Watershed Status Evaluation Protocol (WSEP): Tier 1 watershed-level fish values monitoring 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 responsible for the Wildlife Act is authorised to designate a watershed as a Fisheries Sensitive Watershed (FSW). To qualify as an 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 an 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. 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, sixty FSWs have been designated by the province and there are plans to continue 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 working to develop a comprehensive multi-tiered (i.e., remote sensed-based and field-based) monitoring framework for FSWs and other provincial watersheds of high priority. A series of reports in 2008 and 2009 (Wieckowski et al. 2008; Wieckowski et al. 2009; Pickard et al. 2009) provided a conceptual framework for monitoring FWSs, as well as laying out a work plan to pilot the FSW monitoring framework. The proposed monitoring framework coupled with the 2009 work plan provided the foundation for pilot testing of data collection and analysis for Tier 1 (GIS-based) and Tier 2 (field-based) data collection and analysis. This original work focused on FSWs has evolved into the Watershed Status Evaluation Protocol (WSEP) (described in Porter et al. 2019) which has application to any watershed in the province of high conservation priority. Testing of the WSEP has now been undertaken in designated FSWs throughout various regions of British Columbia.

1.2 Report purpose

The purpose of this document is to provide the scientific rationale for the Tier 1 (GIS-based) component of the WSEP (see Porter et al. 2019). This document can be broken down into three sections. The first section of the document provides an overview of the province's existing formal Watershed Assessment Procedure (WAP) and provides much of the initial thinking and structure around the GIS-based WSEP Tier 1 procedure for monitoring watersheds. The intent of WSEP Tier 1 monitoring is to provide a coarse "WAP-lite" approach to determining potential threats to watershed condition that can be effectively applied broadly across the province's watersheds, using readily available provincial GIS layers/datasets. The second section identifies the GIS-based indicators used for WSEP Tier 1 monitoring, the rationale behind selecting each of the indicators and their respective metrics for comparison, 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 1 indicators. Work in this regard will be complimentary to ongoing indicator development and application by the Provincial Aquatic Ecosystems Technical Working Group (PAETWG) (PAETWG 2017) in support of the province's Cumulative Effects Framework.

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 primary 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 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 heavily influenced by the cumulative effects of landuse activities which can be measured by indicators such as road density, riparian disturbance, stream crossing density, landslide occurrence, equivalent clear-cut area, surface erosion, etc. Watershed 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. While WAPs are traditionally focused on forestry-related issues, the indicators and impact categories assessed can also relate to impacts caused by other land use activities or by natural disturbance events such as fire or forest insect attack.

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 WSEP 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 primarily on readily and broadly available provincial GIS datasets/layers. This data is intended to inform consistent assessments of the province's FSWs (and other high priority watersheds of concern) on a regular repeat basis (Pickard *et al*. 2009). WSEP indicators are also intended to both inform and build upon parallel processes for development of aquatic indicators within the province's Cumulative Effects Framework.

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. 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 indicators 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 indicators 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 indicator 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 indicators when the impacts of timber harvesting within watersheds are evaluated (BC MOF 2001). Table A2.1 in MOF *(*2001*)* highlights the range of assumptions that can be considered 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). Porter et al. (2019) provides different estimated snowpack recovery factors resulting from forest regeneration growth that can be used in interior vs. coastal watersheds (recovery factors for interior watersheds

derived from Winkler and Boon 2015; recovery factors for coastal watersheds are derived from Hudson and Horel 2007).

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 H_{60} line** is defined as the elevation above which 60% of the watershed lies, the H_{60} 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 H_{60} line (or other agreed-to contour elevation representing the snow sensitive area in a watershed), because roads located on steeper, high elevation areas 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 indicators 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 indicator 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. Detailed soil maps that accurately define erodible soils are currently only available for a limited number of watersheds in British Columbia (D. Filatow, pers. comm.) (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 are currently only available for a limited number of watersheds in the province (D. Filatow, pers. comm.). 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 once available 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 for instream structure, 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 deteriorate. 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 indicators for an overall assessment of risk to the riparian zone within a watershed, with the second indicator 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 (or otherwise disturbed)**

2. **Portion of fish-bearing streams logged (or otherwise disturbed)**

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 coarse and 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 indicators 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 (which is currently not done) 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 potentially 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% (or >50% for watersheds in Haida Gwaii as indicated by PAETWG 2017). This criterion has traditionally been used in BC (R. Guthrie pers. comm.) although with recognition that the potential impacts in regard to slope will be different on the coast vs. the interior. Until provincial-scale scale terrain stability maps become available for broad use road densities on slopes >60% (or 50%) 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 (or otherwise disturbed) on steep slopes** Logging or other development disturbance on steep slopes greatly compromises the stability of ground surfaces within a watershed. The extent of logging around streams on steep slopes >60% (or 50% on Haida Gwaii) 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% (or 50%) 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).

