Chapter 9 Appendices

9.1 Skeena River Water Conservation Project Summary Document, July 2011 (Cortex Consultants)

9.2 Workshop Summary: Defining Methods for Evaluating Indicators of Stream Health

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Appendix 9.1

Skeena River Water Conservation Project

Project Summary

31 July 2011

Preface

WATER…Linking pristine mountaintops to lakeshore and ocean communities, water is the ultimate integrator of every activity that occurs in a landscape. The quantity and quality of freshwater are affected by changes in ecosystem structure and function resulting from global processes, such as climate change, and by local development, such as forest harvesting.

From 2007 – 2011, World Wildlife Fund–Canada (WWF-C) provided funding to develop a framework that places water conservation as one of the primary goals of resource development. The Skeena River Water Conservation Project (SRWCP) was designed to develop and test an approach for managing water values and resource development, using existing land management objectives and scenarios about possible future conditions.

The SRWCP developed over 6 Phases, from July 1 2007 – July 31 2011. Cortex Consultants Inc. was awarded the initial contract for this project in September 2008, and has been involved in each phase of the project since December 2008.

Contract Period	Major Activities
Dec 15, 2008 – Feb 28, 2009	Phases 1,2: internal project communications, action plan, preliminary project charter, preliminary work to establish project steering committee, establish technical team
Jun 11 – Aug 31 2009	Phase 3a: project charter, key audiences, communication materials, overview analytical methods, preliminary desired outcomes/issues, preliminary indicators
Sep 1 – Nov 16 2009	Review FFESC proposals; attend related meetings regarding integration with SRWCP
Jan 13 – Mar 31 2010	Phase 3b: update project charter, update communications materials, complete related initiatives report ,develop internal project mgmt website, support establishment of technical team and domain experts, prepare database design document, develop spatial database, develop Phase 4 workplan
Apr 12 – May 2010	Phase 4: recruit domain experts, revise desired outcomes and issues document, draft model requirements document, implement the spatial data model
Aug 17 – Nov 30 2010	Phase 5: summarize project evolution to August 31, 2010; revise approach to develop proof of concept (POC) prototype and scenario; specify initial scenarios for POC prototype; prepare raster datasets for POC prototype; document prototype models of disturbance processes; document methods, yield tables, and management assumptions for POC prototype; update: issues and outcomes, indicators and requirements documents based on feedback; review InVEST document and develop plan for integration with IWMF; implement forest model for POC scenario; develop and demonstrate prototype to Project Partners; document prototype results; develop phase 6 workplan
Feb 25 – July 31 2011	Phase 6: create a working prototype of the SRWCP analytical framework that is capable of producing illustrative outputs; complete the forestry model and limited versions of other components of the modeling framework (anthropogenic disturbance generator and accumulator, and indicator calculation) and generation of sample outputs; reduce Phase 5 proof-of-concept scenario (POCS) to fit the reduced scope of the modeling framework but include climate change parameters; report and map indicators.

During Phase 4, a significant shift in the focus of the project moved it away from a full pilot towards developing a proof-of-concept analytical framework.

This Project Summary document has been written to provide a full summary of the project and the resulting proof-of-concept analytical framework. The document summarizes the project background, history, and development, describes the characteristics of the project area, and describes the framework used for analyses within the project area (the Integrated Watershed

Management Framework or IWMF, a component of Cortex's CREATe approach for assessing cumulative effects at a landscape scale). Results from the preliminary, proof-of-concept analyses conducted in Phase 6 using the IWMF are also summarized in this document. These preliminary analyses include the following components:

- A process-based forest estate model, built using an optimization approach in Remsoft Spatial Planning Software (RSPS), which provides a base case scenario to use as a proof-of-concept for evaluating the effects of development on values of importance within the project area. Outputs include a series of figures and tables showing harvest levels in different BEC variants in five-year time steps (year 0 – year 250). In the future, this process-based model could be used to explore a variety of different forest management scenarios, the effects of climate change on forest management and associated values, and further development processes could be added to the model.
- Placement of cutblocks and roads during each five-year time step, using a simulation approach in SELES (Spatially Explicit Landscape Event Simulator) to spatially locate cutblocks and roads within the project area, based on outputs from forest estate model in RSPS.
- Generation of indicators using SELES at each five-year time step from present. Two types of indicators are tracked:
  - Areal Indicators: the analysis framework produces comprehensive tables that stratify the study area by several landscape attributes (e.g., landscape unit, BEC variant, seral stage presence of roads or streams, steep slopes) and report the area represented by each strata. From these tables, a wide range of indicators can be produced (e.g., length of roads by slope class, forest harvested by BEC variant, density of road stream crossings by watershed) to assist experts from different fields in assessing potential impacts on a variety of values. In addition, several key indicators are calculated directly from these tables by the analysis framework and presented as maps.
  - Network Indicators: the IWMF is also capable of tracking network indicators—spatial relationships among a number of different networks (e.g., roads, transmission lines, streams) within the landscape. Network indicators take into account the connectivity and hierarchical structure of network elements, such as the accumulation of effects moving down a stream network from headwaters to any point downstream.
- Indicators produced by the current implementation of the analysis framework focus on values related to hydrology, aquatic habitat, and forestry. In addition, the model produces some generalized indicators that would useful for assessing other values, such as those related to wildlife.
  - Concurrent modeling of potential climate change impacts on values within the SRWCP. Three climate scenarios currently accepted as representing a range of potential climatic conditions in B.C. (CGCM3 A2 run 4; HadCM3 B1 run 1; HadGEM A1B run 1; Murdock and Spittlehouse 2010) are used to explore the range of potential shifts in bioclimatic conditions (represented by projecting potential BEC variants) and their potential effects on growth and yield throughout much of the SRWCP project area. Outputs from this modeling may be used in future analyses to modify the forest estate model or to modify indicators of values of interest (e.g., hydrology).

This summary document demonstrates the potential for using the IWMF as a framework for future analyses of cumulative effects within the SRWCP project area. It is hoped that this framework can provide guidance for the development of similar analyses in other areas of the world.

Table of Contents

List of Figures

List of Tables

SRWCP Project Summary

1 Introduction

1.1 Purpose of this document

This document describes the *Skeena River Watershed Conservation Project* (SRWCP), a project that was undertaken by World Wildlife Canada (WWF), in collaboration with Coast Tsimshian Resources (CTR). Initiated in 2007, the SRWCP was designed to develop and test a framework for integrated watershed management in a portion of the Skeena River Basin of northwestern British Columbia.

Over three years of project development (2008-2011), the project's scope changed significantly. Initially designed as a fully developed pilot project, the project scope was reduced in 2010 due to priority changes within WWF-Canada. In the end, the project was completed as a "proof of concept," intended to demonstrate how an integrated watershed management framework (IWMF), a component of Cortex' CREATe[1] approach, could be used at a strategic scale to help make development decisions and assess cumulative effects.

Because of the changes in project scope, no single document accurately describes the final scope, methodology and results from the SRWCP. In addition, no document currently exists that describes the history and evolution of the project from a full pilot to a proof of concept.

This document is designed to fill these purposes, in addition to providing a register of the many documents and products developed over Cortex's three years of involvement with the project. The purpose of this document is therefore:

- To describe the history and evolution of the SRWCP from full pilot to proof-of concept;
- To describe the current scope, methodology and proof-of-concept results from the SRWCP;
- To provide guidance for future cumulative effects analysis projects;
- To provide a register of all documents and products developed by Cortex Consultants Inc. from 2008 – 2011 for the SRWCP.

Section 1 of this document describes background information, project objectives, and affiliated projects. Section 2 describes the history and development of the SRWCP. Section 3 describes biophysical and socio-economic characteristics of the project area. Section 4 describes the methodology employed in the project and the results from Cortex's analyses. Section 5 describes the results of scenario analysis. Section 6 provides a list of all references for the project. All documents referenced in this document are listed in Section 7 (Appendices) and included in a folder appended to this document.

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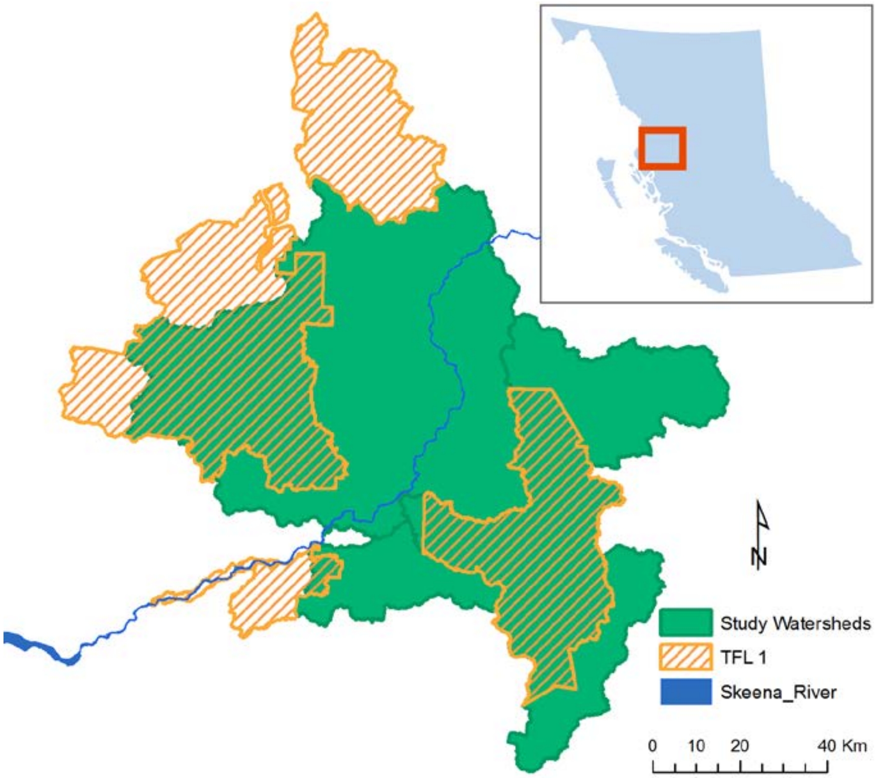
[1] CREATe = Cumulative Regional Effects Assessment Tool: a strategic, integrated framework to assess cumulative effects of different development scenarios on a landscape scale. The CREATe approach is described in Cortex, 2011. Regional Cumulative Effects Analysis: Keeping BC Open for Business. Available for download at: http://www.cortex.ca/d-CEA-KeepingBCOpenForBusiness-15Mar11.pdf.

1.2 Project Background

Citizens, governments, and corporations both in Canada and around the world increasingly recognize the importance of high quality freshwater for sustaining environmental values, economies and healthy societies and ecosystems. The *Skeena River Water Conservation Project* (SRWCP) was commissioned by the World Wildlife Fund Canada to develop and apply an analytical framework that facilitates structured decision-making for resource management activities in a regional study area. This framework is compatible with other decision-making frameworks undertaken by WWF that seek to balance wise resource use with land management objectives (e.g., InVEST; Tallis et al. 2010).

The SRWCP study area includes three watersheds (the Kalum River, Zygometz River, and Lakelse) and those portions of Tree Farm Licence #1 (TFL 1) that extend beyond the three major watersheds (Figure 1). Resource management activities in the study area currently include forestry, fishing (commercial and recreational), tourism, and mining. Pipelines, independent power projects (IPPs), and associated roads and transmission lines have been proposed for the area.

Figure 1. Map view of the SRWCP study area



1.3 Project Partners

Coast Tsimshian Resources (CTR) LP (wholly owned by the Lax Kw'alaams First Nation and supported by Brinkman Forest Limited) agreed to work in partnership with WWF-Canada in the development and implementation of the *Skeena River Water Conservation Project*.

The partners shared a common desire to address freshwater conservation issues as a means of conserving or improving the wellbeing of communities facing impacts of climate change. Each partner (through its implementing agencies) also had specific interests:

- WWF-Canada was interested in developing:
  - a systematic understanding of how disturbances due to climate change, resource and infrastructure developments will affect ecosystem functions
  - a process for assessing the aggregate effects of development, as constrained by various federal and provincial policies (e.g., federal wild salmon policy[2], BC Water Act[3]), on local and regional freshwater conservation values
- The Lax Kw'alaams First Nation[4] was seeking the highest standard of forest management through their investments in the forest industry, achievement of the highest level of social, economic and environmental benefits from their resource interests, as well as stewardship of biodiversity and cultural values on their traditional territory.
- As the tenure holder for Tree Farm Licence #1 (TFL 1), Coast Tsimshian Resources LP (CTR)[5], wholly owned by the Lax Kw'alaams First Nation, was seeking to apply innovative, effective approaches to meeting its land management goals and regulatory obligations, demonstrate leadership among First Nations licensees in the region, while building a competitive, profitable forest products company.
- As the operations manager for the forest tenures of CTR, Brinkman Forest Ltd[6] was obligated to implement financially feasible forest practices consistent with higher-level plans and government regulations.

1.4 Project Methodology

The SRWCP was designed as a strategic, scenario-based process that used indicators to explore the impact of multiple disturbance types, landscape dynamics and climate change scenarios on values of importance within the project area, including water quality, ecological and social objectives.

The process[7] for developing the SRWCP project included the following steps:

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[2] Fisheries and Oceans Canada, 2005. Canada's Policy for the Conservation of Wild Pacific Salmon. http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/default_e.htm

[3] http://www.qp.gov.bc.ca/statreg/stat/W/96483_01.htm

[4] http://www.laxkwalaams.ca/

[5] http://www.ctrlp.ca/

[6] http://www.brinkmanforest.com/page140.htm

[7] Note that this describes the approach used in the final, proof of concept version of the SRWCP. The original project plan was collaborative in nature, and including working within a clearly defined governance model that incorporated project advisors (all First Nations with traditional territories in the area, and high level government support); technical advisors (representatives for all of the values being incorporated into the SRWCP) and domain experts (specific technical expertise for values that were of particular interest in the project area). The original governance structure for the project is described in *SRWCP Project Governance, April 2010* and in Section 2.0 of this report. The full process, developed by Cortex Consultants and based on work done in previous cumulative effects analyses, has been termed "CREATe": Cumulative

1. Delineate the spatial and temporal extent for the project, and the spatial and temporal resolution for analysis.
2. Identify values (outcomes and issues) important within the project area[8].
3. Compile all data sources into an SRWCP data dictionary.
4. Identify appropriate indicators (numerical representatives) for each of the values of interest within the project area. Indicators must work at the scale of analysis and be projectable through time.
5. Develop the modeling framework, using a combination of Remsoft Spatial Planning Suite (RSPS), SELES, ArcGIS, and other analysis tools as required.
6. Run the modeling framework on a proof-of-concept management scenario, and three climate change scenarios[9] for a subset of indicators. Assess scenarios for their impacts on water conservation and other environmental, social, and economic values[10].
7. Fully document the approach and the framework, to facilitate further analysis (including adding other values and exploring other scenarios) in the future.

1.5 Project Objectives

As stated in the SRWCP Project Charter V4.1 (29 March 2010), the *Skeena River Water Conservation Project* originally had seven objectives:

1. **Identify water management issues and objectives in the lower Skeena River basin.**
2. **Develop an analytical framework for integrating water and biodiversity objectives, climate change effects, anthropogenic disturbance, and existing policy and regulation.**
3. *Develop a project governance structure and project organization that is appropriate for integrating environmental, social, and economic objectives in the context of climate change.*
4. *Promote watershed governance through collaborative working relationships.*
5. *Identify the required changes, if any, to legislation, regulation, and policies to manage for water conservation objectives in the context of climate change.*

Regional Effects Analysis Tool. Section 4.0 of this report describes the CREATe process and identifies which parts of the process were implemented in the SRWCP.

[8] Initially this work was done through a review of existing land use plans and other reference documents; however, in the final version of the SRWCP, the analysis focused on hydrological and aquatic values, economic values related to timber harvesting, and an assortment of other metrics related to wildlife habitat and ecosystem structure.

[9] The original project plan included development of multiple scenarios that incorporate assumptions about disturbances (e.g., harvesting intensity and methods, increases in precipitation and water temperature) and management of development (e.g., integrating ecological integrity and human wellbeing, constraints on pipeline location, minimum span networks of transmission lines).

[10] The original project plan included exploring a large number of values (e.g., water quality and quantify, forest management, wildlife habitat, connectivity, etc.) and development impacts (e.g., forest harvesting, independent power producers, mining, pipelines, etc.); however, these lists were curtailed in the final project iteration to include only forest estate modeling, aquatic indicators, hydrology, and climate change.

6. **Inform strategic and operational planning on TFL 1 with respect to water conservation issues in the study area.**
7. **Document the project structure and methodology, its findings, and what was learned about the process, and discuss how this framework could be applied in other watersheds.**

Of these original seven objectives, aspects of the four listed in bold pertain to the final form of the project[11].

1.6 Project Scope

The initial project scope for the SRWCP is defined in the SRWCP Charter (Version 4.1, 29-Mar-10). The geographical scope of the project has not changed, nor has the strategic scale of analysis. However, the scope of development impacts and values under consideration in the final iteration of the project has changed significantly, as has the scope of involvement for other parties.

1.7 Affiliated Projects

The SRWCP is affiliated with “Climate Change Adaptation Planning for Northwest Skeena Communities”, a research project funded by the Future Forest Ecosystem Science Council (FFESC) of British Columbia.

Results from the SRWCP are expected to inform forest planning by CTR on TFL 1 (see Figure 1).

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[11] Objective 6—informing planning on TFL 1—was only partially achieved. Early in the project, CTR declined to contribute financially to the project due to business reasons, but provided access to proprietary forest cover data. No economic data pertaining to the value of the forest cover, nor operating costs, were available to the project, which limited the utility of the analysis to inform operational and strategic planning on TFL 1.

2.0 SRWCP History and Development

This section describes how the Skeena River Water Conservation Project (SRWCP) developed from its initial scoping in 2007, to June 2011. The content has been summarized from an earlier document (*SRWCP Project Evolution V1*). Portions of this document are excerpted below; the full document is provided in Appendix A.

2.1 Project Initiation and Timeline

In 2007, WWF-Canada was interested in selecting a candidate area in British Columbia to pilot a new approach to watershed development. They envisioned partnerships with local governments and land managers to guide the project and ensure results were integrated into policy, collaboration with local stakeholders to ensure values of importance were reflected in the analysis, and the development of an integrated watershed management framework that could be applied in other areas to assess the cumulative impacts of development and climate change on water and water-based resources.

In 2007-2008, initial work on developing preliminary goals, objectives, approach, assessing candidate watersheds for the pilot project study area, and determining high level costs and timeline was carried out by Bill Bourgeois, New Direction Resource Management Limited[12].

After evaluating six candidate areas in northwestern British Columbia, WWF-Canada selected the project area as defined in Figure 1 of this report (Section 1.4). This area was well suited for piloting a new approach to watershed development: local collaborators were interested and engaged, considerable work had been done previously on water quality and fish habitat, and the area is under increasing pressure for environmental services.

2.2 Role of Cortex Consultants Inc.

In 2008, WWF-Canada selected Cortex Consultants Inc. (Cortex) as the service provider for development of the SRWCP. Cortex's involvement in the project is summarized in Table 1, below.

Table 1. Cortex SRWCP contract history

Contract Period	Major Activities
Dec 15, 2008 – Feb 28, 2009	Phases 1,2: internal project communications, action plan, preliminary project charter, preliminary work to establish project steering committee, establish technical team
Jun 11 – Aug 31 2009	Phase 3a: project charter, key audiences, communication materials, overview analytical methods, preliminary desired outcomes/issues, preliminary indicators
Sep 1 – Nov 16 2009	Review FFESC proposals; attend related meetings regarding integration with SRWCP
Jan 13 – Mar 31 2010	Phase 3b: update project charter, update communications materials, complete related initiatives report ,develop internal project mgmt website, support establishment of technical team and domain experts, prepare database design document, develop spatial database, develop Phase 4 workplan
Apr 12 – May 2010	Phase 4: recruit domain experts, revise desired outcomes and issues document, draft model requirements document, implement the spatial data model
Aug 17 – Oct 31 2010	Phase 5: summarize project evolution to August 31, 2010; revise approach to develop

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[12] *WWF–Canada Water Management Project Phase 1 Report. January 29, 2008.*

	proof of concept (POC) prototype and scenario; specify initial scenarios for POC prototype; prepare raster datasets for POC prototype; document prototype models of disturbance processes; document methods, yield tables, and management assumptions for POC prototype; update: issues and outcomes, indicators and requirements documents based on feedback; review InVEST document and develop plan for integration with IWMF; implement forest model for POC scenario; develop and demonstrate prototype to Project Partners; document prototype results; develop phase 6 workplan
Feb 25 – July 31 2011	Phase 6: create a working prototype of the SRWCP analytical framework that is capable of producing illustrative outputs; complete the forest cover model and limited versions of all other components of the modeling framework (anthropogenic disturbance generator and accumulator, and indicator calculation) and generation of sample outputs; reduce proof-of-concept scenario (POCS) to fit the reduced scope of the modeling framework but include climate change parameters; report and map indicators.

2.3 Project Phases

Table 2 describes all phases of the project and illustrates succinctly how the project evolved from a fully-developed pilot project, as it was originally conceived, to the proof-of-concept (POC) version of the SRWCP.

As noted below, the project shifted from its original scope first in March 2010, when the role of project coordinator was discontinued, signaling a desire within WWF-Canada to coordinate this project internally, and again in July 2010, when difficulties with securing technical advisors and domain experts (see next section for a description of these roles) necessitated the move to a proof-of-concept approach.

Table 2. SRWCP key products and milestones, July 2007 to June 2011

Project Scoping	
Jul 2007	Overview of important biological and physical values of Kalum, Lakelse, and Zygometz watersheds; natural and anthropogenic processes; current land use, research, and conservation initiatives (Cambria Gordon)
Aug 2007	Identification of preliminary goals, objectives, and approach to developing a pilot project to demonstrate a collaborative approach to integrated watershed management (Bourgeois)
Jan 2008	Recommendations for WWF-Canada “Water Management Project” (which would eventually become the Skeena River Watershed Conservation Project), including scope, goals, objectives, outcomes, strategic framework (Bourgeois)
	Determination of initial costs and initiation of fundraising for project (Bourgeois, WWF)
May 2008	SRWCP planning framework (Bourgeois)
June 2008	Draft SRWCP vision and goal statements (Bourgeois)
July 2008	Cortex submits a proposal and makes a presentation in response to WWF Request for Proposals
Aug 2008	Draft SRWCP governance model (Bourgeois)
Sept 2008	WWF notifies Cortex that it will be awarded a contract for SRWCP modeling services. A second project was to be initiated with Coast Tsimshian Resources (CTR) to assist with development of Management Plan 11 for TFL 1.
	Cortex presents its interpretation of the SRWCP project requirements to WWF staff (Michelle Patterson, James Casey) and SRWCP Project Coordinator (Bourgeois).
Dec 2008	SRWCP overview (Bourgeois)

Project Initiation	
Jan 2009	Letter of Agreement between WWF-Canada and Coast Tsimshian Resources for the period Jan 2 – Dec 31, 2009, outlining their collaborative relationship and commitments related to organizing, implementing, and reporting on the SRWCP
Mar – Jun 2009	Project Charter version 1 and workplan (Cortex).
	Proposed project governance structure, including members of a technical team and constituent domain experts.
	Clarification of the linkages between the SRWCP and TFL 1 Management Plan 11.
May 2009	Cortex presentation to CTR/Brinkman re: SRWCP and its relationship to TFL1 MP 11; tasks involved in preparing MP 11
June 2009	Cortex presentation to WWF and CTR Brinkman re: overview of SRWCP and analytical approach
Nov 2009	Federal Regional Adaptation Collaborative (RAC) funds approved for SRWCP
Dec 2009	Michele Patterson resigns from WWF; Darcy Dobell is appointed Regional VP and assumes responsibility for WWF role in SRWCP
Jan 2010	Dirk Brinkman replaces Brendan Wilson/Jon Schulz as CTR representative for SRWCP, and Richard Chavez replaces Duncan Dow as CTR Project Leader
Feb 2010	CTR delays development of TFL 1 Management Plan 11 and reduces its participation in SRWCP (ground-truthing SRWCP results; developing operational guidelines)
Mar 2010	Revise project governance structure and roles of project advisors, technical advisors, and domain experts (Cortex) Project Coordinator contract ends and role is discontinued
Project Planning	
Jan 2009	Develop phase 2 workplan, budget
Jun 2009	Develop phase 3a workplan, budget
Sep 2009	Meetings regarding coordination and integration of SRWCP/TFL 1 MP 11 and FFESC project “Climate Change Adaptation Planning for Northwest Skeena Communities”
Jan 2010	Develop phase 3b workplan, budget
Feb - Mar 2010	Develop phase 4 workplan, budget
	Identify and assess project risks, develop risk responses (Risk Register V2)
Jul 2010	Revise SRWCP project approach to focus on the development of a partial prototype of the forest model and cumulative effects integrator by September 30, 2010 (Phase 5)
Jan 2011	Develop phase 6: working prototype of the SRWCP analytical framework that is capable of producing illustrative outputs. Report on results and conclude project.
Project Execution	
Jun – Aug 2009	Development and completion of Phase 3a deliverables: • SRWCP target audiences and recommended communication products, • Profiles of local initiatives in Skeena River watersheds deemed to be relevant to SRWCP • SRWCP overview document and PowerPoint presentation for stakeholders and funders • SRWCP analytical methods overview • SRWCP synthesis of outcomes and issues from regional and sub-regional land use plans • SRWCP preliminary recommendations on indicators and data requirements • SRWCP Project Charter updates (versions 2, 3).

