INTEGRATING GIS AND GROUND-BASED METHODOLOGIES WITH POUR-POINT SAMPLE DESIGN FOR ROUTINE-LEVEL WATERSHED ASSESSMENT

FREP

TECHNICAL GUIDANCE #7

July 2020

Lisa Nordin and Leah Malkinson

INTRODUCTION

In 2019, the Forest and Range Evaluation Program (FREP) piloted a study with multiple objectives, one of which was to test an integrated method for effectively assessing watershed conditions that could be repeated by trained non-specialists with a working knowledge of GIS. The creation of this pilot evolved from an increasing interest in expanding stream and riparian assessments from a local scale to one that more effectively captures processes at a watershed level. Prior to this new methodology, there was only one watershed sampling protocol within FREP, which had been developed for fisheries-sensitive watersheds (FSWs). The FSW design uses stratified-random site selection derived from sections of a grid overlay of the drainage area. The overall results subsequently roll up in an additive manner by fish/non-fish stream grouping to conclude on watershed condition. The fisheries-sensitive watershed assessment includes conservative thresholds for the protection of fish and fish habitat that are applicable to areas where important fish values could be at risk; however, the intensive sampling design requires substantial resources to complete. This often precludes use of the FSW protocol for routine-level assessments, hence the desire to create a less intensive assessment methodology such as the one described here.

WATERSHED SELECTION

The sample design used for this methodology can be applied to watersheds of any scale, with the caveat that larger watersheds will require more sample sites to be adequately represented. The identification of a specific watershed for sampling can be made based on a variety of factors including, but not limited to, public interest, ecological sensitivity, or resource district needs to support management decisions. Existing regional or provincial cumulative effects model output layers can assist in the identification of watersheds that might be at high risk owing to potential increases in peak flows, sedimentation, or riparian disturbance. As watershed patterns are hierarchical or "nested" it is important to understand the level of resources available for sampling before deciding on the scale of watershed for assessment. The scale does not have to align with existing mapped boundaries, such as those basins identified in current spatial layers, but if the watershed has a customized scale to meet specific objectives, additional GIS work to define the drainage boundary will have to be completed. The Freshwater Atlas and other topographic spatial layers are useful tools to help determine height of land and drainage direction if drawing a custom boundary.

POUR-POINT DESIGN AND RATIONALE

Watersheds can be described as a patchwork of sub-catchments that together contribute to the overall representation of functioning condition. Thirteen years of FREP data (2006-2018 inclusive) has shown that small (headwater) stream assessment results can be highly variable and tightly linked to localized effects, while those lower in the watershed are more reflective of cumulative upstream conditions. This can lead to an assortment of habitat and hydrological conditions across a watershed which can vary with upstream sub-catchment size, elevation, aspect, gradient, geology, stream order, stream magnitude, and morphology. Together, these variables can result in a range of responses to upstream development or "stressors" such as roads, forestry, agriculture, ranching, recreation, mining, oil and gas, and urbanization. To capture the resulting inherent variability within a watershed, it is best to maximize sampling efforts across a range of sub-basin sizes without constraining data collection to a specific stream order.

FREP Vision:
Collect and communicate trusted and scientifically robust natural resource monitoring information to inform decision making and improve resource management outcomes.

This method uses a "pour-point" design to identify potential field sites, which involves systematic selection near the mouth of different sized sub-catchments, thereby allowing for the unbiased evaluation of a watershed. Once the main watershed of interest is delineated for assessment, the Freshwater Atlas 1: 20 000 stream spatial layer can be used to establish the lowest accessible point in the mainstem as the first sample site. Sub-catchments are then identified by moving upstream from the initial site, looking for confluences from tributary branches that represent an upslope drainage basin. Choose sites on these tributaries that are ~100 m upstream of the confluence with the mainstem to avoid any potential effects from blockages and/or flooding in the main channel that may influence indicators in the lower portions of the sample reaches. If a sub-catchment is particularly large, it may be divided into smaller branches and each branch sampled separately. It is important to recognize the potential inaccuracy of stream information in the GIS layer. For example, in many interior watersheds, first-order streams on a map are often not found on the ground or are very small drainages with limited upstream areas that will not contribute significantly to overall watershed condition. Deciding on whether to include a first-order tributary that drains directly into the mainstem as a sub-catchment should depend on local knowledge and ease of access to the site to achieve a good return on effort.

