FINAL REPORT

EFFECTIVENESS EVALUATION FRAMEWORK: *FOREST PRACTICES CODE* AND DRINKING WATER

Prepared for:

Forest Practices Branch
Ministry of Forests
P.O Box 9513, Stn Prov Govt
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File: 975-50/Water

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Reference: **559-25.01**

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Senior Policy Specialist
Forest Practices Branch
Ministry of Forests
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Victoria, B.C.
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Dear Ms. Webber Atkins:

Re: Effectiveness Evaluation Framework: *Forest Practices Code* and Drinking Water

Summit Environmental Consultants Ltd. is pleased to submit three bound copies and one unbound copy of the final report for the above project. The report proposes an integrated effectiveness evaluation program that includes "on the land" inspections and audits, development and tracking of indicators, and water quality monitoring.

We trust that this completes our assignment to your satisfaction. Please call if you have any questions.

Yours truly,

Summit Environmental Consultants Ltd.

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

EXECUTIVE SUMMARY

Roughly a quarter of B.C. residents obtain their drinking water from surface water supplies outside of the Vancouver and Victoria water systems. Most of these watersheds support multiple uses, and many water users are concerned about the impacts of forestry and range activities on Crown Land on the quality and safety of their drinking water supply. The *Forest Practices Code of British Columbia Act* (FPC) was designed to ensure that forest and range activities do not adversely affect water quality. Now, after implementing and refining the FPC for a number of years, the Ministry of Forests and the Ministry of Water, Land and Air Protection, in cooperation with the Ministry of Health Services, intend to evaluate the effectiveness of the FPC in achieving it's intended goal of protecting drinking water sources. This document presents the proposed framework for review and discussion.

Forestry activities may affect streamflow and runoff patterns; increase the risk of erosion, mass wasting, and sedimentation; alter inputs of organic material and light into stream systems; and alter fluxes of nutrients and ions. Range activities can result in stream sedimentation and may introduce fecal matter to watercourses, which can increase concentrations of bacteria and protozoa. All of these processes have the potential to have a detrimental effect on drinking water quality. These are the reasons why the current FPC includes rules to reduce risks to water resources, as well as additional guidelines for Community watersheds.

Except in B.C., Canadian provinces do not generally consider drinking water a "forestry" issue. Although most provinces are currently revising drinking water policy following several outbreaks of water-borne disease, managing forestry activities is a minor part of source protection plans except in B.C. Much more attention is directed towards intensive livestock agriculture. The apparent lack of forest policy or evaluation programs in other parts of Canada is due to the low proportion of drinking water that is obtained from watersheds on Crown land. Where forests are the source of drinking water, the quality is very good compared to other surface sources. Also, land use activities in forested watersheds elsewhere in Canada generally occur on lower-risk terrain than in B.C., and concerns over forest practices are weighted to impacts on aquatic habitat.

The relationship between forest practices and drinking water is an issue of public debate in the U.S. Pacific northwest, especially Oregon. The federal *Clean Water Act* not only requires States to implement water quality protection programs, it also requires some form of effectiveness evaluation (EE). This must include some linkage between the use of "on the land" Best Management Practices (BMPs) and actual "in the stream" water quality. In Oregon the Forest Practices Monitoring Program has been implemented to evaluate effectiveness through "scientifically valid study designs". Monitoring for EE includes field inspections of BMP compliance, "desired future condition" evaluations, and water quality monitoring. Other States have generally put less effort into EE but there are a series of EPA-sponsored BMP demonstration projects. As in Canada, water quality from forested watersheds is very good and other land uses are higher priority for BMP evaluation.

Criteria and indicators (C&I) have become key components of evaluating progress towards sustainability in the forest sector, and water-related C&I have been developed. The Canadian Council of Forest Ministers and Montreal Process C&I related to water tend to be rather broad (i.e. applied at a provincial scale) and are not sensitive enough for drinking water EE. In B.C. the Arrow IFPA is working with UBC researchers to develop a set of local C&I for sustainable forestry, and has begun a pilot project to test the C&I at the landscape unit scale in the Slocan Valley. The goal is to evaluate the suitability of indicators to serve as "results" in a results-based FPC.

In general, EE programs include: 1) inspections and audits of forest and range practices (including assessments and management systems as well as actual field practices); 2) tracking of criteria and indicators; and 3) water quality monitoring to determine the relationship between forest/range practices and water quality at the intake. Each of these general approaches has some limitations that would make it difficult to draw firm conclusions about policy effectiveness, especially in the context of a results-based Code. Therefore we recommend that the drinking water EE framework for 2002 and onwards be comprised of an integrated program that includes three major elements:

1. "On the land" inspections and audits of BMPs with the results maintained and tracked in a central database. Inspections and audits would be completed relatively frequently and in all Forest Districts;

2. Development and tracking of a set of indicators in selected Forest Districts (i.e. those with ≥10 Community watersheds). The recommended indicators are:
   - Kilometres of new road built in a watershed within the last three years;
   - Equivalent clearcut area (ECA) above 20%;
   - Kilometres of active roads within 50 m of watercourses and number of road crossings on 1:20,000 scale maps;
   - Lengths of road on Class IV and V terrain;
   - Proportion of stream length with clearcut riparian harvest;
   - Number of livestock "animal units" (range and farm) in a watershed;
   - Number of water intakes and the total licensed water volume; and
   - Number of boil water advisories.

   All of the recommended indicators can be calculated in the office from maps and silvicultural files, or from data that is available to the public. The indicators would be compiled and reported every three years; and

3. Water quality monitoring to evaluate BMP effectiveness and refine BMPs. This should be at least at the scale of a demonstration project with two or more watersheds in B.C. However, a demonstration project would not likely provide sufficient assurance to a broad range of stakeholders that the Results-based Code (RBC) is protecting water quality. For this reason a basic trend and impact assessment program is recommended for at least three regions. Such a program would be consistent with programs in Alberta and the U.S. An experienced statistician should be involved throughout the design and implementation of any monitoring program.

All of the above future EE programs would benefit from first reviewing regional summaries of FRBC-funded Water Resource Inventory Program reports, where available, to evaluate drinking water protection under the 1995-2002 FPC. Such a review is also critical for developing monitoring program design. If they are unavailable in certain areas then summaries should be completed before proceeding with a design. Completion of regional summaries will also help prioritize watersheds for all three levels of the future effectiveness evaluations.

Finally, the Province should seek input on the development and design of the monitoring and public reporting programs that are to be implemented by water purveyors under the *Drinking Water Protection Act*. Use of this data for effectiveness evaluation of watershed policy has the potential to be very cost effective compared to developing stand-alone monitoring, as long as the study designs are appropriate for trend analysis.

ACKNOWLEDGEMENTS

Summit Environmental Consultants Ltd. thanks those people who took the time to answer our questions and provide reference material for this report. In particular we thank Dr. Paul Adams (Oregon State University), Liz Dent (Oregon Department of Forestry), Doug Fitting (Idaho Department of Lands), and Paul Jeakins (Arrow IFPA).

The project was directed by Garth Webber Atkins, R.P.F., of the B.C. Ministry of Forests, Forest Practices Branch. The report was prepared by Dr. Hugh Hamilton. P.Ag. with input from Dr. Michael Paine (Paine, Ledge and Associates) and David Hayward, R.P.Bio. Editorial and technical review was provided by Dr. Brian Guy, P.Geo., P.H.

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

Roughly a quarter of British Columbians obtain their drinking water from surface water supplies outside of the Vancouver and Victoria water systems. Most of these watersheds support multiple uses, and many water users are concerned about the impacts of forestry and range activities on the quality and safety of their drinking water supply. The *Forest Practices Code of British Columbia Act* (Forest Practices Code or FPC or "the Code") was designed to ensure that forest and range activities do not adversely affect water quality. Now, after implementing and refining the Code for a number of years, the Ministry of Forests and the Ministry of Water, Land and Air Protection, in cooperation with the Ministry of Health Services, intend to evaluate the effectiveness of the FPC in achieving it's intended goal of protecting drinking water sources.

In January 2002 the Ministry of Forests (MOF) Forest Practices Branch, in association with the Ministry of Water, Land and Air Protection (MWLAP), retained Summit Environmental Consultants Ltd. to develop a proposed framework for evaluating the effectiveness of the *Forest Practices Code* in protecting drinking water quality. The framework is to be used to evaluate the effectiveness of the FPC since it came into effect and in its future more results-based form.

1.2 PROJECT OBJECTIVES

The general objective of this study is to develop a proposed framework that would provide the basis for planning, organizing, scheduling, and conducting evaluations of the effectiveness of the FPC in protecting drinking water. The Forest Practices Branch (2001) defines this type of evaluation as "assessing forest practices to determine the level at which they meet the intent of the policies that guide them or assessing the policies for their ecological, social, or operational appropriateness." The proposed framework is to be suitable for review by stakeholders, leading towards establishment of a working framework. Specific objectives are to:

1. Assemble information on current and proposed approaches to surface water quality protection effectiveness evaluations in jurisdictions outside B.C., including other Canadian provinces, the United States, and other countries;
2. Complete a critical review of the approaches used elsewhere, addressing evaluation design, spatial and temporal context, types of forest and range practices evaluated, and applicability to B.C.;
3. Consider the utility of the reviewed approaches in a "results-based" FPC;
4. Develop a proposed framework for effectiveness evaluation, including a set of appropriate measures of effectiveness and recommendations on appropriate levels or scales of evaluations;
5. Prepare a draft report covering both the jurisdictional review and the framework development; and
6. Prepare a final report, addressing any comments and edits received regarding the draft report.

2.0 METHODS

2.1 LITERATURE AND INTERNET SEARCH

A literature search was initiated by commissioning a search of abstracts and databases by the University of Victoria library. The sources that were searched included Biological Abstracts, Tree CD, Web of Science, Environmental Knowledge Online, Agricola, and the university's own catalogue. The key words and phrases that were used in the search included effectiveness evaluation, drinking water, forest policy, watershed management, water supply, water quality, forest practices, forest best management practices, forest BMPs, range management, range policy, and drinking water protection. The commissioned search was supplemented by a search of the catalogues of the Universities of British Columbia and Alberta using the ProCite bibliographic software. Finally, a search of the catalogue of Okanagan University College was completed on-site.

The literature search resulted in obtaining about 150 references, of which about 50 were considered somewhat relevant to this study. Of those, about 20 are cited in this report. The majority of the references that have not been included were examples of research on the effects of forestry or range activities on water quality, but were not considered directly relevant to effectiveness evaluation.

An internet search was also conducted using the same key words as used for the literature search. The search employed the Google and Yahoo search engines. In addition, relevant web sites from federal (Canada and U.S.), provincial, and U.S. state government agencies were searched along with web sites from several other countries and international organizations (e.g. United Nations Environment Program).

2.2 INTERVIEWS

The literature and web site searches were supported by telephone interviews with persons working in the fields of forest hydrology, drinking water supply, and forest policy. The purpose of the interviews was to obtain information on on-going research and policy initiatives. The list of people contacted is provided in Table 1.

3.0 OVERVIEW OF POTENTIAL FORESTRY & RANGE EFFECTS ON WATER QUALITY

Forest harvest and associated activities may affect streamflow and runoff patterns; increase the risk of erosion, mass wasting, and sedimentation; alter inputs of organic material and light into stream systems; and alter fluxes of nutrients and ions (MacDonald et al., 1991; Calder, 1993). All of these processes have the potential to have a detrimental effect on drinking water quality. Range activities can result in disturbance to stream banks and riparian areas, which can lead to sedimentation, and introduce fecal matter to watercourses, which can increase concentrations of bacteria and protozoa (Buckhouse, 2000). Table 2 provides a brief outline of the groups of water quantity and quality variables that are typically

Table 1. Persons contacted for information.

Name	Position	Affiliation	e-mail
Jamie Wuite	Water quality specialist	Alberta Ministry of Agriculture	Jamie.wuite@gov.ab.ca
Paul Jeakins	Manager	Arrow Innovative Forest Practices Agreement Group	paulj@kgis.com
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Dr. Rita Winkler	Research Hydrologist	BC Ministry of Forests, Kamloops Region	Rita.Winkler@gems7.gov.bc.ca
Dave Toews,	Research Hydrologist	BC Ministry of Forests, Nelson Region	toews@netidea.com
Dr. Robin Quenet	Research Scientist	Canadian Forest Service, Pacific Forestry Centre. Victoria	rquenet@pfc.cfs.nrcan.gc.ca
William Anderson	Research Associate/Manager	Canadian Water Network (a national Centre of Excellence, housed at University of Waterloo)	Wbanderson@uwaterloo.ca
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Dr. Paul Adams	Professor & Extension Specialist	Oregon State University	Paul.adams@orst.edu
Gordon Will	Engineer	Saskatchewan Environment & Resource Management	GWill@serm.gov.sk.ca
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Dr. Bruce MacLock,	Network Manager	Sustainable Forest Management Network (a national Centre of Excellence, housed at University of Alberta)	Bmaclock@gpu.srv.ualberta.ca
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Randy Acker		Washington Department of Natural Resources	Randy.acker@wadnr.gov

affected by forest and range practices in B.C. and that could be included in forest water monitoring programs. Additional detail is provided in Appendix A.

