Interim Assessment Protocol for Aquatic Ecosystems in British Columbia

DECEMBER 2020

VERSION 1.3

Standards for Assessing the Condition of Aquatic Ecosystems under British Columbia's Cumulative Effects Framework

PREPARED BY: Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy & Ministry of Forests, Lands, Natural Resource Operations and Rural Development

BRITISH COLUMBIA

CEF Cumulative Effects Framework

Disclaimer

The Interim Assessment Protocol (the Protocol) provides an initial standard method for assessing the current condition of the value selected for cumulative effects assessment across the Province of British Columbia (B.C.). The Protocol is currently designed to be a coarse-level approach to depict data at a broader (provincial) scale and to allow for refinements in data at a finer (regional) scale or for multi-scaled analyses where desired and appropriate.

The assessment results based on this Protocol indicate the modelled condition of the value derived from Geographic Information System (GIS) analysis. Results are intended to inform strategic and tactical decision making and may also provide relevant context for operational decision making. Engaging local value experts to identify additional regional scale information – if applicable – and to support interpretation and application of results is encouraged.

The Protocol outlined in this document is subject to a) periodic review to support continuous improvement and b) regionally specific modifications, consistent with criteria for enabling regional variability. Where regional modifications are approved, they will be documented in this protocol, and become the standard for assessment in that area. If applicable, regional modifications are listed in the appendices of this document.

Document Control

Version	Date	Comments
1.0	Jan 2017	• Interim Approved by NRS ADMs
1.1	Dec 2017	• Minor Copy Edit • Updated conceptual model
1.2	May 2019	• Additional indicators added, benchmarks updated • Updated conceptual model • Added regional modifications for Thompson Okanagan, Cariboo and Omineca Natural Resource Regions
1.3	Dec 2020	• Added details for human disturbance criteria; dual road density benchmarks to account for watershed sensitivities; peak flow metrics, which now include fire and insect disturbance; and revised component rollups.

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1 Introduction

Watersheds are the geographic areas that channel drainage into a river or stream system. They are defined by topographic boundaries and – depending on where they are located – might encompass complex natural ecosystems, highly urbanized landscapes, or elements of both. Watersheds have three distinct characteristics: (1) upland zones that intercept, infiltrate, and transport rain as groundwater and surface water flow, (2) riparian zones that border surface water bodies, filter surface water runoff, and provide shade that can lower water temperature, and (3) surface water bodies, such as rivers and lakes, that provide habitat, food, and water to aquatic and terrestrial species (Wieckowski et al. 2008). Naturally functioning watersheds can also provide migratory corridors and habitat connectivity for birds and mammals. The term "watershed processes" refers to the dynamic suite of physical, chemical and biological interactions that form and maintain landscape functions on the scale of an entire watershed.

Human development activities have the potential to impact the natural state of hydrological processes within a watershed by, among things, altering the timing and intensity of peak flows, accelerating surface erosion, degrading the condition of riparian zones, and/or triggering mass wasting events (Sawyer and Mayhood 1998). Impacts on hydrologic processes can influence both water quality and quantity and will dictate the state of aquatic habitats for fish and other biota using the watershed. Knowledge as to the state of indicators of watershed processes can inform decision-makers and serve as proxy data for assessing overall watershed condition as land development continues over time (Gustavson and Brown 2002; Pike et al. 2010). Developing quantitative indicators with associated benchmarks of concern that can be used for evaluating the status of key hydrological processes in B.C.'s coastal and interior watersheds has been a focus of past provincial Watershed Assessment Procedure (WAP) guideline documents (MOF 1995a, 1995b, 1999) and this work provides the foundation for continued development of a broader set of indicators that can be used to evaluate watershed status.

The *Assessment Protocol for Aquatic Ecosystems in British Columbia* (the Protocol) is based on a scientific understanding of watershed processes. It is intended to provide the initial foundation for a consistent approach to province-wide watershed assessments employing standardized GIS-based methodologies and consistent data sources.

The subset of pressure indicators (Tier 1 indicators) described in this document form the basis of the assessment. Additional GIS-based pressure indicators, indicators of landscape vulnerability and field-based watershed condition/state indicators (Tier 2 indicators) will be added in the future (as information becomes available) to improve the resolution of watershed status. Further development and continuous improvement of watershed assessment indicators beyond the core set presented in this document has been a focus of the province's cumulative effects implementation.

1.1 Cumulative Effects Framework and Aquatic Ecosystems

In B.C.'s Cumulative Effects Framework (CEF), cumulative effects are defined as "changes to environmental, social, and economic values caused by the combined effect of past, present, and potential future activities and natural processes" (CEF, 2016). The process for a cumulative effects assessment is predicated on a value assessment based on best-available scientific knowledge, information, and understanding. This science-based assessment relies on benchmarks to support the interpretation of the condition of the value. The desired outcome from this assessment is the long-term resilience or proper functioning of the value.

The value assessment supports the CEF's assessment of objectives set by government for the value, or for components of the value. Objectives are defined as the desired condition of a value (or a component or indicator associated with a value) as defined in legislation, policy, or agreements with First Nations. Objectives for aquatic ecosystems include both broad objectives that are over-arching descriptions of desired conditions, as well as specific objectives that have metrics directly associated with them.

Objectives for aquatic ecosystems were derived from various provincial legislation and regulations that provide both broad and specific direction in the form of objectives about sustaining these systems. Some of these pieces of legislation include:

- *Water Sustainability Act* (WSA 2014) – Objectives for Water Quality, Water Quantity and Aquatic Ecosystems
- *Forest and Range Practices Act* (FRPA 2002) – Fisheries Sensitive Watershed designations; Riparian retention objectives, Water Quality objectives
- *Oil and Gas Activities Act* (OGAA 2008) – Fisheries Sensitive Watershed designations; Riparian retention objectives, Water Quality objectives
- *Land Act* (LA 1996) – Important Watershed designations and land use plan direction and objectives specific to components of Aquatic Ecosystems

Based on a review of existing direction for the management of watersheds and aquatic ecosystems, existing broad objectives can be categorized into three themes that guide the assessment procedure:

1. Sustain water quality;
2. Sustain water quantity; and
3. Sustain hydrological and aquatic ecosystem functions and processes.

2 Protocol Overview

2.1 Background and Conceptual Model

The Protocol describes the derivation of a set of watershed indicators that can be calculated consistently across the province using GIS data layers readily available from DataBC or other ministry providers. The initial set of indicators capture different aspects of watershed functions and are designed to inform a range of watershed management decisions relating to mitigating the impacts of localized development pressures.

The indicators described in the Protocol reflect a range of sediment production and transport processes, hydrologic processes, the composition, structure, as well as dynamics of upslope vegetation cover, and riparian conditions that could be affected by land management activities within a watershed. The conceptual model for the provincial Aquatic Ecosystem value links the selected watershed indicators to identified aquatic ecosystem components, functions, processes, and factors within a nested hierarchy (Figure 1). Each of the components of the conceptual model (i.e. Water Quantity, Water Quality, and Aquatic Habitat) are illustrated in Figures 1 to 5 to identify the specific functions and processes, factors, and indicators that are relevant to that particular component.

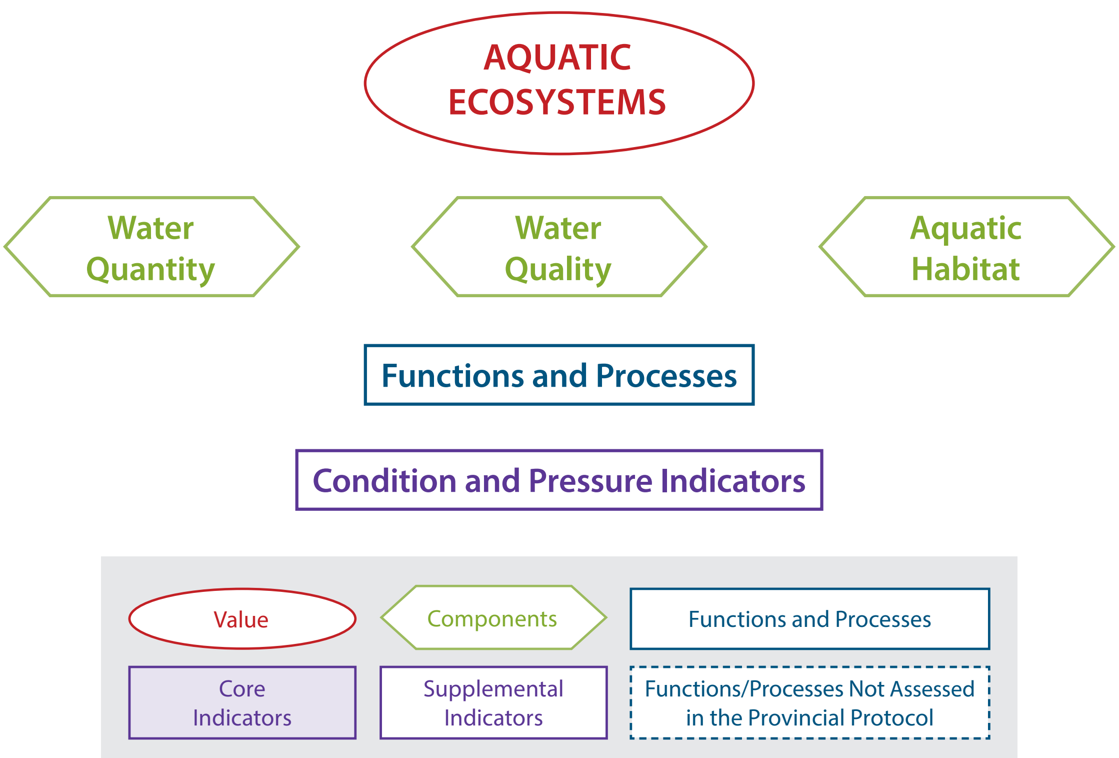

Figure 1. *A generalized conceptual model used to describe Aquatic Ecosystems.*

**Note: Aquatic biota are an important component in aquatic ecosystems, however, it is not reflected in the protocol at this time.*

