AN APPLICATION OF THE HYDRORIPARIAN PLANNING GUIDE IN SIX BRITISH COLUMBIA COASTAL WATERSHEDS

by

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ABSTRACT

British Columbia's Hydroriparian Planning Guide establishes a process for identifying hydoriparian ecosystems at the watershed scale. In this study I test the Hydroriparian Planning Guide by mapping hydoriparian ecosystems and reserves using electronic spatial data for six different watersheds along the BC coast: three in the South Coast, and three in the Central Coast. I also compare the resulting hydoriparian reserve networks between study watersheds to investigate trends and look for relationships between reserve area and watershed characteristics (e.g., gradient). I identified 37%-69% of each watershed as part of the hydoriparian reserve network. In comparing reserve networks between watersheds, the watershed characteristics of mainstem gradient and tributary gradient appear to be important factors, but due to the small sample size I cannot establish definitive relationships.

Keywords: hydoriparian ecosystems; riparian; ecosystem-based management; watershed planning; GIS

Subject Terms: Ecosystem management -- Canada; Biodiversity conservation -- Canada; Sustainable forestry -- Canada; Riparian areas -- Management; Watershed management -- British Columbia
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CHAPTER 1: INTRODUCTION

Hydroriparian ecosystems are found at the intersections of terrestrial, aquatic, and groundwater ecosystems (Naiman et al. 2000) and provide high levels of biological diversity, often higher than associated upland areas (Decamps et al. 2004, Gregory et al. 1991, Naiman and Decamps 1997). Many species not only use hydroriparian ecosystems for food, water, or to complete lifecycle requirements (Kaufman et al. 2001), but depend on these areas for their survival and reproduction (Pollock et al. 1998). Maintaining healthy hydroriparian ecosystems is an important component of maintaining the overall biodiversity in a watershed (Northcote and Hartman 2004).

In an effort to improve land management for the North and Central coast of British Columbia (BC), a new framework for land-use planning has been developed called Ecosystem-Based Management (EBM). The non-government science body called the Coast Information Team developed the Ecosystem-Based Management Planning Handbook (CIT 2004a) or 'EBM handbook'. The EBM handbook is intended to be implemented by March 31st 2009 (ILMB 2006a) and a definition of what constitutes full implementation has been agreed upon by the Joint Land and Resource Forums (Joint Land and Resource Forums 2007). Ecosystem-based management (EBM) as expressed in the handbook recognizes the importance of hydoriparian species and ecosystems; as reflected in a companion document to the EBM handbook called the Hydoriparian Planning Guide (CIT 2004b). The Hydoriparian Planning Guide (HPG) was developed
to protect hydoriparian species and ecosystems while still allowing various types of land use, such as timber harvesting or recreational use (CIT 2004b).

Before full implementation in March 2009, the guidelines of the HPG need to be tested and evaluated for ease of application and effectiveness. My research will test the process outlined in the HPG for identifying hydoriparian reserves. The HPG guidelines are organized into four spatial scales of planning: the subregional (map scale 1:250,000); landscape (map scale 1:50,000); watershed (map scale 1:20,000); and site levels (e.g. 100m stream reach). I will focus on applying the HPG at the watershed scale as the watershed is increasingly recognized as an appropriate unit for managing freshwater biodiversity (Dudgeon et al. 2006). Under the HPG, hydoriparian ecosystems are identified primarily using GIS and existing data. Once hydoriparian ecosystems are identified, a buffer may be applied, if required by the HPG. A buffer is an area of fixed distance from the edge of the hydoriparian ecosystem where harvesting or other activities are limited or restricted to reduce their effects on the ecosystem to be protected. Together, the hydoriparian ecosystems and their buffers result in hydoriparian reserves. I will apply hydoriparian reserves according to the HPG in case study watersheds. Assessing the accuracy of these reserves on the ground is also important, but due to time and access restraints I will not be able to address the question of accuracy within the scope of my research.
1.1 Study Purpose and Objectives

In this study I apply the Hydroriparian Planning Guide (HPG) guidelines to six different watersheds along the BC coast, three in the South Coast, and three in the Central Coast. In doing so, I have two major objectives:

1. To test the process of mapping hydroriparian reserves using the Hydroriparian Planning Guide and associated Legal Objectives.

2. To compare resulting hydroriparian reserve areas between study watersheds to investigate trends and look for relationships between reserve area and watershed characteristics (e.g. gradient).

I began by selecting 6 watersheds along the coast which vary in their characteristics, such as gradient, hydrology, temperature, and nutrients. BC coastal watersheds are highly variable in their characteristics (Price 2003, Ciruna et al. 2007). Therefore, it is important to test the HPG in a variety of watersheds as the variability in watershed characteristics is likely to affect the proportion of a watershed that is designated as hydroriparian reserve (e.g. FEMA 1993). I used the HPG guidelines to identify hydroriparian ecosystems within each watershed and add buffers where prescribed, thus identifying the hydroriparian ecosystem network of reserves as defined in the HPG. Once the maps were completed I compared reserve areas between watersheds, using statistical methods to identify potential relationships between watershed characteristics and resulting reserve areas.

