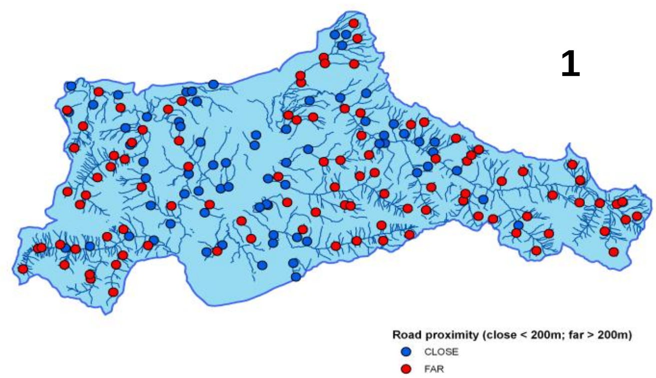
A particularly favorable feature of GRTS is that it is possible to dynamically add points to the sample as non-target or inaccessible points are encountered, while at the same time maintaining a spatially well-balanced sample. To account for errors in GIS delineations of the sampling frame and strata, landowner denials, physically inaccessible stream sites, and various other issues that could affect actual field sampling an oversample of ordered points is generally incorporated into the GRTS draw provided to field crews. This helps ensure that the desired number of sample sites can be visited within the defined field season (i.e. provides the ability to “replace” samples that are lost due to being non-target or inaccessible) (Stevens and Olsen 2004).

Figure 2 provides some mapped examples of GRTS points generated within various defined stream reach strata (single strata and combined strata) in the Lakelse watershed whileTable ***1*** shows GIS database outputs of a GRTS draw; in this example 10 selected points (plus 5 oversample points) in each of two road proximity strata (CLOSE, FAR).

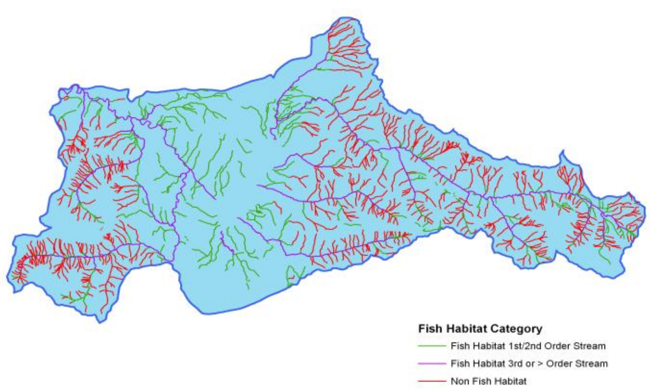
1:20K stream reaches in relation to road proximity within the Lakesle drainage



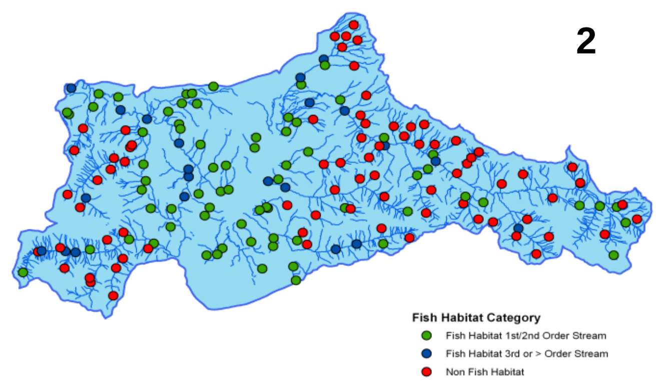
GRTS selected sample points based on road proximity strata (> or < 200m from a road)



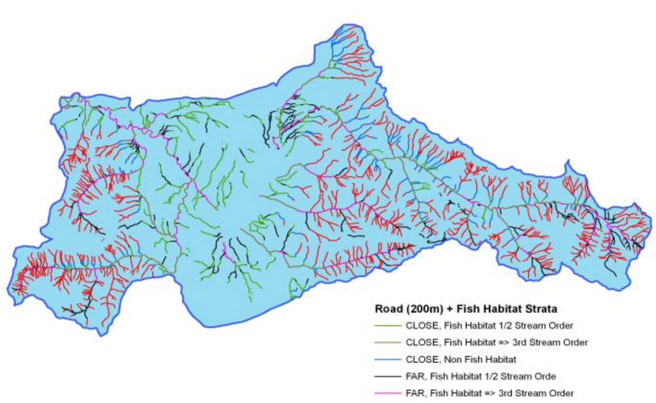
1:20K stream reaches in relation to fish habitat categories within the Lakesle drainage



GRTS selected sample points based on three fish habitat strata categories



1:20K stream reaches in relation to both road proximity and fish habitat categories in the Lakesle drainage



GRTS selected sample points based on both road proximity and fish habitat categories

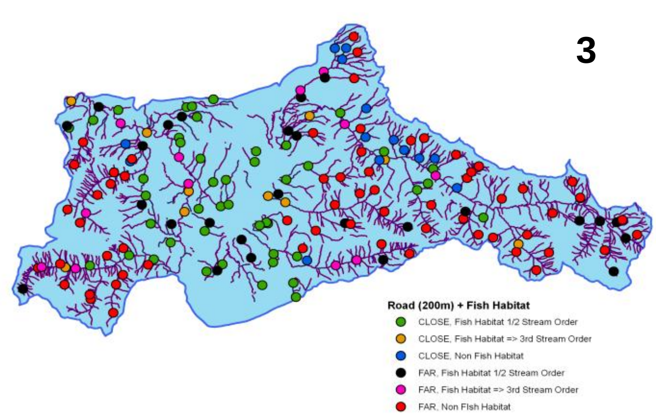


Figure 2. Generation of GRTS sampling points along the 1:20K stream network based on selected sampling strata. Examples are shown for: 1) Road proximity strata, 2) Fish Habitat strata, and 3) Combined road proximity and fish habitat strata.

Table 1. An example (ArcGIS database) list of 10 GRTS sample points selected from the larger pool of potential GRTS points in each of the 200m road proximity strata (CLOSE, FAR) for the Lakelse drainage. An additional 5 oversample points were also selected in this example to be used in the advent that any of the initial 10 points selected cannot be sampled for some reason. All ordered points selected will conform to desired design criteria of randomization and spatial balance.

Attributes of example_road_filter_draw

FID	Shape *	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	fish_hab	logging	length
0	Point	STRATIFIED_byRoads-001	851292.889491	1043155.51469	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	RECENT_CUT	366.593177
1	Point	STRATIFIED_byRoads-002	825781.553873	1046210.08174	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	NEVER_CUT	1240.06188
2	Point	STRATIFIED_byRoads-003	829177.846327	1045221.45644	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_3_	OLDER_CUT	223.294654
3	Point	STRATIFIED_byRoads-004	846484.329397	1047825.42005	Equal	7546.793182	CLOSE	Panel_1	NON_FISH_HAB	OLDER_CUT	128.212428
4	Point	STRATIFIED_byRoads-005	831706.049382	1039480.50009	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	OLDER_CUT	343.615423
5	Point	STRATIFIED_byRoads-006	822004.272548	1050831.05945	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	RECENT_CUT	645.482216
6	Point	STRATIFIED_byRoads-007	835126.126247	1042697.23987	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	NEVER_CUT	402.708377
7	Point	STRATIFIED_byRoads-008	847643.797673	1047807.37026	Equal	7546.793182	CLOSE	Panel_1	NON_FISH_HAB	OLDER_CUT	365.98202
8	Point	STRATIFIED_byRoads-009	838046.577307	1039784.8173	Equal	7546.793182	CLOSE	Panel_1	NON_FISH_HAB	NEVER_CUT	211.384643
9	Point	STRATIFIED_byRoads-010	838140.539129	1047219.13002	Equal	7546.793182	CLOSE	Panel_1	FISH_HAB_1_2	OLDER_CUT	161.038656
10	Point	STRATIFIED_byRoads-021	830520.602116	1038913.30379	Equal	7546.793182	CLOSE	OverSamp	FISH_HAB_1_2	NEVER_CUT	462.368374
11	Point	STRATIFIED_byRoads-022	820363.5178	1052341.55854	Equal	7546.793182	CLOSE	OverSamp	FISH_HAB_3_	OLDER_CUT	522.617996
12	Point	STRATIFIED_byRoads-023	834495.197298	1042544.94603	Equal	7546.793182	CLOSE	OverSamp	FISH_HAB_1_2	OLDER_CUT	1237.216357
13	Point	STRATIFIED_byRoads-024	845348.810305	1048486.2375	Equal	7546.793182	CLOSE	OverSamp	NON_FISH_HAB	RECENT_CUT	248.006503
14	Point	STRATIFIED_byRoads-025	837019.923465	1038008.6888	Equal	7546.793182	CLOSE	OverSamp	FISH_HAB_1_2	NEVER_CUT	1183.781366
15	Point	STRATIFIED_byRoads-071	816738.524657	1037523.38052	Equal	17895.373325	FAR	Panel_1	FISH_HAB_1_2	NEVER_CUT	732.080626
16	Point	STRATIFIED_byRoads-072	850956.340115	1047199.95235	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	NEVER_CUT	495.135708
17	Point	STRATIFIED_byRoads-073	837740.365862	1040734.48398	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	NEVER_CUT	1110.653459
18	Point	STRATIFIED_byRoads-074	823557.747745	1046712.17317	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	RECENT_CUT	487.195137
19	Point	STRATIFIED_byRoads-075	828661.860583	1051123.14351	Equal	17895.373325	FAR	Panel_1	FISH_HAB_1_2	OLDER_CUT	387.882323
20	Point	STRATIFIED_byRoads-076	846989.620803	1042308.01805	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	NEVER_CUT	555.354803
21	Point	STRATIFIED_byRoads-077	842143.547554	1048337.32585	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	RECENT_CUT	327.899443
22	Point	STRATIFIED_byRoads-078	822328.472402	1044946.11359	Equal	17895.373325	FAR	Panel_1	NON_FISH_HAB	NEVER_CUT	1155.64049
23	Point	STRATIFIED_byRoads-079	839319.877542	1054656.91891	Equal	17895.373325	FAR	Panel_1	FISH_HAB_3_	RECENT_CUT	5210.937344
24	Point	STRATIFIED_byRoads-080	847709.445876	1046469.73826	Equal	17895.373325	FAR	Panel_1	FISH_HAB_3_	RECENT_CUT	742.769019
25	Point	STRATIFIED_byRoads-121	838515.691084	1049822.99579	Equal	17895.373325	FAR	OverSamp	NON_FISH_HAB	NEVER_CUT	528.477747
26	Point	STRATIFIED_byRoads-122	821254.231186	1049105.68492	Equal	17895.373325	FAR	OverSamp	NON_FISH_HAB	RECENT_CUT	453.993404
27	Point	STRATIFIED_byRoads-123	841839.263082	1056203.12044	Equal	17895.373325	FAR	OverSamp	NON_FISH_HAB	NEVER_CUT	822.876724
28	Point	STRATIFIED_byRoads-124	850389.497808	1046746.43628	Equal	17895.373325	FAR	OverSamp	NON_FISH_HAB	NEVER_CUT	317.016395
29	Point	STRATIFIED_byRoads-125	840567.708788	1046340.34853	Equal	17895.373325	FAR	OverSamp	NON_FISH_HAB	NEVER_CUT	468.563771

In the Field

A broad field reconnaissance of pre-selected GRTS sampling points in the watershed is recommended prior to initiating actual field sampling. Reconnaissance will identify/document sample points that are inaccessible or inappropriate for various reasons and that should be replaced with the next ordered alternative GRTS points on the oversample list. It is critical that oversample points must be selected from the next point in the ordered sequence of available GRTS points so as to preserve the randomized, spatially balanced nature of the samples selected. After finalizing the location of all GRTS points that will be sampled during the field season it will be helpful to identify clusters of sites that are physically close together. These could perhaps be more efficiently sampled (time wise, cost, logistically, etc.) if approached as a combined sampling package (i.e., not necessarily sampling sites in exactly the same ordered sequence as in the GRTS list). This is acceptable if all selected sites are sampled as planned over the season. If some sites within the ordered list are missed the properties of the GRTS design (i.e. random, spatially balanced) will be disrupted, violating the associated assumptions required for statistical analyses. If a site can not be sampled for some reason, the point may be replaced, but the reason for dropping the sample must be clearly documented to enable any potential biases to be addressed.

2.3 When to sample?

Within Year

The FREP Riparian and Water Quality protocols as well as the BC MOE Fish Passage protocols that will be used for field-based monitoring of FSWs have each been designed to allow assessments over a wide range of environmental conditions. As such, FSW monitoring could theoretically be undertaken anytime of the year as long as the streambed and ground conditions in the riparian area were clearly visible. However it is recommended that monitoring should be constrained to the time between late spring, when all snow has left sampling areas and mid autumn, before the snow returns. Valid assessments would be difficult in winter, when streams may be frozen and stream and riparian areas covered in snow. The optimum time for assessments will be the low flow period during the active growing season, when the streambed, stream banks, and ground in the riparian area are clearly visible, there is flowing water in the stream, and vegetation foliage is full developed (Tripp et al. 2009). For most areas of BC, FREP considers this period of optimum conditions for evaluations to coincide with the summer low flow period from July 1 to September 30. However, many streams, particularly streams in areas that lack snow cover or have early spring run-off, can be assessed at other times of the year. Lower-elevation sites in coastal BC, for example, can often be assessed in April, May, or June after plants have leafed out, or in October before leaf fall or fall rains (Tripp et al. 2009). Appendix 2 provides an example of a single season field sampling design developed for FSWs in the pilot Lakelse study area, incorporating elements of sampling strata, sampling intensities, and timing of sampling.

Between Years

Long term recommendations on the frequency of FSW monitoring at different spatial scales should not be made at this time. The technical document provides an overview of the tradeoffs which must be considered. The main consideration is the spatial/temporal scale of the underlying question of interest. The recommendation will be different for the overall FSW monitoring plan than for a single watershed such as the Lakelse pilot study. It is likely that there will be two spatial scales to ultimately consider[2]: sampling of FSWs from the list of designated FSWs and sampling within a given FSW. The smallest scale of interest for trends is probably the FSW itself and so it is unlikely that repeat sampling of specific sites would be required within an FSW over time (unless there was some specific experiment or study underway). Instead sample sites would be re-randomized for each revisit to an FSW.

[2] Larger spatial scale questions have not been addressed in this document which is focused on the Lakelse pilot. The ultimate design will likely be a multi-stage design with FSWs as the primary sampling unit and sites within a given FSW as the secondary sampling unit, but this has not been discussed yet.

However, it may be of interest to revisit some subset of FSW's over time or in a formalized panel design[3] to improve the ability to estimate trends over time at the scale of an FSW. These designs are complex and probably not worth investing in until a few years of data have been obtained and until there is a better understanding of how the sampling frame will change over time (i.e., how many new FSWs will continue to be added).

3.0 Indicators and Field Protocols

3.1 FREP Riparian Protocol

The basic sampling unit for riparian monitoring purposes will be designated stream sample reaches, with center points pre-determined through a randomization process undertaken in the office (see Section 2.2). The minimum length of stream reach suggested for sampling within FREP's Riparian Protocol (Tripp et al. 2009) has both fixed distance (i.e., 100m for small streams) and proportional distance criteria (i.e., distance equal to 30 channel widths for larger streams). Other environmental agencies have recommended a variable mix of fixed distance (e.g., 100m: Massachusetts DEP 1995; 150-200m: Ohio EPA 1987) and proportional distance criteria (e.g., 40x low flow wetted width: Klemm and Lazorach 1995; 20x channel width: Missouri DNR 2003) for stream habitat monitoring. For FSW monitoring we recommend using two fixed distance criteria: 100m distance for "small" streams (i.e., those defined as 1st or 2nd order streams within the 1:20K stream layer) and 200m for "large" streams (i.e., those defined as 3rd order or greater within the 1:20K stream layer). Conceptually, the intent is minimize potential overlap of stream sampling sites while still capturing a sufficient length of stream in all cases to provide a mixture of the habitats in the reach and provide, at a minimum, duplicate physical and structural elements such as riffle/pool sequences. FREP riparian indicators (see Section 3.1) will be evaluated over the defined length of each sample reach.