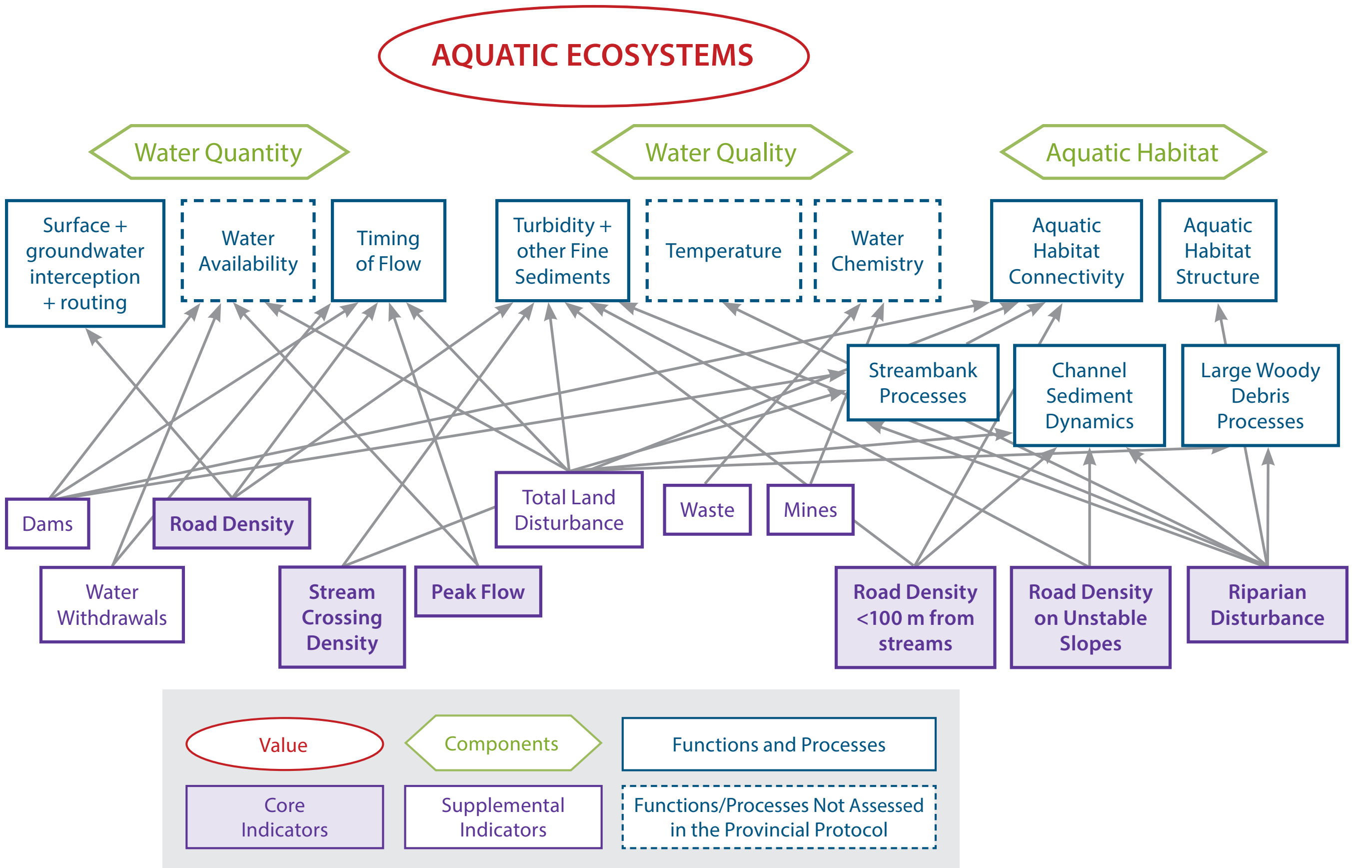

Figure 2. *Detailed conceptual model used to describe Aquatic Ecosystems.*

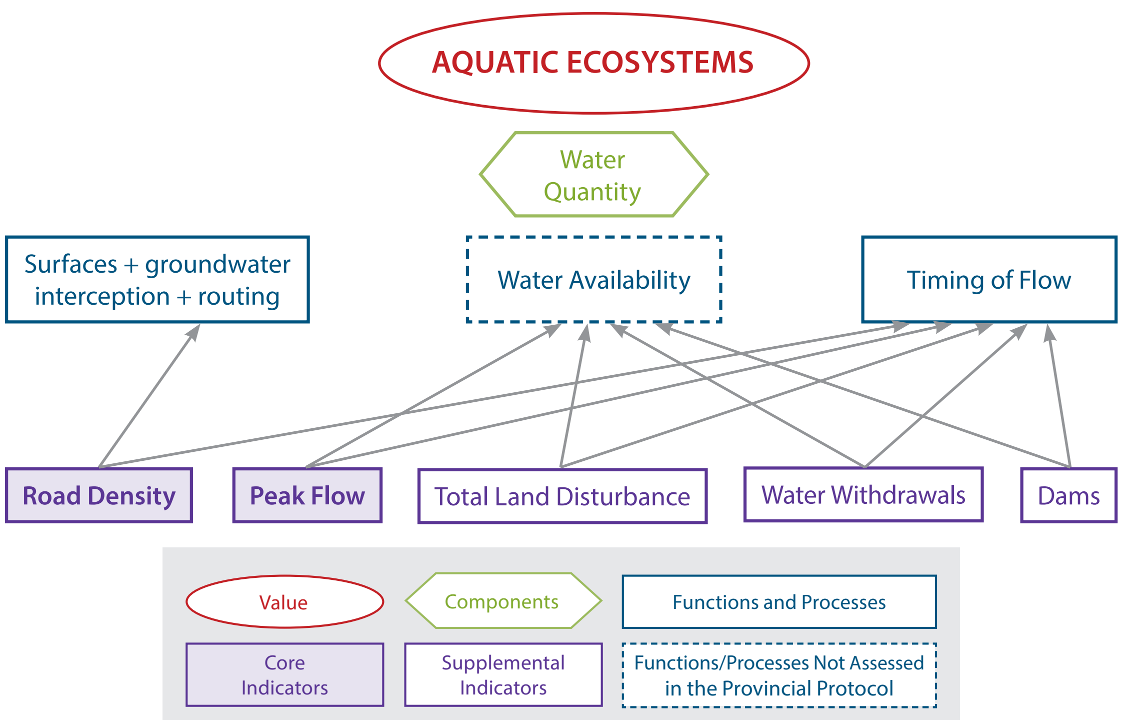

Figure 3. *Generalized component conceptual model – Water Quantity.*

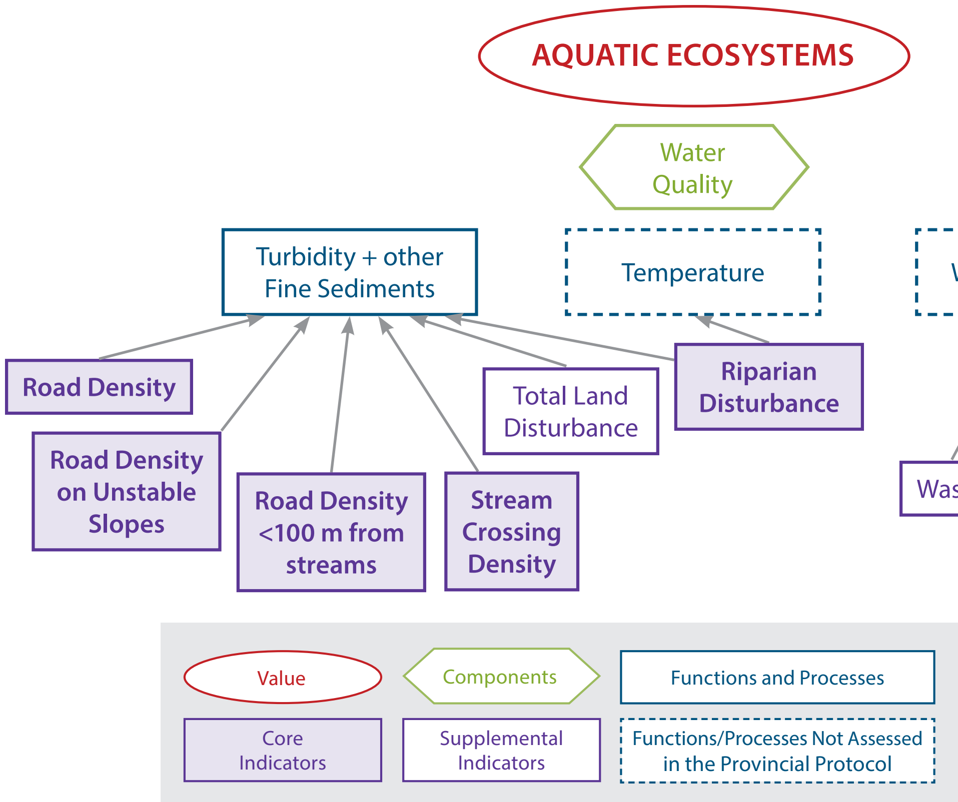

Figure 4. *Generalized component conceptual model – Water Quality.*

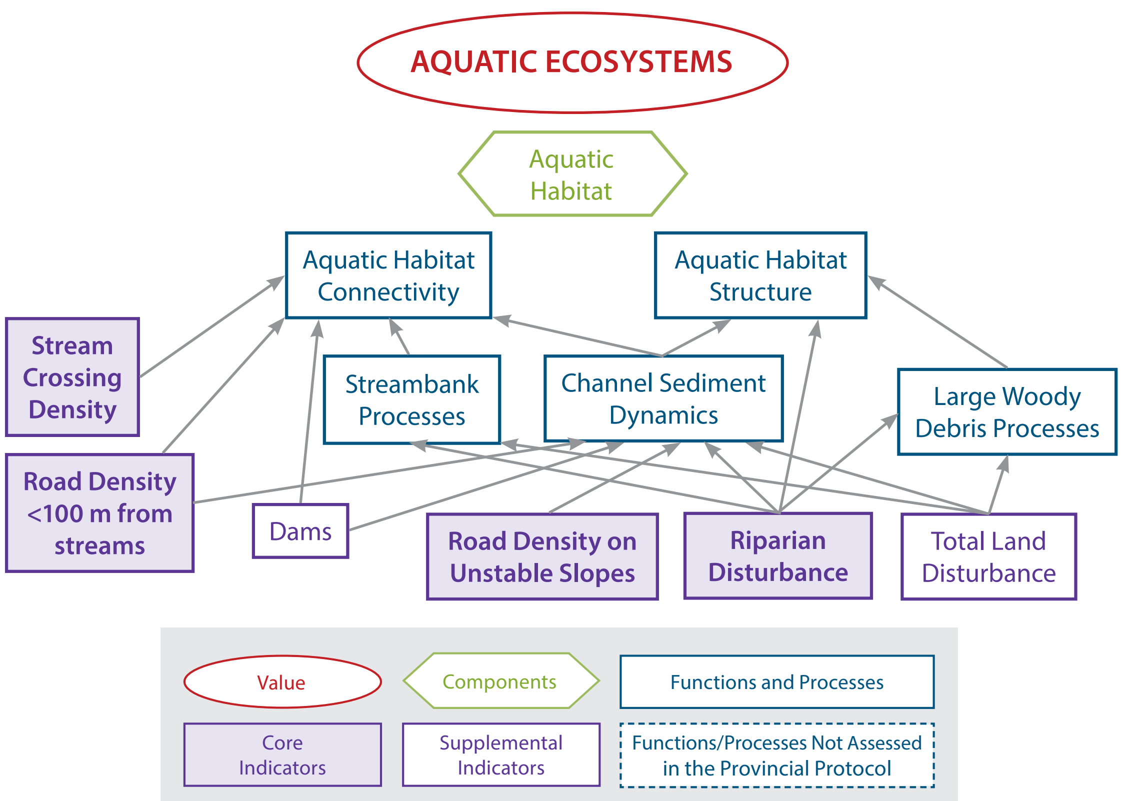

Figure 5. *Generalized component conceptual model – Aquatic Habitat.*

2.2 Management Context

Identified indicators for the Aquatic Ecosystems assessment procedure will support tracking of the status of B.C.'s aquatic ecosystems and can help inform agency decisions related to:

- Government Actions Regulation (GAR)- section 14
- Fisheries Sensitive Watersheds
- *Forest and Range Practices Act* (2002)
- *Riparian Areas Protection Act* (1997)
- *Navigation Protection Act* (1985)

2.3 Regional Modifications

While the Protocol is intended to be applied consistently across the province, assessment procedures may vary in some of the FLNRORD Natural Resource Regions. This may be a result of multiple factors such as: the regional scale availability of validated assessments, additional available regional datasets or field-based data to support the assessment, and/or the refinement of condition, hazard and/or risk where applicable. These regional modifications may include additional indicators and considerations of other factors, and ultimately aims to reduce uncertainty in the assessment. Currently, Indigenous knowledge is not incorporated into the Protocol or any regional modifications to the Protocol but will be explored further in the future.

Additional details around regional modifications and the list of modifications that currently apply are described in Appendix 1.

3 Aquatic Ecosystems Indicators

This assessment protocol estimates the potential sensitivity of watersheds to additional disturbance through the interpretation of multiple indicators. The indicators are divided into two groupings – core indicators and supplemental indicators. These indicators are supported by agency datasets and scientific knowledge/information and are used to support provincial-scale GIS assessments at this time.

The default spatial scale for provincial-scale reporting on the indicator uses the BC Freshwater Atlas (FWA) Assessment Watershed Units.

Core indicators are those for which both widely available agency spatial datasets are available and have supporting science and knowledge to identify benchmarks to support interpretation of the estimated condition of the watershed based on the indicator's performance. Defining broadly applicable benchmarks for any indicators, including our selected core indicators, is a difficult exercise. That being the case, in identifying benchmarks for our indicators we aimed to satisfy, as much as possible, meeting three key criteria:

1. Benchmarks align well with *Forest Practices Code Act* government policy, the Watershed Assessment Procedure Guidebooks (BC MOF 2001).
2. Benchmarks are as consistent as possible with expert-elicitation processes that were conducted under this project to solicit current and best available information on benchmarks (ESSA 2017).
3. Benchmarks align well with regionally-based watershed assessment procedures implemented as part of the Cumulative Effects Framework.

Supplemental indicators are indicators that are assessed provincially but do not have the necessary science and knowledge available to support the identification of benchmarks at this time. Supplemental indicators are intended to provide greater context to the state of the landscape and can support local subject-matter experts and decision makers in understanding other potential pressures on the land base of interest. They can serve as a useful point of entry for focusing the synthesis of existing data, prioritizing monitoring, or securing more detailed knowledge through other means.

