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A Framework for Effective Watershed Monitoring

Dave Wilford and Richard Lalonde

The Bulkley Land and Resource Management Plan (LRMP) requires that monitoring be undertaken to ensure that water and fish habitat objectives are met (Bulkley Valley Community Resources Board and Interagency Planning Team 1998). An interagency/licensee committee (see Acknowledgements) was asked to develop a monitoring plan. This was a major task, given 68 watersheds with diverse hydrology, geomorphology, and aquatic resources within a 7620 km^2 timber supply area (TSA). The committee recognized that each watershed needed to be reviewed individually to identify values that would be sensitive to forestry-induced watershed changes. Also, the committee reviewed existing approaches, such as watershed assessments (B.C. Ministry of Forests and BC Environment 1999) and watershed classification (Cheong 1996), and discussed the challenge with hydrologists and geomorphologists. The conclusion was that we needed to create a process-based, watershed overview approach to identify appropriate parameters. The committee also recognized that it would be impossible to individually examine each watershed, so a simple approach to ranking watersheds, based on past/proposed forest harvesting and aquatic values was adopted. We ranked all 68 watersheds and identified appropriate monitoring approaches in 29 watersheds over five weeks. This article details our approach to watershed monitoring.

We ranked all 68 watersheds and identified appropriate monitoring approaches in 29 watersheds over five weeks.

The Framework

Our approach had two components: ranking the watersheds and identifying suitable parameters and appropriate spatial sampling scale (e.g., site, tributary stream, multiple locations on main stream).

Ranking the Watersheds

Given time and financial constraints, we developed a ranking system to ensure watersheds with high aquatic values were examined and received monitoring decisions. Community watersheds, key fish-producing watersheds, and watersheds with red- or blue-listed fish species were rated as having high aquatic values. Watersheds rated moderate had limited fish species and numbers of fish in a regional context. Watersheds with low aquatic values had few or no fish present. All watersheds were then ranked according to the percentage of watershed area with past and proposed forest harvesting: low potential of risk to aquatic resources was less than 20%, moderate risk was 20–30%, and high risk was greater than 30%. The values and potential risks were numerically ranked (Table 1) to produce an overall priority ranking for each watershed. The controlling factor in the numerical

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ranking is forest harvesting (as opposed to aquatic values), because the focus is on the potential risk of past and proposed forestry activities to aquatic resources. All watersheds with a rank of five or less were examined. Watersheds with a rank greater than five were slated for potential examination in the future, subject to funding.

Table 1. Matrix of aquatic values and potential watershed impacts

		Potential impact		
Values		L	M	H
	L	7	5	3
	M	6	4	2
	H	5	3	1

Examining the Watersheds

Physical processes and aquatic resources in the highest ranked watersheds were analyzed using geographic information system (GIS) software. High priority watersheds were delineated and a series of overlays were prepared including: topography, ortho-photographs, terrain stability or environmentally sensitive areas for soils (ESAs), surface erosion hazard, past forest harvesting, proposed forest harvesting, roads, natural disturbances (primarily wildfires), stream classes, fish inventory, water intakes for community watersheds, and past studies (e.g., research, watershed assessments, fisheries studies). The GIS data, in combination with the group's experience and supplemental background studies, were used to answer questions regarding geomorphology, hydrology, aquatic resources, and forest harvesting (Table 2). These questions were selected to develop a clear picture of a watershed, which is central to the selection of both appropriate indicators and spatial scale for monitoring.

The GIS data, the group's experience, and background studies were used to answer questions regarding geomorphology, hydrology, aquatic resources, and forest harvesting.

Developing the Questions

Geomorphology

Geomorphology questions focus on the availability of sediment to the stream channel, characteristics of the stream channel, and selected physical watershed features. In reviewing the high ranked watersheds, several key points/assumptions emerged. In watersheds with high natural sediment source levels, we considered that it would most likely be difficult to detect changes due to forest management at the watershed (main stream) level. We understood that stream channels with high bedload transport most likely have a low population of aquatic invertebrates (due to substrate instability); therefore using the Benthic Index of Biological Integrity alone would be inappropriate for detecting land use impacts (Karr and Chu 1999; Bennett and Rysavy 2003a, 2003b; Weigel 2003). We recognized that channel morphology changes over time can be determined from aerial photographs. However, it is necessary for the channel to be visible on aerial photographs (at least 20 m wide) and for there to be an adequate time series (e.g., two sets of photos taken before forestry activities and two sets after forestry activities—work that can be undertaken as monitoring for proposed harvesting).