To allow assessment of average stream and riparian conditions across the defined strata for a FSW the FREP Riparian Management Routine Effectiveness Evaluation field protocol (Tripp et al. 2009a) will be undertaken at each GRTS-selected riparian sampling site. The FREP Riparian Protocol requires addressing 15 distinct questions (***Table 2***) relating to the characteristics of healthy streams and their riparian habitats. The assessment of the relative condition of the sampled site is based on the total number of **No** answers to the questions as follows:

- 0–2 No answers – the stream and riparian habitat at the sample site is in properly functioning condition;
- 3–4 No answers – the stream and riparian habitat at the sample site is in properly functioning condition, but at risk;
- 5–6 No answers – the stream and riparian habitat at the sample site is in properly functioning condition, but at high risk;
- 7 or more No answers – the stream and riparian habitat at the site is not functioning properly.

Table 2. Fifteen questions used to assess the relative health, or "functioning condition" of a stream and its' riparian habitat (Tripp et al. 2009).

[3] Panel design: a formalized approach to determining when to revisit units within the target population. There are many variations of these designs (see Wieckowski et al. 2008).

Question 1.	Is the channel bed undisturbed?
Question 2.	Are the channel banks intact?
Question 3.	Are channel LWD processes intact?
Question 4.	Is the channel morphology intact?
Question 5.	Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?
Question 6.	Does the stream support a good diversity of fish cover attributes?
Question 7.	Does the amount of moss present on the substrates indicate a stable and productive system?
Question 8.	Has the introduction of fine inorganic sediments been minimized?
Question 9.	Does the stream support a diversity of aquatic invertebrates?
Question 10.	Has the vegetation retained in the RMA been sufficiently protected from windthrow?
Question 11.	Has the amount of bare erodible ground or soil disturbance in the riparian area been minimized?
Question 12.	Has sufficient vegetation been retained to maintain an adequate root network or LWD supply?
Question 13.	Has sufficient vegetation been retained to provide shade and reduce bank microclimate change?
Question 14.	Have the number of disturbance-increaser species, noxious weeds and/or invasive plant species present been limited to a satisfactory level?
Question 15.	Is the riparian vegetation within the first 10 m from the edge of the stream generally characteristic of what the healthy, unmanaged riparian plant community would normally be along the reach?

To help evaluators answer each of these questions the FREP riparian protocol provides a number of “indicator” statements, each of which also require a **Yes** or **No** answer. The indicator statements refer to specific site attributes that can be more easily assessed or measured in the field than the more general questions. The number of **Yes** or **No** answers to the indicator statements determines the appropriate responses for the general questions at a particular sample site. The scored categorizations of stream/riparian functioning condition from each sampled site will then be rolled up to generate summaries of the average and range of functioning condition within specific strata, as well as across the entire FSW.

Details on assessing, recording and summarizing riparian protocol “indicators” for a sample site and example completed Riparian Protocol field assessment forms are provided in Tripp et al. (2009a and 2009b). Riparian Protocol assessment forms can be downloaded from the FREP website at: http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/FS-1247-Riparian-Field-Card-March11-2009.pdf and are also provided in Appendix 3 of this report. FREP’s Riparian Protocol should be applicable as written for FSW monitoring purposes, with two exceptions: 1) much of the detailed information relating to specific cutblock plans or Riparian Management Areas (first page of field assessment forms) will not be directly relevant for FSW monitoring, and 2) sampled reaches will be standardized for FSW monitoring at 100m in length for all 1:20K defined 1st and 2nd order streams and

200m for all 1:20K defined 3rd order or greater streams (as opposed to the sometimes variable sample reach lengths (i.e., 30 channel widths) used normally within FREP's Riparian Protocol).

3.2 FREP Water Quality Protocol

To provide further assessment of average water quality conditions across forestry managed areas within a FSW the FREP Water Quality Management Routine Effectiveness Evaluation field protocol (Carson et al. 2009) will be undertaken at a sample of road stream crossings (bridges and culverts). The FREP Water Quality Protocol combines an estimate of the extent of connectivity between managed areas and natural drainages with a measure of the associated fine sediment generated to provide an assessment of water quality at a sample site. The resultant Water Quality (WQ) Index provides an "order of magnitude" ranking for the relative amount of fine sediment being generated by the site. Each sampled site is assigned to one of five water quality rankings: "Very Low,", "Low,", "Moderate," "High," or "Very High" based on the volume of sediment with the potential to reach the stream (***Table 3***). The scored ratings of water quality condition from each sampled site will then be rolled up to generate summaries of the average and range of water quality conditions within specific strata, as well as across the extent of forestry managed areas within the FSW.

Table 3. Rating of total fine sediment generation from a site (independent of stream size) (Carson et al. 2009).

Total Volume of Fine Sediment Generated (WQ Index)	Water Quality Rating
< 0.2 m^3	Very Low
0.2 - 1 m^3	Low
1 - 5 m^3	Moderate
5 - 20 m^3	High
> 20 m^3	Very High

Details on assessing, recording and summarizing Water Quality Protocol assessment tables for a sample site and example Water Quality Protocol field assessment forms are provided in Carson et al. (2009). Water Quality assessment forms can be downloaded from the FREP website at: http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/WQ%20field%20cards20090401.pdf1 and are also provided in Appendix 4 of this report. FREP's Water Quality Protocol as written should be applicable for use in monitoring water quality at selected stream road crossings within an FSW.

3.3 BC MOE Fish Passage Assessment Protocol

To provide further assessment of the overall connectivity of fish populations within a FSW the BC MOE's Field Assessment for Fish Passage Determination of Closed Bottom Structures (MOE 2009) will be undertaken at a sample of road stream crossings (bridges and culverts) that are selected using the same approach as described for the FREP Water Quality assessments. BC MOE's Fish Passage field protocol uses a cumulative scoring approach involving a suite of indicators to determine the likelihood that a close bottomed culvert at a stream crossing provides safe fish passage. The cumulative score across the suite of passage indicators is used to determine whether a sampled culvert is considered to be: “Passble,” “Potential Barrier,” or “Barrier” (***Table 4***). The BC MOE Fish Passage protocol focuses on closed bottom structure because of the known problems that are associated with fish passage if these structures are not properly designed and installed. All bridges and open bottomed structures (i.e. log and arch culverts) encountered at stream crossings will as a general default be rated as Passable to fish. The scored ratings for fish passage from each sampled site will then be rolled up to generate summaries of the degree of fish passage problems (i.e. assessment of how well fish population connectivity is being maintained) within specific strata, as well as across the extent of forestry managed areas within the FSW.

Table 4. Fish barrier result (BC MOE 2009).

Cumulative Score	Result
0 - 14	Passable
14- 19	Potential Barrier
> 20	Barrier

Details on assessing, recording and summarizing Fish Passage Protocol indicators for a sample site and example Fish Passage Protocol field assessment forms are provided in BC MOE (2009) and are also provided in Appendix 5 of this report. Fish Passage assessment spreadsheets can be downloaded from the Fish Passage Technical Working Group website at: http://www.for.gov.bc.ca/ftp/hcp/external/!publish/web/fia/CulvertFieldDataSubmissionForm-2008.xls. The BC MOE Fish Passage Protocol as written should be applicable for use in monitoring fish passage at selected stream road crossings within an FSW.

Three possible strategies for selecting a sample of road crossings for use in assessing both water quality and fish passage are described here and will be evaluated as part of the pilot sampling in the Lakesle drainage. Options a and b make use of the 1:20,000 road crossing layer that is available for the province. Options b and c are fully integrated with the GRTS based sampling framework recommended for the riparian protocol.

Option a) Independent GRTS draw of points from the 1:20,000 stream crossing layer (using the same stratification as described in Section 2.2)

The advantage of this approach is that there will be very few missing values (i.e., wasted trips) as every point in the sampling frame should have a crossing unless there is an error with the GIS layer. However, this would result in a sample that is completely independent of the riparian sample and so the overall number of locations visited would be greater. It is not clear how big of a concern that is given that road crossings should be readily accessible and many of the crossings may be sampled as the field crew drives to and from their riparian sites. Due to the limited spatial scale of the Lakelse pilot study, this disadvantage may not be substantial. If the study is expanded to a larger spatial scale this would likely be more serious. Given some initial estimates of time to travel among sites, we should be able to explicitly evaluate the time implications of using independent designs for the different protocols. Another disadvantage of this approach is there are some road crossings that won’t be captured in the 1:20,000 sampling frame.

Option b) Start with riparian GRTS sample points and then look up the closest road crossing in the 1:20,000 stream crossing layer.

This strategy would also minimize the number of missing values, and has the same bias for small road crossings that are not part of the sampling frame. The advantage of this approach over option a) is that it may be more efficient to implement in the field since it is directly tied to the riparian sample location. Finding the stream crossing in the field even if it is quite far from the riparian point will likely be relatively simple as by definition a crossing occurs on a road. However, this approach might lead to situations where the GRTS selected point was from stratum A and the closest stream crossing is in Stratum B. The analytical consequences of this need to be carefully considered, for example: it may be necessary to post-stratify the results for the water quality and fish passage protocols and that may lead to lower sample sizes and therefore less precise estimates in some strata.

Option c) Start with riparian GRTS sample points and identify a starting point (i.e., closest point on the nearest road) walk 250m each way and select all road crossing within the unit.

The main advantage of this approach is that it allows us to assess the potential bias of using the 1:20K road crossing layer. This approach would find additional small crossings and would let us estimate how many of these exist as well as their condition relative to the other crossings, thereby providing an estimate of the bias. This method may result in a large number of missing values (i.e., locations where no road crossings were found within the specified 500m sampling unit).

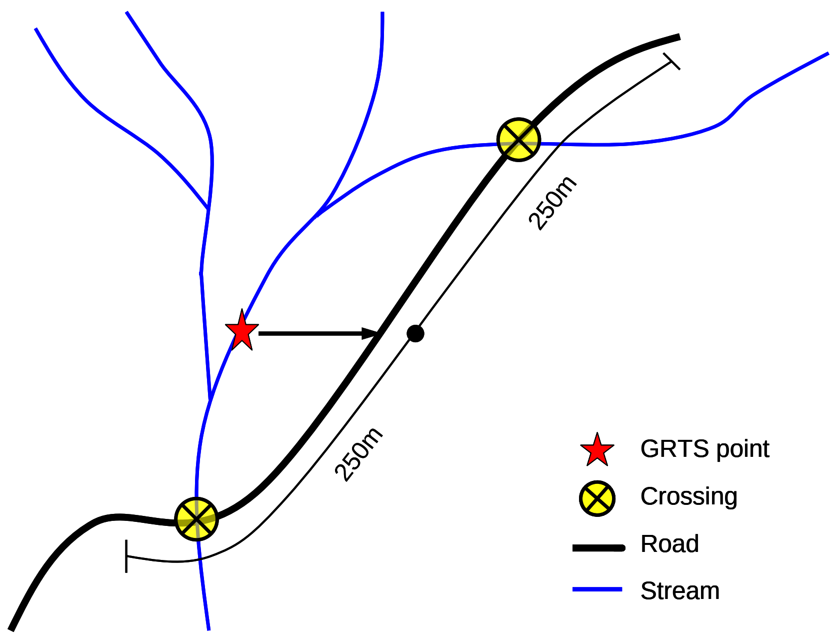


Figure 3. *This figure illustrates how a field crew would identify road crossings to sample under option c).*

Given that fish passage assessments have been completed at all road crossings in the 1:20K road crossing layer within the Lakelse watershed (i.e. a full census), if there is any concern about potential bias of the 1:20K stream crossing layer, then option c) should be completed for the pilot study. These results (i.e., the number of crossings missed and the water quality/fish passage data) can then be compared to the existing data to determine which option to recommend for the long term design. The same design and sampling units would be used for both the water quality protocol and the fish passage assessments.

3.4 FSW Specific Field Protocols and Reporting

Unique elements that will need to be incorporated into the FSW monitoring protocol (i.e. are not effectively captured currently within the FREP/MOE riparian, water quality or fish passage protocols themselves) are being identified through pilot field work. A preliminary draft of the FSW Supplementary Field Card is provided in Appendix 6. This reporting will be expanded and refined through continued assessment of specific Tier II data needs within the FSW monitoring framework.

3.5 Determining functioning condition of an FSW

In general, the FSW approach builds on existing protocols and consistent with this, the first step in the aggregation of data is to calculate the protocol specific score for each sampling unit using the methods described in each protocol.

Riparian: 4 possible levels from: properly functioning to not properly functioning
Water Quality: 5 possible levels from: very low quality to very high quality
Fish Passage Assessment: 3 possible levels: passable, potential barrier, barrier

The second step is to summarize these results for the stratum and then watershed. We recommend reporting the percentage of sites in each of the categories for each protocol separately.

The final step is determining how to combine these different types of information into an overall assessment of the watershed function. As described in the introduction (Section 1.1) there are two ways in which a watershed may be assessed as properly functioning:

1. the extent and rate of such disturbances are on average, small and within a watershed's natural range of variability, or
2. large and beyond the rate of natural variability in no more than a small portion of the overall habitat

For each protocol, each category must be lumped as either within or outside the natural range of variability, see **Table 5** for an example (yet to be reviewed). Given this information it should be possible to create a 3 dimensional matrix that incorporates the results for each protocol and identifies whether the watershed is either: properly functioning (green), impaired (yellow), or not properly functioning (red) as described in the conceptual framework (Wieckowski et al. 2008) for all possible indicator combinations. A two-dimensional version of this concept was proposed by the Interior Columbia Technical Recovery Team (IC-TRT) for assessing viability of Chinook (ICTRT 2005). **Figure 4** illustrates the concept in 2 dimensions. The binning in **Table 5** and **Figure 4** requires further input from the FSW MTWG and will require ongoing refinement. Identifying regions that are obviously red or obviously green should be fairly straightforward but defining intermediate zones (i.e. yellow) will be difficult.

Table 5. Example of how results may be interpreted for each protocol.

Protocol	Out of range	Within range
Riparian	properly functioning condition, but at high risk; is not functioning properly	properly functioning - properly functioning condition; but at risk
Water Quality	Very low-Moderate	High-Very High

Fish Passage Assessment	Potential barrier; barrier	Passable

Example rules:

If >20% fall into the ‘out of range category’ then **red** (may or may not apply to all protocols equally)

If >80% fall into the ‘in range category’ for all protocols then **green**

% of streams within range (water quality protocol)	% of streams within range (riparian protocol)				
	<20	20-40	40-60	60-80	>80
<20					
20-40					
40-60					
60-80					
>80					

Figure 4. *Illustration of a potential overall aggregation approach (based here on only 2 dimensions) for evaluating FSW condition (green = properly functioning, yellow = impaired, red = not properly functioning).*

3.6 Incorporation of climate change indicators

The currently established FREP/MOE field-based protocols (i.e., riparian, water quality, fish passage) that in combination are intended to form the core of Tier II FSW monitoring have been developed to assess current habitat condition in relation to local land management actions. They are themselves fairly insensitive to identifying changes in fish habitat condition that could instead be caused by broader climate change-related effects. An additional element in continued development of the overall FSW monitoring framework would therefore be to incorporate climate-change sensitive indicators, and establish targeted sampling designs that could allow a separation of potential climate change vs. localized land management effects on habitat condition. Specifically we will seek to incorporate expanded year round water temperature logger and flow gauge monitoring within FSWs as possible, with an intent to establish control/treatment areas with FSWs that could allow for parcing of local land management effects from the possible effects of climate change. This will require integration with broader provincial (e.g., Temperature Sensitive Streams monitoring) and federal initiatives (e.g. Hydromet flow monitoring network) that are independently seeking expanded geographic coverage for tracking of predicted climate change impacts.