2.3 Additional indicators for Tier 1 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 indicators into these impact categories, or even develop additional impact categories, within an expanded version of WSEP Tier 1 watershed monitoring. Additional monitoring indicators that may be explored within continued iterative development of WSEP Tier 1 monitoring nclude (but are not limited to):

- **Habitat Accessibility/Connectivity.** Land use 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 2 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 (see Jones and Post 2004; Perry and Jones 2016). The FSW MTWG has begun exploring development of a novel Equivalent Second Growth Area (ESGA) indicator that could potentially be incorporated into WSEP Tier 1 watershed assessments in this regard. This indicator would be intended to reflect the

maturity of any particular watershed and its presumed hydrologic stability in regard 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., mining, 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). Determining relevant indicators to use in regard to additional monitoring of land use activities and their associated benchmarks of concern purposes will be an anticipated focus for further evolution of the WSEP Tier 1 monitoring protocol into a more broadly comprehensive assessment of watershed risks and is also a focus of ongoing discussions by the Provincial Aquatic Ecosystems Technical Working Group.

2.4 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 have 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
- Declining 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, drought, and extreme rainfall events
- 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)

Potential indicators that could be used to reflect risk factors associated with climate change-induced impacts include snowfields and glacier extent, flow sensitivity modeling outputs, watershed hydrogeomorphic vulnerability modeling outputs, and climate change-related forest disturbances. Developing remotely-sensed approaches to quantifying climate change indicators merits further investigation in subsequent iterations of the WSEP Tier 1 protocol. Suggested climate change indicators for future WSEP Tier 1 development 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 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 water 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 Cyrosphere 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).

Flow sensitivity modeling. A recent, extensive provincial overview analysis has identified regions of the province that are considered low flow sensitive. Using historical flow data collected from the provincial hydro network and analytical 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 a 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 downscale 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-related forest disturbances. Impacts to forest health linked to climate change (e.g., forest disease, insect attack, etc.) 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., the overall watershed 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 1 Monitoring and Assessment

3.1 Indicator selection process

The FSW MTWG is tasked with selection of indicators that could be used for WSEP Tier 1 monitoring of watershed status and identifying benchmarks of concern that could be used to inform Tier 1 assessments. The FSW MTWG has sought to develop an initial list of indicators and associated indicators/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/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.