Hydrology

Hydrology-related questions focus on streamflow characteristics, potential for water temperature issues, and watershed physiography. Several cautions/challenges were encountered in collecting/interpreting the data. Because watershed-specific hydrometric data were not available for most of our watersheds, it was necessary to consider relief and size/location of lakes to determine streamflow characteristics. These estimates were balanced against our combined local knowledge to address seasonal and long-term streamflow characteristics. These characteristics are a central factor with regards to channel and benthic stability (Lamberti *et al.* 1991; Knighton 1998). With several exceptions, specific water temperature data were not available, so we identified watersheds with potential high-temperature issues based on the size and location of lakes and wetlands, and the nature of riparian zones (e.g., watersheds with extensive lakes and wetlands, and shrubby riparian zones were identified as having potential high-temperature issues). We wanted to know if large peak flows (e.g., 25-year return-period flood) had recently destabilized a stream channel. Destabilized channels characteristically carry high bedload levels and may have high suspended-sediment loads. We recognized that watersheds with these channel qualities may present challenges for separating forest management effects from natural levels at the upper end of the range of natural conditions. Watersheds that have major tributaries with significantly different characteristics will most likely require different approaches in monitoring each tributary. Several watershed assessments offered useful guidance for monitoring.

Fish

Fish-related questions focus on the fish species present, location in a watershed, habitat requirements, instream enhancement or restoration

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Table 2. Watershed-specific questions

1. Geomorphology

- Do natural landslides run into streams?
- What is the extent of naturally unstable terrain (e.g., using environmentally sensitive areas [ESA], terrain stability or sediment source maps, or aerial photos)?
- Does the watershed have "gentle-over-steep" terrain?
- Is surface erosion likely to be an issue (e.g., lacustrine deposits)?
- Are glaciers present in the watershed?
- Does the stream channel carry a high bedload?
- Are there multiple channels or back/side channels?
- What is the relative relief of the watershed?
- Is the stream channel visible on aerial photographs?
- Are historic aerial photographs available?

2. Hydrology

- Are lakes or wetlands present in the watershed?
- Location of lakes/wetlands: upper, middle, lower watershed?
- Aspect of the watershed (for snowmelt)?
- Runoff characteristics: rapid, moderate, slow?
- Are there major tributaries with significantly different characteristics (e.g., relief, erosion, stream channels)?
- Are gauging stations present in the watershed or adjacent watersheds?
- Have there been recent, large destabilizing peak flows?
- Have natural disturbances influenced the forest cover (e.g., wildfires, insect epidemics, windthrow)?
- Are natural disturbances expected to influence the forest cover (e.g., mountain pine beetle)?
- Are there past hydrologic studies (e.g., professional reports, inventories, monitoring)?

3. Fish

- Where are fish located in the watershed?
- What are the key habitat requirements of the species present (e.g., spawning and rearing)?
- Are red- or blue-listed species present?
- Have critical habitats been identified?
- Are there any known fish barriers (e.g., natural or related to land use)?
- Have habitat investments been planned or implemented in the watershed?
- Do natural factors limit or threaten fisheries (e.g., low or high flows, high temperatures, winter icing of spawning areas)?
- Are there past studies (e.g., professional reports, inventories, monitoring)?
- What is the level of detail of current inventories and have they been repeated?
- Has there been a history of issues with the fish species present (e.g., related to land use in the watershed, escapement)? Specify the issues.

4. Other Aquatic Resources

- What other aquatic resources are present in the watersheds (e.g., domestic water, blue- or red-listed aquatic life forms)?
- Location of the resources within the watershed?
- Are there past studies (e.g., professional reports, inventories, monitoring)?
- Has there been a history of issues regarding other aquatic resources (e.g., low flows, land use, over-commitment of resources through licensing or use)?

5. Past Forest Harvesting

- What are the extent and location of past logging (e.g., factors calculated for watershed assessments - % watershed logged, current equivalent clearcut area, road density, extent of riparian logging, site preparation methods)?
- Have non-status and inactive roads been deactivated?
- Have there been stream quality crossing or similar assessments?
- Are roads contributing sediment to streams (e.g., observed or monitoring data)?
- Have there been landslides from roads or logged areas?
- Have there been water resource issues associated with past logging?

6. Proposed Forest Harvesting

- Will unstable terrain be logged or roaded?
- What special measures or prescriptions are planned?
- Will "gentle-over-steep" terrain be logged?
- What are the extent and rate of proposed harvesting?
- Will special measures be taken for logging or road building?

7. First Approximation Monitoring Decisions

- Given the natural hydrologic and geomorphic processes in the watershed, issues associated with aquatic resources, and effects of past forest harvesting, what is the potential for the planned forestry activities to affect aquatic resources?
- What specific water or aquatic habitat values could be influenced by the planned forestry activities?
- Given the natural processes in this watershed, is it possible to measure changes in these values (which parameters)?
- What is the appropriate spatial scale for monitoring?
- What techniques or equipment could be used to measure the parameters?

