WORKING DRAFT

# Fish Values:

*Watershed Status Evaluation Protocol*

Ministry of Forests, Lands and Natural Resource Operations

Tripp & Assoc. Ltd.

Version 1.0

# Fish Values

*Watershed Status Evaluation Protocol*

*Prepared for:*
British Columbia Ministry of Forests, Lands and Natural Resource Operations and British Columbia Ministry of Environment

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Williams Creek (Darcy Pickard)



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# Acknowledgements

We would like to acknowledge the efforts of those responsible for the development of several Forest and Range Evaluation Program (FREP) monitoring protocols. These protocols[1] provide the foundation for the field-based component of the Fish Values: Watershed Status Evaluation Protocol (WSEP) described in this document. We would like to thank all of the volunteers who assisted in the pilot field data collection within the Williams, Memekay, and Wanokana Creek watersheds.  Funding for ongoing development of the Watershed Status Evaluation Protocol (WSEP) has been provided by MOE, FLNRO, ESSA Technologies Ltd., National Resources Canada (NRCAN), the Future Forest Ecosystems Scientific Council of British Columbia (FFESC), Tides Canada, and the Kitimat-Stikine Regional District (KSRD).

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

# 1 Introduction

Water and Fish are values that the Province of British Columbia manages and conserves to ensure they exist for future generations. Monitoring of these values is important so that government decision makers can understand how well we are doing relative to legal objectives and ecological benchmarks that reflect the status and sustainability of the value. Fish and their habitats are specifically recognized in B.C. through designations under several statutes (e.g., Forest and Range Practices Act, Oil and Gas Activities Act, and the Land Act). A designation under one of these statutes requires the respective sector(s) to operate such that they do not adversely impact aquatic habitat values necessary for fish. Assessing watershed status, and understanding the effectiveness of legalized watershed designations under these statutes, is critical to conserving Fish, Water and other associated values, and improving management activities occurring in these watersheds.

Historically, assessments of condition of stream habitats and organisms have typically occurred at a sub-watershed scale, for example: a 'representative stream reach', sometimes associated with a forestry 'cutblock', or an 'index stream'. The Watershed Status Evaluation Protocol (WSEP) described in this document instead uses the watershed boundary as the unit of assessment, enabling a better understanding of the status and relationships among all components of the watershed. This protocol could theoretically be applied to watersheds of any scale depending on the questions of interest; however, it was developed to assess watersheds of roughly 50 to 500 km2. Repeatable rapid biological assessment protocols were developed to collect key field data at a broad spatial scale with limited budgets. In addition, we provide an approach for integrating a broad suite of indicators from several protocols to describe watershed status. The WSEP was tested and refined during three pilot applications of the protocol: (a) in the Williams Creek watershed near Terrace (2011), Memekay River watershed near Campbell River (2012), and Wanokana Creek near Port McNeil (2013)

This document describes a standardized methodology for the WSEP, incorporating field and remote-sensed based monitoring of watershed status that can be applied to any high-fish-value watershed in the province of BC.

## 1.1 What is watershed status?

Watershed status refers to the combination and interaction of a variety of watershed components (i.e., upslope, riparian, and stream channel) that together provide the suite of hydrological, vegetation, soil, channel structure, thermal energy transfer and system productivity processes that create the conditions necessary to support fish (see Wieckowski et al 2007). The status of a watershed would be considered "good" if the overall state of these attributes is considered intact and sufficient to provide resilient fish habitats, and support a high diversity and abundance of associated aquatic and riparian-dependent species. Within the

WSEP, watershed status is not defined directly (i.e., there is not a single pooled score representing a direct quantification of “good” vs. “bad” watershed status) but is instead reflected indirectly through a quantified two tiered assessment of habitat indicators representing landscape pressures acting on the watershed (Tier I) and the current condition of habitats on the ground (Tier II) (i.e. if habitat pressures within the watershed are rated low and fish habitat attributes are rated as being in properly functioning condition then the overall watershed status would be considered generally “good”). The WSEP indicators are captured through a combination of mapped, remote sensed (Tier I) and field-collected (Tier II) information that allows for evaluations across the three primary subsystems (upslope, riparian, and stream channel) that will together affect status of the watershed.

## 1.2 How is Watershed Status assessed?

Watershed status will be evaluated through a combination of monitoring undertaken by using two distinct approaches. The first approach (referred to hereafter as Tier I) incorporates evaluation of remote-sensed or broad-scale habitat data available for all watersheds in regularly updated and readily accessible agency GIS layers. A second, more intense level of monitoring (referred to as Tier II) incorporates field-based surveys. This approach is consistent with the DFO Wild Salmon Policy Strategy 2 recommendation to monitor both pressure and state indicators when assessing freshwater habitats (Stahlberg et al. 2009). Tier I – monitoring of remote sensed indicators is used to assess watershed ‘pressures’ (risk) and Tier II – monitoring of field based indicators is used to assess current watershed ‘condition’ or ‘state’.

### 1.2.1 Watershed Condition

The *Forest and Range Practices Act* (FRPA) (2004) requires managers to prevent the cumulative hydrological effects of primary forest activities in fisheries sensitive watersheds from resulting in a material adverse impact on the habitat of the fish species for which the fisheries sensitive watershed was established. In all watersheds FRPA has an objective to conserve, at the landscape level, the water quality, fish habitat, wildlife habitat and biodiversity associated with those riparian areas. These objectives have been broadly interpreted to mean that watersheds and their associated components should remain in a properly functioning condition.

Consistent with FRPA’s definition of properly functioning condition, watersheds considered to be properly functioning are not necessarily pristine watersheds lacking human or natural disturbance. Rather, properly functioning implies that the extent and range of such disturbances are within a watershed’s natural range of variability. Properly functioning watersheds are expected to maintain a majority of streams that can withstand normal peak flood events without experiencing accelerated soil loss, channel movement or bank destabilization; 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 and large woody debris supply; and can provide shade and reduce bank microclimate change. Properly functioning watersheds should also maintain direct access to potential spawning and rearing habitats for all resident or anadromous fish populations with well designed, installed and maintained culverts and other structures on stream-intersecting resource roads that provide for adequate fish passage.

### 1.2.2 Watershed pressures

There is well-documented evidence that human-induced alterations in landscape/watershed processes can damage fish habitats and ultimately affect survival, distribution, and abundance of fish populations Potential pathways of effects between landscape-scale pressures and subsequent impairments to fish habitats can include effects on quantity and quality of spawning and rearing habitats, habitat conditions within migratory corridors for salmon smolts / adults; and habitat conditions in estuary areas used for staging before ocean entry. The first level of watershed status evaluation (Tier I) within the WSEP is therefore focused on assessing the potential “risk” to watershed habitats from landscape pressures. Watershed risk is quantified through use of defined pressure indicators that represent proactive measures of potential impacts on fish habitats. Based on remote-sensed information, pressure indicators can be captured/monitored over broad spatial extents. The suite of habitat pressure indicators evaluated within the Tier I WSEP is intended to provide an overall summary of the relative degree of land development stresses across watershed habitats. In watersheds where defined benchmarks/thresholds of concern for Tier I pressure indicators have been exceeded, watershed habitat conditions are considered potentially at risk. More detailed evaluation of how these pressures (risks) are actually effecting conditions on-the-ground (the second level of watershed status evaluation) is then undertaken through detailed field-based assessment of the state of fish habitats across a watershed (WSEP Tier II monitoring - riparian, water quality and fish passage protocols).

## 1.3 Organization of protocol

This protocol strategically builds on existing provincial assessment protocols (e.g., FREP Riparian, Water Quality, Fish Passage) so as to avoid redundancy and to facilitate integration of data and utilization of trained personnel across different monitoring programs. It is modular in nature so that new components may easily be added depending on the needs of a specific monitoring program (Figure 1)

This document provides overall guidance for how Tier I and Tier II monitoring should be implemented and interpreted to complete a watershed status summary.

Section 2 provides a brief introduction to Tier I monitoring and references the detailed protocol and rationale. Section 3 consists of a series of Tier II field protocols or modules which may be selected depending on the questions of interest. For each Tier II module this document provides:

- Site level protocol
- Site level scoring
- Watershed-level sampling design
- Watershed-level application of the protocol
- Watershed-level scoring

Section 4 of this document provides guidance on how to summarize the key information from both Tier I and Tier II data to produce a concise watershed synthesis and a consistent watershed report.

A series of appendices provide additional detail where necessary.

- **Appendix A:**Priority items to address uncertainties in the WSEP .
- **Appendix B**:**:** Supplementary Tier II field protocosl that are considered important for improving the value of the WSEP and that are recommended for future development.
- **Appendix C**:**:** Supplemental page for watershed application of riparian protocol at a watershed scale.
- **Appendix D**:**:** Describes how to characterize the riparian condition for the reach. A consequence of randomly selected reaches is that the riparian condition may not be homogeneous within the entire sample reach and therefore further guidance is required beyond the standard FREP riparian protocol.
- **Appendix E**:**:** Describes the GIS steps involved in generating the sample frame for the field protocols.
- **Appendix F**:: Describes the Generalized Random Tessellated Stratified (GRTS) design used for selecting riparian sites and the master sample concept. describes the GIS steps involved in generating the sample frame for the field protocols.
- **Appendix G**:**:** Describes how sample size requirements can be evaluated concurrent with sampling using ‘running plots’.
- **Appendix H**:**:** Describes the FREP Information Management System.
- **Appendix I**:**:** Describes the critieria for separating new, old, and recent wood in the riparian protocol.
- **Appendix J**:**:** Describes the rationale behind the preliminary sediment delivery criteria for watershed scale scoring.

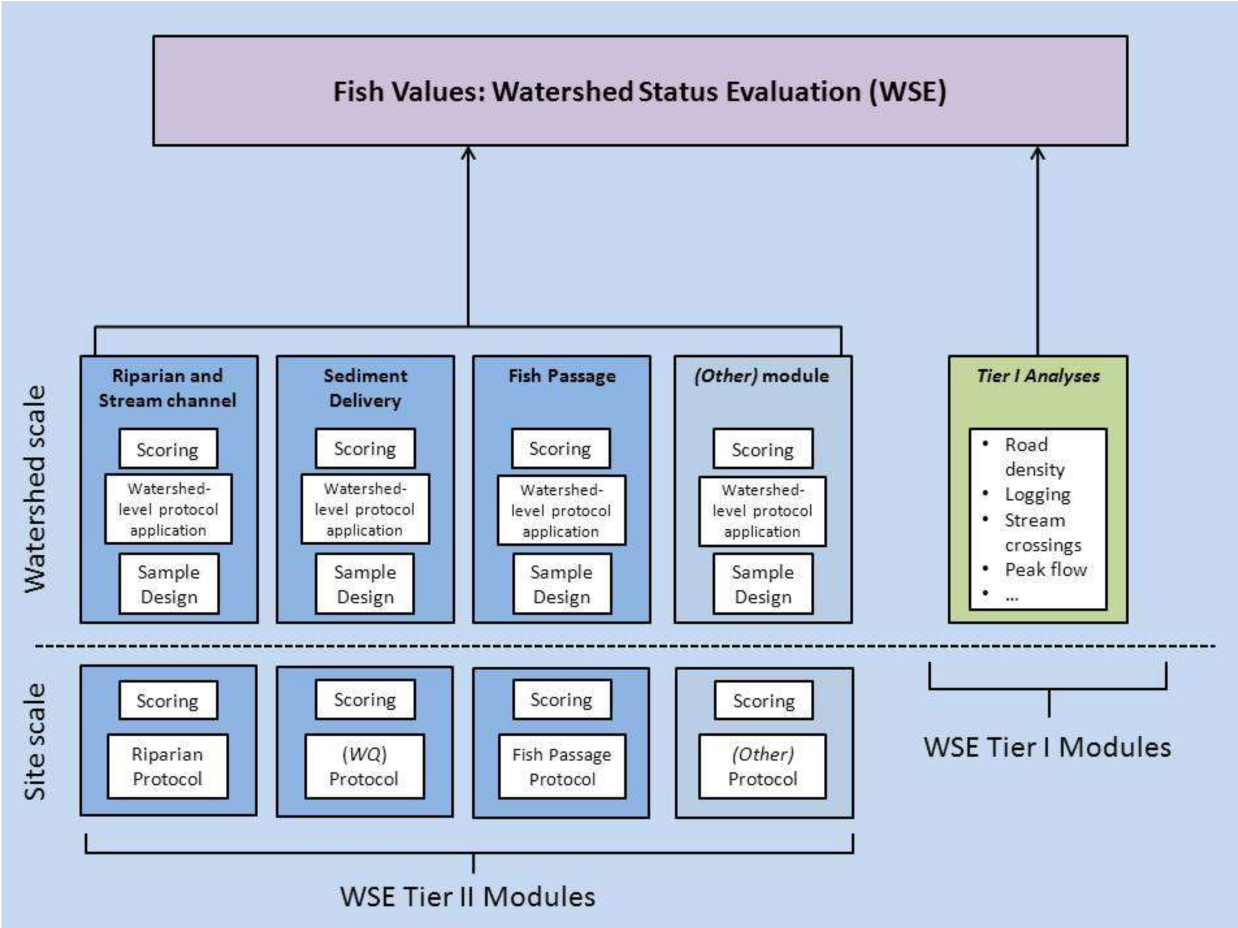


Figure 1. This figure illustrates the structure of the protocol and the flow of information eventually leading to the final watershed status evaluation report.