Each of the indicators, core and supplemental, is described within this document using the following structure:

- **Scientific Context –** An overview of the scientific basis for the indicator;
- **Indicator –** A general description of the indicator and an outline of methods for its generation with examples and data sources;
- **Components Supported by Indicator –** Key linkages within the province's aquatic ecosystem value conceptual model supported by the indicators;
- **Data Sources –** The core GIS layers that inform derivation and quantification of the indicator
- **Data Assumptions and Limitations –** Any particular data assumptions or limitations of note in regard to indicator derivation or GIS layers used in the assessment. In general, accuracy, completeness, and currentness of GIS data inputs may vary.

- **Benchmarks**[1] **–** Low and high reference points based on best available scientific information that will be used to identify the differential state of aquatic ecosystem and habitat degradation in relation to indicator values.

Details of the GIS-based derivation methods (data inputs, assessment criteria, data outputs) for each assessment indicator are presented in the GIS Data Dictionary.

[1] A subset of indicators calculated did not have defined benchmarks associated with them due to: uncertainty in available research, absence in research, or uncertainty in subject-matter expert opinion. These indicators are considered and presented as supporting context for the core indicators with defined benchmarks.

Core Indicators

3.1 Road Density (km/km^2)

Scientific Context

As road densities increase, more surface materials are exposed to erosion, which can result in an increase in the mobilization of sediment to nearby waterways (Meehan 1991). Human-constructed fire guards present an additional source of sediment and are becoming more prevalent in the landscape with increased fire activity in recent years.

Peak flows within a watershed may be magnified as road density increases because the compact nature of roads resists water infiltration and facilitates surface water runoff (Smith & Redding 2012). Road density can also influence low flow and water temperature by decreasing infiltration capacity, thus modifying subsurface flows (Meehan 1991).

Ditchlines that run perpendicular to slopes intercept sub-surface and surface flows as well as collect run off from roads, all of which are then rapidly transported to nearby stream channels (Forman and Alexander 1998; Gustavson and Brown 2002). During heavy precipitation and/or snow melting events, these processes are exacerbated as high levels of water and sediments are diverted to streams via roads and ditchlines.

Indicator Metric	Components Supported by Indicator
• Total length of roads divided by the total watershed area (km/km2) • 'Roads' may include fire guards, where available	• Water Quality • Water Quantity

Benchmarks

Benchmarks – Water Quantity (sensitive watersheds) and Water Quality (all)

- < 0.6 km/km^2 (low)
- 0.6 – 1.2 km/km^2 (moderate)
- > 1.2 km/km^2 (high)

Benchmarks – Water Quantity (all other watersheds)

- < 1.5 km/km^2 (low)
- 1.5 – 2.1 km/km^2 (moderate)
- > 2.1 km/km^2 (high)

Suggested initial benchmarks to be used for this indicator within the CEF were based on an integration of information from review of past Watershed Assessment Procedure (WAP) benchmarks (MOF 1995a, b, 1999), evaluation of supporting literature regarding potential thresholds of concern for road density related to fish and fish habitats (Quigley et al. 1996; Rieman et al. 1997; Bradford and Irvine 2000; Stalberg et al. 2009; Cooper 2011), and results from an expert elicitation exercise (ESSA 2017). Regional review and validation has found that these initial benchmarks may be too low to accurately represent the influence of roads on the water quantity component in some areas, resulting in high-risk predictions related to timing and quantity of flow where there has been no past evidence of such. This could be a result of the overestimation of roads in the spatial layers (see data limitations) and/or a function of topography where interception of surface and sub-surface flows from upslope areas are minimal in watersheds with low topographic relief. To account for the differing sensitivities that may occur among watersheds, additional benchmarks based on the original IWAP/CWAP protocols have been incorporated into the data model. Results from both sets of benchmarks are made available with the lower set recommended for designated or proposed fisheries sensitive watersheds or those with increased sensitivities to runoff interception such as in areas of mountainous terrain.

Data Sources	Data Assumptions
• B.C. Cumulative Effects (BCCE) Consolidated Roads layer: representing a composite from DRA, FTEN, OGC, and RESULTS • BC Wildfire fire guards representing machine and hand guards. This is restricted internal BC Government data.	• Includes in-block roads • Fire guards are used where available, but reliability and completeness may vary. Weighted road/fire guard lengths are used for road density for the Water Quality component, where weights are assigned as outlined in Table 1 (from provincial FREP WQ database 2006-2018).

Data Limitations
May overestimate forest tenure roads in cases where a road permit was issued, but the road was not subsequently built. Accuracy and completeness may vary. Deactivated, gated, or over-grown roads are inconsistently tracked. Fire guard information may not be entirely complete and is subject to change.

Table 1. *Road and Fire Guard Weighting Scheme for Coastal and Interior Watersheds used in water quality component modelling.*

Road/Fire Guard Type/Category	Weighted Length Coast	Weighted Length Interior
1. Main FSR, unpaved arterial/collector/local/resource/recreational road – highest potential impact, more heavily used than permit rds • Machine fire guards	0.7	1
2. Permit, rough/loose, seasonal, unclassified, unknown surface – moderate impact, assumed less traffic than FSR • Hand fire guards	0.4	0.7
3. Paved, overgrown, assumed limited travel, etc – least impact to sediment generation potential/water quality • Re-habbed fire guards (hand or machine) – if rehab status is known	0.1	0.1

3.2 Road Density < 100 m from a Stream (km/km^2)

Scientific Context

High road density near streams may contribute significant amounts of sediment to streams, affecting water quality, stream bed morphology and biota (Carson et al. 2009). Erosion and transport processes are dependent on precipitation, soil texture, road construction and maintenance practices (Gucinski et al. 2001; Carson et al. 2009).

Indicator Metric	Components Supported by Indicator
• Total length of roads within 100m of a stream, divided by the total watershed area (km/km^2) • 'Roads' may include fire guards, where available	• Water Quality • Aquatic Habitat

Benchmarks

- < 0.12 km/km^2 (low)
- 0.12 – 0.30 km/km^2 (moderate)
- > 0.30 km/km^2 (high)

Suggested initial benchmarks to be used for this indicator within the CEF are based on an integration of information from: (i) a review of past WAP benchmarks (MOF 1995a, b, 1999), (ii) evaluation of supporting literature regarding potential thresholds of concern for road density related to fish and fish habitats (Valdal and Quinn 2011), and (iii) results from an expert elicitation exercise (ESSA 2017).

Data Sources	Data Assumptions
• BCCE Consolidated Roads layer: representing a composite from DRA, FTEN, OGC, and RESULTS • FWA stream network and double line rivers • BC Wildfire fire guards representing machine and hand guards. This is restricted internal BC Government data.	• Use of a 100m riparian buffer: (i) captures possible discrepancies in resolution of spatial data, (ii) is supported by literature on spatial extent of riparian buffer functions. • All FWA streams are used for analysis, including intermittent and indefinite streams. • Fire guards are used where available, but are considered as in-progress. Reliability and completeness may vary. • Weighted road/fire guard lengths are used for road density near streams for the Water Quality component. See Table 1 above.

Data Limitations

- The 1:20,000 FWA layer may overestimate or underestimate first-order streams in the interior and coast respectively.
- See 'Road Density' Limitations.

3.3 Road Density on potentially unstable slopes (km/km²)

Scientific Context

Roads on unstable terrain increase the chance of mass wasting by undermining or loading slopes, by saturating soils and by reducing soil root networks (Sawyer and Mayhood 1998; Gustavson and Brown 2002; Jordan 2002; Jordan et al. 2010). Roads can alter surface drainage patterns and divert subsurface flow to the surface increasing the chance of soil saturation and gulley erosion (Pike et al. 2007). Clearings associated with roads reduce the root network that provides structural support to soil and they increase the chance of soil saturation by reducing rainfall interception and increasing snowmelt rates (Smith and Redding 2012).

Mapping of terrain stability is only available at local scales for a limited number of watersheds. However, several methodologies suggest that potentially unstable terrain can be defined (as a default) as slopes > 60% (Sawyer and Mayhood 1998; Gustavson and Brown 2002) or >50% on Haida Gwaii (B. Floyd, pers. comm.). This criterion has traditionally been used in B.C., although with recognition that the potential impacts in regards to slope will likely be different on the coast versus the interior of the province. Until provincial-scale scale terrain stability maps become available for broad use, road densities on steep slopes can represent a surrogate threshold in relation to potential mass wasting on unstable soils.

Fans, gullies, and gentle over steep terrain are other important types of unstable terrain but are not considered at the general scale of the watershed assessment protocol.

Indicator Metric	Components Supported by Indicator
• Total length of roads and fire guards found on steep slopes divided by the total watershed area (km/km²) Note: Steep is defined as >50% for Haida Gwaii and >60% for the remainder of B.C.	• Water Quality • Aquatic Habitat

Benchmarks

- < 0.12 km/km² (low)
- 0.12 – 0.25 km/km² (moderate)
- > 0.25 km/km² (high)

Suggested initial benchmarks to be used for this indicator within the CEF are based on an integration of information from review of past WAP benchmarks (MOF 1995a, b, 1999), evaluation of supporting literature regarding potential thresholds of concern for road density to fish and fish habitats (Lewis et al. 2016), and results from an expert elicitation exercise (ESSA 2017).

Data Sources	Data Assumptions
• BCCE Consolidated Roads layer: representing a composite from DRA, FTEN, OGC, and RESULTS • Digital Elevation Model (DEM) • BC Wildfire fire guards representing machine and hand guards. This is restricted internal BC Government data.	• 25m DEM used to define areas with steep slopes; • Weighted road/fire guard lengths are used for road density on potentially unstable slopes for the Water Quality component. See Table 1 above.

Data Limitations

- Roads on steep slopes are assumed to have a potential impact on mass wasting. Future iterations may consider refining this metric by including a modifier to limit inclusion to only where adjacent hillslopes have the potential to facilitate the transfer of flow and material to a stream (coupling).
- See 'Road Density' above.

3.4 Stream Crossing Density (#/km²)

Scientific Context

Stream crossings (i.e. roads, utility lines, other linear developments) represent a potential focal point for local sediment and flow delivery (Reid and Dunne 1984; Anderson 1996; Haskins and Mayhood 1997; Anderson et al. 1998; Brown 1999; Reid and Anderson 1999). Crossing structures can be a barrier to upstream fish passage, thereby restricting habitat and potentially fragmenting populations (Marshall 1996; Harper and Quigley 2000; BC MOF 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 versus closed box culverts), as well as the condition of stream crossing structures (MOF 1995a, b; Smith and Redding 2012).

Indicator Metric	Components Supported by Indicator
• Total number of stream crossings divided by the total watershed area (#/km²)	• Water Quality • Aquatic Habitat

Benchmarks

Interior watersheds
- < 0.24/km² – (low)
- 0.24 - 0.60/km² – (moderate)
- > 0.60/km² – (high)

Coastal watersheds
- < 0.60/km² – (low)
- 0.60 - 1.40/km² – (moderate)
- > 1.40/km² – (high)

Suggested initial benchmarks to be used for this indicator within the CEF are based on an integration of information from review of past WAP benchmarks (MOF 1995a, b, 1999), evaluation of supporting literature regarding potential thresholds of concern for stream crossings related to fish and fish habitats (i.e. Antoniuk and Ainslie 2003), and results from an expert elicitation exercise (ESSA 2017).

Data Sources	Data Assumptions
• BCCE Consolidated Roads layer: representing a composite from DRA, FTEN, OGC, and RESULTS • 1:20K FWA stream network, Ecological Aquatic Units of BC (EAUBC) Ecoregions used for delineation of coastal versus interior areas	• Coastal considered to be EAUBC FRESHWATER_ECOREGION = 'North Pacific Coastal'. • All other areas in B.C. are considered to be 'Interior'. • See 'Road Density' above.

Data Limitations

- Deactivated, gated, or over-grown roads are inconsistently tracked.
- The 1:20,000 FWA layer may overestimate or underestimate first-order streams in the interior and coast respectively, resulting in respective deviations from the true number of crossings.
- See 'Road Density' above.

3.5 Riparian Disturbance (km/km) Streams – Linear Based Measurement

Scientific Context

Riparian areas are intimately connected with stream, lake and wetland ecosystems, providing a wide variety of ecological services and functions. 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).

Riparian areas can regulate channel morphology and contribute to aquatic habitats through the provision of large wood. Riparian areas also influence water quality, provide shade, and are sources of food and nutrients to aquatic ecosystems. The maintenance of these functions and services depends upon the intactness of riparian areas (Meehan 1991; Gustavson and Brown 2002).

