

Tier I watershed-level fish values monitoring protocol rationale

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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). To qualify as a FSW, watersheds are required to meet two criteria; they must have: 1) significant fisheries values and 2) watershed sensitivity. For a full 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. It provides the legal framework that requires forest and range operators to undertake practices in FSWs 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 province and over the course of the next several years there are plans to identify and designate additional watersheds throughout British Columbia as FSWs (L. Reese-Hansen, FLNRO, pers. comm.).

FSW designation has been undertaken for two primary 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 and other land use activities proceed. Effectiveness monitoring is required to determine if FSW designation has achieved this goal.

FLNRO and MOE have been working with ESSA Technologies Ltd. to develop a comprehensive multi-tiered (i.e., remote sensed-based and field-based) monitoring framework for FSWs and other provincial watersheds of concern. 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 2009, ESSA drafted a framework for monitoring FSWs and other watersheds of concern (Wieckowski et al. 2009) which was reviewed by the FSW Monitoring Technical Working Group. Their review of the proposed monitoring framework coupled with the 2009 work plan, provided the foundation for pilot GIS-based and field-based data collection and analysis that was undertaken in designated FSWs within the Lakelse drainage (Skeena Region) in 2011.

1.2 Report purpose

This purpose of this document is to provide the scientific rationale for the Tier 1 GIS-based watershed monitoring protocol (see Porter et al. 2012). 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-based Tier I protocol for monitoring watersheds. The intent of the Tier 1 monitoring protocol is to function as a coarse "WAP-lite" approach to determining watershed condition that can be effectively applied more broadly across the province's watersheds, using readily available provincial data layers. The second section identifies the remote sensed

indicators used in the Tier I monitoring 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 broad implementation of the GIS-based Tier I watershed monitoring protocol.

2.0 Overview of Watershed Assessment Procedures

2.1 Purpose

A fundamental role of forest hydrologists 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). 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). 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 landuse indicators such as road density, riparian disturbance, stream crossing density, landslide occurrence, equivalent clear-cut area, surface erosion, etc. Water assessment procedures provide information on the status of these indicators; information that can be used to inform integrated watershed management planning and operational programs and that can help guide watershed restoration activities. Using the results from a WAP, forest managers can develop approaches to mitigate or even prevent the impacts of forestry-related activities in a watershed.

2.2 Impact categories

A common challenge with any watershed assessment procedure is finding a 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 commonly used in a WAP include recent aerial photographs for an area, 1:20,000 TRIM topographic data, local geologic and soils maps, aquatic features, local forest cover maps, road features, zones dominated by snowpack, snowmelt, etc. For Tier 1 watershed 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 readily and broadly available provincial GIS datasets/layers. This data will be used to inform consistent assessments of the province's FSWs (and conceivably other watersheds of concern) 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, long-term analysis of watershed environments. Numerous agencies in British Columbia currently assemble and provide remote sensed datasets that can be used to map and quantify forest habitat and to evaluate various elements of watershed condition (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 impact categories of a WAP which together influence water quality, quantity, and aquatic habitats. Information on these impact categories can provide information to decision-makers and serve as proxy data for assessing overall watershed health as land development continues over time (Gustavson and Brown 2002; Pike *et al.* 2007). Undesirable changes in these impact categories can suggest a failure in watershed management, thus triggering an investigation into the changes of concern and leading to resultant remediation or mitigation strategies (Gustavson and Brown 2002). Quantitative metrics for evaluating the status of these impact categories in BC's coastal and interior watersheds have been developed within past WAP guideline documents (MOF 1995a, 1995b, 2001).

2.2.1. Peak flow

The first of four main impact categories incorporates specific metrics that reflect potential changes in peak flow events:

1. **Peak flow index:** 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, with higher flows resulting in an increase of erosive power by streams (Sawyer and Mayhood 1998).
2. **Equivalent clear-cut area (ECA):** the underlying 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 in respect to harvesting rate and location of logging in watersheds (Gustavson and Brown 2002). It 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.

3. **Road density for the entire sub-basin:** peak flows are magnified as road density increases because roads act as surface drainage networks that increase runoff (MOF 2001). During heavy precipitation or snow 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).
4. **Road density above the H60 line:** 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 on peak flows are expected when road density is high above the H60 line, because roads located on steeper, high elevation roads will act as channels to rapidly transport melting snowpack downhill.