# 2 Tier I: Remote sense monitoring and evaluation

Tier I monitoring of watersheds is based on assessment of landscape-scale habitat “pressure” indicators, analogous to the approach used for the province’s earlier air-photo interpretation-based Watershed Assessment Procedures (WAP) (MOF 1995a, 1995b), but modified to use now widely available provincial-scale GIS data 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 accumulation of the impacts from a series of natural and anthropogenic events (cumulative effects) and have been measured typically using a suite of indicators including road density, riparian disturbance, stream crossing density, landslide occurrence, equivalent clear-cut area, and surface erosion. The intent of the Tier I “WAP-lite” monitoring is to similarly determine the magnitude of these landscape “pressure” indicators so as to allow for a general coarse assessment of a watershed’s perceived current ”risk” of habitat degradation and its possible current and future habitat state as a result of ongoing human and natural disturbances (i.e., anticipated trends in habitat condition). A WSEP Tier I assessment indicating a high level of pressure/risk is used to signal the need for further assessment of condition using the various WSEP Tier II protocols. The Tier I protocol and rationale are described in greater detail in Porter et al. (2013 a, b).

# 3 Tier II: Field monitoring and evaluation

Depending on the outcome of the Tier I analysis and other factors (local concerns, uncertainty associated with Tier I data) a more intensive assessment of current condition can be undertaken through implementation of a series of field based monitoring protocols. The WSEP currently consists of three field modules designed to evaluate the current condition of the watershed in terms of: 1) riparian and stream channel function; 2) sediment delivery processes; and 3) habitat connectivity for fish. Several other modules have been proposed and will be developed in future iterations of the WSEP (Appendix A:). The site level and watershed level components for each of the current modules are described here.

## 3.1 Riparian and stream channel assessment

Riparian areas are the complex interface between aquatic and terrestrial environments within watersheds (Tschaplinski and Pike 2010). These areas have been described as three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, and that extend down into the groundwater, up above the forest canopy, outward across the floodplain, laterally into the near-slopes to various distances into terrestrial areas, and along watercourses at variable widths (Ilhardt et al. 2000). Riparian meadows and forests extend from the smallest headwater tributaries to the mouths of the highest-order streams within watersheds. Riparian areas thus form the key boundary that moderates all hydrological, geomorphological, and biological processes associated with the interconnected stream channel network (Swanson et al. 1988). Properly functioning riparian areas maintain ecological linkages throughout the watershed, connecting hillsides to streams and upper headwaters to lower valley bottoms. No other landscape features within watersheds provide linkages that are as extensive and complex as those provided by riparian ecotones (B.C. Ministry of Forests and B.C. Ministry of Environment 1995; Tschaplinski and Pike 2010).

Riparian areas support streams and other aquatic ecosystems and associated fish populations through several functions. Riparian vegetation regulates aquatic ecosystem processes with inputs of light, nutrients, and organic matter. Riparian areas provide food for aquatic and terrestrial organisms, stabilize the streambanks, modify sediment inputs from the adjacent terrestrial ecosystem, and are a source large wood important for habitat cover and channel structure in woody debris dependent streams. These ecological services and functions can be changed dramatically when riparian vegetation is altered such as by streamside forest harvesting.

Riparian areas are highly vulnerable to disturbance from both natural processes and events and human-related activities occurring on site and upslope and upstream because of the relatively small size of these zones and the extensive longitudinal and lateral connections between aquatic and terrestrial ecosystems. Therefore, assessing the functioning condition of stream-riparian systems is considered key to determining the overall state of watersheds.

### 3.1.1 Site level protocol

The WSEP has adopted the FREP Riparian Protocol (Tripp et al. 2009) for the purpose of assessing the condition of stream channels and adjacent riparian areas. The Riparian protocol is an indicator-based field assessment procedure first developed to determine whether forest and range practices under the Forest Practices Code and the FRPA had been effective in maintaining the structural integrity and ecological functions of stream reaches and associated riparian areas, and in particular, the associated FRPA "Fish" value at the stream reach scale (Tschaplinski 2010). This site-level assessment has been the foundation for determining the effectiveness (or effects) of riparian management strategies and practices as well as road-stream crossings on post-harvest ecological conditions within a stream reach. The protocol guides assessors to identify and distinguish these site or "cutblock-level" outcomes from impacts delivered to the site from upstream or upslope sources and processes.

The FREP Riparian Protocol requires addressing 15 distinct questions (Table 1) relating to the characteristics of healthy streams and their aquatic and riparian habitats. Each of these questions are used to evaluate a main or overarching physical or biological indicator of stream channel or riparian area condition. The overarching **indicators for the stream channel** are: (1) channel bed disturbance, (2) channel bank disturbance, (3) large woody debris (LWD) characteristics, (4) channel morphology, (5) aquatic connectivity, (6) fish cover diversity (for fish-bearing reaches only), (7) moss abundance and condition, (8) fine sediments, and (9) aquatic invertebrate diversity. The principal **indicators for the adjacent riparian area** are: (1) windthrow frequency, (2) riparian soil disturbance/bare ground, (3) LWD supply/root network, (4) shade and microclimate, (5) disturbance increaser plants, noxious weeds, and invasive plants, and (6) vegetation form, vigour, and structure (Tschaplinski 2010).

Table 1. Fifteen questions used to access the relative health, or "functioning condition" of a stream and its' riparian habitat.

| | |
|---|---|
| Question 1. | Is the channel bed undisturbed? |
| Question 2. | Are the channel banks intact? |
| Question 3. | Are channel LWD processes intact? |
| Question 4. | Is the channel morphology intact? |
| Question 5. | Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments? |
| Question 6. | Does the stream support a good diversity of fish cover attributes? |
| Question 7. | Does the amount of moss present on the substrates indicate a stable and productive system? |
| Question 8. | Has the introduction of fine inorganic sediments been minimized? |

| | |
|---|---|
| Question 9. | Does the stream support a diversity of aquatic invertebrates? |
| Question 10. | Has the vegetation retained in the RMA been sufficiently protected from windthrow? |
| Question 11. | Has the amount of bare erodible ground or soil disturbance in the riparian area been minimized? |
| Question 12. | Has sufficient vegetation been retained to maintain an adequate root network or LWD supply? |
| Question 13. | Has sufficient vegetation been retained to provide shade and reduce bank microclimate change? |
| Question 14. | Have the number of disturbance-increaser species, noxious weeds and/or invasive plant species present been limited to a satisfactory level? |
| Question 15. | Is the riparian vegetation within the first 10 m from the edge of the stream generally characteristic of what the healthy, unmanaged riparian plant community would normally be along the reach? |

To help evaluators answer each of these questions the FREP riparian protocol provides a number of statements representing specific indicators, each of which also require a **Yes** or **No** answer. The indicator statements refer to specific site attributes that can be more easily assessed or measured in the field than the more general questions. The number of **Yes** or **No** answers to the indicator statements determines the appropriate responses for the 15 general questions at a particular sample site. Depending on channel morphology type, substrate conditions, and fish use, 114–120 measurements, estimates, and observations are required to complete a stream-riparian assessment based on 38–60 specific indicators that cover the 11–15 main checklist questions. Each assessment also includes measurements of channel width, depth, and gradient as well as vegetation retention in the riparian management area (RMA).

The scored categorizations of stream/riparian functioning condition from each sampled site will then be rolled up to generate summaries of the average and range of functioning condition within specific strata, as well as across the entire watershed.

**Where to find the complete riparian and stream channel site-level protocol:** Details on assessing, recording and summarizing riparian protocol “indicators” for a sample site and example completed Riparian Protocol field assessment forms are provided in Tripp et al. (2009). Riparian Protocol assessment forms can be downloaded from the FREP website at: http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/FS-1247-Riparian-Field-Card-March11-2009.pdf.

### 3.1.2 Site level scoring

The assessment of the relative condition of the sampled site is based on the total number of **No** answers to the questions as follows:

- 0–2 No answers – the stream and riparian habitat at the sample site is in properly functioning condition (**PFC**);

- 3–4 No answers – the stream and riparian habitat at the sample site is in properly functioning condition, but at risk (also termed PFC with limited impacts or **PFC-L**);
- 5–6 No answers – the stream and riparian habitat at the sample site is in properly functioning condition, but at high risk (also termed PFC with intermediate-level impacts or **PFC-I**);
- 7 or more No answers – the stream and riparian habitat at the site is not properly functioning (**NPF**).

### 3.1.3 Watershed scale sample design

A key difference between the FREP protocol and the WSEP is the watershed scale sample design. The sample design described within the FREP riparian protocol is not appropriate for use when interested in assessing watershed level condition of riparian areas. The FREP sample design is focused specifically on evaluating condition of streams beside or within recently harvested cut-blocks, whereas the WSEP is interested in generalized assessment of riparian and stream channel condition over the entire watershed.

#### *Target Population*

The target population is all stream reaches within the designated study watershed. The study watershed boundaries will be represented by one or more (as required) watersheds as delineated within the province's Freshwater Atlas (FWA) 1:20K watersheds GIS layer.

#### *Sample frame and sample unit*

The basic **sampling units** are stream sample reaches, with center points pre-determined through a randomization process undertaken in the office. The sample reach length is determined using the BC criteria defined within FREP: a minimum sample reach length of 100m for streams < 3.3m average bankful width, and a sample reach length equal to 30x the average channel width for streams > 3.3 m bankful width.  FREP riparian indicators are evaluated over the defined length of each sample reach.

The **sample frame** is provided by the province's FWA stream network, an electronic (1:20K scale) representation of streams found within provincial watersheds. There is some lack of correspondence between the tangible, physical population of stream reaches and this defined sample frame. Two potential sources of non-correspondence are incomplete coverage (i.e., there are streams in the landscape that don't have corresponding mapped depictions in the 1:20K sample frame) and over-coverage (i.e., there may be stream traces indicated in the sample frame that do not correspond to flowing streams in the field, particularly at the upper end of first order streams) (Stevens 2002). In order to minimize the frequency of encountering a non-classified drainage (NCD) in the field, the sample frame for coastal watersheds is constrained by removing the upper 200m of 1st order streams depicted by the 1:20K GIS layer.[2] Lakes and wetlands are also removed from the sampling frame to avoid having a riparian sample point fall in the middle of a water body. Alpine areas can be removed from the sample frame, if forestry related impacts are the primary focus, however, depending on the type of management activity of interest in the area, these areas may need to be included. Details on generating the sample frame are described in Appendix E:.

### *Strata*

Three strata based on stream order and fish habitat categorization are recommended for watershed level riparian assessments. A number of other potential strata were considered and tested during pilot studies including: harvest history and stream proximity to roads. The following three strata resulted in the most efficient and logistically feasible sampling design (Pickard et al. 2014b). Appendix E: describes the GIS steps involved in identifying the strata.

Stratum 1) Non-Fish Habitat

- All stream reaches within the sample frame which don't intersect with fish habitat as defined by the BC Fish Habitat Model or local fish habitat maps[3].

Stratum 2) Fish Habitat < 3rd order

- All 1st or 2nd order stream reaches within the sample frame, which intersect with fish habitat as defined by the BC Fish Habitat Model or local fish habitat maps.

Stratum 3) Fish Habitat > 3rd order

- All 3rd order or greater stream reaches within the sample frame, which intersect with fish habitat as defined by the BC Fish Habitat Model or local fish habitat maps.

Exceptions: Additional strata may be added if necessary. For example, if there was a rare habitat type for which data were required (e.g., watersheds where un-harvested areas are very rare). Alternatively, if any of the three default strata represented a very small portion of the watershed, they may not be necessary (e.g., if non-fish habitat in a watershed were too limited for a viable strata).

### *Selection of sites in office*

Riparian sample sites are to be selected based on a Generalized Random Tessellation Stratified (GRTS) sampling algorithm (refer to Appendix F: for a description of GRTS). The basic steps required to generate the GRTS sample draw for this application are:

- Generate the GIS sample frame as described in Appendix D:.

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[2] Interior watersheds may require a different distance for restricting the sample frame given terrain differences, although this has not yet been determined and will require further assessment in pilot watersheds.

[3]Use the best available information on fish distribution. The default is the BC Fish Habitat Model, however where detailed inventories exist these should supersede the modeled fish distribution.

- Summarize the sample frame by strata (i.e., stream lengths (m) located within each stratum)
- Determine if there are any special cases in the watershed which require special consideration (e.g., the estuary, wildlife habitat area(s), a park, recent fires etc.). If there are any additional features which need to be monitored preferentially, add strata as necessary.
- Estimate the approximate number of sample units possible within each stratum to determine if there will be any significant overlap issues. Divide the stream length by 500m in Stratum 1 & 2, and by 1000m in stratum 3. This provides a rough estimate of how many sites are possible without encountering too many overlap issues. If any of the strata are very small (i.e., less than 10 samples are possible without overlap) then it may be worth considering merging strata or simply completing a census of the stratum (dividing the stratum into appropriate stream segment lengths while working from top to bottom). The latter case may occasionally be appropriate for mainstem habitat within small watersheds.
- Once the final strata are determined, a GRTS master sample for the watershed is generated using average spacing of 500m for 1st and 2nd order strata, and 1000m for 3rd order strata.
- The master sample is an ordered list of samples for each stratum. When sampled in order every sample is spatially balanced. The first 10 sites within a stratum are a spatially balanced sample, the first 20 sites are also a spatially balanced sample, etc.
- The sample list is provided to the crew by taking the first n+x sites from each stratum (see example sample GRTS draw/mapped locations from Memekey watershed in Figure 2). Where n is the desired sample size and x is the oversample (usually ~10[4]). For example, if 30 sites is the desired number of samples, 40 sites might actually be provided. This oversample provides the crew with replacement samples if any in the original list need to be dropped.

[4] Technically there is no limit to how many oversample points are provided, however it is recommended that the number is kept as small as possible as there is a tendency for crews to treat all points equally rather than strictly following the sample order. If too many points are given, they may simply select the closest or most convenient of the sites rather than trying to follow the order. The random spatial balance is only maintained when sampled in order (Appendix F). Depending on the landscape you may anticipate more or less issues with access (e.g., land ownership, rugged terrain etc.) and can adjust the size of the oversample accordingly.