As the proportion of disturbed streams increases within a watershed, so does the risk of surface erosion and mass-transport of sediment during heavy precipitation events (MOF 1995a, b). When riparian vegetation is lost, stream channels are weakened due to the lack of root structures, and intensified surface erosion and mass-wasting are common outcomes.

Riparian disturbance is limited to human causes as natural events such as fires or insect damage will retain large wood and provide a measure of other riparian functions until the forest regenerates.

Indicator Metric	Components Supported by Indicator
• Total length of stream within 30m of disturbance divided by the total length of streams in the watershed (km/km)	• Water Quality • Aquatic Habitat

Benchmarks

- < 0.12 km/km (<12%) (low)
- 0.12 – 0.21 km/km (12 -21%) (moderate)
- > 0.21 km/km (>21%) (high)

These benchmark criteria are suggested to apply for both fish and non-fish bearing streams. Future iterations may define more risk-averse benchmarks for fish bearing streams.

Suggested initial benchmarks to be used for this indicator within the CEF are based on an integration of information from review of past WAP benchmarks (MOF 1995a, b, 1999), evaluation of supporting literature regarding potential thresholds of concern for riparian disturbance related to fish and fish habitats (Antoniuk and Ainslie 2003), and results from an expert elicitation exercise (ESSA 2017).

Data Sources	Data Assumptions
• FWA stream network • Custom 'human disturbance' data from various sources including Tantalis, OGC, and BTM (Baseline Thematic Mapping). See Appendix 2. • Disturbance includes clearing allowances on roads and fire guard linework. • FAIB Consolidated Cutblocks • RESULTS Harvest Reserves (treed vegetation greater than or equal to 90 years old) for exclusion of stream reaches within minimum 30 m riparian reserves containing mature timber. Reserves less than 90 years old are assumed to have some level of disturbance.	• Riparian related disturbance is defined as that occurring within 30m of a single line stream, wetland flow, or canal flow. For double line rivers, disturbance is measured from within 30m of the closest river bank for a maximum 100 m flow segment. • Total disturbance includes: Human disturbance (rail, transmission, major rights of way, harvesting, mining, oil & gas, seismic, agriculture, and urban activity, etc.), including historical harvesting (prior to last 20 yrs; 1998); and roads and fire guards of variable widths. • Natural non-treed areas such as lakes, meadows, rocks, and swamps are assumed to be undisturbed. • Age information for reserved timber is first taken from RESULTS if available; otherwise it is taken from the VRI. Reserves > 90 yrs are assumed to be providing adequate riparian function.

Data Limitations
• 1:20,000 FWA may overestimate or underestimate first order streams in the interior and coast respectively, and these smaller streams typically have the most riparian disturbance because of the lack of mandatory reserves. • RESULTS Reserves are less accurately tracked/reliable pre-2013. Reserves may not be maintained/interpreted into VRI if they are less than one hectare. • To account for potential inaccuracy in stream and reserve locations, if a reserve is within 30m of a stream reach, the reserve is assumed to provide some degree of protection (LWD) for that stream. • Accuracy, completeness, and currentness of disturbance information may vary.

3.6 Peak Flow

Scientific Context

The peak flow indicator is an estimate of the likelihood that harmful changes in streamflow will result from current land use activities. A large proportion (up to 80%) of total annual water yield is discharged in the peak flow period. Peak flows are of considerable management concern as they can result in channel forming events, important when considering the design of stream crossings, in-stream structures or the effects of flooding on downstream values. In particular, an increase in peak flow frequency and magnitude may result in harmful hydro- geomorphic events such as floods, bank erosion, channel instability, debris floods, and debris flows.

Peak flows are regulated by a combination of factors, including those that are linked to *natural runoff generation potential, surface flow attenuation, and equivalent clearcut area (ECA)*. It is the combination of these factors that control the magnitude, timing, and duration of peak flows.

Natural runoff generation potential considers bio-geoclimatic (BEC) subzone and alpine non-forested areas. It accounts for the degree of change in peak flows resulting from development using the assumption that watersheds grouped in specific sub-zone clusters with varying degrees of natural non-forested areas will generate different degrees of additional runoff after forest canopy loss or alteration (Winkler et al. 2010a).

Surface flow attenuation refers to how efficiently hillslope and stream runoff is slowed, captured and stored as it is routed through the watershed, and is represented by *drainage density ruggedness* and *absence of lakes and wetlands. Drainage density ruggedness* indicates the potential for rapid runoff delivery to and through streams, which may contribute to harmful flood events (Patton and Baker, 1976).

The absence of lakes and wetlands and man-made reservoirs in a watershed can have an influence on peak flow discharges because lakes and wetlands are shown to mitigate peak flows (Acreman and Holden 2013, Woltenmade and Potter 1994, Taylor and Pierson 1985). The size and placement of wetlands within a watershed has also shown to influence attenuation, with larger lakes and wetlands located on the main-stem channel lower in a watershed being more effective at reducing downstream flooding (Acreman and Holden 2013, Delaney 1995, Ogawa and Male 1986).

Equivalent Clearcut Area (ECA) is a modeled metric that relates the influence of forest cover disturbance (e.g. clearcuts) to changes in stream flow (MOF 2001; Smith and Redding 2012). ECA includes the area of land that has been harvested or otherwise cleared. Natural disturbance is included in ECA calculations to account for increases in surface water runoff due to changes in forest structure and function. Hydrologic recovery curves reflecting changes in flows resulting from the regenerating forest are used to modify the ECA values (Sawyer and Mayhood 1998; Hudson and Horel 2007; Winkler and Boon 2015).

Indicator Sub-Metric

- **Natural runoff generation potential** is calculated using:

  i. a relative Biogeoclimatic Ecosystem Classification (BEC)unit sensitivity ranking as an indicator of average annual precipitation, average snowpack accumulation and persistence (Lewis et al., 2016; Smith et al. 2019), The BEC score is binned into 3 classes for the assessment unit:

    1. Low (0 – 0.5)
    2. Moderate (>= 0.5 – 1.5)
    3. High (>= 1.5)

  See Appendix 2, tab 'BEC Sensitivity Scores'.

  ii. percent alpine non-forested areas – in particular, natural alpine areas and associated features (ice/snow, rock/rubble, moraine) – to estimate the potential for peak flow under natural conditions. The proportion of alpine non-forested is classified into 3 classes:

    1. >=70%
    2. 30-70%
    3. <30%

  These two scores are combined to give the Runoff Generation Potential ranking, ranked from Very Low to Very High (Table 2) (Lewis et al, 2016).

Table 2. *Scoring matrix to derive runoff generation potential ranking.*

		BEC Unit Score		
		1	2	3
Proportion of Alpine Non-Forested Area (%)	<30	Moderate	High	Very High
	31-70	Low	Moderate	High
	>70	Very Low	Low	Moderate

- **Surface flow attenuation** is derived from a matrix that includes *Drainage Density Ruggedness* (DDR) and *Absence of Lakes and Wetlands*.

  i. *Drainage Density Ruggedness* (Melton, 1957) is the dimensionless product of drainage density (stream length per unit area – km/km^2) and total elevation relief (the difference between the highest and lowest points in the watershed relative to watershed length (in km) (Schumm 1956).

  DDR is binned into 3 classes:

    1. <2000 km/km^2
    2. 2001-4000
    3. >4000 -3

  ii. *Absence of Lakes and Wetlands* are calculated using the 1:20,000 FWA lakes and wetlands layers to measure the area of lakes and wetlands within the lower 30%, mid 30% and upper 40% of each AU. The area-weighted proportion (%) covered by lakes and wetlands is calculated by weighting the lower 30% of the AU area by 100% , the middle 30% by 75%, and the upper 40% by 25%. This gives greater weight to larger lakes and wetlands situated lower in a watershed, which are more likely to attenuate runoff (Lewis et al, 2016).

The proportion of lakes and wetlands and position in the watershed score is binned into 3 classes:

1. >6.1%
2. 2.1-6
3. 0-2

These two scores are combined to give the Surface Flow/Runoff Attenuation ranking, ranked from Very Low to Very High (Table 3) (Lewis et al, 2016).

Table 3. *Scoring matrix to derive runoff attenuation ranking*

		Drainage Density Ruggedness		
		<2000	2001-4000	>4000
Location Weighted Percent Area of Lakes/Wetlands	0-2	Moderate	Low	Very Low
	2.1-6.0	High	Moderate	Low
	>6.1	Very High	High	Moderate

Runoff Generation Potential and Surface Flow Attenuation results are combined to indicate the Hydrologic Response Potential Rating (Lewis et al, 2016). These scores range from 4 to 12, and are classified as follows:

1. Very Low (VL): < 6
2. Low (L): >= 6 and < 8
3. Moderate (M): >= 8 and < 9
4. High (H): >= 9 and < 11
5. Very High (VH): >= 11

- **Equivalent Clearcut Area (ECA)** within a watershed divided by the total watershed area (%), modified by recovering forest. Human disturbance, fire disturbance, and mountain pine beetle (MPB) disturbance is considered in the ECA calculation. ECA is reported as the percent of the AU, or 'Insufficient Data' where >50% of AU has VRI unreported.

The Hydrologic Response Potential Rating is combined with the Proportion of ECA in the watershed in the following matrix to result in a Peak Flow Index Number (Table 4) (Lewis et al, 2016).

Table 4. *Scoring matrix to derive Peak Flow Index Number*

		Peak Flow Index Number																			
Hydrologic Response Potential Class	VH	0.05	0.1	0.21	0.23	0.31	0.33	0.43	0.45	0.56	0.58	0.6	0.63	0.66	0.7	0.75	0.8	0.85	0.9	0.95	1
	H	0.04	0.09	0.14	0.22	0.25	0.32	0.35	0.44	0.47	0.57	0.59	0.62	0.65	0.69	0.74	0.79	0.84	0.89	0.94	0.99
	M	0.03	0.08	0.13	0.17	0.24	0.27	0.34	0.37	0.46	0.48	0.5	0.61	0.64	0.68	0.73	0.78	0.83	0.88	0.93	0.98
	L	0.02	0.07	0.12	0.16	0.19	0.26	0.29	0.36	0.39	0.41	0.49	0.52	0.54	0.67	0.72	0.77	0.82	0.87	0.92	0.97
	VL	0.01	0.06	0.11	0.15	0.18	0.2	0.28	0.3	0.38	0.4	0.42	0.51	0.53	0.55	0.71	0.76	0.81	0.86	0.91	0.96
		0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100
			ECA																		

Components Supported by Indicator

- Water Quantity

Benchmarks

- <0.3 (low)
- 0.3-0.42 (moderate)
- 0>0.42 (high)

Data Sources

- Biogeoclimatic ranking (Smith et al. 2019; Grant et al. 2008)
- 1:20K FWA streams, lakes and wetlands
- 25 m DEM (TRIM)
- VRI updated with additional harvesting from FAIB Consolidated Cutblocks and RESULTS (including height info if available);
- Human disturbance layers (various); roads and fire guard buffers. (See Appendix 2, 'meta Disturbance 2018' tab, Ranks 0 to 11-1).
- Coastal and interior watersheds designation is based on the Ecological Aquatic Units of BC (EAUBC) watershed classification
- BC Wildfire fire perimeters and fire severity information
- Mountain Pine Beetle (MPB) proportion of stand dead and year of attack information from VRI.

Data Assumptions

- Alpine non-forested areas include natural alpine areas and associated features (ice/snow, rock/rubble, moraine).
- ECA is based on forest stand height and disturbance assumptions for stand recovery. Hydrologic recovery is calculated as per Hudson & Horel, Winkler & Boon, for coastal vs interior watersheds. See Appendix 2 tab 'ECA Recovery Curves'. Coastal/Interior classification is based on EAUBC watershed classes.
- ECA is applied to harvested (current or historical) or disturbed areas including fire, mountain pine beetle, and human disturbance (see below). This includes historical logging found in the Baseline Thematic mapping layer.
- Where re-interpreted height was not available in VRI (e.g. for recent harvesting and fire), equations within the Forest Analysis and Inventory Branch (FAIB) Site Tools calculator were used to estimate height (https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-inventory/growth-and-yield-modelling/site-index-tools-sitetools). Site Tools uses age (in this case, age since disturbance plus two years for a natural regeneration period), leading species, and site index to estimate height. This height was then plugged in to the recovery curve formula to estimate ECA.
- Where species or site index was not available, age since disturbance was used as a general surrogate: 1-10 yrs = 100% ECA, 11-20 = 75%, 21-40 = 25% and 40-50 yrs 5%. (It is expected that as the lag in VRI updates improves, it will not be required to use the age surrogates – i.e. height info should be more readily available in VRI.)
- For Mountain Pine Beetle affected areas, an additional ECA factor is calculated based on time since attack, proportion of stand dead, and BEC moisture class (moist or dry). This MPB factor is additive with the height or age based ECA, where there is no salvage/harvest or fire post MPB attack.