2.2.2. Surface erosion

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

WAP metrics that have been developed for monitoring the risk of surface erosion:

1. **Road density on erodible soils:** risks of fine sediment inputs to streams resulting from road construction and road use are greater in areas that are more naturally prone to erosion. This metric requires an inventory of soil types throughout the extent of the watershed. A qualified hydrologist or geologist must delineate the soils most susceptible to erosion. Extent of surface erosion may also be influenced by road condition, road traffic, slope, and climatic patterns. Soil maps that accurately define erodible soils are currently only available for a limited number of watersheds in British Columbia (but see future soil and surficial geology mapping products described in Appendix A)
2. **Density of stream crossings:** stream crossings (i.e., road culverts) represent a potential focal point for local sediment and intercepted flow delivery, as well as representing a potential physical impediment to connectivity of fish populations (Gustavson and Brown 2002). A higher density of stream crossings in a watershed is generally indicative of greater risks of fine sediment inputs, although these risks will be dependent on the construction type (i.e., open box vs. closed box), as well as the condition of stream crossing structures.

3. **Density of roads <100m from a stream:** high road density in close proximity to streams will create an increased risk of fine sediment inputs from surface erosion. The extent of this erosion risk will depend on road type, road maintenance and road use.
4. **Density of roads on erodible soils <100m from a stream:** roads on erodible soils that are also located close to streams present an even greater relative risk 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 for a limited number of watersheds in the province. Extensive provincial 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 that can be used to define these risk factors more broadly across watersheds.

2.2.3. Riparian buffer

The riparian zone is the land adjacent to the normal high water line in a stream, river, lake, or pond and extending to the portion of land influenced by the presence of the adjacent ponded or channeled water (MOF 1995a). Riparian habitat is crucial for maintaining the integrity of stream channels, providing stream shading, supplying large woody debris, and preventing wind-throw related impacts that increase bank disturbance and fine sediment delivery (Gustavson and Brown 2002). Logging in riparian zones can result in increased bank erosion, loss of in-channel islands, increased size and frequency of sediment wedges, and altered stream shape (MOF 1995a). When riparian forests are cleared, bank cohesion and stability deteriorates. This linkage between disturbance of riparian vegetation and channel stability is determined by factors including channel slope, stream flow and the composition of bank materials (Gustavson and Brown 2002). Changes in wood inputs and cover provided by riparian vegetation effect runoff timing, water temperature, contaminant levels, sediment loads, fish habitat availability, nutrient availability, micro climates and overall system productivity (Wieckowski *et al.* 2008). Multiple factors contribute to riparian condition including water quality, watershed area, distribution and types of vegetation, regulatory compliance, vegetation disturbance, form and structure (Stalberg *et al.* 2009).

The riparian assessment for a WAP recognizes the important role that riparian vegetation and associated large woody debris inputs provide in maintaining stream channel structural integrity and general stream functioning, and how these roles are affected by logging (BC MOF 2001). The riparian buffer impact category incorporates two metrics for an overall assessment of risk to the riparian zone within a watershed, with the second metric reflecting the particular importance of a riparian buffer to stream ecology within fish-bearing streams (e.g. provides nutrients and fish food through plant materials and insects that fall into the stream, regulates water temperature through tree canopy shading, provides LWD inputs that create pool habitats for fish, and provides streamside vegetation for fish hiding cover (MOF 1995a):

1. **Portion of streams logged**
2. **Portion of fish-bearing streams logged**

2.2.4. Mass wasting

Mass wasting events can affect stream conditions and aquatic productivity throughout a watershed. Tracking of mass wasting events can act as a surrogate indicator for the extent of

fine 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 any individual mass wasting event (Sawyer and Mayhood 1998). Frequency of mass wasting events 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.