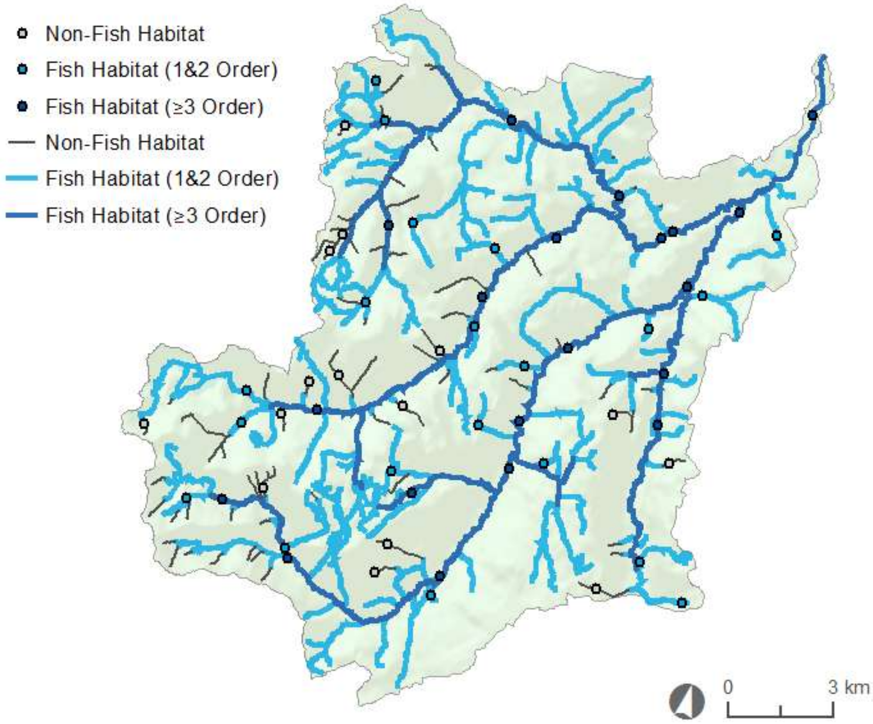


Figure 2. Illustration of a possible GRTS sample for the Memekay Watershed, near Campbell River; a random spatially balanced design across three strata of interest: non-fish habitat (n=15), fish habitat (1&2 order) (n=20), fish habitat (≥3 order) (n=20).

***Sample size***

Required sample size depends on the desired precision and the variability within strata. It does not depend on the size of the strata, except in the case where the size of the stratum is very small (i.e., there is a finite population and the number of possible samples without replacement is limited). Based on data from the pilot watersheds and the proposed analyses for these data, the default recommended sample size for all strata is 30 sites (Pickard et al. 2014). As described above, if the number of possible samples is very small (i.e. less than 10) completing a census or dropping the stratum is recommended. Where the number of possible samples is between 10 and 30, a minimum of 10-15 samples is recommended. None of these recommended sample sizes are based on hard and fast rules, but instead provide general guidance intended to achieve estimates with sufficient precision to make useful statements about the watershed. It is also possible to use running plots (Appendix G:) to determine in real time when the estimates stabilize and perhaps reduce the total number of samples required. However, this requires strict adherence to sample sequence as described in Appendix F:.

### 3.1.4 Watershed scale application of protocol

FREP's Riparian Protocol is generally applicable as written for watershed-level application; however, there are several changes in addition to the sample design to be aware of.

**Reach selection:** Center points of sample reaches are randomly selected and don't necessarily lie in homogeneous reaches, like they do under the FREP design. This affects the application of the first page of the field assessment forms. For example, ½ of the right bank might have been recently harvested, but the remainder of the reach never harvested. A supplemental first page to the field cards is provided to more fully describe the reach when applying the FREP riparian protocol to a watershed (Appendix C:).

**Reconnaissance:** A broad field reconnaissance of pre-selected GRTS sampling points in the watershed is strongly recommended prior to initiating actual field sampling. Reconnaissance can be accomplished by driving throughout the watershed where there is road access, consulting people with local expertise, or by overview flight and examining the watershed using aerial imagery. The reconnaissance will help identify/document sample points that are inaccessible or inappropriate for various reasons and that should be replaced with the next ordered alternative GRTS points on the oversample list. It will also help to plan the most efficient sampling routes and help identify any potential hazards.

After finalizing the location of all GRTS points that will be sampled during the field season it will be helpful to identify clusters of sites that are physically close together. These could perhaps be more efficiently sampled (time wise, cost, logistically, etc.) if approached as a combined sampling package (i.e., not necessarily sampling sites in exactly the same ordered sequence as in the GRTS list). This is acceptable only if **all** selected sites are eventually sampled as planned over the field season.

**Dropping sites:** Where selected sites cannot be sampled for some reason, the reason for dropping the site must be clearly documented on the supplementary field card (Appendix C:) so as to enable identification of any potential sampling biases. A site may be dropped during the reconnaissance stage or a site may be dropped in the field. Common reasons for dropping sites:

**During reconnaissance stage:**

- A portion of the watershed is deemed inaccessible without excessive cost/risk. For example, helicopter access or multi-day hikes. Access often depends on the season, as some areas may be flooded or snow covered temporarily prohibiting access.

**In the field:**

- Safety. Site is permanently inaccessible due to safety risk (e.g., canyon).
- Access. Temporary or permanent access restrictions (e.g., current logging) or road washed out and no alternative transportation.
- Non Classified Drainage (NCD)/poor mapping. See below for details.
- Beaver Pond. See below for details.

Where possible, sites which are dropped temporarily due to access should be visited later and included in the evaluation.

**Replacing sites:** It is **critical** that replacement sites (oversample points) must be selected from the next point in the ordered sequence of available points in the GRTS oversample table, so as to preserve the spatially balanced nature of the samples selected. If some sites within the ordered list are missed the properties of the GRTS design (i.e. random, spatially balanced) will be disrupted, thereby violating the associated assumptions required for statistical analyses. Appendix F describes how the GRTS Master List should be used.

**Headwaters, inaccurate mapping & Non-classified drainages**

In some cases the GIS sample frame will not accurately map the headwater streams. The mapped stream may not exist, i.e., non-classified drainage (NCD), and so the riparian/stream channel protocol is not appropriate. Alternatively, the stream may exist, but not where expected. Refer to the key for identifying fish streams, non-fish streams, FSZs and NCDs in Tripp et al. 2009 (page 12) to determine if the site is within a non-classified drainage. If so take photos at the center point and record the site as a NCD (Appendix C:). If a stream of the same stream order exists within 50m of the site coordinates (including directly downstream), move to the closest position in the actual stream channel, record the new coordinates, and complete the protocol. In the event that the randomly located center point is too close to head of the stream, shift reach downstream so that the full sample reach (usually 100m) is available.

**Beaver ponds:** Occasionally a random site will lie within an unmapped beaver pond (example in Figure 3). A protocol is planned to assess the properly functioning condition of a wetland. Until that protocol has been developed the current practice is to identify the site as a beaver pond, describe the extent of it (e.g., width, length if known) and the site characteristics (e.g., type of wetland, vegetation, and harvest history) on the supplemental cover page (Appendix B:). As described in the FREP protocol, try to find a section that represents the normal width of the stream had it not been ponded. Use the width of this section to determine how much of the stream length should be assessed and attempt to complete transects. If not feasible, document this and move on. Photographs should be taken regardless. Data from beaver pond sites will be summarized separately from the rest of the stream channel sites.

Figure 3. Example of an unmapped beaver pond encountered in the Lakelse watershed.

**Overlapping stream reaches:** The spatial balance built into the GRTS design minimizes the frequency of overlapping sites. The average spacing of sites in the master sample is determined by the density of points specified. However, there may be cases where two sample points are located in such close proximity that the stream reaches overlap. In the event that you end up in the field and recognize this overlap (point sample flagging) complete both sample reaches as normal, sharing data where possible. For example, if each sample reach is 1000m, and they share 200m, the data for the 200m overlap can be collected once, and used in both site assessments (e.g., 15m of disturbed bank is counted in the 200m overlap section and is added to the total disturbed bank for each sample point).

**Confluence mid-reach:** Occasionally, a sample reach will intersect a confluence with another stream, resulting in confusion about where to sample. If the confluence is with a stream that is of smaller order, continue sampling along the main channel. If the confluence is with a stream that is of the same order, follow the left-hand[5] bank. If the confluence is with a stream that is a larger order, instead shift the start point of your sample reach so that the confluence is the downstream end of your sample reach.

**Side channels:** Occasionally, side-channels will be indicated in the GIS layer as a distinct channel. To the extent possible, if the side-channels are part of an active floodplain (i.e., minimal established vegetation) they should be considered part of the main channel and assessed as such (using the stream order of the main channel). If they are distinct vegetated channels identified by the GIS, treat them as independent of the main channel.

**Assessing Riparian Buffer Widths and % Retention:** Data entry on riparian buffer widths and percent retention on Page 1 of the FREP riparian field cards often causes problems or confusion when applying the WSEP. The main reason for the problems or confusion is

[5] This is an arbitrary choice, but is intended to prevent any observer bias from affecting the decision about which channel to survey under this situation.

because, unlike standard FREP riparian-stream sample design where the sample reaches are selected because they are located within or adjacent to a recent cutblock (recent defined as 1995 or newer), which typically results in a sample reach where riparian conditions may be relatively similar. Riparian conditions along WSEP riparian sample reaches may be highly variable. Some reaches may encompass riparian conditions that vary along the reach, with stable mature or old forest conditions along some sections of the reach, and recently disturbed or younger forests along other sections. Or even, in some cases, the site may have been harvested more than once. The variation can extend not only longitudinally up and down the reach it can also vary laterally from the stream edge to upslope areas on one or both sides of the reach. Riparian areas that have undergone some form of partial-cut (e.g. small patch, selective, high grade harvests etc.) further complicates things, resulting in stands with a mixture of mature or old growth characteristics and more recently logged characteristics.

The observer should describe the riparian buffer width (intact and never logged, old logging estimate age) and % retention for the entire stream reach, providing a sketch on the WSEP supplemental cover page. See Appendix C: for examples on how to complete the cover page and how to interpret the sample reach harvest data.

**Definition of old vs. new instream wood (Question 3):** In the FREP assessments, sites are usually associated with cutblocks of known age, and new wood is defined as anything introduced to the stream post-harvest which is relatively easy to assess given the harvest date. However, in the WSEP assessments sample sites may have encountered: no harvest, old harvest, recent harvest, or multiple harvests. This confuses the definition of old vs. new wood. The key concept behind the 'new wood' measurement is to **identify if the wood in the channel is natural or treatment related**, where treatment is usually harvest (i.e., logging) but may be any management activity (e.g.,. cattle grazing, urban development, hydro or other similar corridor development etc.). If the treatment occurred many years ago, it may be difficult to determine whether the wood is natural or treatment related. As the system recovers and treatment related wood is incorporated, it should no longer be considered 'new' wood. Regardless of the age of the wood, if it has been recently deposited it is evidence of disturbance and should be counted as new (Appendix I:)

### 3.1.5 Watershed scale scoring

All three strata are considered to be independently important to the overall watershed condition. Therefore, all three strata must meet the criteria in Table 2 for the watershed to be considered Green or properly functioning, with respect to riparian and stream channel condition. A single stratum exceeding the Moderate criterion and the watershed is considered outside the natural range of variability. A single stratum exceeding the High criterion and the watershed is considered not properly functioning. These criteria were determined based on a Provincial review of 51 pristine or reference condition streams (Tripp 2013).

If any strata are not applicable (e.g., no non-fish habitat), they are ignored in the aggregation. If any strata were added (e.g., protected area, recently burned area etc.), then either a new rule needs to be applied to this additional strata, or it should be post-stratified into one of the three defaults.[6]

Table 2. Criteria for evaluating riparian condition at the watershed scale.

| Stratum | Low | Moderate | High |
|---|---|---|---|
| Non-fish habitat | >80% of sites must be PFC or PFC-L | All other cases | If >10% of the sites are NPF or >25% PFC-I |
| Fish Habitat < 3rd order | >85% of sites must be PFC or PFC-L | All other cases | If >5% of the sites are NPF or PFC-I >20% |
| Fish Habitat ≥3rd order | >90% of sites must be PFC or PFC-L | All other cases | If >0% of the sites are NPF or >15% PFC-I |
| Additional strata (e.g., beaver ponds, or WHAs) | Explicitly define rule if applicable | | |

## 3.2 Sediment delivery assessment

Fine and coarse sediment have direct impacts on fish health and their habitat (Robertson et al. 2006; Hogan et al. 1998). Carson (2014) describes the potential sources (natural and artificial) of sediment delivery and related impacts to the watershed. The objective of this module is to determine the extent and nature of artificial sediment delivery on the ground at the watershed scale. Sediment sources (i.e., places where sediment may be artificially delivered to a stream) may include: stream crossings (site type A), locations where the road is within close proximity of a stream (site type B), road induced mass wasting events connected to a stream (site type C), any other location where a management activity intersects a stream or riparian area (site type D), and artificial drainages (e.g., where a road ditch collects water from previously non-classified drainages) (site type E). Table 3, adapted from Carson et al. 2009, provides a list of potential sediment sources. This is a critical supplement to the Tier I indicator summaries which can identify the extent of various pressures but cannot determine the extent to which

[6] In the latter case, ensure care is taken to weight the samples appropriately. For example, if a critical habitat area (e.g., Wildlife Habitat Area) exists within the watershed, it may be considered independently important and therefore a 4th criterion would be added to the watershed score. However, if the 4th stratum was added to assess some other question such as impacts of fire within the broader watershed, the data points could be post-stratified (i.e., assigned to one of the three default strata), so long as care was taken to weight the points appropriately based on their probability of selection.

those pressures result in impacts. For example, road density can be estimated using remote sensed data, but road quality cannot.