The successful application of the HPG on the BC coast, measured by the maintenance of healthy ecosystems and human communities, will rely on understanding hydroriparian ecosystems and successful implementation of the broader EBM framework.
I preface my analysis with an introduction to EBM concepts, EBM application outside and within BC, and the HPG in particular. I then describe hydoriparian ecosystems, their functions, and a brief history of their management and related challenges.

1.2 Ecosystem-Based Management

There is no universal definition of EBM. Several terms exist that describe a cluster of related concepts, including: ecosystem-based management, ecosystem management, and integrated environmental management (Margerum and Hooper 2001, Butler and Koontz 2005). There has been much discussion in the literature over the last decade about what constitutes an ecosystem-based approach to land management (Clark et al. 1991, Grumbine 1994, Montgomery et al. 1995, Brunner and Clark 1997, Grumbine 1997, Kohm et al. 1997, Szaro et al. 1998, Binkley 1999, Imperial 1999, Bissix and Rees 2001). One of the most widely cited definitions is provided by Grumbine (1994), as the integration of “scientific knowledge of ecological relationships within a complex socio-political and values framework toward the general goal of protecting native ecosystem integrity over the long term.” Grumbine (1994) also notes that the common themes of ecosystem management are: an emphasis on data collection and monitoring, working across administrative boundaries, incorporation of adaptive management, interagency cooperation, organizational change, and a focus on the maintenance of biodiversity.

EBM focuses on ecological interactions, emphasizing what is left behind on the landscape after harvest, rather than what is taken away (CSSP 1995, Mitchell and Beese 2002, CIT 2004a). More specifically, EBM involves managing forests at multiple scales with an emphasis on the ecosystem level where understanding ecological systems, considering longer time scales relevant to species and populations, and recognizing the
interconnection between ecological processes, humans, and other organisms are integral to the management process (Yaffee et al. 1996).

The concept of EBM has been gaining popularity with many resource managers and politicians as an approach acceptable by many stakeholders (Christensen 1996, CIT 2004a, Smith and Sterritt 2007). However, there is also recognition that implementing EBM successfully is a challenge (Imperial 1999, Margerum and Hooper 2001, Wright et al. 2004, Butler and Koontz 2005), in part because implementing EBM requires changes in scientific practices as well as social and political practices (Butler and Koontz 2005). In order for EBM to be successful there must be mechanisms in place to experiment with new management approaches and adapt and change these as we learn about their effectiveness (Boesch 2005) Such mechanisms are incorporated into the HPG as adaptive management.

While there are numerous potential benefits of EBM, the implementation of recommendations such as those but forward by FEMAT (1993) and CSSP (1995) have not been easy (Gray 2000). My search of the literature found frequent discussion of EBM, but very few actual published case studies, a finding also shared by Wright et al. (2004). EBM implementation is a challenge because not only are environments dynamic and complex, but so are the social and political relationships. When implementing a collaborative land-use approach such as the Coastal Land and Resource Management Plans in BC, accounting for differences between managers and stakeholders is key. Particularly as different groups of stakeholders, as well as managers, often have different views on environmental and social priorities (Lamont 2006). There is also the possibility of power imbalances between stakeholders, and a lack of information flow from
managers to stakeholders. However, the wider the range of stakeholders included in the process, the more likely the outcome will have long-term community support (Lamont 2006).

The concept of ecosystem management in land management gained widespread recognition in the United States when it was a major component of the recommendations put forward in 1993 by the Forest Ecosystem Management Assessment Team (FEMAT), an interdisciplinary team of researchers and specialists. Since then, some US federal land management agencies, including the US Forest Service have been implementing ecosystem-based approaches (Haeuber 1996, Yaffee et al. 1996, Imperial 1999, Gray 2004). Tools for applications of EBM have also increased in number and are shared via a website coordinated by the US based organization NatureServe (www.ebmtools.org).

Recognition and use of the EBM concept has also grown in Canada. Federal adoption of the EBM approach is apparent in the revised Canada National Parks Act (Department of Justice Canada 2000) and in the Species at Risk Act (Government of Canada 2002). Parks Canada was one of the early implementers of EBM, using this approach in their management plan for notable parks such as Banff National Park (Parks Canada 2008). In a comparison study of EBM application in Canada and the US, Quinn and Theberge (2004) found that while EBM is increasingly applied in both countries Canada has fewer grassroots initiatives and less formal institutional commitment than in the US. Quinn and Theberge (2004) speculate that this may be because the history of EBM in the US emerged as a part of the FEMAT recommendations, which had strong federal implications that extended beyond the Pacific Northwest. Development of EBM
in Canada was influenced by the US, but the use of EBM in protected areas, particularly National Parks, was perhaps more influential (Quinn and Theberge 2004).

EBM was first used in BC by the Clayoquot Sound Scientific Panel (CSSP) in their recommendations for forest management in Clayoquot Sound (CSSP 1995). The implementation of the Scientific Panel’s recommendations is perhaps the best example of EBM implementation in BC in a forestry context. In BC, the Gitga’at First Nation has recently conducted pilot studies of EBM on the north coast as part of the Coastal LRMP process (CIT 2004a) and EBM is set to be applied on the Central and North Coasts by March 31st 2009 (ILMB 2006a).