Feb – May 2010	Development and completion of Phase 3b deliverables: • SWCP Project Charter update (version 4) • Communication product updates (Key Audiences; Related Initiatives; Overview document and PowerPoint) • SWCP project management website • SWCP spatial database – design documents and initial spatial database • SWCP Integrated Watershed Management Framework (IWMF) conceptual model.
Feb 2010 - ongoing	Solicitation of project advisors (SRWCP Project Leaders), technical advisors, domain experts (Cortex)
Aug 31 2010	Completion of Phase 4 deliverables to Aug 31, 2010: • Project evolution to Aug 31, 2010 (status, issues, key learnings) • Revised approach to develop proof of concept (POC) prototype and scenario" • Initial scenario specifications for POC prototype • Raster datasets for POC prototype • Document describing prototype models of disturbance processes • Methods, yield tables, and management assumptions for POC prototype • Updated SWCP Integrated Watershed Management Framework (IWMF) conceptual model with Indicators and added ongoing methodology changes • Review InVEST document and develop plan for integration with IWMF
Nov 30 2010	Completion of Phase 5 deliverables to Nov 30, 2010: • Implementation of forest model for POC for SRWCP study area • Develop disturbance and indicator database structure code • Demonstrate functional model to project partners • Populate disturbance and indicator database with prototype POC results • Develop brief document describing cumulative disturbances, resulting indicators and impacts on values • Document project completion and scenario analysis
July 31 2011	Completion of Phase 6 deliverables to July 31, 2011: • Implement aquatic indicators and provide documentation to WWF-Canada • Make revisions to the forecasts from the Forest Estate Model and spatialized harvest schedule • Implement and provide documentation to WWF-Canada of climate change effects and hydrology indicators. Provide document of revised POC scenario assumptions and results. • Provide WWF-Canada with final documentation of analysis framework • Run POC scenario with implemented changes • Complete project

2.4 Initial Governance Structure

The initial governance structure for the SRWCP is described in SRWCP Project Governance (*SRWCP Governance Overview V2*). The seven roles highlighted in this document are described below.

Project Partners and Project Leaders

Project partners and project leaders were responsible for:

- confirming SRWCP vision, objectives, and values to be considered
- providing senior management oversight and key partner decision making to the project
- adjudicating project implementation problems and governance issues

- recommending the preferred scenario(s) to decision makers.

Project Manager

The project manager was intended to work closely with the project leaders and modeling team, managing project scope, costs, and schedules to meet the project objectives.

Project Advisors

Project advisors were intended to be drawn from key BC Ministries and First Nations with traditional territories in the study area, to provide high-level advice to the project leaders on strategic issues in the study area, and ensure First Nations and stakeholder values were considered.

Technical Advisors

Technical advisors were intended to provide advice on design of the IWMF, interpretation of scenario results, and on inclusion of socioeconomic, cultural, and environmental values not explicitly considered in the modeling framework (i.e., issues and associated indicators not under review by a specified domain expert).

Domain Experts

Domain experts, a subset of the technical advisors, were intended to provide input to the modeling team on IWMF design and scenario analysis related to specific areas of expertise.

Modeling Team

The modeling team, provided by Cortex Consultants Inc., was tasked with:

- developing the Integrated Watershed Modeling Framework (IWMF)
- collaborating with domain experts to ensure that the IWMF appropriately represents processes and/or generates indicators that they require for analysis of effects
- coordinating the development and analysis of scenarios
- reporting findings to the project manager, project leaders, and project partners.

A process for soliciting project advisors, technical advisors and domain experts was outlined in *SRWCP Advisors Solicitation V5*.

2.5 Final Governance Structure

The final governance structure for the SRWCP was limited to the following roles:

- Project Partners and Project Leaders
- Project Manager (from Cortex Consultants Inc.)
- Modeling Team (from Cortex Consultants Inc.)

The SRWCP Project Evolution document describes in some detail the effort made to secure technical advisors and domain experts, and the reasons that these roles were dropped in the final version of the SRWCP (*SRWCP Project Evolution V1*, Section 4.3; full document available in Appendix A).

2.6 Stakeholder Involvement

The SRWCP was originally conceived and funded as an autonomous strategic planning initiative in the lower Skeena River basin. Its objectives work towards developing an implementable approach to conserving and maintaining regional water quality and quantity objectives within the context of human activities (industrial, agricultural, recreational, and traditional), conservation objectives, and the potential effects of climate change. The project was intended to build on and contribute to other regional initiatives.

A document identifying key stakeholders and appropriate communication materials, and summarizing related initiatives in the study area was produced in March 2010 (*SRWCP Related Initiatives*). A list of SRWCP audiences was also produced in March 2010 (*SRWCP Audiences*).

WWF assumed responsibility for developing and implementing communication plans for First Nations and stakeholders in the area, as of June 2010. It is unknown whether communications with stakeholders and First Nations will continue once the technical analysis for this project has been completed; both WWF-Canada and Cortex Consultants agree that effective communications with stakeholders, First Nations and decision-makers is an integral part of ensuring the results from the SRWCP can be implemented within the project area.

Other issues with regards to communications with stakeholders are noted in the *SRWCP Project Evolution* document.

2.7 Changes in Technical Analysis

The SRWCP was originally conceived as a fully developed pilot project that would analyze, at a strategic scale, the cumulative effects of multiple disturbances on myriad of values over a 250-year time frame. While the scope of analysis and the technical approach to the analytical framework did not change, considerable difficulties with securing involvement from technical advisors and domain experts, combined with a reduction in funding from WWF-Canada, made it necessary to reduce the number of disturbances and values considered in the final, proof of concept version of the analysis.

The original analysis framework involved identifying values of importance, identifying potential indicators for these values, securing sources of data to support those indicators, building the analysis framework and the data dictionary, identifying scenarios to explore based on multiple future disturbances planned for the area (*learning scenarios* and *policy scenarios*), and producing results for those scenarios. In the final iteration of the SRWCP proof-of-concept, three disturbance factors were selected as the focus (forestry, roads and climate change). These three factors were explored for their impacts on hydrology, aquatic habitat, and harvest levels, using one “base-case” scenario and three potential climate change scenarios for selected components.

Earlier technical documents from the SRWCP describe the original analytical concept and identify potential indicators to explore values of interest within the SRWCP project area (*SRWCP Analytical Methods 05Aug09; SRWCP Preliminary Indicators Associated Data Apr10; SRWCP Outcomes and Issues May10*). These documents are included in Appendix B, for reference. Together, these documents present a very useful summary of the issues of importance within the SRWCP project area, and should be referenced if future analysis work is done in the project area.

The overall technical approach is described in *IWMF Conceptual Model 26Aug10* and two presentations (*POC Presentation 30Nov10; FFESC Presentation 17Feb11*). Initial scenario specification (Proof-of-Concept Scenario – POCS), management assumptions and modeling methodology for the forest management disturbance model component of the Integrated Watershed Management Framework (IWMF) are described in *SRWCP POCS Forest Model Data, Methods and Management Assumptions 26Aug10*; the current state of anthropogenic disturbance modeling (excluding forestry) within the IWMF is described in *SRWCP POCS Anthropogenic Disturbance Model Methods and Assumptions 31Aug10*. Indicators used in the POC version of the SRWCP are described in *SRWCP POCS Indicators 30Nov10*. The SRWCP database is described in two documents (*SRWCP Data Model Spatial Database 28Feb10; SRWCP_Raster_Datasets_for_Forest_Anthropogenic_and_CEA_Model 26Aug10*). Results from the forest landbase analysis are summarized in *SRWCP Forest Model Base Case Figures 29Nov10*.

All of the documents listed above are included in Appendix B of this summary document.

Some aspects of the IWMF have changed since these documents were produced; this summary document includes a full description of all framework components implemented for the final SRWC POC scenario.

2.8 Conclusion – Moving Forward with the Proof of Concept in the SRWCP

Significant changes to the SRWCP have resulted in a much narrower scope for the final version of the project. Reduced coordination with interested parties in the region and minimal ongoing project communications significantly reduced the likelihood that current project outcomes will be incorporated into resource management decision-making. The lack of meaningful involvement from technical advisors, and particularly domain experts, significantly reduced the analytical scope, primarily to the technical expertise Cortex was able to provide in-house. The implications of these changes are outlined in some detail in the *SRWCP Project Evolution* document.

With those limitations noted, the final proof-of-concept version of the SRWCP does have some significant benefits. By developing a robust analytical framework based on a real life situation, Cortex has successfully demonstrated that this type of approach can support a strategic-scale analysis of cumulative impacts within a defined project area. The approach is flexible and could be applied to other, strategic scale cumulative effects analyses. Furthermore, WWF has expressed interest in pursuing collaboration with communities, industry, and other stakeholders to further develop and implement the analytical framework.

The remainder of this document focuses on the proof-of-concept version of the SRWCP. Differences between the original project plan and the POC version continue to be highlighted where appropriate.

3.0 Characteristics of the Project Area

3.1 Project location

The SRWCP is located within the Skeena River Basin, fully encompassing three watersheds (the Kalum River, Zygometz River, and Lakelse) and those portions of Tree Farm Licence #1 (TFL 1) that extend outside the three major watersheds (Figure 1).

3.2 Biophysical Characteristics of the Project Area

The project area is found within the transition zone between coastal and interior biogeoclimatic zones. The majority of the area falls within the Coastal Western Hemlock zone and the Mountain Hemlock zone, while some eastern portions fall within the Interior Cedar Hemlock zone, the Engelmann Spruce – Subalpine Fir zone, and the Sub-boreal Spruce zone. Elevation within the project area varies from 2 m to 2751 m above sea level.

The study area is characterized by extreme topographical relief resulting in narrow watercourses at the base of steep slopes. The hydrology of the Skeena River basin is characterized by a spring/early summer peak discharge driven by snowmelt; most floods occur during this period (de Groot, 2005). Smaller watercourses within the project area may be more affected by peak flows in fall/winter, characteristic of smaller, coastal watersheds (Gottesfeld et al. 2002). The climate is submaritime and has warm moist summers with significant dry periods and very wet winters (Banner et al. 1993).

The SRWCP project area supports important wildlife habitat. The Skeena River basin is the second most productive salmon river in BC. The area provides habitat for many other fish species, as well as terrestrial wildlife such as grizzly bears, black bears, moose, caribou, mountain goats, and numerous other wildlife species. A more detailed description can be found in section 3.6.1.

3.3 Natural disturbances within the Project Area

Natural disturbances such as wildfires and some forest pests (insects, fungi) can affect large patches of the landscape and can have a very intense effect within these patches, often resulting in the death and sometimes removal of the majority of the overstorey trees. The prevalence of these disturbances varies greatly among regions and ecosystems. For example, stand-replacing fires are common throughout much of the interior of British Columbia; however, fire is very rare in wetter coastal ecosystems (Wong *et al.* 2003).

For most of the SRWCP project area, forest fires are generally expected to occur very infrequently, with gap-dynamics dominating as the primary disturbance process; however, some eastern portions of the study area may be more likely to experience stand-replacing wildfires (Wong *et al.* 2003). The national Large Fire Database[13] shows very few, small fires in the SRWCP study area from 1959-1999. Changes in climate variables, such as increases in annual temperature and potential changes in precipitation patterns, may increase the underlying susceptibility of the landscape to forest fires.

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[13] Canadian Wildland Fire Information System Large Fire Database – Point Version http://cwfis.cfs.nrcan.gc.ca/en_CA/lfdb/59-99. Accessed 31 May 2010.

There is little history of stand-replacing forest pest disturbances in the SRWCP study area. More geographically constrained natural disturbance types (small-scale windthrow events, local landslides, ground fires, etc.) do occur throughout the area and can be incorporated within the SRWCP analytical framework as adjustments to forest and hydrology state variable values.

3.4 Potential Impacts of Climate Change

The initial review of projected climate conditions for the study area indicates that: (1) increases in average temperatures are expected, and (2) summer precipitation is expected either to not change over historical levels or may be expected to increase[14]. The magnitude of changes is strongly dependent on the climate change scenario examined. The three climate change scenarios chosen deliberately cover a wide range of potential future climates, because the effects of assumptions about future emissions controls, economic development and potential mitigation measures are quite uncertain. Note that CGCM3 A2 run 4 may be termed a "global business as usual" (BAU) climate scenario with generally high emissions, but with a regionally diverse world that is rapidly growing; HadCM3 B1 run 1 projects generally cooler and moister conditions globally than BAU. It assumes the lowest emissions of the three climate scenarios, and assumes global sustainability. HadGEM A1B run 1 is a generally hotter and drier global climate assuming intermediate emissions but with a more homogenous world and rapid growth (see Murdock and Spittlehouse 2010; Crookston et al. 2010).

Predictions of future effects of climate change in the study region are very uncertain for several reasons. These include: (1) uncertainties in the magnitude of contributing sources (e.g., anthropogenic and natural) and in the carbon cycle response (Zickfeld et al. 2009); (2) challenges in downscaling predicted climatic patterns in individual variables to the fine-scale resolutions desired for ecological analysis (Murdock and Spittlehouse 2010), and (3) because of linkages between regional-continental climate regimes and oceanic conditions affecting sea-surface temperatures (e.g., the El Niño-Southern Oscillation (ENSO), and Pacific Decadal Oscillation (PDO) (see Kitzberger et al. 2007). Therefore, we caution that any projections of indicators under one or more climate change scenario should not be interpreted as a prediction, but rather used only in a comparative sense to explore relative sensitivities of values to potential climatic futures.

3.5 Land Use Plans and Management Tenures

The SRWCP project area falls primarily within the Kalum Forest District, with portions extending into the Skeena-Stikine, Nadine and North Coast Forest Districts. Management in the area is guided by several higher level plans (HLPs), including the Kalum LRMP (Land and Resource Management Plan) and SRMP (Sustainable Resource Management Plan), the Bulkley LRMP, the Kispiox LRMP and SRMP, the Morice LRMP, and various First Nations land use plans.

As of 2011, there is one tree farm license (TFL) in the area (TFL 1) along with the TSAs (Timber Supply Areas) associated with each forest district. Coast Tsimshian Resources LP (CTR), wholly owned by the Lax Kw'alaams First Nation, holds the tenure for TFL 1. Brinkman Forest Ltd is the operations manager for the forest tenures of CTR.

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[14] The Pacific Climate Impacts Consortium – Climate Overview
http://pacificclimate.org/resources/climateimpacts/overview/. Accessed 31 May 2010.

3.6 Desired Outcomes and Associated Issues from Land Use Plans

Cortex's project team used existing land use plans and management plans to identify important values within the SRWCP project area (*SRWCP Outcomes Issues May10,* Appendix B). Because the Kalum Forest District covers 77% of the study area, its planning documents were particularly relied upon for defining values of importance within the study area. The TFL 1 Management Plan 10, and the most recent TFL 1 AAC Rationale were also used as sources of information for the SRWCP. A brief summary of the values and desired outcomes detailed in these planning documents follows.

3.6.1 Ecological Values

The Skeena River is the second most productive salmon river in BC with annual escapements of nearly 2 million fish. The study area is used by many fish including all five species of Pacific salmon, Dolly Varden, steelhead, and cutthroat. Resident species present in the system include rainbow trout, cutthroat trout, Dolly Varden, bull trout, mountain whitefish, and the following coarse fish: prickly sculpin, largescale suckers, redside shiners, northern pikeminnow, peamouth chub, and threespine stickleback (Skeena Fisheries Commission 2003).

There are 19 vascular plant species, and 12 wildlife species on the CDC Red and Blue lists for the Kalum Forest District. A number of rare mosses are also known in the area (de Groot 2005). Species of wildlife that are specifically mentioned in planning documents for the study area include moose, marmots, Kermode bears, grizzly bears, black bears, mountain goats, trumpeter swans, bats, eagles, caribou, tailed frogs, fisher, northern goshawk, deer, and great blue herons.

Protecting threatened/endangered plant communities and habitats for aquatic animals (particularly salmon) and species at risk occurring in the study are highlighted within relevant planning documents as key issues related to the ecological values in the area.

3.6.2 Socio-economic Values

Historically, the local economy has been based on forest harvesting, although recreation and tourism are increasing in importance. Other areas of increasing economic activity include independent power production and mineral extraction.

A desire to maintain community sustainability and socioeconomic wellbeing is either directly or indirectly stated in most of the HLPs, although only the Morice LRMP directly states economic issues and objectives. However, key issues related to the local economy can be inferred from all the HLPs including maintaining community resiliency through cultural and economic diversity and sustainable revenue from forest harvesting.

Forest harvesting

Timber harvesting and sawmilling have long been key components of the local economy throughout the study area and the HLPs recognize the continued importance of these activities to the socioeconomic well-being of the region. The primary issue related to timber harvesting is the increased recognition and accommodation of other forest resources and values. Due to potential reductions in the area of forest land and/or the volume of timber available for harvesting, the HLPs discuss the need to focus on silviculture to increase stand volume and value. The HLPs also mention the need for a sustainable long-term flow of timber and the need to maintain indigenous tree species diversity.

Trapping

Trapping is a traditional activity of First Nations within the study area and has a long history among non-First Nations residents. Therefore, it is important to maintain opportunities for trapping throughout the study area. Issues associated with trapping primarily focus on ensuring viable populations of fur-bearing animals by protecting their habitat, which is often associated with conserving mature forest. Specific species mentioned in higher-level plans include beaver, fox, skunk, squirrel, weasel, lynx, bobcat, wolverine, fisher, otter, rabbits, marten, grouse, wolf, coyote, and black bear. An additional issue associated with trapping is maintaining access to trap-line areas and cabins.

Mineral Development

Little mention is made in the planning documents of objectives, outcomes, and issues associated with mineral development apart from its possible contribution to the local community, possible impacts of mineral development on other resource values, and limited access possibly restricting exploration activities.

Agriculture

The majority of agriculture that occurs in the study area is range-related although there is some crop-based farming as well. The primary issue with respect to agriculture is the loss of rangelands to forest encroachment and full consideration of range values relative to other values when making land-use decisions.

Independent Power Production

Though there is little mention of IPPs in existing planning documents, several run-of-the-river hydro-electric projects have been proposed within the project area. Collectively, these may constitute a significant impact in the future.

Other

Other socio-economic values in the area include pipelines and non-timber forest products; these are not discussed at length in the land use plans consulted for this project.

4.0 SRWCP Analytical Framework

4.1 CREATe – Cumulative Regional Effects Analysis Tool

Cortex's modeling team has been involved with three landscape scale cumulative effects analyses in British Columbia, and has developed some of the pioneering work on regional CEAs in BC. Through this experience, the modeling team has developed an approach that can be used to analyze the cumulative impacts of multiple anthropogenic and natural disturbance factors on watersheds at a strategic scale. Cortex's approach is called CREATe[15], a cumulative regional effects analysis tool that can be adapted for use across different landscapes and to meet varying requirements for stakeholder and community involvement, depending on the requirements of the cumulative effects analysis (CEA).

The CREATe approach has been designed with the following key characteristics:

- **Collaborative or consultative**, depending on the requirements of the CEA process. This flexibility is in place to acknowledge the fact that, while CEA processes should be fully collaborative, involving all decision-makers and stakeholders who are concerned about future development impacts within a defined area, funding constraints sometimes restrict the capacity for processes to be fully collaborative.
- **Spatially explicit**, with the capacity to show where future development will take place. This factor is important for stakeholders and decision-makers to visualize where future development impacts may occur.
- **Incorporates broad societal values**, building on values identified through previous or ongoing planning processes (e.g., Land and Resource Management Plans, First Nations land use plans, Sustainable Resource Management Plans, or other planning documents) and values identified upfront within the CEA process.
- **Scenario-based**, with scenario analysis used to predict management outcomes under different sets of assumptions about exogenous processes, societal values, and the timeline and outcome of management activities. Further information on the scenario analysis component of the CREATe framework is provided later in this section.
- **Incorporates climate change**, to look at the interaction between development impacts and potential future climates within a defined project area.
- **Involves local and domain experts**. This component is critical to ensure that results are interpreted by local technical experts who understand the nuances of interpreting indicator values at a local level.

The CREATe approach includes three broad components, each of which are critical for the development of an effective cumulative effects analysis that can be interpreted and applied at a local level:

- **Component 1:** Project Development, which includes defining the following components for a specific CEA:
  - Define purpose (goals, objectives)
  - Determine scope (baselines, spatial and temporal extent)

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[15] The CREATe approach is described in Cortex, 2011. Regional Cumulative Effects Analysis: Keeping BC Open for Business. Available for download at: http://www.cortex.ca/d-CEA-KeepingBCOpenForBusiness-15Mar11.pdf.

  - Identify audiences
  - Develop governance model
  - Identify values and issues
- **Component 2:** Analysis Framework, which includes the steps listed below. Components listed in blue text are those that require involvement from local and domain experts:
  - Define indicators based on values and issues, available models, available data, and predictive strength.
  - Select scenarios to explore. These are typically divided into *learning* scenarios, which explore extremes to help define the limits of a particular landscape; and *policy* scenarios, which explore more realistic potential futures for a project area. Potential future climate scenarios are also defined within this component of the CREATe framework.
  - Forecast future landscapes, integrating disturbances of interest, which may include: climate change, forestry, roads, run-of-the-river hydro-electric projects, mining and mineral extraction, natural disturbances, and other anthropogenic disturbances specific to a particular study area.
  - Predict indicators. More information on indicators is included below.
  - Interpret indicator values for impacts on values such as employment, air quality, water quality, wildlife impacts, salmon populations, etc.
- **Component 3**: Application of results, which includes working with regional decision-makers and key stakeholders to identify key changes that need to occur to allow for implementation of results. Theoretically[16], this component could include:
  - Developing an implementation strategy (identifying key audiences, desired outcomes, and strategies to achieve desired outcomes);
  - Implementing the strategy (selecting priority actions; piloting strategies to ensure effectiveness; broad roll-out of strategies; evaluating effectiveness);
  - Feedback to analysis framework.

The CREATe framework is depicted in Figure 2, below. Portions of Cortex's CREATe approach were implemented in the SRWCP, particularly component 2 (the analysis framework). The remainder of section 4 describes the analysis framework of CREATe (the Integrated Watershed Assessment Framework), and highlights which portions of the analysis framework were implemented in the SRWCP.