Table 3. Summary of possible sediment delivery sites considered in this protocol (adapted from Table 1 Carson et al. 2009). The category refers to how the sites are identified for assessment.

| Site Type | Description | Category (How sites are identified) |
|---|---|---|
| A | Stream crossings | GIS analysis |
| B | Road within 20m of stream | GIS analysis |
| C | Road induced mass wasting events | Detected in Field |
| D | Other management activity intersects stream / riparian area (e.g., cattle grazing; silviculture; forestry equipment) | Detected in Field |
| E | Artificial drainages | Detected in Field |

### 3.2.1 Site level protocol

Currently, three important Tier II or field indicators of sediment delivery are identified: fine sediment generation, coarse sediment generation, and artificial drainages impact on peak flow. These are assessed in the field at the site scale using the FREP Water Quality Protocol (Carson et al. 2009). Carson 2014 provides additional rationale and description of these three indicators, particularly coarse sediment and artificial drainages. All three are summarized in the Jan 2014 version of the Water Quality App for use with iPads. A road mass wasting protocol is currently under discussion, but has not yet been established.

**Where to find the complete Water Quality site-level protocol:**

http://www.for.gov.bc.ca/HFP/frep/site_files/indicators/Indicators-WaterQuality-Protocol-2009.pdf

### 3.2.2 Site level scoring

The ratings proposed for each indicator are meant to reflect degree of water quality impacts at the site and whether there are management opportunities for mitigation. There is a research need to improve the understanding of the linkages between these indicators and fish health/watershed function. The thresholds for coarse sediment and artificial drainages (Table 5 & Table 6) are preliminary based on expert opinion. Fine sediment (Table 4) has been estimated broadly (over 4000 sites in BC) via the FREP water quality protocol and so there is a greater understanding of the relationship between artificial impacts and fine sediment generation.

Table 4. **Fine Sediment:** This table provides the FREP recommended breakdown into five sediment generating classes as well as the simplified three class scoring used to summarize results at the watershed scale within the WSEP.

| Total Volume of Fine Sediment | FREP Classes | WFVM simplified scoring |
|---|---|---|
| < 0.2( $m^3$) | Very Low | Low |
| 0.2 - 1 ($m^3$) | Low | |
| 1 - 5 ($m^3$) | Moderate | Moderate |
| 5 - 20 ($m^3$) | High | High |
| > 20 ($m^3$) | Very High | |

Table 5. **Coarse Sediment:** Rating of coarse sediment input at site. As more information about coarse sediment impacts on channel conditions becomes available, these thresholds for ratings may be modified.

| Total coarse sediment from site ($m^3$ ) | Coarse Sediment Rating: Impact on Channel |
|---|---|
| <0.2 -1 | Low |
| 1-5 | Moderate |
| >5 | High |

Table 6. **Artificial Drainages:** Proposed thresholds for effects of mini-catchment size on peak flow. The limits for areas chosen reflect the range of road drainage areas encountered and their observed significance to downstream concentrated flow. The user is advised that these thresholds are tentative and should be revised if and when better information becomes available.

| Total area of mini catchment draining site (m2) | Artificial drainage Rating: Contribution to Peak Flow |
|---|---|
| <599 | Low |
| 600-1499 | Moderate |
| >1500 | High |

### Combined site level score

Table 7 illustrates how the three sediment delivery elements area combined for a site. For each site, the lowest score across the three indicators is used to represent the sediment delivery condition at the site scale. This reflects the understanding that each of the three indicators is independently important. This is a simple approach which highlights limiting factors with respect to sediment delivery across the watershed. It avoids the potential to have good and bad results cancel each other out numerically, when in reality these indicators impact the watershed status in different ways. While sites may be selected in different ways, they all transport sediment to the stream and are assessed and scored in the same way.

Table 7. **Combined site level score:** this table illustrates an example of how the three sediment delivery indicators are combined to represent the site.

| Site # | Fine Sediment Generation | Coarse Sediment Generation | Increase to Peak flow | Combined site level score |
|---|---|---|---|---|
| 1 | L | L | L | L |
| 2 | L | L | L | L |
| 3 | M | L | M | M |
| 4 | L | L | L | L |
| 5 | L | H | L | H |
| 6 | L | L | L | L |
| 7 | L | L | M | M |
| 8 | H | H | H | H |
| … | … | … | … | |

### 3.2.3 Watershed scale sample design

The sampling design for sediment delivery is still under development. This section describes the components of the design which have been resolved and the approach applied in the Memekay and the Wanokana pilot watersheds. The primary complication is that not all sites can be detected ahead of time from GIS analyses and therefore the design must consider strategies for both categories of sites.

#### *Target population*

The target population is the collection of locations (i.e., all occurrences of all site types) within the watershed of interest where human activity could potentially impact sediment generation or changes to peak flow.

#### *Sample frame and sample unit*

For all site types (A-E) the **sample unit** is the site where the assessment occurs. Where the sites differ is in the **sample frame** and options for selection.

Sample frame:
Site type A:

The **sample frame** is identified by taking the intersection of streams and roads within the watershed.

Site type B: The sample frame is identified by first applying a 20m buffer to all streams in the watershed, and then taking the intersection of roads and this buffer (after removing crossings – site Type A).

Site types C-E Sites cannot be identified apriori, therefore the sample frame is the road network, from which points, segments, or routes may be sampled. In this case a two-stage sampling design is required. The first stage consists of selecting a road segment and the second stage consists of sampling sites which are detected along the segment.

In all cases:

- **Streams** are defined by the BC Freshwater Atlas, 1:20K stream network layer.
- **Roads** are defined by the best available data for the watershed, at a minimum the Digital Road Atlas (DRA) and Forestry Tenure (FTEN) should be included, but local Natural Resource District staff, forestry licencees or other local sources should be consulted to obtain any improved local datasets. If possible, rail-lines, hydro-electric right-of-ways, pipelines, and any other non-road related crossings should be included.

### *Strata*

For all site types the sampling frame will be divided into strata based on road class. There are three main road classes of interest: spur roads, branch roads, and main roads. This stratification allows for preferential sampling of road classes of interest (e.g., those with heavier use) or those with greater variability thus improving the overall precision of estimates while still maintaining a statistically robust design. Road class should be derived from pre-existing GIS layers in the office prior to sampling. Having road class defined for the entire watershed enables estimates of sediment generation from individual sites to be expanded to an estimate of the total artificial sediment generation by strata and for the watershed as a whole.

**Spur roads** are used to access the harvest block or area of industrial activity and are rarely used outside the initial activity such as harvesting of the block, building the pipeline. There is only room for one logging truck on road at one time. After logging or other development they typically will only be accessed by pickups and recreation vehicles.

**Branch roads** are roads that join up to main lines. They are used to access harvest and will have loaded logging truck traffic usually at least a portion of the year. Such roads are occasionally graded. Passing of loaded and unloaded logging trucks can occur at selected locations on radio controlled roads.

**Main lines** are primary roads accessing the watershed usually connecting the logging road network to pavement. They are wide enough that two logging trucks (one loaded, the other not can find sufficient pullouts to pass each other almost everywhere. Most blocks harvested in a watershed make use of the mainline at least a portion of each trip to transport wood. Mainlines are graded frequently and experience daily use by loaded logging trucks or other industrial users.

### *Selection of sites*

Route based sampling using random starting points - applied to Memekay Pilot

A multi-stage sampling design was used in the Memekay watershed. The first stage consisted of selecting a random set of transects, the second stage consisted of sampling crossings within each transect. The primary reason for using this approach was to improve the efficiency of the sampling. It is much easier and faster to sample sequential crossings while driving out of the watershed resulting in more crossings evaluated for a fixed level of effort. The trade-off is that the sites sub-sampled within transects are not as informative as if they were drawn at random from the population. Whether or not this approach is more efficient in the end (i.e., more precision for same effort) depends on the variability within and between transects and the increase in number of sites samples resulting from this method (Cochran 1977).

A random set of starting points was selected for each of the major sub-basins of the watershed where roads have been developed. The starting points are a GRTS draw (Appendix F:) from stream crossings high up in the watershed (i.e., 1st and 2nd order stream crossings) (Figure 4). Transects are defined from the starting points, running 'downstream' from the starting point to the bottom of the watershed following the normal route that a loaded logging truck would take to remove logs from the watershed (i.e., the normal traffic pattern), so as to observe all major road types and usage that occur within the watershed. Like with any random sample, the start points should be selected in order from the list to ensure no surveyor bias.

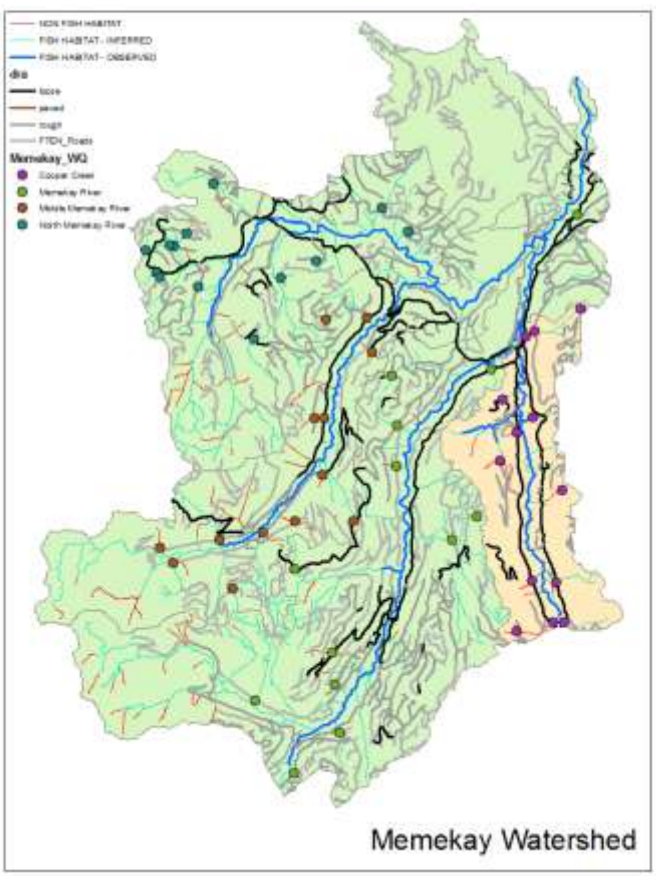

Figure 4. Illustration of randomly selected starting points (1&2nd order stream crossings) for the Memekay Watershed.

### *Sample size*

**Number of transects**

Transects are laid out in the office, and all potential monitoring sites are identified including: stream crossings (site type A) and locations where the road is within 20m of the stream (site type B); other sites (C-E) must be observed in the field. A minimum of ten starting points (i.e., transects) should be selected[7]. The initial office assessment will determine the stream crossing density along a transect by road type and that in turn can allow the evaluator to consider the means to best sample a specific transect.

**Number of sites to assess within a transect**

**Stream crossings (site type A)**

To maximize logistical efficiencies, the objective is for each field crew to sample a minimum of one transect per day. Field crews should be able to evaluate around 10 sites per day. For the majority of BC's watersheds a transect will consist of less than 10 potential monitoring sites as drainage densities are typically low and therefore all sites within the transect can be assessed. However where stream density is higher such as in the coastal mountains, the number of potential sites along a transect often exceeds the feasible number for a day. **When all sites within a transect cannot be assessed the evaluator should try to sample: 3 spur road sites, 3 branch road sites, and 4 mainline sites.** It is important that the samples chosen are selected without bias to ensure inference can be made to un-sampled sites. Any attempts to use expert judgement to select 'representative' sites will mean the results cannot be used to make inference to other sites and therefore results in significantly less value for the effort. Random selection of sites within a transect is the best approach, but is difficult to implement in the field. Use of a simple pre-defined rule (e.g., first 3 sites per road type or every other site) are simple alternatives, which are not expected to have severe biases. For example, the field crew would sample the first 3 sites along a particular road class and then drive to the next road class junction downslope and begin the sampling again below the junction to capture road segments of increasing traffic. In most coastal instances as the field crew moves downstream, the transect will eventually overlap and the field crew will encounter crossings which have already been assessed. When this occurs, the field crew should skip to the next crossing they encounter in that road type. The majority of the overlap will occur on mainline roads, it is anticipated that because all transects eventually leave the watershed on the same road that a census (or close to it) of mainline roads will occur. This reduces the concern about assessing the inclusion probabilities of crossings which are downstream of multiple starting points.

**Stream within 20m of road (site type B)**

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[7] In the Memekay, each sub-basin was sub-sampled to ensure spatial coverage. Moving forward this is not recommended as it increases the total number of transects required for the watershed and the GRTS draw is adequate to ensure spatial balance.

The same approach should be taken as with stream crossings. If possible, complete a census. If not possible, sample the first: **n spur road sites, n branch road sites, and n mainline sites.** The location of the site should be recorded even if it is deemed not connected to the stream so that results can be inferred to sites which are not measured in the field (e.g., what proportion of these sites are connected to the stream).

**Other sites (Type C-E)**

Incidental sampling of other sites encountered while driving along the sample route. Assessment involves:

- documenting the position (UTM coordinates) and photographing the site;
- determining whether or not the disturbance is hydrologically connected to a stream
- if connected, estimating the volume of sediment as per the FREP Water Quality protocol, pro-rated for age (e.g., volume/years since failure occurred)

All sites should be documented and assessed. If possible, complete a census. If not uses same approach as for site types A & B.

Advantages:

- Route based sampling – provides strategy for detecting and assessing other site types which would not be picked up from the GIS data.
- Start points on 1&2$^{nd}$ order streams ensures multiple road types are evaluated.
- Random selection of start points allows extrapolation from one transect to others.
- Logistically efficient to begin at the back end of the watershed and drive a simple route out.

Disadvantages:

- Route based sampling results in clusters of sample sites being evaluated within transects, sites can't be treated as independent (this is a form of pseudo-replication). The value of 10 sites close together is much less than 10 sites randomly selected from watershed as whole. The true sample size is the number of transects, not the number of points within each transect.
- Proper estimates by strata or for the watershed are difficult as it is difficult to determine the inclusion probabilities of any individual site. For example, some sites are downstream of multiple starting points where as others are only downstream of a single starting point. Proper estimates require all of these inclusion probabilities to be described; this is not straight-forward.