A key mandate from the provincial government for the Coastal LRMP process was to incorporate EBM, as outlined in the General Protocol Agreement on Land Use Planning and Interim Measures signed in 2001 between the BC Government and First Nations (BC Government 2001). The LRMP process involves a planning table composed of participants ranging from public stakeholders to all levels of government including First Nations striving to reach consensus on a land use plan (see the following chapter on the Hydroriparian Planning Guide for more information on the LRMP process). In order to inform the Coastal LRMP planning tables, an interdisciplinary science team, known as the Coast Information Team (CIT) was formed. The CIT definition of EBM includes a heavier emphasis on human wellbeing than that of Grumbine (1994) in their definition of EBM: “an adaptive approach to managing human activities that seeks to ensure the coexistence of healthy, fully functioning ecosystems and human communities” (CIT 2004a). The inclusion of healthy human communities adds a further dimension to the application of the HPG. My test of the HPG focuses on the ecological aspects of the HPG.
and the identification of hydoriparian reserves to maintain functioning hydoriparian ecosystems.

1.3 Hydoriparian Ecosystems

Hydoriparian ecosystems are found at the intersections of an aquatic ecosystem, terrestrial ecosystem, and the hyporheic zone (McKenzie-Smith et al. 2006) as described in Figure 1. The HPG recognizes hydoriparian ecosystems such as streams, lakes, wetlands, and forested swamps (CIT 2004b). The term riparian has been used for many years to describe the interface of terrestrial and aquatic ecosystems, but does not include the stream itself (Vannote et al. 1980, Gregory et al. 1991, Naiman and Decamps 1997) or the interaction with groundwater. The more recent term, hydoriparian, explicitly includes the whole system (CSSP 1995, Naiman et al. 2000). The term hydoriparian was first used and defined in the United States by Johnson et al. (1984) and in Canada by the Clayoquot Sound Scientific Panel reports (CSSP 1995). Hydoriparian ecosystems, and riparian systems, have received growing recognition for their unique habitats and ecosystem functions (Vannote et al. 1980, Gregory et al. 1991, Naiman et al. 2000, Price and McLennan 2001, CIT 2004b, Northcote and Hartman 2004).
The interactions of a hydoriparian ecosystem, comprised of forest ecosystems, aquatic ecosystems, and the hyporheic zone, play an important role in maintaining ecosystem biodiversity and functions (Fig 1). Using a stream as an example, terrestrial and aquatic ecosystems are linked, as terrestrial vegetation shades the water (moderating light and temperature), provides organic matter inputs, assists retention of sediment and organic materials, stabilizes banks, and supports fish habitat (Gregory et al. 1991, Ralph et al. 1994, Fetherston et al. 1995, Olson et al. 2007). Aquatic ecosystems also contribute to terrestrial ecosystems through the inputs of water and sediment (Naiman et al. 2000). The hyporheic zone provides minerals and cool water year round that helps to maintain stream flow and moderate temperatures during the summer season (Stanford and Ward 1993, Story et al. 2003). The hyporheic zone also transports excess nutrients from
terrestrial systems (e.g. from agricultural practices) that enter the groundwater system and are taken up by plant roots before entering the stream, thereby maintaining balanced nutrient availability (Stanford and Ward 1993, Boulton 1998, Clinton et al. 2002).

The management of hydriparian ecosystems requires consideration of both physical and biological variables (Fig. 1). Physical variation in hydriparian ecosystems can result from differences in local interactions between basin geology, hydrology, and inputs of inorganic and organic material from upland areas (Gregory et al. 1991, Abbe and Montgomery 1996). The local patterns in geomorphic structure also affect hydriparian plant communities and the distribution of aquatic species (Vadas et al. 1997, Poole 2002). Hydriparian ecosystems also provide many important ecosystem services. The physical processes of hydriparian ecosystems maintain water quality, provide flood control, and stabilize soils and stream banks (Gregory et al. 1991, Brooks 1997, Angradi et al. 2004). The biological processes of hydriparian ecosystems result in high species diversity; and these systems are sometimes referred to as biodiversity ‘hotspots’ (Naiman et al. 1993, Ward 1998, Ward and Tockner 2001, Decamps et al. 2004, Meyer et al. 2007). Hydriparian ecosystems also provide important wildlife corridors, facilitate nutrient cycling, and provide habitat for many rare and important species (Allan and Flecker 1993, Naiman et al. 1993, Glenn et al. 1997, Jansson et al. 2007).

Hydriparian ecosystems are a challenge to manage because of the numerous interactions between aquatic, hyporheic, and terrestrial systems (Fig. 2). In addition, hydriparian ecosystems are dynamic and can experience frequent disturbances, which can increase biodiversity, but also make long range planning more difficult (Palmer et al.
1995, Pollock et al. 1998, Swanson et al. 1988, Ward 1998, Wallace et al. 2001, Macdonald et al. 2004). Disturbances can include landslides, fires, insect outbreaks, floods, or shifts in channel position (Ward 1998, Bisson et al. 2003, Nitschke 2005). These disturbances can range on temporal scales (months, years, decades, and centuries) and spatial scales (a few meters to large basins). Because of the variety of disturbances, hydroriparian ecosystems are often more heterogeneous and diverse than upslope ecosystems (Gregory et al. 1991, Ward 1998). Hydroriparian ecosystems are also challenging to map accurately. Because they are not always easily visible from the air, many small or ephemeral streams and water bodies are difficult to locate without the assistance of field reconnaissance (Meyer & Wallace 2001, Meyer et al. 2007).

