

FINAL REPORT

COMMUNITY WATERSHED ADAPTIVE MANAGEMENT TRIALS: FFT Work Project 21

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Project 550-26.01

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Reference: 550-26.01

B.C. Ministry of Environment
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Attention: Mr. Doug Lewis

Re: Community Watershed Adaptive Management Trials: FFT Work Project 21

Summit Environmental Consultants Ltd. (Summit) is pleased to provide this **final report** on the above-noted project.

The report presents the methodology for conducting the adaptive management trials, including recommendations for which study area watersheds would be included. The key elements of the recommended approach to the trials include selecting watersheds with an existing database of water quality, conducting the trials in multiple watersheds, initiating the program with a comprehensive watershed assessment (including an inventory of Mountain pine beetle infestation), and conducting water quality monitoring at the point of diversion. An evaluation team should be appointed to guide the trials and to develop appropriate adaptive responses to the results of the monitoring and assessment tasks. The assembled data should be housed in a central database.

We trust this completes our assignment to your satisfaction. Please contact me if you have any comments or questions.

Yours truly,

Summit Environmental Consultants Ltd.

Hugh Hamilton, Ph.D., P.Ag
Senior Environmental Scientist

cc Lorree Lucas, R.P.F. – Forsite Consultants



EXECUTIVE SUMMARY

B.C. is currently experiencing the largest outbreak of Mountain pine beetle (MPB) in the past century, which could have a significant impact on the hydrological regime and water quality of affected watersheds. This has implications for human health because many residents of southern B.C. obtain their drinking water from surface water in forested watersheds. To address a lack of information on MPB effects on water resources the B.C. Ministry of Environment (MOE) is planning to conduct adaptive management trials in a number of community watersheds in the Kamloops and Cascades Forest Districts (“the study area”). The adaptive management trials would provide a means to assess these effects and to support the development of strategies and practices to mitigate negative impacts to water values in both the long and short term.

The major elements of the proposed approach to the adaptive management trials, as outlined in this document, are as follows:

- Conduct the trials in a minimum of three Community Watersheds. If the budget allows, consider conducting the trials in six or more watersheds, with two or three of the watersheds serving as controls (i.e. low levels of MPB infestation);
- Establish an evaluation team to select the trial watersheds and to review the assessment and monitoring results each year and develop the appropriate adaptive responses;
- Select watersheds with available water quality data and watershed assessment information from the recent past. Given that MPB has already made its way into the study area, the availability of water quality/watershed assessment information is important to have an understanding of pre-MPB conditions and to achieve some elements of a scientific monitoring design. The priority watersheds for the trial program are Cornwall Creek, Murray Creek, Leonie Creek, Peterson Creek, Jimmies Creek, Paul Lake, Paul Creek, Tranquille River, Dillard Creek, and Kwinshatin Creek;
- The trials should begin as soon as possible in 2006 with initial inventory and assessment work and run for at least five years and ideally for about 10 years. All trials should begin with a watershed assessment, a detailed assessment of riparian function, and an inventory of MPB-affected and potentially affected stands;
- The results of the riparian assessment should be used to develop the riparian management plan for the trial watersheds on a reach-specific basis. Elements of the plan include RRZ and RMA widths, basal area retention, harvesting guidelines, any experimental procedures, and the schedule for follow-up assessments;
- The trials should include one or more MPB-affected watersheds that have not yet undergone salvage logging, but where significant harvesting of lodgepole pine is planned (e.g. where the resulting watershed ECA is >35%). This will provide an opportunity to test the effectiveness of forest development methods aimed at minimizing effects on water resources. These include retaining patches of non-pine species within cutblocks, retaining buffers of dead or dying pine around these non-pine patches, minimizing salvage in areas where intermixed pine represents <40% of the species mix, use of Best Management Practices for road and trail construction, and prompt deactivation of roads;

- Monitoring of physical and chemical water quality should take place at or just above the point of diversion for the drinking water purveyor (or at the site of any previous monitoring). A basic, cost-effective program would include continuous monitoring of water level, turbidity, and water temperature using automated equipment from mid-April to mid-July (or preferably to about mid-October). The automated monitoring should be supplemented with regular (i.e. weekly) grab sampling for turbidity, TSS, coliform bacteria, pH, specific conductance, and true colour;
- To guard against the potential for variations in the monitoring budget it is critical to implement a consistent core monitoring program that runs for the same 12-14 week period each year. If it is possible to expand the sampling period and/or the list of variables than do so, but it is essential to ensure that the core program is maintained to facilitate trend analyses or comparisons between watersheds;
- A customized database should be established in MS-Access to house information for all the trials. The water quality data should be transferred to the provincial EMS system;
- Brief annual reports should be prepared each autumn for the evaluation team's review. The team would then develop the recommendations for any adaptations to the trial procedures for the following year (e.g. changes to the monitoring program and/or restoration prescriptions). Restoration options include:
 - Additional road and landing deactivation;
 - Maintenance and upgrades of drainage infrastructure (e.g. culverts, bridges, ditches, cross-drains, and sumps as guided by an evaluation completed by a qualified professional);
 - In-fill planting of cut blocks and riparian areas;
 - Stream channel restoration/reinforcement to reduce bank erosion and guard against future erosion;
 - Riparian restoration;
 - Landslide restoration;
 - Hydro-seeding of cutslopes and ditches; and
 - Thinning, spacing, and/or fertilization to quicken tree growth in re-planted areas.

The next steps in implementing the adaptive management trial program are to:

1. Establish the multi-agency evaluation team that will select the trial watersheds and guide the trial program. Possible participating agencies and groups include the provincial Ministries of Environment, Forests and Range, and Health; the Water Supply Association of B.C.; forest licensees; and individual water purveyors;
2. Confirm the program budget;
3. Select the trial watersheds; and
4. Finalize the initial assessment and monitoring programs based on the available budget.

ACKNOWLEDGEMENTS

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The report was prepared by Hugh Hamilton, P.Ag., David Brisco, R.P.Bio., R.P.F., and Allison Tremain, G.I.T., with input from Lars Uunila, P.Geo. (Section 2.2.1). The maps were prepared by Brian de Jong and review of the project report was by Lars Uunila, P.Geo.

TABLE OF CONTENTS

LETTER OF TRANSMITTAL	i
EXECUTIVE SUMMARY.....	ii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES	vi
LIST OF ACRONYMS	vii
1.0 INTRODUCTION	1
1.1 Project Background.....	1
1.2 Project Objectives	2
2.0 OVERVIEW OF EFFECTS OF MOUNTAIN PINE BEETLE ON FORESTED WATERSHEDS.....	3
2.1 Current and Projected Extent of Mountain Pine Beetle in the Study Area.....	3
2.2 Direct and Indirect Effects on Water Quantity and Quality	4
2.2.1 Effects on Hydrologic Regime and Streamflow	4
2.2.2 Effects on Water Quality	9
2.3 Mountain Pine Beetle Restoration Initiatives in B.C.....	11
3.0 TRIAL WATERSHED SELECTION	13
3.1 Community Watershed Screening and Criteria Development.....	13
3.2 Priority Trial Watersheds.....	16
4.0 WATERSHED TRIAL PROTOCOLS AND METHODS	20
4.1 General Trial Design and Schedule	20
4.2 Silvicultural Procedures	22
4.2.1 Background.....	22
4.2.2 Guidance for Large-Scale Beetle Salvage within Community Watersheds	24
4.3 Initial Inventory and Watershed Assessment Work.....	26
4.4 Riparian Function Assessment and Monitoring.....	27
4.5 Watershed Restoration Guidelines.....	30
4.5.1 General Principles for Salvage Operations	30
4.5.2 Prompt Reforestation	31
4.5.3 Road Deactivation.....	31
4.5.4 Retention of Structural Components of Historical Stands.....	32
4.5.5 Range Management Considerations	33
4.5.6 Drainage Management	34
4.6 Water Quantity and Quality Monitoring.....	36
4.6.1 Background and Rationale.....	36
4.6.2 Variable Selection.....	40
4.6.3 Implementation Options.....	42
4.7 Data Management and Reporting	46
4.8 Adaptive Management Response Framework	47

4.9	Cost Considerations	47
5.0	SUMMARY AND RECOMMENDATIONS.....	48
6.0	REFERENCES	52
7.0	GLOSSARY	58

Appendix A Study area community watersheds characteristics and available information.

Appendix B Checklist of water-related rules under the *Forest and Range Practices Act*.

Attachments

Map 1. Locations of study area community watersheds in relation to Mountain Pine Beetle Infestations.

LIST OF TABLES

Table 1.	Summary of research on the hydrologic impacts of beetle infestation.	6
Table 2.	Summary of criteria for prioritizing watersheds for inclusion in the Adaptive Management Trials.....	14
Table 3.	Candidate watershed prioritization process.....	17
Table 4.	Biophysical characteristics of the Level 1 Priority watersheds.....	19
Table 5.	Recommended levels of retention within large-scale harvesting areas of community watersheds.	26
Table 6.	Effects on drinking water, and sensitivity to watershed activities for water quality monitoring variables.....	41
Table 7.	Features and approximate costs of alternative adaptive management programs.	44

LIST OF ACRONYMS

AAC	Annual allowable cut
BACI	Before, After, Control, Impact (a type of study design)
CAP	Channel assessment procedure
ECA	Equivalent clearcut area
EMS	Environmental Monitoring System
FPC	<i>Forest Practices Code</i>
FRPA	<i>Forest and Range Practices Act</i>
FSP	Forest Stewardship Plan
MAL	Ministry of Agriculture and Lands
MELP	Ministry of Environment, Lands and Parks (now MOE)
MOF	Ministry of Forests (now MOFR)
MOFR	Ministry of Forests and Range
MOE	Ministry of Environment
MPB	Mountain Pine Beetle
MWLAP	Ministry of Water, Land & Air Protection (now MOE)
PFC	(Riparian) Proper Functioning Condition
RAPP	Riparian assessment and prescription procedure
RAR	Riparian Areas Regulation (of the B.C. <i>Fish Protection Act</i>)
RSP	Range Stewardship Plan
RUP	Range Use Plan
RMA	Riparian Management Areas
RMZ	Riparian Management Zone
RRZ	Riparian Reserve Zone
TSA	Timber Supply Area
WAP	Watershed Assessment Procedure
WSABC	Water Supply Association of B.C.
WQG	Water quality guideline
WQO	Water quality objective

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

British Columbia is currently experiencing the largest outbreak of Mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) in the past century. The MPB infestations have the potential to cause significant mortality of lodgepole pine (*Pinus contorta*) throughout central and southern B.C., and current estimates indicate that over 480 million m³ of mature pine has been infested, totalling over 48% of the existing mature pine stock (Chatwin et al. 2004). The Ministry of Forestry and Range (MOFR) Research Branch anticipates that the current MPB epidemic may consume up to 1 billion m³ before this infestation exhausts its food supply and collapses (Eng et al. 2005). To reduce the economic impacts of the MPB outbreak, large-scale timber salvage operations have been initiated to harvest affected stands before the structural integrity of the wood is compromised. The salvage operations also extend to pine stands with high probability of being infected by MPB within the foreseeable future. MPB infestations also increase the risk of wildfires because of the increase volume of dead woody material, and the salvage helps to reduce this risk.

In the B.C. Southern Interior surface water is the primary source of water used for drinking and other domestic purposes. Although the effects of forestry activities on water quality and quantity have been studied for more than 50 years in the Southern Interior, less is known about the effects of large-scale disturbance by MPB and wildfire. This is because commercial forestry operations usually affect only a portion of a watershed and road building and harvesting are phased in over time. In contrast, the disturbance from MPB and associated salvage can happen more quickly and result in a large portion of a watershed being disturbed. For example, the equivalent clearcut area (ECA)¹ in community watersheds has typically been kept below about 25-30% since the *Forest Practices Code* was implemented in 1994, while MPB has the potential to result in ECA levels that are considerably higher.

¹ Technical terms are defined in the glossary at the end of this report.

To address the lack of information on MPB effects on water quality and quantity the B.C. Ministry of Environment (MOE) is planning to conduct adaptive management trials in a number of community watersheds in the Kamloops and Cascades² Forest Districts (“the study area”). The adaptive management trials (“the trials”) would provide a means to assess these effects and to support the development of strategies and practices to mitigate negative impacts to water values in both the long and short term. This document presents the methodology for conducting the adaptive management trials, including recommendations for which study area watersheds should be included.

1.2 PROJECT OBJECTIVES

The general objective of this study is to develop an Adaptive Management Trial program for community watersheds affected by MPB within the study area. Adaptive Management is “a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs” (MOF, no date). Specific objectives are to:

1. Review and summarize the direct and indirect effects of MPB infestation, wildfire, and associated forest harvest on water quality and quantity;
2. Review and summarize potential silvicultural and ecosystem restoration strategies that could be used to mitigate the effects of MPB infestations, wildfire, and associated salvage harvesting activities;
3. Identify the community watersheds that are located within the study area and develop criteria to determine their priority for inclusion in the adaptive management trials;
4. Based on the criteria, set priorities for which community watersheds should be included in the trials;
5. Develop the recommended silvicultural and restoration strategies to be implemented in the trial watersheds;
6. Develop the recommended water quality and quantity monitoring program to assess effects of infestation, fire, and salvage;

² Formerly the Merritt and Lillooet Forest Districts, which were combined in 2001.

7. Develop the recommended program to monitor the effectiveness of the restoration strategies; and
8. Develop guidelines for adaptive management in response to the results of the monitoring programs.

2.0 OVERVIEW OF EFFECTS OF MOUNTAIN PINE BEETLE ON FORESTED WATERSHEDS

2.1 CURRENT AND PROJECTED EXTENT OF MOUNTAIN PINE BEETLE IN THE STUDY AREA

As noted earlier, about half the existing mature lodgepole pine stock in B.C. is currently infected by MPB and this could double before the current infestation collapses because it has exhausted its food supply. There is an indication, however, that MPB are attacking younger stands of lodgepole pine than previously thought, which could further extend the resulting scale of ecological change (Maclauchlan 2006). Information on MPB in B.C. and the strategy to address it is found online at http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/.

Within the study area the MPB infestation has been moving generally from the north towards the south, although there are areas in the most southern part of the Cascades Forest District that have been experiencing significant MPB outbreaks for some time. As of 2005, 290,466 ha of forest had been impacted in the Kamloops Forest District and 103,640 ha were impacted in the Cascades Forest District (MOFR, 2006). These figures represent 6.0% and 2.2% of the 4.8 million hectare area infested in the Southern Interior Forest Region respectively. By comparison, the Chilcotin and Quesnel Districts collectively account for 55% of the total area impacted in the region, but the proportion affected in the study area could eventually reach these levels.