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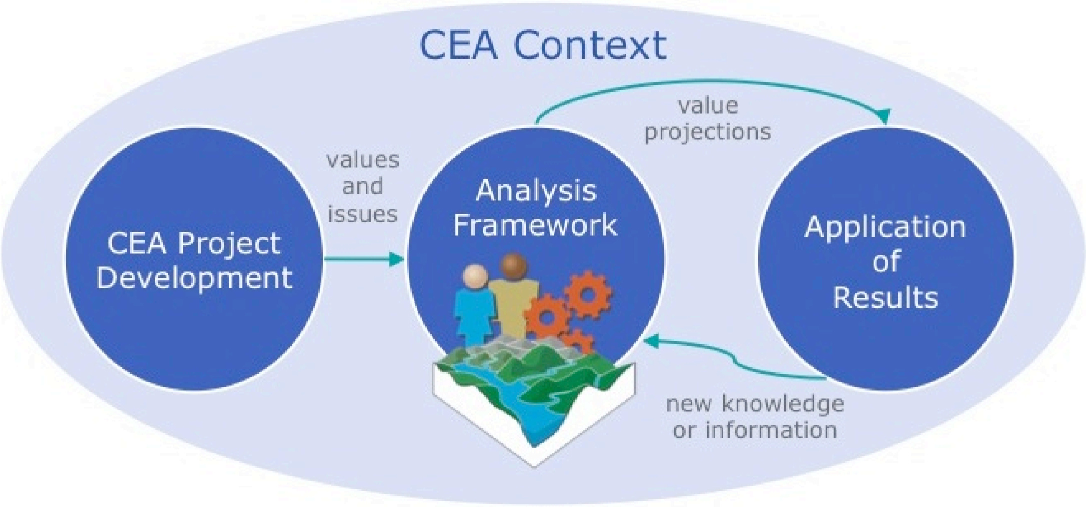
[16] This component of CREATe has yet to be implemented and requires further development.

Figure 2. The CREATe Framework – a model for strategic cumulative effects analysis



4.2 Integrated Watershed Management Framework

4.2.1 IWMF Overview

The SRWCP has focused on developing a robust analysis framework for assessing cumulative effects. Despite the many changes that occurred throughout the development of this project and the resulting curtailment of the Project Development and Application of Results components of the CREATe approach, the analysis framework itself is fully developed and can serve as a basis for future cumulative effects analyses.

This section describes the analytical framework (the Integrated Watershed Assessment Framework or IWMF) developed by Cortex Consultants in some detail. It draws heavily from three earlier documents: *SRWCP Outcomes and Issues May10; SRWCP Prelim Indicators and Associated Data Apr10;* and *IWMF Conceptual Model 26Aug10*. The full text for these documents can be found in Appendix B.

The modeling framework has three functions:

1. examining how management outcomes are affected by future land management activities, interactions of land management activities with natural processes, and the effects of climate change on land management activities and natural processes;
2. identifying trade-offs among different management objectives; and
3. providing an analytical basis for recommending spatial and temporal patterns of development that are most likely to achieve a specified set of objectives and management priorities, given acknowledged uncertainty in expected future conditions (e.g., climate change, resource markets).

Because the actual ecological, economic, and socio-cultural values of interest (e.g., number of salmon; number of local jobs) can often be difficult to model directly (i.e. using predictive process models), a series of indicators are selected as proxies for each of the values (e.g., stream crossings by roads; annual harvest volume).

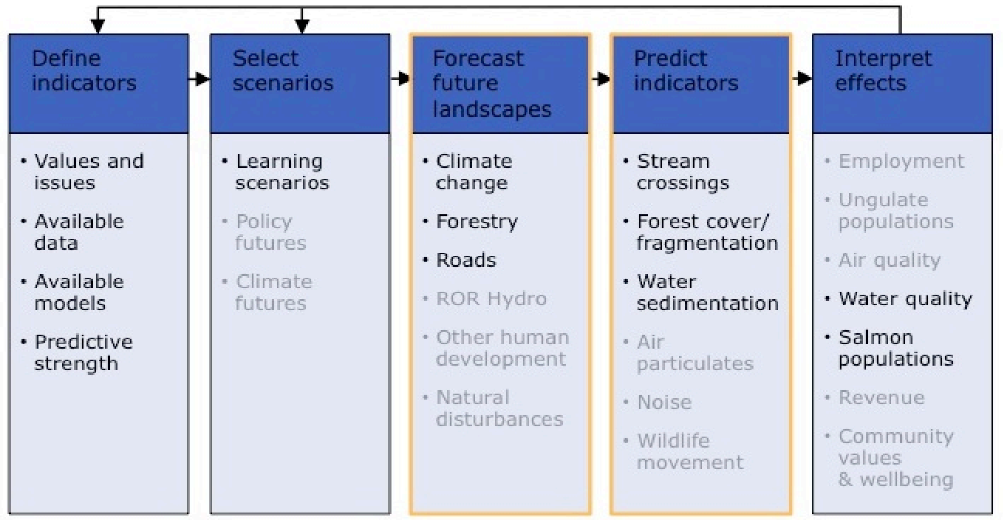
The IWMF is intended to be strategic rather than operational in focus. Strategic models focus on long-term assessments of broad policy objectives (e.g., assessments of sustainable resource supplies) generally over large geographic areas, whereas tactical and operational models progressively focus on assessing feasibility of applying the policies at specific locations. Strategic models tend to have broader spatial and temporal extents and coarser-grained spatial and temporal resolutions than operational models, although there are broad overlaps between these types.

Two modeling approaches were considered for the IWMF: 'simulation' (using SELES and/or ArcGIS) and 'optimization' (using the Remsoft Spatial Planning System – RSPS). Both approaches use scenario analysis to consider the effects of different modeling assumptions on predictions. In the simulation approach, a variety of scenarios (based on development options and modeling assumptions) are explored to examine the effects of these scenarios on values of importance. In the optimization approach, a series of objectives are specified at the outset (e.g., maximize value of timber harvested; minimize impacts to salmon) and the model is used to find the best possible combination of management actions to achieve these objectives. Compared to the simulation approach, the optimization approach is better at producing the "best management options" for a particular set of objectives, but is more limited in the types of indicators and processes that can be considered.

The Integrated Watershed Modeling Framework (IWMF) is a hybrid of optimization and simulation approaches that uses the strengths of both. Indicators and processes that are compatible with the RSPS can be optimized relative to objectives for each of the values as specified in the scenario, while remaining indicators and processes are dealt with through the simulation approach. The framework is flexible: in cases where most of the indicators and processes are not compatible with the RSPS, the optimization component can be skipped and all the analysis done via simulation and scenario analysis. Similarly, when all indicators and processes are compatible with the RSPS the simulation component can be skipped.

An overview of key elements in the IWMF is shown in Figure 3. Highlighted steps were applied within the SRWCP proof-of-concept (POC); greyed out steps were not implemented in the POC. Each of these steps is described further in the following sections.

Figure 3. Integrated Watershed Management Framework, highlighting components implemented within the SRWCP POC.



4.2.2 Defining Indicators

The first step of the IWMF involves defining indicators, based on values and issues, available data, available models, and the required predictive strength. In general, an indicator is a quantitative or qualitative value (or parameter) that can be assessed in relation to a criterion. Indicators by themselves have no implied direction, or reference value, although that information can be applied to help interpret the information provided by an indicator.

A discussion of the theoretical process for defining indicators is presented in Section 2.2 of *SRWCP Preliminary Indicators and Associated Data Apr10.* According to this document, indicators for the SRWCP were to be guided by the following criteria:

1. Effectiveness in the socio-ecological context of the assessment, as measured in several ways. Where possible, selected indicators should:
    - be linked to management policy and objectives applicable to the SRWCP. Indicators should identify impacts of a proposed management action and allow managers to make informed choices about tradeoffs.
    - be science-based (i.e. have an empirical foundation)
    - enable assessments of effects of management actions over both short time period (e.g., 4-5 years) and also useful in identifying trends over long time frames (e.g., 50-100 or more years).
    - as much as possible, be uncorrelated with other indicators.
    - be “linkable” to decisions or prescriptions over which managers have control. That is indicators must explicitly relate to management objectives and desired end-points and/or targets.
    - be amenable to aggregation into summary indicator sets or indices to illustrate macro-scale (e.g., ecosystem behaviour) outcomes arising from complex ecological and socio-economic processes.

  - correspond to obtainable targets and thresholds that allow conclusions to be drawn about the state of the system (e.g., by comparison to "benchmarks" or ranges of values occurring under natural conditions). These targets and thresholds can be defined either objectively or subjectively based on expert opinion.
  - be informative (together with their defined targets or thresholds) about the limits of acceptable change before cumulative impacts become a concern.
  - be able to be weighted in light of different objectives and individual indicators to facilitate assessment. Failure to define weights (quantitatively or qualitatively) will either imply all indicators are of equal weight or allow discretionary weights to be assigned "covertly" by others).

2. Related to the policy environment within which decisions are currently made in the SRWCP (or may be made in the future):
   - Indicators must link to current SFM planning indicators, GHG and carbon accounting protocols, and emerging methods for accounting for ecosystem services
   - where possible, indicators must be relevant to third party certification and/or BC Forest Practices Board audits
   - where possible, selected indicators must be used by local and regional organizations and apply to surrounding ecosystems
3. Practicality:
   - indicators must be directly or indirectly obtainable from the data and projection models used in the SRWCP assessment.
   - indicators must be easily related to empirical measurements using one or more of the following methods:
     - field and/or monitoring data currently being collected at different scales
     - cost effective remote sensing
     - be derived from standard hydrologic analyses
     - link to available climate data and/or climate change scenarios
     - for projected indicators (i.e. those resulting from model projections), each must be verifiable from available data and model functions.
     - projected indicators relating to species' status are habitat-focused, and do not directly require estimates of population sizes. Populations fluctuate for many reasons that are difficult to model in a strategic analysis. For some species, probability of occurrence may be a practical surrogate indicator for populations.
4. The indicator set should be efficient and parsimonious. More indicators are not always better.

Using these criteria, potential indicators for the SRWCP were defined. They are summarized in *SRWCP Outcomes Issues May10* (Appendix B). This document describes possible desired outcomes and issues associated with achieving these outcomes for each value of interest within the project area, as well as potential indicators for each value.

Indicators selected for use in the SRWCP can be divided into two types: areal indicators and network indicators. Each of these indicator types is described below.

Influence of available data on indicator selection

Indicator selection must be based on available data for the project area. To inform indicator selection, a spatial database was assembled for the SRWCP (*SRWCP Data Model Spatial Database 28Feb10*; Appendix B). This spatial database was assembled based on perceived data requirements early in the project, and is thus far more comprehensive than the datasets used for the POC version of the SRWCP. However, it proved useful during the analysis phase to locate required specific pieces of data, and includes a lot of information that will be useful if additional values/indicators are added to the model and for future scenario analysis.

Areal Indicators

With development (e.g., forestry, mining), natural processes (e.g., fire, succession), and climate change, the areal distribution of landscape features changes. Tracking changes in particular features of interest is a good way to understand the effects of a particular set of management actions or assumptions. However, the full set of features of interest is not always clear at the outset of a planning or modeling exercise. For example, the number of times a road crosses a stream within a watershed can be used as an indicator of impact on aquatic habitat. However, using model projections to understand what management actions can minimize stream crossings may require further detail on where these crossings are occurring. For example, crossings at stream headwaters may have a different set of effects than crossings within a floodplain. Therefore, the approach used by the IWMF is to track changes for all combinations of a range of landscape features; the IWMF approach also permits inclusion of additional features with minimal effort.

For the areal based indicators, a set of landscape features are specified to include different aspects of the landscape condition that are relevant to assessing effects of management actions and associated decision-making. Each feature consists of a number of elements[17] or possible states. The indicator component of the IWMF reports on the area (and length for linear features) of the landscape that is in the state specified by each potential combination of strata elements. The indicator component can also summarize the area of key indicators – defined by a particular combination of strata elements (e.g., steep slopes adjacent to fish bearing streams) – for common reporting units (e.g., FWA assessment watersheds).

Due to the factorial nature of tracking additional landscape features, there is a computational limit to the number of features that can be combined in a single reporting table. This limit is directly related to the number of elements for each feature. For example, two features with three elements each would result in 9 rows in the reporting table; however, if one of these features had 100 elements the reporting table would then have 300 rows. To avoid being limited by computational resources the indicator projection component of the IWMF can break up all possible features into separate tables, grouping features that are likely to be considered together (e.g., aquatic factors, habitat-related factors).

Linear features are challenging to represent in a raster-analysis environment, where the landscape is represented as a grid of cells. Summing the area of cells representing a linear feature does not necessarily give the area occupied by the feature for two reasons: 1) the width of the linear feature may not match the width of the cell; and 2) diagonal linear features are represented as a jagged, stepped line in a raster which is not a good representation of the real world feature. Similarly, the length of the linear feature cannot be directly ascertained by summing the width of

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[17] Elements are different values possible for a feature. For example, a feature representing the presence of roads would have two elements (roads; no roads), while a feature representing landscape unit may have several elements, one for each landscape unit.

all cells representing the feature. To determine the actual length or area represented in a raster, scaling factors must be applied. Based on visual assessment of data for the SRWCP study area, the scale of curves in both road and stream features is greater than the 25m cell-sized used for analysis. Therefore, for length we used a correction factor of 0.794, based on the correction required for a randomly oriented, straight-line segment that crosses a cell (Theobald 2000; Goodchild 1980). The actual distance for a linear raster feature is calculated by multiplying the summed width of the cells by the correction factor. Further exploration of SRWCP data found 0.794 to be a good approximation for the actual ratio of linear feature length to summed raster cell width for road and stream layers used in the model.

Network Indicators

The IWMF is able to track and project spatial relationships among a number of different networks (e.g., roads, transmission lines, streams) within the landscape, in addition to the spatial relationships between these networks and other landscape features described in the previous section on areal indicators. The key distinction between network indicators and areal indicators is that network indicators take into account the connectivity and hierarchical structure of network elements. For example, the continuity of headwater streams with higher order streams and rivers can be used to assess the cumulative effects of management actions along the stream network.

The IWMF is capable of incorporating other types of network indicators. These indicators include other factors accumulating along stream networks such as the run-of-the-river hydro projects and area of harvesting within a particular distance of the stream, and along other networks such as traffic on roads or load on transmission lines. In addition to linear networks, the IWMF supports addition of analyses based on networks of patches such as habitat or a particular type of development. Examples of indicators that could be applied to these patch networks include the size and distribution of connected patches of wildlife habitat, or the cost of connecting a particular set of developments to existing infrastructure (allowing minimization of this cost).

4.2.3 Selecting Scenarios

Scenario analysis is used within the IWMF to predict management outcomes under different sets of assumptions about exogenous processes (i.e., processes that affect management objectives and outcomes, but are external to the factors affected by management decisions), societal values, and the timeline and outcome of management activities.

There are two key components to specifying a scenario:

- Defining the analytical purpose for the scenario (e.g., test modeling assumptions, predict effects of particular management strategy); and
- Determining the set of objectives that describe desired management outcomes relative to ecological, economic, and socio-cultural values.

Below are some critical characteristics relative to scenario selection and scenarios in general:

- Scenarios that test modeling assumptions and/or optimize management activities relative to each objective are called "*learning scenarios*"
- Scenarios that predict the effects of particular management strategies are called "*policy futures*"
- The objective of scenario analysis is not to find and agree upon one future scenario; rather, the purpose of scenario analysis is to compare the results of multiple scenarios to highlight trade-offs and/or dependencies among objectives, and highlight where management

outcomes are sensitive to modeling assumptions and the timeline of anthropogenic development in the study area.

Scenarios Applied in SRWCP POC

The original goal of scenario analysis within the SRWCP was to design and analyze multiple scenarios with the goal of using the IWMF broadly to inform policy decisions within the region. Scenarios were to be defined that specified climate change parameters and resource management objectives, constrained the scope and intensity of disturbance activities to achieve management objectives and desired outcomes, and covered the range of uncertainty in exogenous processes.

Scenario development was to include the following steps:

1. Define the objectives for each scenario. These will include management objectives (e.g., harvest targets, water quality parameters) and analysis objectives (e.g., compare alternative riparian management strategies). To facilitate comparison of results, scenarios will have contrasting objectives. A key aspect of this step is defining the development timelines (including infrastructure build-out, maintenance, and decommissioning).
2. Translate each management objective into a quantitative list of indicator criteria, each of which is affected by one or more landscape change processes (e.g., anthropogenic and natural disturbances).
3. Specify management assumptions (e.g., rate of cut, riparian buffer widths) and modeling assumptions (e.g., stand regeneration parameters).
4. Select the climate change scenario from current climate modeling datasets (see Section 6.3 for further information on selection of climate change scenarios). The indicators and spatial data layers will determine the climate variables that are required by the analysis.

The types of parameters that could vary among scenarios are detailed in Table 3.

Table 3. Types of parameters that could vary among scenarios

Parameter type	Reason for inclusion
Climate change scenarios	Understand the range of climate change impacts on values in the study area; assess effects on recommended management actions of different assumptions regarding climate change
Development timelines and intensity	Examine impacts of different development options on values in study area; examine possible range of development timelines under different economic and social conditions
Indicator criteria	Specify indicator values or ranges that will achieve management objectives for maintaining values (e.g., maximum stream temperature to maintain fish habitat); verify expected relationships between indicators/criteria and development activities
Management objectives	Understand effect of different management objectives on full suite of indicators and associated values; explore trade-offs among management objectives; explore effects of different management regulations
Model assumptions	Test how modeling assumptions affect predictions and recommended management actions

Within the POC version of the SRWCP, analysis is limited to one management scenario (the “base case” of forest development over the next 250 years) and three climate change scenarios (CGCM3 A2 run 4; HadCM3 B1 run 1; HadGEM A1B run 1; Murdock and Spittlehouse 2010) capturing a range of potential climate futures for BC as projected over the 21st century, and projected forward over 250 years. These scenarios are described in more detail in Section 5 of this document. The forest development scenario is also described in *SRWCP POC Forest Model Data, Methods and Management Assumptions 26Aug10*, the full text for which can be found in Appendix B.

4.2.4 Forecasting Future Landscapes

This step of the IWMF forecasts future landscapes based on anthropogenic and natural disturbances. It also tracks and updates landscape state variables associated with development/disturbances. For example, timber management activities are represented in this component by growing and harvesting trees; these in turn affect landscape state variables such as stand age and land cover type.

Spatial and temporal resolution

The spatial extent of the modeling and indicator development is defined by the intensive analysis area, along with the Flood Plain and TFL 1-Nass Blocks. The framework is currently set up to project landscape conditions and indicators for fifty years, but this parameter is flexible depending on the objectives of analysis.

The spatial resolution of modeling framework is flexible and depends on consideration of at least three factors: 1) the resolution of the spatial data available (e.g., digital elevation model data in BC is typically available as a 25m raster); 2) the finest scale process or processes that are modeled (e.g., road infrastructure); 3) computing resources required – finer spatial resolutions require more memory and processing time.

The spatial resolution used for analysis is typically much finer than the spatial resolution that should be used for interpretation of results. Although fine-scale analyses may be necessary to accurately represent processes such as road building or stream networks, many of the data inputs may only be available at coarser resolutions (e.g., most forest cover polygons represent areas of at least several hectares).

The spatial resolution currently used within the IWMF is 25 m, while the temporal resolution is a 5-year time step. A finer scale of resolution is possible; however, this resolution represents a compromise between the desired level of detail and the required analysis time. Results may be reported at a coarser time resolution (e.g., 10 years or more). Input climate projections are at a coarser time steps (30 years), although interpolated versions of these variables can be reported at finer time intervals (e.g., 5 years). Time series of outputs from the scenario projections can be generated with varying time horizons, depending on the needs of the analysis.

Land Management Projection

The land management projection step of the IWMF is implemented using Remsoft's Spatial Planning System (RSPS). The RSPS software allows for optimization and spatial representation of land management activities and consequences, based on predefined management objectives (goals) and criteria.

While the inputs and outputs of the RSPS are spatial, the analysis itself is not spatially-explicit. Instead, RSPS is used to optimize a spatially-stratified landbase based on the predefined management objectives. The RSPS outputs—a time series showing various characteristics of the landbase (e.g., forest age, BEC, harvest volume)—are used as inputs into the SELES simulation model. SELES then maps the location of features of interest such as cutblocks and roads based on spatially-explicit criteria (e.g., maximum roads allowed in an area; maximum cutblock size; adjacency; etc.).

The RSPS software is capable of representing any anthropogenic disturbance that is based on landscape state variables, and scheduled spatially and temporally. However, the current implementation of the IWMF for the POC version of the SRWCP uses RSPS only for scheduling forest management activities. Other anthropogenic disturbances could be incorporated as process-based sub-models or a time series of activities obtained from publicized planning schedules (see below).

Forest Estate Modeling in the SRWCP POC

The timber supply analysis for the SRWCP POC is conducted using Remsoft's Spatial Planning System (RSPS) software suite. The aspatial component (Woodstock) of the system is used to determine the long-term sustainable harvest level given the forest management objectives including forest products, visual quality, and seral stage requirements. The major inputs to the Woodstock model include management zone definitions, forest cover objectives and constraints, yield tables, and inventory information (age and area). Woodstock is capable of using optimization or simulation and in this analysis, optimization is used in conjunction with the linear programming software MOSEK. The optimization is subject to a number of harvest constraints including the requirement to produce a long-term sustainable harvest forecast.

The model uses five-year planning periods and has been run for a 250-year planning horizon. The harvest level is prioritized according to the short, mid, and long-term and the long-term harvest (LTHL) levels are established once harvest from managed stands exceeds 80% (usually 80 to 100 years from now). The LTHL is set at a level that provides a non-declining growing stock 80 years from now.

SELES is the spatial component used to apply the Woodstock harvest forecast to specific portions on the land base. SELES aggregates individual cells into suitable harvest units (blocks) based on specified minimum, maximum and target block sizes. The SELES model also enforces green-up and adjacency requirements as it schedules the harvest spatially.

Further details on the forest estate model can be found in *SRWCP POCS Forest Model Data, Methods and Management Assumptions 26Aug10*, in Appendix B.

Modeling Other Anthropogenic Disturbances in SRWCP POC

Two approaches are used to model anthropogenic disturbances within the SRWCP. One approach uses a process-based "sub-model" to generate results for each time period. The other approach assesses the static landscape at each time period to determine the spatial extent of the anthropogenic disturbance. Table 4 lists all the anthropogenic disturbances considered for inclusion within the SRWCP, and describes how each disturbance could be included.

The modeling team has produced preliminary sub-models for two anthropogenic disturbances (mining, run-of-the-river power generation; see Table 4). These process models have not been implemented within the POC version of the SRWCP. At this time, these disturbance modeling components are intended to seed discussions with domain experts about how to implement disturbances and to provide examples of the type of outputs that could be produced in future versions of the IMWF. The preliminary sub-models developed by the modeling team are based on informal scoping discussion with some industry experts and preliminary research of factors affecting development. The modeling team expects substantial improvements to model representation of development activities following more formal consultation and collaboration with industry experts.

To date, the modeling team has taken the following steps towards modeling disturbances:

- Review potential disturbances in the study area

- Review potential data sources for modeling identified disturbances
- Based on prevalence of the disturbance in the study area and available data, decide on approach for representing each disturbance in the IWMF (e.g., time series vs. process model)
- Develop initial conceptual approach for modeling disturbances represented as process models. Note these models are still at the proof-of-concept stage and will require further refinement following consultation with industry experts and domain experts
- Implement proof-of-concept process models in the SELES (Spatially Explicit Landscape Event Simulator) modeling environment. SELES is a raster-based modeling language and user interface that facilitates development and implementation of spatially- and temporally-explicit landscape models.