Hydroriparian ecosystem managers also face many socio-political challenges (Fig 2). For example, riparian trees are often the most commercially valuable within a watershed because of their large size, making them very desirable to the forest industry. As well, in narrow, steep-walled coastal valleys the valley bottoms where hydroriparian ecosystems are found may be the only feasible place to build roads (Jones et al. 2000). Salmon require hydroriparian ecosystems for breeding and rearing, and contribute valuable nutrients to the hydroriparian ecosystem, but are also commercially valuable and are dwindling in many places in BC (Slaney et al. 1996; Gries and Juanes 1998). Additional complexities arise with salmon because they are under federal jurisdiction and terrestrial vegetation and freshwater are mainly under provincial jurisdiction. Therefore, salmon management necessitates cooperation between provincial and federal governments (DFO 2005). Salmon management is also of interest to many groups and governments such as First Nations, recreational fishers, the tourism industry, and the
The HPG appears to be an attempt to address these complex issues while still maintaining hydoriparian ecosystem health.

Figure 2 Socio-Ecological Model of Hydoriparian Ecosystems. The three components of the hydoriparian ecosystem (hyporheic, terrestrial, and aquatic ecosystems) are shown along with the processes that connect them. Arrows indicate the direction of influence. Examples of governing bodies with related legislation and interested stakeholders are included for each component. This model shows the many interconnections and overlapping jurisdictions encountered when managing hydoriparian ecosystems. LWD: large woody debris, MDN: marine derived nutrients, ENGOs: environmental non-governmental organizations.

Since the LRMP process is unique to BC, in the following chapter I outline some more details of the process, and some unique aspects that were developed for the central and north coast. For example, I provide more information about the interdisciplinary Coast Information Team and the products they produced. I also outline the major
sections of the HPG and provide more detail on the guidelines for watershed planning, on which I base my methods.
CHAPTER 2: HYDRORIPARIAN PLANNING GUIDE

The Hydroriparian Planning Guide (HPG) is a product of the North Coast and Central Coast Land and Resource Management Planning (LRMP) processes (CIT 2004b). While LRMP processes have been in existence in various settings in BC since 1992 (Cashore 2001), there have been some unique aspects developed through the North and Central Coast LRMP processes. To appreciate the opportunities and challenges of implementing the HPG it is useful to understand the LRMP process and how it contributed to the development of the HPG.

2.1 LRMP Background

Awareness of the potentially large-scale effects of land use, such as forest harvesting, on ecosystems in BC grew in the early 1990’s (Tripp et al. 1992a, Tripp et al. 1992b, Tripp 1994, Chatwin et al. 1998). In 1992, the provincial government began implementing a new planning approach for land management, the Land and Resource Management Plan (Cashore 2001). The LRMP process involves stakeholders in regional land use planning coming together and developing a detailed land use plan following consensus based decision making (Cashore 2001, NC LRMP 2005). The plans establish direction for land use and specify resource management objectives and strategies that will guide more detailed planning (Province of BC 1996). Some of the recent LRMPs to be finalized are the North Coast and Central Coast LRMPs (NC LRMP 2005, CC LRMP 2004). The Central and North Coast LRMPs are unique because they are the first LRMPs to: 1) use an EBM framework with goals of maintaining healthy ecosystems and human
communities, and 2) consult with First Nations on a government-to-government basis (NC LRMP 2005).

2.2 Coast Information Team

The Hydroriparian Planning Guide (HPG) was developed by the Coast Information Team (CIT), a group of scientists, practitioners, and traditional and local experts created to provide independent scientific information and analyses to the Central, North Coast and Haida Gwaii LRMP tables (CIT 2004a). The CIT was formed in 2001 by the B.C. government and was dissolved in 2004 after the Coastal LRMPs were finalised (Cortex 2004). The CIT functioned as an independent source of information for members of the coastal LRMP roundtables (Hadley 2004). In particular, the CIT was asked to provide management guidelines based on an ecosystem-based management (EBM) framework, regional and subregional analyses, a hydoriparian decision tool, and technical support for pilot projects applying EBM (CIT 2004a). The CIT produced four EBM guides, one of which is the Hydroriparian Planning Guide (CIT 2004b).

The four EBM guides are:

2. Scientific Basis of EBM (Mar 2004)
4. EBM Framework (Apr 2004)
The Hydroriparian Planning Guide provides guidelines intended to maintain the functions of aquatic and riparian ecosystems, with a focus on watershed level planning (CIT 2004b).

2.3 Hydroriparian Planning Guide

The EBM framework mandated for the Coastal LRMPs is reflected in the Hydroriparian Planning Guide (HPG). The purpose of the HPG is to assist managers to develop forest management plans likely to maintain hydroriparian ecosystem functions at the watershed scale (CIT 2004b). The first three chapters of the HPG build on the concepts covered in the EBM Planning Handbook (CIT 2004a), describing hydroriparian ecosystems, the risks to functions of hydroriparian ecosystems following land uses such as forest harvesting, and an introduction to adaptive management. The risk and adaptive management chapters outline two approaches for management planning within the HPG: a precautionary approach and a risk assessment approach. The precautionary approach adopted in the HPG uses expert judgment to guide decisions about the sustainable management of forest and hydroriparian ecosystems. This is a conservative approach that appears to be intended for watersheds of particular concern, either ecologically or politically. Because this option advocates reserves wherever there are significant risks it results in a significant loss of harvestable area (Price 2003). Therefore, the likelihood of voluntary use of this approach by the forest industry is low. The second approach outlined by the HPG, the risk assessment approach, is intended for use in less sensitive areas to allow greater access to resources than the precautionary guidelines approach. The risk assessment approach recognizes the uncertainty in predicting outcomes of management decisions. To manage the increased risk, the integration of adaptive
management is mandatory when using this approach, including monitoring and adjustments to management if needed (CIT 2004b).