4.0 SUMMARY OF APPROACHES USED ELSEWHERE

4.1 CANADIAN PROVINCES

4.1.1 Drinking Water & Forested Watersheds Elsewhere in Canada

Forest management and water management are both primarily the responsibility of the provinces in Canada, and most provinces have policies and programs that address water resources in forested watersheds. In general, these have more to do with the protection of aquatic life than with drinking water quality. This is because most provinces obtain only a small proportion of their total drinking water supplies from Crown land watersheds, and have not felt the need to institute drinking water-specific policies for forestry. This may change soon as most Canadian provinces are currently reviewing their drinking water policies in reaction to the Walkerton tragedy.

In Alberta there are no current programs that assess drinking water quality protection in forested watersheds (Wuite, pers. comm., 2002). However, some communities do obtain water from watersheds with considerable cattle grazing and other livestock-related farming activity. Most of the concerns are in areas that are primarily private land rather than Crown land. Recently the Alberta Department of Agriculture, Food and Rural Development initiated a long-term stream monitoring program as part of the Alberta Environmentally Sustainable Agriculture (AESA) program. Twenty-three watersheds were selected for long-term trend monitoring beginning in 1997, grouped into three levels of agricultural intensity (low, moderate, and high). The monitoring is intended to track changes in water quality as agricultural activity grows and as farm practices change (Alberta Agriculture, 2001). The AESA program also includes Best Management Practice (BMP) education and pilot projects.

Table 2. Summary of potential effects of forestry and range practices on drinking water quality.

Water Quality Variable	**Forestry**	**Range**
Discharge	• Increased magnitude of peak flows, thus increasing bank erosion • Changed timing of peak & low flows • Increase water yield	• Negligible potential for direct effects.
Suspended Sediment (Turbidity & Total Suspended Solids)	• Increased erosion & sediment delivery from roads & trails • Increased bank erosion.	• Trampling of banks and riparian areas by livestock.
Temperature	• Increased mean and maximum daily water temperature through loss of riparian vegetation.	• Slows re-growth of riparian vegetation in areas previously harvested.
Coliform Bacteria	• Negligible potential for direct effects. Increased sediment loads may increase bacteria transport.	• Livestock may directly introduce fecal matter to streams & riparian areas.
Parasites (e.g. *Giardia*, *Cryptosporidium*)	• Negligible potential for direct effects. Increased sediment loads may increase (oo)cyst transport.	• Livestock may directly introduce fecal matter to streams & riparian areas.
Nutrients	• Small "first flush" after harvest in most cases. • Fertilization and slash burning in silviculture could increase concentrations.	• Livestock may directly introduce fecal matter to streams & riparian areas, which may increase nutrient loads
Dissolved Solids & Hardness	• Increased infiltration in cutblocks transports ions to watercourses; usually a small "first flush" effect.	• Negligible potential for direct effects.
Organic Carbon & Colour	• Small potential for direct effects – machine traffic on organic soils or increased infiltration. • Spills from machinery may introduce petroleum hydrocarbons.	• Trampling of organic soils may increase total organic carbon (TOC) or colour.
Metals	• Negligible potential for direct effects unless soils have very low pH.	• Negligible potential for effects.

In Saskatchewan, only about two to three percent of surface water users obtain their water from watersheds that are non-agricultural (Will, pers. comm., 2002). The recently formed Saskatchewan Watershed Authority will be responsible for watershed management plans, including issues related to agricultural practices.

Drinking water from forested watersheds does not have any specific protection legislation or policies in Ontario (Anderson, pers. comm., 2002) and water quality is not generally viewed as a "forestry" issue (Bryan, pers. comm., 2002). Beef and dairy cattle production takes place almost exclusively on private land. Programs to protect water quality in agricultural areas have been implemented sporadically over the years, including loans and grants for farmers to implement BMPs like riparian buffers and manure storage and treatment systems. University of Waterloo researchers are currently studying the effectiveness of the Region of Waterloo's Rural Water Quality Program in reducing pathogen risks to municipal water supplies. The Ontario provincial government is currently preparing the Nutrient Management Act (Bill 81) that would set and enforce standards for manure management on farms.

In Quebec there are no specific policies or evaluation programs related to drinking water from forested watersheds or rangelands (Munson, pers. comm., 2002). In New Brunswick, about 40% of the population obtains its drinking water from surface sources. As of 2001 the *Watershed Protected Area Designation Order* was implemented. This order defines what can take place within each of three zones within a designated municipal watershed: 1) the watercourse, 2) a 75 m setback zone, and 3) the rest of the basin (New Brunswick Department of Environment & Local Government, 2002). The only forest practices mentioned in the *Order* are select cut and clearcut harvest, with rules on minimum distances from the watercourse. There is also a supporting program of voluntary BMPs for forestry and agriculture. The *Order* makes no mention of monitoring or other measures of effectiveness.

About 88% of the population of Newfoundland and Labrador obtain their drinking water from surface sources (Government of Newfoundland and Labrador, 2001), and there are more than 240 "Protected Water Supply Areas." Increased source protection measures are currently proposed, including a geographic information system (GIS) to monitor watershed activities (i.e. logging, quarrying) and ensure that they do not "compromise the integrity of drinking water sources."

Searches of the web sites of the remaining Canadian provinces not discussed above (Nova Scotia, Prince Edward Island, and Manitoba) could find no information regarding forest and range management with respect to drinking water.

To summarize, the apparent lack of forest policy or evaluation programs in other parts of Canada is due to:

- The low proportion of drinking water that is obtained from Crown land watersheds. Where forests are the source of drinking water, the quality is good compared to water from other surface sources, and most pre- and post-Walkerton initiatives are aimed at higher-risk land use activities; and
- Land use activities in forested watersheds generally occur on lower-risk terrain than in B.C., and concerns over forest practices are heavily weighted to direct impacts on aquatic and riparian habitat rather than on water column effects.

As noted above, some provincial water agencies in Canada are actively reviewing their policies. Additional watershed protection measures, and associated effectiveness evaluations, are possible outcomes of those reviews.

4.1.2 Overview of Canadian Criteria & Indicator Programs

An indicator is a piece of evidence or signal that tells us about conditions around us (Environment Canada, 2000). Interest in indicators of environmental quality began in Canada in the 1970s, but serious development work began in the early 1990s under the federal Green Plan. An Environment Canada (1991) report from that time stated that in a time of "information overload" there was a need for "authoritative, easy-to-use indicators of environmental performance and progress toward sustainable development."

Forest Sector

In the forest management sector, criteria and indicators (C&I) have become key components of evaluating progress towards sustainability (see Glossary for definitions – Section 13.1). The "Montreal Process" of 1994 and the follow-up 1995 "Santiago Declaration" committed the temperate and boreal forest nations, including Canada, U.S. and Mexico, to use C&I to provide a common understanding about what is meant by "sustainable forest management" (Woodley et al., 2000). The Montreal Process originally grew out of the C&I program of the Canadian Council of Forest Ministers (CCFM), but the Montreal Process and CCFM each eventually developed sets of C&I that do not completely overlap. The CCFM system is hierarchical, with principles (P) at the top level, followed by criteria (C) and indicators (I). CCFM principles, criteria, and indicators relevant to water quality are listed in Table 3.

Woodley at al. (2000) completed an independent review of North American C&I, including both office analyses by a group of experts and detailed field studies in the Boise National Forest in Idaho. The review was part of a larger review conducted by the Centre for International Forestry Research (CIFOR) that included tests in Europe, Africa, and Asia. The North American review evaluated the CCFM C&I as well as C&I developed by CIFOR, CIFOR's basic assessment guide (CIFOR-BAG) for human well-being, and a number of new ones specifically identified for the North American test. Each criterion and indicator were either accepted, accepted with modifications, or combined with another indicator because of duplications. Table 3 includes the result of the CIFOR review of the CCFM C&I.

Reasons for the decision are provided in Appendix K of the Woodley et al. (2000) report. Chemical/physical measures (Indicator 3.1.3) were rejected because of 1) the need for a sophisticated, potentially long-term monitoring program, 2) high costs for small landowners,

Table 3. CCFM criteria and indicators relevant to water quality and CIFOR review results.

Number	Description	CIFOR Review Result
3.0 (P)	Conservation of soil and water resources	Combined with "Maintenance of ecological integrity"
3.1 (C)	Physical environmental factors	Accepted as key criterion
3.1.1 (I)	Percentage of harvested area having significant soil compaction, displacement, erosion, puddling, loss of organic matter, etc.	Accepted with modifications
3.1.3 (I)	Water quality as measured by water chemistry, turbidity, etc.	Rejected
3.1.4 (I)	Trends & timing of events in stream flows from forest catchments	Accepted
3.2 (C)	Policy & protection forest factors	Rejected as abstract
3.2.1 (I)	Percentage of forest managed primarily for soil and water protection	Rejected – covered by other indicators
3.2.2 (I)	Percentage of forested area having road construction and stream crossing guidelines in place	Rejected – covered by other indicators

(P) principle (C) criteria (I) indicator

Source: Woodley et al. (2000).

3) lack of existing data, and 4) inconsistency of data collection in different North American jurisdictions. Trends/timing of stream flows (Indicator 3.1.4) was accepted as relevant, but considered impractical due to the need for long term trend monitoring, unless predictive models can be developed as a surrogate.

In B.C. the Arrow Innovative Forest Practices Agreement (Arrow IFPA) Group is working with UBC researchers to develop a set of local C&I for sustainable forestry, and has begun a pilot project in the Lemon Landscape Unit to test the indicators in the Slocan Valley (Arrow IFPA, 2001). The goal is to evaluate the suitability of the indicators to serve as the "results" in a results-based FPC. Two alternative sets of indicators are under consideration. The first is based on chemical/physical water quality and quantity data since monitoring has been conducted in two of the landscape unit's streams. The second is comprised of indicators of land use pressures on water quality.

Other C&I Initiatives

At the federal level, Environment Canada currently runs the National Environmental Indicator Series that uses statistics aggregated at the national level to show trends for 18 environmental issues (Environment Canada, 2000). The only water indicators pertain to municipal water use, i) daily municipal water use, ii) metered residential water use, and iii) municipal population served by wastewater treatment. None of the indicators include physical, chemical, or biological measures of water quality. The federal government also coordinates the Ecological Monitoring and Assessment Network (EMAN) that is a network of monitoring and research sites that carry out long-term studies. The network includes federal and provincial government research centres, universities, and volunteer groups, some of which undertake water-related work (see www.cciw.ca/eman).

In British Columbia, MWLAP has developed two general water quality indicators:

1. Trends in water quality are based on long term monitoring and are compared to water quality guidelines or objectives to determine their environmental significance; and

2. The Provincial Water Quality Index (WQI) translates whether water quality guidelines or objectives are achieved into ratings from “poor” to “excellent” and a numerical score between 0 for best water quality and 100 for worst water quality (MELP, 2000).

Both indicators are based on the provincial Water Quality Guidelines (WQG) or on site-specific Water Quality Objectives (WQO), where they exist. The WQI is customized for each water body, depending on the number of objectives or guidelines that are of interest. This makes the direct comparisons of streams somewhat problematic. The WQI has been calculated for about 125 water bodies in B.C.

4.2 UNITED STATES

4.2.1 Federal Initiatives

Water quality protection issues in the United States are primarily driven by the *Clean Water Act* (1972). Its goal is to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” (Bauer and Burton, 1993). An amendment in 1987 (Section 319) placed more emphasis on non-point source pollution than did the original act, which emphasised point-source pollution. Section 319 gives primary responsibility for non-point source pollution prevention to the states and all states eventually developed non-point source management programs. However, much of the guidance for program implementation, monitoring, and evaluation comes from the federal United States Environmental Protection Agency (EPA).

The emphasis of the state non-point source (NPS) programs is the development and implementation of Best Management Practices (BMPs), as required by Section 208 of the *Clean Water Act*. The EPA defined BMPs (within regulations for implementing Section 208) as:

> “A practice or combination of practices that are determined … to be the most effective, practicable (including technological, economic and institutional considerations) means of

preventing or reducing the amount of pollution generated by non-point to a level compatible with water quality goals."

Specific BMP examples are described in Section 6.0. The EPA and U.S. Forest Service have produced a plethora of documents to assist the states in evaluating the success of forest and range BMPs in avoiding or reducing NPS pollution (e.g., MacDonald et al., 1991; Bauer and Burton, 1993; Dissmeyer, 1994; Tetra Tech Inc., 1997a, 1997b; EPA, 1997). The recommended evaluation programs include two major elements:

1. "On-land" monitoring to determine if BMPs have been implemented; and
2. Monitoring of water quality (including physical, chemical, biological, and habitat variables) to determine the linkage between the BMP and the resources they are intended to protect (Dissmeyer, 1994).

Discussion of state initiatives to implement and evaluate the effectiveness of BMPs is provided in the next section. The U.S federal government funds a wide range of water monitoring programs for a variety of objectives, and steps have been taken recently to improve statistical designs to provide shareable information and optimise costs (Olsen et al., 1999).

The U.S. federal government is also active in criteria and indicator development. The EPA's Environmental Monitoring and Assessment Program (EMAP) includes efforts at regional customization. Most relevant to B.C. is the Western Surface Waters Pilot, a five-year research project aimed at developing monitoring tools (indicators, study designs, and estimates of reference conditions) to produce unbiased estimates of the ecological condition of surface waters in the western U.S. (U.S. EPA, 2000a).