WAP metrics that have been developed for assessing the risk of mass wasting events:

1. **Density of landslides:** 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 can be very costly, and often covers small areas. For regular monitoring of large mass wasting events, multiple series of satellite/aerial imagery – updated at frequent intervals – will be required to support change-detection of the relative density of landslides within a watershed (i.e., landslide frequencies beyond naturally expected background levels). Tracking of landslides across provincial watersheds will require sufficient funds for regular remote-sensed inventory and analysis. Identifying very localized and smaller-scale mass wasting events will be a difficult task even with high resolution remote sensing data. This may require some level of supplementary field assessment.
2. **Density of roads on unstable slopes:** roads constructed on naturally unstable slopes will increase the risk of local mass wasting events. Mapping of terrain stability is, however, currently available only at local 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 > 60%. This criterion has traditionally been used in BC (R. Guthrie pers. comm.) although with recognition that the potential impacts in regards to slope will be different on the coast vs. the interior. Until provincial-scale terrain stability maps become available for broad use road densities on slopes >60% can represent a surrogate threshold in relation to landslide risk on unstable soils. 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 identification of potentially unstable slopes across the province.
3. **Density of streambanks logged on slopes > 60%:** logging of steep slopes greatly compromises the stability of ground surfaces within a watershed. The extent of logging around streams on slopes >60% reflects the potential risk of mass wasting events likely to have most impact on streams. 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 can result 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 Tier I monitoring consideration

To supplement the four standard impact categories used traditionally for provincial WAPs (Peak Flow, Surface Erosion, Riparian Buffer and Mass Wasting), it may be useful to incorporate new

monitoring metrics into these impact categories or even develop additional impact categories within an expanded version of Tier 1 watershed monitoring. Additional monitoring indicators/metrics that may be explored within continued iterative development of the Tier I monitoring protocol include (but is not limited to):

- **Habitat Accessibility/Connectivity:** landuse activities can restrict fish access to and movement within their historical stream networks. Barriers to fish movement can limit spawning and rearing opportunities, and restrict overall habitat availability in a watershed (Gustavson and Brown 2002). Quantifying the effects of barriers to fish habitat accessibility requires determining the number of locations where fish movements are currently blocked and the amount and type of historical fish habitat that has been made inaccessible (Stalberg *et al.* 2009). Evaluating effects on connectivity broadly across a watershed will require coupling the Tier 1 GIS-based inventory of all potential stream obstructions (e.g. identifying all stream crossing locations) with field-based assessments of fish passage probabilities (MOE 2009) at a representative sample of stream crossing sites (see Tier II protocols described in Pickard *et al.* 2012a) or a census of sites if possible. The interpretation of habitat accessibility/connectivity also requires the ability to distinguish between natural and anthropogenic obstructions in order to accurately link forestry or other landuse development to impacts on watershed connectivity.
- **Low Flow Regime:** it may be possible to assess risk of potential disruptions to natural low flow patterns in a watershed based on a measure of the percent area dominated by vigorously regenerating second growth forest. The FSW MTWG has begun exploring development of an novel Equivalent Second Growth Area (ESGA) metric that could potentially be incorporated into Tier I watershed assessments in this regard (see discussion of draft method in Porter *et al.* 2012). This metric would reflect the maturity of any particular watershed and its presumed hydrologic stability in regards to maintaining a natural low flow regime, provided forest cutblock and land cover data is reliable and updated frequently.
- Other land use activities (e.g., mines, range use, urbanization, oil/natural gas development, independent power production (IPP) projects, water extractions, water diversions, point source / non-points source pollution of surface water / groundwater, etc.): while traditional WAPs focus on the impacts of forestry, watershed condition may be affected by a larger range of land use/land management activities (i.e. a wider suite of potential cumulative impacts). Quantifying the extent and/or intensity of these activities and determining individual or interactive metrics/benchmarks of concern for monitoring purposes will be an anticipated focus for future evolution of the Tier I monitoring protocol into a more broadly comprehensive watershed risk assessment.

2.2.6. Climate Change indicators

Climate change is likely to compound and exacerbate existing watershed stresses from local land management activities. In recognition of climate change and the variety of potential watershed level impacts that may result from these changes, there has been various guidance documents published that tackle this topic (e.g. TRIG 2012). While the form and type of impacts to watersheds in BC will vary depending on geographic location, typical risk factors expected to increase impacts to watershed condition include:

- Warmer air and water temperatures

- Declines glacier and snowfield area resulting in water quality and quantity impacts (e.g. increased turbidity, reduced temperature moderating influences, and decreased summertime flows)
- Changes in normal seasonal precipitation patterns
- Changes in streamflow timing, magnitude, and temperature (e.g. earlier freshets and lower summer flows)
- Increased extent, intensity and frequency of wildfires and other natural disturbances (Stahl 2006; TRIG 2012; Woods 2005)