Map 1 shows areas infested by MPB from 1990 to 2004 (red, orange, and grey polygons). The yellow polygons indicate the pine-leading (>40% pine) areas projected by MOFR to be impacted through to 2009 (lighter to darker shades of yellow indicate increasing cumulative

volume of pine impacted). The green polygons are pine-leading areas that are not considered susceptible to MPB before 2009 because they are too young (<60 years). The areas affected by MPB or predicted to be affected are concentrated in the mid-elevation forests in the Merritt and Kamloops TSAs. Higher elevation areas in the western and north-eastern parts of the study area are less affected. The white areas in the Thompson and Nicola Valleys on Map 1 represent areas where grasslands are dominant.

2.2 DIRECT AND INDIRECT EFFECTS ON WATER QUANTITY AND QUALITY

2.2.1 Effects on Hydrologic Regime and Streamflow

There is general understanding that MPB could have a large effect on hydrologic regimes in B.C. watersheds (Uunila et al., 2006). However, information to address these questions is limited to a handful of research studies. While local initiatives to address knowledge gaps are underway (Wiensczyk 2005), questions remain regarding the impact of MPB on annual water yield, peak flows, low flows, soil moisture, and groundwater levels, and related changes to water chemistry and erosion and sedimentation (Hélie 2005). Answers to these questions are required as BC moves towards a large-scale timber salvage strategy (Snetsinger 2005).

Changes in the forest structure resulting from beetle-kill could modify key hydrologic processes (MacDonald and Stednick 2003). In the interior pine forests of BC, the annual accumulation and melt of the snowpack principally drive the hydrologic regime. This accumulation and melt are modified by the hydrologic processes of interception, evaporation, transpiration, snowpack redistribution (i.e., wind patterns), snowpack energy absorption, and groundwater storage. The effects of beetle-kill on these processes, with or without salvage harvesting, is unknown (Maloney 2005) but may mimic that of conventional timber harvesting of similar size and extent. While transpiration is expected to be similar between beetle-killed stands and recently harvested areas (since dead trees do not transpire), the effects of beetle-kill on hydrologic processes may be different than the effects of timber harvesting. For sometime beetle-killed trees retain their needles and branches, stay standing, and potentially affect forest regeneration after they have been killed. Furthermore, beetle-

killed stands may retain live understory vegetation and without salvage are not impacted by road development, unlike conventionally harvested stands.

A summary of the few available research studies on hydrologic effects of MPB is presented in Table 1. Highlights of these studies are provided below.

Watershed-scale Investigations

In 1955, Love described an Engelmann spruce beetle epidemic in the White River watershed (1,974 km²) of Colorado. The epidemic killed up to 80% of the trees, which covered 30% of the watershed. Based on an evaluation of streamflow and snow course data from White River and nearby non-infested Elk River watershed (534 km²), Love concluded that annual water yield increased by about 31 mm (12%) during the beetle epidemic and about 58 mm (22%) after the epidemic. The increase in annual water yield was attributed to reductions in snow interception and evapotranspiration. Following some criticism of these results from Bue et al. (1955), Mitchell and Love (1973) re-analyzed the data from White River and maintained that annual water yield increases associated with the beetle epidemic were significant at 40–48 mm (15–18% increase).

Bethlahmy (1974) re-examined the White River infestation using additional data, including a second infested watershed, Yampa River (1,564 km²). An analysis of covariance on the pre- and post-infestation periods showed that annual water yield increased on average 31.8 mm and 23.6 mm in the White and Yampa rivers, respectively. Furthermore, analysis water yield increases were smallest during the first 5 post-infestation years, steadily increased until 15–20 years following infestation, and declined but were still present 25 years after the infestation began. Additional analysis by Bethlahmy (1975) was consistent with earlier work, indicating that annual water yield increases in the infested watersheds over a 20-year post-infestation period averaged over 30 mm. Between 15 and 20 years after the infestation, the increase in annual water yield peaked at 51.7 mm (21%) and 63.0 mm (28%) in the White and Yampa rivers, respectively. Bethlahmy (1975) emphasized that even 25 years post-infestation, annual water yields remained 10% greater. Fall low flows were on average 1.6

Table 1. Summary of research on the hydrologic impacts of beetle infestation.

Location	Drainage area (km ²)	Dominant forest cover	% of watershed infested	Average change in annual water yield	Change in monthly low flow (late summer-fall)	Change in monthly high flow (spring)	Change in instant. peak flow	Expected time for hydrologic recovery to pre-disturbance conditions	References
White River, Colorado	1974	Engelmann spruce	80% of trees covering 30% of watershed	+50 mm (19%)	-	-	-	-	Love (1955)
				+40–48 mm (15–18%)	-	-	-	-	Mitchell and Love (1973)
				+31.8 mm (12%)	-	-	-	-	Bethlahmy (1974)
				+37.9 mm (15%)	+1.6 mm (31.4%)	+14.9 mm (22%)	+20.2 m ³ /s (27%)	>25 years	Bethlahmy (1975)
Yampa River, Colorado	1564	Engelmann spruce	80% of trees covering 30% of watershed	+23.6 mm (11%)	-	-	-	>25 years	Bethlahmy (1974)
				+35.2 mm (16%)	+1.2 mm (9.6%)	+12.0 mm (14%)	no sig. change	>25 years	Bethlahmy (1975)
Jack Creek, Montana	133	Lodgepole pine	35% of trees (50–60% of trees > 18 cm dbh.)	+45 mm (15%)	+2 mm (10%)	+26 mm (52%)	no sig. change to magnitude; peak 2 weeks earlier	>5 years	Potts (1984)
North Platte River, Wyoming & Colorado	1978	Engelmann spruce	Assumed 30–50% tree mortality	+56 mm	-	-	-	60–70 years	Troendle and Nankervis (2000)
Interior BC	Varying	Lodgepole pine	In progress						Alila (2005)

Source: Uunila et al. (2006).

mm (31%) and 1.2 mm (10%) greater in the White and Yampa rivers, respectively. Monthly flows in spring were on average 14.9 mm (22%) and 12.0 mm (14%) greater in the White and Yampa rivers, respectively. However, peak instantaneous flows increased only in the White River (a predominantly west-facing watershed with relatively greater inputs of solar radiation) and not in Yampa River, which is largely north-facing.

Potts (1984) represents one of the few documented studies of the hydrologic effects specifically associated with MPB. Based on statistical and hydrograph analyses of pre- and post-epidemic years in the Jack Creek watershed (133 km²; 35% of the timber killed by MPB) in Montana, Potts' identified a 45 mm (15%) increase in annual water yield, a 2 mm (10%) increase in low flows, a 2-week advancement in the timing of spring runoff, but little change in instantaneous peak flows. Monthly flows in spring were on average 26 mm (52%) higher. These changes were associated with reduced evapotranspiration losses, alteration of snow accumulation and melt processes associated with forest canopy changes, and changes in soil moisture (Potts 1984). Some have criticized Potts' conclusions, particularly his interpretation of the results based on a double mass analysis. Although the method suggests a possible change in water yield after the epidemic, the statistical significance of this break was not reported and according to Uunila et al. (2006) is not statistically significant.

Stand-scale Investigations

Most of the earlier watershed-scale investigations (noted above) simply assume that infested forests are dead or alive. However, a stand-scale investigation in the Rocky Mountains of Colorado by Schmid et al. (1991) found that infested forests are generally more complex and identified the understory as potentially important in understanding the hydrologic impacts of MPB. In a multi-storied, uneven-aged stand where about 52–70% of the trees were infested by MPB, Schmid et al. (1991) monitored snowpack accumulation and summer rainfall interception in small infestations and controls over 4 years following infestation. Results indicated that net precipitation (i.e., that which reaches the ground) in each infested area was generally not significantly different from its respective control. Possible reasons for this finding included needle retention by beetle-killed trees (at least over the first 2 years), low precipitation during the study, and sampling design (i.e., sample size, transect location, and

aspect). The presence of a multi-storied stand (with live understory) was also considered a major factor mitigating the impacts of beetle-kill. As a result, Schmid et al. (1991) concluded that small infestations in multi-storied, uneven-aged stands do not increase net precipitation.

The mitigating effect of a multi-storied stand supports the recent recommendation of BC's chief forester to increase retention levels when salvaging beetle-killed stands (Snetsinger 2005). Retaining structure such as live trees (including understory) and standing and fallen dead trees may reduce the risks of large-scale salvage, particularly until watersheds have reached hydrologic recovery (Snetsinger 2005).

Hydrologic Modeling

Recently, greater emphasis has been placed on the development and use of hydrologic models. Troendle and Nankervis (2000), for example, modeled a spruce bark beetle epidemic in the North Platte River watershed of Wyoming and Colorado using the Water Resources Evaluation of Non-Point Silvicultural Sources (WRENSS) Hydrological Model. By assuming 30–50% tree mortality, average water yield increased by up to 56 mm by the 10th year after infestation. The model also suggested that these increases would continue, although at a continually reduced rate over 60–70 years (Troendle and Nankervis 2000).

Researchers at the University of British Columbia are currently investigating MPB effects and salvage logging on streamflow characteristics in the Okanagan and north-central BC (Alila 2005). Using the UBC Watershed Model they can estimate the post-infestation hydrograph. The accuracy of these estimates varies depending on parameter of interest (e.g., low flows are difficult to model given unknown groundwater contributions), assumptions used (e.g., canopy closure), and degree of calibration and testing. Initial runs that have not been verified suggest that watersheds with severe beetle-kill may respond with considerable increases in peak flows and water yield (Alila 2005).

Summary

Overall, the research summarized in Table 1 suggests that the effects of MPB on forest hydrology may be similar to those experienced after forest harvesting. Within even-aged stands without significant understory these effects include (1) increases in annual water yield, (2) increases in late summer and fall low flows, (3) variable responses (no change or increases) in peak flow size, and (4) possibly earlier timing of peak flows. Furthermore, these effects may last up to 60–70 years. The presence of uneven-aged, multi-storied stands will likely reduce these impacts (Schmid et al. 1991).

2.2.2 Effects on Water Quality

Effects on surface water quality from MPB could result from the combination of:

- Changes in the hydrological regime described in Section 2.2.1, in particular from increases in the magnitude of peak flows;
- Salvage harvest activities, especially the construction of new roads to access the affected timber or timber that could potentially be affected;
- Replanting techniques that expose soils to erosive action (e.g. site preparation); and
- Changes in the functions of riparian areas that influence water quality including sediment filtration capacity, the role of trees in stream bank strength, woody debris recruitment, and shade.

In general, it is only changes in peak flows (not normal flows) that cause bank erosion and transport large debris and coarse sediment, and thus have undesirable implications for water quality, channel stability, and aquatic habitat. As outlined above, there is the suggestion that MPB kill on its own would not cause a significant increase in peak flows if there is significant understory present (and retained), and the results of both field observations and modeling indicate the potential for wide variation in peak flow effects. Part of the variation may be due to different densities and patterns of roads within affected watersheds. Roads (with ditches and cross-drain culverts) facilitate the more-rapid routing of runoff through the watersheds, so affected MPB watersheds with a high road density would tend to be more likely to exhibit changes in peak flow with water quality implications. Detrimental effects

on water from increased peak flows are most likely when the channel is sensitive to bank and bed erosion. Sensitivity is a function of the combination of natural characteristics (i.e. an alluvial channel is more sensitive to changes in peak flow than a bedrock channel) and land use history (e.g. where riparian harvest has reduced the bank strength normally afforded by large trees).

Erosion from forest roads is generally a major human-caused sediment source in a watershed, and any new roads established to facilitate MPB salvage would increase water quality hazards. Sediment delivery from new roads usually declines over time as the road prism stabilizes (Elliot, 2000). Researchers have documented erosion rates in the range of 11-1,232 tonnes/ha/year from roads (Elliot, 2000), although the mass of sediment delivered to the watershed outlet per unit area is usually much lower as sediment is naturally trapped and filtered. Mass failures such as landslides caused by poor forest road design, construction, and/or maintenance can also be a major source of sediment where the slope is coupled to the stream network. Landslides not only contribute relatively large volumes of sediment over a short time frame, but unvegetated landslide scars can produce more sediment per unit area than do forest roads (McClelland et al. 1998). Reviews of the effects of roads on sedimentation are provided in Adams and Ringer (1994), Elliot (2000), and Carson (2002).

Riparian zones serve to maintain drinking water quality through a number of mechanisms including:

- The root masses of larger trees provide the bank strength necessary to resist bank erosion;
- Trees contribute large woody debris to the channel which acts to dissipate stream flow energy and reduce erosion;
- Shrubs and small plants filter sediment delivered from roads and upland areas;
- Shade moderates water temperatures. This is primarily an aesthetic consideration but warm temperatures can promote bacterial growth; and
- Trees growing in the riparian zone create hydraulic roughness that reduces the velocity of any floods that overtop the banks.

The potential for MPB to directly impair these functions depends on the amount of pine in the riparian zone. Where MPB already has a significant presence in a watershed there may be little value in selectively removing pine from riparian areas (e.g. sanitation harvesting), especially if it reduces the riparian functions listed above. The roots of dead pine trees would contribute to bank strength and hydraulic roughness for several years after they die, so affected trees retain their value to water quality for some time. On streams wide enough to normally require both a reserve zone and a management zone (i.e. >1.5 m wide), there is potential for there to be a significant amount of pine in the management zone (i.e. more than 20 m from the bank) and salvage may therefore be desirable. In this case it would be important to assess the role of the management zone in maintaining water quality on a reach-specific basis (see Section 4.4).

2.3 MOUNTAIN PINE BEETLE RESTORATION INITIATIVES IN B.C.

Ecological restoration has been defined as an intentional activity that initiates or accelerates the functional recovery of an ecosystem that has been degraded, damaged, or destroyed, as the direct or indirect result of human activities (SERI 2004). Various forms of ecosystem restoration activities have been pursued in B.C. over the past 75 years, from the first silvicultural plantings in the 1930s to the restoration of Garry Oak ecosystems on Vancouver Island in 1999 (Gayton 2001). In 1994 MOE and MOFR initiated the Watershed Restoration Program (WRP-1995) and the Terrestrial Ecosystem Restoration Program (TERP-2000) under Forest Renewal B.C. (FRBC). These programs focussed primarily on the restoration of those areas in watersheds (terrestrial, stream, and riparian) that had been damaged through past inappropriate forest practices. Some elements of these programs continue under current Forest Investment Account (FIA) programs but the level of activity is a fraction of what went on in the mid-1990s. However, the FRBC/FIA programs ensured that watershed restoration methods were developed, tested, and refined, and there is an existing pool of professional and technical expertise in B.C.

