Tier II watershed-level fish values monitoring protocol rationale

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

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1.0 Introduction

1.1 Background

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

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

1.2 Report purpose

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

2.0 Field-Based Indicators and Protocols

In order to promote greater harmonization of monitoring approaches across the province and to leverage past efforts, field-based data inputs into the decisions for the Tier II watershed-level fish values monitoring program will be a combination of performance measures collected using existing Forest and Range Evaluation Program (FREP) and BC MOE protocols. These are rapid assessment protocols that have been developed for evaluating the condition of streams and riparian areas (Tripp et al 2009), assessing water quality (Carson et al. 2009) and determining impairments to fish passage (BC MOE 2009). Rapid assessment protocols are cost effective assessments that use semi-quantitative methods to quickly collect, compile, analyze, and interpret environmental indicator data to facilitate management decisions (Barbour et al. 1999).

The indicators used by FREP were selected by a multi-agency and multi-disciplinary team of scientists and technical specialists that evaluated a large number of potential indicators assembled from a thorough review of scientific and technical resource management literature. Criteria used for indicator selection included foundation in reliable scientific data; relevance and responsiveness to forestry practices, particularly riparian management and road systems; broad geographic coverage; and capability to measure changes in ecological processes and conditions (Tschaplinski and Brownie 2010). FREP's Riparian Protocol utilizes a suite of over 50 indicators, allowing comprehensive assessment of both biological and physical components of stream/riparian ecosystems. The Tier II watershed-level fish values monitoring initiative will benefit from incorporating the data collection methodologies already established under FREP and MOE by: 1) achieving efficiencies in cost of program development and personnel training; 2) establishing data compatibility across sites that are monitored under different programs; and 3) allowing for potential comparisons between FSWs and other designated watersheds and non-designated watersheds across the province.

3.0 Monitoring Design

3.1 General overview of alternatives

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

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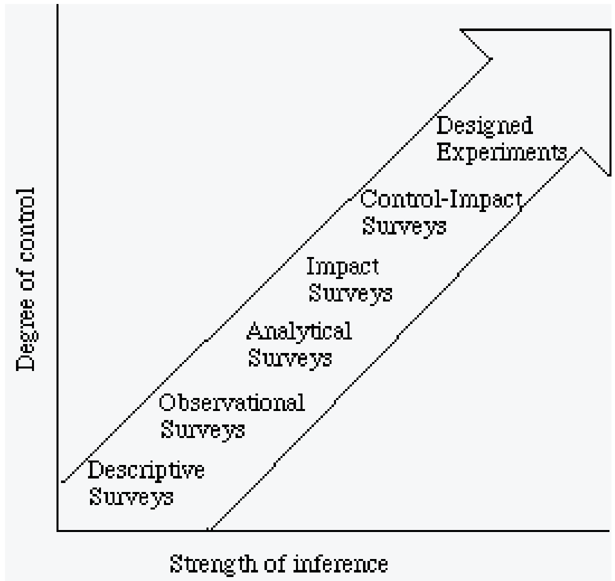

Figure 1. Relationship between degree of control, strength of inference (and ability to determine causation), and type of study design (modified from Schwarz 2006).

3.2 Description of target population

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

3.3 Temporal considerations

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

Within years: As habitat conditions within watersheds will vary seasonally (e.g., temperature, stream flow, vegetation cover, etc.) it will be important to be consistent with the timing of sampling and reporting of indicator metrics. Optimal timing could relate to critical periods in the ecology of the watershed, key components of forest management actions or logistical issues around sampling. The FREP protocols for riparian and water quality monitoring as well as the MOE Fish Passage protocols that in combination will be used for Tier II watershed-level fish values monitoring already incorporate these factors into their guidance documents (Tripp et al.

2009; Carson et al. 2009, MOE 2009) and suggest that the optimal period for sampling is between late spring, when all snow has left sampling areas and mid autumn, before the snow returns. The actual months when these conditions apply will vary regionally.