- The random start points are based on stream crossings and so any sites (B-E) which occur above a start point have zero probability of being selected and therefore it is impossible to make inference to these points.

**Wanokana Pilot**

The Wanokana is an example of a small watershed where sampling is of limited value. The total number of crossings is small (Figure 5) and it is probably about as efficient to attempt a census and not worry about any of the complexities related to sampling. With only 5 transects based on 5 random starting points you would cover many of the sites, but you would also end up driving the same road many times at the downstream end where the transects converge. With the same 5 days of effort you could probably complete a census or close to it, therefore removing any of the implementation and analytical complexities associated with sampling.

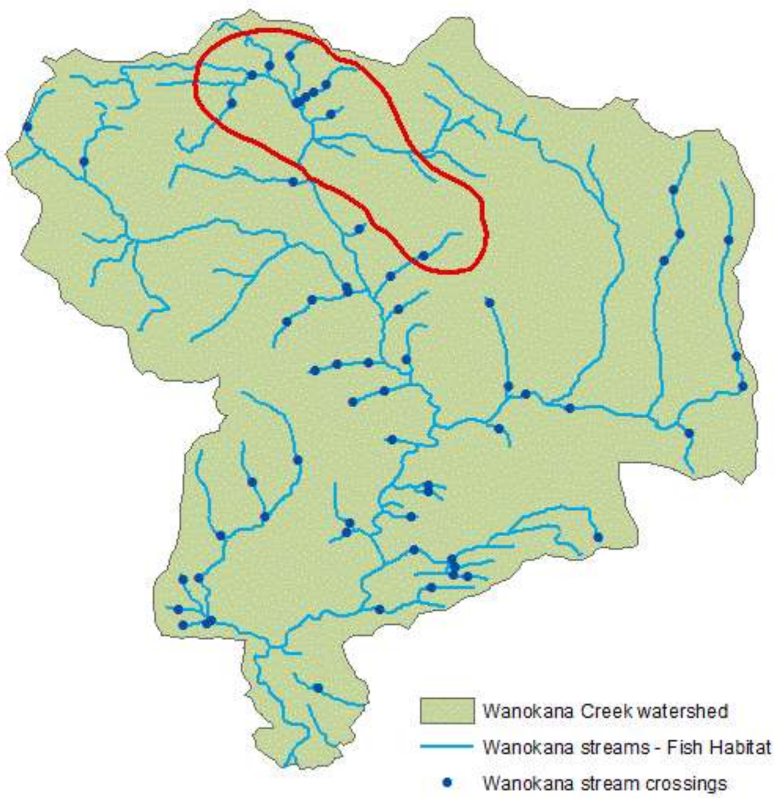


Figure 5. Illustration of all stream crossings (n=63) in the Wanokana Watershed. The area depicted in red is not accessible at this time leaving a total of 53 sites (type A) available to be sampled.

### 3.2.4 Watershed scale application of protocol

The FREP Water Quality (WQ) Protocol (Carson et al. 2009) as written for the site scale is applicable for use in monitoring potential fine sediment delivery at stream crossings. The differences are in the way sites are selected for sampling (Section 3.2.3) and the way site specific results are summarized to make statements about the watershed (Section 3.2.5),

**Reconnaissance:** A broad field reconnaissance of pre-selected GRTS sampling points and roads in the watershed is strongly recommended prior to initiating actual field sampling. Reconnaissance can be accomplished by driving throughout the watershed where there is road access, consulting people with local expertise, or by overview flight and examining the watershed using aerial imagery. The reconnaissance will help identify/document sample points that are inaccessible or inappropriate for various reasons. It will also help to plan the most efficient sampling routes and help identify any potential hazards. Sites which are dropped from the sample for any reason (e.g., access, safety, applicability) either in the office or in the field should be documented and the reason explained.

### 3.2.5 Watershed scale scoring

All three road type strata are considered to be independently important to the overall watershed condition. Therefore, all three strata must meet the criteria for the watershed to be considered Green or properly functioning, with respect to riparian and stream channel condition. The scored ratings for sediment delivery from each sampled site are summarized by road type to generate an assessment of sediment delivery processes within the watershed.

For a watershed to be considered properly functioning (Green) with respect to sediment delivery, the criteria (Table 8) for all strata must be met (Low). If any strata receive a Moderate or High score, the watershed is identified as not properly functioning (Red) with respect to sediment delivery. It is important to ensure all sites are weighted appropriately in the analysis and watershed scoring. If data from different site types and strata are combined the inclusion probabilities need to be considered to ensure no inadvertent bias is created8. If strata are kept independent the analysis is easier (i.e., if all sites within a strata have equal probability of being selected then a simple average accurately represents the strata).

Scientifically based criteria for how cumulative impacts of sediment delivery (i.e., fine sediment delivery, coarse sediment delivery, and artificial drainage impacts on peak flow) affect ecological function of the watershed is an area requiring more research. The WSEP suggests a simple comparative approach to roll up site scale evaluation of fine sediment delivery within a watershed into general classes of cumulative impact.  The thresholds used to of define ranges for each cumulative impact class are taken directly from provincial WQ data covering over 4033 sites evaluated over the previous 5 years (Appendix J:).  This approach enables us to understand how a watershed compares to other watersheds in the province. It provides useful information until more rigorous approaches are developed. However, the reader is reminded that these criteria are not grounded in scientific evidence of an ecological threshold.

[8] For example if you sample 30 out of 50 mainline sites and only 10 out of 50 spur roads, if you take a simple average the estimate will be biased towards the results for mainline roads.

If the provincial average is in reality poor from an ecological point of view, then a 'better than average' result may not be good enough. Alternatively, the reverse is possible.

Table 8. Criteria for evaluating fine sediment delivery at the watershed scale.

| | **Compilation of water quality impact ratings evaluated within watershed (all site types)** | | |
|---|---|---|---|
| **Cumulative impact on watershed** | **Portion of low impact sites in watershed** | **Portion of moderate impact sites in watershed** | **Portion of high impact sites in watershed** |
| **Lesser cumulative fine sediment impact than average** | >80 | <20% | <3% |
| **Average cumulative fine sediment impact** | 70% +- 10% | 25 +- 5% | *5% +- 2%* |
| **Greater cumulative fine sediment impact than average** | <60% | >30% | >7 % |

## 3.3 Fish passage assessment

Fish passage failure at road crossings constitute a major, if not the major, loss of freshwater habitat by both migratory and resident fish populations in British Columbia (Northcote and Hartman, 2004; GAO, 2001). A special investigation Forest Practices Board report (FPB 2009) highlighted the need to remove barriers to fish passage at fish stream crossings. Culverts can be barriers to fish passage due to primarily to: (i) turbulence and increased velocity; (ii) no streambed substrate and low flow issues; and (iii) perched culverts. Watersheds that maintain the free movement of aquatic organisms are more resilient in the face of ever growing pressures from climate change and human activity. A Tier I indicator of stream crossing density can give you a general idea of the potential risk to fish habitat if road stream crossings are a barrier. The field based assessment collects the necessary data to evaluate with greater certainty the extent of fish habitat fragmentation in the watershed.

### 3.3.1 Site level protocol

WSEP has adopted the province's Field Assessment for Fish Passage Determination of Closed Bottom Structures (MOE 2009) to assess fish passage stream crossings throughout the watershed. The protocol uses a cumulative scoring approach involving a suite of indicators

(Table 9) to determine the likelihood that a close bottomed culvert at a stream crossing provides safe fish passage. The cumulative score across the suite of passage indicators is used to determine whether a sampled culvert is considered to be: "Passable," "Potential Barrier," or "Barrier" (Table 10). The BC MOE Fish Passage protocol focuses on closed bottom structures because of the known problems that are associated with fish passage if these structures are not properly designed and installed. All bridges and open bottomed structures (i.e., log and arch culverts) encountered at stream crossings in a watershed will as a general default be rated as Passable to fish.

Table 9. Summary of indicators used to assess fish passage, adapted from Table 2 Fish Passage Assessment (2011)

| | Possible range of scores – see site protocol for details | | |
|---|---|---|---|
| Indicator | Good | Fair | Poor |
| Embeddedness of culvert bottom | 0 | 5 | 10 |
| Outlet drop height | 0 | 5 | 10 |
| Stream width ratio | 0 | 3 | 6 |
| Culvert Slope | 0 | 5 | 10 |
| Culvert length | 0 | 3 | 6 |

**Where to find the complete fish passage site-level protocol:** Details on assessing, recording and summarizing Fish Passage Protocol indicators for a sample site and example Fish Passage Protocol field assessment forms are provided in BC MOE (2011). Fish Passage assessment spreadsheets can be downloaded from the Fish Passage Technical Working Group website at: https://www.for.gov.bc.ca/ftp/hcp/external/!publish/web/fia/Field-Assessment-for-Determining-Fish-Passage-Status-of-CBS.pdf.

### 3.3.2 Site level scoring

For each of the five indicators identified in Table 9 the resulting scores are summed giving a cumulative score that can range from 0 to 42. Any cumulative score of 20 or greater is considered to be a barrier to fish passage.

Table 10. Criteria for evaluating fish passage condition at the site scale.

| Cumulative Score | Result |
|---|---|
| 0 - 14 | Passable |
| 14- 19 | Potential Barrier |
| > 20 | Barrier |

### 3.3.3 Watershed scale sample design

***Target population***

The target population for Fish Passage assessments is all stream crossings in the watershed that occur within fish habitat.

***Sample frame and sample unit***

The **sample unit** for this protocol is a location where a road intersects a stream, i.e., a stream crossing. The **sample frame** for all strata is identified by taking the intersection of streams and roads within fish habitat, where:

- **Streams** are defined by the BC Freshwater Atlas, 1:20K stream network layer.
- **Roads** are defined by the best available data for the watershed, at a minimum the Digital Road Atlas (DRA) and Forestry Tenure (FTEN) should be included, but local forestry companies or managers should be consulted to obtain any improved local datasets. If possible, rail-lines and any other non-road related crossings (e.g., hydro or pipeline right of way) should be included.
- **Fish Habitat** is defined by the province's Fish Habitat model or better fish habitat layers that may exist locally.

This GIS based sample frame under represents the target population of stream crossings as some roads or streams may not be accurately mapped. Unmapped crossings on larger streams are identified in the field, but unmapped crossings for smaller streams are not assessed and so no inference can be made to these.

***Strata***

Barriers to fish passage restrict access to all habitat upstream of the barrier, the lower in the watershed the barrier the greater the impact. Therefore, the assessment of crossings on 4th order and larger streams are prioritized. Off-channel and small stream habitats along the fluvial margins (floodplain) of large streams are also prioritized. Four categories of stream crossings are identified, each with their own sampling approach.

***Selection of sites and sample size***

Stratum 1) > 4th order stream crossings

- A census of all crossings intersecting > 4th order streams in Fish Habitat. This includes both stream crossings identified in the GIS based sample frame and any other unmapped crossings encountered in the field along these streams.

Stratum 2) <4th order streams or off-channel habitat within floodplain of large streams

- This stratum is used to assess (potential) impact to off-channel and small-stream habitats along the fluvial margins (floodplain) of large streams. The sampling units within this stratum are identified as all stream crossings on smaller order streams in fish habitat that lie within a defined search area buffer. The variable buffer width for this additional search of stream crossings is defined as the distance from a > 4th order stream's top of bank on each side to the adjoining upslope point where the terrain gradient becomes > 8%, a pre-defined GIS layer derived from a Digital Elevation Model (DEM).9 A census will also be undertaken for this stratum.

Stratum 3) All remaining 3rd order streams

- If a census of third order stream crossings (due to time constraints or other factors) is infeasible, a random GRTS (Appendix F:) sample of stream crossings will be assessed. Any mapped 3rd order stream crossings included in Stratum 2, should be removed prior to sampling. The sample size required depends on the desired precision and the stratum variability. Without prior information, a sample size of 30 stream crossings is recommended (Pickard et al. 2014). However, the actual number of sites sampled may be adjusted on the go, based on running proportions (Appendix G:), if strict adherence to sample sequence is followed as described in Appendix F:.

Stratum 4) All remaining 1st and 2nd order streams

- If a census of 1st/2nd order streams is infeasible, a random GRTS (Appendix F:) sample of stream crossings will be assessed. Any mapped 1st or 2nd order stream crossings included in Stratum 2, should be removed prior to sampling. The sample size required depends on the desired precision and the stratum variability. Without prior information, a sample size of 30 stream crossings is recommended (Pickard et al. 2014). However, the actual number of sites sampled may be adjusted on the go, based on running proportions (Appendix G:), if strict adherence to sample sequence is followed as described in Appendix F:.

### 3.3.4 Watershed scale application of protocol

The BC MOE Fish Passage Protocol as written is applicable for use in monitoring fish passage at stream crossings within a watershed. The only differences are in the way sites are selected for sampling (Section 3.3.3) and the way site specific results are summarized to make statements about the watershed (Section 3.3.5).

[9] The feasibility of sampling this stratum has not yet been tested. The details may need to be revised to account for unforeseen logistical problems with implementation.

### 3.3.5 Watershed scale scoring

The scored ratings for fish passage from each sampled site are summarized by strata (Table 11) to generate an assessment of how well fish population connectivity is being maintained within the watershed. Different criteria are used for each stream classification. Less stringent criteria are applied to smaller streams for two reasons: 1) we have less confidence in fish habitat models for small streams (i.e., some small streams identified as fish habitat by the province's Fish Habitat model may not actually support fish); 2) smaller streams will generally have less upstream habitat and therefore fish passage barriers will have less of an impact on smaller streams than on larger streams. For a watershed to be considered properly functioning (Green) with respect to fish passage, the criteria for all strata must be met (Low or Moderate). If any of the strata exceed the high criterion, the watershed is identified as not properly functioning (Red) with respect to fish passage.