The resulting number of sites and sub-catchments will vary with the overall size and accessibility of the watershed. The objective is to compile an unconstrained mosaic of sub-catchment data that, when combined, characterizes the watershed. Private land and topography can limit accessibility and site locations may have to be adjusted from the office-based selections once in the field. If time permits, a reconnaissance of the field sites prior to sampling will help confirm suitability or provide justification to readjust as needed. As the planned versus actual number and location of sites may differ, the delineation and subsequent calculation of upstream sub-catchment areas should be done after field sampling is completed.

The pour-point approach described above is termed "intensive watershed monitoring" in the United States, and has been in effect since 2006, beginning in the Snake River watershed (Minnesota Pollution Control Agency 2019). Since the introduction of this methodology, sampling has been completed in the Pomme de Terre, North Fork Crow, Le Sueur, Root, Little Fork, Sauk, Mississippi River-Red Wing, Tamarac, and the Upper Red River watersheds. Sampling methods for this design in the U.S. include biological, water chemistry, and fish contaminants for the purposes of water quality determinations. In the study design described here, sample site assessments include existing ground based FREP protocols along with habitat connectivity evaluations and GIS-derived indices of riparian disturbance.

FIELD DATA COLLECTION

The two FREP protocols used in the ground-based portion of this assessment include the Riparian Management Routine Effectiveness Evaluation (RMREE) and the Water Quality Effectiveness Evaluation (WQEE) (FLNRORD 2019a). The RMREE was developed for routine-level post-harvest assessment of a stream reach and has been an important part of FREP since 2006. The protocol contains 100+ attributes that are measured, counted, or estimated to answer 15 main indicator questions. Together, these indicators reflect on the form and function of both the stream and its riparian area at a sample reach that is the greater of 100 m or 30 times the channel width in length.

Unlike the riparian indicators that only reflect site-level conditions, indicators associated with the stream channel can be also be indicative of upstream activity. Studies have found increases in flow (Moore and Wondzell 2005; Winkler et al. 2017) and sediment regimes (Lewis et al. 2001; Gateuille et al. 2019) after logging or other development, and this can affect the condition of stream channel indicators measured at downstream reaches (Nordin et al. 2009a). Therefore, for the extrapolation of RMREE data to a watershed scale, only the values representing the *stream* indicators (Q 1-9) are utilized from the ground surveys. The remaining six main indicators (Q 10-15) are specific to the reach-level *riparian* vegetation and are not appropriate for extrapolation to a watershed scale. Instead, riparian disturbance is later evaluated using GIS. The decision to collect only the stream channel data or to complete the entire RMREE assessment at the field sites should be made based on the cost/benefit in relation to the utility of collecting the full suite of data. Time spent at each site will vary between 1-3 hours, depending on local site conditions and the decision to collect information on just the stream indicators or to complete the entire assessment. If there are questions around reach-level riparian management at the sample sites, it might be beneficial to include the riparian indicator data collection, although this will not be used in the watershed condition analysis.

The data collected using the WQEE do not feed into the analyses of functioning condition but is used to provide supplementary information regarding the risk of fluvial sedimentation from roads and associated cut/fill slopes and ditch lines. These assessments are conducted at all types of road crossings and include a component that evaluates fish passage at culverted sites. If there are too many crossings to conduct a complete census in the study watershed, the recommended approach is to reduce the sample size by only visiting the crossings passed on the way to the RMREE stream sample reaches. Information at these sites will generally be more valuable in terms of connectivity to fish-bearing reaches compared to crossings over headwater streams. If there are still too many sites to sample with the resources available, a list of eligible locations may be compiled using a random number generator and sites selected sequentially starting from the top. The total number of sites will be dependent on time and resources, but the greater of 10 sites or 10% of the total number of crossings in the watershed should be completed at a minimum. Account for approximately 30 minutes for each assessment.

If there are additional questions or concerns around specific components of a watershed during the planning stage, more assessments can be added. FREP has a wetlands effectiveness evaluation that may be utilized, and there are published standards to assess fish and fish habitat, water quality (pathogens), and water quantity here: https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/laws-policies-standards-guidance/inventory-standards/aquatic-ecosystems.

Deciding how many other supplemental assessments to include will depend on the project objectives and available field support.