The final four chapters (4-7) of the HPG outline a series of steps consistent with the EBM Planning Handbook (CIT 2004a) needed to maintain hydoriparian functions at a watershed scale, recognizing that the watershed scale is nested within larger scales of concern and has nested within it smaller scales. This series of steps addresses methods for planning at four different spatial scales. The coarsest scale is the subregion (map scale 1:250,000), followed by the landscape (map scale 1:50,000), the watershed (map scale 1:20,000), and finally the site (e.g. 100m stream reach) at the finest scale (CIT 2004b). The descriptions of planning required by the HPG for each of the four scales can be summarized as a number of steps:

1. Define subregion (Chapter 4)
   a. Determine subregion of interest
   b. Describe subregion character and condition
   c. Plan adaptive management strategy
2. Define landscape (Chapter 5)
   a. Determine landscape of interest
   b. Describe landscape character and condition
   c. Identify and assess risk to rare ecosystems, biodiversity, and stream channel morphology
   d. Design adaptive management procedures
3. Develop watershed plan (Chapter 6)
   a. Develop interpretive maps of watershed character and condition
   b. Determine targets for retention and development based on precautionary guidelines of risk assessment
   c. Design reserves (the “hydoriparian ecosystem network”) and harvestable area
   d. Develop monitoring plan for adaptive management within the watershed
4. Develop site plan (Chapter 7)
   a. Assess in the field, and revise the components of the hydoriparian ecosystem network as needed
   b. Establish site-level reserves, and retention and management zones necessary to protect hydoriparian ecosystem function(s)
   c. Identify harvest area (cutblock or multiple cutblock) components
   d. Integrate site-level information into watershed-level plan and into monitoring and adaptive management plans
   e. Enter specific information into a hydoriparian database

I focused my testing of the HPG on the watershed scale for many reasons. First, the HPG emphasizes watershed scale planning because watersheds are considered a fundamental unit of landscape planning (Montgomery 1995, Brooks 1997) and therefore are the appropriate scale to consider hydoriparian function (Jensen 2000). In addition, watersheds are ecologically and geomorphologically relevant management units rather than subjective political boundaries (Brooks 1997). Finally, ecosystem management at the watershed scale facilitates the recognition of interrelationships between land and water use and their many effects (FEMAT 1993).

Watershed plans are designed to identify zones within the watershed will be available and unavailable for harvest over time (CIT 2004b). Areas unavailable for harvest are identified first to determine what areas remain available in the timber harvesting landbase. The goal of a watershed plan is to identify the hydoriparian ecosystem network and apply reserves so that these systems will be protected in “no-harvest”, or limited harvest, zones. Some of the maps needed to identify hydoriparian reserves are created by following steps outlined in the HPG (e.g. hydoriparian process zones) while others, such as the terrestrial ecosystem maps, are derived from other EBM
planning processes that are expected to occur concurrently with planning to protect hydoriparian ecosystems, such as planning for cultural uses and tourism (CIT 2004b). Beyond these maps created as a part of the HPG or overall EBM process there is an underlying assumption in the HPG that certain basic information about the land and forest will be available, such as forest inventories, TRIM, terrain mapping, and some form of ecological mapping (CIT 2004b). It became clear in the course of my work that this assumption cannot be met for many areas of the north and central coast where the HPG is meant to be applied.

In order to identify the hydoriparian ecosystem network, several maps must be obtained, either from other planning processes or by creating them *de novo* for this purpose:

1) Unstable Terrain (may already exist)
   a. Class 4 and 5 terrain

2) Hydoriparian Process Zones (must be created)
   a. Transportation and Deposition zones
   b. Stream slope

3) High Value Fish Habitat (relies on existing information which may be available)
   a. Stream classification and upland streams
   b. Active fluvial units and floodplains

4) Hydoriparian Ecosystems (must be created)
   a. Floodplains and fans
   b. Lakes
   c. Forested Swamps, Bogs, Sedge Fens, Wetlands
   d. Streams > 20% and streams < 20% slope

5) Terrestrial ecosystem maps (may already exist from other processes)
   a. Site series
   b. Stand age and leading species
   c. Rare Ecosystems
While the concepts of EBM, precautionary approach, risk assessment, and adaptive management are progressive ideas that are discussed in the current resource management literature (Habron 2003, McDaniels and Gregory 2004, Allan and Curtis 2005, Butler and Koontz 2005, Lamont 2006, Foxcroft et al. 2007), the steps for implementing them via the HPG are more conceptual than practical. The theory in the HPG outlining why particular hydoriparian features should be reserved is very useful, however it is not very clear exactly how the specific hydoriparian features are to be identified, or what buffer width to use to protect these features. The need for more details was recognized in an earlier test of the HPG (Wartig and Landers 2003). To address this need the EBM Working Group has recently developed Legal Objectives for the HPG (ILMB 2007 and Appendix 1). Legal Objectives are an important legal mechanism for implementing strategic land use processes such as LRMPs, as they provide specific direction for land use activities (ILMB 2006b). There is increasing recognition that management goals need to be considered at both the conceptual and operational level (O’Boyle and Jamieson 2006), and the Legal Objectives offer direction for the operational level. The language used in the Legal Objectives leaves much room for interpretation, using phrases such as ‘to the extent practicable’ (ILMB 2007). There is flexibility within the objectives to significantly reduce buffer areas and reserve areas to a certain point, however the Forest and Range Practices Act (FRPA 2004) is still the underlying legislation and provides a minimum of protection.