A recent EMAP report provides guidelines for evaluating indicator suitability, using three case studies drawn from estuarine water quality studies (Jackson et al., 2000). The report also gives a brief history of the *Pressure-State-Response* (PSR) conceptual framework for environmental indicators developed by the Organization for Economic Cooperation and Development (OECD). The OECD framework includes indicators of human activities (pressures), environmental condition (state), and resulting societal activities (response). (OECD, 1993). The EPA used the framework to develop its indicators of “clean water and safe drinking water” (EPA, 1996) and added “effects” to the framework (i.e., PSR/E). The EPA’s approach is to guide the customization of indicators to meet the specific goals of individual environmental assessments, rather than developing a generic set.

4.2.2 State Initiatives

American BMP programs are a mixture of rules, minimum standards, licensing requirements, incentive programs, and voluntary guidelines. BMP effectiveness evaluation includes reviews of forest development plans to ensure that BMPs are included, field inspections and audits, and water quality monitoring. The field audits are generally done by interdisciplinary teams (Dent and Robben, 1999). Table 4 provides a summary of BMP programs in eight U.S. states, including the Pacific Northwest states that are biophysically similar to B.C.

According to Ice et al. (1997), there has been scepticism about the effectiveness of State non-point source control programs in forestry since they began in the 1970s. Surveys completed in the mid-1990s, however, have found high levels of compliance with BMP implementation guidelines, generally 85% or higher with an improving trend. At the time that the paper was published, not all states had gone beyond compliance audits to test BMP effectiveness through other means such as monitoring. However, the authors note that there appeared to be a merging of regulatory and non-regulatory elements in individual states. States with rules-based BMP programs were increasing voluntary stewardship programs, while states with non-regulatory programs were adopting some rules. An example is Montana where there are laws mandating forest practices within riparian areas, but most other BMPs are non-mandatory guidelines (Table 4).

In Oregon most of the drinking water for the State’s largest cities comes from forested watersheds (Oregon Forest Resources Institute, 2001; Adams and Taratoot, 2001), and

Table 4. BMP program summary for selected U.S. states.

State	BMP Program Components	Effectiveness Evaluation
Washington	• *Forest Practices Act* includes rules for BMPs	• Multidisciplinary audit teams evaluate rule compliance
Oregon	• BMPs are mandated by rules under the *Oregon Forest Practices Act*	• The Forest Practices Monitoring Program evaluates effectiveness through "scientifically valid study designs" • Has set guidelines for the number of audits (sample size) needed to draw conclusions about rule effectiveness
Idaho	• Idaho *Forest Practices Act* sets minimum standards (rules) for forest practices	• Audits done annually by Department of Lands by six-member audit teams. Also done every four years by Dep't of Environmental Quality and published. • Water quality monitoring programs under *Clean Water Act* included assessments of land use in the watershed.
Montana	• Water quality protection program provides voluntary BMP standards. In riparian areas there are also regulatory standards.	• BMP audits assess whether BMPs are being applied and if they are effective. Done bi-annually. • No formal supporting water quality monitoring.
California	• The *Z'Berg-Nejedly Forest Practices Act* requires BMPs with Timber Harvesting Plans.	• California Department of Forestry conducts an inspection program to ensure compliance.
Utah	• BMPs are voluntary guidelines.	• There are current five watersheds being monitored for water quality to evaluate BMP effectiveness. Includes chemical, physical & biological monitoring.
Maine	• BMPs are voluntary guidelines.	• A procedure for monitoring implementation is in development.

Source: www.usabmp.net and contacts with State agencies.

Oregon appears to be the State with the most thorough EE program. The Forest Practices Monitoring Program (FPMP) has been implemented to evaluate effectiveness through "scientifically valid study designs" (see http://www.odf.state.or.us/FP/fpmp). A set of monitoring questions were developed that guide monitoring to determine if forest practice rules are effective, implemented properly, and based on accurate assumptions. The questions were developed with input from the public and interest groups. Monitoring for effectiveness includes field inspections of BMP compliance (e.g., Dent and Robben, 1999; Dent, 2001), "desired future condition" evaluations (Oregon Department of Forestry, 2000), and water quality monitoring (Dent and Robben, 2000). The audit program has also included development of a valid study design, determining, for example, that inspections of about 100 stream crossings are needed to evaluate BMP compliance across the State.

In Idaho the Department of Lands conducts annual internal forest practice audits that evaluate how effective BMPs are at protecting the designated water quality standards for a given waterbody (Fitting, pers. comm., 2002). These are in addition to the regular operational audits (about 3,500/yr) done by Idaho Department of Lands pertaining to the rules of the Idaho *Forest Practices Act*. The results of the annual audits are not published, but every four years a State-wide audit of BMP effectiveness is conducted at "arms length" by the Idaho Department of Environmental Quality (DEQ). Water quality monitoring is being conducted by the Idaho DEQ along with watershed assessments, as part of Total Maximum Daily Load allocations. The monitoring results are compared against the State water quality standards for salmonid spawning and rearing, which are more stringent than the State's drinking water standards.

Other States have generally put less effort into EE, placing most emphasis on audits and inspections of BMPs. In Montana all evaluation of forest practices and BMPs is done on-site during an audit assessment of whether sediment is entering streams or draws (Ethridge, pers. comm., 2002). A team that includes a forester, fisheries biologist, soil scientist, hydrologist, roads/engineering specialist, and two community members does audits. The audit teams go through a calibration process and the audits are done following standard protocols, including reporting.

There are also a series of EPA-sponsored BMP demonstration projects. Like Canada, water quality from forested watersheds is perceived to be relatively very good and other land uses are higher priority for BMP evaluation.

4.3 EUROPE, ASIA AND THE SOUTH PACIFIC

Finland has recently revised both its *Water Services Act* and its *Forest Act*. As the lead water resource authority, the Finnish Ministry of Agriculture and Forestry manages mainly "by result", including results agreements and monitoring of results (Finnish Ministry of Agriculture and Forestry, 2001). Like most producers of forest products, Finland is developing a certification system for sustainable forest management and is developing its own set of criteria and indicators. Their water-related indicators are water protection in harvesting and site preparation, phosphorus and nitrogen load on water systems caused by logging, water protection plans in drainage projects, and area of forest land in protected forests (Suoheimo, no date). Documents that were reviewed contained no information on how the indicators are compiled and tracked, and did not specifically mention drinking water. Water management issues addressed in the *Forest Act* reflect the boreal forest landscape. For example, drainage of peatlands prior to harvest must be done with care for water quality.

Information for this study was also compiled for Sweden, Germany, and New Zealand, and searches were completed through the web sites of several international organizations. No direct references to drinking water from forested catchments were found. Inquiries regarding international policy are continuing and will be included with the final report.

4.4 IS B.C. A SPECIAL CASE?

There are a number of biophysical, social and political factors that must be considered in adapting effectiveness evaluation (EE) approaches from elsewhere to B.C. The first is the very wide variation in climate and terrain, ranging from mountainous areas with very high precipitation to more level plateaus with significant summer soil moisture deficits. This makes it difficult to have a single approach and suggests that would require some customization by region.

For example, the majority of the communities in the southern Interior that rely on surface water sources are located in valley bottoms. In the Thompson-Okanagan region most of the catchment area of some Community watersheds is rolling upland plateau with many small lakes and wetlands, and dams have been routinely built on plateau lakes to increase storage. However, the water system intake is typically located on the valley sides and the stream channels above the intake are incised through erodible glacial sediments. Potential effects on water quality of land use activities on the plateau are largely mitigated by the capacity of the watershed to store water and sediment, but land use on the valley sides has greater potential to directly impact water quality[1].

In contrast to the plateau watersheds with high storage capacity, the steeply incised watersheds in the Coastal and Columbia Mountains of B.C. respond relatively quickly to runoff-generating processes. As a result, water and sediment is routed quickly from hillsides to stream channels. Sediment from a landslide within the watershed can reach the intake within a few hours, but be flushed from the system after a few days. In general, watersheds with this high routing capacity are more sensitive to poor land use practices than watersheds with high natural storage. EE programs will need to recognize differences in the sensitivity of watersheds to land use change.

Socially, the high proportion of water supplies obtained from Crown Land watersheds in B.C. compared to other jurisdictions provides some advantages, principally the opportunity to set and manage for multiple objectives, i.e. water supply and forestry, range, and recreation. This creates the potential for a coordinated approach to EE. Another unique factor in B.C. is the

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[1] In many plateau watersheds most of the natural sources of sediment come from the area below the plateau, where the channel cuts through glacioflucial and glaciolacustrine deposits. In some cases the intake for the water system has been moved to the plateau and a pipeline built to deliver the water to users on the bottom, thus avoiding these sediment sources. The considerable expense of doing this outweighs the costs of increased treatment.

sheer number of surface water users, especially single-household systems and systems that supply only a few households. Under the B.C. *Water Act*, households do not need a water licence to obtain water from a stream if it is used only for domestic purposes. As a result, there are numerous intakes on streams in rural areas that are not registered.

Politically, the United States has in the *Clean Water Act* a strong piece of federal legislation that directs water policy at the State level and that requires some form of EE. The States then customize their own approaches. There is no equivalent legislation in Canada. Although the federal Canadian *Fisheries Act* has some authority to limit water pollution from "deleterious" substances it applies only to fisheries and there is no formal EE program.

5.0 OVERVIEW OF OPTIONS FOR EFFECTIVENESS EVALUATION

It is important to consider what constitutes policy "effectiveness", since there are difference between demonstrating that steps have been taken to fulfil the intent of a given policy and demonstrating that a policy objective has been met in a scientifically defensible manner. Water quality in forested watersheds is highly variable, both spatially (between watersheds) and temporally (from daily to between years). In many cases effects on water quality from land use activities (i.e. non-point source pollution) is small compared to the natural temporal variation, and demonstrating statistically significant changes in response to a policy requires careful experimental design and a commitment to monitor for at least several years. On the other hand, demonstrating intent could be accomplished by having a management system is in place that ensures that state-of-the-art techniques are used to minimise risk and there is a commitment to continual improvement. This is the approach used in Environmental Management System (EMS) certification programs such as the ISO 14001 registration.

Sections 6.0 through 9.0 review possible approaches to drinking water protection effectiveness evaluation in B.C. Section 6.0 discusses "on the land" BMP monitoring and Section 7.0 describes the design of "in the stream" water quality monitoring programs. Section 8.0 summarizes potential indirect indicators of water quality, divided into indicators of pressure on water resources (Section 8.1) and inventories of non-water column effects that could indicate effects on water quality. Section 9.0 outlines possible human response indicators. The recommended framework for drinking water protection EE is presented in Section 10.0.

6.0 MONITORING OF BEST MANAGEMENT PRACTICES

6.1 WHAT IS A BMP?

The term Best Management Practice (BMP) is used in both Canada and the United States to describe tools, procedures, or systems that avoid or reduce non-point source pollution. In the U.S., Section 208 of the *Clean Water Act* requires states to develop area-wide (watershed or regional) water quality management plans that includes BMPs. Eventually BMPs came to include not only specific practices (i.e. road construction standards) but also operational and maintenance procedures, scheduling, and the development of systems to ensure implementation (Ice and Whitmore, 2001). They apply not only to forestry and range, but also to urban non-point pollution and agriculture.

In B.C., the term BMP is used in guidebooks developed as part of *the Forest Practices Code*. The Riparian Management Area Guidebook (MOF/MELP, 1995a) identifies a series of BMPs for each riparian class, active floodplains, and large rivers. Some are quite specific (e.g. "retain a minimum of 50% of the trees within 20 m …") while others refer to general principles. Some guidebooks do not use the term BMP, but nevertheless provide guidance on techniques to reduce risks to water quality. For example, the Forest Road Engineering Guidebook (MOF/MELP, 1995b) and the Community Watershed Guidebook (MOF/MELP, 1996) both identify specific practices intended to minimize risk of effects on water quality. To date, mandatory practices under the FPC, such as riparian reserve widths, have not been called BMPs (Tschaplinski, pers. comm., 2002). The term has been used to describe recommended approaches that are not legally enforceable.

Table 5 lists a number of BMPs applicable to avoiding or minimizing water quality hazards from forest and range activity. The list is not exhaustive since BMPs can be developed or customized to meet site-specific conditions.

6.2 APPROACHES TO BMP MONITORING

There are two general approaches to monitoring the effectiveness of BMPs:

1. Inspection of the BMPs in the field, to evaluate whether or not they have been implemented and implemented correctly; and
2. Monitoring water quality in watersheds where BMPs have been implemented.

This section discusses the first approach. The second approach is addressed in Section 7.0 below. As noted earlier, under the *Clean Water Act*, U.S. states must connect BMPs to water quality goals, meaning that they must do some water quality monitoring to confirm the on-site evaluation of BMP effectiveness.

Prior to evaluating BMPs it will be necessary for British Columbia to define them and develop guidelines, possibly with some customization for drinking water protection. This should be straightforward since the existing FPC guidebooks already contain many BMPs (even if they are not identified with this terminology). Once defined, decisions will have to be made whether they are mandatory province-wide, selectively mandatory (e.g. as a condition of approval of a Forest Development Plan or cutting permit), or voluntary (see Section 10.0).

Table 5. Examples of water quality-oriented Best Management Practices in forested watersheds.