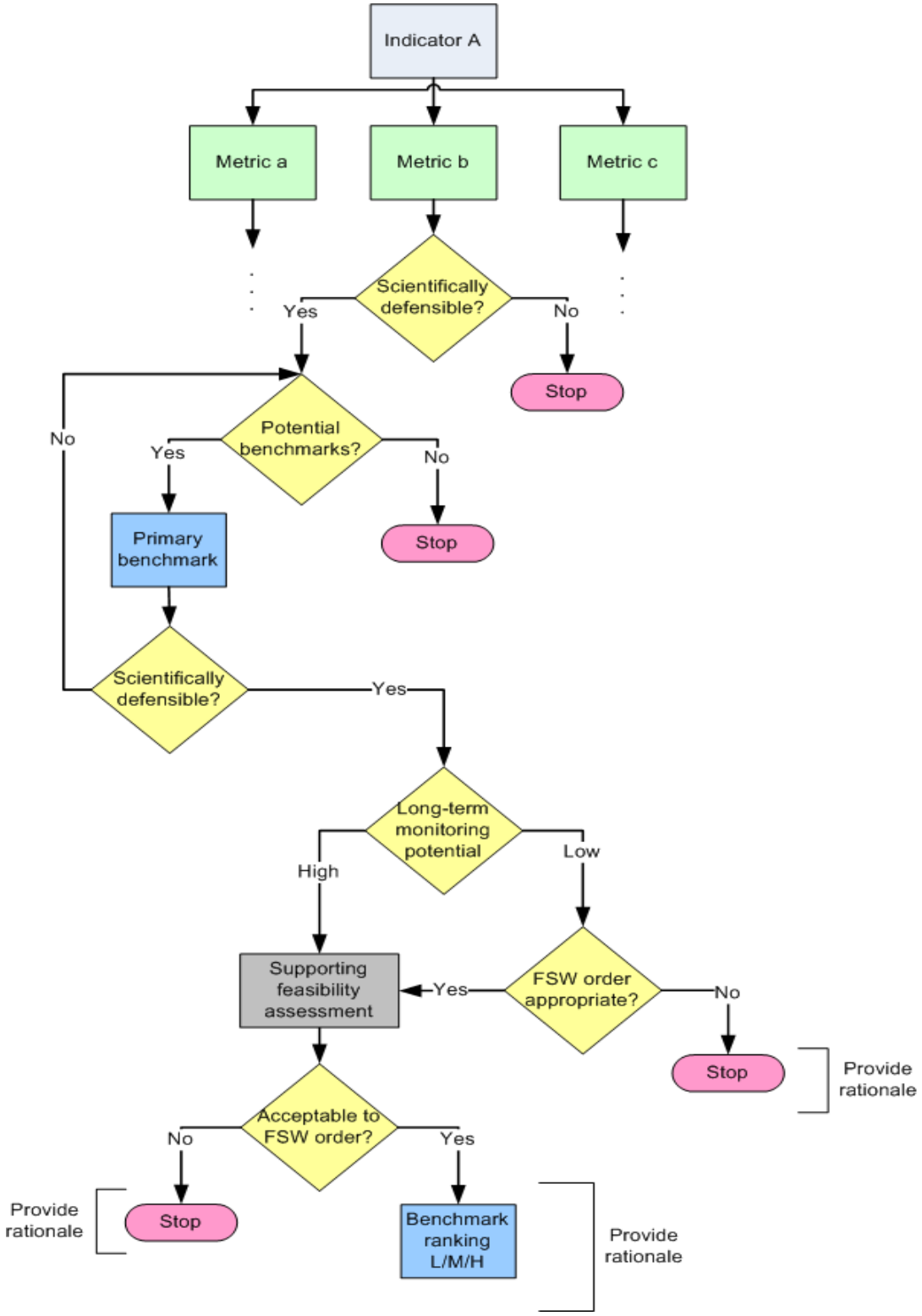

Figure 1 Flow chart of FSW indicator, indicator, and benchmark vetting process that could be used for defining Tier 1 watershed monitoring objectives and setting associated FSW orders.

3.2 Indicator rationales

An initial list of potential indicators and indicators/benchmarks for monitoring FSWs (and other watersheds of high priority concern) suggested by the FSW MTWG is provided in **Table 1**. Summaries of agency data sources that could inform these indicators are provided in **Table 2** (general across indicators) and **Table 3** (indicator specific). Practical assessments of the data to inform Tier 1 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 1 assessments are intended to safely maintain the acceptable characteristics of a healthy watershed (see **Table 1**). As FSWs (or other provincially designated watersheds) have a higher degree of conservation interest these benchmarks are purposely set at lower, risk-adverse values relative to past provincial WAP risk benchmarking exercises. The FSW MTWG has suggested initial default benchmarks for each Tier 1 indicator that could then be applied broadly across watersheds in the absence of more complete/detailed data for a watershed. There would be an expectation that long-term monitoring of FSWs would provide a basis for changing FSW default benchmarks if these were found to be insufficient to protect watershed condition or alternatively unduly restrictive on licensee activities. Licensees would then have the option to collect the necessary information to support alternative benchmarks that may be more specific/appropriate to their particular watershed/management area and argue their case in this regard. The initial listing of Tier 1 indicators, indicators, and benchmarks provided in **Table 1** is also expected to undergo general changes as the FSW MTWG continues with identification of additional indicators for incorporation into broader assessment of watershed risk and also with the refinement of protocols used for calculating remote sensed indicators.

Table 1 Suite of potential indicators, metrics, and suggested initial benchmarks to consider for WSEP Tier 1 monitoring of Fisheries Sensitive Watersheds (FSWs) and other provincially designated high priority watersheds.

Characteristics of a healthy watershed	Potential Indicators	Metrics	Initial low risk benchmark(s) suggested by FSW TMWG for objectives setting and monitoring of FSWs	Supporting references
Sediment production and transport at natural levels: • Landslide rates similar to natural rate • Minimal stream crossings • Low road densities on unstable slopes	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
	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
	Roads	# of stream crossings	• Density of stream crossings across the watershed to remain below the WAP-based moderate risk criteria (0.32/km2 – interior watersheds; 0.8/km2 – 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
	Roads on unstable slopes	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
Peak flow and timing don'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 at high elevation	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

Characteristics of a healthy watershed	Potential Indicators	Metrics	Initial low risk benchmark(s) suggested by FSW TMWG for objectives setting and monitoring of FSWs	Supporting references
Natural low flow regimes	Hydrologic stability/maturity	% of watershed with SG forest	• Net Equivalent Second Growth Area (ESGA)1 (forest stands 25-75 years) not to exceed 40% of forested area of watershed ***(research level, exploratory indicator; not yet developed)***	Jones and Post 2004 Perry and Jones 2016 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	• Overall 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	% of fish habitat accessible	• Maintain access to all potential fish habitat	Tripp et al. 2009 MOE 2011
	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	MOE 2011

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

3.3 Data sources

Table 2 Summary of available agency data sources to inform WSEP Tier 1 monitoring.

Data source	Organisation	Indicator
BC Cumulative Effects (BCCE) Consolidated Roads (DRA, TRIM, FTEN, OGC, RESULTS in-block road)	FLNRORD	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Vegetation Resources Inventory (VRI)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Freshwater Atlas (FWA) Assessment Watersheds	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
EAUBC Ecoregions	DataBC: BCGW	Peak Flow, Surface Erosion,
Freshwater Atlas (FWA): Stream Networks	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Digital Elevation Model (DEM)	GeoBase	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
LandSat satellite imagery	DataBC: WMS	Mass Wasting
SPOT satellite imagery	DataBC: WMS	Mass Wasting
Orthophotos	DataBC: WMS	Mass Wasting
Soil Landscapes of Canada (SLC V2.2)	Agriculture and Agr-foods Canada	Mass Wasting
Research layer for fish habitat and fish passage obstructions	MOE (Richard Thompson – contact)	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Reporting Silviculture Updates and Land Status Tracking System (RESULTS)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Consolidated Cutblocks (FAIB)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
BCCE Provincial Development layers	FLNRO:	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Baseline Thematic Mapping (BTM1)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Tantalis Rights of Way	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Fire Perimeters (current and historical)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Private Land (FOWN)	DataBC: BCGW	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting
Fisheries Sensitive Watersheds (FSW) boundary delineations	FLNRO (Lars Reese-Hansen - contact)	Peak Flow, Surface Erosion, Riparian Buffer, Mass Wasting

Table 3 List of WSEP Tier 1 indicators and their respective data sources.