- Where Fire Severity (based on satellite imagery interpretation) is known (2015+), ECA is adjusted for severity as follows: High Severity = 90% ECA, Medium = 50%, Low = 10%, and Unburned = 1% ECA.
- The following human disturbance types are considered 100% ECA (non-recoverable): Rail, transmission, major rights of way, road buffers, mining, oil&gas, seismic, agriculture, and urban activity. See 'meta Disturbance2018' tab for details.

Where >50% of the watershed has VRI Unreported (e.g. TFL), ECA is recorded as 9999 (insufficient data).

Data Limitations

- Vegetation related information for ECA calculation may not be available for private property, TFLs or other privately managed lands.
- Where VRI Height information is unavailable for newly disturbed stands, ECA is estimated using growth curve calculations or fire severity proxy values for recovery.
- Fire Severity information is only available from 2015 onwards.
- The 1:20,000 FWA layer may overestimate or underestimate first-order streams in the interior and coast respectively, resulting in respective deviations from the true density of streams.

Supplemental Indicators

3.7 Proportion of Riparian Disturbance (%) for Streams, Lakes, and Wetlands – Area Based Measurement

Scientific Context

Riparian areas are intimately connected with stream, lake and wetland ecosystems, providing a wide variety of ecological services and functions. 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).

Riparian areas can affect channel morphology and aquatic habitats through the provision of large wood. Riparian areas also influence water quality, provide shade, and are sources of food and nutrients to aquatic ecosystems. The maintenance of these functions and services depends upon the intactness of riparian areas (Meehan 1991; Gustavson and Brown 2002).

As the proportion of disturbed streams increases within a watershed, so does the risk of surface erosion and mass-transport of sediment during heavy precipitation events (MOF 1995a, b). When riparian vegetation is lost, stream channels are weakened due to the lack of root structures, and intensified surface erosion and mass-wasting are common outcomes.

The riparian area disturbance estimate is given as a supplemental indicator to further quantify the level or magnitude of disturbance to a stream. This will be especially useful information in areas where partial-cutting management strategies were implemented.

Indicator Metric	Components Supported by Indicator
• Area within a 30m riparian buffer, for each of (i) streams and rivers, (ii) lakes and manmade reservoirs and canals, and (iii) wetlands, that is disturbed divided by the total area of the riparian buffer (%).	• Water Quality • Aquatic Habitat

Benchmarks

- No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.

Data Sources	Data Assumptions
• FWA stream network, FWA rivers, FWA manmade waterbodies, FWA lakes, and FWA wetlands • Custom human disturbance data from various sources including Tantalis, OGC, and BTM (Baseline Thematic Mapping); and road and fire guard clearing allowances (buffers) • FAIB Consolidated Cutblocks	• Riparian related disturbance is defined as that occurring within 30m of a stream, lake or wetland. • Total disturbance includes: Current human disturbance (rail, transmission, major rights of way, harvesting, mining, oil & gas, seismic, agriculture, and urban activity, road and fire guard buffers), and historical Logging (prior to last 20 years; 1998).

Data Limitations

- 1:20,000 FWA may overestimate or underestimate first order streams in the interior and coast respectively, and these streams typically have the most riparian disturbance because of the lack of mandatory reserves.
- Also assumes that all disturbances are equal when different types of disturbance may result in variable outcomes. Additionally, riparian disturbance around larger lakes, wetlands, or streams could result in a lower magnitude of impacts as these systems rely more on autochthonous processes.
- Accuracy, completeness, and currentness of disturbance information may vary.

3.8 Wetland Disturbance (%)

Scientific Context

Wetlands serve important hydrological, geochemical, and biological functions (NRC 1995). Thus, the conservation of existing wetlands and the restoration of lost/degraded wetlands are considered important for mitigating flood runoff (Padmanabhan and Bengston 2001), for abating sediment and nutrient loading from land disturbances and human activities (e.g. phosphorus and nitrogen) (Kadlec 2008; Yang et al. 2008), and for the recharge of aquifers (Morris et al. 2002).

Wetland ecosystems are under increasing pressure from human activities such as dredge and fill operations, hydrological modifications, pollutant runoff, eutrophication, impoundments, and fragmentation by roads and ditches (Klemas 2011).

Indicator Metric	Components Supported by Indicator
• Area of wetland polygon interior (vs buffer) that is disturbed, divided by the total area of wetland polygon (%)	• Water Quality • Aquatic Habitat

Benchmarks

- No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.

Data Sources	Data Assumptions
• FWA wetlands • Custom human disturbance data from various sources including Tantalis, OGC, and BTM (Baseline Thematic Mapping); and road and fire guard clearing allowances (buffers). • FAIB Consolidated Cutblocks	• Wetland disturbance is defined as that occurring within the interior of an identified FWA wetland polygon. • Total disturbance includes: Current human disturbance (rail, transmission, major rights of way, harvesting, mining, oil & gas, seismic, agriculture, and urban activity, road and fire guard buffers), and historical Logging (prior to last 20 years; 1998).

Data Limitations

- Consistency and confidence in delineations of wetlands may vary across the province. Wetlands may include open water, marshes, bogs, or vegetated areas.
- Accuracy, completeness, and currentness of disturbance information may vary.

3.9 Total Land Disturbance (Human Disturbance/ Land Use/Land Cover and Natural Disturbance combined) (%)

Scientific Context

Total disturbance represents the sum of all potential cumulative impacts on key watershed processes such as altered hydrologic flows, sediment generation, contaminants, etc. that can affect aquatic habitats (Poff et al. 2006; Stalberg et al. 2009).

Indicator Metric	Components Supported by Indicator
• Area of wetland polygon interior (vs buffer) that is disturbed, divided by the total area of wetland polygon (%)	• Water Quantity • Water Quality • Aquatic Habitat

Benchmarks

- No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.

Data Sources	Data Assumptions
• Custom human disturbance data from various sources including Tantalis, OGC, and BTM (Baseline Thematic Mapping); and road and fire guard clearing allowances (buffers). • FAIB Consolidated Cutblocks • Fire perimeters and severity – current and historic (Wildfire Management Branch) • VRI (for insect disturbance)	• Disturbance types are reported separately, as well as grouped into disturbance categories. • Human disturbance/land use/land cover is reported for 100% of the watershed assessment unit (i.e. with no overlaps). • Where there are overlapping activities, a hierarchy is applied where certain activities take precedence: – Reporting categories are: Unique Disturbance/Land Cover Type; Current Human Disturbance; Historic Harvesting (prior to last 20 yrs; 1998); Total Human Disturbance (current and historic); Total Fire; Total Insect; Total Fire and Insect (no double accounting); Net Fire and Insect (not covered by Human Disturbance); Total Non-Disturbed (not effected by human or natural disturbance)

Data Limitations

- Accuracy, completeness, and currentness of disturbance information may vary.

3.10 Land Ownership (%)

Scientific Context	
Understanding the proportion of Private, Federal and Provincial Lands within a watershed will give decision makers and professional staff a better understanding of the level of responsibility and human footprint as well as provide tools that might be used to facilitate future management decisions.	
Indicator Metric	**Components Supported by Indicator**
• The proportion (%) of private, crown, federal, protected, or unknown ownership within a watershed. See Appendix 2 'meta Ownership' tab.	• Supplementary information
Benchmarks	
• No benchmarks have been defined yet for this indicator.	
Data Sources	**Data Assumptions**
• FAIB Consolidated Ownership	• The source data product is a generalized classification of the primary ownership of forest lands for use in strategic decision making.
Data Limitations	
• This is not an official status, but is rather a generalized ownership class.	

3.11 Mines (#/Watershed)

Scientific Context
Mines can pose a potentially significant threat to aquatic ecosystems (Meehan 1991; Nelson et al. 1991; Kondolf 1997). Fuel and oil spills are a risk at all mine sites where equipment is used. Runoff from mines, quarries, well sites, and mine wastes have potential to contribute sediment, metals, acids, oils, organic contaminants and salts to water bodies (Ongley 1996). Metal mines have potential to generate acid rock drainage (ARD) based on the type of bedrock the mine site is located on (Cooper 2011). Tailings pond failure poses a low probability, but high consequence risk. Toxic chemicals affect water quality and can kill fish and their invertebrate food supply (Nelson et al. 1991; Kondolf 1997). Historic placer mining has also been known to be a significant source of water quality impairment (Meehan 1991; Kondolf 1997). More recent placer mining activity can still pose a threat to channel bank, fan and floodplain stability where not undertaken properly.

Indicator Metric	Components Supported by Indicator
• The total number of mines (of all types) occurring within a watershed (#/watershed)	• Water Quality

Benchmarks
• No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.

Data Sources	Data Assumptions
• MinFile Points: WHSE_MINERAL_TENURE.MINFIL_MINERAL_FILE	• Mine type categories included in assessment are Producer, Past Producer, and Developed Prospect.

Data Limitations
• Results cannot be interpreted without further investigation into mine details.

3.12 Permitted Waste Discharge (#/Watershed)

Scientific Context	
High levels of wastewater discharge from municipal and industrial sources could impact the water quality of salmonid habitats either through excessive nutrient enrichment or chemical contamination. Some industrial waste products can directly injure or kill aquatic life even at low concentration (US EPA 2008) while excessive nutrient levels (eutrophication) can result in depletion of the dissolved oxygen in streams and lakes, starving fish and other aquatic life (Zheng and Paul 2007).	
Indicator Metric	**Components Supported by Indicator**
• The total number of wastewater discharge sites (of all types of discharge) occurring within a watershed (#/watershed)	• Water Quality
Benchmarks	
• No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.	
Data Sources	**Data Assumptions**
• Ministry of Environment (MOE) Authorizations Database	• Only active wastewater discharge sites are included in the assessment.
Data Limitations	
• Waste discharge point location accuracy may vary. Further investigation into waste water type and volume, and potential effects of discharge would be required to determine potential effects on a watershed.	

3.13 Water Withdrawals (#/Watershed)

Scientific Context
Heavy use of both surface and hydraulically connected subsurface water for human purposes can affect salmonid habitats at critical times of year by reducing instream flows to levels that could constrain physical access to spawning and rearing habitats or potentially dewater fish spawning habitats (redds) (Richter et al. 2003). Reductions in both surface water and ground water supplies can also increase water temperatures with resultant impacts on all fish life stages (Hatfield et al. 2003; Douglas 2006).

Indicator Metric	Components Supported by Indicator
• The total number of provincial water licence points of diversion occurring within a watershed (#/watershed)	• Water Quantity

Benchmarks
• No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.

Data Sources	Data Assumptions
• BC Points of Diversion: WHSE_WATER_ MANAGEMENT.WLS_POD_LICENCE_SP	• Only water licences identified as active or applications are used in the assessment.

Data Limitations
• Information describing water licences (long term use) does not account for water allocated or used through temporary water permits (short term use).
• The data is simply count data and further investigation is necessary to be able to infer quantitative impacts to water quantity.
• Future iterations may include inclusion of water quantity withdrawals (volume) within a specific watershed.

3.14 Dams (#/Watershed)

Scientific Context	
Dams (natural and/or man-made) can affect flows, alter water quality, simplify channel morphology, and create barriers or impediments to fish movement (Meehan 1991). Restricted access to spawning streams and/or lakes can have consequent impacts to fish survival and productivity (Stantec 2007).	
Indicator Metric	**Components Supported by Indicator**
• The total number of dams occurring within a watershed (#/watershed)	• Water Quantity • Aquatic Habitat
Benchmarks	
• No benchmarks have been defined yet for this indicator. This requires further review of potential benchmarks based on literature and expert opinion.	
Data Sources	**Data Assumptions**
• Dam Lines: WHSE_WATER_MANAGEMENT.WRIS_DAMS_PUBLIC_SVW	• All dam types are included in the assessment.
Data Limitations	
• This is a basic count of dam features based on linear features. Further investigation into water storage capacity, flow, etc., would be required to determine potential effects on a watershed.	