GIS AND DATA ANALYSES FOR FUNCTIONING CONDITION

Once the ground assessments are completed, the sub-catchments within the study watershed need to be defined using the geo-referenced site coordinates as a starting point. Drawing sub-catchment boundaries upstream of all confirmed sample site locations can be done manually through Arc GIS Editor using topographic layers or by using the Arc Map hydrology tool. The hydrology tool requires a Digital Elevation Model (DEM) or other elevation raster and is a multi-step process that ultimately requires manual fine tuning, especially in flatter regions. The benefits in using one method over the other will depend on the number of sub-catchments sampled and the GIS expertise that is available for the project. Either method should result in a set of polygons that together represent the study watershed. An example of a completed watershed delineation with confirmed sample sites is shown in Figure 1. Areas for each sub-catchment can then be computed as well as the proportion of each as calculated from the total watershed area.

The total number of "No" responses to the RMREE stream indicator questions (Q 1-9) for each sample site are weighted according to the proportion of watershed represented by the sub-catchment area upstream of that site. All adjusted values are then added together to give a weighted stream score by watershed. As previously explained, the RMREE riparian values (Q 10-15) are not used because of their specificity to the sample reach. Instead, riparian disturbance is calculated for the entire stream length within the study watershed using spatial layers.

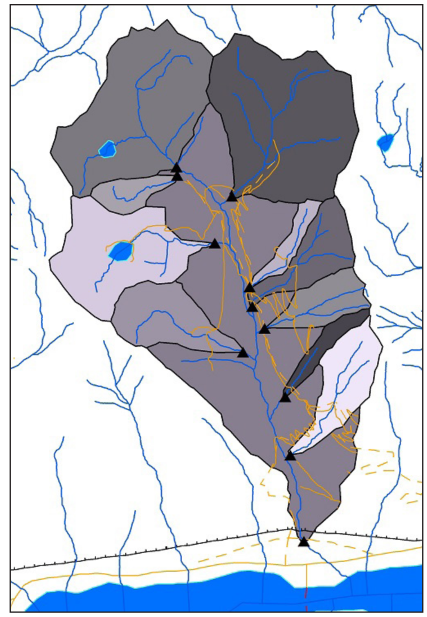

Figure 1. *Sample sites and upstream catchment boundaries in an example 3rd order watershed.*

The provincial cumulative effects (BCCE) consolidated disturbance layer and the BCCE consolidated roads layer should be a priority consideration for use in the GIS analysis, as these layers are the most comprehensive. If these cannot be accessed, regional cumulative effects GIS staff may be able to provide consolidated disturbance and/or roads layers. Another option is to retrieve separate disturbance layers representing roads, cutblocks, and other tenures that may represent development from the DataBC Catalogue and merge them. The BCCE consolidated roads layer includes variable widths to represent clearing allowances for different road types and can be joined to the BCCE disturbance layer using the *union* function in Arc GIS. There are versions of the BCCE consolidated disturbance layer internal to the Ministry that may already incorporate the road information and joining the two may not be necessary. It is best to review all spatial information beforehand or check with the BCCE GIS specialist (Sasha Lees) to ensure the data is the most recent and comprehensive.

Disturbance within 10 m of a streamline is calculated to remain consistent with the area in which the RMREE riparian indicator measurements are taken. After compiling all disturbance into a single layer, add a *buffer* of 10 m and then *clip* all intersecting stream lengths and identify these as "disturbed." This is a more accurate method to quantify the length of stream disturbed compared to buffering the streamlines and intersecting with the disturbance layer. Stream reaches within cutblocks logged more than 20 years previously that have had no other associated disturbance can be down weighted. Note that blocks older than 20 years in the BCCE disturbance layer are already identified in the attribute table rank/subrank values. Identify and extract these older cutblocks to a separate layer, then use the *erase* tool to exclude any overlapping roads or newer development, including their +10 m buffer. Streams within the remaining older harvest area can be clipped and summed to calculate the length of stream for down weighting. A co-efficient of 0.33 is recommended for streams in older harvest areas, which recognizes that even after 20 years, stand structure and LWD supply are not fully recovered. These two components of a properly functioning riparian forest represent 2/6 (33%) of the indicator questions in the RMREE. A previous study conducted 20-30 years after harvesting found a "failure" rate of 33% for the suite of riparian indicators at upper-basin stream reaches that had been logged to the bank (Table 1 in Nordin et al. 2009b) further supporting this value for down weighting. The final calculation for riparian disturbance should resemble the following equation:

((Stream length disturbed - Stream length within older blocks) + (Stream length within older blocks x 0.33)) / Total stream length = Percent stream length disturbed.