8. Development of a Monitoring Plan

- It is necessary to follow a series of steps in developing an effective and successful plan (refer to Wilford 2003)?

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investments, research and assessments, natural factors limiting or threatening populations, and past issues related to forestry activities. Some species such as bull trout require cool water temperatures and thus highlighted a key monitoring parameter for us. In reviewing our watersheds, we found that some required monitoring at the watershed scale if past forest harvesting removed riparian forests in the lower watershed and forest harvesting is proposed in the upper watershed. In other cases, we found it appropriate to monitor temperatures at a site level if past forest harvesting had a limited effect on riparian forests and glacial melt water dominated the main stream temperature. Information about past issues related to forestry activities such as landslides, impassable drainage structures, sediment from road running surfaces, and elevated stream temperatures was important when we selected monitoring parameters.

Other Aquatic Resources

Questions about other aquatic resources (values) highlight domestic water consumption, the presence of blue- or red-listed aquatic life forms (e.g., tailed frogs), the spatial location of these resources, past issues relating to forestry activities, and information derived from past assessments, research, and/or monitoring. We found that, aside from information about domestic and community watershed licences, it was uncommon to find watershed-specific information about other aquatic resources. However, we recognized the value of any available baseline work and recommended repeat inventories for monitoring.

Past and Future Effects of Forest Harvesting

Our methodology uses a series of questions to explore the effect of past forest harvesting. Where watersheds had been assessed using the Watershed Assessment Procedures (WAPs) (B.C. Ministry of Forests and BC Environment 1999), information on the extent of past logging was readily available. Where WAPs had not been undertaken, this information was generated using GIS. Having past and proposed forest harvesting as a GIS layer (using a computer projector) was very useful for group discussions on potential impacts and monitoring opportunities. Information from the Watershed Restoration Program and the local forest licensees helped to answer questions about road deactivation, status of drainage structures, sediment production from surface erosion, forestry-related landslides, and water resources issues associated with past logging.

Questions about the potential effects of proposed logging focused on the types of terrain to be logged, the extent and rate of harvesting, and planned special measures. In a few cases, logging or road building was proposed on unstable terrain. We examined the potential for sediment transport to streams in these areas, and requested information on special measures or prescriptions proposed to prevent detrimental effects. In several watersheds, logging was proposed on gentle terrain upslope of steep terrain. This "gentle-over-steep" terrain (Grainger 2002) has been identified in the Bulkley TSA as a potentially hazardous situation unless special attention is paid to maintaining water routing. Even with careful attention, accelerated snowmelt has reduced slope stability in the steep terrain. The extent of proposed harvesting in a watershed can be a significant factor in selecting monitoring parameters. Specifically, if only limited harvesting is proposed (e.g., < 1% of the watershed), it may not be possible to detect an effect on aquatic resources. The rate of harvesting can also be significant. A rapid rate of harvest, particularly if unstable terrain has been identified, may not allow much time for monitoring feedback to adjust practices (e.g., a delay in the occurrence of landslides due to lack of sufficient precipitation may result in extensive logging on unstable terrain). Fortunately, this was not the case in our watersheds. We considered that it was important to know what special measures would be undertaken with regard to logging or road building. The focus was not only on unstable terrain, but also on stream crossings, logging and silvicultural systems, site preparation, and deactivation. Explicit rationale for these special measures was also considered important (e.g., feedback from adaptive management or application of research results to reduce effects to aquatic resources). Our committee considered monitoring an important feedback mechanism for evaluating these special measures.

The "gentle-over-steep" terrain has been identified in the Bulkley TSA as a potentially hazardous situation.

Developing Watershed-specific Monitoring Strategies

The data collected by answering the questions regarding the physical, biological, and harvesting history of a specific watershed allow for a cumulative watershed analysis: "What is the potential effect of past and planned forestry activities on aquatic resources?" Central to this question is the specific water or aquatic habitat value that could be influenced. However, the sensitivity to changes must be considered in light of the natural processes in each watershed. Once parameters for the values are identified, it is prudent to determine the spatial scale (site, tributary stream, main stream) at which any potential changes might be detected. Several examples from the

Bulkley TSA illustrate this stage of the decision-making process. In our review, some watersheds had little new logging planned. However, in some cases, extensive riparian logging placed watersheds at what was considered by the fisheries agencies to be a threshold for temperature-sensitive fish (Table 3). In such cases, it was determined that the proposed logging in headwater areas may further elevate stream temperatures, even with best management practices. Thus, a monitoring need was identified at the watershed scale (i.e., monitoring throughout the watershed). In other watersheds we examined, past logging was limited and the proposed logging was on terrain with limited potential to affect aquatic resources (i.e., low erosion potential and no streams in the proposed harvesting areas). Monitoring in these cases could be costly and may not provide any substantial information related to achieving the goals of monitoring (i.e., the effects of forest management on aquatic resources would be below the detection limit or may not occur). We also encountered several "gentle-over-steep" situations, with the steep sections actively failing into stream channels. In these cases, the natural sediment loads in the streams were too high to detect forest management influences at the watershed scale and monitoring was therefore most appropriate at the site level. We used repeat sediment source surveys of the slopes directly below the logging to detect incremental changes.