Table 11. Criteria for evaluating fish passage at the watershed scale.

| Stratum | Low | Moderate | High |
|---|---|---|---|
| > 4th order streams in Fish Habitat | 100% rated "Passable" | NA | <100% rated "passable" |
| smaller order streams or off-channel habitat (confirmed in the field) that flows directly into > 4th order streams | 100% rated "Passable" | NA | <100% rated "passable"" |
| 3rd order streams in Fish Habitat | 100% rated "Passable" | <100% rated "passable" | >5% of crossings with "barrier" or "potential barrier" |
| 1st and 2nd order streams in Fish Habitat | 100% rated "Passable" | <100% rated "passable" | >40% of crossings with "barrier" or "potential barrier" |

# 4 Watershed Synthesis and Reporting

Purpose –provide consistent framework for summarizing information on watershed pressures and condition.

Principles:

- Provide as close to raw data as possible to allow reader to make their own conclusions.
- Show data compared with thresholds, so reader doesn't need to trust interpretation but can see how close/far from thresholds we are
- Simple presentation of information
- Identify both strengths and opportunities for improvement

## 4.1 Standard components of the WSE report

The WSE consists of a variety of simple figures and data summaries including: photos, maps, boxplots, thresholds, and summary statistics.

### 4.1.1 Overview:

The first page of the WSE provides an overview of the watershed, with general summary statistics, and provides a map for the watershed. Watershed risk ratings (green, yellow, red) for a suite of habitat pressure indicators derived from remote sensed data are provided in a concise "slider" figure (Porter et al. 2013b).

- Development history
- Landscape summary
- Tier I summary of pressures
- Special legislation (e.g., FSW)
- Fish values

### 4.1.2 Riparian:

Locations of riparian field surveys (Tripp et al. 2009) within the watershed are presented, with each site being coloured green or red on the map based on functioning condition ratings. A box plot displays the range of riparian functioning condition ratings across surveyed stream sites within different habitat categories. A figure showing the frequency of questions answered with "No" provides insights into specific problems that may be impacting stream condition. General statistics on the watershed's riparian system and sampling issues are also provided.

- Beaver ponds
- Summary of what was/wasn't sampled and why.

### 4.1.3 Fish Passage:

Locations of fish passage field surveys (MOE2011) within the watershed are presented, with each site being coloured green or red on the map based on passage ratings. A box plot displays the range of fish passage ratings across surveyed stream crossings by stream order. A figure summarizing the key underlying passage indicators provides insights into specific problems that may be hindering fish passage.

### 4.1.4 Sediment Delivery:

Locations of sediment field surveys (Carson et al., 2009) within the watershed are presented, with each site being coloured green, yellow or red on the map based on fine sediment delivery ratings. A box plot displays the range of fine sediment delivery ratings by road use classification. A table summarizing specific issues at poorly rated sites within the watershed is also provided.

### 4.1.5 Watershed Synthesis:

Nested tables provide the watershed scale evaluation of condition for Riparian, Fish Passage and Fine Sediment Delivery components. All three components are considered independently important to the overall watershed status. Riparian and Fish passage components are further divided into 3 sub-components each with different criteria. Each sub-component is compared to criteria based on ecological function (Pickard et al. 2014). A green score indicates the condition is within the range of natural variability, a yellow score indicates that the moderate threshold has been exceeded, and a red score indicates that the highest threshold has been exceeded. Given that each of the sub-components and components are independently important, a single red score is sufficient to warrant a closer examination of watershed condition.

### 4.1.6 Discussion:

The final page of the WSE provides a summary of the status of the watershed, considering both the evaluation of the pressures (Tier I) on the watershed as well as the current condition of fish habitats (Tier II). Expectations for the future of the watershed are discussed, given observed Tier I and Tier II data in addition to anticipated human development and climate change impacts. Finally, current and potential issues are identified and, where appropriate, opportunities for improving the status of the watershed. In addition, commentary may be provided on the quality of the supporting data or any important data gaps.

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# Appendix A: Priority items to address uncertainties in the WSEP

1. Riparian sample frame: Determine appropriate stream length to remove from the upper end of 1st order streams for interior watersheds.
2. Beaver ponds. We need to improve the guidance for applying the protocol and ensure that the information collected is meaningful.
3. Other landuse impacts: Within the current WSEP impacts and associated thresholds of concern are very forestry based, while other potential land use impacts are not directly assessed. Pressures from other activities or processes not currently captured within the WSEP could also have significant effects on fish habitat condition (hydro right-of-ways, park trails, mines, urbanization, climate change, etc.). In some watersheds the amount of private land present might be one of the best indicators of potential threats to watershed condition. Expansion of Tier I and Tier II indicators to cover as many land use activities and broader scale processes as possible will be good to consider in future iterations of the WSEP.
4. Test feasibility of proposed new stratum for fish habitat

   Stratum 2) <4th order streams within floodplain of large streams

   This stratum is used to assess (potential) impact to off-channel and small-stream habitats along the fluvial margins (floodplain) of large streams. The sampling units within this stratum are identified as all stream crossings on smaller order streams in fish habitat that lie within a defined search area buffer. The variable buffer width for this additional search of stream crossings is defined as the distance from a > 4th order stream's top of bank on each side to the adjoining upslope point where the terrain gradient becomes > 8%, a pre-defined GIS layer derived from a Digital Elevation Model (DEM). A census will also be undertaken for this stratum.

5. Review and refine sediment delivery sample design and address inclusion probabilities and analysis
6. Sediment delivery thresholds – more research is required to link sediment assessments to impacts on fish habitat.

# Appendix B: Future Supplemental Tier II Field Protocols

## Wetland condition protocol

Wetlands are an important aquatic feature in any landscape and can serve an important role in the maintenance of healthy fish habitat as well as diversifying the types of aquatic habitat available to fish within a watershed. Wetlands can be affected by anthropogenic activities in a number of ways and understanding how they are being impacted or changed can be impacted by human activities, in many locations throughout the province wetlands can also be created as an unintended consequence of management activities. For example, harvesting forested swaps can result in the creation of beaver (created) wetland complexes. In some cases these complexes may be beneficial to fish, however they also represent a loss of productive forest land base. To better understand the past and current role of wetlands in the fish and watershed context a protocol that measures the condition of these areas will be required.

## Road mass wasting protocol

Depending on their location, the occurrence of roads, especially as their density increases on hazardous terrain, can present a risk to aquatic conditions. While measuring road density (see Tier I assessments described in Porter et al. 2012) spatially against other known attributes that increase risk provides a good surrogate for the actual risk embodied in the road network contained in a watershed, it can fall short of providing an on-the-ground understanding of the risk that a road network presents to the aquatic health of a watershed. In some cases, in order to better understand the risk associated with roads, a field-based assessment may be necessary. While a road related Tier II protocol that assesses this risk does not currently exist it is proposed that either a modified FREP Water Quality Protocol or a new Road Mass Wasting Assessment Protocol be created to achieve this. Either of these could be informed by road rehabilitation procedures developed in the province (see Moore 1994; Wise et al. 2001) as the risk assessment methodology used in prioritizing roads for rehabilitation treatments would be very similar to those used in a road mass wasting protocol.

## Indicators related to Climate Change

## Stream temperature monitoring protocol

Stream temperature can have a wide variety of impacts on fish populations and their habitat adversely affecting fish species through to entire fish communities. From a climate change impact perspective, stream temperature is expected to be one of the stronger signals of change in the aquatic environment (Reese-Hansen et al. 2012). While it is beyond the scope of the WFV monitoring protocol to develop detailed method to monitor stream temperature to this end there has been some work provincially to lay out appropriate methods for temperature monitoring. One such approach involves the collection of stream data over a period of time and correlating it to atmospheric temperatures and is a reliable way to understand the temperature conditions found in streams. Reese-Hansen et al. (2012) provides more information on stream temperature monitoring and methods referred to in this document may help form the basis of a stream temperature monitoring protocol.

# Mountain Glacio-cryology

To be developed.

# Hydrometric stations monitoring

The amount of water moving through, and out of, a watershed is a strong indicator of the condition of a watershed. There are numerous variables that can affect flow, both inside a watershed and external to it (e.g., precipitation, forest harvesting, water withdrawals, structure that convey water [e.g., roads and ditchlines], impoundments, etc.). By measuring these (particularly those variables which managers have control of at the watershed level), and then comparing them to water yields (flows exiting a watershed as measured at a hydrometric gauging station), land managers can understand the influence that both local anthropogenic activities as well as climatic variations are having on the amount of water flowing out of the watershed and the watershed s overall condition. Establishing and maintaining hydrometric stations requires specialized knowledge and resources. Consequently, it is a difficult and potentially costly to establish these stations on an ad hoc basis as part of watershed condition monitoring exercise. Because this information is integral to understanding the condition of a watershed and how it is responding to management and natural disturbance, it is recommended that the provincial and federal hydrometric network be expanded to representative sites. This recommendation is made in recognition of the efficiencies that would be realized by using organization already adapt (e.g., Water Survey of Canada) to the business of hydrometric network maintenance and monitoring.

# Appendix C: Supplemental page for watershed application of riparian protocol

To be developed.

# Appendix D: Assessment and post stratification of riparian conditions on sample reaches and the degree of buffering present

- Data entry on riparian buffer widths and percent retention on Page 1 of the FREP riparian field cards often causes problems or confusion in WSEP assessments. The main reason for the problems or confusion is because, unlike standard FREP riparian assessments where riparian conditions are the same at every point along a sample reach, riparian conditions at WSEP riparian sites can be highly variable. Some reaches may encompass riparian conditions that vary along the reach, with stable mature or old forest conditions along some sections of the reach, and recently disturbed or younger forests on other sections. The variation can extend not only longitudinally up and down the reach it can also vary laterally from the stream edge to upslope areas on one or both sides of the reach. Riparian areas that are selectively logged further complicates things, resulting in stands with a mixture of mature or old growth characteristics and more recently logged characteristics.

- An overall measure of how "unlogged" or "buffered" the sample reach is recommended for each sample reach. The measure should take into account stream width and depth, fish-bearing status, the presence of fluvial slopes and topographic breaks, and the different dimensions and age of each stand of trees present along the sample reach. "Stand" is a group of trees with the same age and the same stand initiating event. The number of stands present along a stream reach can be very low where all trees in the riparian area are more or less of the same age and species. However, the number of stands can be quite high where there is a complex mosaic of different stand ages with different stand initiating events and different species.

- To assess overall buffer condition, it is recommended that only three basic types of stands be considered, based mainly on tree size (as a surrogate for stand age) and the amount of standing dead wood (SDW) present. Tree size and SDW are scaled to channel depth, such that tree diameter and SDW diameter have to be 10% of channel depth to qualify as trees or SDW. The three basic stands are as follows:

- Riparian classes to define overall buffered conditions on forested streams.

- Class 1) = unlogged (or no recent disturbances) = wood sized mature or old growth trees with conspicuous amounts of standing dead wood (wood-sized snags, dead tops, branches),

- Class 2) = logged (or recently disturbed) but recovering = buffered with sub-wood sized mature or old trees or wood-sized sapling or pole stage trees and at least one piece of standing dead wood (wood-sized snags, dead tops, branches) in every five channel widths of reach length, and

- Class 3) = logged (or recently disturbed) = buffered with sub-wood-sized trees and little or no standing dead wood (wood-sized snags, dead tops, branches).

- To determine overall buffer condition of the riparian area, each stand class needs to be delineated within the riparian area with a sketch. Before delineating each stand, however, the width of the riparian area itself needs to be defined. For WSEP assessments, the default width is the FPC Riparian Management Area (RMA) width. Exceptions where the riparian width might be wider are one, where the slope distance of an inner gorge with a distinct break in the gradient at the top of the gorge exceeds the default width, two, where the width of active fluvial areas (e.g., fans, active floodplains) exceeds the default width, or three, the distance to the top of adjacent fluvial slopes exceeds the default width.

- Once the riparian area is delineated, and all stands identified to class in the riparian area, the total degree of buffering is calculated by weighting the amount of area covered by each stand class. Class 1 stands receive a weighting value of 1 (full buffering), Class 2 a value of 0.5 (partial buffering) and Class 3 (no buffering) a value of 0.0.

- Where a stand is a mixture of two or more different stand classes, the buffer value of the stand should take into account the relative composition of the mixed stand. A mature or old growth stand with 25% of the stand recently harvested would have a buffer value of (0.75 x 1) + (0.25 x 0) = 0.75. An old stand that had 25% of the trees removed 50 years ago and then 50% of the trees removed today (old and second growth harvested equally) would have a buffer value of (0.75 x 1 x 0.5) + (0.25 x 0.5 x 0.5) + (0.5 x 0.0) = 0.4375.

- Examples of the calculations for three scenarios are described below.

- Example 1. A 100m fish bearing stream reach is located in a gorge with 20m side slopes (Figure A). The stream is an S4 stream 1.4m wide and 0.3m deep. Twenty meters of the stream is recently logged to the edge of the gorge on one (the right) side. The rest of the reach has 50m of mature timber on both sides.

- If the top of the gorge is considered the edge of the riparian area, this stream is completely (100%) buffered because the entire riparian area is covered with a Class 1 stand of trees. However, if for some reason the assessor feels the default FPC RMA width (30m) is more appropriate (perhaps because the topographic break is not really very distinct), then the stream is only 96.7% buffered because the recently logged area (20m x 10m = 200m2, Class 3, no buffering) represents 3.3% of the total riparian area (2 x 30m x 100m = 6,000m2).

- On the FREP cards, average distance from the stream edge to the first signs of partial or complete logging would be 50m for the left side and 44m for the right side, to account for the 20m of stream logged to within 20m of the stream edge. Percent retention values for the right side would be 100% for the first 10m, NA for the rest of the RRZ, and 90% for the rest of the RMA. Percent retention on the left side is 100% for the first 10m, NA for the rest of the RRZ and 100% for the rest of the RMA.