Recently, ecological restoration efforts that focus directly upon the environmental impacts of MPB damage, large-scale catastrophic wildfire, and the consequences of the subsequent

timber salvage have become priority issues within MOFR and MOE. The current MPB epidemic has been on the rise for 10 years and shows no signs of diminishing until almost all the mature lodgepole pine within suitable climates has been attacked and killed (Eng et al. 2005). Within the Kamloops TSA, maps generated from aerial surveys suggest that red attacked stands in 2005 represent a 250% increase over 2004, with over 55% of pine-leading stands older than 60 years indicating some level of attack (McKenzie 2006). In combination with the large wildfires that occurred in 2003-2004, the current and future losses of forest cover across the landscape due to bark beetle attack are enormous. As outlined earlier, there is potential for hydrologic impacts to be evident for 20 or more years following initial stand infestation and mortality (Bethlahmy 1975).

Currently, there are broad-reaching initiatives and support from both the federal and provincial governments to address the residual ecological and economic effects of both recent wildfires and MPB infestations. Goals include reducing the spread and impact of MPB and increasing annual allowable cut (AAC) limits to allow accelerated salvage harvest rates to thereby minimize the economic losses from the projected large volumes of dead and dying timber. Provincially, MOE has been coordinating a work plan to address the complex issues arising from the unprecedented ecological “disaster” of the current MPB infestation. This includes both organizing workshops to ensure those workers involved in MPB-focussed activities are educated with the latest information from specialists in these fields, as well as coordinating roundtable discussions with stakeholders to develop priorities for restoration activities and address potential policy changes to ensure appropriate and timely action to MPB pressures (the challenge dialogue process – Holt and Fenger 2006).

In addition, there is a new Ecosystem Restoration Program (ERP) in development within the Environmental Stewardship Division of the MOE (ENAR ESDE 2006). This program is intended to provide strategic direction in the identification of priority forested landscapes and watersheds that would benefit from ecosystem restoration activities. This new ERP is expected to provide incremental assets to other forestry and restoration initiatives, with the overall program goal “To restore ecosystem functioning in areas affected by catastrophic events, notably mountain pine beetle and fires”. These priority areas are identified as those

degraded systems that are furthest outside their natural range of variability, with values sensitive to impacts and likely to respond to treatment (Fenger and Associates 2006). Fenger and Associates (2006) recently compiled a synthesis of MOE's critical concerns and priorities regarding MPB and wildfire through staff interviews. One of the priorities identified by MOE is the conservation and management of community watersheds, so as to maintain a quality domestic water supply. MOE staff also indicated that potential community watershed risks due to MPB/fire would be managed by maintenance of riparian ecosystem functioning, promotion of speedier hydrological recovery, and by reducing surface runoff and sediment.

Additionally, MOE staff identified a number of key gaps in current knowledge, across a broad range of concerns. Two of these identified gaps can be addressed by the monitoring and assessment regime in the proposed adaptive management trials program. These are: (1) Can planting be effective in areas where water tables have been elevated, without major disturbance; and (2) What is the lodgepole pine component within riparian areas and what proportion of riparian zones would contain significant dead pine (and therefore be candidates for restoration by under-planting and other techniques)?

3.0 TRIAL WATERSHED SELECTION

3.1 COMMUNITY WATERSHED SCREENING AND CRITERIA DEVELOPMENT

This section outlines the set of criteria for selecting watersheds for inclusion in the adaptive management trials. Draft criteria were provided to MOE in a memorandum dated February 10, 2006. The comments of Doug Lewis and Bruce McFarlane of MOE were incorporated into the final criteria. The draft criteria were also sent to representatives of MOE, MOFR, and the Interior Health Authority for their comments. No recommendations for changes to the draft criteria were received from the agency representatives. The criteria and their rationale for use in prioritizing watersheds are listed in Table 2. The criteria are based on the assumption that it is desirable to conduct the trials in watersheds where changes in the

Table 2. Summary of criteria for prioritizing watersheds for inclusion in the Adaptive Management Trials.

<i>Criteria</i>	<i>Description</i>	<i>Rationale</i>
Watershed area	Watershed area should be more than 500 ha (5 km ²) and less than 50,000 ha (500 km ²).	Hydrologic response in smaller basins could be overly sensitive to the effects of one clearcut or road; 2) groundwater flows may be a significant source of water at the intake and water quality would therefore be less influenced by MPB or harvest; and 3) forest management practices to control MPB may not be representative of conventional practices. Conversely, MPB effects in larger basins could be masked by the heterogeneity of other factors influencing water quality/quantity. For consistency, the 5-500 km ² range is the same as what is recommended for the Watershed Assessment Procedure (WAP).
MPB Infestation	Infestation (2004 mapping) affects 20% of the watershed area or more.	Changes in peak flows are generally not detectable until the equivalent clearcut area (ECA) exceeds 20%.
Potential for infestation within 2006-2009	Pine-leading (>40% pine) stands older than 60 years account for 30% of watershed area or more.	These watersheds are considered susceptible to MPB within the next few years. Monitoring before infestation occurs would allow some level of “before-after” comparison.
Salvage logging in advance of MPB has occurred	Watershed ECA is 30% or more.	Watershed has been harvested to a level beyond conventional practices for community watersheds. Changes in hydrologic regime are possible.
Existing water quality data	Water quality data exists for relevant variables (at least 2 years of data).	Existing data would permit an evaluation of effects of MPB on water quality by comparing “pre-beetle” to “post-beetle” data (Note: a number of community watersheds in the study area were monitored for 3-5 years during the Watershed Restoration Program).
On-going water quality monitoring	Water purveyor is currently monitoring to meet Drinking Water Protection Regulation requirements	May be cost-effective to “piggy-back” onto monitoring program (e.g. MOE would pay for additional variables of interest since purveyor likely only monitors for coliform bacteria and turbidity).

Table 2. Summary of criteria for prioritizing watersheds for inclusion in the Adaptive Management Trials (cont.)

<i>Criteria</i>	<i>Description</i>	<i>Rationale</i>
Streamflow data	Streamflow data available (historic or ongoing)	Would allow “pre-beetle” and “post-beetle” comparisons. Also, an existing hydrometric station (e.g. WSC, MOE) would avoid the cost of installing a new station.
Watershed assessment information	WAP and related assessment have been completed (e.g. CAP, RAP, terrain stability assessments, sediment source surveys, etc.)	The availability of this information will help interpret the results of the monitoring program.
Watershed similarity	Assess watershed similarity	If feasible, monitoring in two or more watersheds that are biophysically similar would help to clarify effects of silvicultural and management practices. Considers aspect, elevation, hydrologic zone, biogeoclimatic zone(s), bedrock geology, and soils (as indication of erosion hazard).
Practical considerations	<ul style="list-style-type: none"> • Close to a major road • Close to other trial watershed(s) • Permission to access 	These are secondary criteria that would reduce the overall cost of the trial program.
Confounding effects	Minimal presence of non-forestry activities that could affect water quality.	Want to avoid land uses that could make it difficult to determine the effects of MPB and associated management techniques [e.g. presence of a resort, significant agricultural activity (e.g. multiple range permits), or mine within the watershed].

hydrological regime and water quality are likely to occur as a result of either MPB infestation or salvage logging, or some combination of the two. This makes it possible to evaluate the influence of selected mitigation strategies on water quality and quantity.

It has also been assumed that the adaptive management trials will take the form of monitoring watersheds that have already been affected by MPB. This is in order to evaluate impacts on drinking water quality and quantity within relatively short order to further the development of strategies to minimize any observed effects. The general framework for the proposed trials is outlined below in Section 4.1.

3.2 PRIORITY TRIAL WATERSHEDS

The candidate watersheds were ranked by using the information in Appendix A to answer a series questions to assess the suitability of each watersheds for inclusion in the trials. The decision steps in the screening process and the rational behind each decision threshold are outlined in Table 3. The three possible outcomes of this initial screening process are:

1. Level 1 Priority watersheds – the best potential candidates based on the criteria;
2. Level 2 Priority watersheds – lacking important attributes or background data but still potentially useful; and
3. Watersheds no longer under consideration.

The first question in Table 3 addresses watershed area and results in the list of candidate watersheds being reduced to 23. All of the watersheds discarded based on area are smaller than 500 ha. The second question address the fundamental question of whether or not there is significant existing or projected MPB disturbance to have potential to cause changes to water quality and quantity. Question #3 places higher priority on watersheds that are projected to have significant increases (>20% of area) in MPB coverage between 2005 and 2009. This would allow for the trials to document any resulting changes in water values as they occur and provide opportunity to apply and refine mitigation techniques, which is the goal of an adaptive management process.

Table 3. Candidate watershed prioritization process.

No.	Decision question	Rationale
1	Is the watershed area >5 km ² and <5,000 km ² ? <ul style="list-style-type: none"> • If <u>yes</u> go to #2. • If <u>no</u> these watersheds are no longer considered. 	Smaller and larger watersheds present problems for determining cause and effect (see Table 1).
2	Is the total area (current + projected) affected by MPB >20% of the watershed area? <ul style="list-style-type: none"> • If <u>yes</u> go to #3. • If <u>no</u> these watersheds are no longer considered. 	The objective of the adaptive management trials is to evaluate effects of MPB on water values. Twenty percent is a threshold level of disturbance that can result in observed changes in hydrologic regime.
3	Is the projected change in MPB coverage >20%? <ul style="list-style-type: none"> • If <u>yes</u> go to #4. • If <u>no</u> these watersheds are no longer considered. 	A projected large increase in MPB is likely to influence the decision to conduct salvage logging. An increase of this magnitude would lead to high probability of detectable change in water quantity/quality. May allow documentation of “before-after” effects.
4	Are there more than 2 years of water quality monitoring data? <ul style="list-style-type: none"> • If <u>yes</u> go to #5. • If <u>no</u> go to #7 (Level 2 Priority). 	Data from the 1990s (the usual case) will allow for a comparison to the trial data relatively soon after the trial begins.
5	Have watershed assessments and related investigations been completed? <ul style="list-style-type: none"> • If <u>yes</u> go to #6. • If <u>no</u> go to #7 (Level 2 Priority). 	This would provide important background information on water quality hazards and previous restoration and water quality management work.
6	The resulting Level 1 Priority watersheds are: <ul style="list-style-type: none"> ➤ Dillard ➤ Kwinshatin ➤ Tranquille ➤ Murray ➤ Cornwall ➤ Paul Lake ➤ Paul Creek ➤ Leonie ➤ Jimmy’s ➤ Peterson 	
7	The Level 2 Priority watersheds are: <ul style="list-style-type: none"> ➤ Intlpam ➤ Lytton ➤ Six Mile 	

Questions #4 and #5 address the availability of existing information on water quality and on watershed characteristics and existing levels of disturbance. The availability of existing water quality data is critical to meeting one of the key objectives of the adaptive management trials – to determine whether MPB and related salvage activities have a detrimental effect on drinking water quality and test mitigation strategies. Monitoring data prior to about the year 2000 are valuable because they pre-date the current MPB outbreak in the study area and there are supporting data (e.g. regional hydrometric data) that permit an understanding of the hydrological context in which the data were collected (i.e. were those years “wet”, “dry” or “normal”?).

After the screening of the candidate community watersheds into Level 1 and 2 priority lists, the 10 Level 1 Priority watersheds were evaluated to further refine the priority ranking. Table 4 summarizes the biophysical characteristics of these watersheds. The review of the biophysical characteristics suggests a number of more or less natural groupings. These are:

1. **Cornwall, Jimmies, and Murray Creeks** – These watersheds are tributaries of the Thompson River and are all in the Northern Thompson Plateau hydrological zone with significant coverage within the Interior Douglas fir biogeoclimatic zone;
2. **Paul Creek, Paul Lake, and Tranquille River** – All in the Fraser Plateau hydrologic zone and located relatively close together, but Tranquille differs in area and geology. As “near-urban” streams, however, high levels of recreational activity may confound the ability to attribute water quality observations to MPB. Given its size, a sub-basin of Tranquille may be better suited for the trial if comparisons to other watersheds are desired;
3. **Peterson and Leonie Creeks** – Primarily in the Southern Quesnel Highland hydrologic zone and located close together, but different geology, and area; and
4. **Kwinshatin and Dillard Creeks** - Both located south of Merritt with the Montane Spruce biogeoclimatic zone making up a larger portion of the watershed than the Interior Douglas fir zone. Different hydrologic zones and geology.

Table 4. Biophysical characteristics of the Level 1 Priority watersheds.

Watershed	Area (ha)	Hydrologic Zone	Biogeoclimatic Zones (in order of approx. area)	Bedrock Geology	Surficial Materials	Average Elevation (m above seas level)
Cornwall Creek	6,151	Northern Thompson Plateau	IDF/MS	Metamorphic melange	Glaciofluvial / Morainal	1,000
Dillard Creek	3,873	Southern Thompson Plateau	MS/ESSF/IDF	Basaltic volcanic rocks	Glacial till / Colluvium	1,300
Jimmies Creek	1,358	Northern Thompson Plateau	IDF/BG	Undivided volcanic rocks	Glaciofluvial / Morainal	900
Kwinshatin Creek	2,727	Eastern South Coast Mountains	MS/IDF	Undivided volcanic rocks	Glacial till	1,400
Leonie Creek	3,010	Southern Quesnel Highland	IDF/MS	Basaltic volcanic rocks	Glacial till / Glacio-fluvial	1,300
Murray Creek	14,945	Northern Thompson Plateau	IDF/ESSF/MS/BG	Andesitic volcanic flows	Colluvium / Morainal	1,200
Paul Creek	12,460	Fraser Plateau	IDF/BG	Fine clastic sedimentary rocks	Colluvium / Glaciofluvial / morainal	900
Paul Lake	15,164	Fraser Plateau	IDF/MS	Fine clastic sedimentary and undivided volcanic rocks	Colluvium / Glaciofluvial / Morainal	1,100
Peterson Creek	8,201	Southern Quesnel Highland/Fraser Plateau	MS/ICH/IDF	Fine clastic sedimentary rocks	Glacial till / Colluvium	1,100
Tranquille Creek	43,759	Fraser Plateau	ESSF/MS/IDF/BG	Undivided volcanic rocks	Glaciofluvial / Morainal	1,000

Despite the within-group similarities, there are enough differences to indicate only low to moderate suitability for the groups to be monitored as true “paired” watersheds or triplicates. However, selecting all the trial watersheds from one group would provide some basis for comparison while having a number of practical advantages. More important to the adaptive management process is selecting watersheds where the water quality is likely to be influenced by MPB and where it is possible to implement adaptive strategies and evaluate their effectiveness. From this perspective Cornwall, Murray, and Leonie Creeks are the recommended trial watersheds if the program is run in the recommended minimum of three watersheds. If the budget allows, the suggested order of inclusion is Peterson Creek, Jimmies Creek, Paul Lake, Paul Creek, Tranquille River (or a sub-basin), Dillard Creek, and Kwinshatin Creek.