A review of potential indicators that could be used to reflect risk factors associated with climate change induced impacts resulted in the identification of a subset of indicators warranting further exploration and potential incorporation into the Tier I monitoring protocol. These indicators are predominantly those that would be used in the GIS environment but also include field-based measures. Many of the climate change risk indicators are not necessarily, or obviously, representative measures of conditions found in the environment (e.g., they may be modeled information), but rather are linked to factors that affect important watershed processes and would be used in conjunction with other indicators to emphasize (weight) the potential (cumulative) adverse impacts to conditions resulting from climate change. Of the prospective remotely sensed indicators reviewed, those that were selected as having the most utility from a watershed monitoring perspective include: snowfields and glaciers, flow sensitivity modeling, watershed hydrogeomorphic vulnerability modeling, and climate change related forest disturbance. These and other remotely sensed approaches to using climate change indicators merit further investigation in subsequent iterations of the protocol. All of the recommended climate change indicators are elaborated upon below.

Remotely sensed snowfield and glacier monitoring. Permanent snowfields and glaciers are a feature found in many BC watersheds and play an important role in augmenting summer low flows, and moderating high summer water temperatures. Reductions in their size, or the disappearance of these features all together, are predicted outcomes linked to climate change, and will have significant implications for stream conditions, aquatic ecosystems, and the species that live in them. The implications for the aquatic environment are critical and will require evaluation and assessment relative to the parallel effects of local land management activities on overall watershed condition in order to effectively adapt management activities in response to these climate change impacts. Increases in turbidity and temperature are among the impacts already being measured as a result of reductions in the extent (and mass) of these features (Moore et al. 2009).

Discussions with GIS analysts suggest that using remote sensed data to repeatedly measure the extent of permanent snowfields and glaciers on an annual basis can be a useful technique to track changes and reductions in these areas (T. Nelson and N. Coops pers. comm.). Although the science associated with tracking these features efficiently is emerging, recently there have been some examples where applying remote sensing has proven effective and may have direct utility in operationalizing this indicator in the protocol. These include: (i) successfully assessing decadal changes in ice fields across BC using Landsat imagery by Bolch et al. (2010) (see Western Canadian Cryosphere Network for ongoing monitoring and research around changes to glaciers Bolch and other researchers [Anon 2010]), and annual change

measurements of snowpacks (Farmer et al. 2010). Using these techniques along with statistical methods such as “modified staircase” designs (Walters et al. 1998) may prove useful in quantitatively tracking changes and improving certainty around trends.

Flow sensitivity modeling. Recently an extensive provincial overview analysis, conducted by a fish hydrology specialist in the BC MOE, has identified regions of the province that are considered flow sensitive. The first of its type, using data collected from the provincial hydrometric network and methods modified from Tennant (1976), flow sensitivity (for both summer and winter) has been assessed and mapped for the entire province (R. Ptolemy, pers. comm.). Furthermore, the model outputs have been supported by many local validations and links to hydrologic geometry (R. Ptolemy, pers. comm.). This information can be used as an GIS overlay to identify provincial watersheds that may be at increased risk from climate change effects exacerbating low flow events.

Watershed hydrogeomorphic vulnerability modeling. In the future, hydrogeomorphic models may serve as good indicators of risk tied to climate change; however this form of modeling appears to be coarse and requires refinement. The complex topography and climate variability represented in BC (Moore et al. 2011), along with the inability to down scale and apply continental or regional climate change models to the landscape or watershed level, adds an additional complicating factor in developing hydrogeomorphic vulnerability models. Nevertheless, Moore et al. (2011) recently developed a model that “appears” to accurately distinguish between watershed hydrologic regimes at a small scale that are either: pluvial (e.g. rain dominated, coastal, etc.), melt-dominated (e.g. mountainous areas with accumulations of ice and snow), and hybrid (e.g. transitional areas between the former and latter such as the coast range). The model’s ability to distinguish between these hydrologic regimes allows analysts to associate known flow sensitivity characteristics such as those used in the provincial WAP (MOF 1999/2001) to the three watershed types, helping refine predictive responses linked to climate change and land use patterns (Moore et al. 2011).