4 Component Assessment

The indicator with the highest hazard ranking as determined by its associated benchmark value is used to represent the component for each of the three categories (below). This method of assessment is based on the assumption that all core indicators within a component have equal importance, which is consistent with some components of the Coastal and Interior Watershed Assessment Procedures (CWAP; IWAP) but a deviation from others where indicators are combined and averaged. If new information on indicator weighting becomes available across the province, this approach may be revised.

- **Component: Water Quantity**
  - Indicators:
    - Peak flow Index
    - Total road density
- **Component: Water Quality**
  - Indicators:
    - Total road density (weighted for road type/use)
    - Density of roads within 100m of a stream (weighted for road type/use)
    - Road density on potentially unstable slopes
    - Stream crossing density
    - Riparian Disturbance
- **Component: Aquatic Habitat**
  - Indicators:
    - Density of roads within 100m of a stream
    - Road density on potentially unstable slopes
    - Stream crossing density
    - Riparian Disturbance

4.1 Aquatic Ecosystem Value Summary

All components are assumed to be equally important in terms of aquatic ecosystem function. The component with the highest hazard category is considered the limiting factor within each AU and thus it is the highest ranked component that is represented in the overarching Aquatic Ecosystem Value. This type of representation allows for a coarse-level review and comparison across many watersheds with the ability to immediately identify those that might require special management. Further investigation into the specific components and indicators can then be conducted for the watersheds of interest.

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6 Appendices

Appendix 1: Regional Modifications to the Provincial Protocol

The provincial protocol described in this document intends to apply a specific set of indicators consistently across the province. However, in some regions, assessment procedures may vary from the provincial protocol to include additional information, reduce uncertainties and improve assessment results.

Modifications may have been made as a result of one or more of the following:

- The availability of regionally-validated assessment information,
- Additional available regional datasets, field-based data or regional research to better support the assessment,
- Incorporation of local knowledge,
- First Nations involvement in the development of additional indicators,
- Extension and review with Communities of Practice that include First Nations, licensees, or others, and/or
- Refinement of condition, hazard and/or risk where applicable.

Both provincial and regional approaches are consistent over broad scales in flagging watershed condition/aquatic ecosystem concerns that warrant further exploration.

Over time, consistency across regions and with the provincial protocol will be sought where possible and will be continuously improved as new information becomes available.

Currently, regional modifications exist within the Thompson Okanagan, Cariboo and Omineca Natural Resource Regions (Figure A1-1). Details on these modifications are provided below.

Figure A1-1. *Natural Resource Regions where regional modifications exist*

Thompson Okanagan & Cariboo Regions

Background

The Thompson Okanagan Watershed Assessment Procedure (THOK Procedure) (Lewis et al. 2016) is based on a watershed risk analysis developed in the Kamloops Timber Supply Area (TSA) through partnership between MOE and forest licensees in 2006 in response to the Mountain Pine Beetle (MPB) outbreak.

The original Kamloops TSA analysis was intended to identify watersheds sensitive to natural disturbances such as MPB, forest harvest effects, and key elements at risk. The approach was expanded to present a GIS indicator-based watershed risk assessment procedure applicable for a broad scale assessment of cumulative watershed effects in snowmelt-dominated hydrologic regime in the southern interior of British Columbia.

The THOK Procedure was later adopted by Cariboo Region. **Both regions follow the same assessment procedure.**

Overall, for the THOK and Cariboo regions, modifications to the provincial protocol were focused on the following areas: assessment approach and conceptual model, assessment methodology, indicators and benchmarks, and improved data and local research. Further details on the modifications and the differences between the provincial protocol is provided below.

Assessment Approach & Conceptual Model

The THOK Procedure describes a GIS assessment methodology for assessing cumulative watershed effects. Within each hazard category (streamflow, sediment and riparian), indicators represent watershed characteristics and land use activities that affect key hydrologic and geomorphic processes (Figure A1-2). The indicators used in the THOK Procedure are combined to form ratings that are used as outputs from the procedure.

The approach enables the consequence to various downstream elements that may be at risk from potentially harmful changes in watershed processes to be incorporated into the watershed risk analysis. Elements at risk that can be considered are related to watershed-level values for which broad or specific objectives may apply and include, but are not restricted to, aquatic ecosystems, fish, road infrastructure, private land, human health and safety, water quantity, and water quality.

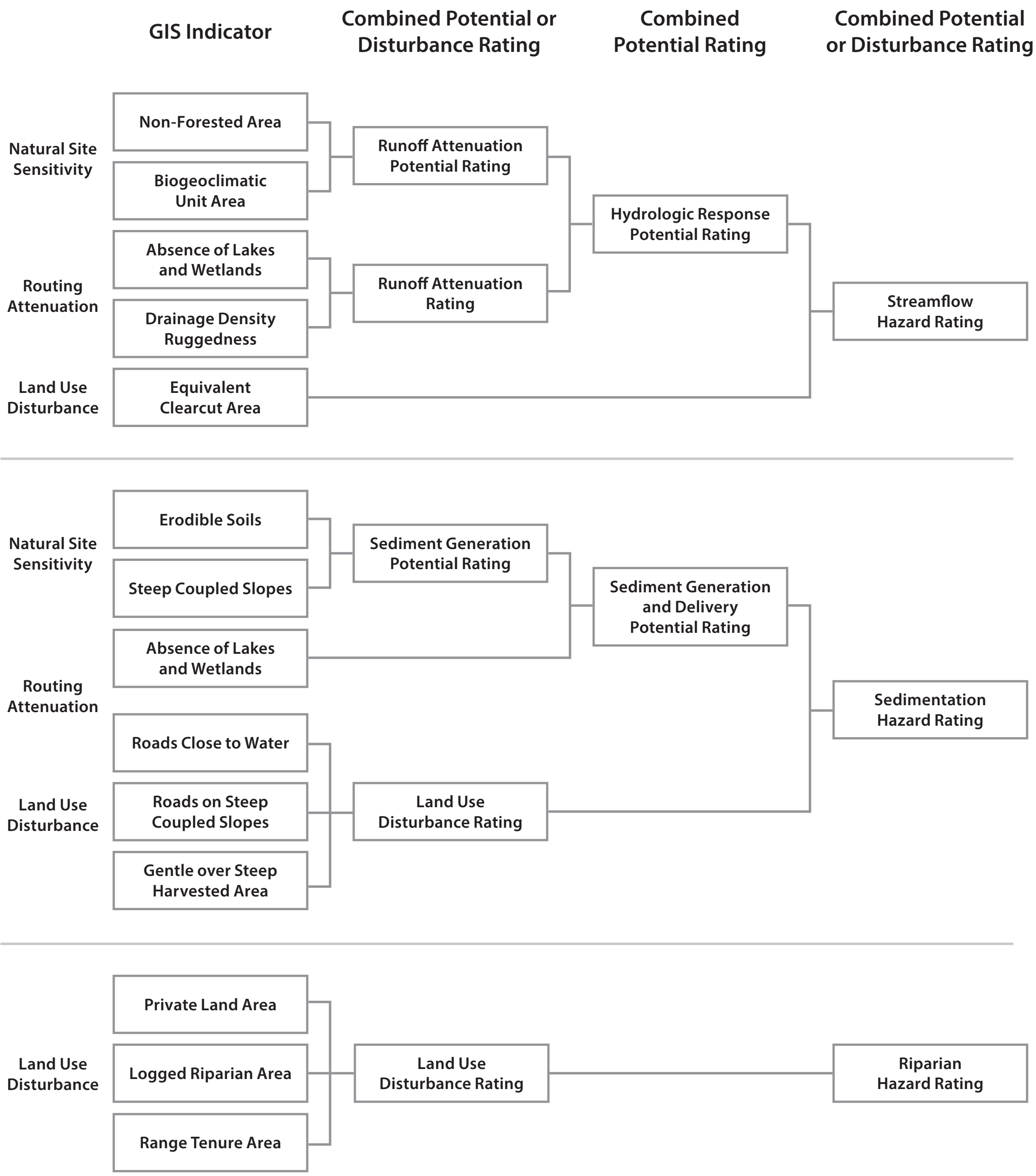


Figure A1-2. *Flowchart illustrating the relationship of combined indicators in the THOK Procedure.*

Assessment Units

Assessment units use the BC Freshwater Atlas (FWA; http://geobc.gov.bc.ca/base-mapping/atlas/fwa/) 1:20,000 Watershed Assessment Unit boundaries (Carver and Gray, 2010) as the base units. The assessment units are combined to create a hierarchical structure consisting of Super Watersheds, Large Watersheds, Watersheds, Basins, Sub-Basins and Residual Units, hereafter collectively referred to assessment units. Information is assessed at multiple watershed scales allowing for multi-scale interpretation of assessment results.

Assessment Methodology

The THOK procedure expands the indicator reporting and roll-up method outlined in the provincial protocol to include the concepts of hazard and consequence to determine risk.

The TOK assessment procedure incorporates a risk-based approach, where risk is the product of hazard and consequence defined by the risk equation: **Risk = Hazard x Consequence**. *Hazards* in this case are a source of potential harm, or a situation with a potential for causing harm in terms of human injury, damage to property, the environment, and other things of value – or some combination of these. Hazard ratings are the measurement or expression of the likelihood of hazard occurrence. In watershed management hazards can include:

1. **Streamflow effects** – increases the frequency and magnitude of hydro-geomorphic events (floods, bank erosion, channel instability, debris floods and debris flows),
2. **Sediment generation and delivery** – reduced water quality as a result of sediment or other deleterious material input to streams from roads, landslides or other upslope sources, and
3. **Riparian Function** – reduced channel bank stability, stream shading and large woody debris inputs.

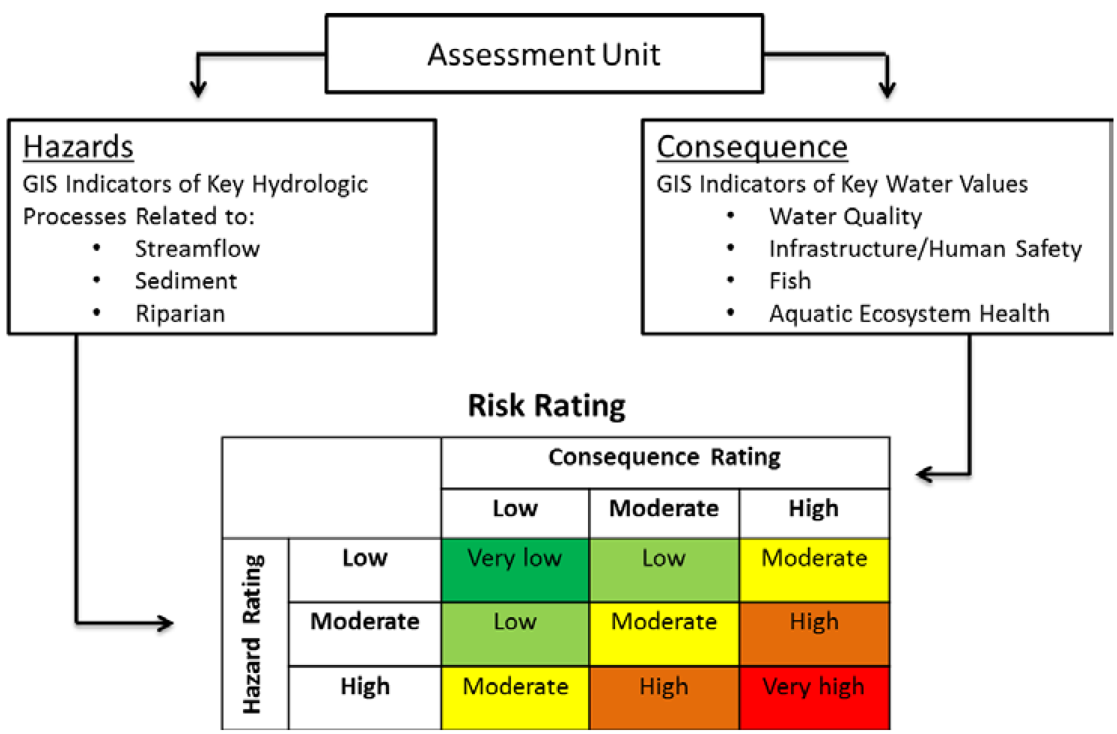


Figure A1-3. *Hazard, consequence and risk rating used in the THOK Procedure.*

Indicators and Benchmarks

The THOK Procedure includes a number of indicators that are slightly different than those presented in the provincial protocol. The THOK Procedure includes additional and/or enhanced indicators that have been developed using regional subject matter input and review processes that reflect regional specificity for the value. Benchmarks were based on scientific literature or local expert judgement where literature is limited.