Silviculture & planning	• Watershed assessments to characterize watershed sensitivity and prescribe specific BMPs • Appropriate riparian buffer design (minimum widths, tree retention in RMAs, etc.) • Appropriate fertilizer use
Roads	• Correctly sized and installed drainage structures and ditches • Adequate cross-drain frequency • Maintain natural drainage patterns • Seeding/vegetating cut and fill slopes • Scheduling of bridge/culvert installation to within "work windows", low flow periods, and dry weather • Grading surfaces only as often as minimally possible • Appropriate designs to pass debris flows, etc. at crossings (including alluvial fans, etc.) • Minimizing the number of stream crossings
Harvesting	• Scheduling blocks so that approval for new blocks is contingent upon successfully implementing BMPs in previous blocks • Minimizing ground disturbance on steep terrain • Proper use, storage, and disposal of petroleum products
Deactivation	• Scheduling to deactivate roads as soon as possible • Completing post-deactivation inspections and maintenance
Range	• Fencing riparian areas • Appropriate schedules within Range Permits • Cattle watering system designs • Setback minimums for salt blocks, corrals, etc. • Restricting cattle access close to intakes

Sources: Lynch and Corbett (1990), Smallidge and Goff (1998), MOF/MELP (1995a; 1995b; 1996), and Campbell and Bawtree (1998).

Field evaluations of effectiveness could include the following:

- Completion and filing of BMP implementation reports by forest licensees and range permit holders, signed by a registered professional where relevant;
- Regular inspection of BMPs by Ministry of Forests staff;
- Audits by the Forest Practices Board or MOF; and/or
- Broader-scale (i.e. Forest District or Region) evaluations completed at regular intervals (e.g. every three years).

A data collection and management system would be necessary to track the results and enable conclusions to be drawn about BMP implementation effectiveness at a Forest District, Forest Region, or provincial scale.

6.3 ADVANTAGES AND DISADVANTAGES OF FIELD BMP MONITORING

The principal advantages of field-based BMP monitoring are:

- Inspections can take place during implementation or shortly afterwards, thus allowing corrective measures to be taken quickly if there is a problem;
- It should be possible to develop simple, objective criteria for determining if BMP implementation is correct;
- Field monitoring provides a "front-line" indication of appropriate forest practices;
- The frequency of inspections and requirements for corrective action can be based on a risk assessment framework (i.e. more inspections required in high hazard-high consequence locations); and
- The frequency of inspections can be increased if there is a history of non-compliance or reduced where the results are consistently good.

Major disadvantages are:

- Using BMP implementation success as an indicator to evaluate drinking water protection assumes that implementation to a certain standard equates to acceptable water quality;

- For some BMPs (e.g. road design on Class IV or V terrain) potential problems with implementation may not be apparent for several years or longer; and
- While providing information on site-specific effectiveness, they may not provide information on cumulative watershed effects.

7.0 WATER COLUMN WATER QUALITY MONITORING

7.1 PROGRAMS SPECIFICALLY FOR EFFECTIVENESS EVALUATION

7.1.1 Background

Water quality monitoring of surface water sources of drinking water has been conducted for a variety of purposes in B.C., ranging from routine monitoring by water system operators to monitoring as part of research on land use effects on water quality. Water purveyors conduct routine monitoring to obtain the information needed to manage their treatment and distribution systems, e.g. to determine the correct loading of coagulants or disinfectants. The *Safe Drinking Water Regulation* (1992) of the *Health Act* requires that purveyors provide potable water to users, but this essentially requires monitoring after treatment rather than before. Historically this monitoring has been primarily for coliform bacteria and/or turbidity and has not been intended to provide information on effects of upstream land use. Implications of the yet to be implemented *Drinking Water Protection Act* for monitoring by purveyors is discussed in Section 7.2.

Monitoring in Community watersheds with forestry and range activity increased considerably in about 1996 after the FPC came into effect in 1995. As part of their obligations under the FPC, MWLAP instigated the province-wide FRBC-funded Water Resources Inventory Program (FRBC-WRIP). According to the MWLAP Kootenay Region web site, the program aimed to "promote an understanding and appreciation of the chemical characteristics and biological health of the area's watersheds by collecting information on the physical, chemical and biological properties in order to:

1. characterize baseline water quality, water quantity and ecological health of streams;
2. track trends in water quality and provide early warning of abnormal changes or conditions that might be damaging to aquatic systems;
3. evaluate impacts of land use activities and assess the efficacy of the *Forest Practices Code* (FPC) in protecting water quality; and
4. use information collected to set water quality objectives for Community watersheds, a FPC requirement" (MWLAP, 2001).

With the wind-up of FRBC on March 31, 2002, most of these programs have come to an end, and annual and water quality objective reports have been prepared or are in progress. Although assessing the efficacy of the FPC in protecting water quality is listed as an objective (#3 above), the individual programs in many cases were not specifically designed to do so. That is they were not set up in a way that would allow forestry and range effects on water quality to be separated from natural variability. Nevertheless, a large amount of information was collected to meet the first objective (baseline characterization), and this information can be used as the basis of future effectiveness evaluation programs. In addition, the availability of existing data makes it much easier to design future water quality monitoring within effectiveness evaluation programs, which is discussed further in the following sections.

7.1.2 Monitoring Goals and Approaches

Water quality monitoring programs consist of two major components: purposes (i.e., goals; objectives; etc.) and activities (Sanders et al., 1983). Non-point source pollution monitoring program often suffer from too little attention being put towards setting clear objectives, which results in study designs that cannot meet all the goals. As noted above, the FRBC-WRIP programs had multiple goals, but most were actually designed to achieve only the baseline characterisation objective.

Monitoring to assess the effectiveness of forest policy and practices (including BMPs) at protecting drinking water could be undertaken in a number of different ways. Possible approaches include:

- **Surveillance monitoring**. The goal is to monitor near enough to a specific activity (e.g. road construction in sensitive terrain) to be able to detect an effect and take action if the effect exceeds a certain threshold. An example would be issuing a stop work order if turbidity exceeds water quality guidelines;
- **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 logged versus unlogged watersheds".

Each of these approaches would have different study designs, although there is quite a bit of overlap and designing to meet multiple objectives can be done, albeit with some incremental cost. The key elements of these different approaches are outlined in Sections 7.1.3 to 7.1.5. Technical terms are defined in the glossary at the end of the report (Section 12.1).

7.1.3 Variable Selection

Water quality monitoring to evaluate the effectiveness of measures to protect drinking water is best focussed on the variables that are relevant to human health and aesthetic considerations, and that have some potential to be influenced by forestry and range activities. Aesthetic variables are those with potential to affect taste, smell, laundry, and home plumbing, but which are not toxic except at very high concentrations. MacDonald et al. (1991, Part I, Chapters 4 and 5) 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. The table also indicates the B.C. ambient water quality guidelines (WQG) where they exist. Several variables have been added for this study to the list given in MacDonald et al. (1991), relevant for monitoring the quality of domestic 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 flow[2], water yield, nitrogen, and phosphorus. A key variable not ranked by MacDonald et al. (1991) is organic carbon, which has been added to Table 2. It is important for drinking water monitoring where water supplies are chlorinated, due to the potential for trihalomethane production. True colour is a useful surrogate for organic carbon because it is also an aesthetic variable.

A fundamental list of drinking water quality variables in compliance, trends, and impact assessment monitoring programs should include discharge, turbidity, TSS, coliform bacteria, and true colour. If the watershed of interest is used for range, then nutrients (nitrate-N and ortho-phosphate) would be added. Specific conductance 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.

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[2] 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. Hicks et al. (1991) found a decrease in late summer flows, but this was attributed to the growth of hardwoods in riparian zones, which took up much more water than the conifers they replaced.

Table 6. Available water quality guidelines (WQG), effects on drinking water, and sensitivity to watershed activities for water quality monitoring variables.

Variable	B.C. WQG for **drinking water** (Water Protection Branch, 2001)	Ranks (from MacDonald et al. [1991])			
		Effects on Domestic use*	Sensitivity to:**		
			Grazing	Harvest	Roads
Water quantity					
Peak flows	None	4	3	1-2	1
Low flows	None	2	2	1	3
Yield	None	2	3	1	3
Physical/chemical					
Temperature	15°C***	3	2	1-2	3
pH	6.5-8.5	1	3	3	3
Conductivity	700 µS/cm***	1	3	3	3
Suspended solids (TSS)	None	1	2	1-3	1
Turbidity	1 NTU/ 5 NTU***	1	2	1-3	1
Water column dissolved oxygen (DO)	None	2	3	3	3
Intergravel DO	None	4	1	2	2
Organic carbon	4 mg/L if chlorinated	NR (2)	NR (2)	NR (3)	NR (4)
True Colour	15 TCU	NR (1)	NR (2)	NR (3)	NR (4)
Nitrogen	10 mg/L nitrate-N	2	1	2	3
Phosphorous	Lakes only	2	1	2	3
Total dissolved solids (TDS)	500 mg/L***	NR	NR	NR	NR
Major ions (Cl, F, Na, SO_4, H_2S)	Varies	NR	NR	NR	NR
Hardness	500 mg/L***	NR	NR	NR	NR
Metals	Varies	NR	NR	NR	NR
Biological					
Bacteria – Total coliforms Fecal coliforms	10 CFU/100mL 0 CFU/100 mL	1	1	4	4
Parasites	none	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.

***Aesthetic guideline.

7.1.4 Surveillance and Compliance Monitoring

Surveillance monitoring is undertaken at relatively small spatial scales that lend themselves to "upstream-downstream" monitoring. An example is monitoring water quality above and below a stream crossing where a bridge is being installed. The sampling sites would be located probably within 50 to 100 m of each other and confounding effects, such as tributaries reaching the stream or changes in soil texture, would be absent. Caux et al. (1997) have prepared a guidance document for this type of monitoring. Advantages of surveillance monitoring include ease of linking cause to effect, the ability to respond quickly to an observed problem, and potentially low cost since turbidity would probably be the only variable of interest in most cases. A disadvantage for effectiveness evaluation is the site-specific nature of the monitoring.

Compliance monitoring is monitoring aimed at specifically determining the frequency with which water quality guidelines (Water Protection Branch, 2001; Health Canada, 1996) or objectives[3] 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 results 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 my water of poor quality?" However answering that question either requires continuous monitoring or some means to interpolate between sampling dates with some confidence.

7.1.5 Trends Monitoring

Trend monitoring here refers to a survey of <u>temporal</u> patterns. Status monitoring refers to a survey of <u>spatial</u> patterns. The two types of monitoring programs are often combined, with the spatial survey repeated at regular intervals (MacDonald et al., 1991). A trend monitoring program would be used in effectiveness monitoring where a change in land use is expected (e.g. an increase or decrease in forest harvest activity). A statistically significant trend could be interpreted as an effect, provided the design is appropriate and monitoring runs for a sufficiently long period.

Variables that could be monitored in a trends program for drinking water effectiveness evaluation include:

- Physical/chemical/biological water quality parameters (e.g. mean, median, and/or 90th percentile turbidity, fecal coliforms, etc.);
- Quantitative indicators of water quality that make use of physical, chemical and biological and data (e.g., Number of days per year in which water quality guidelines are exceeded, the B.C. WQI, etc.); and/or
- Response indicators (e.g. number of boil water advisories per year in a Health Region –see Section 9.0).

Regularly spaced sample times (i.e., systematic sampling) are required for standard parametric time series analyses (Dixon and Chiswell, 1996), and are often used in temporal trend monitoring programs. However, there are non-parametric methods available for analysing irregularly spaced observations (Gilbert, 1987; Shaw and El-Shaarawi, 1995); multivariate techniques such as Principal Components Analyses (PCA) which treat each sample time as a separate variable, can also be used (Dixon and Chiswell, 1996). Underwood (1993, 1994) argues for randomly selected sample times, which can be treated as replicates for various analyses (e.g., ANOVA).

The type of sampling used ultimately depends on the objectives of the trend monitoring program. Regularly spaced sample times are probably best for examining within-year, seasonal trends and removing their influence from longer time series (i.e., multi-year). The spacing depends on the temporal variability of the water quality variable of interest, which in turn depends on watershed characteristics. In mountainous terrain, high turbidity events are

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[3] 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 12.0). The B.C. provincial guidelines apply to water "at the

usually short-lived, since water and sediment are quickly routed through the stream network. Thus turbidity sampling needs to occur at least daily (Toews, pers. comm., 2002). In contrast, Interior plateau watersheds, with significant storage potential, route water and sediment more slowly, and there may be significant serial correlation with daily samples (i.e. daily samples are not independent of each other. See Summit [2001c] for an example). In those cases the samples should be spaced further apart or else the data converted to longer-term means (e.g. the weekly mean). The converted datum then becomes the response (or dependent) variable.

If long-term trends (i.e., among years) only are of interest, almost any type of within-year sampling frequency could be used. Long-term trend analysis is effectively a regression of the response variable(s) on time, with a single observation per year. That annual observation could be an annual mean, estimated from systematic or random sample times within years, or a value from one or more pre-selected sample times (e.g., TSS at low or high discharge). The assumption is that there is little or no serial correlation among years, and that annual observations are therefore independent. As in any regression analysis, the design is improved if sample years are regularly spaced. The power of a regression design to detect trends depends on the range of the independent variable (i.e., duration of the program) as well as on sample size (i.e., the number of years in which sampling actually occurs).