4.0 WATERSHED TRIAL PROTOCOLS AND METHODS

4.1 GENERAL TRIAL DESIGN AND SCHEDULE

The Ministry of Forests has defined Adaptive Management as “a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs” (MOF, no date). Projects such as the proposed trials are designed as “operational experiments to promote learning and better decisions in future”. Adaptive Management acknowledges that managed ecosystems are complex and that our ability to predict future behaviour is imperfect, and allows for management of uncertainties through *adaptation* (Holling, 1978). The general phases in the Adaptive Management process are:

1. Assess the nature of the problem;
2. Plan the trial. The prescribed work plan needs to describe the anticipated outcomes in reference to an undisturbed system (benchmark) or a desired future forest condition;
3. Monitor;
4. Evaluate;

5. Develop and implement an appropriate adaptation and action plan based on the evaluation and a revised understanding of the problem; and
6. Return to step 3.

Key to Adaptive Management is incorporating opportunities to learn from observations and implement a process to use that information to improve practices. In the operational context of the proposed community watershed trials (i.e. these forests have multiple resource values including drinking water and timber supply) it may not be possible to run the trials as formal research projects where all potentially confounding variables are controlled. However some aspects of experimental design should be incorporated to be able to compare the outcomes of selected forest management practices in a meaningful way. This includes:

- Conducting the trials in multiple watersheds. Findings from a single watershed cannot be extrapolated beyond that watershed, and the results from paired-watershed studies (e.g. high MPB infestation vs. low infestation) have similar limitations because the treatments are not replicated. Three (3) watersheds should be seen as the minimum number within a Adaptive Management framework since it allows for some replication of practices, but the ability to draw conclusions applicable to the whole study area is only likely to be achieved with six or more trial watersheds (see Section 4.5 for additional discussion);
- A “Before, After, Control, Impact” (BACI) study design, which provides significant power to link cause to effect. This involves monitoring the selected watersheds for a number of years before the “impact” is applied to some of them, while retaining one or more watersheds as control (not impacted). Given that MPB has already made its way into the study area, the availability of water quality and watershed assessment information from the recent past is important to achieve some elements of a BACI design, which is why data availability is a key watershed ranking criteria (Tables 2 and 3);
- A comprehensive monitoring and assessment program. Monitoring of physical and chemical water quality at the point of diversion is the “bottom line” measure of MPB effects in a community watershed, but it must be supported by inventory and assessment

work within the watershed to evaluate the causes of any observed water quality effects and the effectiveness of mitigation measures; and

- Using standardized approaches to data collection (e.g. RISC methods and use of the same automatic monitoring equipment) across all watersheds.

The trials should begin as soon as possible in 2006. Because the beetle infestation is rapidly moving across the landscape, the initial inventories of watershed conditions must be completed quickly so as to establish a baseline from which to assess future impacts upon water quality of both the actual beetle/fire losses and the salvage harvesting. This will involve working closely with forest tenure holders to obtain current information on forest cover, MPB infestations, ECA and other “report card” variables, and the status of any Forest Development or Forest Stewardship Plans (FSPs)³.

The within-year (seasonal) and between-year variability of the water quality parameters that are linked to forests and range practices are strongly influenced by natural variations in hydrological processes (e.g. streamflow, precipitation). Assessments of impacts on water quality, whether from MPB or land use practices, must therefore look at the “hydrological context.” Was the information collected in a high flow year, a low flow year, or a year that was near average? This means that the trials should run at least five and ideally 10 years or more to assess not only the effects of MPB and/or salvage, but also to provide enough time to test the effectiveness of any restoration measures implemented as an adaptation.

4.2 SILVICULTURAL PROCEDURES

4.2.1 Background

In developing the framework for the adaptive management trials it is assumed that the amount of salvage harvesting will exceed the levels that are typically set for community watersheds. Salvage (post-disturbance) harvesting to capture economic value before it is lost has becoming widespread (Spittlehouse and Stewart 2003), and it is likely that the existing

³ Forest Stewardship Plans will become the primary forest planning document when FRPA is fully implemented later in 2006. Hereafter FSP refers to both FDPs (prepared pre-FRPA) and FSPs.

and proposed harvest would result in ECA levels of 30% or more and increased road densities. In the absence of MPB the maximum ECA in community watersheds is usually set based on the recommendations of a watershed assessment, and is typically in the 15-25% range. Under both the FPC and FRPA community watersheds receive special consideration because of the importance of drinking water supply, and there are a number of regulated restrictions that do not apply to other watersheds. Appendix B contains a checklist of the FRPA rules that apply to community watersheds in particular and water quality in general.

In general, the current and future salvage activity will likely have detectable impacts upon ecological functioning of systems experiencing these operations. While there are small numbers of studies that have identified neutral or positive effects of salvage harvesting, the majority of documented effects of salvage logging are negative (Lindenmayer et al. 2004, Hughes and Drever 2001), and can be assigned to three broad categories: (1) effects on ecosystem processes (including hydrological processes), (2) effects on the structural complexity and composition of stands, and (3) impacts upon elements of the biota (Lindenmayer 2006). As outlined earlier, MPB disturbance and associated salvage harvesting could have a significant effect on the hydrological regime and water quality.

Assuming that the level of disturbance in the trial watersheds will be beyond the threshold where negative effects are possible, the silvicultural plan should include measures to offset and mitigate these detrimental effects as much as possible. General strategies include retention of patches on non-pine species that might otherwise be harvested, minimizing soil disturbance, taking a conservative approach to riparian management, the use of Best Management Practices (BMPs) in road construction and drainage management, ensuring timely restocking of harvested areas, road and spur (non-mainline) deactivation or rehabilitation, reclamation of pre-existing sediment sources, and promoting tree growth through silvicultural techniques.

4.2.2 Guidance for Large-Scale Beetle Salvage within Community Watersheds

Once the watersheds are selected for the adaptive management trials the existing silvicultural plans should be reviewed and updated to meet the goals of the adaptive management program. MOE and any other participating agencies will need to work closely with licensees to develop the updated harvesting and restoration plan and to work out any cost implications. Some of the prescriptions for the trials will likely constrain some components of harvesting, while others may facilitate the removal of damaged/dying stands of timber. It is important that the professionals involved in the development of the detailed plan for each trial watershed consider the full range of techniques to mitigate effects on water quality while recognizing the economic implications to forest tenure holders and local communities.

Within the adaptive management trial framework it may be reasonable to implement different management and/or restoration strategies on different stream reaches or sub-basins to provide a basis for comparison. Any comparisons that are undertaken, however, should consider the differences in stream geomorphology and flow between the reaches or sub-basins before drawing conclusions about the effectiveness of different strategies.

General recommendations and guidelines for harvesting activities that may mitigate the effects of MPB/fire damage in British Columbia have been made by a number of authors (Hughes and Drever 2001; Douglas 2002, 2003; Bunnell et al. 2004; Winkler 2005; Snetsinger 2005). These recommendations are varied, and can be applied at both the stand and at the landscape level. They include:

Stand Level Recommendations

- Generally apply best management practices in salvage areas;
- Greater than normal retention within these blocks of both dead pine and non-pine stands;
- Retain species other than lodgepole pine during logging, as well as small groups (>0.2 ha) of dead pine;
- Provide small buffers of dead lodgepole pine around retained inclusions of other tree species;

- Develop customized plans to maintain and enhance riparian function (see Section 4.4); and
- Reserve riparian and upland hardwoods from harvest.

Landscape Level Recommendations

- Consider the results of watershed assessments to minimize terrain stability and soil erosion hazards;
- The areas to be reserved from harvest and the areas to be harvested should be laid out in a way to minimize road density and thereby reduce erosion hazards;
- Avoid salvage in selected areas where intermixed pine represents <40% of the species mix;
- Get in and out of salvage areas quickly, and deactivate any new roads wherever possible;
- Maintain natural drainage and upgrade the drainage network on permanent roads to accommodate any changes in flow resulting from large-scale harvest (see Section 4.5.6);
- Consider alternative silvicultural systems; and
- Consider leaving some pine stands in place where their role in maintaining water quality and aquatic habitat is judged to be greater than the hazards associated with beetle kill.

It is important to note that a number of these stand- and landscape-level recommendations would also have benefits for wildlife, biodiversity, and visual quality.

Increased Retention within Cutblocks

Increased retention within harvest blocks is a way to reduce the hydrological effects of pine mortality and/or salvage, with the proportion of retention increasing with the size of harvested block (up to 25%). Recommended retention levels as modified from those suggested by the B.C. Chief Forester (Snetsinger 2005) are listed in Table 5.

Table 5. Recommended levels of retention within large-scale harvesting areas of community watersheds.

Opening Size	Percent of harvest block to be retained
<50 ha	15%
50-250 ha	20%
> 1,000 ha	>30%

Modified from Snetsinger (2005).

These retention guidelines are slightly more conservative than the original values recommended by the chief forester, however those recommendations were meant to apply to general forest harvesting and salvage, and they have been modified in Table 5 to reflect the higher conservation values expected within community watersheds.

While it is unlikely that there would be any harvested blocks >1,000 ha within a community watershed, to retain existing ecological functioning in terms of wildlife habitat and landscape biodiversity characteristics, there should be greater than 30% retention within these areas. This retention should include stands of live non-susceptible species, as well as groups of dead pine, particularly very large snags, which when retained will provide wildlife tree habitat and LWD into the future. Stands with low mistletoe infection, intermediate beetle mortality, large live and dead trees, multi-layered stand structure, or moist cool microclimates are particularly good candidates for retention (Hughes and Drever 2006).

4.3 INITIAL INVENTORY AND WATERSHED ASSESSMENT WORK

A number of initial inventories should be completed at the beginning of the trials to form the baseline for documenting changes to drinking water hazards – both negative and positive. The Level 1 priority watersheds identified in section 3.2 have existing watershed assessment information so the characterization of conditions at the beginning of the trials can largely be an update of that information based on maps, aerial photographs, GIS data, and reconnaissance-level field surveys. This includes preparation of a Watershed Report Card

with the standard indicators listed in the Watershed Assessment Procedure Guidebook (MOF 2001a) including ECA, total road density, road length on potentially unstable terrain, numbers of natural and human-caused landslides entering streams, number of stream crossings, and length of stream channel showing signs of human-caused disturbance. Because of their expected importance in maintaining water quality in watersheds with MPB disturbed upland areas, riparian areas should be assessed in more detail (see Section 4.4).

In addition to the basic “report card” watershed variables, the level of current MPB infestation should be inventoried at the beginning of the trials. This can be done through the interpretation of recent aerial photographs supported by ground surveys.

If a sediment source survey has not been completed in the watershed within the past three years it should be updated following the procedure in MOF (1999). Outputs include a map (scale 1:20,000) showing point sources, a table listing the source characteristics, and an assessment of sediment hazards for drinking water quality.

4.4 RIPARIAN FUNCTION ASSESSMENT AND MONITORING

Under current forest practices regulations the default riparian management area (RMA) widths are simple numbers that allow relatively easy measurement from the top of bank during forest development planning. Because of their simplicity they are necessarily conservative with respect to protecting riparian function, which is why forest tenure holders can propose alternative Riparian Management Zone (RMZ) or Reserve Zone (RZ) widths in a Forest Stewardship Plan (FSP) if they demonstrate that riparian function has been considered and maintained when developing the proposed alternative. In the trials the emphasis should be on riparian function rather than simply on RMA width.

There are a number of existing methodologies that can be employed or adapted when evaluating existing riparian function in forested watersheds⁴. These include the U.S. Proper

⁴ The procedure that accompanies the Riparian Areas Regulation of the *Fish Protection Act* is primarily intended for assessments of impacts from urban development, and has only limited applicability in provincial forests.

Functioning Condition (PFC) Assessment (Bureau of Land Management, 1993; 1994; 1998; 1999a; 1999b) and the B.C. Riparian Assessment and Prescription Procedure (RAPP) under the FPC (MELP/MOF, 1999), which is partly based on the PFC assessment. Tripp et al. (2005) have recently published a protocol for evaluating the condition of riparian management areas and stream channels as part of the FRPA effectiveness evaluation program. Like the PFC assessment method it involves asking a series of questions about the main characteristics of healthy streams and their riparian habitats. In addition, there are a number of studies of riparian condition that have been completed where methods applicable to the specific region of study have been used (e.g. Chatwin et al., 2001). These methods can be adapted to assess the multiple functions of riparian areas including fish habitat, water temperature regulation, channel stability, wildlife habitat, biodiversity, and water quality. Although the focus of the trial watershed program is drinking water quality, the assessment of fish and wildlife habitat values is important given the potential for a large proportion of the watershed(s) to be clear cut. Assessing for multiple riparian values at the same time is therefore a cost-effective part of the overall MPB impact evaluation program.

From a drinking water perspective the desired condition for riparian areas is a situation where the streamside vegetation is providing sufficient root strength and cover to protect against accelerated bank erosion, and the riparian zone effectively filters sediment delivered from upslope, minimizing the amount that enters the stream. If these conditions are in place then the functions that are of secondary importance to drinking water quality, such as water temperature, will also likely be achieved. There is considerable overlap between what constitutes a functioning condition for a riparian area and for stream channels, and assessments of these two landscape elements are best done at the same time. The key attribute of a functioning riparian zone is a lack of anthropogenic disturbance, more specifically:

- No evidence of direct disturbance of banks by machinery in the RMAs of S4 streams⁵ (i.e. streams with no RRZ);

⁵ All streams in Community Watersheds are rated as S4 streams or higher. Therefore the only streams without an RZ are those with an average channel width of 1.5 m or less.

- Few streambank trees (trees with some portion of their root mass embedded in the streambanks soils) have been harvested along the banks of alluvial streams.
- Small amount of windthrow in RMAs;
- Channel widening has not caused the width of the natural riparian zone to be reduced. This would be most important where the floodplain is relatively narrow;
- The riparian zone vegetation includes a diverse age-class distribution, especially younger and middle-aged trees. This provides an adequate number of trees to contribute to bank strength and the LWD supply in the future as older trees die off;
- A diversity of vegetation species is present in the RMA, especially species with root masses that can withstand high flow events. Species diversity also helps maintain riparian function in years that are either very dry or very wet;
- The riparian vegetation shades the stream;
- Sufficient ground cover vegetation is present near stream crossings to filter sediment originating from the road prism; and
- Riparian vegetation appears to be healthy and robust, and includes the normal distribution of plant species for the biogeoclimatic zone/site unit where it is found.