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Appendix 1: GRTS Sampling Strata - GIS Workflow

	Title	Description	Notes	Inputs
1000	**Fish habitat criteria**			
1100	***Combine Freshwater Atlas hydrology and fish habitat***			
1110	Import and clip stream network	Import the Freshwater Atlas stream network from the LRDW, and clip to the study area.		1:20K Freshwater Atlas Stream Network (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50648)
1120	Intersect stream network and fish habitat	Intersect the Freshwater Atlas stream network (clipped to study area) with the "Streamgradreaches" layer, and explode multipart features.	"Streamgradreaches" identifies those streams that are classed as fish habitat. This layer does not contain a stream order field though, which is required for this strata. The geometry of these two layers is identical.	"Streamgradreaches" layer from Richard Thompson (Monitoring Unit Head, Ecosystems Protection and Assurance Branch. BC Ministry of Environment. Richard.Thompson@gov.bc.ca); Output from: 1110
1200	***Generate fish habitat strata***			
1210	Add strata field	Add a new text field called "fish_hab" to contain the fish habitat strata.		Output from: 1120
1220	Select non-fish habitat	Select all stream sections that are classed as non-fish habitat, and update their fish_hab attribute to "NON_FISH_HAB".		Output from: 1210
1230	Select fish habitat & first or second order streams	Select all stream sections that are classed as fish habitat AND have a stream order < 3, and update their fish_hab attribute to "FISH_HAB_12".		Output from: 1220
1240	Select fish habitat & third order or above streams	Select all stream sections that are classed as fish habitat AND have a stream order >= 3, and update their fish_hab attribute to "FISH_HAB_3_".		Output from: 1230
1250	Delete fields	Delete all fields except "fish_hab".		Output from: 1240
2000	**Proximity to roads**			

	Title	Description	Notes	Inputs
2100	***Prepare input layers***			
2110	Import and clip DRA	Import the Digital Road Atlas from the LRDW, and clip to the study area.	The DRA road layer is used as the primary road layer.	Digital Road Atlas (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=45674)
2120	Buffer DRA	Buffer DRA road layer by 30 m, dissolving all the output polygons.	This buffer is used to mask out duplicate roads from other input layers. 30 m was enough to cover the maximum difference in location between layers.	Output from: 2110
2130	Import and clip DKM	Import the DKM_ROADS_09 data, and clip to the study area.	The DKM roads layer is maintained by Kalum & North Coast Forest Districts, and updated by digitising from imagery.	DKM_ROADS_09.shp (http://www.for.gov.bc.ca/ftp/dkm/external/!publish/ESF_Spatial/)
2140	Import and clip FTN	Import the Forest Tenure road segments layer from the LRDW, and clip to the study area.		Forest Tenure Road Segment Lines (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=51944)
2200	***Extract additional roads from DKM***			
2210	Select DKM roads within buffer	Select all roads segments from DKM that are WITHIN the DRA buffer.		Output from: 2130; 2120
2220	Switch selection		This leaves only those road segments not already represented in the DRA.	Output from: 2210
2230	Export selection	Export selection to a new layer.		Output from: 2220
2300	***Extract additional roads from FTN***			
2310	Select FTN roads within buffer	Select all roads segments from FTN that are WITHIN the DRA buffer.		Output from: 2140; 2120
2320	Switch selection		This leaves only those road segments not already represented in the DRA.	Output from: 2310

	Title	Description	Notes	Inputs
2330	Export selection	Export selection to a new layer.		Output from: 2320
2400	***Generate final road buffers***			
2410	Merge roads	Merge the additional roads with the DRA layer.	It is not necessary (and too time consuming) to produce a topologically correct network of roads generated from all three input sources; a simple merge is all that is required as the buffer generated in the next step will cover any gaps.	Output from: 2110; 2230; 2330
2420	Buffer roads	Buffer the combined roads layer by 100 m, dissolving all polygons.	200 m and 300 m buffers were also generated.	Output from: 2410
2500	***Generate road strata***			
2510	Add strata field and update	Add a new text field called "road_prox" to the road buffers and update to "1" for all records.		Output from: 2420
2520	Intersect strata and roads	Intersect the fish habitat strata and the road buffers.	The result of this process are all stream sections that are close to a road (within the buffer distance).	Output from: 1250; 2510
2530	Dissolve	Dissolve on "road_prox" and "fish_hab", with no multipart feature output.		Output from: 2520
2540	Erase road buffer	Erase the road buffer layer from the fish habitat strata layer, and explode multipart features.	The result of this process are all stream sections that are far from a road (outside the road buffer).	Output from: 1250; 2510
2550	Merge road strata	Merge the intersect output and the erase output to re-form the hydrology layer.		Output from: 2520; 2540
2560	Update strata field	Update the road_prox field to "CLOSE" where road_prox = 1, and update road_prox to "FAR" for all other records.		Output from: 2550
2570	Delete fields	Delete all fields except fish_hab and road_prox.		Output from: 2560
3000	**Logging influence**			

	Title	Description	Notes	Inputs
3100	***Prepare cutblock input layers***			
3110	Import and clip RESULTS Openings	Import the RESULTS Openings layer from the LRDW, and clip to the study area.		RESULTS Openings (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=52583)
3120	Create pre & post 1995 layers	Select by Attribute using DST_STR_DT to split openings into pre 1995 (< 19950101) and post 1995 (>= 19950101).		Output from: 3110
3130	Import and clip RESULTS Forest Cover	Import the RESULTS Forest Cover Inventory layer from the LRDW, and clip to the study area.		RESULTS Forest Cover Inventory (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=52578)
3140	Join attributes to spatial layer	Join the attributes from RESULTS Openings (Attribute only) table to the RESULTS Forest Cover layer, based on OPENING_ID.	This join will add a disturbance start date field to the forest cover inventory polygons, which can then be used to split it into pre and post 1995.	Output from: 3130; RESULTS Openings - Attribute Only (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=52582)
3150	Create pre & post 1995 layers	Select by Attribute using DISTURBANCE_START_DATE to split openings into pre 1995 (< 19950101) and post 1995 (>= 19950101).		Output from: 3140
3160	Import and clip VRI	Import the Vegetation Resource Inventory (VRI) layer from the LRDW, and clip to the study area.		VRI (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=47574)
3170	Create pre & post 1995 layers	Select by Attribute using HRVSTDT to split openings into pre 1995 (< 19950101) and post 1995 (>= 19950101).		Output from: 3160
3200	***Buffer cutblocks***			

	Title	Description	Notes	Inputs
3210	Merge pre 1995 cutblocks	Merge the pre 1995 cutblock layers from RESULTS openings and forest cover and the VRI.		Output from: 3120; 3150; 3170
3220	Buffer cutblocks	Buffer the merged cutblocks by 50 m, with no dissolve.		Output from: 3210
3230	Merge post 1995 cutblocks	Merge the post 1995 cutblock layers from RESULTS openings and forest cover and the VRI.		Output from: 3120; 3150; 3170
3240	Buffer cutblocks	Buffer the merged cutblocks by 50 m, with no dissolve.		Output from: 3230
3300	***Create hydrologically correct DEM***			
3310	Clean and clip DEM	Clip the DEM to the study area, and interpolate over any gaps.		Canadain Digital Elevation Data (http://geobase.ca/geobase/en/metadata.do?id=3A537B2D-7058-FCED-8D0B-76452EC9D01F)
	The following three steps may not be required, depending on the source, quality and resolution of the DEM. To test the DEM, carry out the following steps: 1) fill sinks; 2) create flow direction raster; 3) create flow accumulation raster. The flow accumulation raster should follow the stream network. If there are any deviations from, or blockages along, the stream network, thses additional steps should fix the problems.			
3320	DEM to Points	Convert DEM raster to point features.		Output from: 3310
3330	Topo to Raster	Create a hydrologically correct DEM using stream and waterbody features. In ArcGIS, use the 'Topo to Raster' tool.		Output from: 3320 (PointElevation); 1110 (Streams) 1:20K Freshwater Atlas Lakes (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50640)

	Title	Description	Notes	Inputs
3340	Burn-in streams	Convert the Freshwater Atlas stream network to a raster and subtract it from the hydrologically correct DEM.	This process burns the stream network into the DEM to make sure that any flow accumulation precisely follows the stream network. Although the stream network is used as part of the Topo to Raster process, the stream network is not always differentiated in areas of flat terrain depending on the quality and resolution of the DEM. Burning them into the DEM ensures that flow will always follow the stream network.	Output from: 3330; 1110
3350	Fill DEM	Remove any remaining sinks from the DEM using the ArcGIS 'Fill' tool.		Output from: 3340
3400	***Calculate cutblock influence (repeat for pre & post 1995)***			
	Note: At the moment the cost analysis treats all accessible cells (i.e. all cells where water will flow) with the same weight. This method might overestimate disturbance in streams that don't have any direct surface flow connectivity to a cutblock. To better reflect the filtering capacity of soils between the cutblock and the stream a higher weight could be assigned to the land surface areas, and leaving the streams as they are, you would hit the 1 km threshold sooner travelling over land than you would travelling along a stream. For example, travelling from a cutblock along a river (with a weight of 1 per cell) you would travel 33 cells (30 m DEM cell size * 33 = 990 m). Over land (with a weight of 2.5 per cell i.e. a max influence distance of 400 m over land) you would only travel 13 cells (30 m * 2.5 * 13 = 975) which is the equivalent of 390 m. If you wanted to even take it a step further, you could assign different weights depending on different land cover types (soil type, vegetation type etc).			
3410	Flow direction	Generate a raster of flow direction using the ArcGIS Spatial Analyst Flow Direction tool.		Output from: 3350
3420	Cutblock polygons to raster	Convert the buffered cutblock polygons to raster.		Output from: 3220/3240
3430	Flow accumulation	Generate a raster of flow accumulation using the ArcGIS Spatial Analyst Flow Accumulation tool, using the cutblock raster as the input weight raster.	Using the cutblock raster as input weight restricts the flow accumulation to output only the flow originating from the cutblock areas.	Output from: 3410; 3420

	Title	Description	Notes	Inputs
3440	Flow accumulation weight	Divide the flow accumulation by itself.	This process results in a raster showing all accessible cells (to the flow of water from the cutblocks).	Output from: 3430
3450	Cost distance	Generate a cost distance raster using the ArcGIS Spatial Analyst Cost Distance tool, using the cutblock raster as the source data and the flow accumulation weight as the input cost raster. Set a maximum distance of 1000 m. (Figure A1 provides a map illustration of the downslope cost distance analysis for some example cutblocks)	The output from the cost distance analysis will be the flow of water from the cutblocks restricted by terrain (i.e. downstream flow only) up to a distance of 1 km.	Output from: 3420; 3440
3600	***Generate logging influence strata***			
	Note: this method relies on the cost distance raster (converted to a polygon) masking out the streams downstream from the cutblocks. The raster may not align exactly with the stream network due to differences in resolution and the fact you are comparing raster to vector. Some manual editing of either the mask or the resulting strata may be required to fill in gaps and make sure the logging influence strata are continuous along the stream network.			
3610	Cost distance raster to polygon	Covert the pre and post 1995 cost distance rasters to polygon.		Output from: 3450
3620	Union cost distance polygons	Union both cost distance polygon layers, and explode multipart features.		Output from: 3610
3630	Add strata field and update	Add a new text field called "logging", and update to "OLDER_CUT" for all pre 1995 polygons and "RECENT_CUT" for all post 1995 polygons. Where the union ouput is an overlap of both pre and post 1995 polygons, update the logging field to "RECENT_CUT".	This output can be considered as the 'logging influence mask'.	Output from: 3620
3640	Intersect strata with logging mask	Intersect the latest strata layer with the logging influence mask, and explode multipart features.	The result of this intersect will be all stream sections that are under influence from the cutblocks.	Output from: 2570; 3630
3650	Erase logging mask	Erase the logging influence mask from the latest strata layer.	The result of this process will be all stream sections outside the influence of cutblock runoff.	Output from: 2570; 3630

	Title	Description	Notes	Inputs
3660	Merge logging strata	Merge the intersect output and the erase output to re-form the hydrology layer.		Output from: 3640; 3650
3670	Update strata field	Update the logging field to "NEVER_CUT" where logging = Null.		Output from: 3660
3680	Delete fields	Delete all fields except fish_hab, road_prox and logging.		Output from: 3670
4000	**General filters**			
4100	***Remove all areas above the timber line***			
4110	Select areas above timber line	Select all BEC polygons where ZONE = "CMA" (Coastal Mountain-heather Alpine), and output to a new layer.		BECs (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=51819)
4110	Erase timber line	Erase the Mountain Heather BEC zone from the latest strata layer.		Output from: 3680; 4110
4200	***Remove all lakes***			
4210	Erase lakes	Erase the Freshwater Atlas Lakes from the latest strata layer.		Output from: 4110; 1:20K Freshwater Atlas Lakes (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50640)

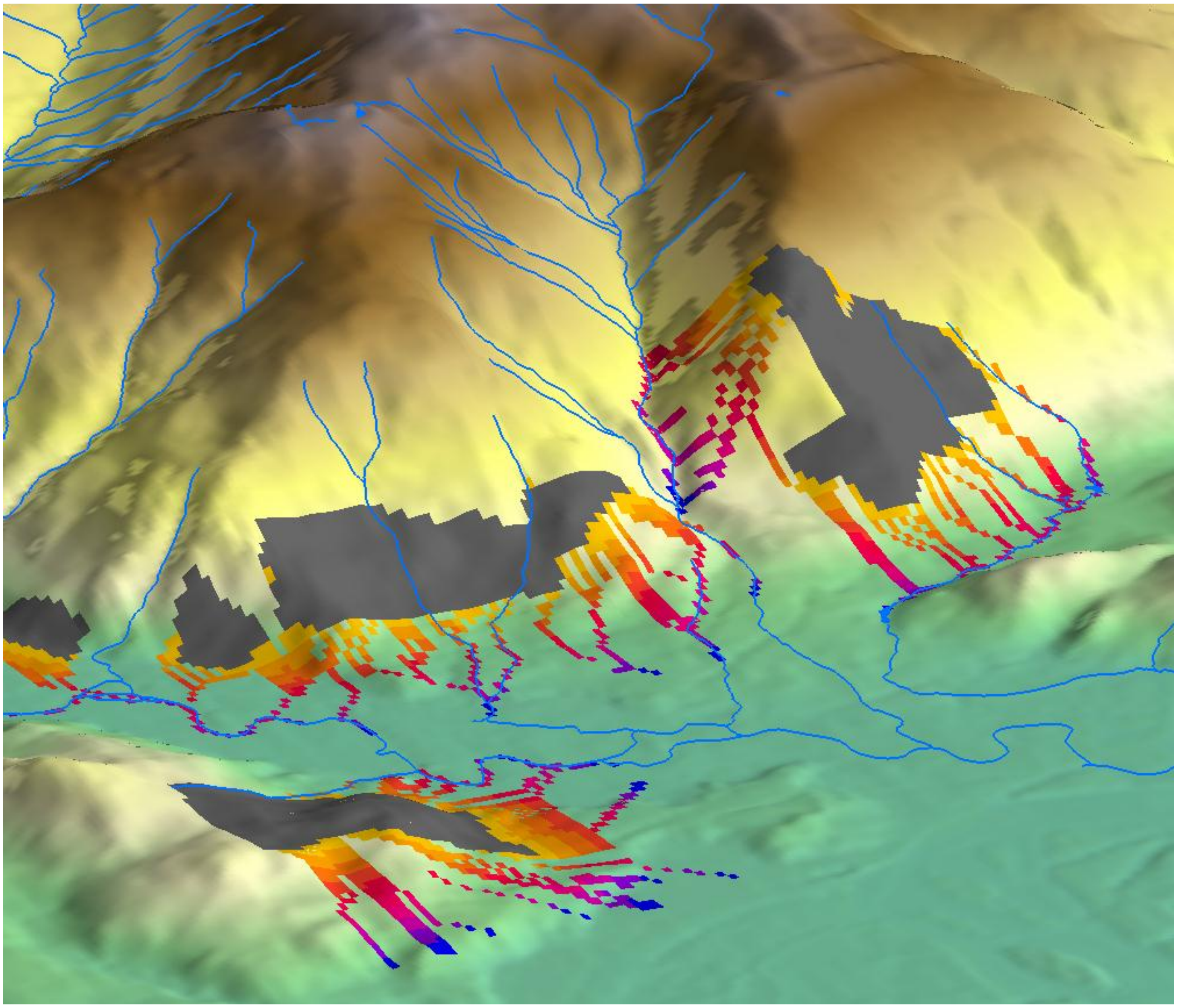


Figure A1. Illustration of cost distance model capture of adjacent downslope streams that could be affected by logging due to the flow of runoff over the terrain. In this example actual cutblocks are shown as grey areas, while modelled downslope areas that could experience cutblock influence are shown as a gradation of colour intensity going from yellow (0 m downstream) through to blue (1 km downstream).