One possible approach to trend monitoring is to treat the first few years as a within-year trend monitoring program, with fairly intensive and regular sampling. Then, the most appropriate sampling times and frequencies (and variables) could be selected for a long-term trend monitoring program once seasonal trends for the chemical and physical water quality variables have been characterised. The FRBC Water Resource Inventory Programs have already accomplished this in some cases.

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intake" while the Canadian Drinking Water Guidelines apply "at the tap" (i.e. after any treatment).

7.1.6 Impact Assessment Monitoring

Impact assessment monitoring is defined here as the collection of data intended to separate the effect of an activity 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. Impact assessment monitoring is usually conducted using Analysis of Variance (ANOVA) or *t*-test statistical designs (see Glossary for definitions). Basic ANOVA designs which have been used to assess the impacts of land use activities on water quality are (MacDonald et al., 1991):

- single-site comparison before versus after logging;
- comparison of a single logged versus a single unlogged watershed, or a single watershed with range cattle versus one without range cattle (i.e., paired sites); and
- comparison of multiple treatment (i.e. logged or with range activity) versus control (i.e. no land use activity) watersheds.

Another approach that has been tried is the "upstream-downstream" comparison, where monitoring takes place upstream and downstream of forestry activity.

The single-site approach should be rejected *a priori*. In the absence of a control or reference site, there will be no confidence that any changes observed after logging would not have occurred naturally (MacDonald et al., 1991). The "upstream-downstream" approach in a single watershed is also generally not valid for impact assessment, unless it is the site-specific surveillance monitoring described above in Section 7.1.4.

Paired-site studies, with one logged watershed compared with one reference or unlogged watershed, have predominated in the past. Paired watershed studies are unreplicated since there is only one watershed per treatment (usually two or more levels of logging activity). Statistically, the conclusions of the study apply only to the specific watersheds studied, *and cannot be generalised to other watersheds* (MacDonald et al., 1991). Conclusions about the impacts of forestry/range are also suspect since there may be natural differences between the two watersheds which may either be mistaken for, or obscure, land use impacts. This can be partly compensated for by implementing a "before-after-control-impact" (BACI) design, where monitoring runs for at least several years before the land use activity (forestry and/or range) begins in the treatment watershed.

Cheong (1992, 1996) has developed a B.C.-specific method to evaluate the biophysical similarity of watersheds based on basin morphology (i.e. basin area, perimeter, channel gradient, etc.), geology, biogeoclimatic zones, and hydrologic zones. The method has been used to both recommend monitoring pairs at the start of a monitoring program(e.g., Summit, 2001a) and to determine if existing data from more than one watershed can be reasonably compared (Summit, 2001b). Other watershed and stream classification systems exist (e.g. Rosgen, 1996) and could also be used to help select similar watersheds (or at least eliminate gross differences). Appendix B provides a description of Cheong's method and an example of its use.

Paired watershed studies (i.e. 2 watersheds) has historically been the most common to impact assessment, because the field and laboratory costs of monitoring multiple watersheds (i.e. >2) can be prohibitive if many monitoring variables are sampled frequently. These typically studies allocate human and financial resources to variables and sampling times (some studies have run for more than a decade) at the expense of locations (i.e. only two). As a result, these paired studies provide a lot of information about a very limited and possibly unrepresentative number of locations. The general conclusions may be applicable to other watersheds, if similar conclusions have been reached in several such studies. However, as results and conclusions become more detailed, they are less likely to apply outside the specific study watersheds, partly defeating the purpose of measuring many variables frequently. Fortunately, monitoring for drinking water quality in forested watersheds can be accomplished with relatively few core variables (Section 7.1.3).

A multiple-site design is the only statistically sound design for assessing the effects of logging impacts over a large geographic area (MacDonald et al., 1991). Multiple replicate locations (watersheds) are required to achieve this design, so the numbers of variables and sampling times must be limited to be cost-effective. The basic multiple watershed design would be a completely randomized (CR) design comparing a random sample of logged and unlogged watersheds. In this design, *n* watersheds would be randomly selected within each of two treatment levels (logged and unlogged or reference). The study watersheds must be a random sample from a larger target population (i.e., all logged or unlogged watersheds in the study area) for sample results to be generalised to those populations (MacDonald et al., 1991; Green and Montagna, 1996). If a particular subpopulation is of interest (e.g., Community watersheds), then that subpopulation should be defined as the target population for selecting the random sample of replicate locations. Results and conclusions will only apply to that subpopulation, and not to the larger population of all watersheds.

Refinements of the basic CR design include:

- multiple treatment levels (i.e., degrees of activity, perhaps expressed as ECA, road density, or range animal units);
- using activities as treatment levels (i.e., road construction, range permits, etc.); and
- using management practices as treatment levels (e.g., different riparian buffer widths; selection logging versus clear-cuts; presence/absence of riparian fencing, etc.)

Comparisons of multiple treatment levels representing quantitative or qualitative gradients are more informative than simpler comparisons of two treatment levels. These relationships may reveal critical "thresholds" (e.g. ECA maximum, RMA width) with important management implications. With equal sample sizes (i.e., numbers of watersheds) for each level, most of the sampling effort is devoted to potentially impacted watersheds rather than split equally between impacted and reference watersheds. This approach not only provides more information about potential impacts than a simple two-level design, it also reduces the number of reference (unlogged) watersheds required. The latter is an important consideration in much of B.C. where reference watersheds may be in short supply.

Designs with multiple treatment levels have some replication within each level (i.e., $n>1$). However, the replication is unnecessary if a regression approach is used. For example, one could randomly select one watershed from each of n levels of ECA; the design is most powerful when those levels are evenly spaced; i.e., 0%, 10%, 20%, 30% ECA (Brereton, 1990). In field studies, there may not be watersheds available for each of those n levels. If two or more independent (X) variables are examined (e.g., ECA, BMP implementation), it becomes even more unlikely that watersheds will exist for each of the combinations required (the same problem exists for CR designs with more than one factor). Most regression approaches in field studies are observational, where the investigator accepts that the design will be sub-optimal (i.e., he or she accepts "what is there"). Those studies provide much weaker support for cause-effect relationships, but can be useful for trend monitoring.

In a CR design, there may be considerable natural variation among watersheds within treatment levels. This variation can be removed by more narrowly defining the target population as, e.g., only watersheds within a certain size range. However, that also reduces the generality of any results and conclusions. Methods for reducing natural variation include randomized complete block design (RCB) or a split-plot or repeated measures (RM) design (Summit, 1998).

In practice, a multiple watershed program for impact assessment relies upon successfully:

- Doing some form of watershed similarity assessment to reduce natural between-watershed variability by selecting similar test watersheds (Appendix B);
- Finding and including several reference or “control” watersheds. These do not necessarily have to be unlogged, but the difference in treatment levels should be very distinct (e.g. ECA <5% vs. ECA >25% for a t-test or ANOVA[4] design); and
- Carrying out monitoring consistently in all watersheds with respect to program duration, schedule, sample size, and methods.

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[4] Water quality data tends to be non-normally distributed, and non-parametric equivalents to ANOVA and t-tests are commonly used for data analysis (van Belle and Hughes, 1984).

If this can be done, a multiple site impact assessment program is clearly the most powerful design for determining if forest practices are or are not having a detrimental effect on drinking water quality. Experience in the Arrow (Summit, 1998) and Kamloops Forest Districts (Summit, 2001a) has indicated that enough biophysically similar watersheds can be located within an area of that size, but locating "control" watersheds can be problematic. In addition, it may be difficult to convince local resource managers to monitor watersheds with little forest harvest or range activity when there is community pressure to monitor "their" water supply watersheds.

7.2 USING DATA COLLECTED BY WATER PURVEYORS

Water purveyors routinely monitor water quality at the intake and within treatment and distribution systems. However the data are not normally made available and the monitoring programs are geared towards treatment operations and compliance with the medical health officer rather than assessing the quality of source water. British Columbia is, however, moving towards implementation of the *Drinking Water Protection Act* (DWPA). The DWPA was passed in April 2001 but was not implemented prior to the change in provincial government in 2001. In September 2001 the Ministers of Water, Land and Air Protection and Health Services established an independent panel to review the DWPA and provide recommendations on changes. The panel reported in February 2002, concluding that B.C. "urgently needs the consolidated legislation that the *Drinking Water Protection Act* provides" (Drinking Water Review Panel, 2002). The government is expected to respond to the panel in spring 2002 and move forward with modifications and implementation shortly afterward.

The panel's recommendations include provisions to make the results of monitoring and source watershed assessments accessible to the public. The information would be made available from each water system purveyor and from a central provincial database. If the implemented *Act* does include these provisions, then the data collected by the purveyors would be available for analysis and interpretation. Advantages to the Ministry of Forests and users of Crown forest and range resources include low or no costs and some consistency in how the data are presented. The details of how such a reporting system would actually work are not yet available, but its usefulness in effectiveness evaluation would depend on the purveyors collecting information that can be analyzed to meet the same monitoring objectives described above under Section 7.1.

The potential advantages of a centralized reporting system that could be used for effectiveness evaluation are considerable. In addition to potential cost efficiencies related to sampling, analysis and data reporting, data collected by purveyors would likely be viewed by the public as independent of the interests of industry. For these reasons the Province should consider designing the monitoring and assessment programs under the DWPA to ensure that the data can be used for effectiveness evaluation, primarily for trend and compliance monitoring. The desired features of a purveyor's monitoring program are:

1. The sampling is of "at the intake" raw water;
2. The sampling schedule and the interval between samples are consistent from year to year;
3. The monitoring variables and methods of analysis are consistent each year. The preferred variables are discharge (or at least stage), pH, specific conductance, turbidity (and/or TSS), coliform bacteria, and true colour. Nitrate-N and ortho-phosphate could be added if the watershed is used for range or if fertilization or large-scale broadcast burning is used in silviculture.

Potential disadvantages of using data collected by drinking water purveyors include having limited influence on sampling procedures, delays in obtaining data, the possibility of having to accept compromises in the study design based on differing objectives, and lack of information on the causes of poor water quality.

Even if the DWPA is not implemented to include mandatory monitoring at the intake and reporting of the data, most water purveyors will continue to collect this data and it may be possible for MOF or forest licensees to obtain it, perhaps by negotiating a cost-sharing arrangement. Forest licensees could then use it as a way to evaluate whether or not they are meeting the required results under the FPC. It would be desirable for MOF or licensees to supplement the monitoring by purveyors by conducting monitoring in one or more reference (control) watersheds.

8.0 MONITORING OF NON-WATER COLUMN INDICATORS

8.1 PRESSURE INDICATORS

In the case of drinking water, “at the intake” water quality is generally the major indicator of interest. As described above, however, implementation of monitoring to detect statistically significant trends or differences between streams can be expensive and would likely only be implemented on a selective basis in B.C. For this reason other indicators could be selected that are more easily compiled or that are being compiled already for other reasons. Pressure indicators for drinking water quality are human activities potentially influencing water quality. Possible pressure indicators include:

- Annual allowable cut (province, Region, or District);
- New roads (i.e. km of roads built with the past 3 years);
- Number of water licences on a stream;
- Human population within the watershed;
- Range animal units (1 unit = 454 kg cow or equivalent forage consumed);
- Number of active mining claims;
- WAP report card variables, i.e. ECA, total road density, road density on unstable and potentially unstable terrain, road density on erodible soils, proportion of stream length with clearcut riparian harvest, and number of road crossings (MOF/MELP, 1999); or
- Number of septic fields.

The rationale behind some of these indicators and the necessary data sources to be discussed in Section 10.2.2.

8.2 STATE INDICATORS

State indicators in the context of drinking water are symptoms or indicators of upstream impacts that may also affect downstream "at the intake" water quality. They could include:

- Number of human-caused landslides in a watershed;
- Proportion of channel disturbed by the build-up of sediment deposits, bank erosion, or scouring;
- Proportion of riparian areas that are disturbed by cattle grazing; and
- Quality of fish habitat (e.g. sediment deposition on spawning habitat).

The major disadvantage of these indicators is that they may correlate only weakly with the water quality characteristics that are important for drinking water. For example, a landslide might deposit a large amount of course sediment in a stream, but any fines are flushed quickly through the system.

9.0 MONITORING OF HUMAN RESPONSES

Response variables are societal actions resulting from perceived changes in water quality. Examples include:

- Number of complaints about water quality to water purveyors;
- Days with boil water advisories;
- Groundwater well drilling activity;
- Enteric illness statistics or hospital admissions (e.g., admissions/10,000 population);
- Number of water licences on a stream; and
- Expenditures by water purveyors on treatment (e.g., $$/m^3 of water supplied).

These indicators may be of limited value in the next few years while public consciousness of drinking water quality issues is high and the *Drinking Water Protection Act* is in the early stages of implementation. People may be more inclined to phone in a complaint if they know that the call would be counted as an indicator. In addition, the reporting of boil water advisories and enteric illnesses is expected to increase under the DWPA, but this does not necessarily mean that the frequency of incidence has actually increased.