Table 2. *Comparison of Provincial and TOK indictors, methodology and benchmarks.*

Provincial Indicator	TOK Indicator	TOK Method	TOK Benchmarks
Road density < 100m from stream	Roads close to water	Proportion of total road length within 50m of stream	Reported as a percentage and given a score 1 = < 10% 2 = 11-30% 3 > 30%
Road density on unstable slopes > 60%	Roads on steep coupled slopes	% total road length on slopes > 50% coupled (within 50m) of stream	Reported as km of road on coupled slopes and given a score 1 = < 0.005 2 = 0.005-0.01 3 = > 0.01
Riparian disturbance	Logged riparian area	% total stream length within 30m of logged	Reported as a percentage and given a score 1 = < 20% 2 = 21-40% 3 > 40%
Peak flow	Streamflow Hazard	Runoff generation potential corrected for attenuation factors and applied to % ECA	Dependent on % ECA. Dimensionless equivalent values are: 0-0.20 = Very Low 0.21-0.3 = Low 0.31-0.42 = Mod 0.43-0.55 – High 0.56-1.00 = V.High
Total land disturbance (no provincial benchmarks)	N/A	N/A	N/A
Alpine Non-Forested Area (no provincial benchmarks)	Alpine Non-Forested area	% of non-forested natural alpine areas and associated features (ice/snow, rock/rubble, moraine) relative to total AU; combined with BEC Unit Score to generate Runoff Generation Hazard Rating	Grouped by percentage range. < 30 % 31-70% > 70%
Absence of lakes and wetlands (no provincial benchmarks)	Absence of lakes and wetlands	Area-weighted proportion (%) covered by lakes and wetlands by weighting the area by 100% in the lower 30% of the AU, 75% in the next higher 30% of the AU and 25% in the upper 40%; combined with Drainage Density Ruggedness to generate Runoff Attenuation score	Grouped by location weighted percent area 0 – 2 2.1 – 6 > 6.1
Drainage density ruggedness (no provincial benchmarks)	Drainage density ruggedness	Combines with Absence of Lakes & Wetlands score to generate a Runoff Attenuation Score	Grouped by binned score. < 2000 2001 – 4000 > 4000
Biogeoclimatic unit Score	Biogeoclimatic unit Score	Expert assigned values by BEC variant	Area-weighted

Provincial Indicator	TOK Indicator	TOK Method	TOK Benchmarks
N/A	Erodible soils	% of AU (quaternary deposits)	Grouped by percentage range. < 10 % 11-20% > 20%
N/A	Steep coupled slopes	Slopes > 50% and base of slope within 50m of stream as a % of AU	Grouped by percentage range. < 10 % 11-20% > 20%
N/A	Gentle over steep harvested area	% of reporting unit with logged area above steep coupled slopes	Reported as a percentage and given a score 1 = < 5% 2 = 5.1-10% 3 = > 10%
Proportion of private land in the watershed	Private land area	% of total stream length within private land	Reported as a percentage and given a score 1 = < 20% 2 = 21-40% 3 = > 40%
N/A	Range tenure area	% total stream length within tenure	Reported as a percentage and given a score 1 = < 30% 2 = 31-60% 3 > 60%
Road density (km/km^2)	N/A		
Stream crossing density	N/A		
Mines	N/A		
Permitted waste discharge	N/A		
Water withdrawals	N/A		
Dams	N/A		

Data/Research:

Work has been done to validate the hazard ratings with field-based riparian and channel assessments targeted across a range of watershed hazard conditions. Targeted riparian assessments across several watersheds and basins that vary in hazard ratings have been completed or are currently underway.

Omineca Region

Background

The Watershed Health Project Omineca Region (WHPOR) was initiated in 2016 to assess the condition of regional watersheds that had experienced more than a decade of disturbance from the MPB epidemic and subsequent salvage harvesting. The objective of the project was to identify current hazard conditions and provide insight to future hazard condition of regional watersheds to inform planning and land-use decisions.

Provincial and international watershed assessment protocols were reviewed to identify consistency of indicators as well as innovative approaches to identifying watershed hazard, risk, or health. Although there were numerous approaches it was recognized that the type of data used in many of these approaches (e.g. water quantity and quality) was not available at sufficient spatial or temporal scope in B.C. and in the Omineca Region specifically.

Consequently, other provincial programs such as interior and coastal watershed assessment procedures (IWAP/CWAP-BCMOF 1995, 1999), watershed evaluation tool (Reese-Hansen 2014), and a cumulative effects model for the Thompson Okanagan Region (Lewis et al., 2014, 2016) were considered to be best suited for the Omineca regional analysis.

Following review, the assessment method used for the Thompson-Okanagan was selected for application in the Omineca. It was selected because it drew upon some of the geophysical hazard indices and thresholds from the well-known IWAP/CWAP procedures and incorporated some measures of watershed sensitivity including transport efficiency such as coupled slopes and drainage density as well as biogeoclimatic zones as a measure of snow load, and the presence and location of wetlands and lakes as potential buffers.

The WHPOR is a level 1 GIS–based assessment that can be used to compare relative geophysical hazard across regional watersheds. The protocol uses a series of watershed sensitivity and development indicators to identify the potential geophysical hazard for peak flow, sediment generation and transport to streams, and riparian condition.

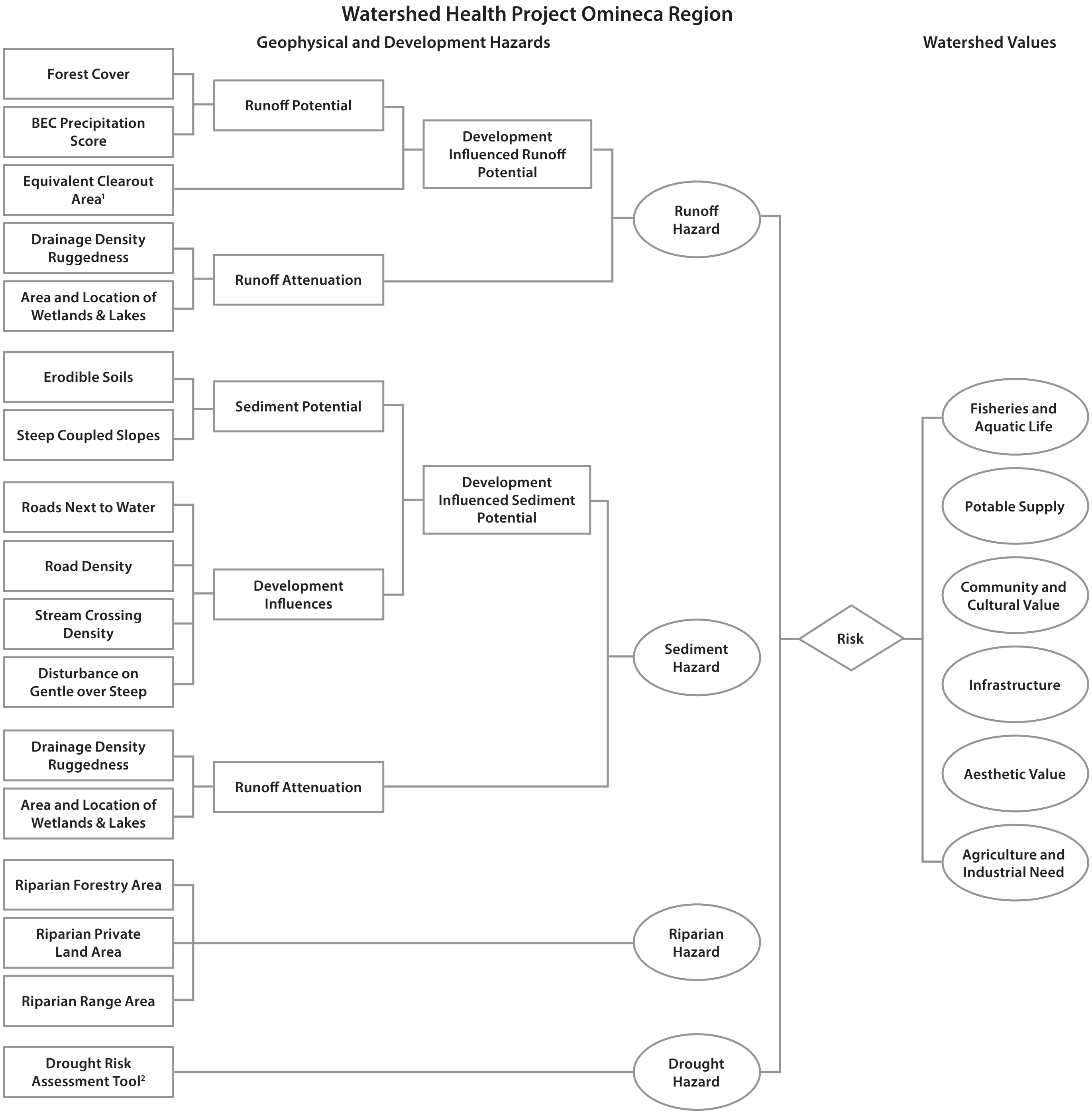
Program and objectives were to:

- Update watershed assessment procedures by developing a regional watershed health assessment protocol merging physical and biological/resource value information to identify current hazard and risk conditions.
- Inform resource managers and decision makers by classifying watersheds as high, moderate and, low hazard/risk along with the rationale for that classification for all watersheds in the Omineca Region.
- Support community sustainability and resource development by informing communities and developers of current watershed conditions.

Assessment Approach & Conceptual Model

In keeping with the IWAP/CWAP, the Lewis et al. (2014, 2016) model uses a series of development indicators to assess hazard but it also brings in geophysical indicators to identify relative watershed hazard ratings for streamflow, sediment, and riparian conditions (Figure A1-3). This approach is consistent for the Omineca region, however, an estimate of drought hazard as well as bringing in aquatic resource values to assess relative risk are also included (Figure A1-4).

Hazard and risk should be considered separately because they may differ. For example, using this approach there may be a low or moderate sediment risk estimated for a watershed because a large lake at the outlet of the watershed provides adequate buffering to reduce sediment export from the watershed. The sediment that settles in the lake may be a moderate to high risk for aquatic life in the lake.



[1] Winkler R. and S. Boon. 2017. Equivalent cleancut area as an indicator of hydrologic change in snow-dominated watersheds of southern British Columbia. Prov. B.C., Victoria, B.C. Exten. Note 118. www.for.gov.bc.ca/hfd/pubs/Docs/En/En118.htm
[2] Foord, V.,C. Delong, and B. Rogers. 2017. A Stand-Level Drought Risk Assessment Tool for considering climate change in forest management. Prov. B.C., Victoria, B.C. Exten. Note 119. www.for.gov.bc.ca/hfd/pubs/Docs/En/En119.htm

Figure A1-4. *Flowchart illustrating the approach applied in the Omineca Region which uses the indicators and hazards from Lewis et al (2014, 2016) along with the addition of stream crossing density, drought hazard (Foord et al., 2017) and aquatic resource values to allow identification of risk, as well as a revised estimate for ECA (Winkler and Boon, 2017).*

Assessment Units

Assessment units use the BC Freshwater Atlas (FWA; http://geobc.gov.bc.ca/base-mapping/atlas/fwa/) 1:20,000 Watershed Assessment Unit boundaries (Carver and Gray, 2010) as the base units. The assessment units are combined to create a hierarchical structure consisting of Super Watersheds, Large Watersheds, Watersheds, Basins, Sub-Basins and Residual Units, hereafter collectively referred to assessment units. Information is assessed at multiple watershed scales allowing for multi-scale interpretation of assessment results.

Assessment Methodology

The WHPOR uses the approach of Lewis et al. (2014, 2016) with some regional modifications. The following section identifies the changes that were made to the approach subsequent to regional validation and additional hazards and indicators in the WHPOR. Additional detailed information on these modifications is available upon request to Cumulative.Effects@gov.bc.ca.

Stream Flow Hazard:

BEC Precipitation Score: Using the scale provided in Lewis et al. (2014, 2016) Omineca BEC zones not represented in the Thompson-Okanagan were relatively ranked according to snow accumulation estimates provided by BEC classification (DeLong et al., 1993 and 1994).