Climate change forest disturbances. Impacts to forest health linked to climate change are becoming evident around the world (Allen et al. 2010) as well as here in BC (Stahl et al. 2006; Woods et al. 2005). Where forest disturbance and mortality can be shown to be attributed to climate change (e.g. Stahl et al. 2006 and Woods et al. 2005) these can be identified and tracked using GIS. Although the determination process of affected areas will be the same, doing so can serve two purposes: (i) show the magnitude of climate change associated with forest-disturbance; and (ii) better inform calculations of peak flow hazard using standard hydrological equivalent clear cut area (ECA). The magnitude of forest disturbance relative to the other areas in the watershed (e.g., to the overall area, or the overall forested land-base, or between anthropogenic disturbances like forest harvesting and those of climate change initiated forest disturbances, etc.) can provide important comparisons for land managers helping them understand the implications of climate change and management activities. When analysed periodically, this information can also be illustrative from a trend monitoring perspective. Additionally, the information can be an important input into peak flow hazard calculations as ECA impacts, regardless of the origin (i.e., natural, anthropogenic, or climate change related). Currently, standard watershed assessments do not necessarily account for naturally occurring

disturbance other than forest fires (WAP 1999/2001). Explicitly accounting for forest disturbances induced by climate change would provide a better measure of risk associated with ECA calculations and potential for peak flow responses.

3.0 Indicators and Benchmarks for Tier I Monitoring and Assessment

3.1 Indicator selection process

The FSW MTWG has been tasked with the final selection of indicators/metrics that could be used for Tier I monitoring of watershed condition and identifying the benchmarks of concern that should be used to inform Tier I assessments. The FSW MTWG has sought 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). Key characteristics of natural, healthy watersheds were identified by the FSW MTWG to guide indicator selection:

- Sediment production and transport at natural levels
 - Landslide rates similar to natural rate
 - Minimal number of 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 stream channel functioning
 - Intact riparian structure
 - Natural aquatic thermal conditions
 - Regular and consistent short and long term LWD contributions
- Minimal cumulative risk of road related impacts
- Unrestricted access of fish to a watershed's stream network

Figure 1 illustrates the process used by the FSW MTWG to structure the discussions of potential indicators/metrics/benchmarks that could capture the characteristics of a healthy watershed and which are also feasible for use by the province in establishing a set of default objectives for FSWs and other watersheds of concern.