The development sub-models do not directly account for the effects of climate change because it is not expected that their projections will change in expected future climates[18]. One possible exception to this assumption is the Run-of-River Power (ROR) Power Generation sub-model; the spatial arrangement of ROR projects could be affected by hydrological changes associated with climate change. At this time, climate change effects have been explicitly considered in the Indicator Projection component of the IWMF.

More information on modeling disturbances can be found in the *IWMF Conceptual Model* document (Appendix B).

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[18] Forestry development is expected to be affected by climate change and thus climate change considerations are included in the forestry model.

Development Activities

Table 4. List of development activities considered for inclusion in the IWMF and how each activity is represented in proof-of-concept disturbance modeling.

Activity	Representation in POC
Resource development	
Forestry	Process model
Oil and Gas	Not represented[1]
Mining	Preliminary process model; not represented in POC[2]
Power generation – run-of-the-river	Preliminary process model; not represented in POC[2]
Power generation – biomass	Not represented in POC[3]
Agriculture	Static, based on current land cover data[3]
Rural and Urban Development	Static, based on current land cover data[3]
Rangeland	Not represented in POC[3]
Outdoor Tourism and Recreation	Not represented in POC[3]
Industrial/manufacturing facilities	Not represented in POC[3]
Guide outfitters	Not represented in POC[3]
Sport fishing	Not represented in POC[3]
Commercial fishing	Not represented in POC[3]
Access infrastructure	
Roads	Process model; time series of activities[5]
Transmission Lines	Not represented in POC[2,5]
Pipelines	Time series of activities[6]
Railways	Static[3,4]

[1] Assumed that oil and gas development is unlikely in the study area; however, an oil and gas development sub-model is available for inclusion in the IWMF.

[2] Development of this disturbance was not funded in the POC version of the SRWCP; however, a sub-model is available for inclusion in the IWMF.

[3] Could be represented in the model as a time series of activities if a suitable data source was identified.

[4] A process model is available for inclusion in IWMF if railway infrastructure is expected to be associated with a particular type of development (e.g., mining).

[5] If sufficient information is available, a time series of known future activities could be used to supplement the process model.

[6] If funding available, a time series of activities could be used to represent pipelines.

A more detailed description of how each of these disturbances could be represented within the IWMF can be found in *SRWCP POCS Anthropogenic Disturbance Model Methods and Assumptions 31Aug10*, which appears in Appendix B of this document.

In the future, the IWMF may be applied in other regions with dominant anthropogenic activities other than forestry, and may also need to account for significant uncertainty and/or flexibility in the temporal and spatial distribution of these activities (e.g., development of oil & gas plays conventional or unconventional). In such cases, it would be worth evaluating options other than RSPS for determining a development trajectory that addresses the desired outcomes and values specified for the project.

Modeling Climate Change in the SRWCP POC

Climate change is a key driver of landscape change that is being considered in the SRWCP. The climate scenarios chosen are intended to represent a commonly accepted range of potential futures, and are consistent with those used in the affiliated project "Climate Change Adaptation Planning for Northwest Skeena Communities". Effects of climate change scenarios are projected using a climate “state-change” transition approach using the methods described below, and the results implemented in the forest estate model via the model’s growth and yield assumptions for the area, as well as potential regeneration assumptions.

Broadly, effects of each climate change scenario were modeled by assembling externally generated suites of key climate variables for each climate change scenario obtained from ClimateWNA outputs (Murdock and Spittlehouse 2010), combining these with climatic envelope projections for the lower Skeena basin, and interpolating and translating these projections into potential site series and site index values using an ecosystem prediction model (Thomae 2006) that was adapted and parameterized for the study area. For the SRWCP, we chose this approach because it allows future states of climate to be linked to projectable vegetation and disturbance condition attributes using presently available databases and ecological relationships. As such, the results are intended to enable comparisons among indicator sets produced by CREATe’s IWMF for different climatic scenarios. This approach does not employ detailed eco-physiological process modeling of the effects of individual climate variables on plant and vegetation growth and mortality. Our overall analysis framework is designed to be upwards compatible with other approaches to predicting climate change effects on stand and ecosystem attributes as they become available.

We undertook four main analytical steps to incorporate data from the three climate change scenarios into the IWMF modeling framework:

1. Obtain georeferenced sets of individual climate variables for the study area from ClimateWNA, as well as projections of climatic envelopes for the area for the three climate change scenarios of interest. The standard time period of these projections is 30 years, and 4 time periods were obtained (historical [1990], 2020, 2050 and 2080) for the purposes of this study.

2. Interpolate climatic envelope maps between the standard 30 year intervals generated by the climate model outputs (e.g., ClimateWNA)s to obtain a time-series of potential transitions between climatic states at the finer temporal resolution of 5-year intervals that is required by the IWMF component models.

3. Infer potential site-series classifications for the interpolated time series of climatic envelope states using topographic, vegetative and bioclimatic rules similar to those used in predictive ecosystem mapping to infer potential relative soil (nutrient) and moisture effects at each interpolated time interval in response to changing climatic states.

4. Infer potential growth rates for leading tree species at each location using updated site index information for each climatic envelope and inferred site series combination.

We describe these steps in more detail in the sections below. Note that it is a key assumption of this methodology that the dominant effects of changing climate on vegetation establishment and growth of key tree species can be captured (for the comparative purposes of this modeling at least) by modifying the relative soil nutrient and soil moisture regimes on sites as a function of the multivariate bioclimatic descriptions implied by the projected BEC variant states. For this proof-of-concept stage, we are not considering changes in vegetation community composition resulting from changing species-level demography (i.e. altered vulnerabilities in growth and mortality rates of each species) due to altered “mean” climate regimes and/or effects of frequency and magnitude of drought conditions or temperature extremes (e.g., Crookston et al. 2010; Clark et al. 2011). However, such relationships can be incorporated through enhancements to this model framework.

Step 1: Obtaining georeferenced input data: climatic and climatic envelope state variables

Climate variables. Recent literature (e.g., Crookston et al. 2010) and consultations with climate researchers (Wang *pers. comm.*) suggested that the core subset of 8 directly calculated annual climate variables generated by ClimateWNA (Wang et al. 2010) provided the key relationships needed to infer effects of climate on vegetation, and also indirect effects on hydrology. These variables are listed in Table 5.

Table 5. List of core set of annual climate variables considered for inclusion in the IWMF and used in proof-of-concept climate change modeling. Adapted from Wang et al. (2010).

Variable	Description
MAT	mean annual temperature (°C)
MWMT	mean warmest month temperature (°C)
MCMT	mean coldest month temperature (°C)
TD	temperature difference between MWMT and MCMT, or continentality (°C)
MAP	mean annual precipitation (mm)
MSP	mean summer (May to Sept.) precipitation (mm)
AHM	annual heat:moisture index (MAT+10)/(MAP/1000))
SHM	summer heat:moisture index ((MWMT)/(MSP/1000))

We generated point sets of these variables at a spacing of 100 m over the full extent of the study area (i.e. the spatial rectangle encompassing the study area) and used ArcGIS to generate rasters of each individual variable at each time period (historical, 2020, 2050 and 2080) for each of the three climate scenarios. This 100m spacing was chosen because: (i) this resolution approximates the scale at which spatial placement of management activities become important, and (ii) below that resolution, uncertainties due to downscaling of projected climate variables in ClimateWNA begin to dominate projections (see Murdock and Spittlehouse [2010]. We used these rasters of individual climate variables for a variety of purposes, particularly interpolating the time-series of climatic envelopes (see below). They form part of the SRWCP data package and may be useful for additional analyses.

Climatic Envelope State Projections

Climatic envelopes representing bioclimatic states representing climatic equivalents of the Biogeoclimatic classification system used in British Columbia were generated based on the methods originally developed by Hamann and Wang (2006), and recently modified and enhanced by Mbogga and Wang (2009), and Wang (*in press*). Because the base algorithms for generating climatic envelopes were not publically available to use at the time of this analysis, we adapted a recently computed set of climatic envelopes for the Skeena watershed (dated November 2010) for the purposes of this analysis[19]. These envelopes were calculated using digital elevation data (DEM) at 90 m resolution, ClimateWNA data for the historical period (1960-1990) and three future periods (midpoints 2020, 2050, 2080) for the three climate change model scenarios as described above. The approach uses the Random Forest model developed by T. Wang and his co-workers (Wang, *pers comm.*) for projecting BEC zone variant classifications for the area. Note that the projections do not cover the portion of the study area outside the Skeena Watershed boundary (e.g., Nass blocks), and a separate approach for extrapolating these envelopes to this area has been conceptually designed.

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[19] Permission to use these climatic envelope projections was given by T. Wang (April 2011), and the resultant data was kindly provided by Don Morgan (BC Ministry of Lands, Forests and Natural Resource Operations, Smithers, B.C.).

Step 2: Interpolating climatic envelope (BEC variant equivalents) state transitions

The climatic envelopes (expressed and mapped as projected BEC variant equivalents) for each climatic scenario are calculated at the same temporal resolution as each climate scenario (e.g., 30 year intervals projected forward from the historical condition). The disturbance and indicator models of the IWMF make spatial decisions about locating future disturbances at 5-year time steps, and the consequences of decisions made at previous time steps affect the decisions made at subsequent time steps. Because the degree of potential landscape change implied by the significant changes in the BEC variant classification of the projected climatic envelopes can be substantial over a 30-year time interval (thus confounding the cumulative effects decision algorithms by coarser-scaled transition jumps), we developed a method of interpolating the transitions at 5-year time intervals. This effectively acts as a temporal “smoothing” of all of the projected BEC variant equivalent state-transitions over the spatial extent of the study area, thus retaining the integrity of the overall decision approach employed in the IWMF modeling sequence.

The conceptual basis of this method is analogous to the bioclimatic-based approaches (e.g., DOMAIN; Carpenter et al. 1993) used to model potential distributions of organisms in response to environmental gradients, including climatic variables. The concept is to employ a point-to-point similarity metric to assign a “relatedness” value to a location (source site) based on its proximity in bio-physical environmental space (e.g., topographic, climatic) in relation to other similar (candidate) sites in the study area. Here, we assumed that source sites whose projected BEC variant classification changed to a new classification (termed target BEC variant equivalent) between one 30 year time interval and the next, would be likely to change earlier if they were quite similar in climatic and topographic conditions to a sample of sites already classed as the target BEC variant equivalent at the start of the interval, and later if the characteristics between source and candidate sites were increasingly dissimilar. Note that this method assumes that climatic variables change linearly with time within a time period. This is the only assumption possible because we do not have the underlying finer-scaled time series of climatic modeling data to challenge that assumption.

Note that this method is based on environmental proximity and is not conditioned on Euclidean proximity. Visual inspection of the projected BEC variant classification indicated that spatial proximity was a much weaker effect than either topographic or climatic variation, therefore we ignored spatial effects for this proof-of-concept. Such spatial conditioning could easily be added as a future enhancement to the algorithm

We implemented this approach using the Gower metric (Gower 1971), which is commonly used in climatic attribute studies to quantify relative similarity between locations based on multiple climatic attributes. We quantified similarity between each source cell and a randomly selected set of 100 candidate sites selected to be topographically similar (i.e. within the same elevation class, and aspect class; see Step 3 below for class definitions) and each having the same projected BEC variant at the start of the time period as does the source cell at the end of the time period. The Gower metric is expressed as a p-dimensional distance d between source$_s$ and candidate$_s$ sites $s_{s\ to\ c}$, defined as:

$$d_{s\ to\ c} = \frac{1}{p}\sum_{k=1}^{p}\left(\frac{|\,S_k - C_k|}{\text{range } k}\right)$$

calculated over the k climatic variables obtained from ClimateWNA (8 in this case). The range of each climate variable k observed over the study area within a climatic scenario and time period was used to standardize the contribution from each climatic variable (Carpenter et al. 1993). For each source-candidate pair, this metric is converted to a complementary similarity measure $s_{s\ to\ c}$ by taking 1- $d_{s\ to\ c}$. Using SELES, we then ranked each $s_{s\ to\ c}$ for the source cells in decreasing order of similarity. We divided the 30 year time interval into 6 5-year time periods, and converted the most similar 16.6% of the total number of source cells to their projected target BEC variant equivalent in the first 5 year time step, the next most similar 16.6% of the source cells in the next 5 year time step, and so on until they were all converted. The resulting interpolations indicated a relatively spatially smooth rate of transition, suggesting that the stratification captured the key determinants of projected BEC variant transitions in the study landscape.

Step 3: Inferring site series classifications from the interpolated BEC variant equivalents

Site units are fundamental descriptors of the ecological characteristics of landscapes in British Columbia, and are used to estimate forest productivity via relative soil moisture and nutrient factors, infer wildlife capability and habitat attributes, and rare and endangered species occurrence, to name only a few common uses. The primary factors influencing site unit classification: relative soil nutrient factors and both relative and actual soil moisture classes are widely expected to be sensitive to impacts of climate change (C. Delong, *pers. comm.*[20]). Currently, landscape-level predictive ecosystem mapping (PEM) and terrestrial ecosystem mapping (TEM) are techniques widely used to map site units, although these generally require an intensive sampling and analytically intensive effort to complete. However, even if complete TEM or PEM coverage exists for an area, a current assessment of site unit classification and distribution is unlikely to represent combinations of relative and actual moisture/nutrient situations potentially experienced at sites under changing climates. Therefore, we required a dynamic approach to estimating potential future site unit characteristics in order to infer possible consequences on future growth and yield.

For this purpose, we adapted an ecosystem prediction model developed by Thomae (2006) to help us develop a time-series of potential site units (i.e. site-series in the BEC system classification) as a way of representing relative changes in forest productivity under the different climate change scenarios via soil moisture and nutrient relationships. This model is relatively comprehensive in its inclusion of topographic, vegetative and climatic factors, although it is not intended to replace full predictive ecosystem mapping. Therefore, the outputs from the approach should not be interpreted as predictions of likely site units, but rather as assessments of possible variations in site potential.

The basis of this modeling approach is to predict potential soil moisture and nutrient regime on the basis of a composite of site factors, and then translate these to potential classifications of site series applicable at each time step. The site series classification uses the edatopic grid structure for BEC units, which uses a relative soil moisture regime (RSMR) scale on one axis and relative nutrient scale on the other axis to display and classify other sites which are drier or wetter/ poorer or richer than the average site for a BEC variant based on their physiographic position and soil characteristics. Thus it serves as an intermediate step between the BEC variant equivalents representing climatic envelopes (itself a simplification into states of the underlying gradients in

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[20] see also the Delong et al. unpublished manuscript describing a stand-level tool for assessing relative and actual soil moisture regimes for BEC variants throughout B.C. (Dec. 2010).

climatic variables), and the resulting potential effects on site productivity for tree species at each point in time, given that climate envelope.

The steps in the potential site series classification are as follows (see also Thomae 2006):

1. Classify three descriptors (elevation, slope and aspect) of the topography at each cell into classes (slope: 10 classes based on percent slope; aspect: 5 classes representing orientation effects on snow accumulation, solar radiation, temperature, drought and wind; and elevation: 10 classes representing a continuum throughout the study area to help represent gradients in precipitation, moisture and humidity within the climatic envelope states.
2. Calculate slope position classes (9) representing relative rates of moisture shedding or accumulation. Nutrients are also affected by slope position.
3. Calculate tree species composition site growing potential based on current percentages of species and historical growth rate. Tree species have different vulnerabilities to drought stress, and current species composition can reflect historical soil and moisture availability. Note that these factors can be made dynamic to reflect on-going changes in tree species composition and site growing potential under changing climate. Dynamics of site growth rate, and age class were dynamically modelled in the proof-of-concept IWMF. Tree species composition is also dynamic in the forest estate model, although the effects of this have not been tested in the proof-of-concept application.
4. Calculate the proximity and types of water bodies in terms of scores (1-10) to estimate their relative influence of water on relative availability of soil moisture and also effects on microclimate.
5. Calculate weighted composite scores for moisture and nutrients using the above factors. Moisture scores include slope, aspect, elevation, tree species composition, water influence; nutrient scores include slope position, tree species composition, site growing potential (x 2), and water influence (x 2)
6. Use the composite scores to generate a projected edatopic grid reference for the current BEC variant equivalent at the site at that time period. This, in combination with the edatopic grid values for BEC variants obtained from the current BEC field guides, estimates the likely site series to which each cell belongs at each point in time. Note that this is an approximation as the edatopic grids used are based on historical observations, and grid structures may change as a consequence of the suite of factors associated with climate regimes. For this reason we emphasize that the projected site series ought not to be treated as predictions, but rather used to compare site sensitivities to the range of soil and moisture regimes expected under the different climate change scenarios.

The above model is implemented in SELES as a component of the IWMF. Results are used to generate a time-series of potential site series for each climate scenario at each 5-year interval.

Step 4: Inferring potential site productivity from the interpolated BEC variant equivalents and potential site series projections

Site growing potential is usually represented by “site index”, a species-specific height at a common age (often 50 years) reached by dominant trees that have always grown without competition (Crookston et al. 2010). Site index is known to be a function of climate, and in general, site index increases from water-deficient to moist sites and decreases again from moist to very wet sites. Within this general moisture relationship, higher site indices are correlated with longer growing seasons and warmer temperatures, provided also that moisture and nutrients are sufficient to sustain growth (Monserud et al. 2008; Crookston et al. 2010). Because the forest estate model uses site quality to estimate tree growth, the IWMF requires a method of estimating potential site growth from potential ranges in climatic envelopes. Although various methods and empirical relationships exist to estimate proportional changes in site quality from one or more climate variables that influence species viability, such estimates require field measurements that are not yet available from the Skeena region.

Accordingly, we used a more heuristic approach that approximates this type of proportional change estimation method. Based on the assumption that the relatively narrow range of environmental conditions (i.e. soil moisture and nutrient gradients) that are indicated by site-series classifications relate to distinct growth potentials for a given tree species[21] , we combined currently known information on site index by each species for each projected BEC variant equivalent (step 2 above) and potential site series (step 3 above), using the SIBEC database maintained by the BC Ministry of Lands, Forests, and Natural Resource Operations (last update: June 2011). However, because the projected BEC variants derived from climate envelopes are "novel" in the region, we needed to develop a method of extrapolating from known BEC variant x site series measurements of site index to estimate potential site indices for novel (i.e. unmeasured) combinations of projected BEC variant equivalents and tree species in the study area in order to implement this approach.

This extrapolation was done as follows:

1. From the SIBEC database, existing site indices for each leading tree species found in the study area were tabulated for all BEC variant and site series combinations that could occur under the climate change scenarios. For any projected combination of BEC variant equivalent, potential site series, and leading species that matched future combinations under climate change, this value was used.
2. Site indices among tree species within a BEC variant tend to be relatively more similar to each other, and also to co-vary in similar ways in response to different site series (i.e. to soils and moisture regimes). Therefore we estimated the average site index among tree species for a BEC variant x site series combination and used this average value for estimating the site index for leading species where that leading species occurs where a novel BEC variant equivalent x projected site series combination may occur in a future time period under one or more climate change scenarios.
3. In some cases, novel projected site series are projected to occur in a projected BEC variant equivalent for which no estimated site indices are available for any species in the current SIBEC database. In this case, we used the Biogeoclimatic system's hierarchical structure to infer potential site indices, first from equivalent site series in closely related variants if data existed for them, then for related types of subzones within a zone (the most common type of extrapolation required), and finally among related types of zones (this was rarely needed).

The resulting site indices are calculated across the distribution of current leading species in the proof-of-concept IWMF, and are represented by time-series. It is easily possible to dynamically link this estimation approach with projected changes in distributions of leading species. Note that there are two key limitations of this approach. First, the more extreme climate change scenarios result in an increasing number of novel combinations of leading species and BEC variant equivalent x projected site series combinations. While the extrapolation approach is structured to

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[21] Based on the Ministry of Lands, Forests and Natural Resource Operations background document entitled "Site Index estimates by Site Series (SIBEC) - second approximation". URL: http://www.for.gov.bc.ca/hre/sibec/SIBEC_RDM_Section_3.htm. Accessed July 21, 2011.

make its estimate using the most related empirical site productivity data available for that potential combination, it is clear that many novel combinations will lead to increasing uncertainty in future potential site productivity. Second, this method does not itself model changes in the extent of productive forest that make gradually occur as a result of climate changes. It is however possible to link to other models that make this type of prediction within the IWMF.

4.2.5 Projecting Indicators

In this step of the IWMF framework, indicators are calculated using SELES, based on the projected landscape time series produced by the development and climate change projection models.

The SELES model uses the forecasted time series of future landscapes to generate indicators at five-year time steps. Two types of indicators are tracked: areal indicators and network indicators. For areal indicators, outputs include comprehensive tables that report the total area contained in each possible combination of indicators (e.g., total area by landscape unit, BEC variant, site index class, cumulative forest landbase, roads, logged, seral stage). Experts from different fields can use these tables of outputs to assess potential impacts on a variety of values, stratified according to landscape unit, BEC variant, seral stage, or other stratifications that may be of interest. The IWMF also tracks network indicators—spatial relationships among a number of different networks (e.g., roads, transmission lines, streams) within the landscape. These network indicators are very useful for tracking cumulative effects of multiple development disturbances on indicators of interest. Examples of indicators that could be applied to these patch networks include the size and distribution of connected patches of wildlife habitat, or the cost of connecting a particular set of developments to existing infrastructure (allowing minimization of this cost).

Currently, these indicators can used to assess the effects of forest development and the associated road network on one values of interest within the SRWCP. Concurrent modeling of climate change impacts within the SRWCP includes using three scenarios (CGCM3 A2 run 4; HadCM3 B1 run 1; HadGEM A1B run 1) to explore potential shifts in BEC variants and growth and yield throughout the SRWCP project area. Outputs from this modeling include a time series of ecological variables (e.g., BEC, PEM, site index) in 5-year time steps, and a time series of climate variables (e.g., mean annual temperature, mean annual precipitation) in 30-year time steps. Outputs from this modeling may be used in future analyses to modify the forest estate model or to modify impacts to indicators of values of interest (e.g., hydrology).

Results from these analyses can be found in Section 5.0.

5.0 Proof-Of-Concept Scenario Analysis Results

5.1 Overview

The objective of the proof-of-concept (POC) scenario is to facilitate specification of management scenarios by demonstrating the types of indicators that can be produced with the model. The purpose of this section is to use the results from the POC scenario completed in July 2011 to demonstrate how IWMF spatial outputs and indicators can be used to generate information that will be useful to domain experts, policy makers, and stakeholders for interpretation of the effects of development and climate change on their values and management objectives. The IWMF produces a very large amount of spatial and tabular data; this section provides general descriptions of the types of information produced, with illustrative examples.

5.2 Forest Estate Model Outputs

Results from the Forest Estate Model are presented in *SRWCP Forest Model Base Case Figures, 29 November 2010 (*Appendix B10).

5.3 SELES Spatial Simulation of Development

Section 4.2.2 outlines the preferred process for identifying and selecting the indicators that are most useful for identifying the effects of climate change and anthropogenic development on the suite of values identified for a particular study area. Key inputs required for this selection process are the identified values and management objectives and input from domain experts on which indicators are most useful for interpreting effects. For the most part domain expertise was not available for selection of indicators, with the exception of initial consultation with a hydrologist on hydrology-related indicators. Furthermore, the primary objective of the proof-of-concept (POC) scenario was to demonstrate the types of information that are currently generated by the modeling framework that may be useful to project partners, stakeholders, and domain experts for interpreting effects of different forecasted landscapes on particular values of interest. Therefore, the indicators chosen for the POC scenario and presented here are intended to be examples of the types of information the model is capable of producing. These results will allow project partners, stakeholders, and domain experts to understand the capabilities of the framework and provide feedback on additional information required to assist with their interpretations of model results and subsequent scenario specification.

The areal indicator results presented for the POC scenario focus on the range of attributes reported by the model that could be used to define strata for indicator generation (e.g., area of roads on steep slopes by BEC zone). We also provide several examples of areal indicators that can be generated using through landscape stratification. These examples are primarily related to indicators of hydrological phenomena.