10.0 INTEGRATED EFFECTIVENESS EVALUATION FRAMEWORK

10.1 REGULATORY BACKGROUND

British Columbia is currently moving towards a *results-based* approach to the *Forest Practices Code* instead of the current *rules-based* system. A results-based approach depends on having sensitive measures of ecosystem change so that forest and range (or other land use) practices can be modified to avoid or correct detrimental change. The goal is to allow forest managers to customize their forest practices to the characteristics of the watershed to optimize resource development opportunities, while ensuring no detrimental change in aquatic ecosystems. In other words, some watersheds are more resistant to impacts from land use than others, and more or different harvest might be allowed with a results-based system as long as there are no detrimental effects on water quality or aquatic habitat. This shift in policy is happening at the same time as there is growing concern in Canada about the safety and adequacy of drinking water supplies.

Evaluation of FPC effectiveness in protecting drinking water should be done according to two distinct periods of time:

1. From Code implementation in 1995 until 2002 (the period of the original FPC); and
2. After 2002 (the period of the new results-based Code).

Evaluation of the 1995-2002 period will have to make use of existing information. Sources of information include the FRBC water resource inventory data and reports, the results of watershed assessments, and data collected by purveyors. These approaches are discussed in Section 10.2.1.

Effectiveness evaluation is expected to be crucial under the results-based Code (RBC) because the ultimate desired "result" in Community and domestic watersheds will be water that is as safe and aesthetically acceptable at the point of intake as it would be in the absence of forestry or range activities. Depending on the wording of the selected rules and results, actual monitoring of water quantity and quality could be required to demonstrate the desired result at the intake in Community and domestic watersheds. For example, to be able to confirm that water quality has not been degraded (or has been maintained) <u>in a scientifically defensible manner</u> it would be necessary to implement a trends monitoring program. A general statistical "rule of thumb" in water quality monitoring is that at least 10 years of data are required to detect a trend. If "quality" means chemical, physical, and bacteriological variables then even a basic monitoring program could cost between $3,000 and $20,000 per watershed per year depending on the variables of interest and watershed characteristics. Surrogates (i.e. state and response variables) could be used as a cheaper alternative, but they may not be acceptable to water purveyors or the public. Nevertheless, the costs of monitoring in a Community watershed to demonstrate compliance would need to be compared against the costs of the FPC *status quo* in community watersheds (i.e. the costs of watershed assessments and other water-related assessments that currently support forest development planning).

If the water-related rules and results essentially refer to BMP implementation, then inspections and audits would be the fundamental approach to effectiveness evaluation in those cases, but some level of supporting water quality monitoring would still be beneficial.

10.2 PROPOSED FRAMEWORK

10.2.1 Evaluation of the 1995-2002 Period

As outlined in Section 7.1.1, the FRBC-sponsored water resource inventory program collected quantity and quality data in Community and domestic watersheds in B.C. during about 1997-2001. The results are typically presented in annual reports, and some water quality objective reports have been completed on a watershed basis. For example, in

MWLAP's Southern Interior Region, water quality objectives have been set in approximately 35 watersheds following a standard procedure based on MWLAP guidance documents (Water Quality Branch, 1996). These reports include information on land use activities in the watersheds, but generally contain limited information on either natural or human-caused effects on water quality. Some regional or licensee-specific summaries have also been prepared (e.g. Summit, 2001b; Summit, 2002) and MWLAP has looked at the water quality monitoring results in relation to the intent of the Code (Einarson, pers. comm., 2002).

The inventory data and reports present the best available resource for assessing the relationship between Code implementation and water quality in the 1997-2001 period, but it is likely that further analysis of information from the monitoring will be required in the majority of cases to complete effectiveness evaluation. This would entail obtaining Forest Development Plans, cutting permits, and WAP reports to determine what was happening in the watersheds during the monitoring period. This is optimally done from a cost perspective at a regional scale (e.g. for a Forest District), to allow some comparison between watersheds and to assess effects of natural processes. For example, it is important to determine the return interval of annual precipitation and peak flow events in the region to see where the monitoring years are positioned within the range of normal. As an illustration of this point, the return intervals of maximum daily flows in the Slocan Valley for the years 1996 to 1999, when monitoring took place, were 4.2, 19, 1.9, and 8.7 years (Summit, 2001b). This indicates that within that period, one year was about average with respect to peak flow, one was slightly above average, and two were relatively high. None of the peak flows approached the design flows of most bridges and culverts (i.e. the 50-year and 100-year instantaneous peak flows). However, in two of the four years the flow was sufficiently high to cause channel erosion, potentially leading to above-average turbidity.

Analysis of the existing inventory data should include determining at least the following:

- Descriptive statistics of the major water quality parameters for each year (e.g., mean, median, 90th percentile, maximum, minimum, and standard deviation);

- The number of samples exceeding water quality guidelines each year and estimates of the number of days not meeting guidelines; and
- Comparisons to natural processes and the presence or absence of forest/range activities, as outlined above.

Watershed assessment reports (both IWAP and CWAP) and related documentation are another source of information regarding FPC effectiveness in Community watersheds. Reviewing WAP reports may give an indication of steps taken to minimize risks to water quality and the role of stakeholders (e.g. water purveyors and water users) in identifying acceptable risk[5]. Water purveyors and Health Units could also be polled to obtain information on water quality during 1995-2001, including monitoring data, numbers of boil water advisories, and treatment effectiveness.

10.2.2 Effectiveness Evaluation from 2002 Onwards

Regardless of the eventual wording of the RBC, it is likely that no single approach to effectiveness evaluations will be adequate for all of B.C. To meet MOF and licensee's obligations under the RBC, an integrated multi-level effectiveness evaluation (EE) framework is recommended. This would be a mixture of:

1. "On the land" inspections/audits of any BMPs required by the rules;
    - Inspections done relatively frequently in all Community watersheds by licensees, using registered professionals where appropriate (e.g. roads on Class IV/V terrain)
    - Audits done by an independent agency (i.e. Forest Practices Board)
    - The outcomes should be compiled in a publicly accessible database.

2. Compilation and tracking of pressure and response indicators;
    - Done at the Forest District scale

[5] MWLAP is currently compiling a database of WAP reports. The MWLAP contact is Dave Gooding at (250) 387-9472.

- Reported every three years; and

3. "In the stream" water quantity and quality monitoring.

Each of these three types of evaluations is discussed in turn below.

BMP Inspections and Audits

As noted earlier, BMPs were originally defined as specific actions or techniques implemented in the field, but the definition has expanded to include management systems and planning principles (see Table 5). Effectiveness evaluations of either techniques or management systems would document both simple implementation (a yes or no answer) and the quality of implementation (has it been implemented correctly and had the desired effect?) To be useful, the BMP EE system must include a database of inspection results and a way to track results over time. Licensees (or their contractors) could do the majority of inspections of forest practices, but some should be done by registered professionals where experienced judgement is needed to determine if implementation has been done correctly.

It is expected that a risk-based approach to BMPs will be employed under the RBC, where:

$$\text{Risk} = \text{Hazard} \times \text{Consequence}$$

This means that a relatively high hazard might be acceptable (e.g. a road built across erodible soils) if the consequence of that action is low (e.g., the stream is neither fish bearing nor a source of drinking water). In Community watersheds the consequence of the failure of a BMP may be assumed to be high, meaning that the acceptable level of hazard resulting from land use practices would be low to moderate. Thus a major part of BMP evaluations will be determining whether or not risk has been evaluated appropriately. This is particularly important where there could be a time lag between BMP implementation and a resulting problem, such as a landslide resulting from an improper road design on potentially unstable terrain.

Generally speaking, the forest practices that are most of interest with respect to drinking water quality management are those that occur close enough to a watercourse for sediment or other contaminants to be routed to the stream. The forest practices that are recommended to be considered for monitoring are listed in Table 7. Inclusion is based on the probability that downstream drinking water quality is sensitive to their implementation. Typical criteria for evaluating the completeness and quality of implementation are also included in Table 7.

Criteria and Indicators

We suggest that a set of indicators be tracked at the Forest District scale. By their nature, indicators of pressure on drinking water resources provide only a rough assessment of actual hazards. There is wide variation in the sensitivity of watersheds to land use activities, and no single indicator of pressure (e.g. road density, ECA, number of range permits, etc.) can adequately characterize risks to water quality. Therefore multiple indicators should be compiled for the Community watersheds in a District and evaluated for the presence of trends. This could be done for a select number of Forest Districts with a significant number of Community and/or domestic watersheds (i.e. more than 10), rather than for all Districts in the province. This is to focus financial resources to areas where drinking water protection is a major forest/range issue and to ensure an adequate sample size in each District.

The current WAP process makes use of multiple indicators in the Watershed Report Card, but we suggest a customized set of drinking water pressure indicators, as follows. The criterion is "Land use activities". The pressure indicators recommended for consideration are:

- Kilometres of new road built in a watershed within the last three years (Rationale: experience shows that roads generate much more sediment during construction and in the first few years after construction than they do after they become established);

Table 7. Recommended forest and range practices for EE monitoring.

Practices	Implementation	Typical Indicators of Quality of Implementation
Assessment of risks to water quality considered in the Forest Development Plan	Yes/no	• Risk assessment (e.g. WAP or equivalent) adequately characterized hazards & consequences • Licensee followed recommendations of Watershed Advisory Committee.
Road location close to streams and road crossings	N/a	• Location and layout has minimized riparian disturbance and potential for sediment transfers to the stream
Ditches & culverts built to minimize erosion	Yes/no	• Ditches adequate size to carry flow without frequent cleaning. • Adequate number of cross drains, placed to maintain natural drainage patterns and properly installed. • Cutslope seeded or other wise vegetated promptly • Sumps installed at cross-drains.
Bridges and culverts	N/a	• Design flow estimation method is appropriate with appropriate factor of safety • Erosion control measures included in design & built appropriately for soil & channel characteristics.
Road inspections	Yes/No	• Inspections occur at correct time (e.g. during peak snowmelt or rainfall) • Problems reported and acted upon promptly
Riparian buffers	RMA is present/absent	• RMA design considered water quality functions, i.e. filtering of sediment, shade, and bank stabilization (i.e. Properly Functioning Condition)
Roads & cutblocks on sensitive terrain	N/a	• Location and design has considered risk of sediment delivery to stream channels
Cattle near watercourses	Range permits have considered water quality. Yes/No	• Range permit schedule consider risks of introducing parasites (e.g. presence of calves near watercourses in the spring). • Range schedules allow for riparian vegetation rest & recovery • Salt licks & watering systems located away from streams • Cattle excluded close to intake or where banks are steep and erodible.

- Kilometres of active roads within 50 m of watercourses on 1:20,000 scale map and number of road crossings (Rationale: These are indicators of potential riparian disturbance and near-stream sediment sources);
- Lengths of road on Class IV and V terrain (Rationale: An indicator of risk of mass movement and introduction of easily-transported sediment);
- Equivalent clearcut area (ECA) above 20% (Rationale: 20% ECA is the general threshold from the scientific literature where changes in flow regime may occur [see Appendix A], thus an increase in ECA is not a pressure indicator unless it exceeds 20%. Therefore ECA values of say 12% and 18% would both be reported as zero in this indicator);
- Proportion of channel length with clearcut riparian harvest (Rationale: This is an indicator of potential for bank erosion and the introduction of fine [i.e. easily transportable] sediment and/or lack of filtering capacity);
- Number of livestock "animal units" (range and farm) in a watershed (Rationale: Livestock may directly introduce contamination or alter riparian zones and stream banks); and
- Number of water intakes and the total licensed water volume (Rationale: These are indicators of the volume of water withdrawn and the presence of infrastructure in or near the creek).

The only suggested response indicator is the number of days with boil water advisories in place. Although this indicator may not be directly linked to land use practices, it is a clear indicator of sub-standard water quality. Like any indicator that is subject to natural variability, however, a high or low number in any given year needs to be put in the context of hydrologic and climatic variation. High turbidity (one of the triggers for a boil water advisory) may be expected in years with above-normal flow or precipitation. High bacteria counts may be recorded when turbidity is high, but also when flows are low and the water is warm (i.e. late summer).

Indicators are the least informative type of effectiveness evaluation of the three types recommended here. Compared to the "on the land" and "in the stream" monitoring they provide only indirect evidence that forest and range management policy maintains drinking water. Thus indicators should be used only in combination with the monitoring programs, to support analyses of why policy is or is not effective.

Water Quality and Quantity Monitoring

Whether or not demonstration of the required RBC results leads to "in the stream" water quality monitoring, we recommend that a multiple watershed water quality/quantity monitoring program be implemented within the EE framework, for the following reasons:

- Monitoring is needed to refine BMP methods and techniques by linking cause to effect, eventually making them more effective and potentially reducing the need for monitoring and/or the frequency of inspections;
- If BMPs are a major part of the RBC, selective water quality/quantity monitoring is likely to be necessary to confirm their effectiveness in the eyes of a potentially skeptical public;
- Effectiveness evaluation of BMPs in the American Pacific Northwest is required by law and includes "in the stream" monitoring linked to "on the land" monitoring, and a B.C. program would therefore not put B.C. at a competitive disadvantage with those States;
- The Review Panel report on the *Drinking Water Protection Act* recommends that drinking water take priority over other uses in "critical or high risk watersheds" (Drinking Water Review Panel, 2002; p. 13). It is prudent to collect the data needed to determine if forestry/range is having a detrimental effect on water quality in those watersheds, rather than face a decision by a Medical Health Officer who is required to have low tolerance for risk; and
- Much of the public debate over forestry and range activities in the past decade has been conducted in the absence of useful data on drinking water quality. A well-designed monitoring program will almost certainly raise the level of that debate.