Appendix 2: Sampling Design Elements for Lakelse FSW Field Monitoring Pilot

Monitoring Target: 4 FSW designation units for the Lakelse Study Area

Sample at least 2 of these watersheds with the highest contrast (suggested ones are Williams Creek and Lakelse River units). Sample the other 2 FSW designation units if funds/time allow.

Sampling Frame:

BC's 1:20K Freshwater Atlas stream hydrology network.

General Filter:

- Remove all areas above timber line from sampling frame.

General Sample Location Methodology Using GRTS

Initial selection of sample points will be based on a GRTS (Generalized Random Tessellated Stratified) design (Stevens and Olsen 2004). This sampling method allows for the greatest level of field flexibility as it draws on the strength of both randomized and systematic or targeted sampling (Wieckowski et al. 2006). For example, using GRTS, where it is discovered that unforeseen access restrictions make it impossible to reach one or more sample sites, these can be dropped in favour of others from a predetermined selection of sample sites. Prior to the end of the current fiscal year mapping will be made available illustrating sample site locations and describing the methodology in more detail.

Timing of Field Work for Pilot Season

The long term hydrographic record shows that the late spring/early summer freshet in the Kitimat Range ecosection peaks in June. Flows then decline albeit remaining fairly high through the early summer months. It is proposed that the field sampling for the 2011 pilot season within the month of June as this time period represents a good balance between stream flows, access constraints and logistical issues (e.g. snow free area, high water, likely availability of field crews, etc.).

Objective I) Riparian Habitat Assessment

Selection of riparian sampling points will be based on a GRTS (Generalized Random Tessellated Stratified) design (Stevens and Olsen 2004)

FREP riparian protocols (Tripp et al. 2009) will be used at each GRTS selected sample site.

Possible Strata for Riparian Sampling:

1) Logging influence (as defined by RESULTS and VRI layers, and supplemented by satellite imagery interpretation):
    a. Never cut

   b. Within cutblock and within 1 km downslope influence of cutblock – recent cut (≥1995) (including 50m fringing buffer area around perimeter of cutblock)
   c. Within cutblock and within 1 km downslope influence of cutblock – older cut (pre-1995) (including 50m fringing buffer area around perimeter of cutblock)

2) Fish habitat criteria for stream reaches (as defined by MOE Fish Passage layer)
   a. Non-Fish habitat
   b. Fish habitat – Stream Order (1st and 2nd)
   c. Fish habitat – Stream Order (≥ 3rd)

3) Proximity to road (as defined by DRA, FTEN and supporting local DKM road layers)
   a. Close (≤ 200m)
   b. Far (> 200m)

Number of Riparian Samples:

Suggested densification of GRTS points = average 250m separation along the 1:20K stream network. This should represent approx. 4000 potential sample points available throughout the full extent of the Lakelse hydrology network (i.e. across all 4 FSW designation units).

Minimum of 4 samples / strata category combination.

Suggested target of 9 samples / strata category combination (or even more if possible; oversampling is useful for initial development of power analyses).

Minimum # total samples / FSW designation unit = **$(3^2 * 2) * 4 = 72$**
Target # of total samples / FSW designation unit = **$(3^2 * 2) * 9 = 162$**

Sampling in some strata may be weighted more heavily (e.g. if there is a need for logistical/cost reasons to focus greatest proportion of sampling on sites near roads).

Objective II) Water Quality Assessment

FREP water quality protocols (Carson et al. 2009) will be undertaken at each selected stream crossing sample site (in conjunction with a paired fish passage assessment).

Alternative Approaches for Water Quality Sample Site Selection:

1) Water quality sites are picked up opportunistically near the GRTS selected riparian sample sites (i.e. any stream crossings observed within 100m both upstream and downstream of the GRTS sample point, as well as 100m in both directions from a random start point on the first parallel road encountered within 100m of the sampled GRTS riparian point (the search for crossings would be incorporated as a field-based protocol, piggybacked on the riparian site design). The number of water quality sample sites that would be captured under this

scenario would thus be dependent on the density of stream crossings in the areas where riparian sampling is being undertaken and could not be determined pre-field sampling.

or

2) Water quality sampling points are pre-selected through a GRTS selection process using known stream crossings (MOE Stream Crossing layer) as the sampling frame (i.e., separate GRTS selection process from that used for the riparian points). Under this second scenario a minimum of 4 water quality sampling sites would be selected in each of the defined strata, and a target of 9 per strata (i.e., same as for riparian sampling). Proximity to road would not be a relevant strata for stream crossings so total number of samples would

Number of Water Quality Samples:

Minimum # total samples / FSW designation unit = $\mathbf{3^2 * 4 = 36}$
Target # of total samples / FSW designation unit = $\mathbf{3^2 * 9 = 81}$

For the pilot we could attempt both options for sampling stream crossings and assess their relative efficacy. For the Lakelse we also have the benefit of the full (close-to) census for the area which we can also incorporate into a comparison analysis.

Objective III) Fish Passage Assessment

MOE Fish Passage protocols (MOE 2009) will be undertaken at each selected stream crossing sample site (in conjunction with a paired FREP water quality assessment).

Approaches to fish passage sample site selection and determination of the total number of fish passage samples / FSW designation unit will be identical to that outlined earlier for water quality sampling (Objective II).

Other Strata Considerations/Options (for all sampling objectives)

Different strata combinations may need to be developed dependent on the possible logistic constraints. Strata may need to be prioritized in this regard. If additional levels are created within a stratum, fewer strata can be evaluated, unless the overall number of samples is increased (i.e., greater time and cost).

Once the sampling frame is finalized we may be able to tweak the design further. For example, some strata combinations may not exist in the field (e.g., what if there are no sites close to roads in areas that have never been logged).

Sampling Intensity

While a range in the number of samples is suggested here the preference will be to maximize sampling so as to achieve the highest benefit from the pilot project (i.e., oversampling will be useful for protocol development and power analyses).

Appendix 3: FREP Riparian Routine Effectiveness Evaluation Field Cards

(from FREP website)

BRITISH COLUMBIA — Forest and Range Evaluation Program

Riparian Management Routine Effectiveness Evaluation

Sample No. ______________ Date: Y Y Y Y / M M / D D Evaluator(s) ______________

Stream/Opening Identification

District: ______________ Opening ID: ______________ Licensee: ______________

Forest Licence: ______________ Block: ______________ Harvest Year: ______________

Range Licence: ______________ Range Unit: ______________

Stream Name: ______________ Stream Location: In block ☐ Beside block ☐

Stream Class on plans: ______ Stream Class in field: ______ Reach length (m): ______

Reach Location: ______ to ______ m US ☐ DS ☐ from ______________

UTM at US ☐ DS ☐ end of reach: Zone: ____ East: __________ North: __________

Channel width (m): _______ Channel depth (m): _______ Channel Gradient (%): _______

Channel Morphology: Riffle/pool or Cascade/pool ☐ Step/pool ☐ Non-alluvial ☐

Riparian Retention Information in RMA

	Left Side	Right Side
Average distance (m) from stream edge to merchantable trees:	______	______
Average distance (m) from stream edge to first signs of current harvesting (partial or complete, max. 100 m):	______	______
Average distance (m) from stream edge to start of complete harvesting (i.e. a road or clearcut, max. 100 m):	______	______

	Dominants & codominants on left side	Dominants & codominants on right side	Understory on left side	Understory on right side
% Retention in first 10 m of the RMA (all classes)	______	______	______	______
% Retention in rest of the RRZ (for S1, S2, S3)	______	______	______	______
% Retention in rest of the RMZ (all classes)	______	______	______	______

Photo Section

Photo #	Photo Description

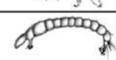
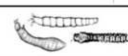
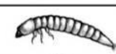
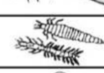
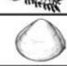
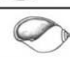
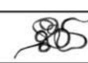
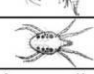
FS 1248 HFP 2009/02 PAGE 1

Sample No. ____________

Field Data

Question Indicator	Point Indicators (Measure at 6 equidistant points or transects along the reach)							Total	Mean
	Transect No.	1	2	3	4	5	6		
Q7(a)	% Moss								
Q8 (a)	% Fines/sands								
Q9 (a)	No. sensitive invertebrate types								
Q9 (b)	No. major invertebrate groups								
Q9 (c)	No. insect types								
Q9 (d)	Total No. invertebrate types								
Q13 (b)	% Shade								
Q14 (a)	% Disturbance - increaser species								
Q14 (b)	% Noxious weeds/invasives								

Record the number of different types of invertebrates observed in each sub-group, at each transect sampled. The numbers recorded under each "transect number" are the numbers you use to complete the point indicators table above.

				Transect Number					
Major Group	Sub Group		Sensitivity	1	2	3	4	5	6
Insects	Mayflies		Yes						
	Stoneflies		Yes						
	Caddisflies		Yes						
	Chironomids ('midges')		No						
	Other Diptera		No						
	Riffle beetle larvae		Yes						
	Other beetle larvae, adults		No						
Bivalves	Clams, mussels		Yes						
Snails	Right side snails		Yes						
	Left side snails		No						
Flatworms	Flatworms ("Planaria")		No						
Nematodes	Nematodes		No						
Worms	Segmented worms		No						
Crustaceans	Crustaceans		No						
Arachnids	Spiders, mites		No						
	Others (Consult field guide in Appendix 2 of Protocol for identification of "other" invertebrates and their sensitivity)								

Sample No. ______________

Field Data					
Question (Indicator) No.	**Stream Type**	**Continuous Indicators** (These are measured all along the reach to determine total length, numbers or areas present, as appropriate. Record the totals in the "Total" column, even if the total is an estimate. Calculate the percentage of the reach length, riparian area or number of trees represented by each total.)		**Total**	**%**
Q1(a)	RC	Mid-channel bars, wedges (m) measure all but no overlap			
Q1(c)	RC	Lateral bars (m) measure all but no overlap			
Q1(b,c)	RCS	Multiple or braided channels (m) measure all but no overlap			
Q1(a)	Non-alluvial	Moss along the channel bed (m) measure all but no overlap			
Q2	All	Non-erodible banks (m) only measure where naturally non-erodible on both sides			
Q2(a,a,b)	All	Recently disturbed bank (m) measure both sides, but no overlap			
Q2(c,c)	RCS	Stable undercut bank (m) measure both sides, but no overlap			
Q2(b,b,a)	All	Deep rooted bank (m) measure both sides, but no overlap			
Q2(d,d,c)	All	Upturned bank root wads (m) measure both sides, but no overlap			
Q4(a)	RC	Pool length (m)			
Q10	All	No. New windthrow			
Q10	All	No. Old windthrow			
Q10	All	No. Standing trees			NA
Q11(a)	All	Bare soil in first 10m (m^2)			
Q13(a)	All	Bare soil exposed to rain in first 10m (m^2)			
Q11(b)	All	Bare soil in first 10m, plus all bare soil hydrologically connected to first 10m (m^2)			
Q11(c)	All	Disturbed ground in first 10m (m^2)			
Q11(d)	All	Disturbed ground in first 10m, plus all disturbed ground hydrologically connected to first 10m (m^2)			

% New Windthrow = (# New Windthrow) / (# New Windthrow + # Standing Trees) X 100
% Old Windthrow = (# Old Windthrow) / (# Old Windthrow + # New Windthrow + # Standing Trees) X 100

Sample No. ______________

Other Indicators to Note (Answer Yes, No, or NA as appropriate for the Questions)				
Q01-04	**Boulder Line/Step Pool Characteristics - For Step-Pool Streams Only** (Use Table 1 to help answer the questions)	**Yes**	**No**	**NA**
Q1(a)	Do 50% or more of the boulder lines/steps span the channel?	☐	☐	☐
Q1(b)	Do 25% or more of the boulder lines/steps have moss?	☐	☐	☐
Q4(a)	Do 25% or more of the boulder lines/steps have plunge pools as deep as the largest rock in the line?	☐	☐	☐
Q4(b)	Do cascades lacking boulder lines/steps represent less than 25% of the reach?	☐	☐	☐
Q01	**Sediment and LWD Storage Characteristics - For Non-Alluvial Streams Only**			
Q1(b)	Do sediment and/or LWD deposits that completely fill the channel up to the top of the banks represent less than 5% of the reach length?	☐	☐	☐
Q1(c)	Are sediment deposits widely distributed in small pockets along the stream reach, not concentrated in a few relatively large compartments?	☐	☐	☐
Q03	**Wood Characteristics** (Use Table 2 to help answer the questions. Q3(b) is NA for non-alluvial streams)			
Q3(a)	Is the wood in the channel mainly old?	☐	☐	
Q3(b)	Do 1-12 accumulations of wood span the channel?	☐	☐	☐
Q3(c,c,b)	Do half or more of the wood accumulations present lack new wood?	☐	☐	
Q3(d,d,c)	Is the wood in the channel mainly across or diagonal to the main axis of the stream?	☐	☐	
Q3(e,e,d)	Is the wood in the channel intact; i.e., not recently lost or removed by hand, catastrophic floods, debris flows, debris torrents?	☐	☐	
Q04	**Surface Sediment Texture - For Riffle and Cascade Pool Streams Only**			
Q4(b)	Is the texture of the surface substrate mainly heterogenous?	☐	☐	☐
Q04	**Deep Pools - For Riffle, Cascade, and Step Pool Streams Only**			
Q4(b)	Are two or more deep pools present? (Tip: A deep pool is a pool whose depth from the deepest spot of the pool to the top of the bank is twice the same depth at riffle crests)	☐	☐	☐
Q05	**Connectivity**			
Q5(a)	Are temporary blockages to fish, sediment or debris absent?	☐	☐	
Q5(b)	Is down-cutting that blocks fish movements or isolates the channel from the adjacent floodplain absent?	☐	☐	
Q5(c)	Are sediment or debris buildups absent at or in all crossing structures?	☐	☐	☐
Q5(d)	Is down-cutting below any crossing structure that blocks fish movements upstream by any size fish at any time absent?	☐	☐	☐
Q5(e)	Are all crossing structures on fish bearing streams open-bottomed structures?	☐	☐	☐