The network indicator results presented for the POC scenario are related to hydrological phenomena and are reported as maps, tables, or charts. Similar to the areal indicators, these network indicators are intended to illustrate the type of results the modeling framework in capable of producing. Subsequent iterations of model development and scenario analysis could include additional landscape attributes that are summed through modeled stream and road networks.

5.3.1 Areal Indicators

Two stratified attribute tables were produced, reporting a total of 17 different strata factors for 5-year time steps from 2010–2060. For each combination of strata factors present in the landscape, for each time step, the following set of attributes was recorded: area, equivalent clearcut area[22] (for all cells in the Crown Forest Land Base), road length, and stream length. The factors included in the POC analysis are listed in Table 6; a subset of the stratified attribute table produced for the POC scenario is presented in Table 7 as an example. The POC scenario has ~82 trillion potential strata (combinations of factor elements); ~15,000-30,000 of these strata are represented at each time step for the POC scenario.

Table 6. Stratification attributes used for areal indicators

Factor	# elements
Landscape Unit (LU)	32
Biogeoclimatic Variant (BEC)	22+[1]
FWA Watershed	287
Site Index Class (SI_cl)	5
Timber Harvesting Land Base (THLB)	2
Roads	2
Transmission Lines (Trans)	2[2]
Logged	2
Mines	2[2]
Run-of-River Hydro (ROR)	2[2]
Seral Stage	5
Within 100m of stream	2
Stream Class S1-S4	2
Stream crossing by road	2
Steep coupled slope[23]	2
Stream adjacent to coupled slope (w/in 50 m)	2
Steep slope (≥ 50%)	2
Fish passage[24]	4

[1] 22 BEC variants in 2010. The number of BEC variants in projected landscapes varies but is generally greater than in the current landscape

[2] These factors were not implemented for the POC scenario

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[22] ECA was calculated according to the CWAP guidelines (B.C. Ministry of Forests 2001). Separate calculations were not done for rain-dominated, transient snow, and snowpack zones. With expert opinion to define the location of these zones it would be simple to add these distinctions. Furthermore, under some climate scenarios the study area becomes much more continental, in which case it may be worthwhile providing separate ECA to account for the location of the major snowmelt zone. To account for historical forest harvesting activity, all stands within the Crown Forest Land Base less than 50 years old were assumed to have a forestry origin. This assumption needs to be verified, and possibly modified, by regional domain experts.

[23] Steep coupled slopes are defined as the portions of the landscape that are steep slopes (≥ 50%) extending to within 50m of a stream (Forsite et al. 2007). Steep coupled streams are streams adjacent to steep coupled slopes.

[24] Based on Norris and Mount 2009

Table 7. Subset of POC stratified attribute table

Yer	Watershed	Site Index Class	THLB	Roads	Trans	Logged	Mines	ROR	Seral stage	Within 100m of stream	S1 – S4	Crossing	Coupled Stream	Coupled Slope	Steep Slope	Fish passage	Area (ha)	ECA (ha)	Road (km)	Stream (km)
2010	400-22…	1	N	N	N	N	N	N	seOld	Y	Y	N	N	N	N	-	77	0	0	24
2010	400-22…	1	N	N	N	N	N	N	seOld	Y	Y	N	Y	Y	Y	Observed	5	0	0	2
2010	400-22…	1	Y	N	N	N	N	N	seMature	Y	N	N	N	N	N	Inferred	2	0	0	1
2010	400-05…	3	N	Y	N	N	N	N	seYoung	N	N	N	N	N	N	-	8	1	3	0
2010	400-22…	1	Y	N	N	N	N	N	seImmature	N	N	N	N	N	N	-	6	1	0	0
2010	400-22…	1	Y	N	N	N	N	N	seImmature	N	N	N	N	N	N	-	15	2	0	0
2035	500-29…	2	Y	N	N	N	N	N	seYoung	N	N	N	N	N	N	-	101	101	0	0
2035	500-29…	2	Y	N	N	N	N	N	seMature	N	N	N	N	N	N	-	31	0	0	0
2035	500-29…	-	N	N	N	N	N	N		N	N	N	N	N	N	-	2	0	0	0
2035	500-29…	2	N	N	N	N	N	N	seMature	N	N	N	N	N	N	-	57	0	0	0
2060	400-05…	1	Y	N	N	N	N	N	seOld	N	N	N	N	N	N	-	228	0	0	0
2060	400-22…	-	N	N	N	N	N	N		Y	N	N	Y	Y	Y	-	4	0	0	0
2060	400-05…	1	Y	N	N	N	N	N	seOld	N	N	N	N	Y	Y	-	248	0	0	0
2060	400-05…	2	Y	N	N	N	N	N	seOld	Y	Y	N	N	Y	Y	-	0	0	0	0
2060	400-05…	1	Y	N	N	N	N	N	seYoung	Y	N	N	N	Y	Y	-	58	51	0	0
2060	400-05…	2	Y	N	N	N	N	N	seYoung	Y	N	N	N	N	Y	-	4	1	0	0
2060	400-05…	1	Y	N	N	N	N	N	seOld	N	N	N	N	N	Y	-	217	0	0	0
2060	400-05…	1	Y	N	N	N	N	N	seYoung	N	N	N	N	Y	Y	-	100	93	0	0
2060	400-05…	1	N	N	N	N	N	N	seOld	N	N	N	N	N	Y	-	185	0	0	0
2060	400-05…	2	Y	N	N	N	N	N	seYoung	Y	Y	N	Y	Y	Y	-	0	0	0	0

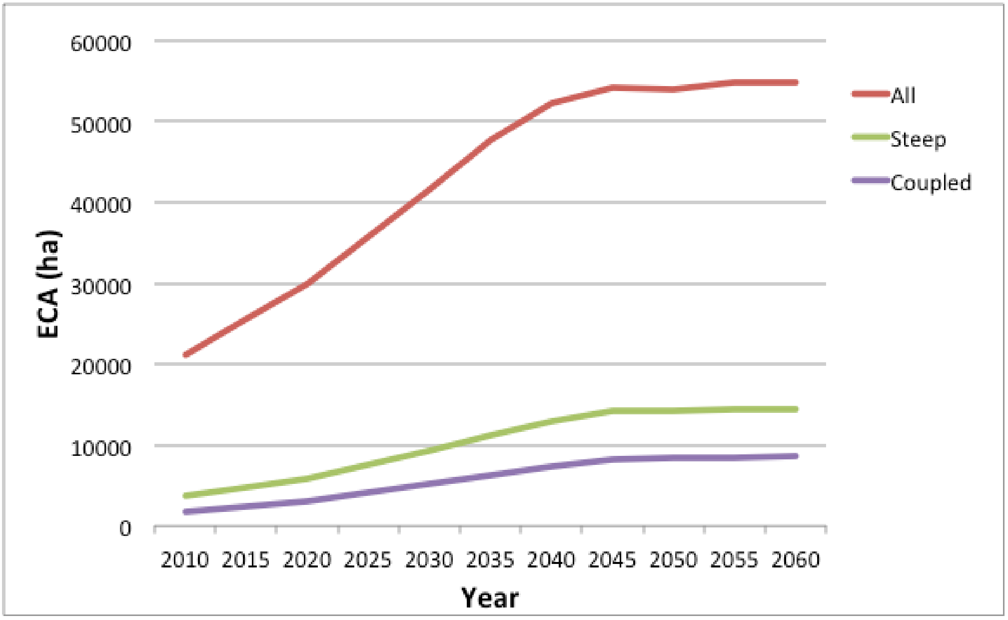
The purpose of the stratified attribute tables is to allow flexibility in the indicators that can be calculated for the landscape time series and the stratification of those indicators. Table 8 provides examples of some the hydrological indicators found in the literature that can be calculated directly from the stratified attribute table. Reporting of each of these indicators can be further stratified according to landscape context, based on any factor in the stratified attribute table (e.g., landscape unit, steep slopes, young forest).

Table 8. Examples of hydrological indicators that can be calculated from stratified attribute table.

Indicator	Units	Examples of use
Equivalent clearcut area	ha	Valdal and Quinn 2010; B.C. Ministry of Forests 2001; Gustavson and Brown 2002; Forsite et al. 2007
Road density	km/km^2	Valdal and Quinn 2010; B.C. Ministry of Forests 2001; Forsite et al. 2007
Road density on steep slopes (>=50%)	km/km^2	Gustavson and Brown 2002
Road density on steep coupled slopes	km/km^2	Forsite et al. 2007
Roads within 100m of stream	km/km^2	Valdal and Quinn 2010; B.C. Ministry of Forests 2001; Forsite et al. 2007
Stream crossing density	#/km^2	Valdal and Quinn 2010; IWAP; Gustavson and Brown 2002
Stream crossing density on steep slopes (>=50%)	km/km^2	Forsite et al. 2007
Logged fish bearing streams	km/km	Valdal and Quinn 2010
Logged S1-S6 streams (all)	km/km	Valdal and Quinn 2010
Logged S1-S6 streams (recent)	km/km	Valdal and Quinn 2010
Disturbed streams	km/km	Valdal and Quinn 2010; Gustavson and Brown 2002
Disturbed S4-S6 streams	% of total length	Gustavson and Brown 2002; B.C. Ministry of Forests 2001
Stream adjacent to sleep slope	km	Forsite et al 2007
Area in alpine and alpine forest	km^2	Forsite et al 2007

Figure 4 provides a graphical example of how these indicators generated from the stratified attribute table can be used to assess the effects of project management actions. In general, ECA increases to 200-300% its current level, before plateauing around 2045. Relative to ECA for the whole Timber Harvesting Land Base (THLB), ECA on steep slopes and steep coupled slopes increases more quickly – from 18–26% of THLB ECA for steep slopes and 8–16% for steep coupled slopes.

Figure 4. Equivalent clearcut area (ECA) over time as percent of Timber Harvesting Landbase (THLB) for entire study area, steep slopes only, and steep coupled slopes only

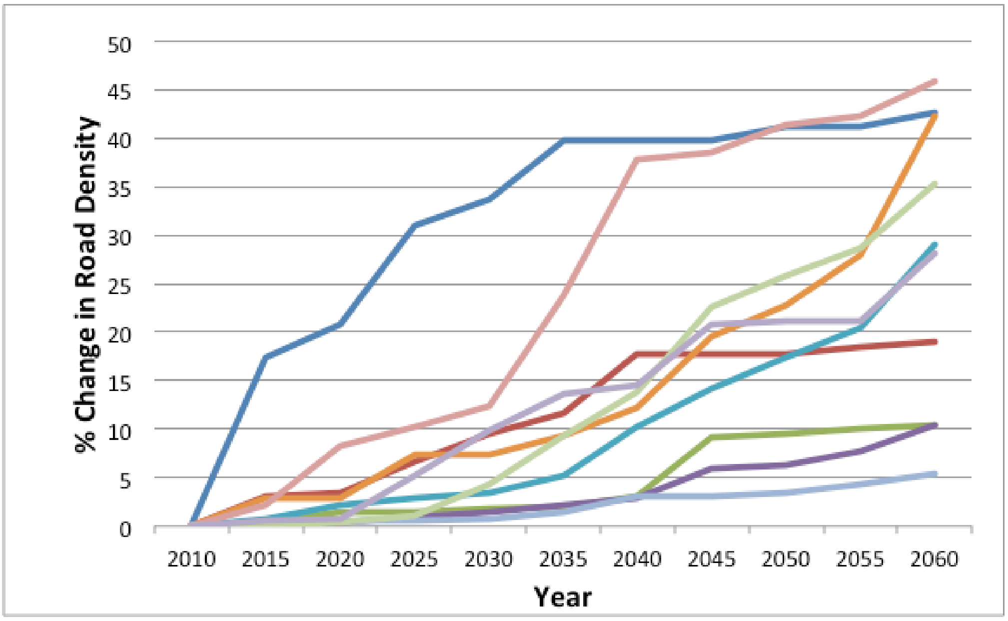


Given the role of water in linking actions and processes across the landscape, watersheds are often used as key summary units for assessment of development effects and associated reporting. The IWMF produces an attribute table summarizing indicators for each Assessment Watershed from the Freshwater Atlas (FWA assessment watersheds - Carver and Gray 2010). These FWA watersheds are spatially explicit and hierarchically linked so that the scale of reporting can be matched to the needs of a particular analysis or management question. Some of the functionality of this summary table is available by using FWA assessment watershed factor in the stratified attribute tables, although considering many attributes for the large number watersheds would result in a table that is prohibitively large. In addition, many indicators may not be captured by the categorical approach used to specify factor elements in the stratified attribute table. Examples include average fish-bearing gradient (Valdal and Quinn 2010), drainage density ruggedness (Forsite et al. 2007), and average summer temperature (Nelitz et al 2008). This component of the IWMF is very flexible; additional columns can easily be added to the table for any indicator that is available as a spatial data layer.

Figure 5 shows how the watershed attribute table can be used to examine changes in road density within the ten most heavily roaded watersheds.

Figure 5. Percent change in road density on steep slopes by FWA assessment watershed over time, for the 10 watersheds with highest road density in 2060

Note that there were watersheds with higher percent changes in road density, but they had lower overall road density in 2060 than the ones listed below.



The flexibility of the IWMF reporting structure allows dynamic exploration of the results to discover and understand patterns at different spatial scales. For example, in the POC scenario, across the study area there is an increase in mature forest over time (Figure 6). However, further investigation reveals that this entire increase can be attributed to a single BEC variant (CWHws1), with some other BEC variants showing significant decreases in mature forest (e.g., the high elevation variants MHmm2 and ESSFwv; Figure 7). By exploring further factors (e.g., location of protected areas, site index class) the specific cause of the increase in mature forest may be further pinpointed, facilitating appropriate management decisions. For example, the overall increase in mature forest may mask a decrease in a particular ecosystem type of interest.

Figure 6. Area of crown forest land base in different seral stages over time.

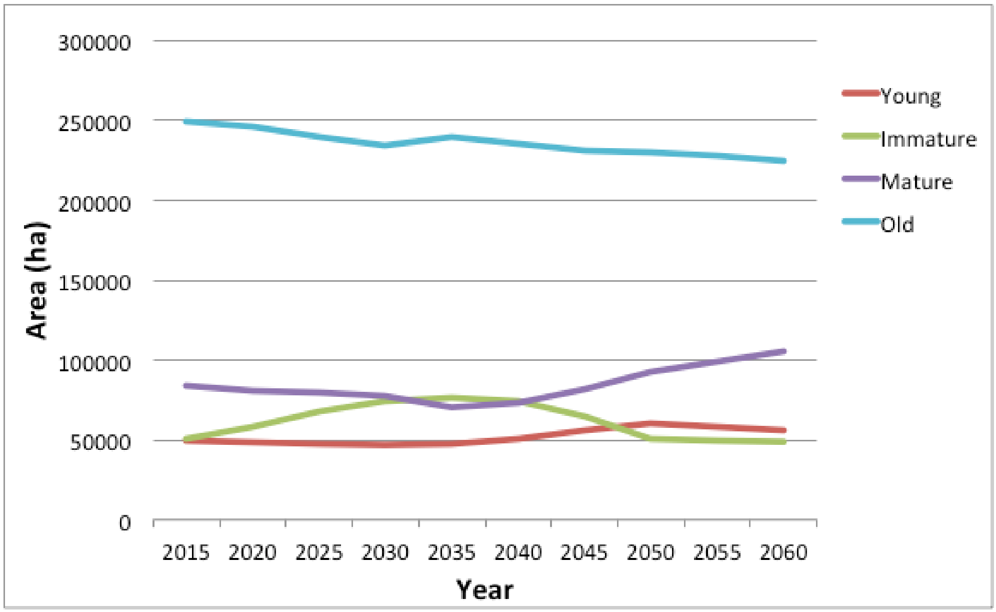
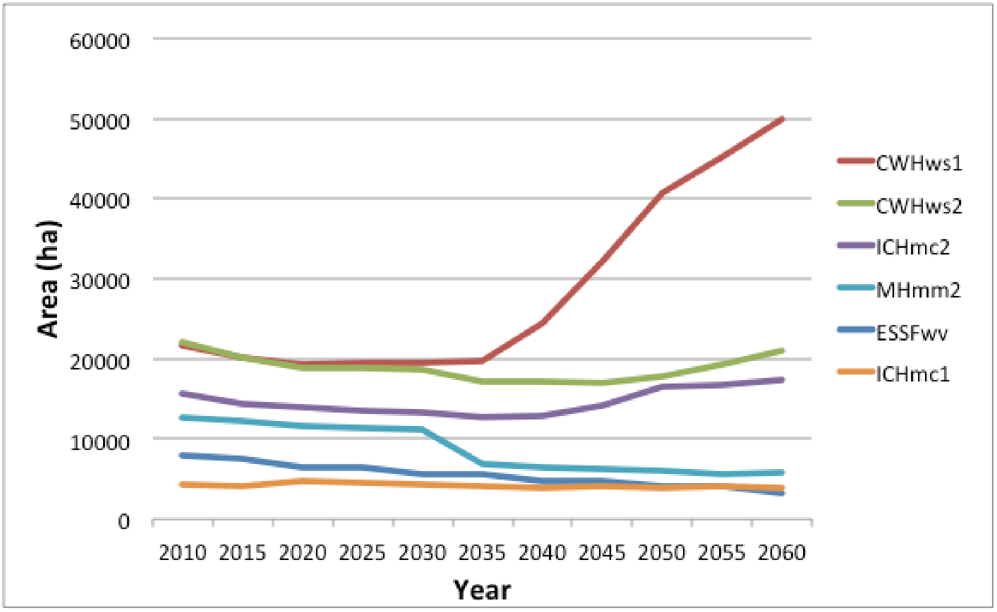


Figure 7. Area of mature forest by common BEC variants over time.



Every strata factor, attribute, and associated indicator tracked by the IMWF is associated with a spatial location. Therefore, in addition to producing tabular and charted outputs of indicators, the model outputs can also be used to produce maps describing the spatial distribution of indicators. For example, model results can be used to produce maps showing differences through time among FWA assessment watersheds in the density of roads (Figure 8) or the percent Equivalent Clearcut Area of each watershed (

Figure 9), both of which are indicators of the hydrological effects of road networks (Table 8).

Figure 8. Density of roads crossing streams by FWA assessment watershed for 2010 and 2060

Black square indicates watershed zoom in Figure 10.

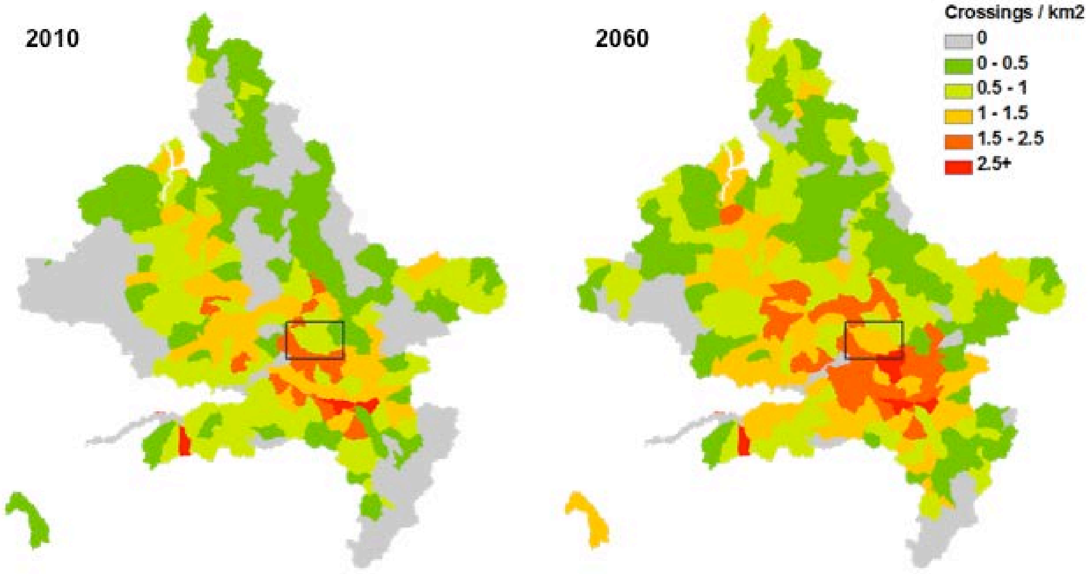
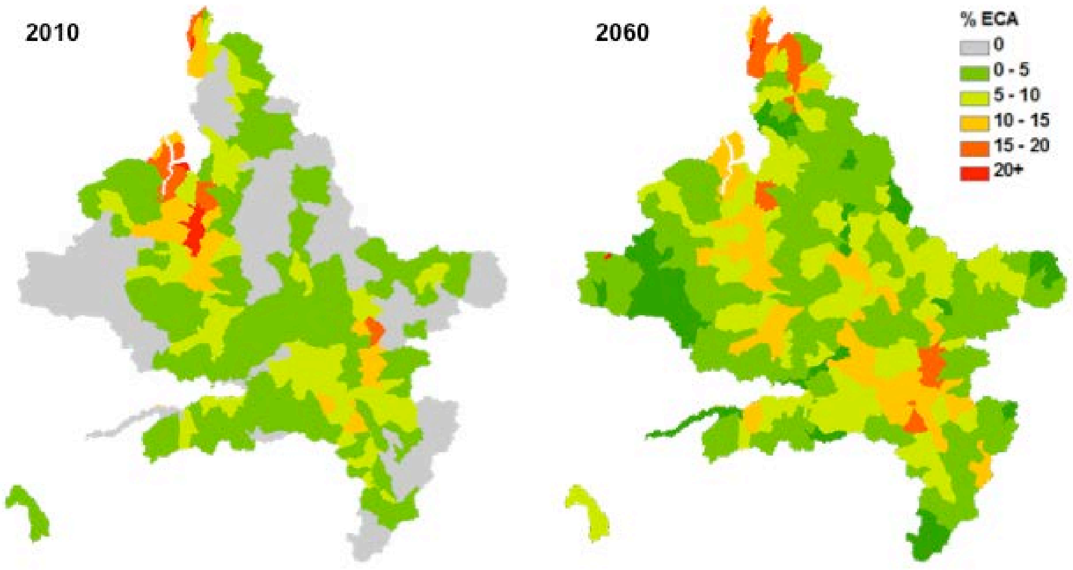


Figure 9. Equivalent clearcut area as % of total FWA assessment watershed area in 2010 and 2060



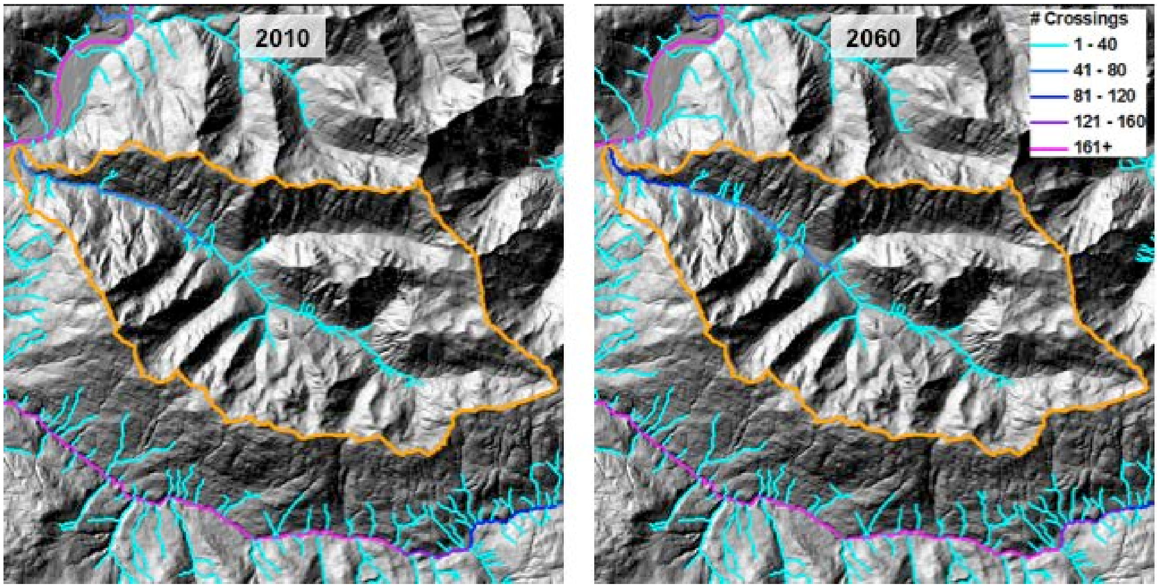
The POC scenario assumed no climate change, so climate-change related attributes were not included in the stratified attribute table. However, if subsequent scenario analysis included alternate climatic regimes, it would be straightforward and advisable to add a stratified attribute table that include all the key climate variables tracked by the modeling framework (see Section 5.4 Climate Change Scenarios).