Once the appropriate parameters and the spatial scale for each specific watershed value have been determined for a watershed, we recommend following a series of steps (Wilford 2003) in developing effective and successful monitoring plans.

Limitations of the Framework

The two main elements in the framework were prioritization and watershed-specific questions. Our prioritization allowed us to quickly rate the watersheds based on the criteria outlined previously. Using the extent of harvesting without regard to location of harvesting resulted in several watersheds with extensive riparian logging being rated incorrectly as "low potential risks" because they had limited overall logging. We also recognized that our approach would not capture

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Table 3. Summary of monitoring decisions for three watersheds

Name	Watershed Attributes	Past–proposed Forest Harvesting	Monitoring Decision
Arnett	50.3 km^2 – upper watershed is a wide basin with the slopes disconnected and a low-power stream. The mid to lower channel reaches are incised with naturally failing banks. There is high bedload transport and rapid runoff.	There has been no past logging. Proposed logging is 6% of the watershed, with some class IV terrain and gentle-over-steep situation with 2 blocks.	Monitoring at the site level – repeat sediment source mapping of the steep terrain below the 2 blocks – pre-harvest and annually for 5 years. Then assess the situation.
Goathorn	187 km^2 – extensive, naturally unstable terrain along stream channels, high bedload transport, north aspect with cold water temperatures. One major tributary has low relief, moderate runoff, and a stable channel. Thirty years of hydrologic and biologic studies associated with a proposed coal mine. High aquatic values (bull trout) and the need to maintain low water temperatures.	Past logging is 17% of the watershed with riparian logging in one reach. Roads have been deactivated and there have been no issues with past logging. Proposed logging is 2% of the watershed over the next 5 years.	Monitor stream temperatures at the site level – small streams in the proposed harvesting area.
IR#5 Nilkitkwa	16.8 km^2 – low relief with slow runoff and generally stable channels. Beaver dams and wetlands in the lower watershed. An IWAP was done in 2000. Coho and rainbow trout are present.	Past logging is 38.9% of the watershed with an equivalent clearcut area of 31.3%. The peak flow index is high. There has been 3 km of clearcut riparian logging. One channel reach is currently unstable as a result of harvesting-related sediment sources. Lack of large woody debris recruitment could lead to channel instability in 3 reaches. Some roads have been deactivated but there have been no road-related sediment issues. Proposed logging is 1.2% of the watershed.	Monitor stream temperatures at the watershed level. Establish benchmark channel reaches – impacted and potentially unstable. Repeat descriptions after major runoff events or every 5 years.

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watersheds with significant issues related to past forest harvesting. As a result, after watersheds were prioritized using percentage of harvested area as the leading factor, we reviewed the list to identify obvious ranking errors. In addition, the rankings were reviewed following the watershed-specific examinations. During the examinations we noted two situations where the ranking was too low: one due to agricultural clearing that was not accounted for, and the other due to incomplete forest harvesting data.

Our committee found that addressing the presented watershed questions resulted in a significant exchange of information. Presenting GIS data visually (using a computer projector) allowed the group to appreciate the watersheds in a short time. To effectively address the questions, at least one person needed to compile information on watersheds (we hired a consultant for five weeks). We were fortunate in the Bulkley TSA because a significant amount of information had been compiled for the LRMP.

We are satisfied that our prioritization and assessment process produced defensible monitoring strategies for the key watersheds in a TSA.

Conclusions

We are satisfied that our prioritization and assessment process produced defensible monitoring strategies for the key watersheds in a TSA. We consider that having the strategies in place will help to ensure that limited funds for monitoring aquatic resources are invested efficiently and effectively in the Bulkley TSA. Monitoring parameters that may change will provide the necessary feedback to ensure that forest management maintains aquatic resources as specified in the Bulkley LRMP.

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For more information, contact:

Dave Wilford, Ph.D, RPF, P.Geo
Research Forest Hydrologist
BC Forest Service
Smithers, BC
E-mail: dave.wilford@gems3.gov.bc.ca
Tel: (250) 847-6392

Richard Lalonde
Forestry Project Manager
Silvicon Services Inc.
Smithers, BC
E-mail: general@silvicon.com
Tel: (250) 847-3680

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