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

3.4 Sampling frame

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

3.5 Stratification options

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

Various potential stratifications for Tier II sampling have been considered based on distinct factors that could influence watershed condition and the habitat response to watershed management actions. Tier II stratifications explored for use in a Tier I and Tier II monitoring pilot study undertaken in the Lakelse drainage of BC's Skeena region in 2011 were:

STRATA:

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

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

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

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

Table 1. Summary of available GIS-based data layers that could be used to inform a Tier II sample frame and associated sampling strata.

Data layer	Data Source	Sample Frame
1:20 000 Freshwater Atlas: Stream Hydrology	GeoBC: LRDW	Stream reaches
1:20 000 Freshwater Atlas: Lakes	GeoBC: LRDW	Stream reaches
		Strata
Digital Road Atlas (DRA)	GeoBC: LRDW	Roads
Forest Tenure Roads (FTN)	GeoBC: LRDW	Roads
DKM roads	Regional Forest District	Roads
Vegetation Resource Index (VRI)	GeoBC: LRDW	Cutblocks, cutblock influence
RESULTS	GeoBC: LRDW	Cutblocks, cutblock influence
Digital Elevation Model (DEM)	GeoBase	Downslope cutblock influence (modeled)
Landsat, SPOT imagery	GeoBC: WMS	Cutblocks
Fish habitat classifications	GeoBC: LRDW	Fish Habitat
Fish passage obstructions (PSCIS)	GeoBC: LRDW	Fish barriers

Biogeoclimatic zones (BEC)	GeoBC: LRDW	Tree line and vegetation types

3.6 Selection of sites

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

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

3.7 Sample size

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

- estimates of variability of monitored indicators within and between sampling strata
- the desired level of accuracy/precision with which to address monitoring questions (i.e., how specific do our answers to these questions need to be and what amount of uncertainty (error) are we are willing to accept around these answers?)
- cost of sampling
- the time and cost of moving between sampling sites
- the significance test of interest (i.e., the difference between two groups or a significant trend over time)
- knowledge about the distribution of the data of interest

Pilot work in the Lakesle drainage has been undertaken to help determine the cost and logistical aspects of sampling across a watershed, and is being used (along with supporting data from past province-wide FREP and MOE water quality and fish passage surveys) from to develop initial estimates of variability within and between watershed sample units (reaches/strata). Within the Lakelse study area sampling was undertaken at a minimum of 4 sample sites per defined strata (where possible), while endeavouring to undertake sampling at the maximum number of sites possible (in the time available) in order to develop the best estimates possible of sample unit variability. While 3 sites would typically be a sufficient minimum sample to generate an average, use of the GRTS design (for which spatial balance is based on a four level quadrat recursive partitioning (Steven and Olsen 2004)) suggests that at least 4 sites should be sampled to maintain the required design assumptions.

4.0 Roll-up to categorize watershed condition

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

5.0 Incorporation of climate change indicators

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

6.0 Next steps/recommendations

Pilot work undertaken in the Lakesle and other drainages (as possible) will help to assess all practical aspects of developing a field-based Tier II monitoring program across multiple watersheds (i.e., cost, logistics, appropriateness of protocols in the field). Pilot data collection and analysis will also be needed to inform appropriate sample sizes for indicator monitoring and to assess the potential benefits and potential draw backs of incorporating various strata into the sample design. Existing datasets from prior agency monitoring are being assembled and will be used to supplement/support analyses from the Lakesle FSW pilot work (e.g. FREP inventories from throughout the province that can be used for developing estimates of sample unit variability; surveys of fish passage conditions at culverts throughout the province that can be used to assess possible biases in alternative designs being considered (Pickard et al. 2012) for selecting sites for fish passage and water quality sampling. A full discussion of required steps to implement a monitoring program for FSWs and other designated watersheds is provided in the workplan outlined in Pickard et al. 2009.

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