Indicator	Indicator	Preferred data source	Rationale	Additional comments
Peak Flow	Peak Flow Index	FAIB Consolidated Cutblocks, BCCE Consolidated Roads, VRI, RESULTS, BCCE Development layers, FOWN, DEM, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by government agencies. FAIB Consolidated Cutblocks layer is updated annually.	
	Equivalent Clear Cut Area	FAIB Consolidated Cutblocks, VRI, RESULTS, FWA streams, FOWN, FWA assessment units, FSW boundary delineations	Attributes of VRI allow for the calculation of regeneration growth for the ECA. FAIB Consolidated Cutblocks layer is updated annually.	
	Road Density for Entire Sub-Basin	BCCE Consolidated Roads, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE.	
	Road Density above H_{60} Line	BCCE Consolidated Roads, DEM, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	H_{60} or else alternative contour line considered to better delineate the snow sensitive zone for a watershed
	Road Density on Erodible Soils	BCCE Consolidated Roads, SLCV V2.2, FWA assessment units, FSW boundary delineations	best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	SLC V2.2 is best currently available source for determining surficial properties at this time. Does not provide full provincial coverage, however. Look for future deliverables from the province in this regard (Appendix A).
Surface Erosion	Road Density <100m from a Stream	BCCE Consolidated Roads, FWA streams, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE.	
	Road Density on Erodible Soils <100m from a Stream	BCCE Consolidated Roads, FWA assessment units, FWA streams, SLCV V2.2, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	SLC V2.2 is best currently available source for determining surficial properties at this time. Does not provide full provincial coverage, however. Look for future deliverables from the province in this regard (Appendix A).
	Density/ Number of	BCCE Consolidated Roads, FWA	Best available data sources for deriving	Research layer with stream crossing

Indicator	Indicator	Preferred data source	Rationale	Additional comments
	Stream Crossings	streams, FWA assessment units, MOE research layer for fish habitat and fish passage obstructions, FSW boundary delineations, EAU BC	indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	summaries available from Richard Thompson MOE
	Road Density for Entire Sub-Basin	BCCE Consolidated Roads, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	
	Roads on Potentially Unstable Slopes	BCCE Consolidated Roads, DEM, SLC V2.2, FWA assessment units, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BC BCCE Consolidated Roads layer is available upon request.	SLC V2.2 is best currently available source for determining surficial properties at this time. Does not provide full provincial coverage, however. Look for future deliverables from the province in this regard (Appendix A).
	Stream Banks Logged on Steep Slopes	FAIB Consolidated Cutblocks, VRI, FWA streans, FWA assessment units, DEM, RESULTS, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. FAIB Consolidated Cutblocks layer is updated annually.	
Riparian Buffer	Road Density <100m from a Stream	BCCE Consolidated Roads, FWA streams, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	
	Portion of Streams Logged or disturbed	FAIB Consolidated Cutblocks, VRI, BCCE Development layers, FWA streams, Fire perimeters (current and historic) FWA assessment units, RESULTS, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	For general analyses we assume that logged streams are not protected by riparian buffers on the ground. 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	FAIB Consolidated Cutblocks, VRI, FWA streams, MOE research layer for fish habitat and fish passage obstructions, RESULTS, FSW boundary delineations	Richard Thompson's (MOE) research model for fish habitat 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	For general analyses we assume that logged 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-

Indicator	Indicator	Preferred data source	Rationale	Additional comments
			time. Also free of charge and maintained by the BC MOE.	by-case scenario of smaller stream reaches. Research layer with modeled fish habitat available from Richard Thompson (MOE).
Mass Wasting	Density of Landslides in the Watershed	Landsat, SPOT, orthophotos, FWA assessment units, 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 better determine landslide susceptibility based upon surficial geology and material. Orthophotos are costly.
	Density of Roads on Unstable/ Potentially Unstable Terrain	BCCE Consolidated Roads, DEM, SLC V2.2, FSW boundary delineations	Best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. BCCE Consolidated Roads layer is available upon request.	SLC V2.2 is best currently available source for determining surficial properties. Does not provide full provincial coverage, however. Look for future deliverables from the province in this regard (Appendix A).
	Portion of Streambanks Logged (or otherwise disturbed on steep slopes (>60% generally, 50% on Haida Gwaii)	FAIB Consolidated Cutblocks, VRI, FWA streams FWA assessment units, DEM, RESULTS, FSW boundary delineations	Reliable and best available data sources for deriving indicator. Available free of charge and maintained by BC MOE. FAIB Consolidated Cutblocks layer is updated annually.	