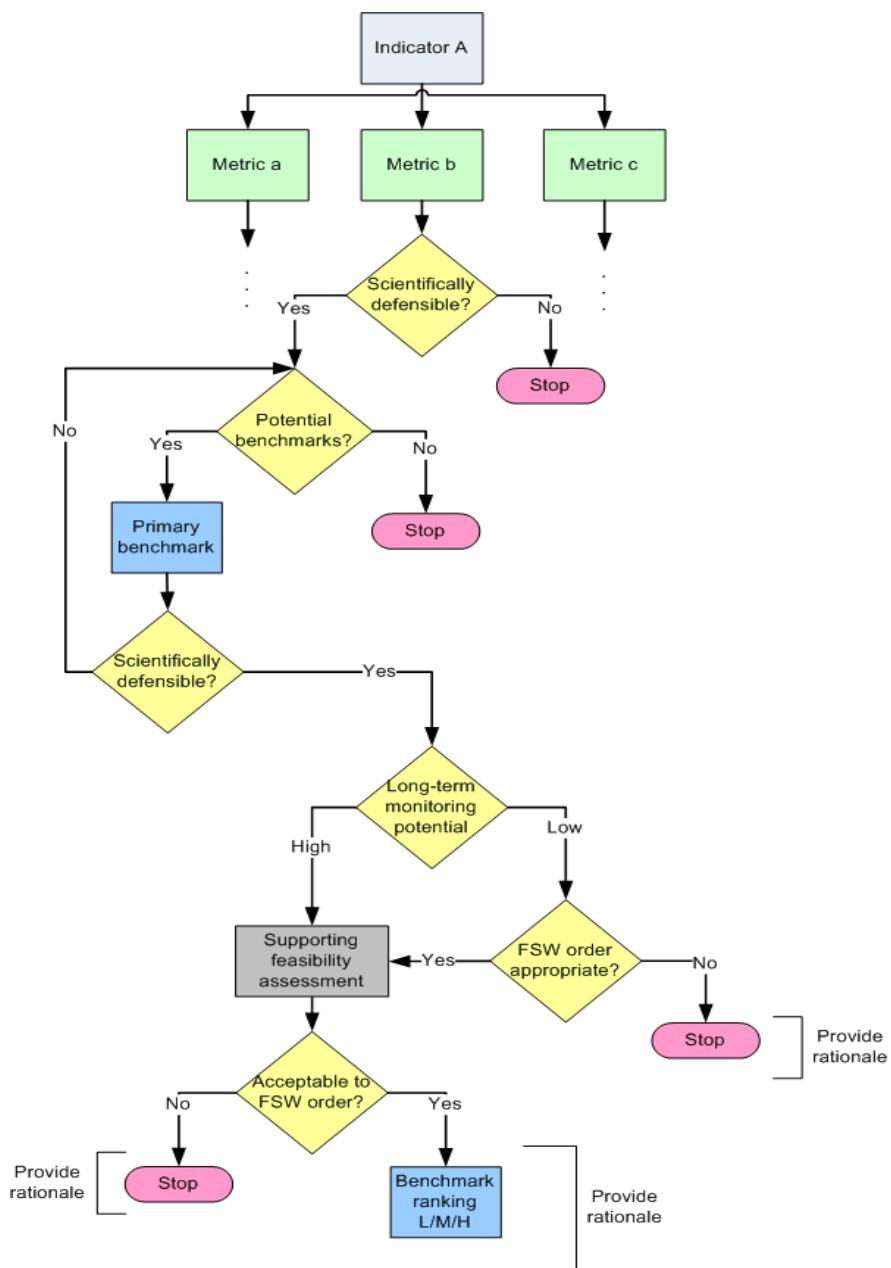


Figure 1 Flow chart of FSW indicator, metric, and benchmark vetting process that could be used for defining Tier I watershed monitoring objectives and setting associated FSW orders.

3.2 Indicator and metric rationale

The list of potential indicators and metrics/benchmarks for monitoring FSWs and other watersheds of concern suggested by the FSW MTWG is provided in [Table 1](#). Summaries of agency data sources that could inform these metrics are provided in [Table 2](#) (general across indicators) and [Table 3](#) (indicator/metric specific). Practical assessments of the data to inform

Tier I indicators (i.e., contacts, current/future data availability, data maintenance, cost, spatial extent/resolution, temporal extent/frequency of updates) are provided in Appendix A.

Proposed benchmarks that have been identified by the FSW TMWG for Tier I assessments are intended to safely maintain the acceptable characteristics of a healthy watershed. As FSWs (or other provincially designated watersheds) have a higher degree of conservation interest these benchmarks are purposely set at low values relative to past provincial WAP risk benchmarking. The FSW MTWG has defined default benchmarks for each Tier 1 indicator that would then be applied broadly across watersheds in the absence of more complete/detailed data for a watershed. Licensees would then have the option to collect the necessary information to support alternative benchmarks that they feel are more specific/appropriate to their particular watershed/management area and argue their case in this regard. Similarly, it is expected that as Tier I monitoring by the province of FSWs and other watersheds of concern occurs over time, these default benchmarks will be validated and/or revised as required. The initial listing of Tier I indicators, metrics, and benchmarks provided in [Table 1](#) is also expected to undergo some general changes as the FSW MTWG continues with identification of additional indicators for incorporation into broader assessment of watershed risk and with the refinement of protocols that can be used for calculating remote sensed metrics.

Table 1

Suite of potential indicators, metrics, and suggested benchmarks for Tier I watershed monitoring.

Characteristics of a healthy watershed	Indicators	Metrics	Suggested low risk benchmark(s) for objectives setting and monitoring for FSWs and other identified watersheds	Supporting references
<ul style="list-style-type: none"> - 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/km ²) (applicable to interior watersheds only)	MOF 1995a
Natural low flow regimes	Hydrologic stability/maturity	% of watershed with second	Net Equivalent Second Growth Area (ESGA) ¹ (forest stands 25-75 years) not to exceed 40% of forested area of watershed	Jones and Post 2004 Perry 2007

¹ Net Equivalent Second Growth Area (net ESGA) = ESGA – ECA (proposed metric for further development by the FSW MTWG)