Although the IWMF has been designed to produce comprehensive and flexible outputs to allow for dynamic specification of indicators and reporting strata, the framework is also capable of calculating specific indicators and producing key maps that are frequently required for linking the state of future landscapes to ecological, social, and economic values. This feature increases efficiency by minimizing post-processing of analysis results and allowing quicker turnaround of model runs during iterative scenario analysis. Some indicators and maps were 'hard-coded' in the POC scenario for the purpose of creating the illustrative outputs included in this document. Additional hard-coding is straightforward and would be implemented based on the needs of project partners, stakeholders, and domain experts.

5.3.2 Network Indicators

Figure 10 shows how the number of stream road crossings that accumulate following the flow of a stream network for a single watershed. Examples of how this information could be used include improving understanding of the cumulative effects of management at various points in the stream network and identifying strategies to reduce impact on sensitive stream reaches.

Figure 10. Cumulative stream crossings by roads along the stream network from headwaters down, for a single watershed in the SRWCP study area, in 2010 and 2060.



Although the connection between upstream activities and downstream effects is well recognized, we were unable to find many examples of indicators relevant to our study area that take this relationship into account. Therefore, little guidance was available in the literature regarding the types of indicators that would useful to a hydrologist, summed along the stream network. In addition, it is possible many the effect of a particular indicator diminishes within distance downstream. For example, the impact of sediment input source might diminish with distance downstream due to settling of suspended particles and dilution by subsequent water flowing into the stream. Refinement of this model component may have to consider this distance relationship when reporting network indicators.

5.4 Climate Change Scenarios

As described in Section 4, methods for evaluating the potential effects of climate change on indicators of future bio-climatic regimes, individual climate variables, and site characteristics, including site productivity have been developed in the IWMF. Based on the projected climatic envelopes for the study area, estimated on the basis of the three climate change scenarios chosen (, a set of indicators have been calculated in the POC describing areal extents and distributions of the potential climatic envelopes associated with these scenarios. These indicators are in turn used by the disturbance, forest estate and indicator models to assess effects of potential climate change on values in the study area.

5.4.1 Climatic envelope time-series

The first and key type of indicator from the climate change scenarios are the interpolated time-series of climatic envelopes derived from the projected envelopes for the study region for the historical, 2020, 2050, and 2080 time periods under each climate change scenario (Figure 11). Interpolated using the stratified similarity approach we developed (see Section 4), the resulting time-series of climatic envelopes can be directly linked to the forest estate model, the disturbance model, or used to develop estimates of changes in habitat quality, and ecosystem composition over time using areal summaries over various strata. (e.g., Figure 12).

Figure 11. Interpolated time-series of projected bioclimatic envelopes (shown here for the Skeena watershed portion of the study area), using the 3 climate change scenarios.

Shown here are 10-year intervals projected out to 2070 (years beyond that are not shown although they are available). Colours approximate the provincial BEC mapping scheme. See Figure 12for a partial legend.

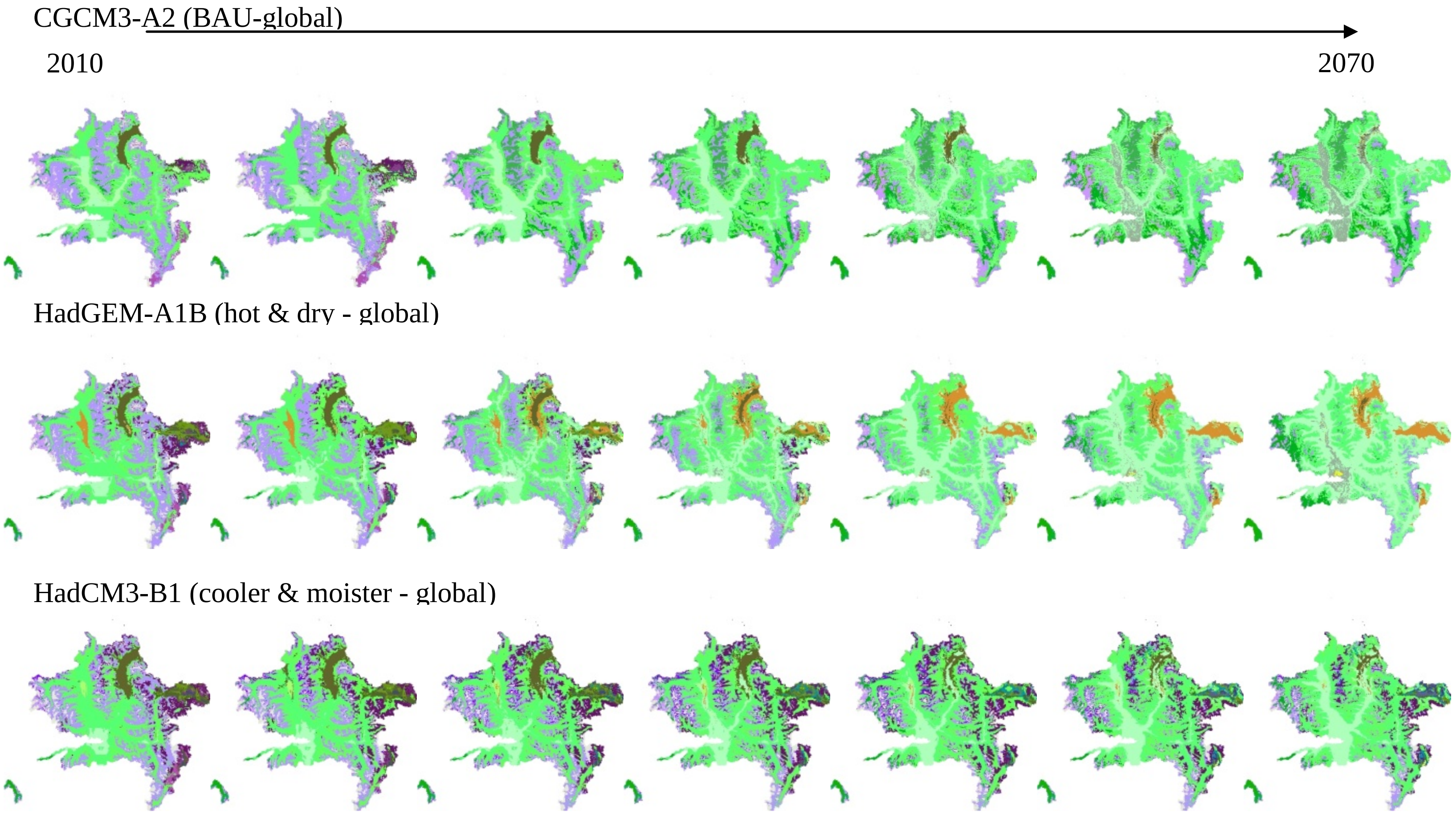
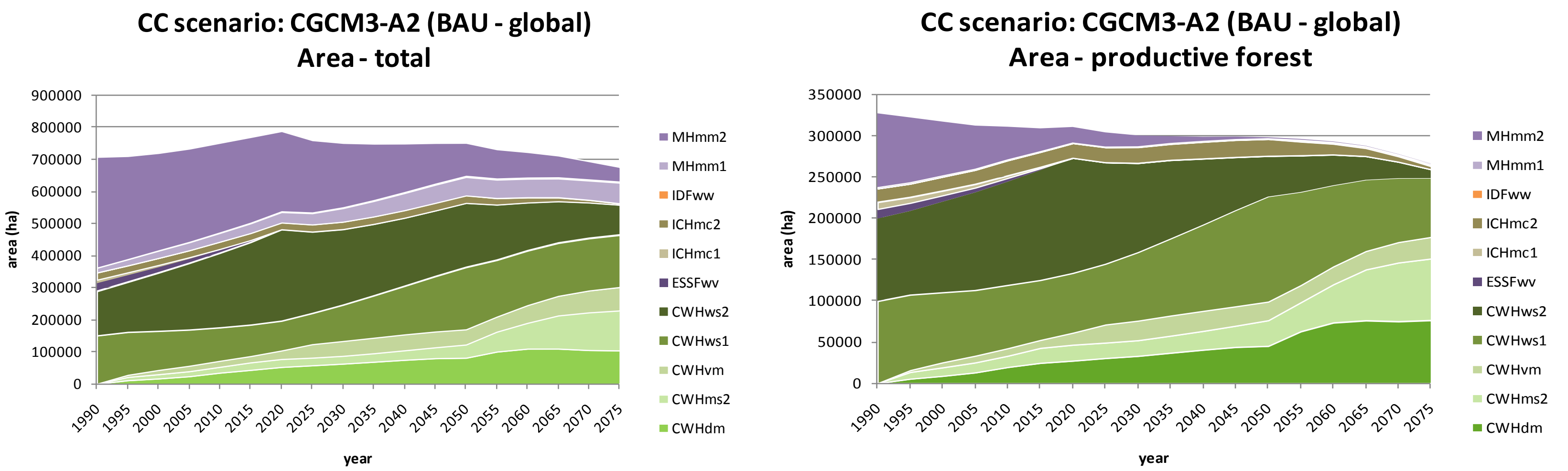
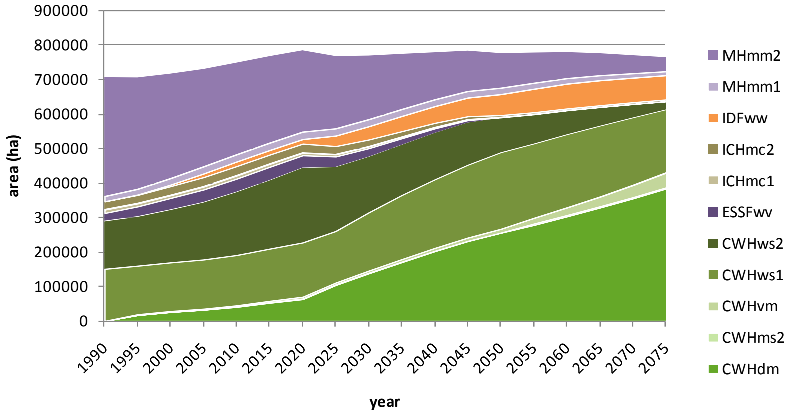


Figure 12. Area of each projected bioclimatic envelope for selected BEC variant equivalents, for the three climate scenarios top, middle, bottom rows).

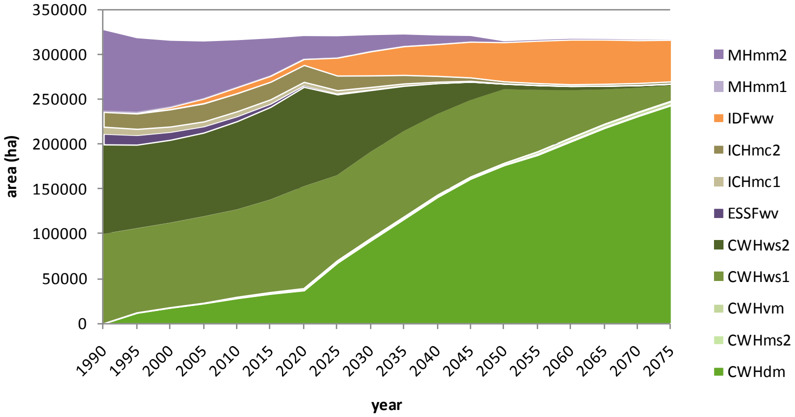
Left graphs show total area in the currently projected study area; right graphs show area in productive forest only. Note that the time period extends prior to 2010 (i.e. can include historical data) and extends to 2075 and beyond.



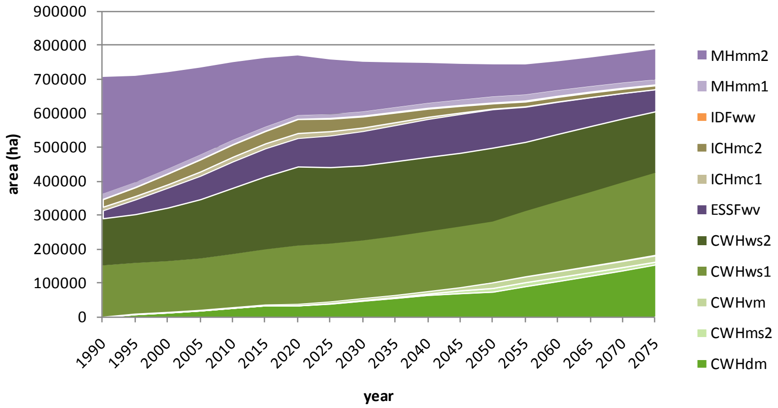
CC scenario: HadGEM-A1B (hot & dry)
Area - total



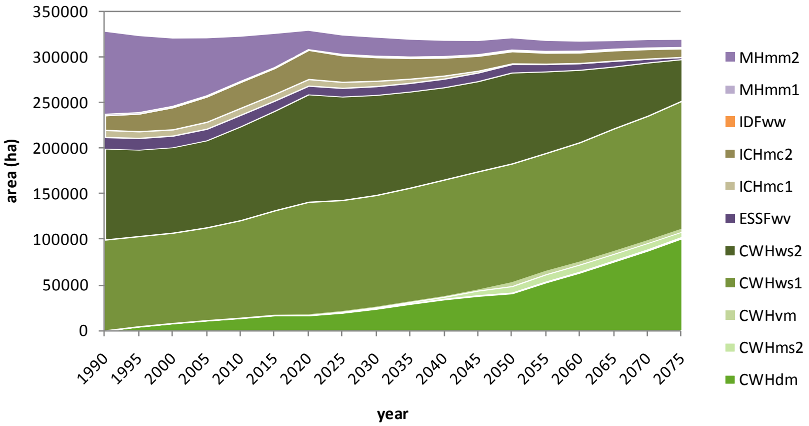
CC scenario: HadGEM-A1B (hot & dry)
Area - productive forest



CC scenario: HadGEM-B1 (cooler-moister)
Area - total



CC scenario: HadCM3-B1 (cooler-moister)
Area - productive forest



5.4.2 Ecosystem-site unit time series

Using the ecosystem prediction modeling approach described in Section 4, a second type of indicator from the climate change scenario are mapped locations of the projected site units for each interpolated BEC variant equivalent map at each 5-year time step. These indicators primarily serve as an intermediate step, linking to potential site index estimates as part of the disturbance and forest estate model components. However, they may additionally be used to support local interpretations of potential zones of wildlife and rare and endangered ecosystem sensitivity to effects of climate change. For example probability maps of the potential site series across the full range of climate scenarios could be used to identify ecological zones exhibiting either convergent trends towards particular site types (esp. types supporting rare community types) across different climate scenarios, or conversely sites showing widely divergent site unit states. These may be candidates for monitoring to determine the rates of fine-scale community changes in response to changing climate patterns.

For this report, we have not shown explicit maps of the projected site series because the projections ought to be reviewed by domain experts in ecological classification before detailed management interpretations are made from them.

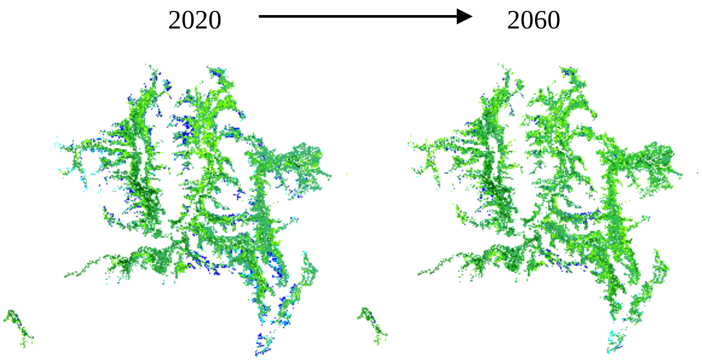
5.4.3 Site productivity time-series

From the site productivity projections, in combination with the projected tree species distributions for the area, and age class time series (as a result of historical and projected disturbances), maps and areal summaries of projected site productivity (i.e. site index) patterns can be generated (Figure 13). The primary purpose of these indicators are to enable the forest estate model to link to the appropriate growth and yield relationship allowing climate-change scenario-specific estimates of potential relative changes in forest growth and regeneration of species to be estimated. As described in the methods description (Section 4) estimation of site productivity is difficult because of the uncertainties in extrapolating from the current suite of site-series x species productivity data to the many types of novel combinations that may be possible in future under the different climate scenarios. Nonetheless, such estimates do permit forest harvesting options to be assessed for their potential sensitivity to changing productivity assumptions under climate change.

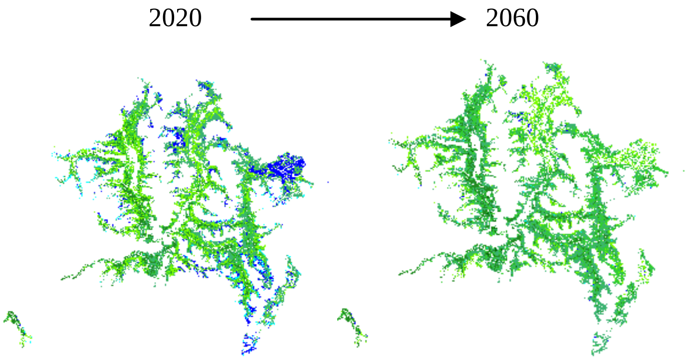
Figure 13. Areal distribution of potential site productivity for each climate change scenario at projection time period 10 (year 2020) and projection time period 50 (year 2060).

Colour ranges are: yellow: SI < 11; blue: SI between 12 and 17; green: SI > 18 with darker colours at the higher SI values in each respective range.

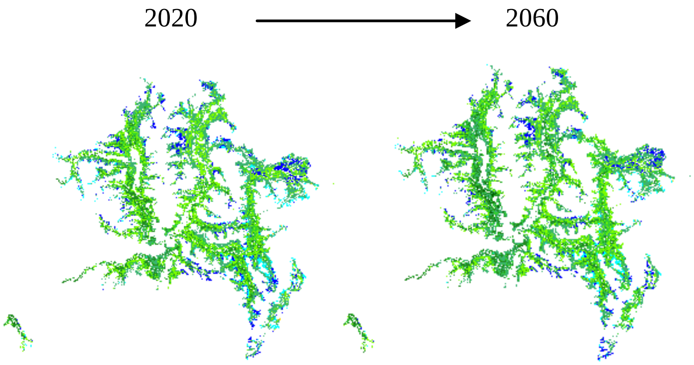
CGCM3-A2 (BAU - global)



HadGEM-A1B (hot & dry - global)



HadCM3-B1 (cooler & moister - global)

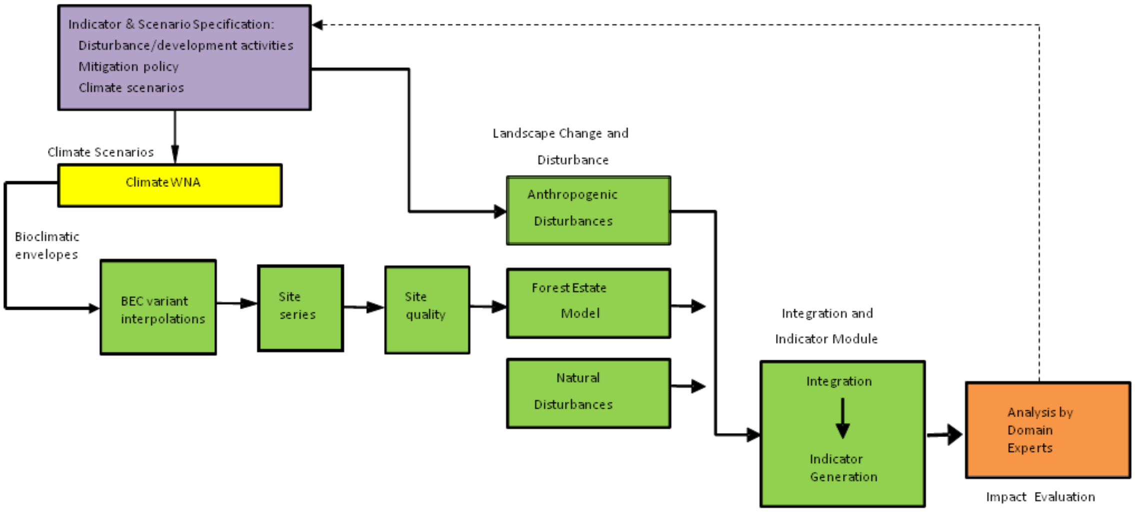


6.0 Current Implementation of the IWMF for the SRWCP POC

The current implementation of the components of the IWMF involved in the SRWCP proof-of-concept project is shown in Figure 14. This implementation focuses primarily on the analytical portion of the IWMF, with the results being used to inform scenario-based planning activities in the study region.

Figure 14. Main modules and information flows for the SRWCP POC implementation of the IWMF.

Interpretation of colours are as follows: purple – inputs (e.g., parameters, GIS data, etc.), yellow – external model projections; green – IWMF submodels and components developed for the SRWCP POC; tan – external expert analysis.



Operation and usage of this implementation is summarized in the steps outlined below. For more details on each step, and its linkages to other components of the IWMF, see the sections referenced within each step below.

Step 1: Indicator selection. Before data can be selected, and scenarios specified, the indicators required to evaluate impacts are selected. Indicators are of two types: areal and network, and the level of detail among indicators depends on the spatial data available for the area (section 4.2.2).

Step 2: Scenario specification. Here, depending on the purpose for which the scenario is run, the user selects the parameters for the scenario (e.g., socio-economic objectives, management assumptions, types of development activities that are expected to occur, and climate change scenario (see Tables 3 and 4). More details on scenario specification are given in section 4.2.3.

Step 3: Forecast future landscapes for a specified time horizon and temporal resolution. Depending on the scenario specification, one or more of the following sub-steps may be undertaken:

> Step 3a: Project anthropogenic disturbances (i.e. location of developments through and their linkages via access points). This step makes use of historical and currently known locations of developments by type, and the parameters specifying types of future developments expected under the scenario.

Step 3b: Project future BEC variant climate envelopes, and their potential effects on ecological characteristics such as future site series and site quality. This step uses projected climatic envelopes for the region in combination with future climatic variables under the given climate change scenario. These are used in combination with current information about topography and the effects of soil nutrient and moisture regimes to estimate potential effects on future growth and yield of leading tree species.
Step 3c: Project future forest conditions on the basis of the development activity and climate scenario. Given the location of developments, the management objectives, and the potential effects of climate, projections of forest growth and changes in species composition as a result of silviculture can be projected.

In the POC, natural disturbances are not simulated for this area. However, their effects can be added in with the inclusion of disturbance models in combination with appropriate parameters.

More details on these steps are given in section 4.2.4.

Step 4. Integration of results in indicator summaries. After the future states of the landscape have been simulated for the given scenario, indicator summaries are produced, either in map format, or as summary tables, stratified by scenario-selected strata chosen to help assess impacts. For each combination of strata factors in the landscape (see Table 6), attributes representing the disturbance effect of the scenario on hydrological variables, management variables, and landscape descriptors are summarized. These can be imported into spreadsheets for further analysis and interpretation, or for further processing by other analytical models. See section 5.3 for more details.