3.4 Roll-up of indicators for 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 values of concern, the results of a WAP can inform scientific recommendations for action. While different monitoring indicators may be used by different agencies or in different regions it is common to follow a general approach where values for the monitoring indicators used are standardized into values between 0 and 1, evaluated within each indicator category and then combined together/rolled-up to arrive at a cumulative hazard index score (Sawyer and Mayhood 1998). The hazard indices are then interpreted using multiple 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 is not functioning as anticipated or desired (Gustavson and Brown 2002). High risk ratings are expected to trigger water and land resource managers to investigate more closely the issues within the specified watershed, and to develop appropriate strategies as needed to mitigate/resolve any adverse impacts.

Risk scores for individual indicators could be rolled up within the WSEP Tier 1 assessment procedure to provide an overall assessment of watershed risk (i.e., overall low, moderate, or high-risk classifications). The final rule set to be applied across the individual risk scores for establishing overall watershed risk ratings (i.e., the actual number or percentage of individual indicator risk scores that must be rated "low" for the overall watershed score to also be rated "low", etc.) is still to be determined through further deliberations of the FSW MTWG. Research undertaken by Sawyer and Mayhood (1998) indicated different potential risks to watershed functioning relative to standard WAP monitoring indicators. They suggested that high risk scores for: Road Density <100m from 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 higher potential impact. High risk scores for the indicators 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 more moderate risks of potential impacts on a watershed (Sawyer and Mayhood 1998). Their analysis suggests that some differential weighting of WSEP Tier 1 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 possible cumulative impact roll-ups within WSEP Tier 1 watershed assessments is a topic that will be explored further by the FSW MTWG.

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Appendix A – Practical Assessment Worksheets

Data Source: *Fisheries Sensitive Watersheds*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
All	All	Layer will be used to delineate all Fisheries Sensitive Watershed (FSW) boundaries and to delineate any potential subunits within the FSWs that are defined as specific management areas

Description of Data Source
The dataset contains approved legal boundaries for fisheries sensitive watersheds.

Data Source:

Contact #1: Tyson Carswell (Ministry of Environment and Climate Change Strategy)
Telephone: 250 698-4056
Email: Tyson.Carswell@gov.bc.ca

Contact #2: Lars Reese-Hansen (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 356-5341
Email: Lars.ReeseHansen@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/fisheries-sensitive-watersheds

Dataset Name: WHSE_WILDLIFE_MANAGEMENT.WCP_FISH_SENSITIVE_WS_POLY

Data/Feature Criteria: A Fisheries Sensitive Watershed (FSW) is a mapped area with specific management objectives intended to guide development activities which may adversely impact important fish values in the FSW.

Data Availability: Available for public access.

Data purchase / collection cost: Free.

Data / indicator maintenance: Data Custodian Organization: ECOINFO - Ecosystem Information Section (Ministry of Environment and Climate Change Strategy)

Spatial extent / resolution: This dataset includes approved legal boundaries for all fisheries sensitive watersheds (FSWs) in British Columbia and any potential subunits within the FSWs that are defined as specific management areas. Additional FSW's are updated and added frequently to expand the extent of FSW coverage throughout the province.

Temporal extent / frequency: Database published 2011-03-09. Last modified 2018-02-14. Resource Status is ongoing. Resource update cycle: daily.

Data Source: *BC Cumulative Effects (BCCE) Consolidated Roads (DRA, TRIM, FTEN, OGC, and RESULTs in-block roads)*

Summary table of indicators informed by the data source:

Impact Categories	Indicators
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
This DRAFT dataset was created specifically for cumulative effects analysis for the Provincial Cumulative Effects Project. It is intended for strategic level analysis of roads and should not be considered as positionally accurate or used for navigation.

Data Source:

Contact: Rob Oostandler (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 398-4604
Email: Rob.Oostlander@gov.bc.ca

Data/Feature Criteria: This dataset contains line work from many sources, some representing built roads and some representing road tenures. It may contain duplicates of some roads that are not within the integration distance (7m), roads that were never built and roads that are now overgrown or impassible for some other reason. It may also be missing roads. All road features in the layer would be applied.

Data Availability: Available upon request to the BC Cumulative Effects GIS Coordinator.

Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: TBD

Spatial extent / resolution: Full provincial coverage.

Temporal extent / frequency: Initial publication: 2015. Revised 2017.
Unknown updates. Information available upon request.

Data Source: *Harvested Areas of BC (Consolidated Cutblocks)*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
Peak Flow	Peak Flow Index	
	Equivalent Clear-Cut Area	
Surface Erosion	Stream Banks Logged on Steep Slopes	
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 Steep Slopes	

Description of Data Source
This is spatial data depicting the cut block boundaries and estimated year of harvest for crown land cut blocks within British Columbia.

