Tier I Fisheries Sensitive Watersheds (FSW) monitoring protocol

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1.0 Introduction

1.1 What is properly functioning condition?

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

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

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

1.2 How is functioning condition assessed?

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

2.0 Components of FSW Tier 1 Monitoring

2.1 Describe the FSW

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

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

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

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

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

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

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

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

2.3 Indentify Tier 1 indicators and associated metrics

2.3.1 Indicator Category: Peak Flow

Metric: ***Peak Flow Index***

How is Peak Flow Index calculated?

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

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

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

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

How are results interpreted?

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

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

How is Equivalent Clear-Cut Area calculated?

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

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

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

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

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

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

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

Table A2.2 in MOF 2001.

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

How are results interpreted?

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

2.3.2 Indicator Category: Surface Erosion

Metric: ***Road density for entire sub-basin (km/km^2)***

How is road density for entire sub-basin calculated?

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

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

How are results interpreted?

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

Metric: ***Road density above the H60 line*** **(km/km^2)**

How is road density above the H60 line calculated?

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

How are results interpreted?

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

Metric: ***Road density <100m from a stream (km/km^2)***

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

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

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

How are results interpreted?

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

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

How is road density on erodible soils calculated?

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

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

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

How are results interpreted?

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

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

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

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

How are results interpreted?

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

Metric: ***Stream Crossing Density (no./km^2)***

How is stream crossing density calculated?

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

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

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

Metric: ***Road Density on unstable slopes (km/km^2)***

How is road density on unstable slopes calculated?

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

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

How are results interpreted?

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

2.3.3 Indicator Category: Riparian Buffer

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

How is portion of streams logged calculated?

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

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

How are results interpreted?

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

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

How is portion of fish-bearing streams calculated?

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

How are results interpreted?

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

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

How is indicator calculated?

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

How are results interpreted?

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

2.3.4 Indicator Category: Mass Wasting

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

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

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

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

How are results interpreted?

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

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

How is density of landslide in the watershed calculated?

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

How are results interpreted?

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

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

How is ESGA calculated?

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

How are results interpreted?

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

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

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

2.4 Tier 1 assessment of functioning condition of FSW

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

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

3.0 Next steps/recommendations

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

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

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

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

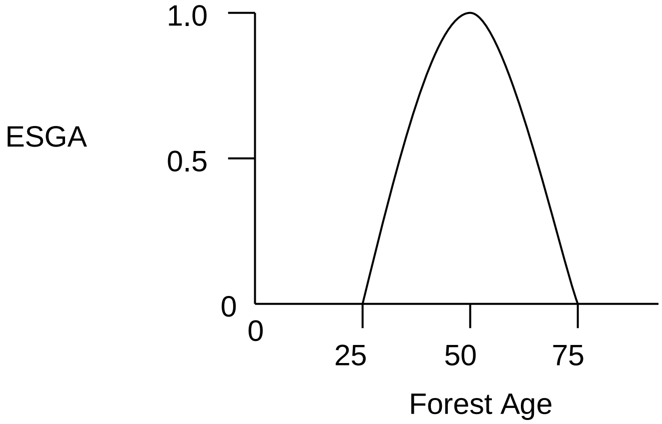

Figure A1. Suggested relationship between forest age and an equivalent second growth area (ESGA) metric for effects on watershed low flows. Shape of relationship is unknown so assumed linearly ascending annual ESGA scores from 0-1 between 25 and 50 years and linearly descending ESGA scores from 1-0 between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

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

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

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

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

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

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

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

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

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

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

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

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

References

Perry, T.D. 2007. Thesis: Do vigorous young forests reduce streamflow? Results from up to 54 years of streamflow records in eight paired-watershed experiments in the H. J. Andrews and South Umpqua Experimental Forests. Masters Thesis. Oregon State Univ., Corvallis, Ore.) http://andrewsforest.oregonstate.edu/pubs/webdocs/reports/pub4297.pdf