Riparian assessments completed within the adaptive management trial framework should be conducted by a small team or person with expertise in hydrology/fluviol geomorphology and riparian/aquatic ecology. In general this requires a minimum of two persons although an experienced riparian specialist can complete the work on their own. The initial assessment of riparian function should be completed at the start of the trial along with the inventory work outlined in Section 4.3. It would be repeated after the major timber salvage work has been completed (if it has not already been completed). After that it would only be repeated on approximately three to five year intervals because significant changes to channels and riparian zones would not be expected within a shorter period.

The primary outcome of the initial riparian assessment should be specific guidelines for riparian management during the period in which the trials will be run. The guidelines should include:

- The recommended RRZ and RMA widths for each stream reach in the watershed;
- Basal area retention within the RMA for each reach;
- Falling and yarding procedures during salvage. In general, best management practices for harvesting and the use of ground-based equipment should be followed (e.g. MOF 1995a);
- Any experimental procedures that are to be investigated as part of the trial. For example, it has been suggested that the stump of any MPB affected trees that are removed from within the RMA be maintained at about 1.5 m height. This would provide hydrological roughness in the event of an overbank flow, thereby limiting the erosive power of the flooding stream;
- Measures to limit livestock access to riparian areas (see Section 4.5.5); and
- Restoration measures to restore riparian function, where previous land use activities have compromised function.

4.5 WATERSHED RESTORATION GUIDELINES

4.5.1 General Principles for Salvage Operations

If disturbance to community watersheds can be minimized during salvage operations than less restoration work will ultimately be required. Therefore, it is most efficient (both economically and operationally) to do undertake salvage operations in a way that minimizes disturbance in community watersheds, with particular emphasis on watercourses, riparian areas, and potentially unstable terrain. Every action taken within the community watershed should be performed with this preventative framework in mind. For the adaptive management trials the logging contractors should be qualified and experienced in appropriate and ecologically-sensitive harvesting techniques, using harvesting equipment and systems suited to the block size and layout, terrain, stem size, and volume to be removed. The use of a logging contractor with a demonstrated commitment to achieving the desired results is essential for successful operations in these critically sensitive systems (Richardson et al. 1999).

4.5.2 Prompt Reforestation

To restore the pre-existing hydrologic regime within the watershed, it is recommended that re-forestation be initiated as soon as possible, with the intention of initiating hydrologic recovery as rapidly as possible. It is important to ensure that seedling orders are placed as soon as estimates for seedling requirements are reliable, with new seedlings in production during the first growing season after harvest. To meet hydrologic goals, these seedlings (appropriately sourced following seed transfer guidelines – MOF 1995b) should be planted the spring following seedling production (second growing season following harvest).

Where feasible, cutover sites should be restocked with non-MPB-susceptible species (i.e. deciduous or Douglas fir/spruce/larch) to break up the previously existing large, contiguous stands of pine. This will introduce mosaic patterns on the landscape and reduce the potential speed and spread of future beetle attack or fire, which has implications for future water quality protection. It will also provide benefit for wildlife by increasing biodiversity in the watershed.

Following reforestation, regularly scheduled silviculture surveys should be completed in the trial watersheds to assess regeneration progress. Consistent with the adaptive management framework, the surveys would be used to develop prescriptions to address any lagging plantations. This could include in-fill planting and fertilizer applications [i.e. where suitable environmental conditions exist as defined by the Forest Fertilization Guidebook (MOF 1995c)]. Fertilization must follow the requirements of FRPA which state that no fertilizer must be applied within 100 m of the point of diversion for a community water supply or within 10 m of a perennial stream (Appendix B); unless an alternative strategy that meets FRPA objectives is proposed.

4.5.3 Road Deactivation

Road deactivation (i.e. culvert removal and cross ditching, often accompanied by seeding of exposed soils) or complete rehabilitation and slope contouring within cutblocks should be done immediately following harvest (while machines are still on site). If this is done before

spring break-up, it reduces the amount of potentially erodible material available prior to peak flows. It is also more efficient to do all these works while equipment is at the site finishing up their other tasks (reduces the costs of additional mobilization and demobilization). Guidance on general road deactivation techniques is available in an on-line field guide assembled by ToMo Consulting and Flip Productions Ltd. (2002) (<http://www.culvertbc.com/fieldguide2/index.html>).

If temporary roads are to be built to facilitate salvage harvest, the roads should be built to facilitate their prompt deconstruction. Use of corduroy (log) methods of road base construction in wetter areas will reduce the need to excessively cut in side slopes and limit the interception of possibly elevated ground water flow (Dobson pers. com. 2006). In an effort to minimize impacts during spring melt/break-up period, smaller temporary stream crossings should be removed prior to freshet, even if the rest of the temporary road network will continue to be utilized following the spring break-up period.

4.5.4 Retention of Structural Components of Historical Stands

Although their effect on watershed hydrology may be minor, the retention of components of dying and dead pine stands, as well as large components of the non-pine stands are important considerations in the conservation of biodiversity and healthy ecosystem functioning at both the local and landscape levels. It is critical to ensure that the planning and practices associated with protecting biodiversity values are in step with the increased rate of salvage harvesting (Snetzinger 2005). The conservation of biodiversity and multi-storied structural stand complexity across the landscape will provide a greater probability of continued ecosystem health and function, which contributes to riparian health and function.

The increased retention of affected stands (even dead ones) in wetter areas reduces the likelihood of disturbance and damage to these sensitive systems, preserving their functional integrity. It would also minimize soil disturbance and erosion potential. These undisturbed areas will help offset the risks associated with increased harvesting rates, and provide

continued sources of large woody debris (LWD) and important habitat for cavity nesters and other vertebrate species (Bunnell et al. 2004).

The quality of advanced regeneration, understory vegetation, and structure of retained stands should be assessed for proper function. In particularly sensitive areas with high mortality and inadequate advanced regeneration and shrub cover, under planting of the retained stands with appropriate species (hardwood or conifer) may be warranted to accelerate hydrologic recovery and function. Similarly, advanced regeneration and minor vegetation should be conserved where possible during salvage harvesting operations.

The retention of dead pine around living stand cohorts may assist in reducing the risk of the live trees succumbing to high velocity wind events. The dead pine will protect the live trees as a buffer against the wind, providing the area with a supply of large woody debris as these snags slowly deteriorate and eventually fall to the ground. Using these dead tree buffers to protect relatively small stands of live trees from wind throw will help avoid increases in ECA beyond those caused by the salvage hazard, which has implications for peak flow hazards.

Stands with less than 30% mortality can be expected to provide similar old forest habitat values as pre-disturbance stands, and are good targets for retention in old growth management areas (OGMAs) and riparian areas (Douglas 2003). The retention of both live and dead trees within the riparian reserve zones will provide continued streambank stability, supplies of LWD in and around the channel, and appropriate habitat for many species displaced by fire and harvesting activity.

4.5.5 Range Management Considerations

Cattle grazing and other agricultural activities are important economic uses of our public lands. However, excessive cattle disturbance in sensitive riparian areas can cause significant damage to channel banks and vegetation, increase sediment loads within the flowing water, and introduce contamination (e.g. fecal coliform bacteria and cryptosporidium). Due to the current and future expectation of increased stand mortality and harvesting activity within the

trial community watersheds, a conservative approach to the number of livestock permitted within these watersheds and livestock access to streams should be considered.

Currently, as required by section 33 of FRPA, ranchers develop a Range Stewardship Plan [RSP – formerly Range Use Plans (RUP)] that provides a map of the areas their livestock will utilize and a schedule of livestock movement. To be consistent with the Okanagan-Shuswap Land and Resource Management Plan (LRMP), all livestock in the trial watersheds should be kept ≥ 30 metres from stream boundaries for at least one kilometre upstream of the community watershed intake. This can be accomplished through the use of natural barriers and fencing. Depending upon the extent of the pine mortality and/or salvage operations in the adjacent locations, and the sensitivity of the riparian area in question, it may be prudent to create even larger boundary areas. Therefore the 30 m width should be considered a minimum.

Because RSPs/RUPs have been very flexible and approvals are discretionary to the MOFR, it is recommended that as future RSPs come under review, livestock activity within the trial community watersheds be minimized to avoid the introduction of confounding factors (or at least made consistent across all the selected watersheds). In those areas where natural barriers to livestock access were destroyed by fire or MPB, directional falling of killed timber may be able to produce new barriers to cattle movement, acting to protect riparian integrity and water quality. This activity should effectively restrict livestock from entering sensitive areas where natural barriers have been destroyed, without the full expense of constructing extensive new fencing.

4.5.6 Drainage Management

As outlined in Section 2.2.1, a substantial loss of forest cover by beetle-kill has potential to affect several hydrologic parameters. Within even-aged stands of beetle-killed pine annual water yield and low flows are expected to increase while peak flows may increase and occur earlier in the spring. Such impacts have implications on near-surface groundwater (and soil moisture) conditions and on drainage infrastructure in a watershed.

Groundwater

General increases in the level of the water table or lengthening of the period over which elevated ground water levels occur have the potential to impact forest operations during harvesting and regeneration. For example, in the Vanderhoof Forest District groundwater levels have reportedly risen in MPB-affected areas, requiring the use of low ground pressure harvesting equipment and a shift in logging operations from summer to winter (MOF 2005). Operators in the trial watersheds should consider these options in order to minimize ground disturbance, particularly in sensitive riparian areas or areas directly coupled to the stream network. Additional site preparation (i.e. mounding) may also be necessary to ensure restocking success if sites exhibit elevated moisture levels. In areas previously dominated by lodgepole pine, elevated groundwater levels or soil moisture conditions may require operators to consider restocking harvested areas with more water tolerant species (such as spruce). Along lowlands and riparian zones, the feasibility of planting native deciduous species that rapidly grow should be considered. Such initial rapid growth (relative to most conifers) will increase the rate of hydrologic recovery and along riparian zones improve root strength and bank stability. The planting of deciduous species will also benefit the forest since they will tend to act as natural firebreaks and/or beetle barriers.

Peak Flows

While the available research suggests that beetle-kill alone has a variable effect (i.e., no change or increase) on peak flows (Section 2.2.1), (salvage) harvesting is generally associated with an increase in peak flows if the total ECA exceeds about 15-20%. Due to the dominant role of snow accumulation and melt processes in driving peak flows in interior B.C., losses of forest cover in the upper portions of the watershed will tend to result in greater increases in peak flows, than the equivalent losses in the lower portions of the watershed (Winkler 2005). Since solar radiation is a major driver of melt processes, loss of forest cover on south-facing aspects tends to produce greater peak flow increases than north-facing aspects (Bethlahmy 1975). Furthermore, watersheds with impermeable soils and/or rugged topography (with minimal wetlands and lakes) will tend to be more sensitive to losses in forest cover, with relatively greater increases in peak flows (Winkler 2005).

An increase in peak flows has a direct effect on the performance of drainage infrastructure. The specifications of ditches and culverts based on design flows under pre-disturbance conditions may be inadequate under post-disturbance conditions. This may result in ditches overflowing and eroding excessively, and culverts having insufficient capacity thereby causing roadway overtopping and/or stream crossing failure. This suggests that drainage infrastructure downslope of areas of considerable beetle-kill and/or harvesting be assessed by a qualified professional in light of the potential for peak flow increases. This professional should identify the potential magnitude of the peak flow increase and specify the post-disturbance design flow. As a result of this assessment, ditches may need to be enlarged and/or require armouring to prevent erosion. Stream crossings may need to be upgraded or be supplemented with secondary structures (e.g., high flow culverts).

4.6 WATER QUANTITY AND QUALITY MONITORING

4.6.1 Background and Rationale

Monitoring of water quality and quantity at the point of diversion in a community watershed is a quantitative way to determine if MPB and associated salvage is having detrimental effects on community water supply and to evaluate the need for watershed restoration. Meeting these goals requires a carefully considered monitoring design. The hydrological regime of the study area is characterized by considerable natural variation in streamflow and water quality both throughout the year and between years, and monitoring program designs need to consider this variation if the data are to be used to detect either a significant negative change in water quality or to document that no significant change has occurred.

Under the requirements of the Drinking Water Protection Regulation (DWPR) water purveyors monitor the quality of raw water at the intake. However, the water suppliers' primary objective is to determine the level of treatment (e.g. chlorination) rather than to assess the effects of disturbance in the watershed, and existing monitoring programs would need to be supplemented to be effective in assessing impacts from MPB and/or salvage operations. Such monitoring could be done in four general ways:

- **Surveillance monitoring.** The goal is to monitor near enough to a specific activity (e.g. installing a new bridge) to be able to detect an effect and take action if the effect exceeds a certain threshold (e.g. water quality guidelines – see below). MOE has published a guidance document for this type of monitoring (Caux et al. 1997);
- **Compliance monitoring.** Monitoring to see if water quality meets water quality guidelines, objectives, or standards;
- **Trends monitoring.** Intended to determine if water quality is changing over time; and
- **Environmental impact assessment monitoring.** This is monitoring to specifically test hypotheses in a scientifically defensible manner, e.g. “differences in water quality are not significantly different in MPB affected versus non-MPB affected watersheds”.

Each of these approaches would have somewhat different study designs, although there is quite a bit of overlap. In surveillance monitoring only one or two key variables are usually monitored, such as turbidity and TSS, in an “upstream-downstream” configuration (i.e. sampling above and below the site of a new bridge). Automatic monitoring equipment consisting of probes and dataloggers are available for some routine variables including water level, turbidity, and temperature, but they require regular calibration and maintenance. The costs of operation and maintenance should be factored in when deciding whether to use automatic or manual monitoring systems, or some combination.

Compliance monitoring is intended to determine the frequency with which existing water quality guidelines (WQG - MWLAP 2001; Health Canada, 2004) or objectives⁶ (WQO) are met or exceeded. Drinking water guidelines are set conservatively and meeting guidelines is a strong indication of low risk to human health or of aesthetic problems. Since the monitoring data are compared against a guideline (i.e. an accepted benchmark), compliance monitoring has the advantage of answering the question “How many days per year is the water at the intake of poor quality?”

⁶ In B.C. water quality guidelines are generic and applied province-wide. Water quality objectives are site-specific criteria implemented for management reasons (see Glossary Section 6.0). The B.C. provincial guidelines apply to raw water “at the intake” while the Canadian Drinking Water Guidelines apply “at the tap” (i.e. after any treatment).