Data Source:

Contact #1: Tim Salkeld (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 387-3650
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Telephone: 250 953-3838
Email: Iaian.McDougall@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-

Dataset Name: WHSE_FOREST_VEGETATION.VEG_CONSOLIDATED_CUT_BLOCKS_SP

Data/Feature Criteria: This layer is created from the provincial Forest Cover, from The RESULTS Reporting system, from Forest Tenures applications and from satellite imagery using change detection processes. It represents the gross opening area when derived from forest cover, RESULTS or Forest Tenure data and does not exclude non-harvested 'reserved' areas. Satellite image change detection represents the area harvested each year and may not be the entire cut block area and will not include non-harvested 'reserve' areas.

Data Availability: Available for public access.

Data purchase / collection: Free.

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

Spatial extent / resolution: Full provincial coverage.

Temporal extent / frequency: Initial publication: 2016-07-21. Last modified 2018-09-26. This data is reasonably accurate for the last 10 years, and usable for the last 20 years. It is unreliable for anything older than this. Resource status is ongoing. Unknown updates. Information available upon request.

Data Source: BC Cumulative Effects (BCCE) *Provincial Development (custom 'Development' layer)*

Summary table of indicators informed by the data source:

Impact Categories	Indicators
Peak Flow	Peak Flow Index
Riparian Buffer	% of streams logged or disturbed

Description of Data Source

This DRAFT dataset was created specifically for analysis of landscape disturbances for the Provincial Cumulative Effects Project. It is intended for strategic level analysis.

Data Source:

Contact #1: Malcolm Gray (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 952-6573
Email: Malcolm.Gray@gov.bc.ca

Contact #2: Rob Oostandler (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 398-4604
Email: Rob.Oostlander@gov.bc.ca

Data/Feature Criteria: This layer contains combined information on a large suite of human disturbances and land cover classifications from various sources: Tantalis, OGC, and BTM (Baseline Thematic Mapping), FAIB Consolidated Cutblocks), Fire perimeters - current and historic (Wildfire Management Branch), VRI (for insect disturbance). Human disturbance types and land cover classifications in the dataset include: Transmission, Railway, Oil and Gas, Tantalis Rights of way, Seismic, Harvested since 1995, Harvested pre 1995, Mining, Urban, Urban Mixed, BTM Logged, Agriculture, Glaciers and Snow, Alpine, Sub Alpine, Barren, Fresh Water, Salt Water, Wetlands and Estuaries, Shrubs, Forest Land, Range/Grassland, Fires (Current and Historic fire perimeters), Insect disturbance.

Data Availability: Available upon request to the Resource Management Objectives Branch of Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: TBD

Spatial extent / resolution: Full provincial coverage.

Temporal extent / frequency: Initial publication: 2015.
Unknown updates. Information available upon request

Data Source: *Vegetation Resources Inventory (VRI)*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
Peak Flow	Peak Flow Index	
	Equivalent Clear-Cut Area	
Surface Erosion	Stream Banks Logged on Steep Slopes	
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 Steep Slopes	

Description of Data Source

A composite table comprising the polygon table attributes joined to the attributes from the non-veg, non-tree, land cover component, map label and history linkage tables. indicating an area on the BC land base with Vegetation Inventory attribution.

Data Source:

Contact #1: Marc Rousseau (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 250 828-4426
Email: Marc.Rousseau@gov.bc.ca

Contact #2: Edward Fong (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 778 974-2638
Email: Edward.Fong@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/vegetation-composite-polygons

and

https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/data-management/standards/vegcomp_poly_rank1_data_dictionary_draft40.pdf (VRI Data Dictionary)

Dataset Name: WHSE_FOREST_VEGETATION.VEG_COMP_POLY

Data/Feature Criteria: This SDE layer coverage contains vegetation cover from the Ministry of Forests. Attribute information is also maintained in this table. Vegetation Cover is comprised of

spatial layers for the collection, manipulation and production of forest inventory data, which has accompanying textual attributes.

Data Availability: Available for public access.

Data purchase / collection: Free.

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

Spatial extent / resolution: Full provincial coverage.

Temporal extent / frequency: Initial publication 2014-12-15. Last modified 2018-11-27. Resource Status is ongoing. Resource update cycle: annually.

Data Source: *RESULTS Openings*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
Surface Erosion	Stream banks Logged on Steep Slopes	
Riparian Buffer	Riparian Forest Logged (%)	
	Portion of Streams Logged	
	Portion of Fish-Bearing Streams Logged	
Mass Wasting	Portion of Stream banks Logged on Steep Slopes	

Description of Data Source

An opening's disturbance and silviculture activities reported into the RESULTS database. This is part of the Silviculture and Land status Tracking dataset, which includes tracking harvesting and silviculture obligations on Crown Land

Data Source:

Contact #1: Caroline MacLeod (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 819 564-4857
Email: Caroline.MacLeod@gov.bc.ca

Contact #2: Matt LeRoy (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 778 974-2405
Email: Matthew.Leroy@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/results-activity-treatment-units

Dataset Name: WHSE_FOREST_VEGETATION.RSLT_ACTIVITY_TREATMENT_SVW

Data/Feature Criteria: Most activities are within opening boundaries with the exception of broadcast treatments. An opening may have more than one activity associated with it. Activities may also overlap each other. Reporting of disturbance and silviculture attribute information is a mandatory requirement while the map is optional.