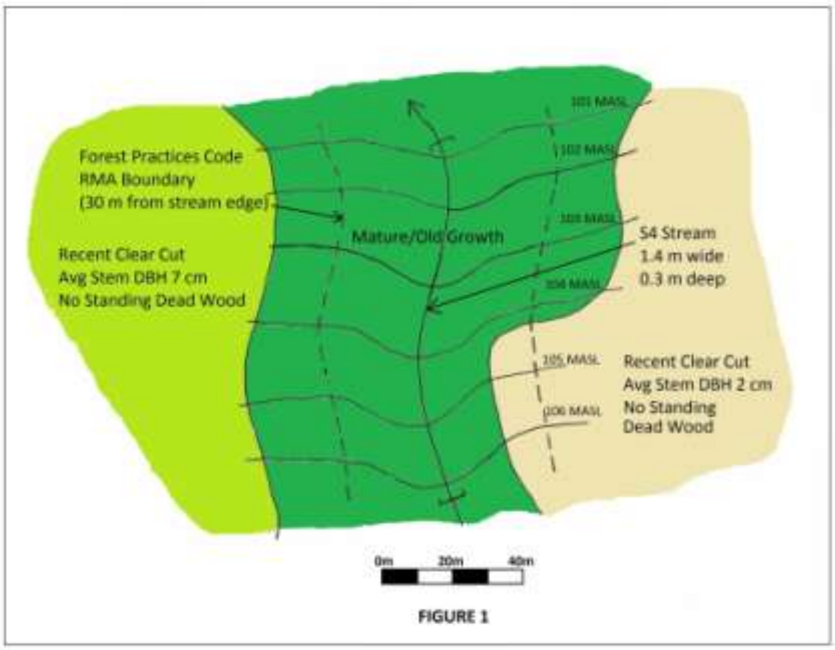


FIGURE 1

**Figure A**

- Example 2. A 10m wide by 1m deep fish bearing stream reach (Figure B) has a high, narrow floodplain and stable side slopes that extend 100-150m to roads on both sides of the stream reach. The left side is unlogged mature/old timber except for a 40m wide road crossing. The right side has the road crossing plus 1 m of old growth beside the stream and then 30 to 50 m of second growth (assume average is 40m) that is 40 years old and has little standing dead wood, other than some suppressed stems. There is new logging above the first logging.

- Since there are no fans, floodplains or fluvial slopes that extend beyond the FPC default distance, the FPC default width (50m) applies. Total riparian area is 300m X 50m x 2 (both sides) = 30,000m2. How buffered is this reach?

- % Class 1 buffer = (260m x 50m + 260m x 1m) = 13,260m2 = 13,260/30,000 x 100 = 44.2% of the total riparian area.
- % Class 2 buffer = 0%. The second growth has no SDW more than 0.1m in diameter and so is essentially still like a recent clear cut as far as wood supply and probably forest structure too.
- Class 3 buffer = (50m x 40mx 2 = 4,000m2 for the road) + (40mx 260m= 10,400m2 for the second growth) + (9mx 260m= 2,340m2 for the new harvesting) = 16,740m2 = 16,740/30,000 x 100 = 50.2% of the total riparian area.
- Total degree of buffering = (44.2% x 1 for the Class 1 buffer area) + (0% x 0.5 for the Class 2 buffer) + (50.2% x 0.0 for the Class 3 buffer area) = 45.9%

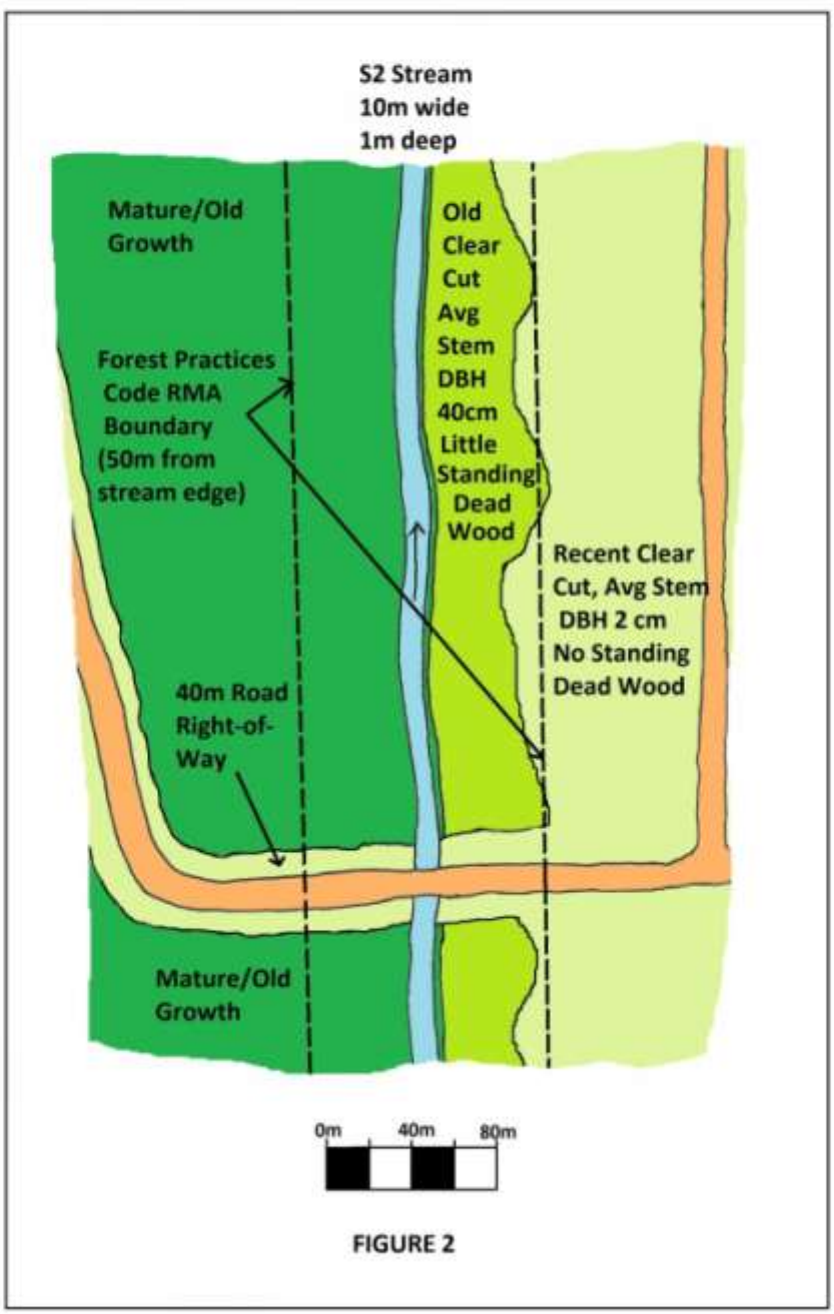



**Figure B**

- If the older second growth had standing dead wood of sufficient abundance and size to be called Class 2, total Class 2 buffer area would be 40mx 260m= 10,400m2, or 34.7% of the total riparian area. Total degree of buffering would then be (44.2% x 1 for the Class 1 buffer area) + (34.7% x 0.5 for the Class 2 buffer) + (21.1% x 0.0 for the Class 3 buffer area) = 61.5%.

- On the FREP cards, average distance from the stream edge to the first signs of partial and complete logging on the left side would be 86.7m (100m for 260m of the reach and 0m for the 40m wide road crossing). For the right side, average distance to the first signs or partial and complete logging would be 0.9m (1m for 260m and 0m for the road crossing). Percent retention values for the left side would be 90% for the first 10m, 90% for the rest of the RRZ, and 90% for the rest of the RMA. Percent retention on the right side is 9% for the first 10m, 0% for the rest of the RRZ and 0% for the rest of the RMA.

- Example 3. A 3m wide fish stream in a beaver dam/pond complex (Figure C) meanders down a strip of grass and medium to tall height deciduous shrubs (alder and willow). Heavily browsed by moose and beavers, the alders and willows have quite a few dead stems. Approximately 24 large but drowned out (dead) conifers are also scattered throughout the complex, but no stumps. Average width of the strip is 20m. Channel depth where it can be measured accurately averages 0.45m. Total active floodplain width averages 15m on the left side and 55m on the right side. The left side of the floodplain is bordered by a steep 5m fluvial slope, while the right side has a 2m fluvial slope that marks the beginning of a high bench flood plain that extends a further 100m to the toe of an old 3m fluvial slope.

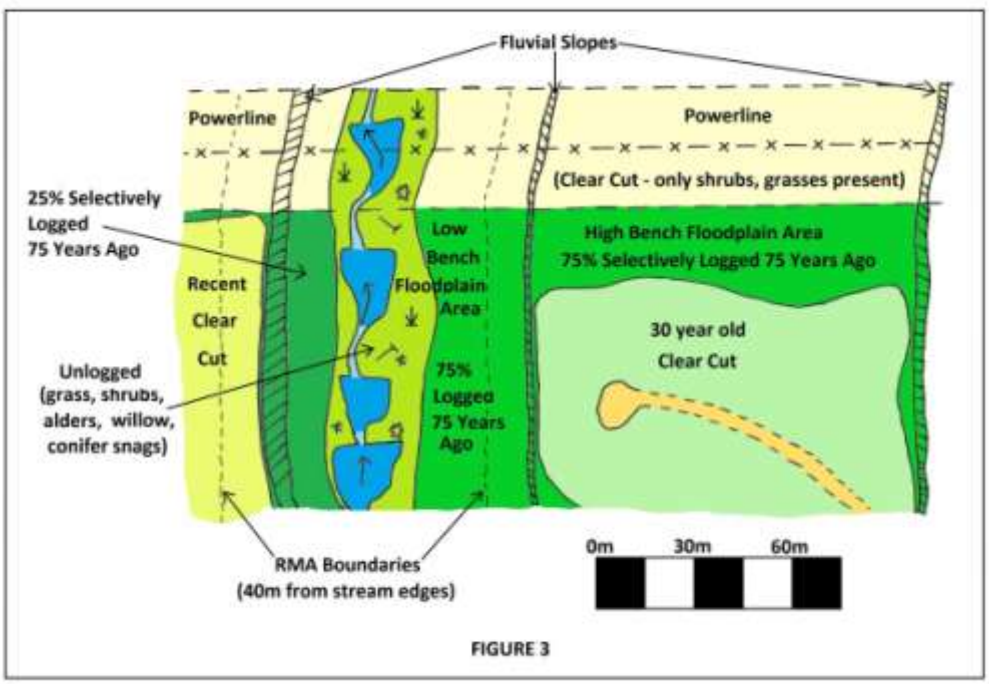



**Figure C**

- Judging by the advanced decay state of the stumps in the forested areas, the left side of the stream was selectively logged a long time ago, approximately 75 years. An estimated 25% the trees were harvested at that time. The trees left behind range in age from 75-200 years old. Snags and other standing dead wood are common, though not so common as in an intact old forest due to the old logging. The other side of the stream was also selectively logged a long time ago to a greater degree (75% of the trees) than the right side. In addition, the upstream half of the high bench flood plain on the right side was clearcut 30 years ago to make way for a new convenience store. The store plans went bust and the area has since become a local dump site. A recent clear-cut starts at the top of the left fluvial slope while a hydro right-of-way crosses the lower 30m of the sample reach.

- FPC RMA width for this stream is 40m on either side of the stream, for a total of 80m not counting stream width. However, the distance between the tops of the adjacent fluvial slopes is also 80m (including 3m of stream width), though it is skewed to the right side of the stream. Since the area between the fluvial slopes defines the natural meander pattern of the stream, it represents the riparian area better than the arbitrary FPC RMA widths. Reach length is 100m, so total riparian area being considered between the tops of the fluvial slopes is 100m X (80m total width – 3m for stream width) = 7,700 m2.

- To determine how buffered this reach is, extra consideration has to be given to the different buffer values of the selectively logged areas. Since the left side is 75% mature or old forest and 25% 75 year old second growth with some snags and dead wood equal to one piece for every five channel widths, overall buffer value for this part of the riparian area is (0.75 x 1) + (0.25 x .5) = 0.875. Similarly, the buffer value of the selectively logged area on the right side which was 75% logged is (0.25 x 1) + (0.75 x 0.5) = 0.625.

- How buffered is this reach?

- % Class 1 buffer. Strictly speaking the only areas of any size that meet this criterion is the flooded and dead conifer sections of the riparian area beside the entire length of the stream. Total area = 100m X 20m = 2,000m2 = 2,000/7,700 x 100 = 26.0% of the total riparian area.

- % Class 1 and Class 2 area on the left side. Total area = 70m x 15m = 1,050m2 = 1,050/7,700 x 100 = 13.6% of the total riparian area.

- % Class 1 and Class 2 area on the right side. Total area = 70m x 42m = 2,940m2 = 2,940/7,700 x 100 = 38.2% of the total area.

- Class 3 buffer area (i.e. the hydro right of way). Total area = 30m x (77m for total width -20m for the alders, willows and dead conifers in the beaver dam/pond complex) = 1,710m2 = 1,710/7,700 x 100 = 22.2% of the total area.

- Total degree of buffering = (26.0% x 1 for the Class 1 buffer area) + (13.6% x 0.875 for the mix of Class 1 and Class 2 buffer classes on the left side) + (38.2% x 0.625

for the mix of Class 1 and Class 2 buffer classes on the right side) + (22.2% x 0.0 for the Class 3 buffer area) = 61.8%.

- On the FREP cards, average distance from the stream edge to the first signs of partial logging on the left side would be 5m, assuming that there was selective logging right down to the edge of the beaver dam/pond complex. Average distance to complete harvesting (the clearcut above the fluvial slope and the hydro right-of-way) is 15.5m, assuming 20m over 70m of reach length for the clearcut and 5m over 30m for the hydro right-of-way. For the right side, average distance to the first signs or partial and complete logging would be 15m, again assuming that selective logging went to the edge of the beaver dam/pond complex. Average distance to complete harvesting is 53m, assuming 15m over 30m of the hydro right-of-way, 57m over 50m for the 30 year old clearcut and 100m maximum for 20m of old selective harvesting only.