Table 8 compares the features of four levels of EE water quality monitoring programs. Included is the number of regions in which the program would operate, the number of watersheds per region, the number of reference watersheds needed, the desired level of

Table 8. Features of alternative EE water quality monitoring programs.

	"BMP Demonstration" or "Pilot Project"	Basic Trend and Impact Assessment Study	Research-oriented Trend and Impact Assessment Study	Water Purveyor
Number of regions	1 or 2	2 - 4	3 - 6	2 – 4
Watersheds per region	1 - 3	5 - 6	≥6 - 12	3 - >6
Total no. of watersheds	1 – 6	10 - 24	>20	6 - >24
Acceptable level of watershed similarity	low	moderate	moderate - high	low (focus on trends)
No. of reference (control) watersheds/region	none	≥2	>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, turbidity pH, SC, precipitation, air temperature, & water temperature	Discharge (or stage), turbidity (plus pH, SC, & temperature)
Core variables – monitored ≈ 10 times/yr.	Fecal coliforms, *E. coli*, TSS, true colour	Fecal coliforms, *E. coli*, TSS, true colour	Fecal coliforms, *E. coli*, TSS, TDS, true colour, TOC	Fecal coliforms, *E. coli*, TSS, true colour
Optional variables – monitored ≤10 times/yr.	TOC, Hardness, TDS, Nitrate-N, Ortho-P	TOC, hardness, TDS, Nitrate-N, Ortho-P	hardness, Nitrate-N, Ortho-P, trihalomethanes	TOC, hardness, TDS, Nitrate-N, Ortho-P
Level of supporting watershed assessment and BMP inspection	high	Moderate	moderate - high	low - high
Probable annual cost[6] per region	$8,400-$25,000	$35,000-$44,000	$75,000-$135,000	$4,000 - $10,000

[6] The costs shown in Table 8 are based on a generic **drinking water** program with sampling done manually by a locally-based person at $150/day. Supervision and report writing assumed done by someone at $500/day. The program assumes about 45 samples/year for the "frequent" core variables and 10/yr for the others, with no optional variables. Analysis by CAEAL-approved laboratory except for pH and SC, which are measured with field meters. Assumes that more than one watershed is monitored to achieve some economy of scale. Does not include costs to administer contracts but does include costs of reporting.

watershed biophysical similarity, recommended monitoring variables, the level of supporting "on the land" monitoring, and probable costs (in 2002 dollars). Costs in all types of monitoring programs can be optimized by selecting watersheds that have already been part of the Water Resource Inventory Program and where a recent WAP has been completed. As discussed in Section 7.1.3, the list of recommended variables is focussed on those that are most relevant for drinking water and which are sensitive to forestry and range practices.

The lowest level is the BMP demonstration project, which could also be used as a pilot project for a more detailed impact assessment or trend-monitoring program. This would involve setting up a few single-watershed programs with "state-of-the-art" BMP implementation in different areas of B.C. The water quality monitoring program would be then set up on a combined compliance and trend schedule. Since only a few watersheds would be included, it would be important to acquire sufficient detail about natural sediment sources and BMP implementation to be able to link the land use practices to the observed water quality. Like all single-watershed programs, it won't be possible to generalize the results to other watersheds.

Ideally, water quality monitoring for effectiveness evaluation would at least consist of a basic trend and impact assessment program (Table 8) that would have the characteristics listed below. These characteristics assume that funds for monitoring will limit the program to the most basic design that still meets program objectives. However, the costs of not implementing a well-designed program may be substantial if there is not public acceptance that the RBC is protecting drinking water.

The recommended trend and impact assessment program should have the following characteristics:

- It should be stratified into about three regions representing combinations of climate regime and watershed physiography (which controls runoff generation and routing). Suggested regions[7] are the coast, the Interior plateau, and the Columbia and Rocky Mountains. Within each region it will likely be necessary to determine what constitutes "typical" watersheds and bias watershed selection accordingly (e.g. select within one hydrological zone). It simply won't be possible to cover the full range of biophysical characteristics in regions of this size.

- Watershed selection should come as close as possible to an Impact Assessment monitoring design (Section 7.1.6). It will likely be difficult to select watersheds that are very biophysically similar. Therefore some differences would be acceptable as long as those differences are quantified and the individual watershed study designs also meet trend monitoring objectives. The basin similarity procedure of Cheong (1996) is recommended as the preferred tool for classifying and screening watersheds, but final selection will require local knowledge. Watersheds with existing data should be considered because that will simplify development of detailed study designs[8].
- Six watersheds per region and a minimum six years of data collection are the statistical "rules of thumb" for preliminary planning purposes. At least two watersheds in each region should be reference watersheds (controls). Fewer watersheds per region would be feasible, but the number of years of data collection may need to increase to compensate since the emphasis would shift to trend assessment.
- There should be clear differences in the level of forestry/range activity between the reference and treatment watersheds, based on standard indicators of forest development (e.g. ECA and road density). This is to minimize the possibility that land use in the watersheds would become more similar over the period of monitoring (i.e. new logging in the reference basins and hydrologic recovery in the treatment basins).
- The water quality variables can be limited to those most relevant to drinking water quality, namely discharge (or stage), turbidity, TSS, true colour, and coliform bacteria. Specific conductance, water temperature, and pH can be added at low cost and will aid in data interpretation. Nutrients should be included in watersheds with range activity or where

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[7] The term "regions" here does not imply Forest Regions.

[8] For example, power analysis can be applied to determine the sample size needed to generate a desired level of statistical significance.

there has been a significant amount of slash burning. Other variables should be added if locally important (e.g. *Cryptosporidium* in watersheds with high range use).

- The water quality monitoring should be supported with some level of watershed assessment to identify sources of sediment and other potential contaminants (Table 8). In general, the smaller the sample size, the greater the need to determine the causes of any observations of poor water quality by conducting within-watershed field investigations.

Table 8 also includes the characteristics of a research-oriented trend and impact design. This is essentially an expansion of a basic design to increase the probability of isolating "impacts" (i.e. effects) from natural variability. It would also provide more information on within-watershed processes rather than just on water quality at the intake, and the results would be more broadly applicable across B.C. This, of course, comes at added cost (Table 8).

Finally, Table 8 includes a program where data collected by water purveyors is assembled and analyzed. The probable costs in Table 8 are for a consultant to complete these tasks and assume that the monitoring expenses are borne by the purveyor. The basic data analysis and summary tasks could be supplemented with watershed and BMP assessments.

10.2.3 Proposed Framework Summary

To summarize, we propose that the drinking water effectiveness evaluation framework for 2002 and onwards be comprised of an integrated program that includes three major elements:

1. "On the land" inspections and audits of BMPs with the results maintained and tracked in a central database. Inspections and audits would be completed relatively frequently and in all Forest Districts.

2. Development and tracking of a set of indicators at the Forest District scale. This would be done for a select number of Forest Districts with a relatively high number of Community and/or domestic watersheds (i.e. ≥10), rather than for all Districts in the province. The recommended indicators are:

- Kilometres of new road built in a watershed within the last three years;
- Kilometres of active roads within 50 m of watercourses on 1:20,000 scale maps and number of road crossings;
- Lengths of road on Class IV and V terrain;
- Equivalent clearcut area (ECA) above 20%;
- Proportion of channel length with riparian clearcut harvest;
- Number of livestock “animal units” (range and farm) in a watershed;
- Number of water intakes and the total licensed water volume; and
- Number of boil water advisories per year.

All of the recommended indicators can be calculated in the office from maps and silvicultural files, or from data that is available to the public. They would be compiled and reported on every three years.

3. Water quality monitoring to evaluate BMP effectiveness and refine BMPs. This should be at least at the scale of a demonstration project with two or more watersheds in B.C. However, a demonstration project would not likely provide sufficient assurance to a broad range of stakeholders that the RBC is protecting water quality. For this reason a basic trend and impact assessment program is recommended for at least three regions in B.C. Such a program would be consistent with the Alberta AESA program and BMP EE programs in the U.S. It is essential that the goals of the program be clarified before start-up and that an experienced statistician be directly involved to ensure that the study design can meet the desired objectives. In addition to water column sampling, the monitoring program should include some level of watershed assessment to inventory natural and human-caused influences on water quality (see Table 8).

All of the above future EE programs would benefit from first reviewing regional summaries of WRIP reports, where available, to evaluate drinking water protection under the 1995-2002 FPC. Such a review is also critical for developing monitoring program design. If they are unavailable in certain areas then summaries should be completed before proceeding with a design. Completion of regional summaries will also help prioritize watersheds for all three levels of the future effectiveness evaluations. The summaries should include not only the results of water quality monitoring, but also any available information on natural and human-caused influences on water quality (i.e. WAP, FHAP, RAPP, or CAP results) in order to establish linkages between land use and water quality.

Finally, the Province should seek input on the development and design of the monitoring and public reporting programs that are to be implemented by water purveyors under the *Drinking Water Protection Act* to ensure that these programs can be used to evaluate the effectiveness of source control policies (including the FPC). Use of this data for effectiveness evaluation has the potential to be very cost effective compared to developing stand-alone monitoring, as long as the study designs are appropriate for trend analysis.

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12.0 GLOSSARY AND ACRONYMS

12.1 GLOSSARY

Analysis of Variance (ANOVA)	A statistical test used to determine whether more than two independent samples are derived from the same population. Variance can be attributed to variation between the means of samples or from within the sample population.
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.
Benthos	Those plants and animals living on the bottom of water bodies (streams, lakes, oceans). In common use for streams, it usually refers to *benthic invertebrates*.
Benthic invertebrates	See benthos.
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 macro-climate 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.
Coefficient of Determination (r^2)	The square of the *correlation coefficient* (r). A statistic which expresses the proportion of the variation in one variable that is explained by the variation of another variable or variables. e.g., $r^2 = 0.72$ indicates that 72% of the variation in one variable is explained by variation in another.
Coefficient of Variation (CV)	A measure of the relative variability of samples. Equals the *standard deviation* of a sample divided by the *mean*. Usually expressed as a percentage.

Correlation coefficient (r)	The degree of relationship between two (or more variables). Values range between 0 (no relationship) and 1 (perfect relationship). A negative r value (e.g., r = -0.69) indicates that one variable decreases as the other increases.
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).
Criteria (in forest sustainability C&I)	A state or aspect of the dynamic process of the forest ecosystem which should be in place as of result of adherence to a *principle*.
Degrees of Freedom (df)	See *Error Degrees of Freedom.*
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. A way to compare the expected hydrologic behaviour of watersheds, based on the idea that as young forests grow, they recover hydrologically.
Error Degrees of Freedom	Error degrees of freedom (n-1, sometimes n-2) is a number used when describing a sample variance as an estimate of the population variance. Named so, because variance is calculated from n deviations from the mean and only n-1 of these deviations can be chosen “freely”. The other deviation is determined by the fact that the n deviations must add up to zero.
Euclidean Distance	A multivariate measure of statistical difference or “distance” between members of a population.
Geomorphology	The study of the physical and chemical processes that create and influence land forms.
Harmonic Mean	Is given by *n* divided by the sum of the reciprocals of the *n* numbers, or HM = $n/(\sum(1/n))$.
Indicator (in forest sustainability C&I)	A quantitative or qualitative parameter which can be assessed in relation to a criterion. Describes in an objective way features of an ecosystem or related social system.

Interval Data	As opposed to point data, interval data describes a range of values so that a value may be fit with a higher level of confidence.
Mean	The average value. Equals the sum of individual observations divided by the number of observations.
Median	The middle value in a set of numbers (50% of samples are smaller and 50% are larger).
Moving average	Statistical method used to "smooth" time series data. The procedure averages values of a series of consecutive points (e.g., annual rainfall), and plots the average value as the "new" value of the middle point. Also called the *running mean.*
Non-parametric test	Any hypothesis test that does not specify the type of data distribution.
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 *point*) sources.
Normal Distribution	A symmetrical, bell-shaped distribution which is completely defined by the mean and variance so that the probability of a single observation in any particular range of values depends only on the mean and standard deviation of the distribution.
Parametric test	Any hypothesis test that specifies the type of data distribution. Usually assumes a normal distribution.
Periphyton	Algae attached to rocks on the bottom of a stream.
Point source pollution	Pollution coming from a single identifiable source, such as a pipe discharging effluent to a stream.
Power (statistical)	The probability that the null hypothesis (H_0) will be rejected when it is false (thus the correct decision). Equals 1 - β.
Principle (in forest sustainability C&I)	A fundamental rule or law, serving as a basis for reasoning and action. An objective or attitude concerning the functioning of the ecosystem.