The B.C. government has developed draft WQO (site-specific guidelines based on the results of monitoring) for a number of Community Watersheds in the province, but the results from the monitoring programs that began in the 1990s in about 50 watersheds have not yet been evaluated. In many cases the WQO, when set, are the same as the province-wide WQG. They are most useful, however, when monitoring has indicated that the WQG are exceeded on a regular basis because of the watershed's natural characteristics (e.g. large coverage of highly erodible soils). In these cases it is in the tenure holder's interest to work with MOE to establish realistic WQO as the baseline for comparison in compliance monitoring. A special report of the Forest Practices Board concluded although WQO are useful for a number of resource management purposes, they do not constitute an enforceable regulatory standard (Forest Practices Board, 2003). Therefore WQO in Community Watersheds are likely to remain as site-specific benchmarks only, and not become a basis for additional regulatory enforcement under FRPA.

Trend monitoring is a survey of changes in water quality over time, and may be an appropriate monitoring approach for a declared result of no adverse changes in water quality. The major limitation on using trends monitoring for this purpose is that it will generally take at least six and usually more years to demonstrate a statistically significant trend or to confirm the absence of a trend (i.e. no adverse change). In addition, trend monitoring generally requires that measurements be taken at the same time interval throughout the monitoring program (Paine, 1998).

Impact assessment monitoring is the collection of data intended to separate the effect of an activity (or, in this case, of a large-scale disturbance) from natural variation. As noted earlier, some of the major drinking water parameters are extremely variable in time, and study design is critical if one is to determine if effects of land use are statistically significant. Basic designs that have been used to assess the impacts of forestry activities on water quality are (MacDonald et al., 1991):

- single-watershed comparison of before versus after logging;

- comparison of a single logged versus a single unlogged watershed (i.e., paired sites); and
- comparison of multiple logged versus unlogged watersheds.

Monitoring of just a single watershed should generally be avoided unless there is a long record of pre-impact data. In the absence of a control or reference site, there will be no confidence that any changes observed after MPB infestation would not have occurred naturally (MacDonald et al., 1991). Paired watersheds can be useful for results monitoring, but again would require a significant number of years of pre-MPB monitoring in both of the study watersheds to be able to say that any after-MPB differences are due to MPB (i.e. a BACI design).

A multiple-watershed monitoring program is needed to confirm an effect because the results of paired-watershed studies cannot be extrapolated beyond that pair. Therefore the trial program should include at least three watersheds. For all monitoring programs there are several “rules of thumb” to guide sample sizes, sampling intervals, monitoring periods, and analysis methods. Additional sources of information on water quality monitoring design include MacDonald et al. (1991), Sanders et al. (1983), and Helsel and Hirsch (1991).

- Statistical analyses are not robust (i.e. valid or effective) unless there are ≥ 10 error degrees of freedom (df) (Green, 1979). Therefore the total number of replicates (sites or times) must be greater than 10. For the sake of simplicity, 12 should be considered the minimum number of samples (times) to be collected per year. Automatic water quality monitoring equipment (e.g. turbidity probes) can, of course, collect many more than 12 data points per year, but automatic sampling should be supported by about 12 grab samples for calibration.
- Water resources data are usually not normally distributed, due to positive skewness, the presence of outliers, and a lower bound of zero (Helsel and Hirsch, 1991). Thus the data must be transformed to be used in parametric statistical tests. Also, water quality data sets often include relatively large amounts of censored data (results less than the laboratory detection limit). For these reasons, non-parametric statistical tests are generally prescribed for analyses.

- Water quality data often exhibits serial correlation (i.e. samples taken close together in time are not independent of one another). Serial correlation must be considered in analyses of trends or when comparing control and treatment watersheds.
- For field sampling, all methods should employ the appropriate Resource Inventory Standards Committee (RISC) protocol to maximize consistency (e.g. RISC, 1997; 1998; 1999 - see <http://srmwww.gov.bc.ca/risc/>). Where RISC methods are not available a consistent, scientifically valid procedure must be used.

4.6.2 Variable Selection

For the adaptive management trials the list of variables that are monitored should be relevant to human health and aesthetic⁷ considerations and have some potential to be influenced by forestry activities. MacDonald et al. (1991) provide principles for selecting water quality monitoring variables, and recommended variables for monitoring impacts from forest harvest, road construction, and grazing of range animals. Table 6 ranks typical water column monitoring variables based on their effects on domestic water and their sensitivity to forest harvest, road construction and range. Several variables have been added for this study to the list given in MacDonald et al. (1991) that are relevant for monitoring the quality of community water supplies.

From Table 6, the only variables that are ranked as “1” under both effects and sensitivity (to any of harvest, road building, or grazing) are turbidity, TSS, and coliform bacteria. Those ranked as a combination of “1” and “2” are low flow⁸, water yield, nitrogen, and phosphorus. A key variable not ranked by MacDonald et al. (1991) is total organic carbon (TOC), which has been added to Table 6. It is important for drinking water monitoring where water supplies are chlorinated, due to the potential for trihalomethane production. True colour is a

⁷ Aesthetic variables are those with potential to affect taste, smell, laundry, and home plumbing, but which are not toxic except at very high concentrations.

⁸ Forest harvest increases water yield and can alter the timing of peak and low flows. In theory this could result in lower flows in late summer in a logged watershed compared to an unlogged watershed, although the majority of studies in both snowmelt and rainfall dominated watersheds in BC and the US Pacific Northwest have found summer flows to increase.

Table 6. Effects on drinking water, and sensitivity to watershed activities for water quality monitoring variables.

Variable	Ranks [from MacDonald et al. (1991)]				
	Effects on:*		Sensitivity to:**		
	Aquatic Life	Domestic use	Grazing	Harvest	Roads
Water quantity					
Peak flows	2	4	3	1-2	1
Low flows	2-3	2	2	1	3
Yield	4	2	3	1	3
Physical/chemical					
Temperature	1	3	2	1-2	3
pH	3	1	3	3	3
Conductivity	4	1	3	3	3
Suspended solids (TSS)	1-2	1	2	1-3	1
Turbidity	1	1	2	1-3	1
Water column dissolved oxygen (DO)	1	2	3	3	3
Intergravel DO	1	4	1	2	2
Total organic carbon	NR	NR (2)	NR (2)	NR (3)	NR (4)
True Colour	NR (4)	NR (1)	NR (2)	NR (3)	NR (4)
Nitrogen	2-3	2	1	2	3
Phosphorous	2-3	2	1	2	3
Total dissolved solids (TDS)	NR	NR	NR	NR	NR
Major ions (Cl, F, Na, SO ₄ , H ₂ S)	NR	NR	NR	NR	NR
Hardness	NR	NR	NR	NR	NR
Metals	NR	NR	NR	NR	NR
Biological					
Bacteria – Total coliforms Fecal coliforms	3-4	1	1	4	4
Parasites	NR	NR (1)	NR (2)	NR (4)	NR (4)

* Ranks range from 1 (designated use directly related and highly sensitive to parameter) to 4 (designated use largely unrelated to and unaffected by parameter). NR not ranked by MacDonald et al. (1991). Ranks in brackets added, if relevant.

** Ranks range from 1 (parameter is highly sensitive to and directly affected by the activity) to 4 (parameter is largely unrelated to and unaffected by the activity). NR not ranked by MacDonald et al. (1991). Ranks in brackets added, if relevant.

useful surrogate for organic carbon because it is also an aesthetic variable. Where true colour values routinely exceed the WQG and chlorination is used, the true colour reading should be calibrated against TOC and trihalomethane concentrations.

The recommended list of drinking water quality variables for compliance, trends, and impact assessment monitoring programs includes discharge (stream flow), turbidity, total suspended solids (TSS), coliform bacteria (fecal coliforms and *E. coli*), and an indication of dissolved organic carbon such as true colour⁹. Specific conductance, temperature, and pH should also be included because they are relatively inexpensive and provide information that can assist in the interpretation of other data. For example, both pH and specific conductance may be relatively low when snowmelt makes up a large component of the total flow. If fertilizers are used in silviculture, then nutrients (nitrate-N, ortho-phosphate, and possibly ammonium-N) would be added. Nutrients could also be included if there is significant range or recreation activities, or if wildfires or prescribed burns have affected significant areas.

Monitoring of biological variables (e.g. benthic invertebrates, algae communities) is not included because of the emphasis on drinking water in the trials. Habitat characteristics are addressed above in the section on riparian function assessment (Section 4.3).

4.6.3 Implementation Options

To meet its objective of providing information applicable to the majority of the study area the adaptive management trial program should be conducted in at least three community watersheds. Ideally it would be conducted in six or more watersheds to obtain a better understanding of the factors that influence drinking water quality. The budget available for the Adaptive Management Trial program is, however, not known at this time, so this section outlines three general options for undertaking the program:

⁹ True colour is an indicator of dissolved organic matter in water in addition to being an important aesthetic variable for drinking water. Organic matter can react with chlorine used for disinfection to create a set of compounds called trihalomethanes (THMs), which are linked to bowel cancer.

- Demonstration Project – Conducted in three watersheds (the minimum acceptable number to meet the program goals). Could include either three watersheds impacted by MPB (“impact watersheds”) or else two impact watersheds and one control watershed (i.e. a watershed not significantly affected by MPB). A relatively high level of field assessment work would be included with the Demonstration Project to support the quantitative monitoring;
- Trend and Impact Assessment Project – Conducted in six or more watersheds to improve the potential to generate statistically significant results from the water quality monitoring component and/or to assess a larger range of watershed management strategies and tools; and
- Water Purveyor Monitoring Project – This approach includes a larger total number of watersheds by directing the project budget to assisting water purveyors to expand their existing raw water monitoring programs to address the Adaptive Management trial goals. This assumes that the additional water quality monitoring would be done by water utility staff at no additional cost to the project (the additional laboratory and data analyses work would be paid for by the project). Because of the larger sample size this program places more emphasis on water quality monitoring and less on field assessment as the basis for evaluation.

Table 7 summarizes the key features of these three general approaches. Within each there are a number of options for monitoring, assessment, and adaptive response depending on the available budget. Water quality monitoring at the point of diversion should be undertaken in all programs but the costs of monitoring for a large suite of variables (i.e. the optional variable in Table 7) may not provide good value. The most basic (i.e. least costly) water quality program that still meets the needs of the Adaptive Management Trial program has the following attributes:

Table 7. Features and approximate costs of alternative adaptive management programs.

	Demonstration Project	Basic Trend and Impact Assessment Study	Water Purveyor
Total no. of watersheds	3	≥6	6 - 12
Acceptable level of watershed similarity	low	moderate	low (focus on trends)
No. of reference (control) watersheds	None or one	≥2	0 - >2
Core variables – monitored continuously or frequently (≥30 times/yr.)	Discharge (or stage), turbidity (plus pH, SC, & temperature)	Discharge (or stage), turbidity (plus pH, SC, & temperature)	Discharge (or stage), turbidity (plus pH, SC, & temperature)
Secondary variables – monitored ≥12 times/yr.	Fecal coliforms, <i>E. coli</i> , turbidity ¹⁰ , TSS, true colour	Fecal coliforms, <i>E. coli</i> , turbidity, TSS, true colour	Fecal coliforms, <i>E. coli</i> , turbidity, TSS, true colour
Optional variables – Monitored ≥12 times/yr.	TOC, Hardness, TDS, Nitrate-N, Ortho-P	TOC, hardness, TDS, Nitrate-N, Ortho-P	TOC, hardness, TDS, Nitrate-N, Ortho-P
Level of supporting watershed assessment and site-specific monitoring	high	moderate	low
Probable cost of initial inventory and watershed assessment work	\$50,000 - \$65,000	\$100,000 – \$150,000	\$12,000 - \$20,000
Probable <u>annual</u> monitoring cost (see Section 4.9)	\$22,000-\$30,000 (\$7-\$10,000/watershed)	\$35,000-\$48,000 (\$6-\$8,000 per watershed)	\$9,000 - \$18,000 (\$1,500 per watershed)

¹⁰ Turbidity measurements taken to confirm the automatic probe data collected continuously.

- The monitoring period can limited to 12-14 weeks between mid-April and mid-July. To optimize the ability to complete future data analysis concerning MPB impacts and trends it is essential that the monitoring period be consistent from year to year (or at least cover a consistent core 12 week period);
- The automatic equipment should be installed before the onset of freshet;
- Weekly grab samples for the secondary variables should be obtained. To facilitate trend assessment it is important that the sampling take place on the same day each week so that the interval between samples is consistent¹¹. Any required stream gauging work or equipment maintenance/calibration can also take place during the weekly visit; and
- With a small increase in budget additional data concerning low-flow water quality can be obtained by keeping the automatic monitoring equipment in place until the autumn, without necessarily increasing the frequency of the supporting grab samples (as long as $n \geq 12$). A final grab samples should be obtained when the automatic station is removed in the fall, in order to close out the data record.

The priorities for additional monitoring, where budgets allow, are:

- Stream gauging to permit calculations of stream discharge (the basic program only includes water level);
- Increasing the frequency of grab sampling for the secondary variables (e.g. conducting weekly sampling for the mid-April to mid-October period and monthly sampling for the rest of the year);
- Conducting “storm sampling” – collecting samples for selected variables (i.e. TSS, turbidity, specific conductance) at frequent intervals (e.g. hourly every 4 hours) during significant rain, rain-on-snow, or snowmelt events. This will facilitate a more complete evaluation of hydrologic and sediment transport processes and allow the characterization of “worst case” conditions;

¹¹ Consistent weekly sampling will also result in obtaining 5 samples within 30 days, the basis of a number of WQG.

- Add within-watershed monitoring stations if there are sites or areas of specific interest or concern. For example, surveillance monitoring could be conducted upstream and downstream of a major sediment source, or a station could be installed at the outlet of a sub-basin that has had a very high level of MPB attack;
- Similar to the above point, within-watershed monitoring could be done on selected sub-basins or reaches to compare different mitigation treatments; and
- Add optional variables to the sampling list where specific conditions warrant their inclusion.

4.7 DATA MANAGEMENT AND REPORTING

A central database should be created for the Adaptive Management Trial program where all data collected for the program would reside, regardless of the number of watersheds that are selected for the trials. In addition to new data collected specifically from the trials, the database should include records for all previously completed reports, including standard bibliographic details (author, title, year published, etc.), key words, and information on where the documents are housed. The database should be created in MS-Access to enable accessibility from a wide group of users.

The water quality data should be collected and tabulated in the database in a format that would allow it to be transferred to the provincial Environmental Monitoring System (EMS) database. Access to the EMS database is available through Ms. Ute Muller (Application Support Analyst – EMS helpdesk; EMSHelp@gov.bc.ca).