Equivalent Clearcut Area (ECA): Research on ECA from nival (snow-melt dominated) environments aims to document differences in snow accumulation, energy fluxes and melt rates between clearcut openings, mature, regenerating, and insect attacked forests (Winker et al. 2010, 2015; Winkler and Boon 2015, 2017). ECA is calculated for each disturbed area by applying an appropriate net-down factor to the total disturbed area, based on tree height as an index of relative hydrologic recovery in the regenerating forest (Figure A1-5). The total disturbed area is then identified as a proportion of the total watershed area to determine the watershed ECA.

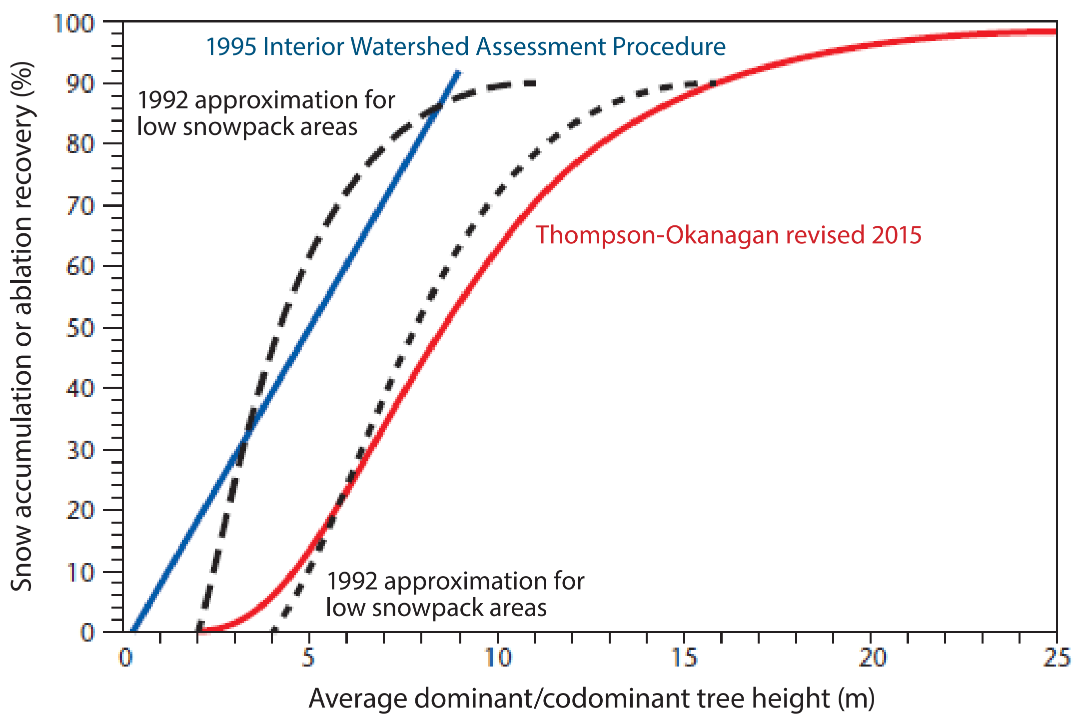


***Figure A1-5.** Comparison of the 1992 low and high snowpack snow recovery curves and the 1995 watershed assessment procedure estimates with the revised curve from 2015 (Source Winkler and Boon, 2015).*

Openings are identified using forest tenure information as well as other land tenure information from Tantalis, and the vegetation resource inventory (VRI) information to identify type and year of disturbance followed by projected tree heights and published hydrologic recovery rates (Winkler and Boon, 2015). Perpetually deforested areas such as urban, agricultural, highways, transmission right of ways were given an ECA of 100% (Table 3). Road use permit information and associated buffers were used to determine affected area. Recent wildfires were modelled the same as clearcut areas assuming these have limited residual structure to influence hydrologic function. For partial forest disturbances (i.e. partial cuts, un-harvested insect attacked stands) ECA values were net-down by factoring in the relative hydrologic function contributed by residual forest cover and forest re-growth in the time since disturbance.

For partial cut forests, we followed estimates provided in the interior Watershed Assessment Guidebook (BC Ministry of Forests, 1999). We applied ECA net-downs for un-harvested Mountain Pine Beetle (MPB) -attacked forests for different BEC subzones using predicted pine mortality (Walton, 2010) with modelled ECA estimates from Lewis and Huggard (2010) to incorporate the hydrologic function of non-affected pine and non-pine overstory and understory trees.

Table 3. *Equivalent clearcut area estimates by tree height and land use.*

Tree Height (m)	ECA	Land Use	ECA
0-2	100	Private and Agricultural Lands	75
2-3	99.8	Gravel Pits, Mines, Roads, Railway, and Pipelines	100
3-4	96.9	Right of Ways (Powerlines)	100
4-5	90.1	FTEN Cutblocks (not in results)	100
5-6	80.7	Wildfires <25 years	100[1]
6-7	70.1	Harvest Authority	na[2]
7-8	59.5	Road Buffer Widths by Road Type • In-Block Roads – 10m • FSR & Road permits – 20m	
8-9	49.7		
9-10	40.9		
10-11	33.3		
11-12	26.9		
12-13	21.7		
13-14	17.3		
14-15	13.8		
15-16	11.0		
16-17	8.7		
17-18	6.9		
18-19	5.4		
>19	0.0		

1 Wildfire inventory information is not consistently available so conservative re-growth estimates selected until field data available.

2 Harvest authority permits can include occupant licence to cut permits with extended dates such that permits or licences issued more than 5 years ago remain as an active status. Depending upon density and footprint of these licences there may be substantial associated ECA.

The 2017 VRI dataset focuses on live stand volume, consequently in those areas affected by the MPB infestation there can be an underestimation of the amount of wood standing or fallen that can still play a role in interception and sublimation. To address this issue, pine content information was brought forward from the 2014 dataset to 2017 so that it was not lost and that Lewis and Huggard (2010) ECA estimates could be applied.

There are instances where VRI information may not agree with the polygons from results or forest tenures openings. For example, an opening or proportion of an opening may remain unharvested yet not be identified as reserve in the VRI. This can occur as a result of the delay in updates to VRI as well as results or opening layers so the default approach taken was to accept the opening information and identify the area separate from other harvested areas as “presumed logged”.

Sediment Hazard

Stream Crossing Density: This was added to the sediment hazard indicator profile because stream crossings can be point source additions of sediment from forest roads to streams

(Carson and Maloney, 2013; Rex and Carmichael,2002). The thresholds selected for this indicator were drawn from the IWAP conversion table for low hazard (< 0.32 crossings/km^2), moderate hazard (0.32 to 0.6 crossings/km^2) and high hazard (> 0.6 crossings km^2).

Riparian Disturbance

Riparian disturbance was estimated by overlaying forest blocks, private land, and range tenures to identify their intersection with riparian zones identified here as being within 20m of stream lines for private land and forest harvesting. Range tenure did not have a buffer however, to ensure it captured cattle operations rather than guide outfitting cattle had to be identified in the polygon attributes. The Omineca approach considers all streams equal, there was no weighting of effect based on stream size as per the original approach (Lewis et al., 2014).

Further, based on the findings of Nordin et al (2009) the threshold for riparian disturbance from forestry or private lands was changed such that riparian intrusion of either type over 30% was identified as a high hazard. Consequently, for both private lands and logged riparian the low category was revised to less than 10%, moderate 11-30%, and high was > 30% riparian intrusion.

Drought Hazard

Drought is associated with an extended period of lower soil moisture and water supply relative to normal levels. Climate change will alter regional temperature and precipitation patterns as well as their extremes including floods and drought. Drought caused by recent regional warming, is believed to be a leading cause of tree mortality.

To identify potential influence of drought on forest stands a collaborative research project involving ecology, soils, and climate researchers was initiated in 2009 under the future forest ecosystems program. This research led to the development of a drought risk assessment tool that predicts tree species mortality risk by BEC variant for projected climatic conditions in 2050 and 2080 (Figure A1-6). It does so by modeling future water balance as relative to absolute soil moisture conditions to identify tree species drought risk at the stand level (Foord et al., 2017).

Currently the tool is available for the Prince George, Cranbrook and Williams Lake TSA’s with hopes of expanding to other areas. This tool will be incorporated into the regional watershed evaluation to identify relative proportion of drought-prone areas. Development is underway in collaboration with developers of the tool.

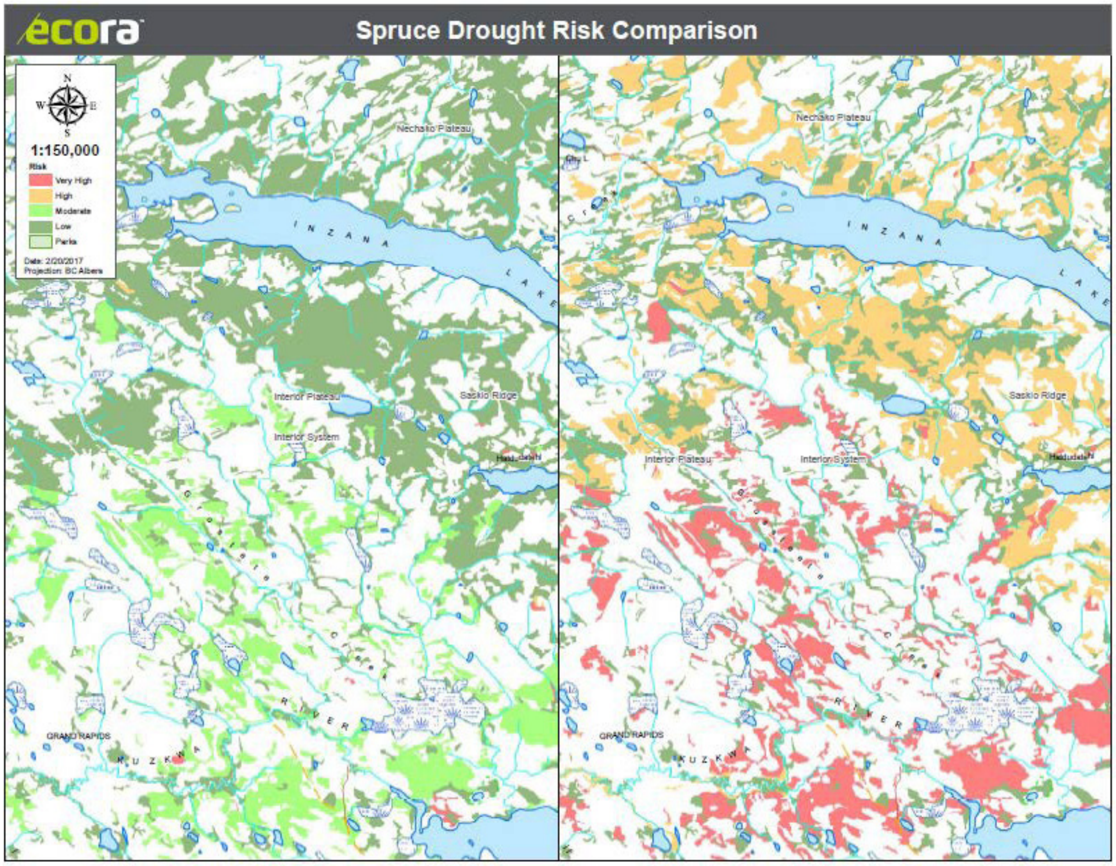


__Figure A1-6.__ Drought risk assessment tool projections for current (left) and 2080 (right) drought risk to mature hybrid spruce in the Inzana Lake area of the Stuart-Nechako District (Figure 2 from Foord et al., 2017)

Future Research:

It is expected that new indicators will be added to the Omineca approach and thresholds will change as science evolves. Future iterations should include ecosystem process information as well as climate change and hydrologic change. As a level 1 assessment tool, the information provided by this process should be updated annually at minimum after winter harvest to help inform decision-making including identifying those watersheds that require more detailed watershed and channel assessments.

Appendix 2: GIS Data Dictionary, Data Inputs, and Indicator Criteria

Indicator definitions, data inputs, output field descriptions, land ownership, and development pseudo-base thematic mapping categories, ECA recovery curves, and BEC sensitivity scores used for Aquatic Ecosystems GIS assessment can be found in the following Microsoft Excel Spreadsheet, available on the CEF Website:

https://www2.gov.bc.ca/gov/content?id=0B16F0B13318402786667E95F064DA93

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