Sample No. ______________

Other Indicators to Note (Answer Yes, No, or NA as appropriate for the Questions)				
		Yes	No	NA
Q5(f)	Is dewatering absent?	☐	☐	
Q5(g)	Are trails, roads or levees that isolate off-channel areas or divert normal overland flow away from the reach absent?	☐	☐	
Q5(h)	Is all water in the stream still flowing in its original channel, not withdrawn or diverted elsewhere?	☐	☐	
Q06	**Fish Cover Diversity – For Fish-Bearing Streams Only** (To be considered present, each type of cover should cover 1% or more of the total channel area)			
Q6(a)	Are deep pools present?	☐	☐	☐
Q6(b)	Are unembedded boulders present?	☐	☐	☐
Q6(c)	Is woody debris or other organic debris present?	☐	☐	☐
Q6(d)	Are undercut banks present?	☐	☐	☐
Q6(e)	Is aquatic vegetation present?	☐	☐	☐
Q6(f)	Is overhanging vegetation present?	☐	☐	☐
Q6(g)	Are there stable gravels and cobbles present with spaces for fish to hide in?	☐	☐	☐
Q08	**Fine Inorganic Sediments**			
Q8(a)	Is the channel free of fine or sand/sized inorganic sediments that "blanket" the streambed anywhere?	☐	☐	
Q8(c)	Is the substrate mostly unembedded?	☐	☐	
Q8(b)	Is the channel free of "quick sand" or "quick gravel"?	☐	☐	
Q13	**Bank Microclimate**			
Q13(c)	Are moisture-loving plants present and in good condition?	☐	☐	
Q13(d)	Are the bank soils all moist and cool?	☐	☐	
Q15	**Riparian Structure** (Use Table 3 to help answer this question)			
Q15(a)	Does the distribution and relative abundance of the vegetation layers and forest components present collectively approach 75% of what the healthy unmanaged riparian plant community would normally have along the reach?	☐	☐	
Q15	**Riparian Form, Vigor, and Recruitment** (Use Table 4 to help answer this question)			
Q15(b)	Does the form, vigor and recruitment of the vegetation layers or forest components present collectively approach 75% of what the healthy unmanaged riparian plant community would normally be along the reach?	☐	☐	
Q15	**Browsing, Grazing**			
Q15(c)	Are all shrubs free of heavy browsing?	☐	☐	
Q15(d)	Is most (90%) of the available forage free of heavy grazing?	☐	☐	

Sample No. ______________

Field Data Summary Tables

Table 1. Boulder-line/step characteristics of step-pool type reaches (Q1B, Q4B)

Number of boulder lines/ steps	Number of channel spanning boulder lines/steps	Number of boulder lines/ steps with moss	Number of boulder lines/steps with a deep plunge pool	Length of reach with no boulder steps and plunge pools

Table 2. Wood characteristics of sample reach (Q3)

Number of wood accumulations	Number of wood accumulations with new wood	Number of channel spanning wood accumulations	Main age of wood in each accumulation (Record "O" for old, "N" for new)	Main orientation of wood in each accumulation (Record "P" for parallel, "X" for across or diagonal)

Table 3. Riparian Structure (Q15a). Using the table below, estimate whether the distribution or relative abundance of the forest components present collectively approach 75% of what the healthy unmanaged riparian plant community would normally be along the reach.

Snags (%)	Gaps (%)	Over-story trees (%)	Under-story trees (%)	Tall shrubs (%)	Low shrubs (%)	Herbs (%)	Mosses (%)	Lichens (%)	CWD (%)	Total (Sum of %'s)	Average % (Answer to Q15a)

Table 4. Riparian Vegetation Form, Vigor, and Recruitment (Q15b). Using Yes or No answers for each table cell below, determine if 75% or more of the cells have Yes answers, indicating that, collectively, form, vigor and recruitment is satisfactory.

	Snags	Gaps	Over-story trees	Under-story trees	Tall shrubs	Low shrubs	Herbs	Mosses	Lichens	CWD	Total possible number of Yes answers	Actual number of Yes answers	% of cells with Yes answers (Answer to Q15b)
Form													
Vigor	NA	NA								NA			
Recruitment													

Sample No. _____________

Riparian Effectiveness Routine Evaluation Checklist

Question 1. Is the channel bed undisturbed?	Yes ☐	No ☐
Note: For Questions 1-4, decide what the predominant channel morphology is and then complete the section for that morphology only (i.e., Part A, B or C).		
A) Riffle-pool or cascade-pool channels		
a) Less than 50% of the reach length is occupied by active sediment wedges or mid-channel bars.	☐	☐
b) Less than 50% of the reach has active multiple channels and/or braids.	☐	☐
c) More than 50% of the reach has lateral bars.	☐	☐
If answer "Yes" to 2 or more, mark Yes box in Question 1.		
B) Step-pool channels		
a) More than 50% of the steps present span the channel.	☐	☐
b) More than 25% of the steps have moss.	☐	☐
c) Less than 25% of the reach has active multiple channels and/or braids.	☐	☐
If answer "Yes" to 2 or more, mark Yes box in Question 1.		
C) Non-alluvial channels		
a) Over 25% of the channel bed length has some moss on the substrate.	☐	☐
b) The channel has space for storage of sediments and debris; i.e., sediment and/or LWD do not fill the channel volume or spill over the banks for any significant distance.	☐	☐
c) Sediments are widely distributed throughout the channel. Sediments are not stored in a few relatively large compartments (e.g., wedged behind an accumulation of immobile rocks or organic debris).	☐	☐
If answer "Yes" to 2 or more, mark Yes box in Question 1.		

Please refer to "What is Stream Channel Morphology" in the riparian protocol for descriptions, tables and figures on channel morphology. If you are using the summary table that describes the general features of each type of channel morphology, base your decision on all the characteristics listed. Take into account all of the features, i.e., try not to focus on just one or two characteristics.

Sample No. ______________

Question 2. Are the channel banks intact?	Yes ☐	No ☐
A) Riffle-pool or cascade-pool channels		
a) Less than 15% of the total reach length has banks recently disturbed by stream flows, windthrow, infilling, animals (hoof shear, watering sites, crossings), roads, or harvest and silviculture activities.	☐	☐
b) More than 65% of the banks on naturally erodible sections of the reach have deeply rooted vegetation (e.g., deep rooting grass species, shrubs, and trees - not moss, shallow rooting grass species, small herbs or forbs).	☐	☐
c) More than 50% of the naturally erodible reach length has stable (usually vegetated) undercut banks.	☐	☐
d) Less than 10% of the total reach length has recently upturned (wind thrown) root wads along the banks.	☐	☐
If answer "Yes" to 3 or more, mark Yes box in Question 2.		
B) Step-pool channels		
a) Less than 10% of the total reach length has banks recently disturbed by stream flows, windthrow, infilling, animals (hoof shear, watering sites, crossings), roads, or harvest and silviculture activities.	☐	☐
b) More than 75% of the banks on naturally erodible sections of the reach have deeply rooted vegetation (e.g., deep rooting grass species, shrubs, and trees - not moss, shallow rooting grass species, small herbs or forbs).	☐	☐
c) More than 50% of the naturally erodible reach length has stable (usually vegetated) undercut banks.	☐	☐
d) Less than 25% of the total reach length has recently upturned (wind thrown) root wads along the banks.	☐	☐
If answer "Yes" to 3 or more, mark Yes box in Question 2.		
C) Non-alluvial channels		
a) More than 75% of the banks on naturally erodible sections of the reach have deeply rooted vegetation (e.g., deep rooting grass species, shrubs or trees - not moss, shallow rooting grass species, small herbs or forbs).	☐	☐
b) Less than 10% of the total reach length has banks recently disturbed by stream flows, windthrow, infilling, animals (hoof shear, watering sites, crossings), roads, or harvest and silviculture activities.	☐	☐
c) Less than 25% of the total reach length has recently upturned (wind thrown) root wads along the banks.	☐	☐
If answer "Yes" to 2 or more, mark Yes box in Question 2.		

Please refer to the Riparian Protocol for more descriptions of stable, vegetated undercut banks versus unstable, overhanging banks.

Sample No. ______________

Question 3. Are channel LWD processes undisturbed?	Yes ☐	No ☐
Note: The words "recent" and "recently" refer to the age of the riparian management activity being assessed.		
A) Riffle-pool or cascade-pool channel		
a) Most wood is old and does not appear to have been recently deposited.	☐	☐
b) One to twelve accumulations of wood **span** the channel.	☐	☐
c) Half or more of all wood accumulations lack new wood (e.g., branches, treetops, bark, small logs with cut ends, recently crushed or shattered logs).	☐	☐
d) Wood oriented parallel to the channel banks (particularly small logs and limbs with lengths much less than the bankfull channel width) is not abundant, relative to the total amount of wood present.	☐	☐
e) There is no indication that natural wood was recently removed from the channel by hand, slides, torrents or catastrophic floods.	☐	☐
If answer "Yes" to 4 or more, mark Yes box in Question 3.		
B) Step-pool channel		
a) Most wood is old and does not appear to have been recently deposited.	☐	☐
b) One to twelve accumulations of wood are present in the channel.	☐	☐
c) Half or more of all wood accumulations lack new wood (e.g., branches, treetops, bark, small logs with cut ends, recently crushed or shattered logs).	☐	☐
d) Wood oriented parallel to the channel banks (particularly small logs and limbs with lengths much less than the bankfull channel width) is not abundant, relative to the total amount of wood present.	☐	☐
e) There is no indication that natural wood was recently removed from the channel by hand, slides, torrents or catastrophic floods.	☐	☐
If answer "Yes" to 4 or more, mark Yes box in Question 3.		
C) Non-alluvial channel		
a) Most wood is old and does not appear to have been recently deposited.	☐	☐
b) Half or more of all wood accumulations lack new wood (e.g., branches, treetops, bark, small logs with cut ends, recently crushed or shattered logs).	☐	☐
c) Wood oriented parallel to the channel banks (particularly small logs and limbs with lengths much less than the bankfull channel width) is not abundant, relative to the total amount of wood present.	☐	☐
d) There is no indication that natural wood was recently removed from the channel by hand, slides, torrents or catastrophic floods.	☐	☐
If answer "Yes" to 3 or more, mark Yes box in Question 3.		

TIP: "Old" wood is wood that was present before the treatment (i.e., the most recent harvesting or road building). "New" wood means wood that was deposited after road building and harvesting was started. This could include stems or branches that were blown off trees after harvesting started.

TIP: If half or more of the reach length is completely filled with wood, consider this to be more than 12 accumulations of wood.

Sample No. ______________

Question 4.	Is the channel morphology intact? (Mark NA if the channel is non-alluvial, and therefore lacking a riffle-pool, cascade-pool or step-pool morphology)	Yes ☐	No ☐	NA ☐
A) Riffle-pool or cascade-pool channel				
a)	Pools are present along >25% of the reach.	☐	☐	
b)	Surface sediment texture is heterogeneous and well sorted; i.e., the number and range of main sediment classes present (fines and sands, gravels, small and large cobbles, small and large boulders) is large and non-randomly distributed.	☐	☐	
c)	At least two deep pools are present. (A deep pool is a pool with a channel depth twice the average channel depth at riffle crests).	☐	☐	
If answer "Yes" to 2 or more, mark Yes box in Question 4.				
B) Step-pool channel				
a)	Plunge pools are frequent (>25% of steps are associated with a plunge pool with depths similar to the size of the largest rock in the step).	☐	☐	
b)	The channel alternates almost exclusively between steps and pools (i.e. less than 25% of the channel consists of relatively long cascades).	☐	☐	
c)	At least two deep pools are present. (A deep pool is a pool with a channel depth twice the average channel depth at riffle crests).	☐	☐	
If answer "Yes" to 2 or more, mark Yes box in Question 4.				

TIP: A stream reach can have aspects of both a cascade-pool and a step-pool morphology. Use the predominant morphology to decide which set (A or B) of indicator statements to use.

TIP: Steep streams (with gradients between approximately 5-15%) that look like long cascades could be step-pool streams that are filled in with abundant sediment. Even steeper streams (with gradients much greater than 15%) are probably non-alluvial, especially small streams.

TIP: Only measure the lengths of the main pools present. These are the pools that extend from one side of the wetted channel to the other. Do not include the small pools that are often present behind boulders in riffles or cascades or the small backwater or back eddy pools that might be present along the margins of riffles and cascades.

Sample No. ______________

Question 5.	Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?	Yes ☐	No ☐	NA
a)	Temporary blockages to fish, debris or sediments because of accumulations of debris or sediments are absent.	☐	☐	
b)	Down cutting in the main channel that now isolates the floodplain from normal flooding or blocks access to tributary streams or off-channel areas is absent.	☐	☐	
c)	Build-ups of sediment or debris above or within any crossing structures are absent.	☐	☐	☐
d)	There is no down cutting present below any crossing structure that blocks fish movements upstream by any size fish at any time.	☐	☐	☐
e)	On fish bearing streams, all crossing structures are open bottom structures.	☐	☐	☐
f)	Dewatering over the entire channel width due to excessive new accumulations of sediment is absent.	☐	☐	
g)	Off-channel or overland flow areas have not been isolated or cut off by roads or levees.	☐	☐	
h)	Water in the stream has not been withdrawn or diverted elsewhere.	☐	☐	
	If the answer is "No" to any statements, mark the "No" box for Question 5.			

TIP: For Question 5, part (a), consider a temporary blockage a "blockage" if more than 2/3 of the flow seeps through or spills over the blockage when the water level is close to the rooted edge. Note that active beaver dams will almost always be temporary blockages.

TIP: "Down cutting" refers to channel incisement; i.e., the vertical movement of the channel downwards into the floodplain.

Question 6.	**Does the stream support a good diversity of fish cover attributes?** To qualify as cover, each cover attribute should represent at least 1% of the total stream area observed. (Mark NA if the stream is non-fish bearing; i.e., classes S5 or S6)	Yes ☐	No ☐	NA ☐
a)	Deep pool habitat is available.	☐	☐	
b)	Stable, unembedded boulders are present.	☐	☐	
c)	Stable rootwads, woody debris or other organic material that fish can hide in is present. "Other" organic debris is made up mostly of uncompacted leaf and/or wood particles that small fish can hide in.	☐	☐	
d)	Stable, deep-rooted undercut banks are present.	☐	☐	
e)	Submerged or emergent aquatic vegetation is present.	☐	☐	
f)	Overhanging vegetation is present within 1 m of the top of the channel.	☐	☐	
g)	Stable unembedded gravels and cobbles with void spaces for fish to hide in are present.	☐	☐	
	If the answer is "Yes" for five or more statements, mark the "Yes" box. Otherwise, mark the "No" box.			

TIP: Question 6 is "NA" if the stream is non-fish bearing. Also, if there are no deep pools, there is no deep pool habitat.

Sample No. ______________

Question 7.	Does the amount of moss present in shallow areas of the channel indicate a stable and productive system? (Mark "NA" if the streambed is mainly organic. "Mainly" is when 90% of the reach is organic or 5 of the 6 point stations are 100% organic.)	Yes ☐	No ☐	NA ☐
a)	Moss patches are easily observed from almost any point along the margins, riffles or shallow pools of the stream. Average coverage on mineral substrates only is 1% or more of the channel bed, from the toe of one bank to the toe of the other bank.	☐	☐	
b)	Half or more of the moss present, even uncommon, occasional or rare patches are generally intact, not embedded with sediments, buried or damaged by scouring. Mark "NA" if no moss is present.	☐	☐	☐
c)	Moss not scoured, silted or buried in sediment is generally vigorous, not stressed or dead. Mark "NA" if no moss is present.	☐	☐	☐
	If the answer is "No" for any statement, mark the No box for Question 7. Otherwise, mark the Yes box.			