Aspects of the HPG have been tested prior to this research. The precautionary approach as developed in the HPG was tested by Price (2003) who found that large areas of the two watersheds she tested were identified as hydoriparian reserves (56% and
64%). Price (2003) also made some recommendations to avoid redundancies and simplify methods, such as the need for terrain mapping of fluvial units to apply the HPG. Two industry applications of the HPG precautionary approach have been completed by Interfor and Western Forest Products (Warttig and Landers 2003, and Green 2006). Warttig and Landers (2003) found the guidelines to be too narrow and commented on the inflexibility of the guidelines to adapt to various watershed conditions. Green (2006) applied the HPG from the risk assessment approach, and outlined a mapping methodology but did not report summary hydoriparian reserve percentages.

In this study I examine the risk assessment approach using the HPG and associated Legal Objectives. My results add to the bank of results from previous tests to give a better understanding of the methods for mapping hydoriparian features according to the HPG. These results also shed light on the relationships between hydoriparian reserve area and watershed characteristics. The mapping methodology I use is clearly outlined, including specific fields queried and assumptions made. The methodology is similar to that of the previous tests of Price (2003) and Warttig and Landers (2003). However, these previous tests were completed before the Legal Objectives were complete. I use the Legal Objectives and some specific requirements relating to which reserves require buffers and the width for those buffers that, to my knowledge, have not been used in any other test of the HPG.
CHAPTER 3: METHODS

3.1 Study Watersheds

I selected six watersheds for this study; three on Princess Royal Island on the central coast of BC, and three on the southwest coast of Vancouver Island in Clayoquot Sound (Figure 3). Because the detailed spatial data required for this study were not available across the coast I was constrained to areas where I could acquire the appropriate data. I was able to obtain data for Clayoquot Sound quite easily because the wide variety of data collected for implementing the Clayoquot Sound Scientific Panel (CSSP) recommendations were available publicly online (ILMB ftp site in November 2006: ftp://ftpnan.env.gov.bc.ca/pub/outgoing/dist/gisdata/clay). I chose three subdrainages to focus on within Clayoquot sound (shown in Figure 3): Flores Island; Cypre West; and Cypre East. Watershed plans to meet the CSSP recommendations for these watershed groups had been completed when I began this study, and maps were available for comparison (ILMB 2006c).
For the north and central coast, no such detailed data sets were publicly available. I was kindly assisted by the Gitga’at First Nation’s resource manager Dan Cardinal in acquiring data sets for an area within Gitga’at traditional territory (northern Princess Royal Island)–see Figure 4 for location). A relatively recent system of classifying river and lake ecosystem types called “Ecological Aquatic Units for BC”, or EAU BC (Ciruna et al. 2007), classifies each 3rd order watershed in BC into a river ecosystem type and is the first detailed aquatic classification system for BC (Ciruna et al. 2007). Within both Clayoquot Sound and Princess Royal Island I used EAU BC (Ciruna et al. 2007) to select watersheds with the greatest variation within the study area.
Ciruna et al. (2007) classified river ecosystems at the watershed scale using key variables such as stream gradient and hydrology and then used multivariate statistics to group river ecosystems into river ecosystem types. River ecosystems of a particular type are expected to have similar physical characteristics and therefore similar habitats and species assemblages (Ciruna et al. 2007). There are 23 river ecosystem types in BC and my six study watersheds represent 3 of these. Using the river ecosystem types and associated watershed characteristics I was able to select watersheds that capture a broad sample of the natural variability present within the landscapes included in my study. Each study watershed and its associated river ecosystem type are listed in Table 1.
Table 1: Study area watersheds and their associated river ecosystem type according to the EAU BC classification.

In the River Ecosystem Types C = Coastal and H = Headwater. In brackets are the 4 attributes used to classify each river ecosystem. G = Gradient class, 1st number = mainstem gradient, 2nd number = tributary gradient. 1 = steep, 2 = moderate, 3 = shallow. H = Hydrology class. 1st four numbers = flow regime in winter, spring, summer, fall where 1 = low flow, 2 = moderate flow, 3 = high flow. T = Temperature class where 1st number = water temperature, 1 = cold, 2 = cool, and 3 = warm and 2nd number = seasonal productivity and 1 = low degree days, 2 = moderate degree days, and 3 = high degree days. N = Nutrient class and 1 = intrusives/metamorphics, 2 = volcanic, 3 = hard sedimentary rock, 4 = soft sedimentary rock, 5 = carbonates, 6 = chemical sediments, and 7 = alluvium. For more information on the terms used to describe the river ecosystem types please see the EAU BC report (Ciruna et al. 2007).