Data Availability: Available for public access.

Data purchase / collection: Free.

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

Spatial extent / resolution: Full provincial coverage.

Temporal extent / frequency: Initial publication 2011-10-12. Last modified on 2017-11-03 on 11/27/2003. Resource status is completed. Daily update cycle.

Data Source: *1:20,000 Freshwater Atlas (FWA): Assessment Watersheds and Stream Network*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
Surface Erosion	Road Density <100m from a Stream	
	Road Density on Erodible Soils <100m from a Stream	
	Stream Banks Logged on Steep Slopes	
	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 Steep Slopes	

Description of Data Source

FWA Assessment Watersheds are 1:20K mesoscale aquatic units based on groupings of fundamental watersheds using FWA watershed code and local code, with a target size of between 2,000ha and 10,000ha.

The FWA Stream Network consists of flow network arcs (observed, inferred and constructed).

Data Source:

Contact: Carol Ogborne (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 819 564-4857
Email: Carol.Ogborne@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-assessment-watersheds

and

https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-stream-network

Dataset Name: WHSE_BASEMAPPING.FWA_ASSESSMENT_WATERSHEDS_POLY
WHSE_BASEMAPPING.FWA_STREAM_NETWORKS_SP

Data/Feature Criteria: FWA Stream Network contains no banks, coast or watershed boundary arcs. Directionalized and connected. Contains hierarchical key and route identifiers. All FWA

streams are used including intermittent and indefinite classifications. Consistency and confidence in these classifications may vary across the province, thus cannot be reliably separated at this point.

Data Availability: Available for public access.

Data purchase / collection: Free.

Data / indicator maintenance: DataBC.

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

Temporal extent / frequency: FWA Assessment Watersheds: Initial publication: 2011-03-09. Last modified 2018-11-27. Resource status is ongoing. Updated as needed.

FWA Stream Network: Initial Publication: 2011-03-09. Last modified 2018-11-27. Resource status is ongoing. Updated as needed.

Data Source: *Provincial Fish Habitat Model and associated Modelled Stream Crossings (research layers)*

Summary table of indicators informed by the data source:

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

Description of Data Source
Modeled fish habitat distribution based on the line layer for the 1:20K Freshwater Atlas Stream Network.

Data Source:

Contact #1: Craig Mount (Ministry of Environment and Climate Change Strategy)
778 698-4016
Craig.Mount@gov.bc.ca

Contact #2: Richard Thompson (Ministry of Environment and Climate Change Strategy)
Telephone: 250 356-5467
Email: Richard.Thompson@gov.bc.ca

References: N/A.

Dataset Name: Aquatic Habitat Modeling Version 2.X

Data/Feature Criteria: Provides a stream line layer broken down into three levels of modelled fish habitat potential: 1) Observed Fish Habitat, 2) Inferred (modeled) Fish Habitat, and 3) Non-Fish Habit. Other layers available include Modelled Crossing Points. Assessed crossing points can be found in the PSCIS Database which is available through the BC Data Warehouse.

Data Availability: Available upon request (subject to confidentiality agreement).

Data purchase / collection: Free

Data / indicator maintenance: Data Custodian: Craig Mount. Ecosystem Information Section (Ministry of Environment and Climate Change Strategy)

Spatial extent/ resolution: Specific area of interest in British Columbia (as requested). Data based upon the 1:20 000 Freshwater Atlas.

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

Data Source: *Provincial Digital Elevation Model (DEM)*

Summary table of indicators informed by the data source:

Impact Categories	Indicators
Peak Flow	Road Density Above the H60 Line (or another designated contour)
Surface Erosion	Stream Banks Logged on Steep Slopes
Mass Wasting	Stream Banks Logged on Steep Slopes

Description of Data Source

Regularly gridded digital elevation model data set for the Province of British Columbia, derived from break lines, areas and mass points. Provides a three-dimensional representation of the province's terrain that can be used for geoid calculations, terrain modelling, flood simulations and telecommunication studies.

Data Source:

Contact #1: Carol Ogborne
Telephone: 819 564-4857
Email: Carol.Ogborne@gov.bc.ca

Contact #2: GeoBase Technical Support.
Telephone: 819 564-4857
Email: SupportGeoBase@nrcan.gc.ca

References: GeoBase: Website: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/elevation/digital-elevation-model

Dataset Name: Digital elevation model (DEM) of British Columbia

Data/Feature Criteria: The grid spacing is 25 metres and is created from the 1:20 000 scale Terrain Resource Information Management (TRIM) Digital Elevation Model (DEM). DEM slope values range from 0 to 100%.

Data Availability: Available for public access.