Once the total percentage of stream length disturbed has been calculated for the entire watershed, use the matrix in Table 1 with the weighted stream score to derive functioning condition for the entire watershed.
The benchmarks in the matrix are reflective of those currently and previously used in provincial watershed assessments for length of disturbed stream (B.C. Ministry of Forests 1995,1999; FLNRORD 2019b). Each riparian disturbance category is given a score, that when added to the weighted stream score can then be assessed for functioning condition using a similar scoring methodology as the RMREE, which assigns a *properly functioning condition* outcome for a score of 2 or less, *functioning, but at risk* for values of 3-4, *functioning, but at high risk* for 5-6, and *not properly functioning* for values over 6. Note that riparian disturbance is given a score from 0-5 in place of the ground-based six riparian indicators in the RMREE because there has never been a case where all six received a No answer at a single site, likely because of the complementary nature of the suite of indicators (FREP data; 2700+ samples since 2006).

Table 1. Integration of ground-based stream data with GIS-derived riparian disturbance for the calculation of watershed condition. PFC = Properly Functioning Condition, FR = Functioning, but at Risk, FHR = Functioning, but at High Risk, NPF = Not Properly Functioning.

Weighted Stream Score		Riparian disturbance within 10 m					
		Low	Moderate		High		V. High
		< 0.12	0.12 <0.16	0.16-0.21	>0.21-0.25	>0.25-0.30	>0.30
	Score	Score 0	Score 1	Score 2	Score 3	Score 4	Score 5
Low	0	PFC	PFC	PFC	FR	FR	FHR
	>0-1	PFC	PFC	FR	FR	FHR	FHR
	>1-2	PFC	FR	FR	FHR	FHR	NPF
Mod	>2-3	FR	FR	FHR	FHR	NPF	NPF
	>3-4	FR	FHR	FHR	NPF	NPF	NPF
High	>4-5	FHR	FHR	NPF	NPF	NPF	NPF
	>5-6	FHR	NPF	NPF	NPF	NPF	NPF
Very High	>6-7	NPF	NPF	NPF	NPF	NPF	NPF
	>7-8	NPF	NPF	NPF	NPF	NPF	NPF
	>8-9	NPF	NPF	NPF	NPF	NPF	NPF

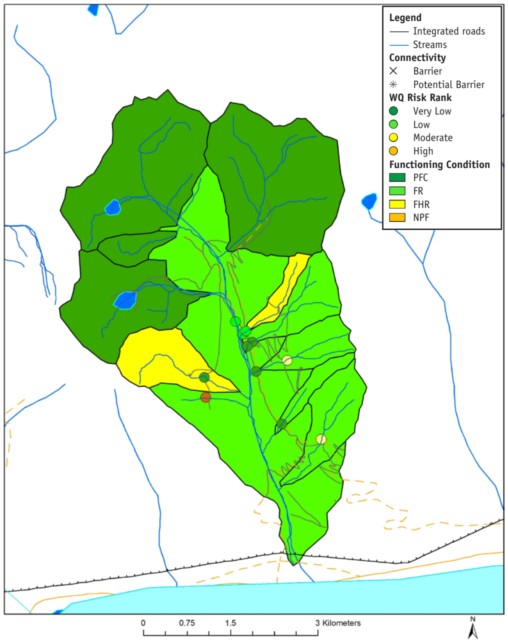

***Figure 2.** Results by catchment in a 3rd order watershed ranked to be in PFC overall. Shading indicates functioning condition; circles are water quality results.*

If the disturbed length of stream is calculated for each sub-catchment as described above, these values can be used with the absolute (unweighted) number of "No" responses to Q 1-9 at each site to conclude on functioning condition for those sub-catchments. The addition of this step is useful to display any sensitivities within a watershed and may support guidance around specific practices in those areas. An example of catchment-specific results within a watershed that was ranked cumulatively to be in *properly functioning condition* is shown in Figure 2.

SUPPLEMENTARY DATA

When reporting out, tables containing supplementary data should be included to help provide a comprehensive depiction of the watershed and identify any potential problem areas for further investigation. For example, if there are any WQEE sites that were ranked as moderate or higher, these could be targeted for inspection and possible remediation. Within the WQEE results, there are other indicators of impairment such as cattle in the stream channel and potential fish passage barriers at culverts. These should be described in as much detail as possible using any other available data to support conclusions or recommendations. For example, a culvert that is a barrier to fish passage may not be an issue if it is appropriately sized and there is no fish habitat upstream. Additionally, cattle accessing a stream reach could have different levels of importance depending on the water users downstream. Obtaining the Provincial Stream Crossing Inventory System (PSCIS) fish habitat data and water licensing information from the DataBC Catalogue or iMapBC is recommended to further define the extent of any issues and support recommendations for improvement.

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