As outlined in Section 4.1, it is important to commit to running the Adaptive Management Trial program for at least five and ideally more than 10 years to evaluate MPB effects and test the effectiveness of adaptive responses. Given the need to develop and implement appropriate adaptation and action plans in response to any “bad news” concerning drinking water quality, brief annual reports should be prepared and reviewed by an evaluation team (see Section 4.8).

4.8 ADAPTIVE MANAGEMENT RESPONSE FRAMEWORK

Adaptive Management processes require that the results of a monitoring program be evaluated and appropriate responses developed and implemented in a timely manner (i.e. Phases 4 and 5 from Section 4.1). A process to complete the evaluations and develop the response strategy is therefore needed. The evaluations should be completed on an annual basis by a small evaluation team. This should be done in the autumn after the monitoring information has been processed, analyzed, and reported. Potential responses in any given year include:

- Continue to follow the existing monitoring program; or
- Change the monitoring program; and/or
- Plan and implement measures to reduce or eliminate any observed detrimental effects. If in-stream works are recommended the prescriptions must consider the work windows for any fish species that are present.

Any decisions made regarding changes to the monitoring program or further mitigation measures should be documented in the Adaptive Management trial database.

4.9 COST CONSIDERATIONS

Regardless of the annual monitoring program that is ultimately selected the adaptive management trials should begin with a review of existing information, completion of a watershed assessment (including a riparian assessment), and mapping. The estimated cost of this initial work is probably in the range of \$10,000 to \$25,000 for each of the selected watersheds.

The water quality costs shown at the lower end of the ranges given for the “demonstration Project” and “Trend and Impact Study” in Table 6 are based on a generic drinking water program using automated equipment for water level and turbidity, with manual sampling and station maintenance done by a locally-based technician at \$400/day. Supervision and report writing are assumed done by a qualified professional at \$600/day. The program assumes

continuous monitoring of stage (water depth), turbidity, and water temperature using automatic probes and a datalogger. Manual (“grab”) samples for the secondary variables would be collected 12 times per year. Laboratory analysis is assumed to be by a certified laboratory, except for pH and specific conductance, which are measured with field meters. Ten percent of the laboratory budget is allocated for Quality Assurance/Quality Control (QA/QC). The estimates assume that three or more watersheds are monitored to achieve some economy of scale. They do include the costs of annual reporting but do not include the costs to administer contracts.

Beyond the initial inventory and assessment work and the water quality monitoring, the additional costs to run the trials may include:

- The costs for the evaluation team to complete the annual evaluations of the monitoring results;
- Costs to develop specific response plans including prescriptions for restoration work or new management practices; and
- Costs to implement the response plans.

The magnitude of these first two costs depends on the eventual scope of the trial program and whether it is managed by MOE staff or consultants. The costs of any adaptations or changes to management practices are also difficult to predict, but local experience with the Watershed Restoration Program (and related FIA) between 1995 and 2002 can be used as a guide for planning purposes.

5.0 SUMMARY AND RECOMMENDATIONS

The proposed adaptive management trials will provide an opportunity to assess the effects of MPB and related salvage on drinking water quality in selected Community Watersheds within the study area and to evaluate the feasibility of mitigating impacts through operational and restoration procedures. The major elements of the proposed approach are as follows:

- Conduct the trials in a minimum of three Community Watersheds. If the budget allows, consider conducting the trials in six or more watersheds, with two or three of the watersheds serving as controls (i.e. low levels of MPB infestation);
- Select watersheds with available water quality data and watershed assessment information from the recent past. Given that MPB has already made its way into the study area, the availability of water quality/watershed assessment information is important to have an understanding of pre-MPB conditions and to achieve some elements of a BACI monitoring design. The Level 1 priority watersheds are (in order of preference) Cornwall, Murray, and Leonie Creeks (all the same rank), Peterson, Jimmies, Paul Lake, Paul Creek, Tranquille River (or a sub-basin), Dillard, and Kwinshatin;
- Establish an evaluation team to review the assessment and monitoring results each year and develop the appropriate adaptive response;
- The trials should begin as soon as possible in 2006 with initial inventory and assessment work and run for at least five years and ideally for about 10 years. All trials should begin with a watershed assessment following the procedures outlined in MOF (1999), a detailed assessment of riparian function, and an inventory of MPB-affected and potentially affected stands;
- The results of the riparian assessment should be used to develop the riparian management plan for the trial watersheds on a reach-specific basis;
- The trials should include one or more MPB-affected watersheds that have not yet undergone salvage logging, but where significant harvesting of lodgepole pine is planned (e.g. where the resulting watershed ECA is >35%). This will provide an opportunity to test the effectiveness of forest development methods aimed at minimizing effects on water resources. These include retaining patches of non-pine species within cutblocks, retaining buffers of dead or dying pine around these non-pine patches, minimizing salvage in areas where intermixed pine represents <40% of the species mix, use of Best Management Practices for road and trail construction, and prompt deactivation of roads;
- Monitoring of physical and chemical water quality should take place at or just above the point of diversion for the drinking water purveyor (or at the site of any previous monitoring). A basic, cost-effective program would include continuous monitoring of

water level, turbidity, and water temperature using automated equipment from mid-April to mid-July (or preferably to about mid-October). The automated monitoring should be supplemented with regular (i.e. weekly) grab sampling for turbidity, TSS, pH, specific conductance, and true colour;

- To guard against the potential for variations in the monitoring budget it is critical to implement a consistent, core monitoring program that runs for the same 12-14 week period each year. If it is possible to expand out from the core program by expanding the sampling period and/or expanding the list of variables than do so, but it is essential to ensure that the core program is maintained to facilitate trend analyses or comparisons between watersheds;
- A customized database should be established in MS-Access to house information for all the trials. It should be possible to transfer the water quality data to the provincial EMS system;
- Brief annual reports should be prepared each autumn for the evaluation team's review. The team would then develop the recommendations for any adaptations to the trial procedures for the following year (e.g. changes to the monitoring program and/or restoration prescriptions). Restoration options include:
 - Additional road and landing deactivation;
 - Maintenance and upgrades of drainage infrastructure (e.g. culverts, bridges, ditches, cross-drains, and sumps as guided by an evaluation completed by a qualified professional);
 - In-fill planting of cut blocks and riparian areas;
 - Stream channel restoration/reinforcement to reduce bank erosion and guard against future erosion;
 - Riparian restoration;
 - Landslide restoration;
 - Hydro-seeding of cutslopes and ditches; and
 - Thinning, spacing, and/or fertilization to quicken tree growth.

The next steps in implementing the adaptive management trial program are to:

1. Establish the multi-agency evaluation team that will select the trial watersheds and guide the trial program. Possible participating agencies and groups include MOE, MOFR, the Interior Health Authority, the Water Supply Association of B.C., forest licensees, and individual water purveyors;
2. Confirm the program budget;
3. Select the trial watersheds; and
4. Finalize the initial assessment and monitoring programs based on the available budget.

6.0

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7.0

GLOSSARY

Adaptive Management	A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. The process requires the flexibility to modify procedures as new information is gained.
Bedload	The portion of the solid material carried along a stream bed by rolling, pushing, or bouncing (saltation). Usually the coarsest fraction of the total sediment load. Finer materials are carried in suspension.
Biodiversity	The diversity of life in all its forms and levels of organization, including genes, species, ecosystems, and the evolutionary and functional processes that link them.
Biogeoclimatic zone	A geographic area having characteristic vegetation with associated climate, soils and animals. In British Columbia, each forested zone is under a broadly similar macroclimate and is usually named by one or more of the dominant tree species which are capable of self-regeneration on most of the zone's habitats (e.g., Coastal Western Hemlock, Interior Douglas fir). In B.C., the biogeoclimatic zones are further subdivided into subzones, variants, and phases.
Control	In comparative studies, the experimental unit (e.g., watershed, laboratory rat) that represents the unmodified situation (e.g., unlogged watershed, patients given a placebo in medical trials).
Discharge	Rate of fluid flow expressed as a volume per unit of time (e.g., m ³ /s)
Equivalent Clear-cut Area (ECA)	Total harvested area in a watershed, discounted by the amount of tree regeneration. Often used as a rough guide to identify the potential that the hydrologic regime of a watershed has changed as a result of previous forest harvesting, or that the hydrologic regime is likely to change in the future as a result of future harvesting.
Non-point source pollution	Pollution resulting from multiple sources (e.g. sediment in a stream coming from farm fields throughout the watershed) rather than from identifiable single (or <i>point</i>)

sources.

Point source pollution

Pollution coming from a single identifiable source, such as a pipe discharging effluent to a stream.

Quality Assurance/Quality Control (QA/QC)

Quality Assurance (QA) refers to externally imposed technical and management practices that ensure the generation of quality and defensible data commensurate with the intended use of the data. Quality Control (QC) is a specific aspect of quality assurance and refers to internal techniques used to measure and assess data quality and remedial actions to be taken if data quality objectives are not met.

Result (in FRPA)

A description of (a) measurable or verifiable outcomes in respect of a particular established objective, and (b) the situations or circumstances that determine where in a forest development unit the outcomes under paragraph (a) will be applied.

Rills

Small channels caused by surface erosion, generally only a few centimeters wide and deep.

Stage

Water level (the elevation of the water surface above a specified datum).

Statistically significant

Two set of numbers are said to be significantly different if the probability that they are drawn from the same population is low. Statistical significance is expressed as the probability (“p” or α) of incorrectly saying that two samples are from different populations when they are actually from the same population. For example, $p < 0.05$ means that there is less than a 5% chance of making that error (a “Type I” error). In scientific studies, statistical tests are usually not considered significant unless $p < 0.05$ (routine studies) or $p < 0.01$ (if the consequences of a Type I error are severe, as in drug trials).

Strategy (in FRPA)

A description of (a) measurable or verifiable steps or practices that will be carried out in respect of a particular established objective, and (b) the situations or circumstances that determine where in a forest development unit the steps or practices will be applied.

Supply limited	In sediment transport, a condition where the mass of sediment being carried by a stream is controlled by the amount of available sediment.
Transport limited	In sediment transport, a condition where the mass of sediment being carried by a stream is limited by the stream transport capacity (i.e. larger particles remain in storage).
Treatment	Alteration or condition applied to experimental units or replicates (e.g., logged watershed, patients given a new drug). Multiple treatment levels (e.g., drug doses) are possible. In observational experiments (i.e., most field studies) the “treatment” is already applied and researchers randomly select experimental units. See Church (1984) for a good discussion of observational <i>vs.</i> manipulative experiments.
Water quality guideline (WQG)	A maximum and/or minimum value for a physical, chemical, or biological characteristic of water, biota, or sediment, applicable province-wide, which should not be exceeded to minimize the risk of specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions.
Water quality objective (WQO)	A water quality criterion adapted to protect the most sensitive designated use at a <u>specific location</u> with an adequate degree of safety, taking local circumstances into account.

APPENDIX A

Study Area Community Watersheds Characteristics and Available Information

Appendix A. Community Watershed Criteria Information

Watershed Name	Area (>500 ha, and <50,000 ha)	Presence of Fire	Map Sheet	Current MPB	Potential MPB	Total MPB in 2009
Number of Watersheds that fit Area Criteria (23)					2006-2009	
	(yes/no)	(yes/no)	NTS 1:50,000	Approximate %	Approximate %	Approximate %
Kamloops Forest District (DKA)						
Cornwall Community Watershed	y	y	92I/13	20	25	45
Jimmies Community Watershed	y	y	92I/10/11/14	2	30	32
Leonie Community Watershed	y	n	92P/1	15	25	40
Nelson Community Watershed	y	n	92P/8	2	10	12
Paul Creek Community Watershed	y	y	92I/9/16	3	35	38
Paul Lake Community Watershed	y	y	92I/9/16	25	15	40
Peterson Community Watershed	y	n	92P/1/8	7	20	27
Skowootum Community Watershed	y	n	92P/8	20	25	45
Tranquille Community Watershed	y	y	92I16/15	30	40	70
Cascades Forest District						
Lillooet Forest District (DLI)						
Dickey Community Watershed	y	n	92I/12,92J/9	10	15	25
Fergusson Community Watershed	y	n	92J/15	0	10	10
Fountain Community Watershed	y	y	92I/12	1	35	36
Gladwin Community Watershed	y	n	92I/3	1	7	8
Intlpam Community Watershed	y	y	92I/5	1	7	8
Lytton Community Watershed	y	y	92I/4/3	0	30	30
Murray Community Watershed	y	n	92I/5/6/11	7	50	57
Nepuchin Community Watershed	y	y	92I/5	0	7	7
Nikaia Community Watershed	y	y	92I/4/3	1	15	16
Six Mile Community Watershed	y	y	92I/3	1	75	76
Town Community Watershed	y	y	92I/12,92J/9	7	10	17
Merrit Forest District (DME)						
Brook Community Watershed	y	y	92H/15	0	40	40
Dillard Community Watershed	y	y	92H/16	3	80	83
Kwinshatin Community Watershed	y	n	92H/15,92I/2	1	70	71

*Note: Total number of community watersheds in the study area is 42.