- Percent retention values for the left side would be 76% for the first 10m, 26% for the rest of the RRZ (i.e. the next 20m), and 0% for the rest of the RMA (the next 20m). Percent retention on the right side is 100% for the first 10m, 38% for the rest of the RRZ and 17% for the rest of the RMA.

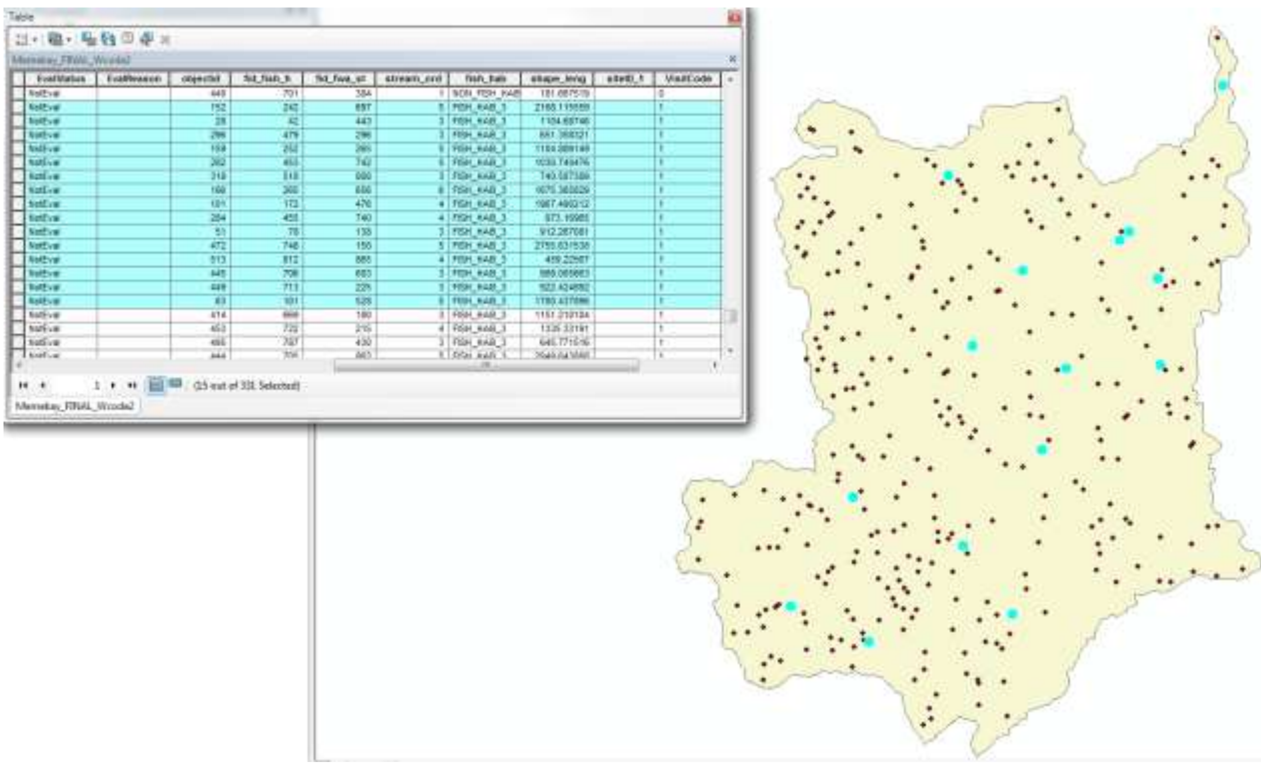
# Appendix E: GIS workflow for creating sample frame of GRTS riparian points sampling strata

| | Title | Description | Notes | Inputs |
|---|---|---|---|---|
| **1000** | **Fish habitat criteria** | | | |
| ***1100*** | ***Combine Freshwater Atlas hydrology and fish habitat*** | | | |
| 1110 | Import and clip stream network | Import the Freshwater Atlas stream network from the LRDW, and clip to the study area. | | 1:20K Freshwater Atlas Stream Network (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50648) |
| 1120 | Intersect stream network and fish habitat | Intersect the Freshwater Atlas stream network (clipped to study area) with the "Streamgradreaches" layer, and explode multipart features. | "Streamgradreaches" identifies those streams that are classed as fish habitat. This layer does not contain a stream order field though, which is required for this stratum. The geometry of these two layers is identical however so stream order can be extracted from the FSW stream network | "Streamgradreaches" layer from Richard Thompson (Monitoring Unit Head, Ecosystems Protection and Assurance Branch. BC Ministry of Environment. Richard.Thompson@gov.bc.ca);<br><br>Output from: 1110 |
| ***1200*** | ***Generate fish habitat strata*** | | | |
| 1210 | Add strata field | Add a new text field called "fish_hab" to contain the fish habitat strata. | | Output from: 1120 |
| 1220 | Select non-fish habitat | Select all stream sections that are classed as non-fish habitat, and update their fish_hab attribute to "NON_FISH_HAB". | | Output from: 1210 |
| 1230 | Select fish habitat & first or second order streams | Select all stream sections that are classed as fish habitat AND have a stream order < 3, and update their fish_hab attribute to "FISH_HAB_12". | | Output from: 1220 |

| | Title | Description | Notes | Inputs |
|---|---|---|---|---|
| 1240 | Select fish habitat & third order or above streams | Select all stream sections that are classed as fish habitat AND have a stream order >= 3, and update their fish_hab attribute to "FISH_HAB_3_". | | Output from: 1230 |
| 1250 | Delete fields | Delete all fields except "fish_hab". | | Output from: 1240 |
| **2000** | **General filters** | | | |
| ***2100*** | ***Remove all areas above the timber line*** | | | |
| 2110 | Select areas above timber line | Select all BEC polygons where ZONE = "CMA" (Coastal Mountain-heather Alpine), and output to a new layer. | | BECs (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=51819) |
| 2120 | Erase timber line | Erase the Mountain Heather BEC zone from the latest strata layer. | | Output from: 2110 |
| ***2200*** | ***Remove all lakes and identified wetlands*** | | | |
| 2210 | Erase lakes | Erase the Freshwater Atlas Lakes from the latest strata layer. | | Output from: 2120;<br><br>1:20K Freshwater Atlas Lakes (https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50640) |
| 2220 | Erase wetlands | Erase the Freshwater Atlas Wetlands from the latest strata layer. | | Output from: 2120;<br><br>1:20K Freshwater Atlas Wetlands https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50653 |

# Appendix F: GRTS methodology and master sample concept

An example (ArcGIS database) list of ten GRTS-selected riparian sample points for 3rd order or greater streams in fish habitat that were selected from a larger pool of potential points generated within the Memekay pilot watershed. An additional five oversample points were also selected to be used in the advent that any of the initial ten points selected could not be sampled for some reason (e.g., access problems, safety concerns, etc.). All ordered points selected through the GRTS procedure will conform to the desired design criteria of randomization and spatial balance. The associated display shows the mapped locations (light blue) for of each of the selected GRTS sample points within the Memekay pilot watershed.



# Appendix G: Sample size determination – running plots

To be developed.

# Appendix H: FREP Information Management System

To be developed.

# Appendix I: Wood - New, Old, Recent

When it comes to wood in streams, “new” and “recent” should be considered synonyms. “Recent” is probably a better word, however, because it also applies to “old” wood that has been in the stream for a long time, but for some reason is now in a “new” location. It also applies to “old” wood that has only recently been added to the stream through windthrow. Regardless of where the “old” wood came from, if it is “recent”, functionally it is just like “new” wood recently introduced to the stream. The wood may be old looking, but it is once again at the early stages of being processed by the stream. It is not well knit into a stable accumulation of wood, nor is it incorporated in any way into the stream bed or stream banks. It might be a “new coat of paint” on an otherwise stable wood accumulation, or it might be just “perched” on gravel bars, the stream bed or the stream banks. “Perched” wood is wood that is not incorporated in any significant way into the stream bed, stream banks or a stable accumulation of wood.

Streams process wood at different rates depending on stream size and the size of the wood. Large streams will process small pieces of wood very quickly, so small pieces of “new” or “recent” wood in large streams become “old” very quickly. Conversely, small streams will process large pieces of “new” or “recent” wood very slowly, so it takes a longer time before new or recent wood in small streams becomes old. This is one of the main impacts of logging around small streams.

Short, large diameter pieces of wood are rare in natural systems. But it can be quite common in logged streams where wood is often cut into shorter pieces. In large streams, these pieces are quickly processed and either transported downstream or incorporated into the stream bed, banks or other wood accumulations. In small streams, however, short, large diameter pieces may stay in one location for long periods of time before they are “processed” i.e. moved downstream, or incorporated into the stream bed or stream banks. Large pieces of wood in small streams therefore act like “new” wood for much longer time periods than the same size pieces in larger streams. Functionally speaking, it is possible that large pieces of wood introduced into small streams will be “new” or “recent” right up to the time the stream is logged again.

“New” wood is easy to identify, but “old” wood that is now “new” or “recent” is hard to distinguish. Wood with needles, bark, branches or fresh looking breaks or cuts is probably new wood. Wood that is dark with little or no bark, stubs for branches and smooth, eroded ends at the break or cut points is old wood if it is also knitted together with other stable wood to form a stable accumulation or jam, or partly buried or embedded in the stream banks or stream bed. If it is old wood that is not knitted into a stable accumulation of wood or debris jam or not partly embedded into the stream bed or stream banks, then it might be better called “recent” wood.

# Appendix J: Approach for watershed scale scoring of sediment delivery

While there is a general understanding of the relationship between fine sediment and water quality, there currently no quantitative approach for combining FREP WQ results from the site scale to make statements about the cumulative impact of fine sediment generation at the watershed scale. This is an area requiring more research for not only fine sediment but all components of sediment delivery (i.e., fine sediment, coarse sediment, artificial drainage impacts on peak flow).

This Appendix suggests a simple comparative approach to roll up a specific WQ evaluation within a watershed into general classes of cumulative impact. The thresholds used to of define ranges for each cumulative impact class are taken directly from provincial WQ data covering over 4033 sites evaluated over the previous 5 years. This approach enables us to understand how a watershed compares to other watersheds in the province. It provides useful information until more rigorous approaches are developed. However, the reader is reminded that these criteria are not grounded in scientific evidence of an ecological threshold. If the provincial average is in reality poor from an ecological point of view, then a ‘better than average’ result may not be good enough. Alternatively, the reverse is possible.

Table 1 shows the district % breakdown of water quality impact ratings for each district over the past 5 years of sampling. The provincial average is 71.3, 23.9 and 4.8 % for Low, Moderate and High WQ impact rating classes. Note the considerable variability within districts is at least in part dependant on both sample size and choice of representative samples.

The “average” cumulative water quality impact rating reflects the provincial average of all sites evaluated through the province. Watersheds with a substantially heavier weighting of higher water quality impact sites are classified as having a “greater” cumulative water quality impacts than average, those with lower proportions of higher impact sites, a “lesser” impact than average. These terms accurately reflect the nature of the data collected and its reliability. However, with higher sample numbers and more representative sample sites, differences in portions reflect differences in potential cumulative impacts on water within the sample populations and contribute directly to the understanding of human impact on the watershed under study.

As an example, the Memekay (with a portion of Low, Moderate and High of 84.2, 13.5 and 1.6%) would fall into a low cumulative impact when compared to the provincial data base. This is consistent with the findings of Carson (2012).

Table 1 showing % of sites within each water quality impact rating class in each district (2008-2012, 4033 sites)

| District | # of sites | % of Low | % of Mod | % of High |
|---|---|---|---|---|
| 100 mile | 119 | 81.5 | 15.1 | 3.4 |
| Cariboo | 181 | 80.1 | 17.1 | 2.8 |
| Quesnel | 44 | 81.8 | 13.6 | 4.5 |
| **Selkirk** | 95 | 83.2 | 15.8 | 1.1 |
| Rocky Mt | 350 | 71.1 | 23.4 | 5.4 |
| Peace | 11 | 90.9 | 0.0 | 9.1 |
| Ft Nelson | 68 | 73.5 | 17.6 | 8.8 |
| Ft St James | 133 | 63.9 | 28.6 | 7.5 |
| Mackenzie | 82 | 47.6 | 35.4 | 17.1 |
| Prince George | 48 | 25.0 | 41.7 | 33.3 |
| Vanderhoof | 127 | 68.5 | 23.6 | 7.9 |
| Cascades | 102 | 40.2 | 49.0 | 10.8 |
| Kamloops | 452 | 65.9 | 28.3 | 5.8 |
| Okanagan | 230 | 66.5 | 29.6 | 3.9 |
| Kalum | 134 | 84.3 | 15.7 | 0.0 |
| Nadina | 220 | 53.6 | 37.7 | 8.6 |
| Skeena | 111 | 96.4 | 2.7 | 0.9 |
| Chilliwack | 212 | 54.7 | 40.1 | 5.2 |
| Squamish | 136 | 59.6 | 37.5 | 2.9 |
| Sunshine coast | 230 | 80.9 | 18.3 | 0.9 |
| Campbell River | 412 | 72.1 | 26.0 | 1.9 |
| Haida Gwaii | 173 | 91.9 | 6.4 | 1.7 |
| North Island | 229 | 82.5 | 13.5 | 3.9 |
| South Island | 134 | 96.3 | 3.0 | 0.7 |
| % of sites BC | | 71.3 | 23.9 | 4.8 |

Table 2 showing Watershed Roll Up for Water Quality Transects

| | **Compilation of water quality impact ratings evaluated within watershed (all site types)** | | |
|---|---|---|---|
| **Cumulative impact on watershed** | **Portion of low impact sites in watershed** | **Portion of moderate impact sites in watershed** | **Portion of high impact sites in watershed** |
| **Lesser cumulative WQ impact than average** | >80 | <20% | <3% |
| **Average cumulative WQ impact** | 70% +- 10% | 25 +- 5% | *5% +- 2%* |
| **Greater cumulative WQ impact than average** | <60% | >30% | >7 % |