Data purchase / collection:

Free (Gridded CDED format DEM - 25 m coarse resolution). This data is the TRIM DEM converted to the Canadian Digital Elevation Data (CDED) format. Gridded CDED format DEMs can be downloaded free by 1:250K mapsheet from https://catalogue.data.gov.bc.ca/dataset/7b4fef7e-7cae-4379-97b8-62b03e9ac83d

$500 per 1:250K mapsheet (TRIM USGS format DEM - 25 m detailed resolution). Distributed by 1:250k mapsheet and can be purchased through the Base Map Online Store https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/base-map-online-store

Data / indicator maintenance: GeoBC

Spatial extent/ resolution: Full provincial coverage. Two available scales: 1:250 000 and 1:50 000, based on the Terrain Resource Information Management (TRIM) 1:20,000 DEM.

Temporal extent/ frequency: Published on 2012-02-20. Last modified 2018-09-04. Resource status: completed. Update period intervals: Unknown.

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

Summary table of indicators informed by the data source:

Impact Categories	Indicators	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

Web service application program interfaces (API) that return georeferenced Landsat satellite map images for the province.

Data Source:

Web Map Connection Service:

Contact: Angus Christian (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 778 974-3634
Email: Angus.Christian@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/landsat-web-map-service

Data Availability:

Available for public access.

Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC DIS - Digital Imagery Services.

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: *SPOT Satellite Imagery: Web Map Connection Service (WMS) and GeoBase*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	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
Web service application program interfaces (API) that return georeferenced Spot satellite map images for the province.

Data Source:
Web Map Connection Service:
Contact: Angus Christian (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 778 974-3634
Email: Angus.Christian@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/imagery-spot-15m-web-map-service.

Data Availability:
Available for public access.

Data purchase / collection: Free.

Data / indicator maintenance: Data Custodian Organization: Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC DIS - Digital Imagery Services.

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. Imagery updates are unknown.

Data Source: *Orthophoto Imagery (for purchase) - Base Map Online Store*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	Comments
Mass Wasting	Density of Landslides in the Watershed	Although this is imagery has very high spatial resolution (1m) it is expensive and does not provide full provincial coverage. However, this may be especially useful in identifying smaller-scale landslides.

Description of Data Source
Georeferenced orthophotos available for the province.

Data Source:
Contact: Angus Christian (Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
Telephone: 778 974-3634
Email: Angus.Christian@gov.bc.ca

References: DataBC: BCGW Website:
https://catalogue.data.gov.bc.ca/dataset/base-map-online-store-maps-and-orthos-search

https://catalogue.data.gov.bc.ca/dataset/00a6c533-6efd-4d07-ada3-1400ac68eb06 (areas for which orthophotos from the provincial collection are available for sale to the public)

Data Availability:
Available for purchase.

Data purchase / collection: $500 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: Data Custodian Organization: Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC DIS - Digital Imagery Services.

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. Resource status is ongoing.

Data Source: *Soil Name and Layer*

Summary table of indicators informed by the data source:

Impact Categories	Indicators
Peak Flow	Density of Roads on Erodible Soils
Surface Erosion	Density of Roads on Erodible Soils <100m from a Stream
Mass Wasting	Density of Roads on Unstable or Potentially Unstable Terrain

Description of Data Source

Attribute information for all B.C. named soils and their soil layers as contained in the National Soil DataBase (NSDB). The Soil Name File contains the general physical and chemical characteristics for soils including soil name, soil code, surficial material, water table characteristics, root restricting layer, soil drainage, parent material texture, chemical properties, position in the landscape, mode of deposition, and soil classification. The Soil Layer File contains average or estimated information about the horizons/layers for each soil name. These include upper and lower depths of each layer, coarse fragment, sand, silt and clay content, organic carbon content, pH, Cation Exchange Capacity (CEC), saturated conductivity, water retention, bulk density, electrical conductivity, calcium carbonate equivalent, Von Post and woody Material content. The Soil Layer File (SLF) data is based upon real measurements where available, but the majority of values are estimates provided by experienced soil scientists.

Data Source:

Contact: Terrestrial Ecosystem Information (TEI) Mailbox (custodian)
Email: TEI_Mail@gov.bc.ca

References: DataBC: BCGW Website: https://catalogue.data.gov.bc.ca/dataset/soil-name-and-layer-files

Data Criteria: This data is related to the data in the Canadian National Soil DataBase (NSDB) available from: http://sis.agr.gc.ca/cansis/soils/provinces.html .

Dataset Name: BCSNF_Soil_Name_File; BCSLF_Soil_Layer_File

Data Availability: Available for public access.

Data purchase / collection: Free.

Data / indicator maintenance: Ministry of Environment and Climate Change Strategy. Knowledge Management.

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. Resource status is ongoing.

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: *Future Soil & Surficial Geology Deliverables*

Summary table of indicators informed by the data source:

Impact Categories	Indicators	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 and Climate Change Strategy: Ecosystem Information Section.
Telephone: (250) 861-7675.
Email Deepa.Filatow@gov.bc.ca

References: N/A.

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

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

Data / indicator maintenance: 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.
- Determining key soils attributes that are useful and commonly identified 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 BCGW, iMap and HaBC should be considered in the solutions.