The following community watersheds were excluded from further evaluation because of their small size (<500 ha):

Kamloops Forest District:

Currie, Rosen, and Toops

Cascades Forest District divided into:

- the former Lillooet Forest District:

Blackbird, Countless, Dicksam, George, Inklyulkinatko, Nekliptum, Omin, President, and Retasket

- the former Merritt Forest District:

Anderson, Bell, Hackett, Lee, Skuagum, and Thomas

Appendix A. Community Watershed Criteria Information

Watershed Name	Watershed ECA Data	Current Water Quality Monitoring	
		Water Quality Data	Water Purveyor
(>500Ha, and <50,000Ha)	Source	>2 years	(Waterworks Authority)
Kamloops Forest District (DKA)		(yes/no)	
Cornwall Community Watershed		y	ASHCROFT INDIAN BAND
Jimmies Community Watershed		y	THOMPSON-NICOLA REGIONAL DISTRICT
Leonie Community Watershed	Summit, 2005.	y	THOMPSON-NICOLA REGIONAL DISTRICT
Nelson Community Watershed		n	WEST VANCOUVER DISTRICT OF
Paul Creek Community Watershed		y	KAMLOOPS INDIAN BAND
Paul Lake Community Watershed		y	
Peterson Community Watershed		y	
Skwootum Community Watershed	Summit, 2005.	n	SIMPCW FIRST NATION
Tranquille Community Watershed	Summit, 2001.	y	BRITISH COLUMBIA WILDERNESS TOURS INC
Cascades Forest District			
Lillooet Forest District (DLI)			
Dickey Community Watershed		n	LILLOOET DISTRICT OF
Fergusson Community Watershed		n	GOLD BRIDGE WATERWORKS DISTRICT
Fountain Community Watershed		n	FOUNTAIN INDIAN BAND
Gladwin Community Watershed		n	LYTTON VILLAGE OF
Intlpam Community Watershed		y	LYTTON FIRST NATION
Lytton Community Watershed		y	LYTTON VILLAGE OF
Murray Community Watershed		y	SPENCES BRIDGE WATERWORKS DIST
Nepuchin Community Watershed		n	LYTTON FIRST NATION
Nikaia Community Watershed		n	LYTTON FIRST NATION
Six Mile Community Watershed		y	
Town Community Watershed		y	
Merrit Forest District (DME)			
Brook Community Watershed		y	BROOKMERE WUC
Dillard Community Watershed		y	MISSEZULA LAKE WATERWORKS DISTRICT
Kwinshatin Community Watershed	MoF, 2001	y	COLDWATER INDIAN BAND

Table 1.1 Community Watershed Criteria Information

Watershed Name	Streamflow Data		Elevation (m)		
	Hydrometric Station	Aspect	Lowest	Highest	Average
	(yes/no)				
Kamloops Forest District (DKA)					
Cornwall Community Watershed	y	SE	600	1400	1000
Jimmies Community Watershed	n	N	360	1500	930
Leonie Community Watershed	downstream	W	1000	1600	1300
Nelson Community Watershed	y	E	800	1200	1000
Paul Creek Community Watershed	y	W	600	1200	900
Paul Lake Community Watershed	y	W	1000	1200	1100
Peterson Community Watershed	y	E	800	1400	1100
Skwootum Community Watershed	n	SW	800	1600	1200
Tranquille Community Watershed	y	SE	600	1400	1000
Cascades Forest District					
Lillooet Forest District (DLI)					
Dickey Community Watershed	y	E	600	2000	1300
Fergusson Community Watershed	n	N	1000	2400	1700
Fountain Community Watershed	y	N	800	2000	1400
Gladwin Community Watershed	y	N	600	1800	1200
Intlpam Community Watershed	n	E	400	2400	1400
Lytton Community Watershed	y	W	600	1800	1200
Murray Community Watershed	y	SE	400	2000	1200
Nepuchin Community Watershed	n	E	400	2300	1350
Nikaia Community Watershed	n	NE	400	2000	1200
Six Mile Community Watershed	y	N	400	1800	1100
Town Community Watershed	y	SE	400	2000	1200
Merrit Forest District (DME)					
Brook Community Watershed	n	NE			0
Dillard Community Watershed	y	W			0
Kwinshatin Community Watershed	y	NE			0

Table 1.1 Community Watershed Criteria Information

	Hydrologic Zone	Biogeoclimatic Zone (Dominant/Lesser Zones)
Kamloops Forest District (DKA)		
Cornwall Community Watershed	Northern Thompson Plateau	IDF/MS
Jimmies Community Watershed	Northern Thompson Plateau	IDF/BG
Leonie Community Watershed	Southern Quesnel Highland	IDF/MS
Nelson Community Watershed	Southern Quesnel Highland	MS/ICH/IDF
Paul Creek Community Watershed	Fraser Plateau	IDF/BG
Paul Lake Community Watershed	Fraser Plateau	IDF/MS
Peterson Community Watershed	Southern Quesnel Highland/Fraser Plateau	MS/ICH/IDF
Skwootum Community Watershed	Southern Quesnel Highland	MS/ESSF
Tranquille Community Watershed	Fraser Plateau	ESSF/MS/IDF/BG
Cascades Forest District		
Lillooet Forest District (DLI)		
Dickey Community Watershed	Fraser Plateau	ESSF/IDF
Fergusson Community Watershed	Fraser Plateau	MS/ESSF
Fountain Community Watershed	Northern Thompson Plateau	IDF/ESSF
Gladwin Community Watershed	Eastern South Coast Mountains	IDF/PP/ESSF
Intlpam Community Watershed	Northern Thompson Plateau	IDF/MS
Lytton Community Watershed	Eastern South Coast Mountains	IDF/ESSF
Murray Community Watershed	Northern Thompson Plateau	IDF/ESSF/MS/BG
Nepuchin Community Watershed	Eastern South Coast Mountains	IDF
Nikaia Community Watershed	Eastern South Coast Mountains	ESSF/IDF
Six Mile Community Watershed	Eastern South Coast Mountains	ESSF/IDF
Town Community Watershed	Fraser Plateau	IDF/ESSF
Merrit Forest District (DME)		
Brook Community Watershed	Eastern South Coast Mountains	ESSF/MS/IDF
Dillard Community Watershed	Southern Thompson Plateau	MS/ESSF/IDF
Kwinshatin Community Watershed	Eastern South Coast Mountains	MS/IDF

Table 1.1 Community Watershed Criteria Information

Biophysical Description		
	Bedrock Geology	Surficial Materials
Kamloops Forest District (DKA)		
Cornwall Community Watershed	Metamorphic melange	Glaciofluvial / Morainal
Jimnies Community Watershed	Undivided volcanic rocks	Glaciofluvial / Morainal
Leonie Community Watershed	Basaltic volcanic rocks	Glacial till / Glacio-fluvial
Nelson Community Watershed	Fine clastic sedimentary rocks	Glacial till
Paul Creek Community Watershed	Fine clastic sedimentary rocks	Colluvium / Glaciofluvial / Morainal
Paul Lake Community Watershed	Fine clastic sedimentary and undivided volcanic rocks	Colluvium / Glaciofluvial / Morainal
Peterson Community Watershed	Fine clastic sedimentary rocks	Glacial till / Colluvium
Skowootum Community Watershed	Basaltic volcanic rocks	Colluvium / Glacial till / Fluvial
Tranquille Community Watershed	Undivided volcanic rocks	Glaciofluvial / Morainal
Cascades Forest District		
Lillooet Forest District (DLI)		
Dickey Community Watershed	Marine, sedimentary and volcanic rocks	Colluvium / Glaciofluvial / Morainal
Fergusson Community Watershed	Marine, sedimentary and volcanic rocks	
Fountain Community Watershed	Andesitic volcanic flows	Colluvium
Gladwin Community Watershed	Dioritic intrusive rocks	Colluvium / Morainal
Intlpam Community Watershed	Granodioritic intrusive rocks	Glaciofluvial / Colluvium
Lytton Community Watershed	Dioritic intrusive rocks	Colluvium / Morainal
Murray Community Watershed	Andesitic volcanic flows	Colluvium / Morainal
Nepuchin Community Watershed	Granodioritic intrusive rocks	Colluvium
Nikaia Community Watershed	Granodioritic intrusive rocks	Colluvium
Six Mile Community Watershed	Dioritic intrusive rocks	Colluvium / Morainal
Town Community Watershed	Marine, sedimentary and volcanic rocks	Colluvium / Glaciofluvial / Morainal
Merrit Forest District (DME)		
Brook Community Watershed	Dioritic intrusive and undivided volcanic rocks	Glacial till / Colluvium
Dillard Community Watershed	Basaltic volcanic rocks	Glacial till / Colluvium
Kwinshatin Community Watershed	Undivided volcanic rocks	Glacial till

Table 1.1 Community Watershed Criteria Information

		Accessibility
	Soils	
Kamloops Forest District (DKA)		
Cornwall Community Watershed	Degraded Eutric Brunisol / Orthic Gray Luvisol / Orthic Brown	Multiple roads
Jimmies Community Watershed	Degraded Eutric Brunisol / Orthic Gray Luvisol / Orthic Dark Brown	Multiple roads
Leonie Community Watershed	Orthic Eutric Brunisol / Brunisolic Gray Luvisol	Multiple roads
Nelson Community Watershed	Brunisolic Gray Luvisol	Multiple roads
Paul Creek Community Watershed	Degraded Eutric Brunisol / Orthic Brown/Dark Brown/Black	Multiple roads
Paul Lake Community Watershed	Brunisolic Gray Luvisol	Multiple roads
Peterson Community Watershed	Brunisolic Gray Luvisol	Multiple roads
Skwootum Community Watershed	Degraded Eutric Brunisol / Brunisolic Gray Luvisol	Multiple roads
Tranquille Community Watershed	Degraded Eutric Brunisol / Orthic Brown	Multiple roads
Cascades Forest District		
Lillooet Forest District (DLI)		
Dickey Community Watershed	Orthic Dystric Brunisol	No roads
Fergusson Community Watershed	Orthic Sombric Brunisol	Multiple roads
Fountain Community Watershed	Degraded Eutric Brunisol / Orthic Gray Luvisol	One road
Gladwin Community Watershed	Orthic Dystric Brunisol / Orthic Gray Luvisol	Multiple roads
Intlpam Community Watershed	Orthic Dystric Brunisol / Orthic Brown / Degraded Eutric Brunisol	Road to mouth
Lytton Community Watershed	Orthic Gray Luvisol / Orthic Dystric Brunisol	Road to mouth
Murray Community Watershed	Degraded Eutric Brunisol / Orthic Gray Luvisol	One road
Nepuchin Community Watershed	Orthic Humo-Ferric Podzol / Degraded Eutric Brunisol / Degraded Dystric	Road to mouth
Nikaia Community Watershed	Orthic Humo-Ferric Podzol	Multiple roads
Six Mile Community Watershed	Orthic Gray Luvisol / Orthic Dystric Brunisol	One road
Town Community Watershed	Degraded Eutric Brunisol	Road to mouth
Merrit Forest District (DME)		
Brook Community Watershed	Degraded Eutric Brunisol / Orthic Eutric Brunisol	Multiple roads
Dillard Community Watershed	Lithic Orthic Eutric Brunisol / Lithic Gray Luvisol	Multiple roads
Kwinshatin Community Watershed	Lithic Gray Luvisol / Orthic Dark Gray	Multiple roads

Watershed Assessments
Level 1 IWAP 1997, Terrain 1998, IWRP 1998, Sediment 1997, Level 1 IFHAP
Level 1 IWAP 1997, Terrain 1998, IWRP 1998, Sediment 1997, Level 1 IFHAP
Level 1 IWAP 1997, TSILC 1998, IWRP 1997, Sediment 1996, IWRP 1997, Channel 1998
Level 1 IWAP 2001, Terrain 1998
WQTR 2002, Restoration Plan 2001
Level 1 IWAP 2000, Terrain 1998, IWRP & CWS IWAP 2002, Restoration Plan 2001, Geotech 1996
Level 1 IWAP 2002 (IWRP, FHAP, Sediment), Restoration Plan 2001, Terrain 1998, Major Works 1997, Geotech 1996
Level 1 IWAP 1996, IWRP 1997, TSILC 1998, Channel 1998, Sediment 1996
Level 1 IWAP 1996, (IWRP, Sediment, FHAP, WQTR) 2002, Restoration Plan 2001, Stream restoration 1999-2000, Geotech 1996
none listed
none listed
none listed
none listed
none listed
none listed
none listed
IWRP 1997 includes IWAP and SSS (not FHAP), Channel 1999
none listed
IWRP 1998, Restoration plan 2001-2003, Surface Erosion 2000, Channel 1999
none listed
Level 1 IWAP 1998
none listed
CWS Restoration Plan 2001-2003, IWAP 1999, Fish Passage Culvert Inspection 2001
CAP 2000, Restoration plan 2001, ECA 2001

APPENDIX B

Checklist of Water-Related Rules under the *Forest and Range Practices Act*

Appendix B. Checklist of forest practices applicable to water quality required under FRPA.

Practice	<i>Forest Planning & Practices Regulation</i> Section number	Currently satisfactory ? and/or	Does the FSP address it or has an alternative strategy been proposed? or	Has Minister granted exemption or alternative?	Defining conditions
1. Practices in Community Watersheds (Division 4)					
Material that is harmful to human health must not be deposited in, or transported to water that is diverted for human consumption by a licensed waterworks.	59				
Timber must not be harvested or a road built within a 100 m radius upslope from a licensed water intake where the water is used for human consumption.	60				
An excavated or bladed trail must not cause sediment to enter a stream, lake or wetland from which water is diverted for human consumption.	61				
A road must not be constructed within a 100 m radius upslope of a spring in a Community Watershed.	62				
Fertilizer must not be applied within 100 m upslope of the intake to a licensed waterworks.	63				Caused nutrient concentrations to exceed specified limits. Not including spot applications.
Fertilizer must not be applied within 10 m of a perennial stream.	63				
2. Riparian Area Practice Requirements Relevant to Water Quality					
Default <u>stream</u> RMA, RZ, and RMZ widths been followed for each stream class?	47				May depend on active floodplain width
Default <u>wetland</u> RMA, RZ, and RMZ widths must be followed for each wetland class.	48				
Default <u>lake</u> RMA, RZ, and RMZ widths must be followed for each lake class.	49				
Roads are not to be built in an RMA.	50				Unless not doing so causes more sediment-ation
Trees in RZs must not be cut, modified or removed.	51(1)				Nine allowable purposes
Broadcast herbicide applications or grazing for vegetation control (brushing) must not take place in RZs.	51(3)				
Mechanized site preparation, broadcast burning, spacing or thinning must not occur in a RZ.	51(3)				

Continued ...

Appendix B. Checklist of forest practices applicable to water quality required under FRPA (continued).

	<i>Forest Planning & Practices Regulation</i> Section number	Currently satisfactory? and/or	Does the FSP address it or has an alternative strategy been proposed? or	Has Minister granted exemption or alternative?	Defining conditions
Specified minimal basal areas must be retained in RMZs for each riparian class.	52				
Forestry activity must not cause an alluvial fan to be de-stabilized.	54				
All stream crossings must protect the channel and bank immediately above and below the stream crossing.	55(1)				
Any disturbance to the channel and bank at a stream crossing must be mitigated.	55(1)				
3. Soil Disturbance Limits Relevant to Water Quality					
Soil disturbance must not impair the hydrological function of soils (e.g. by compacting soils or increasing soil erosion).	35				Depends on hazard rating & location (Interior or Coastal B.C.)
Landslides caused by forestry activity must not affect water quality.	37				
Debris torrents or other gully processes caused by forestry activity must not affect water quality.	38				
Natural drainage patterns must be maintained during the construction and operation of roads and other access structures.	39				
After a road has been deactivated for 2 years or longer, re-vegetation must prevent soil erosion from causing sediment to enter a water body.	40				
4. Road Requirements Relevant to Water Quality					
All bridges and culverts must be designed to pass the specified return-interval peak flow.	74				Depends on period that bridge/culvert will remain in place
All roads (including bridges, culverts & fords) must be maintained.	79				
The drainage system of the road network must be functional.	79(6)(b)				
For deactivated roads, bridges and culverts must be removed and the road prism stable.	82(1)				Substructures removed only if they affect water quality
All water licensees in Community Watersheds must be notified 48 hours before road construction or deactivation.	84				