Question 8.	Has the introduction of fine inorganic sediments been minimized? (Mark "NA" if the streambed is mainly organic. "Mainly" is when 90% of the reach is organic, or 5 of the 6 point stations are 100% organic.)	Yes ☐	No ☐	NA ☐
a)	Inorganic ("gritty" feeling) fine and sand-sized sediments on the substrate are best described as little or lacking. Average coverage at point sites is less than 10%, with no sites over 50%, and no areas equal to 1% or more of the channel area between sites that can be described as "blanketed".	☐	☐	
b)	Individual wetted areas of gravel, sand or fine sized sediments that a foot can be easily pushed or wiggled into are all smaller than an area equal to 1% of the total channel area. Mark "NA" if the stream is dry.	☐	☐	☐
c)	Gravels and cobbles are not embedded or buried in a matrix of sand or finer sized particles. The sides of individual gravel and cobble particles can generally be seen touching each other.	☐	☐	
d)	An average of one or more sensitive invertebrate type(s) is present at invertebrate sample sites. Mark "NA" if no invertebrates are found at all or the stream is dry.	☐	☐	☐
	If the answer is "No" to any statement, mark the "No" box for Question 8. Otherwise, mark the "Yes" box.			

Question 9.	Does the stream support a diversity of aquatic invertebrates? (Mark "NA" if no invertebrates at all are found or the stream is dry.)	Yes ☐	No ☐	NA ☐
a)	An average of one sensitive invertebrate (e.g., a caddisfly, stonefly, mayfly or freshwater clam) is present at the sites sampled.	☐	☐	
b)	An average of two different major invertebrate groups (e.g., insects, worms, crustaceans, etc.) is present at the sites sampled.	☐	☐	
c)	An average of three recognizably different insects is present at the sites sampled.	☐	☐	
d)	An average of four recognizably different invertebrates is present at the sites sampled.	☐	☐	
	Mark the "Yes" box for Question 9 if two of the statements are "Yes". Otherwise, mark "No".			

Sample No. ______________

Question 10. Has the vegetation retained in the RMA been sufficiently protected from windthrow?	Yes ☐	No ☐	NA
a) The incidence of post-treatment windthrow in S1-S3 RRZs or S4-S6 RMZs with WTPs does not exceed 5% of the stems, over and above what occurs naturally in the area. Mark NA and answer 10 b) if there is no reserve zone, or management zone with wildlife trees or wildlife tree patches.	☐	☐	☐
b) The incidence of post-treatment windthrow in S4-S6 RMZs that are not part of a WTP does not exceed 10% of the stems, over and above what occurs naturally in the area. Mark NA if there is a reserve zone or wildlife tree patch adjacent to the stream, and answer 10 a).	☐	☐	☐
c) Designated wildlife trees are still standing, or if windthrown, still functional as wildlife trees (e.g., aboveground bear dens). Mark NA if there are no designated wildlife trees.	☐	☐	☐
If the answer is "No" to any statement, mark the "No" box for Question 10. Otherwise, mark the "Yes" box.			

Calculating % Windthrow:

1. % Old Windthrow = $\frac{\text{(\# Old Windthrown Trees)}}{\text{(\# Standing Trees + \# Old Windthrown + \# New Windthrown)}}$ X 100

2. % New Windthrow = $\frac{\text{(\# New Windthrow)}}{\text{(\# Standing Trees + \# New Windthrow)}}$ X 100

To calculate % new windthrow over and above the natural pre-treatment windthrow, subtract (1) from (2).

Question 11. Has the amount of bare erodible ground or soil disturbance in the riparian area been minimized?	Yes ☐	No ☐
a) Total bare erodible ground in the first 10 m of the riparian zone outside of active road areas is less than 1%.	☐	☐
b) Total bare erodible ground present in the first 10 m of the riparian zone, plus all other bare erodible ground hydrologically linked to the first 10 m of riparian zone is less than 5%.	☐	☐
c) Total area disturbed by animals or machinery in the first 10 m of the riparian zone is less than 10%.	☐	☐
d) Total area disturbed by animals or machinery in the first 10 m of the riparian zone, plus all other disturbed areas hydrologically linked to the first 10 m of riparian zone is less than 15%.	☐	☐
If the answer is "Yes" for all statements, mark the "Yes" box. Otherwise, mark the "No" box.		

TIP: Sediment deposited on the ground from upslope sources is considered bare ground for Question 11, but not if the sediment is deposited due to flooding (i.e., overbank deposits).

Sample No. ______________

Question 12.	Has sufficient vegetation been retained to maintain an adequate root network or LWD supply?	Yes ☐	No ☐	NA
a)	On all streams, nonmerchantable conifer trees, understory deciduous trees, shrubs, and herbaceous vegetation are present to the fullest extent possible within 5 m of the channel.	☐	☐	
b)	On S1 to S3 size streams, the first 10 m of the riparian reserve zone is intact (regardless of windthrow), thereby providing for 80% or more of the LWD normally supplied to streams with no additional inputs from upstream or the adjacent hillslopes.	☐	☐	☐
c)	On S4 streams, where the windthrow hazard was not assessed, or where windthrow hazard was assessed as not high, all windfirm trees with roots embedded in the bank, and 50% of all other trees (excluding dominant conifers) within 10 m of the stream bank are present.	☐	☐	☐
d)	On S4 streams, where the windthrow hazard was assessed as high, all conifers < 30 cm DBH are present within 10 m of the stream bank.	☐	☐	☐
e)	On valley bottom S5 streams with alluvial banks and a floodplain, 50% of dominant and codominant windfirm stems within 30 m of the stream bank are present.	☐	☐	☐
f)	On non-valley, LWD dependent S5 streams, all leaners within 10 m of the channel and all conifer stems < 30 cm DBH within 5 m of the stream bank are present.	☐	☐	☐
g)	On LWD dependent S6 streams, or S6 that flow directly into fish-bearing waters, at least 10 trees < 30 cm DBH per 100 m of streambank are present within 5 m of the stream bank.	☐	☐	☐
	Mark the "No" box for Question 12 if there are any "No" answers. Otherwise, mark the "Yes" box.			

TIP: All streams require an answer to indicator statement 12 (a). At most, only one other indicator statement will be applicable.

TIP: Stream crossing right-of-ways should not be considered a factor for Question 12 unless the right-of-ways represent more than 25% of the riparian habitat.

Question 13.	Has sufficient vegetation been retained to provide shade and reduce bank microclimate change?	Yes ☐	No ☐
a)	With the exception of active roads at stream crossings, bare erodible ground directly exposed to rain is less than 1% of the riparian habitat in plan view.	☐	☐
b)	Shade (the average amount of sky not visible due to vegetation) averages more than 60%, as estimated visually for any two of the east, south and west aspects at 60° above the horizontal.	☐	☐
c)	Moisture loving macrophytes, mosses, ferns or other bryophytes are present and in vigorous condition, with no indication of stress due to sunburn, drought or desiccation.	☐	☐
d)	Soil in the riparian habitat is moist and cool to the touch.	☐	☐
	Mark the "Yes" box for Question 13 if 3 or more answers are "Yes". Otherwise, mark the "No" box.		

Sample No. ______________

Question 14. Have the number of disturbance-increaser species, noxious weeds, and/or invasive plant species present been limited to a satisfactory level?	Yes ☐	No ☐
a) Disturbance-increaser plants (domestic grasses, dandelions, pineapple weed, buttercups, etc.) occupy less than 25% of total area in the first 10 m of the riparian zone.	☐	☐
b) Noxious weeds and/or other invasive plant species occupy less than 5% of total area in the first 10 m of the riparian area.	☐	☐
Mark the "Yes" box for Question 14 if all statements are "Yes". Otherwise, mark "No".		

TIP: To estimate coverage by disturbance-increaser plants or weeds and other invasive plants at a sample site, try estimating the percentage of a 10 m long line transect that is occupied by these plants. Start the line transects at the edge of the stream and go 10 m at right angles to the main axis of the stream reach.

Question 15. Is the riparian vegetation and forest structure within the first 10 m from the edge of the stream generally characteristic of what the healthy unmanaged riparian plant community would normally be along the reach?	Yes ☐	No ☐
a) All the major vegetation layers and structural components of the expected healthy unmanaged riparian plant community (e.g., snags, CWD, gaps, tall trees, understory, tall shrubs, low shrubs, herbaceous plants, mosses and lichens) are adequately represented. Adequate representation is 1) the presence of all expected layers and components over 75% of the reach, 2) 75% of the expected layers or components over all of the reach, or 3), any combination of 1) and 2) that collectively averages 75% or more.	☐	☐
b) The major vegetation layers and structural components of a healthy unmanaged riparian plant community should exhibit good vigor, normal growth form, and satisfactory recruitment. Vigor or growth form is poor if plants are discolored, defoliated, brittle, burned, broken, heavily browsed, "mushroomed", wind thrown, harvested or dead. Mark "No" if collectively less than 75% of all the plants and structural components expected show good vigor, form, and recruitment.	☐	☐
c) Heavy browse is absent on a preferred browse species in the shrub layer. Heavy browse on a plant is browse down to second year wood over most (>50% of the branches) of the plant.	☐	☐
d) Heavy grazing occupies <10% of the available grazing area. Heavy grazing is defined as less than the recommended target stubble height for the dominant forage species present.	☐	☐
Mark the "Yes" box for Question 15 if 3 or more answers are "Yes". Otherwise, mark the "No" box.		

TIP: All four statements can always be answered "Yes" or "No". There are no NA statements.

TIP: If more than 25% of the total reach length is more or less bare of vegetation, as could be the case at road crossings, then 15(a) and 15(b) should probably be marked "No". If more than 25% of all the vegetation along both sides of the total reach length is removed, as would be the case for a complete clearcut along the reach, then 15(a) and 15(b) would again be marked "No".

Please refer to the Riparian Protocol for a description of "heavy browse".

Sample No. ______________

Summary

QUESTION		Yes	No	NA
Question 1.	Is the channel bed undisturbed?	☐	☐	
Question 2.	Are the channel banks intact?	☐	☐	
Question 3.	Are channel LWD processes intact?	☐	☐	
Question 4.	Is the channel morphology intact?	☐	☐	☐
Question 5.	Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?	☐	☐	
Question 6.	Does the stream support a good diversity of fish cover attributes?	☐	☐	☐
Question 7.	Does the amount of moss present on the substrates indicate a stable and productive system?	☐	☐	☐
Question 8.	Has the introduction of fine sediments been minimized?	☐	☐	☐
Question 9.	Does the stream support a diversity of aquatic invertebrates?	☐	☐	☐
Question 10.	Has the vegetation retained in the RMA been sufficiently protected from windthrow?	☐	☐	
Question 11.	Has the amount of bare erodible ground or soil disturbance in the riparian area been minimized?	☐	☐	
Question 12.	Has sufficient vegetation been retained to maintain an adequate root network or LWD supply?	☐	☐	
Question 13.	Has sufficient vegetation been retained to provide shade and reduce bank microclimate change?	☐	☐	
Question 14.	Have the number of disturbance-increaser plants, noxious weeds and/or invasive plant species present been limited to a satisfactory level?	☐	☐	
Question 15.	Is the riparian vegetation within the first 10m from the edge of the stream generally characteristic of what the healthy unmanaged riparian plant community would normally be along the reach?	☐	☐	

of "Yes" answers: ____ + # of "No" answers: ____ + # of "NA" answers: ____ = Total # of answers: _____

Conclusion on Functioning Condition (check one):

☐ Properly Functioning (0-2 "No's")
☐ Properly Functioning but at Risk (3-4 "No's")
☐ Properly Functioning but at High Risk (5-6 "No's")
☐ Not Properly Functioning (>6 "No's")

List the questions that had a "No" answer below, and check what you believe was the **main reason(s)** for the problem. A "No" answer due to natural causes would include any natural events such as insects, fires, floods, slides, diseases etc. that were clearly unrelated to man's activities in the stream or adjacent riparian area. Check Logging, Livestock, Roads or Other Manmade as a cause if these factors directly affected the stream or riparian area assessed in this evaluation. Check Upstream Factors if the No answer was the result of some event or condition that occurred upstream, regardless if it was manmade or natural.

"No" answer questions	Cause of "No" Answers					
	Logging	Livestock	Roads	Other Manmade	Natural Events	Upstream Factors
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐

Sample No. _____________

Checklist of Specific Impacts for All "NO" Answers. Use this table to elaborate on the causes of the main impacts identified on Page 16. Please record the Question numbers that had "No' answers in the space provided beside the specific impacts.

	Select Impacts that Apply	
LOGGING RELATED IMPACTS	Within Stream Reach	Above Stream Reach
Falling and yarding (slash/cut logs in channel)		
Machine disturbance during harvesting		
Machine disturbance during site preparation		
Windthrow		
Low retention		
Old logging		
Slides/sloughs		
Torrenting		
Water courses diverted		
ROADS, CROSSINGS		
Running surface eroding into stream		
Ditches eroding into stream		
Fill or cut slopes eroding into stream		
Road prism failing/collapsing		
Cross ditching inadequate		
Ditch blocks inadequate		
Cross drains inadequate		
Sediment traps inadequate		
Berms/ruts trap water on road		
Crossing leaks fines into stream		
Water courses diverted		
Crossing opening too small		
Crossing misaligned		
Crossing not open-bottomed		
Culvert evert too high		
Culvert damaged		
Culvert plugged		
ANIMAL DISTURBANCE		
Excessive grazing/browsing (livestock)		
Excessive grazing/browsing (other ungulates)		
Excessive browsing (beavers)		
Trampling (livestock)		
Trampling (other animals)		
Stream dammed (beavers)		
Excessive manure		
NATURAL IMPACTS		
High natural background sediment levels		
Organic stream bed		
Fire		
Beetle kills		
Other diseases, epidemics		
Wind		
Slides/sloughs		
Torrents		
Floods		
Unknown		
OTHER IMPACTS (list)		

Sample No. ______________

Final Comments

	Yes	No
Does the conclusion on functioning condition generally agree with your personal opinion on the functioning condition of this stream reach? If not, please describe why not.	☐	☐

____

____

____

	Yes	No
All No answers are weighted equally. Were any specific problems identified that affected the assessment more than others?	☐	☐

____

____

____

	Yes	No
Do you have any recommendations for improving the Riparian Effectiveness Routine Evaluation Checklist or Protocol?	☐	☐

____

____

____

	Yes	No
Have you marked the stream reach assessed on a map in a way that will be legible when photocopied?	☐	☐
Were any invasive plants observed? Remember to complete an Invasive Plant field card if the answer is "Yes".	☐	☐

Additional Riparian Information Requested

	Yes	No
Does the retention information on Page 1 accurately describe the conditions present along the stream reach? (If you feel the answer is "No", please describe the retention further by completing statements (A) to (H) below. Or attach a sketch showing a typical cross section of the two riparian areas, showing the widths and retention levels of the riparian area from the edges of the stream to the edge of a road or clearcut (maximum distance 500 m).)	☐	☐

	Left Side	Right Side
(A) Average distance from stream edge to merchantable trees (m, max. 100)	______	______
(B) Average distance from stream edge to first signs of most recent harvesting (partial or complete, m, max. 100)	______	______
(C) Average distance from stream edge to start of most recent complete harvesting (i.e. a road or clearcut, m, max 100. Note that the riparian area between "B" and "C" is the partly harvested riparian area referred to in "E" to "H")	______	______
(D) Approximate age (yrs) of most recent harvesting in first 100m. Mark NA if there has not been any harvesting	______	______
(E) % of riparian area that was partly harvested that were merchantable coniferous trees (% merchantable X % coniferous). Mark NA if there is no partly harvested area	______	______
(F) % of riparian area that was partly harvested that were merchantable deciduous trees (% merchantable X % deciduous). Mark NA if there is no partly harvested area	______	______
(G) % of merchantable coniferous trees retained in the partly harvested area. Mark NA if there is no partly harvested area	______	______
(H) % of merchantable deciduous trees retained in the partly harvested area. Mark NA if there is no partly harvested area	______	______

Appendix 4: FREP Water Quality Effectiveness Evaluation Field Cards
(from FREP website)

BRITISH COLUMBIA
The Best Place on Earth

Forest and Range
Evaluation Program

Water Quality
Resource Stewardship Monitoring
Sample Area Information Card - Form 1 Side 1

1 Identification

page _____ of _____

Assessed by ______________________ Date M M / D D / Y Y Y Y
District ________________ Opening ID __________ Road ID __________
Watershed/Stream ____

2 Description

Is the watershed being used for drinking water? ☐ Yes ☐ No ☐ NA

Where is (are) the intake(s)? (Locate on map if known)

What is the distance and what is the connectivity between intake and cutblock ______________________ km

Comments: ______________________________ ☐ Direct via stream
______________________________ ☐ Indirect (lake, wetland)
____

Are there other special resource values associated with watershed? ☐ Yes ☐ No ☐ NA

If yes, explain: ____
____
____

Within the probable sampling areas, what are the approximate length, age and status of the access roads?