Step 5. Interpretation of effects by domain experts. This is the main interpretation step in the assessment of cumulative effects for the given scenario. The interpretation involved consultation with experts in each main area of concern in the scenario (socio-economic, management, hydrology, vegetation ecology, wildlife ecology, etc.). Results from the interpretation step can be used to refine specifications for additional scenarios.

7.0 Acknowledgements

We thank the World Wildlife Fund - Canada for supporting this project from its inception. In particular, James Casey, Michele Patterson and Darcy Dobell (WWF) have worked closely with us from the beginning of the project. Many others have contributed ideas, time and discussions of approaches at several points in the evolution of this project: Bill Bourgeois, Brendan Wilson, Richard Chavez, Duncan Dow of Coast Tsimshian Resources (CTR), Dirk Brinkman, and Katie McPherson, (Brinkman Reforestation, Ltd.), and various members of the FFESC research group. For the climate change component we are grateful to Tongli Wang (UBC), Don Morgan, Craig Delong, Walt Klenner, Shirley Mah (MLFNRO), Don Robinson, Joe Melton and Jed Kaplan (ESSA) for many helpful discussions about methodology, and in particular D. Morgan, T. Wang, and D. Robinson for critical data without which that portion of the project would not have been possible to complete.

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Appendix A SRWCP Governance and Communications Documents

This appendix lists all governance and communications documents developed by Cortex Consultants for the SRWCP. Note that many of these documents was maintain to the end of the Phase 4 of the project, at which point external communications and project coordination were taken over by WWF. These documents are included in an appended folder, named per the list below. Where possible, each document includes a disclaimer following the title page, explaining the relevance of the document to the final, POC version of the SRWCP.

A1 SRWCP Project Charter V 4.1

A2 SRWCP Risk Register

A3 SRWCP Project Overview

A4 SRWCP Governance Overview

A5 SRWCP Related Initiatives

A6 SRWCP Audiences

A7 SRWCP Advisors Solicitation

A8 SRWCP Project Evolution

Appendix B SRWCP Technical Documents

This appendix lists all technical documents developed by Cortex Consultants for the SRWCP. The documents are listed chronologically and can be divided into two sections: those developed before the project shifted from a full pilot to the more narrowly focused proof-of-concept (B1 – B4), and those developed after the project shifted to the proof-of-concept version (B5 – B13). These documents are included in an appended folder, named per the list below (dates have been retained to reflect chronology). Where possible, each document includes a disclaimer upfront, explaining the relevance of its contents to the final, POC version of the SRWCP.

B1 SRWCP Analytical Methods, 05 Aug 2009

B2 SRWCP Data Model Spatial Database, 28 February 2010

B3 SRWCP Preliminary Indicators Associated Data, 01 April 2010

B4 SRWCP Proposed Outcomes and Issues, 01 May 2010

B5 IWMF Conceptual Model, 26 August 2010

B6 InVEST Review, 31 August 2010

B7 SRWCP POCS Forest Model Data, Methods and Management Assumptions, 26 August 2010

B8 SRWCP POCS Anthropogenic Disturbance Model Methods and Assumptions, 31 August 2010

B9 SRWCP Raster Datasets for Forest, Anthropogenic and CEA Model, 26 August 2010

B10 SRWCP Forest Model Base Case Figures, 29 November 2010

B11 SRWCP POCS Indicators, 30 November 2010

B12 SRWCP POC Presentation, 30 November 2010

B13 SRWCP FFESC Presentation, 17 February 2011

Workshop Summary: Refining Methods for Evaluating Impacts to Stream Health

Workshop held November 14, 2011, Northwest Community College, Terrace, BC

Summary prepared by
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Nov 30, 2011

For
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Part of
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Richard Chavez	Coast Tsimshian Resources
Kris Pucci	Department of Fisheries and Oceans

1. Introduction

1.1. Background[1]

This workshop contributes to the Skeena River Water Conservation Project, initiated in 2007. In this project, the World Wildlife Fund of Canada (WWFC) has been collaborating with the Coast Tsimshian Resources (owned by Lax Kw'alaams First Nation), and their forest management consultant Brinkman & Associates, to develop and test an approach for informing forest management decisions, particularly those affecting aquatic ecosystems. Fisheries values in watersheds feeding the Skeena River are high. Canadian Fisheries and Oceans staff who have responsibility for salmon habitat have been collaborating with the project. Lars Reese-Hansen (MFLNRO), who is developing Fisheries Sensitive Watershed (FSW) indicators, has also been collaborating with this project. A few of the watersheds in the study area retain their historically-designated FSW status. Several more are likely candidates for FSW status. FSW management is thus an important issue in the area.

WWFC engaged Cortex Consultants to lead development of the decision-support approach, now referred to as the Integrated Watershed Management Framework. The Integrated Watershed Management Framework is based on the analysis framework embedded in Cortex's Cumulative Regional Effects Assessment Tool. Cortex's work to date has focussed on developing the analytical models used to characterize forestry development and to calculate indicators of stream health. The models have not yet been used to assess alternative forest management scenarios. In the future, the models can be expanded to consider other types of development and values other than stream health, if desired.

1.2. Purpose of workshop

The Integrated Watershed Management Framework intends to foster collaboration among decision-makers and stakeholders. This workshop provided an opportunity for decision-makers and stakeholders to review the Cortex models to assess strengths and weaknesses and to suggest improvements. Specifically, the purpose of the workshop was to

- evaluate the capability of the Cortex model to project impacts on aquatic ecosystems and to serve as a useful forest management tool;
- recommend model revisions;
- identify any additional steps (i.e., future work) necessary to better estimate impacts on aquatic systems

Workshop results aim to provide sufficient information for Cortex to wrap up the primary development phase of their analytical models; they aim to guide any future work contemplated.

1.3. Geographic and development context

The geographic scope of the Skeena River Water Conservation Project covers several large watersheds (Lakelse, Kalum, Zygometz/Copper) near Terrace which are influenced by Coast Tsimshian Resources' forest management (in TFL1). The watersheds are also affected by other forestry companies (volume-based tenures) and by other types of human activity, including fishing, tourism and mining. Proposed projects in the area include pipelines, independent power projects, and related roads and transmission lines.

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[1] For details, see Cortex Consultants. 2011. Skeena River water conservation project: project summary.

1.4. Content of this summary

The workshop consisted of a series of presentations (by James Casey, Kris Pucci and Jason Smith) and interspersed participatory discussions. Workshop discussion was fairly wide ranging over the day. This summary organises discussion by topic rather than chronologically. The remainder of this summary presents the following sections:

2. Factors affecting aquatic ecosystems (including issues with clear-span crossings)
3. Cortex analysis framework
4. Indicators of stream health
5. Future work
6. The role of models in decision support

2. Factors affecting aquatic ecosystems

In relation to stream health, properly functioning condition is defined in the province's Forests and Range Practices Act (FRPA) as:

> *The ability of a stream, river, wetland, or lake and its riparian area to: 1) withstand normal peak flood events without experiencing accelerated soil loss, channel movement or bank movement, 2) filter runoff, and 3) store and safely release water*[1].

2.1. Conceptual model of factors affecting streams

Broadly speaking, the main factors affecting aquatic ecosystems are dams, water withdrawals, land use/alteration and climate change (James Casey's presentation). In the study area, land use is the main factor affecting stream health, but climate change could become important.

Workshop participants contributed to a conceptual model linking forest development activities to stream health (Figure 1). At a coarse scale, forestry developments that affect streams include roads, stream crossings and harvesting. Both the amount and location of development is important. At a finer spatial and temporal scale, the standard (i.e., workmanship) of road construction, maintenance and deactivation affects stream health. Similarly, at finer scales, the pattern of riparian forest left behind in cutblocks influences stream health. Monitoring can provide feedback regarding the quality and consequences of fine-scale practices. Where knowledge is limited, best and worst case scenarios can be used to characterize uncertainty.

High stream temperatures (related primarily to climate change but also to riparian management) and sedimentation (related primarily to transport infrastructure development, but also to climate change), are a concern in the study area.

High temperatures in the Lakelse mainstem (~20^0C in August 2010) are likely affecting Chinook production in the Coldwater tributary (~8^0C in August 2010)—the best Chinook river in the Lakelse watershed. Chinook juveniles do not tolerate warm temperatures. In August 2010, Chinook juveniles were found in the Coldwater River, but not in the Lakelse mainstem (pers. comm. Dave Rolston). Whitefish, which tolerate higher temperatures and lower dissolved oxygen concentrations, were found in the Lakelse mainstem. Adult Chinook spawners must pass through the Lakelse mainstem to reach the Coldwater River. High temperatures and low dissolved oxygen concentrations make the adult fish sluggish and easier prey to fishers.

About eight years ago, high temperatures in the Kumealon River (~ 20^0C) during and after chum spawning likely caused faster than normal development of eggs and may have caused an early hatch of chum (January versus the typical April/May)—a time when food supply is limited (pers. comm. Dave Rolston).

Historic logging has likely contributed to Coho salmon habitat degradation in the Kumealon River. Logging (heavy circa 1948 and ongoing but spotty since then) has contributed to landslides and mass wasting, particularly along the Canyon Creek tributary (pers. comm. Dave Rolston). Resulting sediment filled pools and reduced surface flow in the Kumealon and is likely responsible for a switch from Coho to Pink dominance. Unlike Coho, Pink do not need to use pools. Also, Pink eggs can tolerate lower surface flow, and hence oxygen supply, because they are relatively small and have a high surface area to volume ratio (allowing greater oxygen absorption per unit volume).

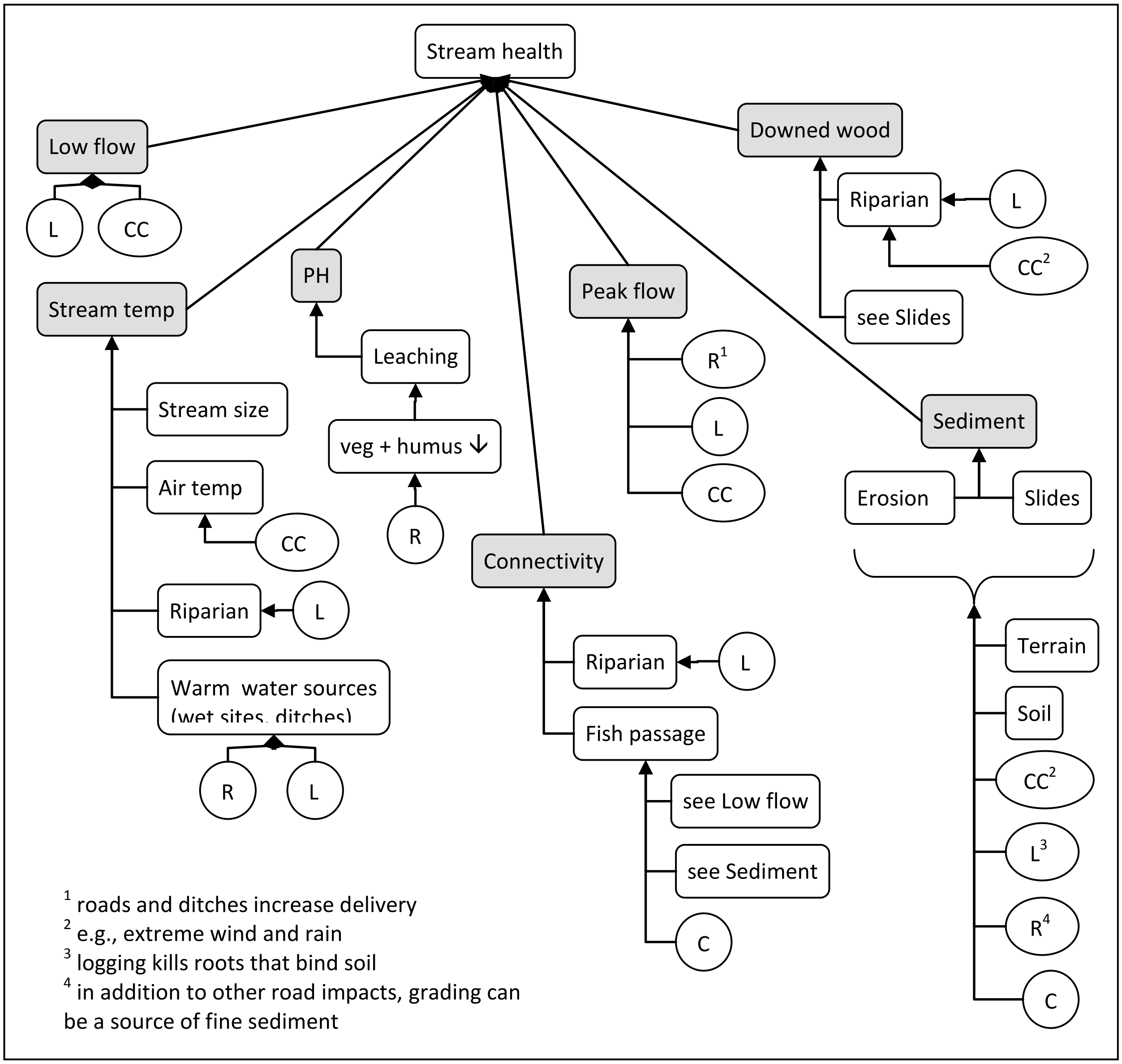
Agriculture and human settlement affect water quantity by increasing snowmelt and overland flow, which in turn increases erosion. Runoff from agriculture and urban areas delivers excess nutrients and toxic chemicals to aquatic ecosystems.

Climate change can potentially affect streams in several ways. Possible changes include

- increased peak flows due to increased early winter rainfall (more precipitation and a high proportion falling as rain) and more extreme storm events;
- reduced low flows due to an earlier spring freshet, a reduced snowpack (warmer winters) and warmer, drier summers (e.g., very low flows and warm temperatures in 2010; pers. comm. Dave Rolston);
- increased blowdown in exposed riparian areas due to more extreme storm events;
- increased sediment input due to increased peak flows and increased extreme rainfall events.

Climate change and industrial development combine to increase the risk to streams. In particular, roads, bridges and culverts should be designed to tolerate projected future climatic and streamflow conditions for both economic and ecological reasons.

Uncertainty about the magnitude, and in some cases even the direction, of climate change is huge. Hydrological models are needed to better evaluate the impacts of climate change on aquatic ecosystems. Several hydrological modelling projects may provide information about the Skeena River system in the near future (e.g., see work by Jack Stanford, University of Montana and Marcus Schnorbus, Pacific Climate Impacts Consortium)



[1] roads and ditches increase delivery
[2] e.g., extreme wind and rain
[3] logging kills roots that bind soil
[4] in addition to other road impacts, grading can be a source of fine sediment

Figure 1. Conceptual model showing pathways by which roads (R), stream crossings (C), logging (L) and climate change (CC) affect stream health. Arrows show direction of influence. The main variables related to stream health are shown in shaded boxes.

2.2. Clear-span stream crossings

Stream crossing quality is a fine-scale factor that influences interpretation of coarse-scale strategic indicators (e.g., number of crossings).

Where stream crossings do not alter in-stream habitat (e.g., clear-span bridges), DFO does not technically need to review the project, however, forest managers must be clear that their construction practices will not harm fish habitat. Forest managers can assess the risk of their proposed crossing and the need for further DFO involvement by filling in a DFO Operational Statement[2]. Operational

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[2] see DFO website: www.pac.dfo-mpo.gc.ca/habitat/index-eng.htm

statements include criteria to ensure that projects are low risk and include measures necessary to protect in-stream habitat.

Problems with clear-span bridge installations noted in a recent study include
- spoil piles < 15m from stream;
- riprap located below high-water mark.

The study noted that Operational Statements could be improved by providing different standards for
- temporary versus permanent installations;
- for different terrain types (e.g., gullies).

The study also noted that impacts to streams should be characterized in terms of both percent of stream affected and area affected and that previously-existing impacts need to be separated from recent impacts.

3. Cortex analysis framework

To address stream health for the Skeena River Water Conservation Project, Cortex followed steps described in their analysis framework ("Integrated Watershed Management Framework"; Figure 2). This framework contributes to the Cortex Cumulative Regional Effects Assessment process[1]. Work to date has focussed on model development and testing, rather than on policy analysis (i.e., comparison of management options).

Models provide an important component of the knowledge base influencing decisions and need to be flexible enough to address changing circumstances. Cortex uses a modular approach to analysis. Different models can be "plugged in" to the Cortex "analysis framework" to expand the scope of analysis or to include more types of development or to consider impacts on a wider variety of values. As new, better models are developed, older model components can be replaced. Currently Cortex is using Woodstock[3] (an non-spatial model) to calculate harvest volumes and SELES[4] (a spatial model, using 25m x 25m raster, in this case) to simulate road and cutblock locations and to calculate stream health indicators. Mine locations are also simulated. Cortex is also developing a module to locate independent (hydro) power projects.

Models cannot characterize the details of all development activities. Some activities that affect streams happen at a finer temporal/spatial scale than the model represents. For example, the quality of the road and bridge construction, maintenance and deactivation process can substantially affect aquatic ecosystems. Obtaining information about these processes requires field monitoring. This information provides important context for determining risk to streams from indicators of road and streams.

Models store and synthesize knowledge and project logical consequences. Models do not provide answers—model results need interpretation. Models need to be used in the context of a decision support process.

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[3] see http://www.remsoft.com/
[4] see http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/fall_andrew/fall.html

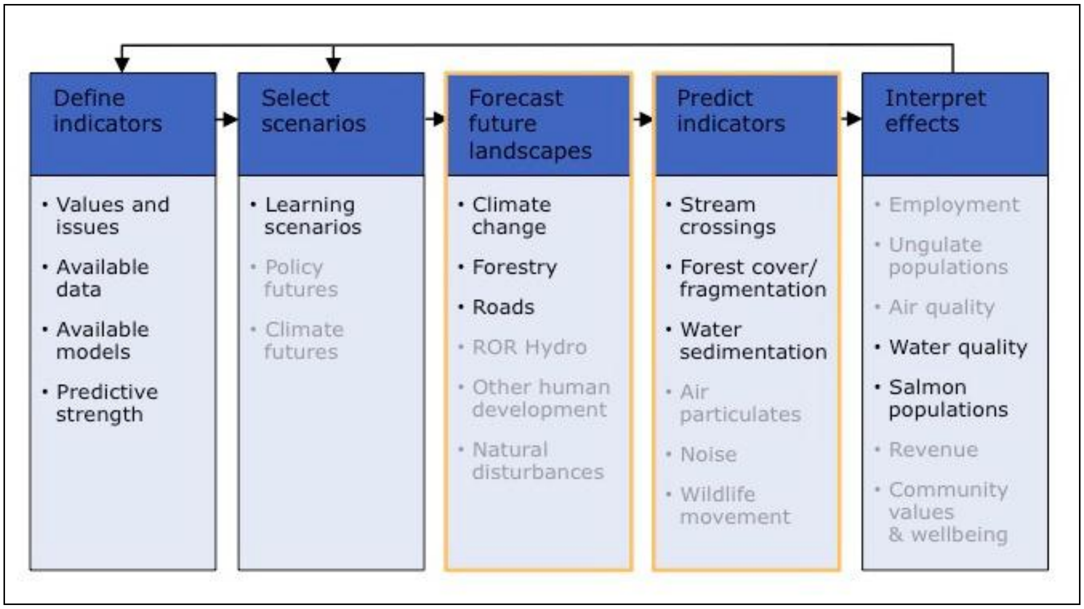

Figure 2. Integrated Watershed Management Framework (Retrieved from Cortex Consultants 2011)[1]. Highlighted components have been implemented in the Skeena River Water Conservation Project.

4. Indicators of activities affecting stream health

The Cortex model simulates forestry (and mine) development and generates indicators related to stream health. One of the main goals of the workshop was to review and revise stream health indicators.

4.1. Types of indicators

Two classes of indicators can be used to assess impacts to stream health. Indicators can be used to measure a variety of factors correlated with stream health (e.g., flow regimes, channel structure, benthic invertebrates, fish populations). In managed systems, these indicators are often referred to as **effectiveness indicators** because they assess the consequences (outcomes) of development; consequences that meet objectives indicate effective management.

Indicators can also be used to characterize landscape changes that are known to influence stream health. These indicators can include changes due to natural and anthropogenic forces. For the purposes of planning, **indicators of anthropogenic activity** are particularly important because they can be used to estimate consequences of proposed management. The Cortex model focuses on indicators of activity. By analogy in humans, diet and exercise are indicators of activity; weight and blood pressure are indicators of effectiveness.

Indicators of activity describe the amount of different types of development in different biophysical units. The types of development and of biophysical units to include in an indicator are selected for their ability to characterize landscape changes relevant to stream health. Indicators can be used to estimate impacts of existing development or of projected development.

Indicators of activity describe broad changes in the amount of development. They do not characterize the quality or “workmanship” of roads, crossings and cutblocks. Ideally, interpretation of indicators of activity should consider the historic quality of development in the area.

4.2. Cortex model indicators

The Cortex model has not yet arrived at a “final” set of indicators relevant to stream health. Rather, at this stage, it aims to include the variables describing development activity and biophysical units needed to create any relevant indicator (based on Jason Smith’s presentation—see Appendix 1).

The Cortex model includes the following variables describing forestry and development activity:

- harvested area;
- seral stage area;
- equivalent clearcut area (area harvested, modified to account for forest regeneration and hydrological recovery);
- road length;
- stream crossings (road-stream intersections);
- transmission lines;
- mine sites;
- run-of-river hydro sites.

Relevant biophysical variables include zones and linear features:

- landscape units;
- biogeoclimatic variants;
- freshwater assessment watersheds;
- site index classes;
- timber harvesting land base;
- streams by size class and fish presence (S1-S4 from Forest Planning and Practices Regulation);
- salmon-bearing reaches (based on fish-passage maps that consider stream slope and known barriers);
- riparian buffers (area within 100m of a stream);
- steep potentially unstable slopes (estimated as slopes > 50 %);
- coupled slopes (steep slopes within 50m of a stream);
- coupled streams (streams within 50m of steep slopes);
- upstream reaches (used to summarize upstream crossings).

The next section provides an overview of how the variables were calculated.

Combinations of forestry/development activity variables and biophysical variables form indicators (e.g., roads on steep slopes (km/km^2).

Indicators can be summarized at different spatial scales. The Cortex model uses Fresh Water Assessment Units[5] to represent watersheds. The smallest units in these maps range from several hundred to several thousand hectares. These assessment units are nested: sub-basin names include a reference to the larger sub-basins that they sit in. Thus, in most cases, indicators from sub-basins can simply be summed to address larger watersheds.

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[5] Carver, M. and M. Gray. 2010. Assessment watersheds for regional application in British Columbia. Streamline. 13(2): 60-64. Available online.

4.2.1. Methods used to calculate variables in Cortex Model

To calculate variables, the Cortex model divides the landscape into 17 different land cover classes (“stratification attributes”; Table 1); classes can overlap. For each combination of classes, the model records the following: area, equivalent clearcut area[6] (for all raster cells in the Crown Forest Land Base), road length, and stream length. From these variables, an enormous number of indicators could potentially be created (more than a trillion). Variables are calculated every five years during simulation.

Table 1. Stratification attributes used for areal indicators

Factor	# elements
Logged	2
Seral Stage	5
Roads	2
Stream crossing by road	2
Transmission Lines (Trans)	2
Mines	2
Run-of-River Hydro (ROR)	2
Landscape Unit (LU)	32
Biogeoclimatic Variant (BEC)	22+
FWA Watershed	287
Site Index Class (SI_cl)	5
Timber Harvesting Land Base (THLB)	2
Stream Class S1-S4	2
Fish passage[7]	4
Within 100m of stream	2
Steep slope (≥ 50%)	2
Steep coupled slope[8]	2
Stream adjacent to coupled slope (w/in 50 m)	2

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[6] ECA was calculated according to the CWAP guidelines (B.C. Ministry of Forests 2001). Separate calculations were not done for rain-dominated, transient snow, and snowpack zones. With expert opinion to define the location of these zones it would be simple to add these distinctions. Furthermore, under some climate scenarios the study area becomes much more continental, in which case it may be worthwhile providing separate ECA to account for the location of the major snowmelt zone. To account for historical forest harvesting activity, all stands within the Crown Forest Land Base less than 50 years old were assumed to have a forestry origin. This assumption needs to be verified, and possibly modified, by regional domain experts.