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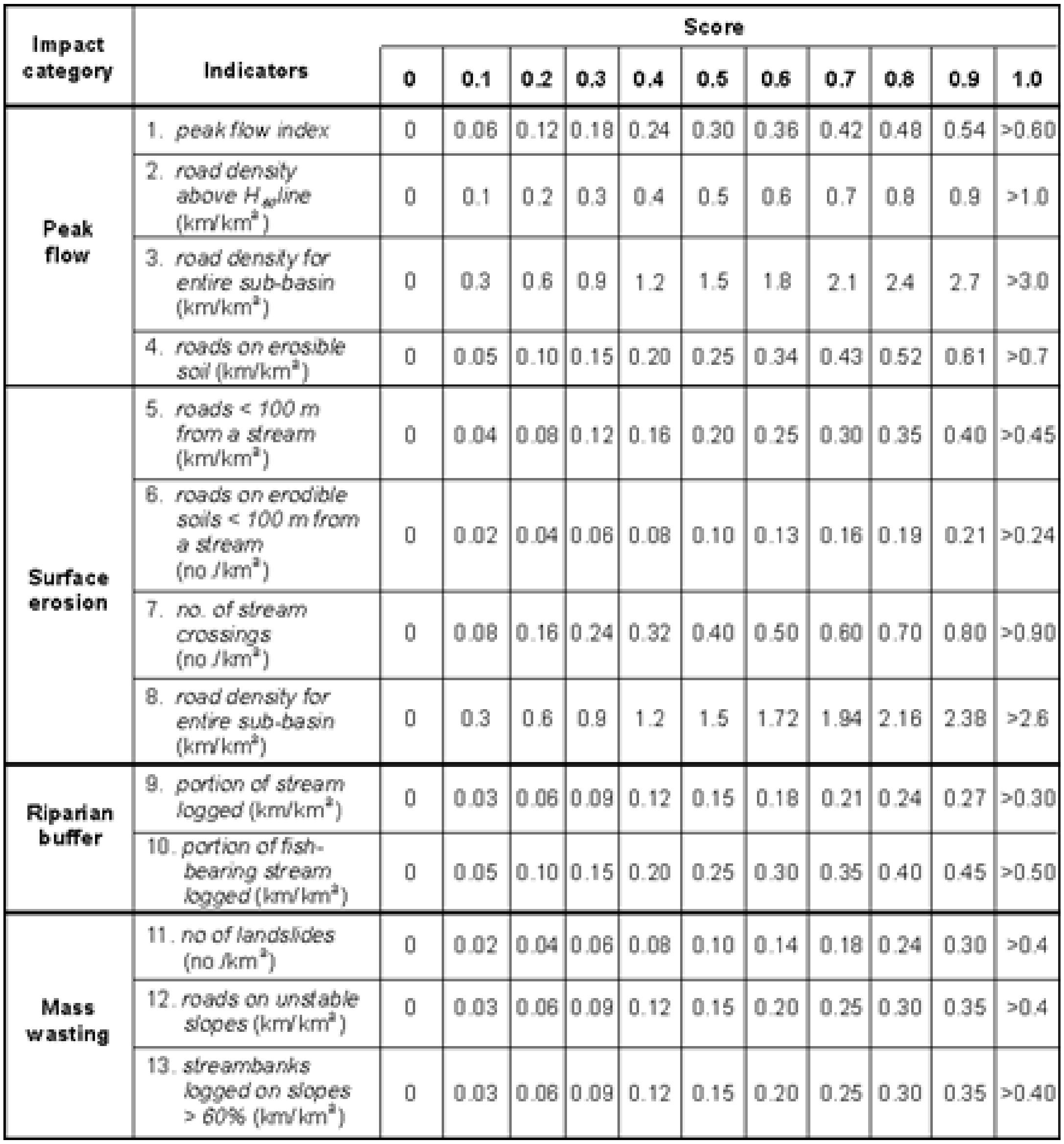
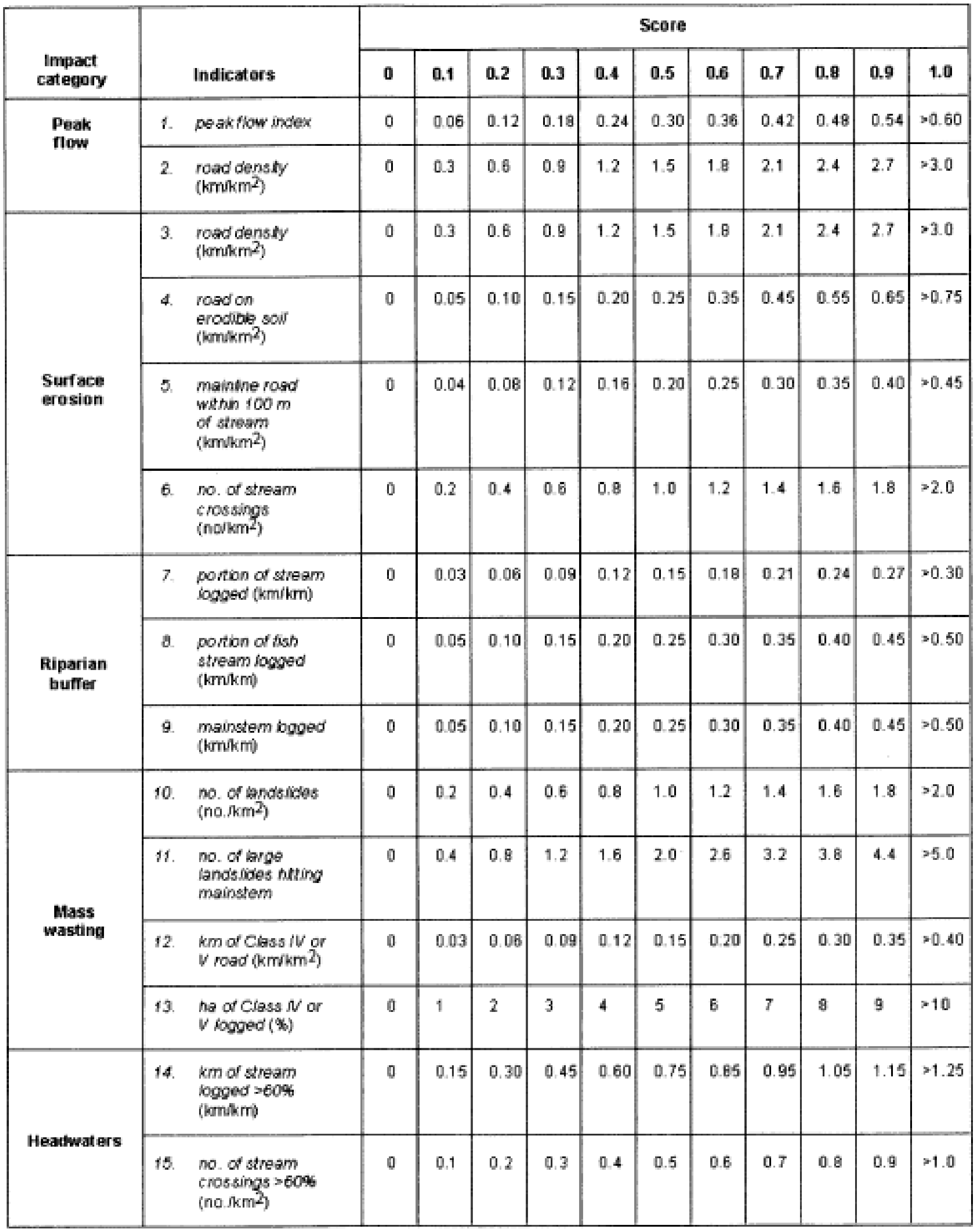
Appendix 2. IWAP and CWAP Level 1 assessment conversion tables (Table A1 and A2) for scoring WAP indicator values.

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



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

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



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