<table>
<thead>
<tr>
<th>Clayoquot Sound Watersheds</th>
<th>Watershed</th>
<th>River Ecosystem Type</th>
<th>Description</th>
</tr>
</thead>
</table>
|                           | Cypre West | C1a                  | *Exposed Outer Coast and Island Coastal Rivers*  
|                           |           | (G21_H2312_T33_N2)  | Lowest mean elevation (181m) of all river types. Shallow mainstem stream gradients with a range of shallow to steep tributary gradients. Relatively high mean annual temperature and smallest average drainage area of the coastal river types. Flows predominantly through CWH (98%) BEC zone and intrusive-metamorphic bedrock. |
|                           | Flores Island | H1b                  | *Lower Relief, Coast Headwaters*  
|                           |           | (G22_H3312_T33_N1)  | Combination of shallow, moderate, and steep mainstream gradients with steep tributary gradients. Second highest mean annual precipitation (3,442 mm/yr) and smallest average drainage area of all river types. Predominantly flows through CWH (75%) and MH (20%) BEC zones and intrusive-metamorphic and volcanic bedrock. |
|                           | Cypre East | C2b                  | *Lower Inner Coast and Fjord Coastal Rivers*  
<p>|                           |           | (G11_H2312_T33_N2)  | Steep mainstem and tributary gradients creating V-shaped valleys. Highest mean annual precipitation of all river types. Relatively high mean annual temperature and small drainage area. Flows predominantly through CWH and MH BEC zones and intrusive-metamorphic bedrock. |</p>
<table>
<thead>
<tr>
<th>Watershed</th>
<th>River Ecosystem Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| Whalen North   | C2b (G12_H1312_T23_N1) | Lower Inner Coast and Fjord Coastal Rivers  
Steep mainstem and tributary gradients creating V-shaped valleys. Highest mean annual precipitation (3,727 mm/yr) of all river types. Relatively high mean annual temperature and small drainage area. Flows predominantly through CWH (78%) and MH (17%) BEC zones and intrusive-metamorphic bedrock. |
| Whalen Lake    | C2b (G32_H1312_T33_N1) | Same as above                                                               |
| Whalen South   | C2b (G31_H1312_T23_N1) | Same as above                                                               |

General characteristics of each river ecosystem type are also defined in EAU BC by the ecological drainage unit (EDU) each river ecosystem type is nested within. EDUs represent distinct major drainage basins with unique fish assemblages (Ciruna et al. 2007). The Princess Royal watersheds are within the Central Coastal EDU which consists of a series of small, high gradient independent rivers on the central coast of mainland BC. The fish within this EDU are mostly euryhaline species such as salmon, tolerating a wide range of salinities, with some strictly freshwater species present as well. A defining characteristic of this EDU is that the anadromous fish within it migrate northward to the Alaskan Gyre rather than southward (Ciruna et al. 2007).

The Clayoquot Sound watersheds are within the Vancouver Island EDU which includes Vancouver Island and associated islands in the Georgia Strait (Ciruna et al. 2007). Watersheds in the Vancouver Island EDU are typically mountainous except for a few narrow lowland strips. Therefore, the river ecosystems in the Vancouver Island EDU
are mostly short with high gradients. The fish species in this EDU are almost entirely
euryhaline (primarily salmon), but characterized by a small number of notable freshwater
fish on Vancouver Island, primarily the Peamouth *Mylocheilus caurinus*, Vancouver
Island Lamprey *Lampetra macrostoma*, and the Enos Lake pair of sympatric threespine
sticklebacks *Gasterosteus aculeatus* (Ciruna et al. 2007). EAU BC provides some
general information about the study watersheds, but identifying the hydoriparian network
requires many data sets and analysis steps as explained below.

3.2 Objective 1:

My first objective in this study is to test the process of mapping a hydoriparian
ecosystem network according to the HPG and accompanying land use objectives. The
legal land use objectives to accompany the HPG were recently developed by the EBM
Working Group and are now available to the public on the Coast Land Use Decision
section of the ILMB website (ILMB 2007). These land use objectives outline specifics
for EBM implementation such as buffer widths and how much of those buffers need to be
retained to maintain hydoriparian functions. The section of the Legal Objectives that
outlines the specific steps to protect aquatic habitats is presented at the end of this
document in Appendix 1.

3.3 Applying the Hydoriparian Planning Guide

In this section I summarize the methods I used to create each of the maps
necessary to identify the hydoriparian ecosystem network in accordance with the HPG.
For all mapping and data processing I used ArcGIS version 9.1 or 9.2 (ESRI 2006). I had
access to different data sets for Princess Royal Island and Clayoquot Sound; therefore in
some cases the methods vary slightly and are explained as they arise in each section. The data sets I had available, their resolution, and source are shown in Table 2.

The HPG identifies five maps that contain hydoriparian features considered necessary for watershed planning (CIT 2004b). I created four of these five maps (unstable terrain, hydoriparian process zones, high value fish habitat, and hydoriparian ecosystems). I elected not to create the 5th map (terrestrial ecosystem map) because the terrestrial vegetation information within that map is not used to delineate hydoriparian reserves; rather it is used in the broader EBM process to identify stand age, seral stage and rare ecosystems.