Type	Status[1]	Approximate Length (km)	Age of Road (years)
Main line			
Branch line			
Spur			
Winter use roads			

[1] active, inactive, temporarily or permanently deactivated

Areas of sensitive soils and unstable terrain associated with cutblock and access road? ☐ Yes ☐ No ☐ NA

3 Reported Disturbance

page _____ of _____

Type of Disturbance	Year of Occurrence	Type of Disturbance	Year of Occurrence
☐ Landslide		☐ Road slump	
☐ Debris torrent		☐ Heavy gullying	

4 Report Use Of

	On Road right of way	Within Block
Fertilizer	☐	☐
Herbicide	☐	☐
Pesticide	☐	☐

5 Locate on 1:20,000 Map Showing Cutblocks, Roads and Streams

a. Approximate Extent of Sample Area (randomly selected cutblock or as-built road and access)

b. Sample Sites associated with forestry activities requiring field checking including: (check applicable)

☐ Stream crossings (bridges, culverts)

☐ Roads running parallel to stream (within 20 m)

☐ Potential unstable slopes along, in or down slope from road or cutblock

☐ Potential sensitive soils

☐ Harvesting adjacent to stream

☐ Potential livestock concerns

☐ Other ____________________

Travel mode:

☐ Truck

☐ Quad

☐ Helicopter

☐ Other

Time(hrs) to complete evaluation of area:

_____ travel time (hrs)

\+ _____ field time (hrs)

x _____ crew size

_____ total time (hrs)

6 Comments

____

____

____

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Forest and Range
Evaluation Program

Water Quality
Resource Stewardship Monitoring
Form 2 Side 1

Sample Site ID: ____________________ Opening ID: ________________________ District: ________________________

UTM Zone: ____________________ Easting: ___________________________ Northing: ___________________________ Road Ref: __________________________

Watershed/stream: _____________________________ Known Domestic Intake Downstream (circle) Yes / No

Stream Channel Width (m) ______________ Opening ID: ________________________ Date Completed: MM / DD / YYYY

Site Type (Stream crossings, inter-drainage culverts, road failures, riparian harvesting/ yarding, skidder/harvester trails, other forestry disturbances)

Components and their Characteristics			**a. Mass Wasting Contribution (see back of card)**	**b. Surface Erosion Contribution**										
Column 1 Identify individual components of site within shared drainage. (Table 2) (road surface, road cutbank, road ditch, road sidecast, rills or gullies, mass failures, upturned root wads, livestock disturbance noted, etc)	Column 2 Estimate connectiity between artificial and natural drainage (Table 3 & 4) Chose from: none (0) little (.2) half (0.5) a lot (0.8) all (1)	Column 3 Estimate **portion of fine sediment** in matrix of eroded/ erodible material (Table 5) Chose from: none (0) little (.2) half (0.5) a lot (0.8) all (1) active road surfaces always 1	Columns 4-7	Column 8 (Estimate erodible surface area of identified components within mini catchment) Gross area of component x portion erodible = Net area For portion erodible, choose from: None (0), a little (.2), half (0.5), a lot (0.8), all (1) (Portion of active road surface erodible always considered to be 1)			Column 9a *Required for Road Surfaces only* ***Slope*** 0-2 % 2-10 % >10%	Column 9b ***Road Use*** Heavy, Moderate, Light, Deactivated	Column 9c ***Road Surface Quality*** Paved, Good, Average, Poor	Column 9d Estimate depth of erosion expected for surface of each component Road Surfaces (Table 6 a, b, c)\ All other surfaces (Table 7) (m^3)	Column 10 Calculate **volume** of material removed by surface erosion C8(net) x C(9d) (m^3)	Column 11 Calculate **total sediment** contribution from surface erosion C2 x C10 (m^3)	Column 12 Calculate **fine sediment** contribution from surface erosion C3 X C11 (m^3)
				l x w (m^2)	Portion of surface erodible	Net (m^2)							

FS 1247-2 HFP 2009/03 (SEE OVER)

Total Fine Sediment Generation from Surface Erosion for Site	

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Forest and Range Evaluation Program

Water Quality
Resource Stewardship Monitoring
Mass Wasting Contributions – Form 2 Side 2

Sample Site ID: ____________________ Opening ID: ________________________

Mass Wasting Contributions (> 1/2m³)

Column 1 Identify individual components of site Fill slumps (F) Gullys (rills) (G) Landslides (L)	*Column 3* Estimate portion of fine sediment in eroded/ erodible material Choose from none (0) little (.2) half (0.5) a lot (0.8) all (1) (Active road surfaces usually 0.2)	*Column 4* Estimate volume of material removed by mass wasting and gullying processes L x W x D of failure(s) gully(s) m³	*Column 5* Estimate volume of failed material still on site L x W x D of failure(s) gully(s) m³	*Column 6* Calculate total volume of sediment reaching stream C4-C5 m³	*Column 7* Calculate volume of fine sediment from mass wasting/ gullys reaching stream C6 x C3 m³

a. Total fine sediment generation from mass wasting at site	
b. Total fine sediment generation from surface erosion at site (from Side 1)	
Grand Total Fine Sediment for Site (a.+ b.)	

Optional
Rating of Water Quality Impact for fish bearing stream immediately downstream of site From Table 9 [ ]

Optional
Rating of Water Quality Impact for domestic intake immediately downstream of site From Table 10 [ ]

FS 1247-2 HFP 2009/03

Site Diagram: Sketch of site components, drainage pathways and connectivity

Required Rating for FREP Evaluations
(CIRCLE)

Grand Total Fine Sediment	Rating
<0.2	Very Low
0.2–1	Low
1–5	Moderate
5–20	High
>20	Very High

(From Table 8)

Possible means to reduce stream sedimentation from this sample site (required if site rated moderate, high or very high (see Table 11)

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________

Comments on site

Appendix 5: BC MOE Fish Passage Assessment for Closed Bottom Structures Field Cards (from MOE 2009)

Appendix 1: Closed Bottom Structure (CBS) Field Measurement Form

Closed Bottom Structure (CBS) Field Measurement Form										
1	*Date*				13	*Culvert Length*				
2	*Crossing ID No.*				14	*Outlet resid. Pool depth (cm) (C-B)*	*ToP – BoP (C)*	*ToP – BoC (B)*	*OPD*	
3	*Crew Name*				15	*Stream Slope (%)*				
4	*UTM/GPS (include grid number) eg. 10u*	*Grid*			16	*Habitat Value*	*Low*	*Mod.*	*High.*	
5	*Stream Name?*				17	*Depth of Fill (m)*				
6	*Road Name and km*				18	*Valley Fill*	*DF*	*SF*	*BR*	
7	*MoF District?*				19	*Beaver Activity*	*Yes*	*No*		
8	*Crossing Type*	*RC PA EC EA other*			20	*Inlet drop*	*Yes*	*No*		
9	*Embedded? (mark x)*	*None discon.*	*Partial cont.*	*Full*	21	*Backwatered?*	*0 25 50 75 100*			
10	*Outlet Drop (A+B)*	*Invert-ToP (A)*	*ToP – BoC (B)*	*OD*	22	*Fish Sighted?*				
11	*Stream Width Ratio* Channel widths	*Channel Width*	*Culvert Width*	*SWR*	23	*Culvert Fix*	*RM OBS SS EM BW*			
12	*Culvert Slope %*				24	*Photo (Circle) Documentation*	*D/S Out Bar In U/S #'s -*			
25. Comments										

Fish Barrier Scoring[1]

Risk	Embedded[2]	value	Outlet drop	value	Slope	value	SWR	value	Length	value
low	> 30 cm. or > 20% of Diameter and continuous	0	< 15	0	< 1	0	< 1.0	0	< 15	0
mod	< 30 cm. or 20% of Diameter but continuous	5	15 - 30	5	1 - 3	5	1.0 - 1.3	3	15 – 30	3
high	No embeddment or discontinuous	10	> 30	10	> 3	10	> 1.3	6	> 30	6

Notes

1. For the barrier determination of multiple culverts, use the metrics from the pipe lowest in elevation at the outlet. For pipes installed at the same elevation at the outlet, add diameters for SWR criteria and use the highest slope, and length measurement.

2 Properly embedded culverts are considered passable as per natural stream channel. No further consideration of other surrogates is required.

Cumulative Score	Result
0 - 14	passable
15 - 19	potential barrier
> 20	barrier

Appendix 6: Fisheries Sensitive Watershed (FSW) Supplementary Field Card (DRAFT)

(Page 1 of 3)

Sample Identification (All Protocols)

Date:
Sample no.:
FSW/Watershed:
Stream Class (in field):
Actual Sample Center Point UTM:
Opening ID (if applicable):
Evaluator(s):
District:
Stream Name:
Access Road Reference No.:
Opening Info: *(provided with GRTS draw)*
(Other info TBD)

Dropped Sample (All Protocol)

If sample site is dropped provided details/rational:
(e.g. Sample was in a mtn canyon.)

Sample Center Point (Plot) Adjustment (Riparian Protocol)

Was sample center point relocated? y/n
Was sample center point relocated as per protocol? y/n
If sample center location was adjusted but not according to protocol give rational and method of relocation:

Harvest Age Information (Riparian Protocol)

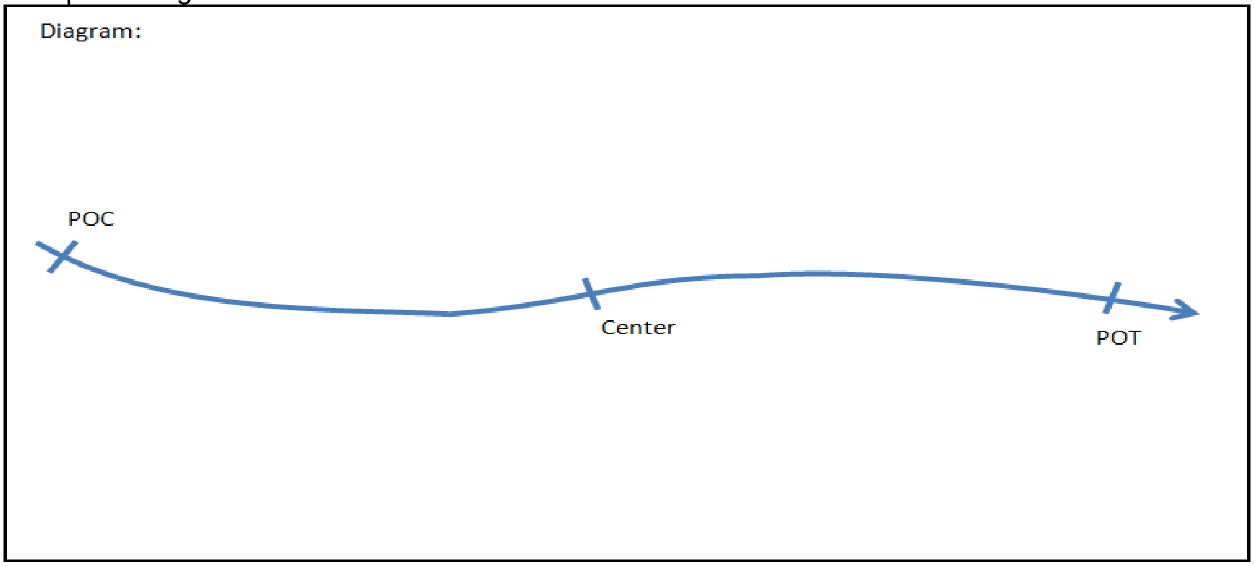
Are there any indications that the stand has been harvested/disturbed in a way contrary to the VRI/GIS data?
Most Recent (2^{nd} Pass) Harvest Age:
Estimate of Old (1^{st} pass) Harvest Age:
Estimate of Old (1^{st} pass) Harvest Method: Selection/High-grade/Patch/Clearcut
1^{st} Pass Age Determined on What Basis: *(will offer some guidance here – e.g. log/stump decay classes, etc.)*

(Page 2 of 3)

Multiple Riparian Forest Strata Description (Riparian Protocol)

How many riparian forest stratum occur along sample reach (Clear cut vs. No cut vs. Partial cut, etc.)?
Brief description of each stratum and its proportion of overall reach:
1)
2)
3)
4)

Complete diagram:



Were photos taken of determining evidence and site? y/n photo no.s

Wetland Conversions (beaver complexes)

Is stream sample site in a beaver wetland complex or beaver meadow?
Was the beaver wetland complex created post forest harvesting (or other disturbance)?
Describe disturbance type and evidence used to support determination?
Were photos taken of determining evidence and site? y/n photo no.s
In your opinion does the modified (post disturbance) site support fish in? Why? With reference to fish, how may have this changed from conditions pre disturbance?