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.
Quartile	Values that cut observations into four equal lots: i.e. 25% of values are less than or equal to Quartile 1 (Q_1), 50% are less than or equal to Quartile 2 (Q_2 – also the *median*), and 75% are less than or equal to Quartile 3 (Q_3).
Random sampling	The likelihood of selection of each member of a population is equal. A random number generator can be used for member selection.
Regression	Regression analysis determines the degree of relationship between variables and is used to quantitatively predict (with an equation) or forecast by interpolation. For two variables, one (the dependent variable - on the y axis) is plotted against the other (the independent variable – on the x axis) and an equation fit through the points.
Replicate	In experimental design, when more than one experimental unit is given the same treatment in order to estimate variability.
Salmonid	Species belonging to the family of fishes known as the Salmonidae and includes Pacific salmon, trout, chars, whitefishes, and graylings.
Stage	Water level (the elevation of the water surface above a specified datum).
Standard deviation	A measure of the variability in a set of data. Is the measure of the average departure of individual samples from the mean for all samples (see *mean, coefficient of variation*).
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).
Stratified random sampling	The population is divided into groups. Within each group, the individuals to be sampled are selected at random.
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.
t-test	Common *parametric* statistical test to determine if there is a significant difference in the means of two groups. Typically used for samples of less than 30 observations.
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 *vs*. 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 specific location with an adequate degree of safety, taking local circumstances into account.

12.2 ACRONYMS AND SYMBOLS

ANOVA	Analysis of Variance
asl	Above sea level
BACI	"Before-after-control-impact"
BMP	Best Management Practice (or Beneficial Management Practice)
C&I	Criteria and Indicators
CAEAL	Canadian Association of Environmental Analytical Laboratories
CAP	Channel Assessment Procedure
CR	Completely randomized
CV	Coefficient of variation
df	Degrees of freedom
DFO	Fisheries & Oceans Canada
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DWPA	Drinking Water Protection Act
EC	Electrical conductivity (specific conductance)
EE	Effectiveness evaluation
EPA	United States Environmental Protection Agency
FHAP	Fish Habitat Assessment Procedure
FPC	Forest Practices Code
FRBC	Forest Renewal British Columbia
IFPA	Innovative Forest Practices Agreement
IWAP	Interior Watershed Assessment Procedure
MELP	Ministry of Environment, Lands & Parks
MHO	Medical Health Officer
MOF	Ministry of Forests
MWLAP	Ministry of Water Land & Air Protection
NTU	Nephelometric turbidity units
OBS	Optical back scatter
RIC	Resource Inventory Committee
RBC	Results-based Code
RCB	Randomized Complete Block
RFP	Request for proposal
SC	Specific conductance
SD	Standard deviation
SEE	Standard error of the estimate
TCU	True colour units
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
TTHM	Trihalomethanes
U.S. EPA	United States Environmental Protection Agency
WAP	Watershed Assessment Procedure
WQG	Water Quality Guideline

WQI	B.C. Water Quality Index
WQO	Water Quality Objective
WRIP	Water Resource Inventory Program (an FRBC-sponsored program)
WSC	Water Survey of Canada (a branch of Environment Canada)

APPENDIX A

Summary of Effects of Forestry and Range Activities on Water Quality

APPENDIX A

Summary of Effects of Forestry and Range Activities on Water Quality

Streamflow (Discharge)

All of the water quality monitoring programs have included some measurement of stream discharge. Numerous studies from around the world have shown that removal of forest vegetation results in increased water yield from watersheds, caused by reductions in water losses from interception, evaporation, and transpiration when trees are removed (Bosch and Hewlett 1982)[1]. However, the harvest threshold at which changes in hydrologic regime are detectable is usually reported as about 20% equivalent clearcut area (ECA) (Reksten, 1991; Stednick, 1996). Forest harvest can also influence the timing of flows and the magnitude of peak flows, the latter effect through a combination of ECA and road drainage effects. In general, it is only changes in peak flows (not ordinary flows) which cause bank erosion and transport large debris and coarse sediment, and thus have undesirable implications for water quality, channel stability, and aquatic habitat.

Sediment (measured as Total Suspended Solids and Turbidity)

Increased risks of erosion and sedimentation can result from forest road and landing construction and operation, although cutblock erosion, streambank erosion (where there have been changes in peak flows), livestock watering, and recreation can also contribute to increased sediment loads in streams. The two principal methods for measuring *suspended* sediment (i.e., sediment carried in the water column) are 1) as mass per unit volume (total suspended solids [TSS]) and 2) turbidity (a measure of the amount of light scattered by suspended matter). Turbidity is usually of more interest from the perspective of drinking water quality, while TSS is more relevant for studies of effects on aquatic life and for developing sediment budgets.

The Canadian drinking water guidelines for turbidity are:

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[1] References are listed in the reference section of the main report (Section 11.0).

- a maximum acceptable concentration of 1 nephelometric turbidity units (NTU) for water entering a distribution system (unless there is a history of acceptable microbiological water quality at higher values), and
- an aesthetic objective of ≤5 NTU at the point of consumption (Health Canada, 1999).

The B.C. turbidity guideline for untreated drinking water is 1 NTU maximum induced turbidity where background is less than 5 NTU, and total turbidity should not exceed 5 NTU at any time (Water Protection Branch, 2001). "Induced" in the case of non-point source sedimentation means changes compared to a reference condition, either before forest development occurred or in a suitable control (e.g., unlogged) stream. "Upstream-downstream" monitoring in a single watershed is almost never a suitable comparison in B.C. streams due to significant differences in stream power and soil characteristics as streams flow down through watersheds.

The B.C. guidelines for aquatic life for turbidity and TSS do differentiate between "clear flow" and "turbid flow" periods, and between events that raise sediment levels for ≤24 hours and those that last up to 30 days (in the clear flow period). "Background" and "induced" are also part of the aquatic life TSS/turbidity guidelines. There is also a streambed substrate composition guideline for potential salmonid sampling sites.

Total dissolved solids (measured or estimated from Specific Conductance)

Specific conductance (conductivity) refers to the ability of water to carry an electrical current, which is a function of the concentration of dissolved ions and water temperature. It is an easy-to-measure alternative to measuring total dissolved solids (TDS), which can be estimated from specific conductance by multiplying by a factor of between 0.55 and 0.75 for natural waters (McCutcheon et al., 1993). Changes in TDS can result from forest harvest if reduced evapotranspiration leads to a greater volume of water infiltrating through the soil. Such changes in conductivity are rarely large enough to influence either potability or fish habitat, but conductivity is measured in most monitoring projects because it is a basic indicator of water quality and can help infer the relative contribution of throughflow and direct runoff.

Water temperature

Water temperature is a basic water quality variable that is strongly related to biological activity in aquatic systems. A rule of thumb is that a rise of 10°C doubles the metabolic rate of cold-blooded organisms (Keeton 1967, cited by MacDonald et al., 1991). Reduced forest cover along streams can increase direct solar radiation reaching streams, and can cause water temperature to increase. Oliver and Fidler (2000) recently prepared a literature review on causes and effects of water temperatures on aquatic biota, plus a review of temperature guidelines in North American and European jurisdictions. The current B.C. water quality guidelines for temperature call for different guidelines depending on the most sensitive species present (Water Protection Branch, 2001). The B.C. drinking water guideline of 15ºC maximum is an aesthetic guideline.

Coliform Bacteria

The coliform group of bacteria has been used as an indicator of the bacteriological safety of water for many years (Health Canada, 1999). These bacteria are always present in the digestive tracts and feces of warm-blooded animals, and their presence in water may indicate pollution. Not all strains of coliform bacteria cause illness in humans, but their presence indicates that pathogens[2] could be present. The most common indicator of fecal pollution is *Escherichia coli*. Complete definition of *E. coli* can be difficult and fecal coliforms (a group including the genera *Escherichi*, *Klebsiella*, and *Enterobacter*) is usually used as a surrogate when assessing water quality. However, once fecal coliforms are detected, follow-up monitoring usually seeks to confirm if *E. coli* is actually present.

The link between forestry activities and the presence of coliforms in streams is somewhat tenuous, although increased surface erosion could transport fecal matter to streams and warmer water could enhance bacteria growth. However, the bulk of increased sediment loads attributable to forestry activity comes from sub-soils (road surfaces and ditches, landslides) rather than topsoil. Increases in coliform bacteria are more likely to arise

[2] Fecal coliforms can be indicators of the presence of other pathogens including *Salmonella*, *Shigella*, *Campylobacter jejuni*, and *Yersinia entercolitica*. They are <u>not</u> good indicators of *Giardia* and *Cryptosporidium* (see Health Canada, 1999).

from other forest activities, notably recreation and range use, which are in some cases indirectly related to forestry development (e.g., new forest roads increasing access). Since warm-blooded wildlife naturally occupy the riparian zones of forest watersheds, identifying the effects of land use change can be difficult.

Canadian drinking water guidelines for coliforms fall into two categories (Health Canada, 1999). The first is used to define the appropriate treatment methods (some combination of coagulation, flocculation, sedimentation, filtration, and disinfection) based on the frequency of fecal and total coliform counts in raw water. The second defines potable water quality, giving a maximum acceptable concentration (MAC) for fecal coliforms of "no organisms detectable" (0 colonies/100 mL). For total coliforms, no sample should contain more than 10 colonies/100 mL. These guidelines have been adopted by B.C.

Giardia and Cryptosporidium

Risks to domestic water supplies from *Giardia* and *Cryptosporidium* have recently drawn considerable attention throughout North America. These organisms are present naturally in watersheds from wildlife, but range use has the potential to increase their presence in water supplies where cattle are permitted to be close to streams. Calves consistently shed more *Cryptosporidium* oocysts than older animals, and the number of oocysts that are shed is significantly reduced after four months (Atwill, 1996). This suggests that keeping calves away from streams is core strategy for reducing risk.

Although both *Giardia* and *Cryptosporidium* are common in cattle, they risks to water quality are only increased if the cysts and oocysts are transported to water bodies. Although small, (oo)cysts are nevertheless particles and must be physically transported to the stream. They settle in fluid at a rate that is roughly described by Stokes law, but tend to attach to larger particles and transport to water bodies is largely governed by the sedimentation characteristics of water bodies (Medema, et al., 1998). Isaac-Renton et al. (1996) found that *Giardia* cyst concentrations were significantly lower in reservoir-settled water than in raw water in the Black Mountain Irrigation District system near

Kelowna. This suggests that cattle grazing upstream from lakes and reservoirs could pose less risk than in streams lacking storage.

Metals

The mechanisms by which metal concentrations in streams could increase as a result of forest harvest activity are limited. Increased surface erosion and leaching could result in increased metal mobility, especially where precipitation pH and soil pH is low, but there is little in the literature to suggest this is the case in B.C. Metals are not even ranked as contaminants of concern from forestry activities in the Pacific Northwest by the U.S. EPA (MacDonald et al. 1991). If metal mobility were to increase, concentrations of iron and aluminum in streams would be most sensitive. Water quality guidelines for aluminum are 0.2 mg/L and 0.1 mg/L (pH >6.5) *dissolved* aluminum for drinking water and aquatic life respectively. The freshwater working guideline for iron is 0.3 mg/L *total* iron, which is the same as the drinking water guideline (aesthetic objective).

APPENDIX B

Watershed Similarity Evaluation:
Case Studies

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An implicit goal of many monitoring programs conducted to assess effects of land use on water quality and quantity is to select streams for monitoring which are sufficiently similar to other streams within the study area to permit some extrapolation of results. However, there is often limited quantitative evaluation of watershed similarity prior to monitoring. This is not surprising, since it is probably impossible to find two (or more) "identical" watersheds with respect to all the variables that influence hydrological and geomorphologic processes. As a result, researchers accept some differences. Determining the degree of acceptable difference is the greatest challenge in setting up impact assessment watershed monitoring programs.

Confronted with this issue, Cheong (1996)[1] developed a method for B.C. to evaluate watershed similarity. The method involves measuring 14 watershed morphometric variables on 1:50,000 scale NTS topographic maps to classify each watershed into one of 11 types. These morphometric variables are highly correlated to hydrological and geomorphologic processes, describe the basic geometry of fluvial landscapes, and are relatively easily measured[2]. They include watershed area, basin perimeter, average slope gradient, length of the main channel, channel gradient, and the areas of ice and lakes.

Summit (1998) used the method to classify and compare 100 West Kootenay watersheds prior to establishing a monitoring network. The watershed types present in the study area are:

Type 2 High proportions of ice and lake, low proportions of steepland (1 watershed);

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[1] The list of references is provided in the main report (Section 11.0).
[2] Our experience is that a technician with the right tools can measure the 14 variables in about 30 to 45 minutes.

Type 5	Quite high proportions of ice and relatively large amounts of steepland (2 watersheds);
Type 7	Low proportions of ice, lake and valley flat; large extents of steepland (47 watersheds);
Type 8	Low proportions of ice and lake cover, and relatively high extents of steepland and valley flat (17 watersheds);
Type 10	Low proportions of ice, lake, steepland, and valley flat (33 watersheds).

Once classified by Watershed Type, a computer program is used to calculate the dissimilarity of watershed pairs, where dissimilarity is scaled Euclidean distance (i.e. the smaller the number the greater the similarity).

The next step is to compare watersheds by four biophysical "filters": geology, soils, biogeoclimatic subzones, and hydrological zone. The watershed pairs that meet all these criteria and have a small dissimilarity value would be the "best" candidates for paired monitoring studies. It is still possible to select pairs with a lower degree of similarity depending on the goals of the monitoring program, and providing that there the statistical monitoring design accounts for these differences.

The Cheong method has also been used to screen watersheds for the location of a paired-watershed study near Cache Creek (Summit, 2001a) and to confirm the suitability of comparing water quality results from three sub-basins (one control and two treatment) in the Upper Penticton Creek hydrological research study (Summit, 2001c).