Characteristics of a healthy watershed	Indicators	Metrics	Suggested low risk benchmark(s) for objectives setting and monitoring for FSWs and other identified watersheds	Supporting references
		growth forest		Derek Tripp, pers. comm.
Natural riparian and channel function <ul style="list-style-type: none"> 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), Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by government agencies.	
	Equivalent Clear-Cut Area	Vegetation Resource Index (VRI), Freshwater Atlas, FSW Boundary Delineations	Attributes of VRI index allow for the calculation of regeneration growth for the ECA. Both sources are free and maintained by BC MOE.	
	Road Density for Entire Sub-Basin	Digital Road Atlas (DRA), Vegetation Resource Index (VRI), Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by BC MOE.	
	Road Density Above H60 Line	Digital Road Atlas (DRA), Digital Elevation Model (DEM), Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by government agencies. DRA is updated annually.	
	Road Density on Erodible Soils	Digital Road Atlas (DRA), Soil Landscapes of Canada, Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by government 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 maintained by government 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 maintained by government 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 maintained by government agencies.	
	Road Density for Entire Sub-Basin	Digital Road Atlas (DRA), Vegetation Resource Index (VRI) , Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by government agencies.	
	Roads on Unstable Slopes	Digital Road Atlas (DRA), Digital Elevation Model (DEM), Soil Landscapes of Canada, Freshwater Atlas, FSW Boundary Delineations	Reliable and best available data sources for included monitoring metrics. Available free of charge, and maintained by government 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 maintained by government 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 maintained by government 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 maintained by the BC MOE.	For WAP analyses we assume that streams are not protected by buffers. In some cases there will be buffers, 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	For WAP analyses we assume that fish-bearing streams are not protected by buffers. In some cases there will be buffers, which should be noted. Cross-reference may be required on a case-by-case

Indicator	Metric	Preferred data source	Rationale	Additional comments
			maintained by the BC MOE.	scenario of smaller stream reaches.
	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 maintained by the BC MOE.	A buffer (minimum 100m) will need to be placed along all stream reaches in order to identify the riparian zone for this metric.
Mass Wasting	Density of Landslides in the Watershed	Landsat, SPOT, Orthophotos, Freshwater Atlas, 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 maintained by government 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 maintained by government 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), Freshwater Atlas, 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 (%)			

3.4 Roll-up and overall watershed risk categorization

Watershed assessments are implemented to improve forest practices, planning policies, adaptive management, and risk mitigation (Pike et al. 2007). The information provided from an assessment helps to strengthen management of watershed regions, which will influence aquatic productivity and health, water quality, and riparian status. When risk 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 Mayhood 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 individual or combined hazard indices act as an “alarm signal,” showing that something within the impact category was not functioning as anticipated or desired (Gustavson and Brown 2002). High risk ratings are expected to trigger water and land resource managers to investigate the issues within the specified watershed, and to develop appropriate strategies as needed to mitigate/resolve any adverse impacts.

Risk scores for individual indicators will be rolled up within the Tier I assessment procedure to provide an overall assessment of watershed risk (i.e., overall low risk (green), moderate risk (yellow), high risk (red) classification). The final rule set to be applied across the individual risk scores for establishing overall watershed risk ratings is still to be determined through further deliberations of the FSW MTWG (i.e., the actual number (%) of individual indicator risk scores that must be rated “green” for the overall watershed score to be coded “green”, etc.). Research undertaken by Sawyer and Mayhood (1998) indicated different potential risk to watershed functioning relative to monitoring indicators. They suggested that high risk scores for: 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 had relatively high potential impact. High risk scores for Peak flow index, Road density for the entire sub-basin, and Portion of fish-bearing streams logged to the banks alternatively were found to represent only moderate potential impact on a watershed. This analysis suggests that some differential weighting of Tier I indicators may be appropriate before rolling-up individual indicator risk scores into an overall assessment of watershed risk. Potential differential weighting of individual indicators for overall Tier 1 watershed assessments is a topic that will be explored by the FSW MTWG.

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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 Erodeable Soils <100m from a Stream	
	Stream Banks Logged on Slopes >60%	
Riparian Buffer	Density/ Number of Stream Crossings	
	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/ilmbroad>

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 Fisheries Sensitive Watershed (FSW) boundaries

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.