Fish and Other Aquatic Vertebrate Observations (Riparian & Fish Passage Protocol)

Species **(Generic or specific name)**	**Location**	**Life stage**	**Notes**
e.g. "fish" or "coho"	*10m D/S of POC*	*Fry*	*Approx 20 sighted undercut bank*
"Tailed frog" or "Ascaphus truei"			

Fish Stream determination (Fish Passage Protocols)

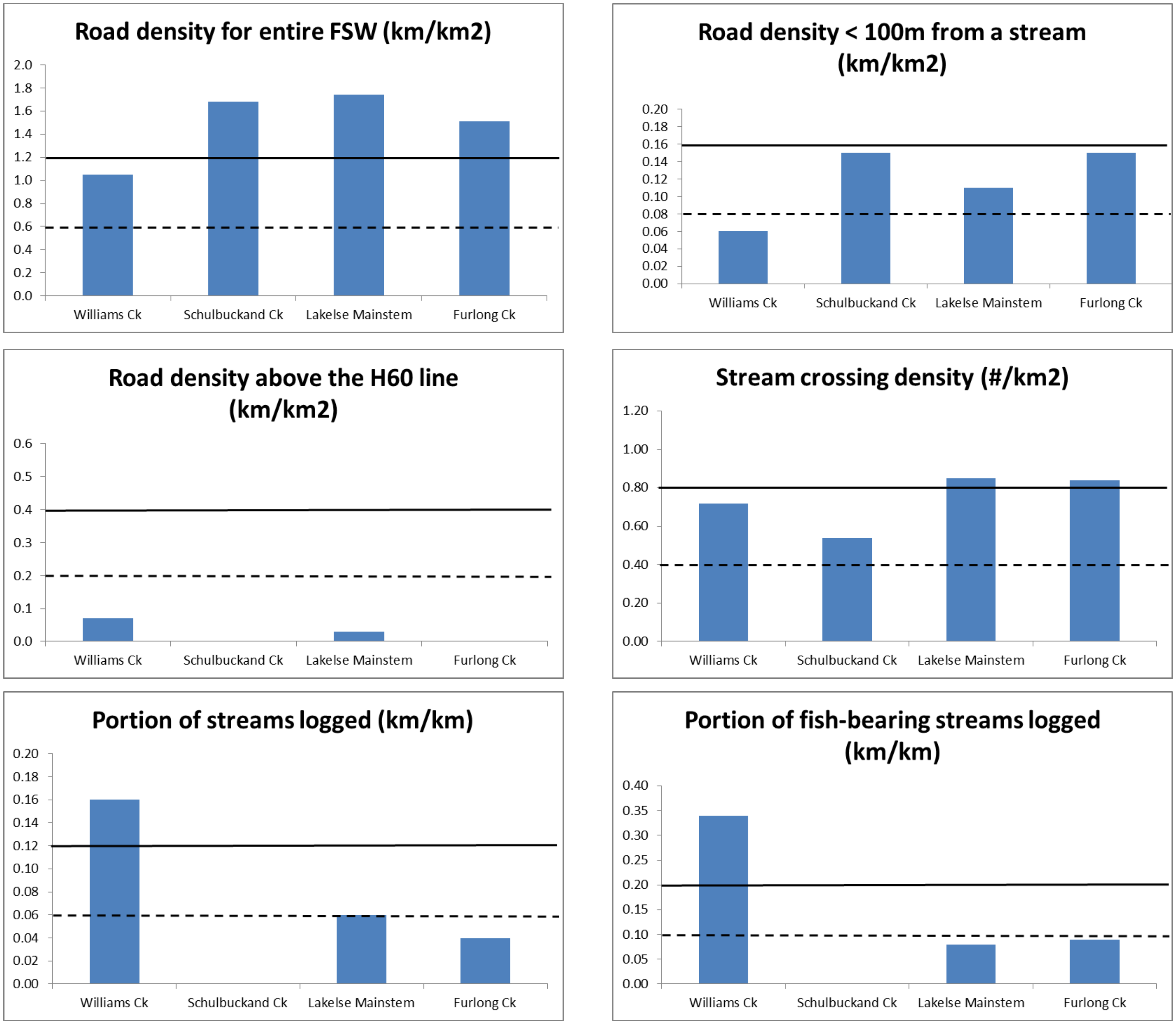
(Guidance to be provided here helping field crews determine whether a stream may be fish habitat.)

Photo Record (All Protocols)

Photo #	Description of scene

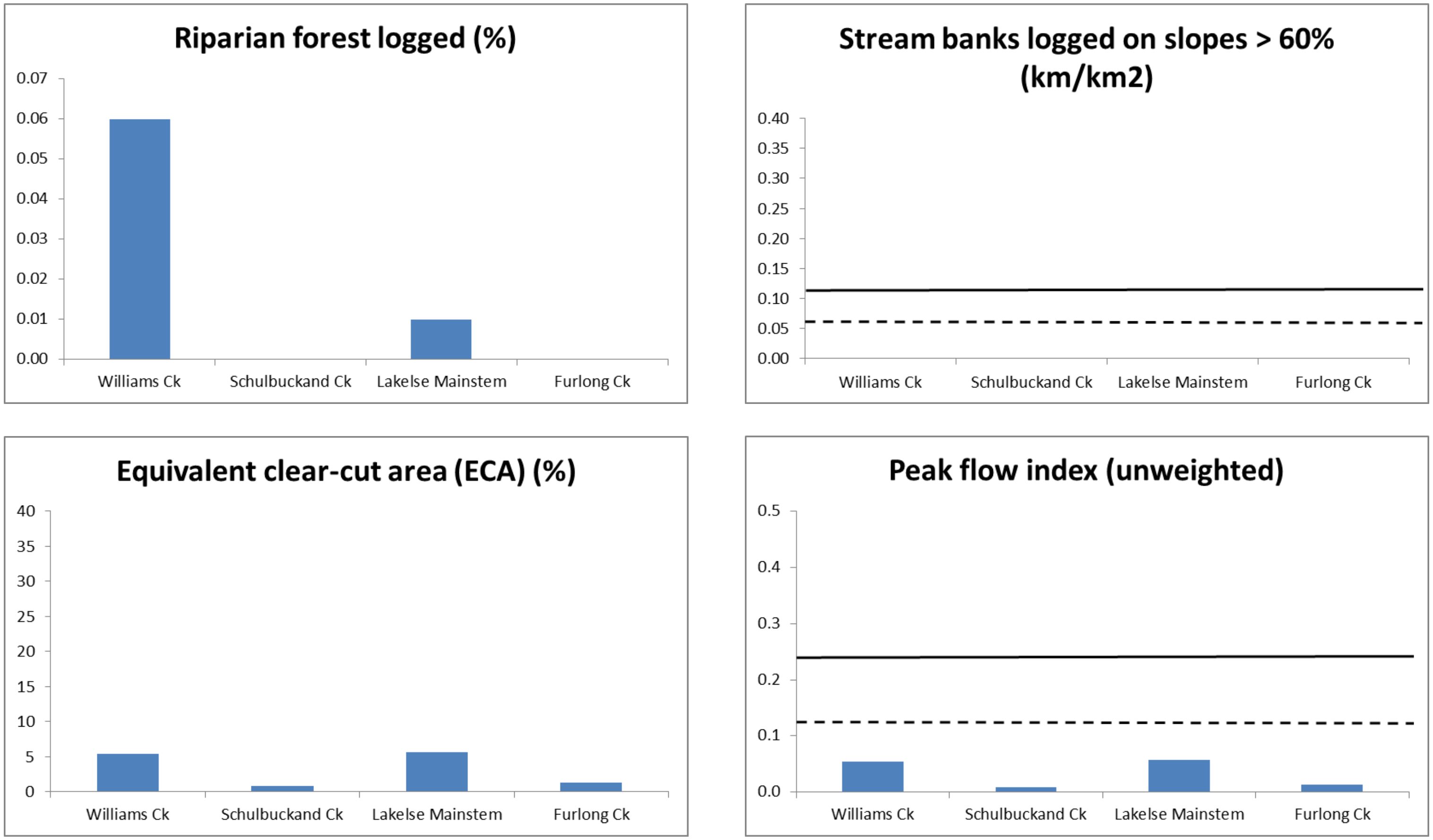
General Observations & Comments (All Protocols)

Tier I (remote sensed) habitat indicator metrics for Fisheries Sensitive Watersheds (FSW) in the Lakelse drainage – Dec. 2012.



——— BC Watershed Assessment Procedure (WAP) moderate risk rating, Score = 0.4)

- - - BC Watershed Assessment Procedure (WAP) lower risk rating, Score = 0.2)



BC Watershed Assessment Procedure (WAP) moderate risk rating, Score = 0.4)

BC Watershed Assessment Procedure (WAP) lower risk rating, Score = 0.2)

Williams Creek Fisheries Sensitive Watershed

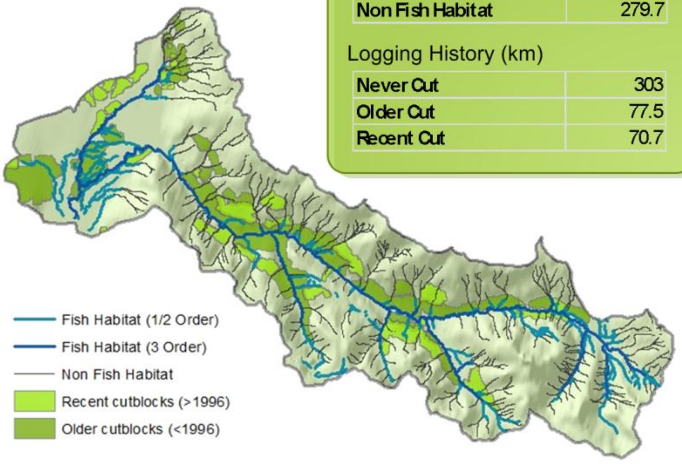
STUDY AREA

Habitat Type (km)

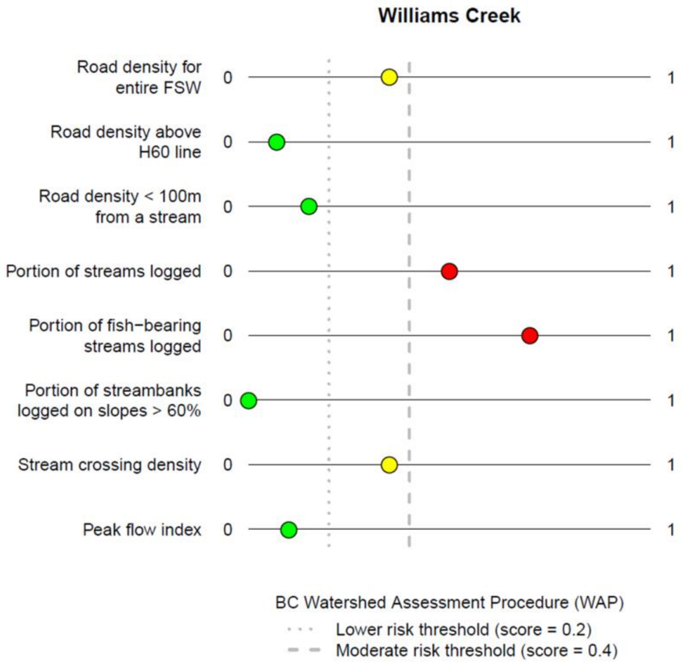
Fish Habitat (1/2 Order)	105.5
Fish Habitat (3 Order)	65.9
Non Fish Habitat	279.7

Logging History (km)

Never Cut	303
Older Cut	77.5
Recent Cut	70.7

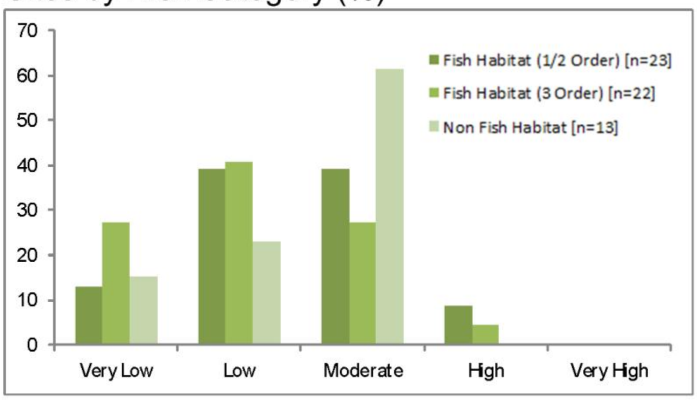


REMOTELY SENSED GIS METRICS



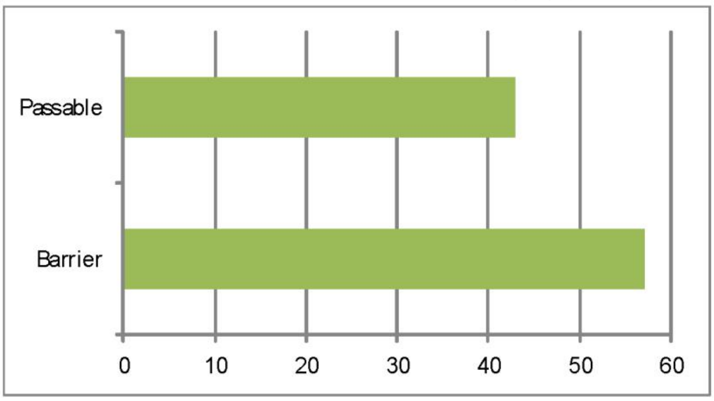
WATER QUALITY

Sites by Risk Category (%)

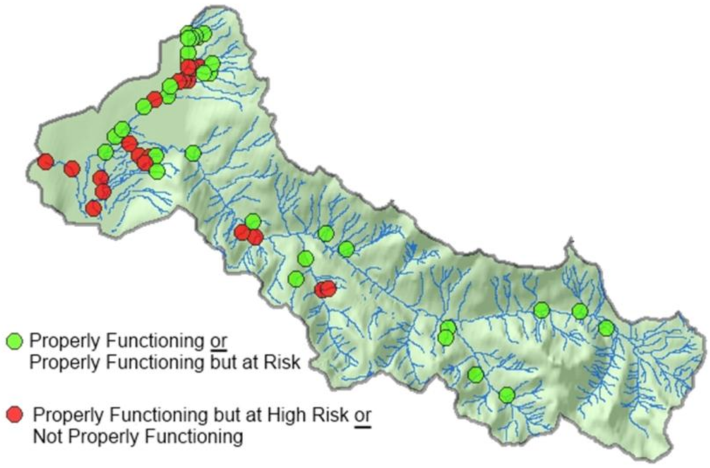


FISH PASSAGE

Sample Sites – Barrier or Passable (%) [n=14]

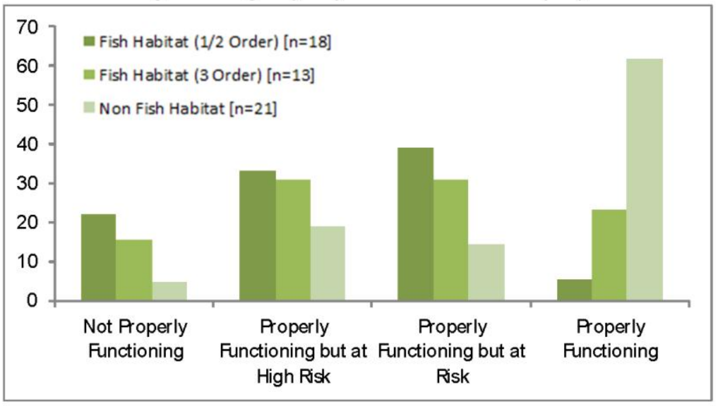


Riparian Sample Site Condition

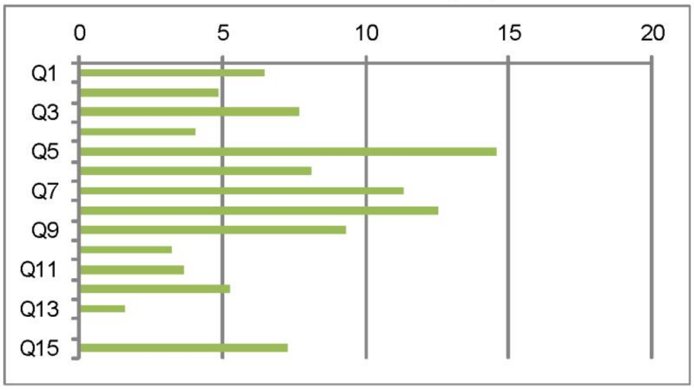


RIPARIAN

Functioning Category by Fish Habitat (%)



Questions Answered with "No" (%)



Q1: Channel bed undisturbed?
Q2: Channel banks intact?
Q3: Channel LWD processes intact?
Q4: Channel morphologically intact?
Q5: Allow unimpeded flow of fish, organic debris, and sediments?
Q6: Good diversity of fish cover attributes?
Q7: Sufficient moss to indicate a stable and productive system?
Q8: Introduction of fine sediments minimized?
Q9: Support a diversity of invertebrates?
Q10: Vegetation sufficiently protected from windthrow?
Q11: Bare erodible ground or soil disturbance minimized?
Q12: Sufficient vegetation to maintain root network and LWD supply?
Q13: Sufficient vegetation to provide shade and reduce microclimate change?
Q14: Presence of noxious weeds and/or invasive plants is limited?
Q15: Vegetation within 10m of stream healthy?