[7] Based on Norris, S. and C. Mount. 2009. Fish Passage GIS Analysis: Methodology and Output Data Specifications. Unpublished report prepared for the BC Ministry of Environment.

[8] Steep coupled slopes are defined as the portions of the landscape that are steep slopes (≥ 50%) extending to within 50m of a stream (Forsite Consulting Ltd., Grainger and Associates Consulting Ltd., M.J. Milne and Associates Lrd,. and Key Forest Resources. 2007. A Risk Based Watershed Screening Procedure for the Kamloops TSA. Unpublished report prepared for Kamloops TSA Licensees and BC Ministry of Environment.). Steep coupled streams are streams adjacent to steep coupled slopes.

4.3. Draft fisheries sensitive watershed indicators

To assess the appropriateness of the variables used to define indicators in the Cortex model, the Cortex variables can be compared to variables used to create Fisheries Sensitive Watershed (FSW) indicators. The FSW indicators are currently in draft form and should still be viewed with caution. They include the following variables to characterize development[9]:

- harvested area;
- equivalent clearcut area (area harvested, modified to account for regeneration and hydrological recovery);
- equivalent second growth area (area of dense forest 25 to 75 yr old);
- roads;
- stream crossings (bridges and culverts).

Landslides also provide a useful indicator that can be used to characterize natural levels of sediment input. Changes in landslide frequency related to development can also serve as an indicator of the effectiveness of management of unstable terrain.

FSW indicators include the following variables to characterize biophysical features:

- streams;
- fish-bearing streams;
- riparian forest (assume a 100m buffer around streams);
- slopes > 60%;
- erodible soils (from soil maps);
- elevation zones (e.g., snow or rain dominated; to be determined by hydrologist);
- high elevation zone—above H60 line (elevation above which 60% of watershed lies);

Lack of soils maps and terrain hazard maps limit calculation of indicators of stream health.

4.4. Interpreting multiple indicators

Options for interpreting suites of stream health indicators include

- risk matrices that apply scores to each indicator and then consider all scores (Appendix 2)
- simple models that combine risks from different indicators to estimate overall risk (e.g., Bayesian belief networks)

In either case, domain experts should be involved in interpretation.

5. Future work

Over the course of the workshop, participants identified potential changes to the Cortex model, subject to budget limitations. They also identified future work to complete over the longer-term, if warranted.

5.1. Candidate model revisions

Potential tasks to improve the Cortex model, identified at the workshop, include

1. assess the potential to include deactivated roads;

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[9] Wieckowski, K., M. Porter, E. Snead, S. Casley. 2011. GIS-based protocol for Tier 1 monitoring of Fisheries Sensitive Watersheds (FSW). Draft report prepared by ESSA Technologies Ltd. for BC Ministry of the Environment (MOE), Victoria, BC. 16 p.

2. distinguish gradients that support fish (< 20%) from high gradient (>20%) reaches;
3. include known spawning grounds (data for Lakelse available from DFO);
4. include modeled sockeye habitat as a stratification attribute;
5. identify confluences as potential fans; regeneration has partially stabilised historically logged fans; upstream logging that increases flows or scour could destabilize fans again, thus activities upstream of fans may be a useful indicator;
6. consider including Equivalent Second Growth Area (discuss value with Lars Reese-Hansen)
7. use terrain maps from TFL 1 to estimate the relationship between terrain stability and slope class; seek advice from local experts about using > 50% or > 60% to identify potentially unstable terrain;
8. roughly account for agricultural and settlement impacts (e.g., area of agricultural and settlement lands near streams); note that these would be static attributes as the model does not project changes in agriculture or settlement extent.

5.2. Long-term future work

During the workshop, participants identified other actions that would contribute to managing stream health:

1. To support the calculation and interpretation of indicators, compile existing information describing biophysical features in the study area, including
    a. obtain Lakelse Level One Watershed Assessment from MFLNRO research staff in Smithers (e.g., Dave Wilford or Matt Sakals);
    b. obtain terrain stability maps from MFLNRO research staff (e.g., Matt Sakals) or from the MFLNRO District Office;
    c. obtain/digitize old Skeena Cellulose reports (e.g., fish presence/absence) for TFL 1 from CTR.
    d. obtain copies of known spawning grounds from DFO;
    e. obtain copies of historic logging of streams from DFO.

2. After assessing existing information, fill information gaps:
    a. improving coverage of terrain hazard maps;
    b. creating fish presence/absence maps;
    c. determine need to collect Dolly Varden habitat information by monitoring conservation status of Dolly Varden (currently being considered for listing under the Species at Risk Act);
    d. monitor status of BC-scale soils maps[10];
    e. monitor use of deactivated roads by ATVs—could be a major source of sediment on glacial till and unstable slopes.

3. Ideally, compile a knowledge base for the study area that includes relevant maps and reports (see for example Babine Watershed Monitoring Trust knowledge base at http://www.babinetrust.ca/).

4. Develop a process to bring together forest tenure holders, other developers (e.g., independent power producers), affected First Nations and stakeholders to examine cumulative effects on stream health and to establish a collaborative watershed management approach. Affected First Nations include Lax Kw'alaams, Kitselas, Kitsumkalum and Gitanyow. DFO may have funding to support collaborative planning workshops. WWFC is currently selecting ten important and iconic rivers in

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[10] See Appendix A in Wieckowski, K., M. Porter, E. Snead, S. Casley. 2011. Fisheries Sensitive Watersheds (FSW) – Tier 1 monitoring protocol rationale. Draft report prepared by ESSA Technologies Ltd. for BC Ministry of the Environment (MOE), Victoria, BC. 29 p.

Canada to focus on. Future opportunities for collaboration with WWFC may exist if the Skeena is selected.

5. In support of action 4 above, expand Cortex model to better address other development activities and other values (i.e., cumulative effects); existing habitat models can be easily added to the Cortex model; a tailed frog model may be a high priority to add; also, improve the ECA calculation by including elevation zones.

6. Assess impacts of climate change using hydrological modelling. Models applicable to the Skeena may be available in the near future from two sources:
    a. Jack Stanford, University of Montana. See http://rap.ntsg.umt.edu/ ;
    b. Marcus Schnorbus, hydrological modeller for the Pacific Climate Impacts Consortium. The Variable Infiltration Capacity (VIC) hydrological model may be applied across BC. See http://pacificclimate.org/project/hydrologic-modelling-peace-campbell-and-columbia-river-watersheds.

7. Other tasks to consider include
    a. Assess the potential to link operational planning to strategic-scale Cortex model;
    b. Assess the potential of models to identify cutblocks that face high risk of exceeding the 7% maximum disturbance limits.

6. The role of models in decision support

Over the course of the workshop, participants discussed the role of models in decision-making. Models do not provide answers nor make decisions. They can, however, be an important component of a larger decision support process. With the support of analysts and domain experts, information generated by models can help inform decision-makers. Models also help to document and share knowledge and provide a focal point for informed discussion among stakeholders.

Figure 3 presents one vision of a decision-support process (based on a sketch from the workshop). Bold text in the figure is also shown in bold below. **Decision-makers and stakeholders** define management issues and develop **management alternatives**. Analysts use **models** to characterize different **management alternatives** in terms of indicators that are relevant to one or more values (e.g., stream health). **Domain experts** interpret **indicators of activity** within a specific biophysical context (e.g., roads on unstable slopes) to estimate **risk to streams**; they also consider indicators of change due to natural forces (e.g., natural landslides) and global warming[11]. **Decision-makers**, usually in consultation with stakeholders, consider risks and benefits to multiple values and then arrive at strategic decisions determining the **amount and location of development** (e.g., amount of roads and harvesting in different watersheds); subsequently, decision-makers oversee the **workmanship** of the development processes (e.g., road construction). Ultimately the amount, location and quality of development, coupled with "natural" events will impact **stream health**. Domain experts use **monitoring** information to improve their understanding of development processes (implementation) and consequences (effectiveness). Better understanding feeds back to improve analytical models and the interpretation of model results.

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[11] The workshop focused on indicators of activity rather than on indicators that capture natural changes or climate change; models should include natural processes and climate change.

The Cortex Cumulative Regional Effects Analysis Tool provides a model-based, decision-support process that is similar to the one described above.

Institutional structures (e.g., government policy, market forces, standard practices) can prevent the application of new knowledge to decision-making. In the forest industry, where profitability drives decision-making, management practices that are more expensive than the minimum standard required by the Forest and Range Practices Act and other legislation are unlikely to be adopted, unless some short-term benefit is likely (e.g., culverts bigger than minimum size may reduce long-term maintenance costs). Decision-support tools only help where institutional structures reward good management.

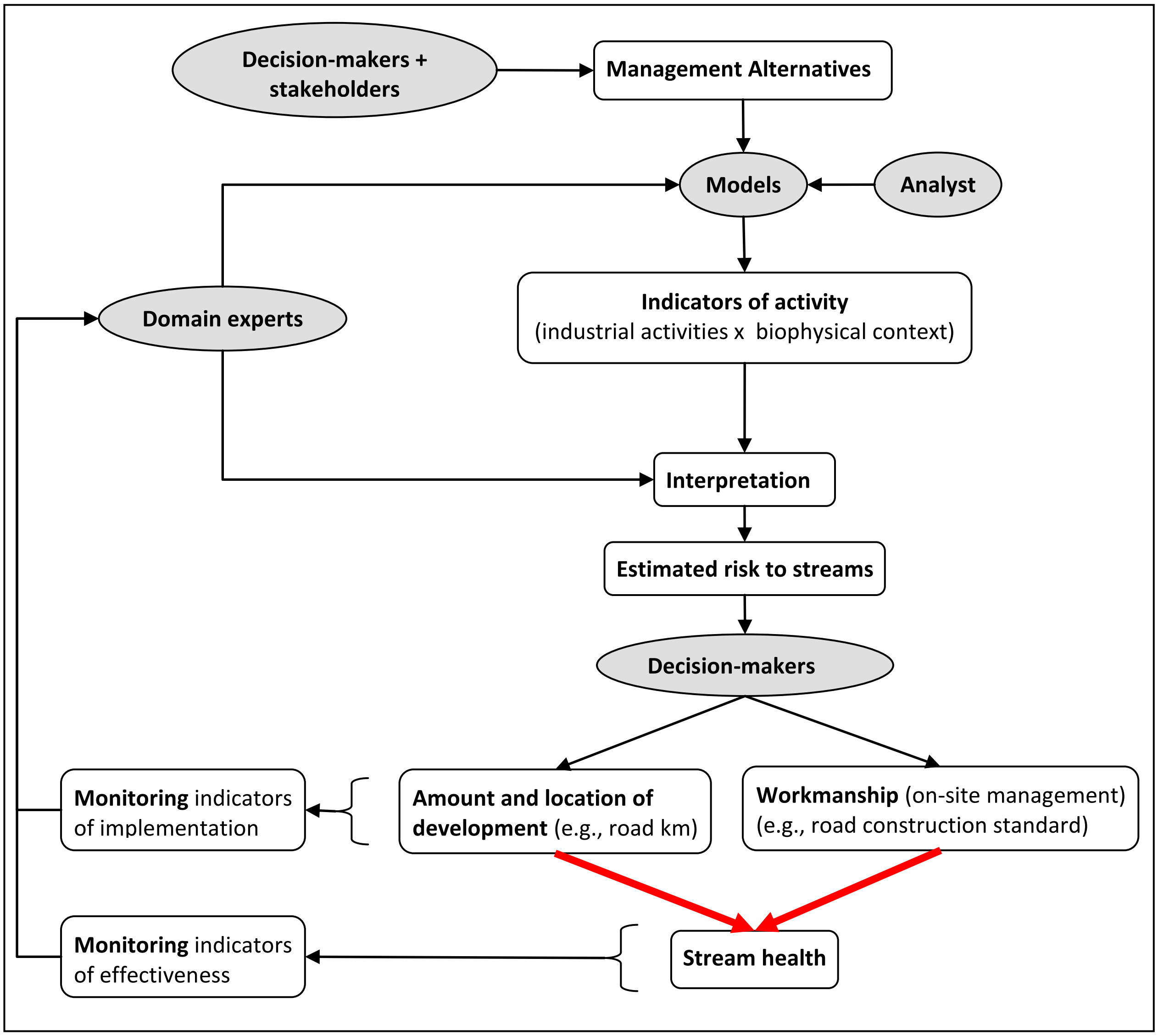
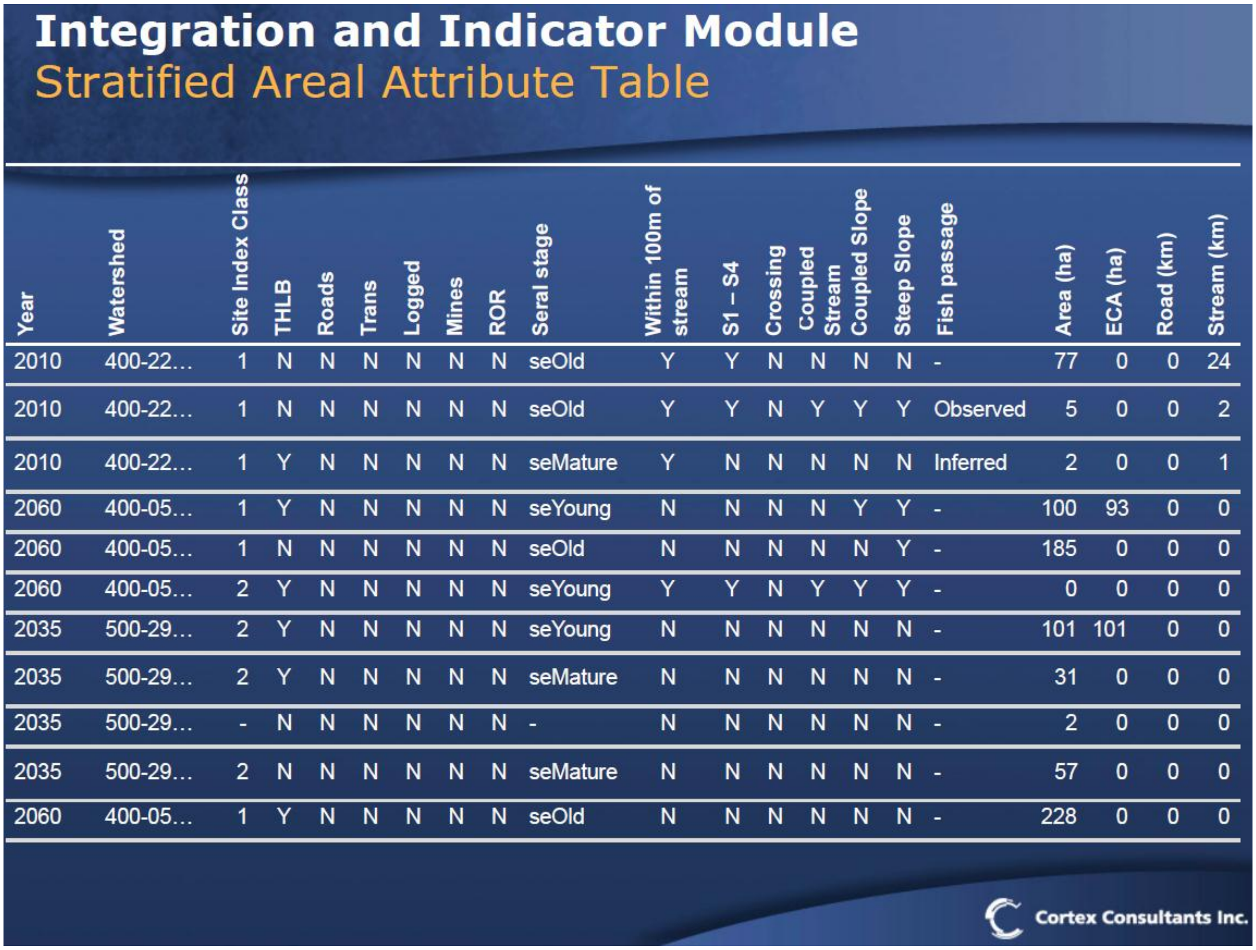


Figure 3. Conceptual model of a decision support process focussing on stream health. The grey boxes show the main sources of knowledge used in the process; monitoring provides feedback that facilitates learning. Arrows show the flow of information; bold red arrows show the flow of impacts.

Appendix 1. Variables used to create indicators

Jason Smith presented a this table of variables which can be combined to create indicators.



Integration and Indicator Module

Stratified Areal Attribute Table

Year	Watershed	Site Index Class	THLB	Roads	Trans	Logged	Mines	ROR	Seral stage	Within 100m of stream	S1 – S4	Crossing	Coupled Stream	Coupled Slope	Steep Slope	Fish passage	Area (ha)	ECA (ha)	Road (km)	Stream (km)
2010	400-22…	1	N	N	N	N	N	N	seOld	Y	Y	N	N	N	N	-	77	0	0	24
2010	400-22…	1	N	N	N	N	N	N	seOld	Y	Y	N	Y	Y	Y	Observed	5	0	0	2
2010	400-22…	1	Y	N	N	N	N	N	seMature	Y	N	N	N	N	N	Inferred	2	0	0	1
2060	400-05…	1	Y	N	N	N	N	N	seYoung	N	N	N	N	Y	Y	-	100	93	0	0
2060	400-05…	1	N	N	N	N	N	N	seOld	N	N	N	N	N	Y	-	185	0	0	0
2060	400-05…	2	Y	N	N	N	N	N	seYoung	Y	Y	N	Y	Y	Y	-	0	0	0	0
2035	500-29…	2	Y	N	N	N	N	N	seYoung	N	N	N	N	N	N	-	101	101	0	0
2035	500-29…	2	Y	N	N	N	N	N	seMature	N	N	N	N	N	N	-	31	0	0	0
2035	500-29…	-	N	N	N	N	N	N	-	N	N	N	N	N	N	-	2	0	0	0
2035	500-29…	2	N	N	N	N	N	N	seMature	N	N	N	N	N	N	-	57	0	0	0
2060	400-05…	1	Y	N	N	N	N	N	seOld	N	N	N	N	N	N	-	228	0	0	0

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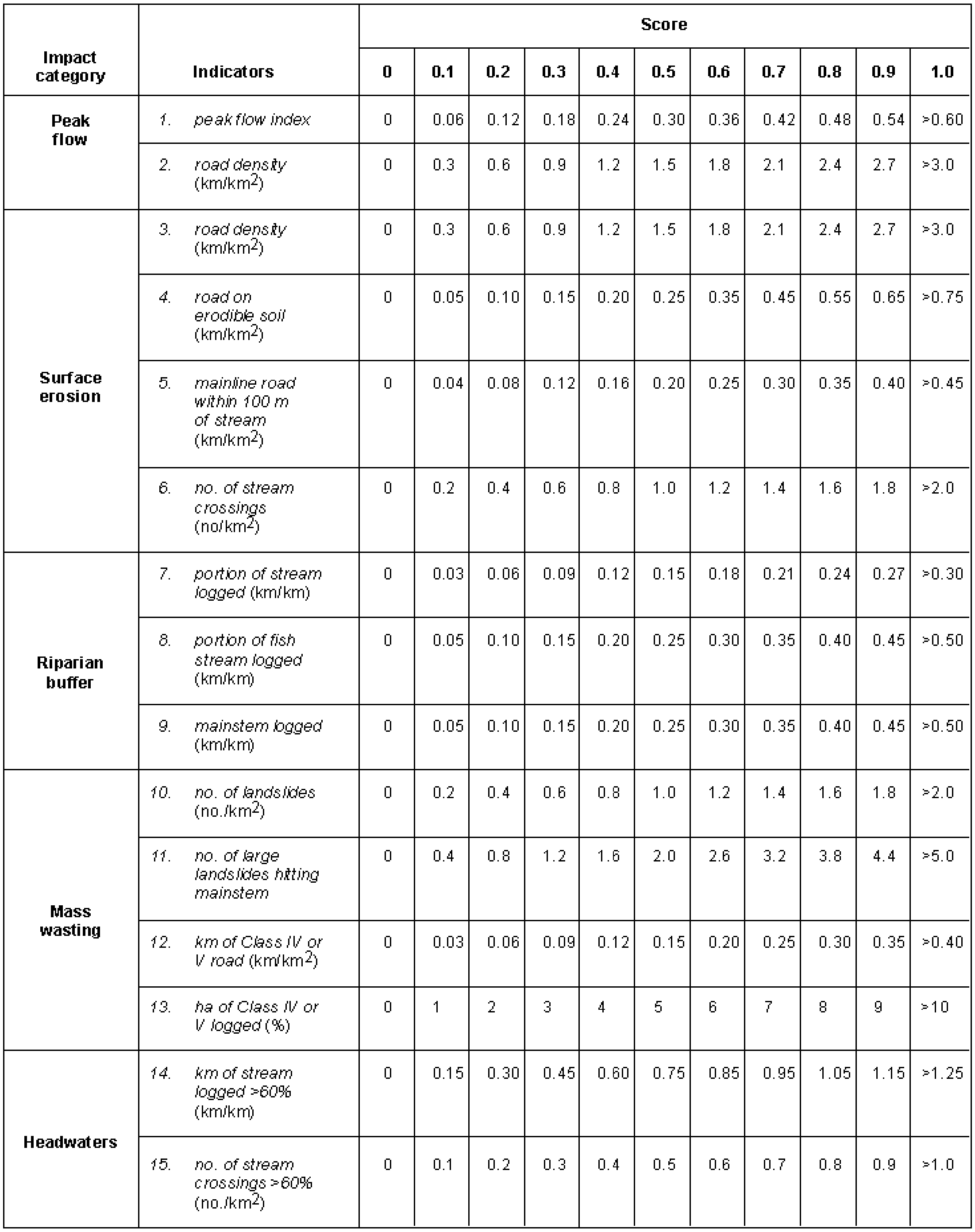
Appendix 2. Example method of scoring indicators

Table A2-1. Coastal watershed assessment conversion table[12]. Scores less than 0.4 mean low impact, 0.4–0.6 means potential moderate impact, and greater than 0.6 means potential high impact



Impact category	Indicators	Score										
		0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
Peak flow	*1. peak flow index*	0	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	>0.60
	2. road density (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
Surface erosion	*3. road density* (km/km^2)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	>3.0
	4. road on erodible soil (km/km^2)	0	0.05	0.10	0.15	0.20	0.25	0.35	0.45	0.55	0.65	>0.75
	5. mainline road within 100 m of stream (km/km^2)	0	0.04	0.08	0.12	0.16	0.20	0.25	0.30	0.35	0.40	>0.45
	6. no. of stream crossings (no/km^2)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	>2.0
Riparian buffer	*7. portion of stream logged* (km/km)	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	>0.30
	8. portion of fish stream logged (km/km)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	>0.50
	9. mainstem logged (km/km)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	>0.50
Mass wasting	*10. no. of landslides* (no./km^2)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	>2.0
	11. no. of large landslides hitting mainstem	0	0.4	0.8	1.2	1.6	2.0	2.6	3.2	3.8	4.4	>5.0
	12. km of Class IV or V road (km/km^2)	0	0.03	0.06	0.09	0.12	0.15	0.20	0.25	0.30	0.35	>0.40
	13. ha of Class IV or V logged (%)	0	1	2	3	4	5	6	7	8	9	>10
Headwaters	*14. km of stream logged >60%* (km/km)	0	0.15	0.30	0.45	0.60	0.75	0.85	0.95	1.05	1.15	>1.25
	15. no. of stream crossings >60% (no./km^2)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	>1.0

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[12] BC Ministry of Forests (MOF). 1995. Coastal watershed assessment procedure guidebook (CWAP). http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/coastal/cwaptoc.htm