Each hydoriparian feature identified in each of these four maps becomes a part of the hydoriparian reserve network, and some also have a buffer applied. Buffer width was based on the direction given in the Legal Objectives (ILMB 2007 and Appendix 1) and was either 1.0 x dominant tree height (DTH) or 1.5 x DTH. Within the Legal Objectives there is flexibility to adjust the buffer width +/- 0.5 DTH when the buffers are applied at the site level. I used the suggested buffer widths in the Legal Objectives for mapping at the watershed scale. To be consistent with methods used by Price (2003), who tested the HPG on the north coast, I used 30m as the assumed DTH. Therefore, buffer widths ranged from 30-45 meters. I felt this was a reasonable range considering that the recommendations from the Clayoquot Sound Scientific Panel for hydoriparian buffers range from 20-50 meters. More detailed analysis using forest cover information could be used to identify dominant tree height within forest stands in a watershed, should a higher degree of accuracy be required at the watershed scale plan. Site level planning would incorporate field measurements to determine actual buffer widths on the ground.
Further details on how I developed each of the four maps and where buffers were required are set out in the following sections.
Table 2 Data layers used in this study along with their resolution, source, and the date they were produced. DEM: Digital Elevation Map, TEM: Terrestrial Ecosystem Map, VRI: Vegetation Resources Inventory (the new version of forest cover). PEM: Predictive Ecosystem Map

<table>
<thead>
<tr>
<th>Clayoquot Sound Watersheds</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>Resolution</td>
<td>Source</td>
<td>Date</td>
</tr>
<tr>
<td>VRI</td>
<td>1:20,000</td>
<td>As above</td>
<td>1996</td>
</tr>
<tr>
<td>Terrain Stability</td>
<td>1:20,000</td>
<td>As above</td>
<td>1996</td>
</tr>
<tr>
<td>Streams</td>
<td>1:20,000</td>
<td>As above</td>
<td>1996</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Princess Royal Watersheds</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>Resolution</td>
<td>Source</td>
<td>Date</td>
</tr>
<tr>
<td>DEM</td>
<td>10m</td>
<td>Gitga’at First Nation</td>
<td>2000</td>
</tr>
<tr>
<td>TEM</td>
<td>1:50,000</td>
<td>Gitga’at First Nation</td>
<td>1998</td>
</tr>
<tr>
<td>Forest Cover</td>
<td>1:20,000</td>
<td>Gitga’at First Nation</td>
<td>1999</td>
</tr>
<tr>
<td>Terrain Stability</td>
<td>1:20,000</td>
<td>Only digitally available for the Whalen Lake watershed For all 3 watersheds I used the 10m DEM and ArcGIS extension SinMap version 2 to model terrain stability</td>
<td>2001</td>
</tr>
<tr>
<td>Streams</td>
<td>1:20,000</td>
<td>Gitga’at First Nation</td>
<td>1997</td>
</tr>
<tr>
<td>PEM</td>
<td>1:20,000</td>
<td>Gitga’at First Nation</td>
<td>2000</td>
</tr>
</tbody>
</table>
Unstable Terrain Maps

Class 4 and 5 terrain

For the Clayoquot Sound watersheds I used traditional digital terrain stability data (RIC 1998) to identify polygons of Class 4 and 5 terrain stability. Class 4 terrain stability indicates areas with a moderate likelihood of landslide initiation as a result of disturbances such as timber harvesting or road construction (Howes and Kenk 1997). Class 5 is the most unstable class and indicates areas of high likelihood of landslide initiation as a result of disturbance (Howes and Kenk 1997). Class 4 and 5 terrain is identified in the terrain stability data by the SLPSTB_CLS field (see Table 3). I selected Class 4 and 5 polygons and then created a new layer containing just Class 4 and 5 polygons. No buffering of unstable terrain polygons is required by the Legal Objectives (ILMB 2007). The new layer containing Class 4 and 5 polygons is the final map of unstable terrain.

For the Princess Royal watersheds, traditional terrain stability class data were only available for one of the three watersheds (Whalen Lake). An alternative to traditional terrain data is an ArcGIS extension, Stability Index Mapping version 2 (SinMap 2) (Pack et al. 2005). SinMap has previously been used to predict terrain stability classes in BC watersheds using a digital elevation model (DEM) and calibration parameters to predict areas of unstable terrain (Pack et al. 1998, 2001, 2005; Gordon 2003). Ideally, SinMap should be used in combination with aerial photo analyses and field mapping techniques (Pack 1998), neither of which were available for this area. To improve the interpretation of the DEM by SinMap, I was able to obtain calibration parameters for SinMap for this area from Dan Cardinall (pers. comm. 2007).
Although there is uncertainty in the accuracy of the unstable terrain identified by SinMap, for the purposes of watershed scale planning I felt that the SinMap results would be better than no digital data. The availability of the two data sets (SinMap and Class 4&5 terrain mapping) for the Whalen Lake watershed also offered an opportunity to compare the results from each. Using SinMap, for the Princess Royal watersheds, I created a stability index map and selected Class 4 and 5 polygons and created a new layer as above. I used the resulting Class 4 and 5 polygon map to compare with the traditional terrain stability results for the same watershed, looking at overlap and overall area identified as either Class 4 or 5.

**Hydroriparian Process Zone Maps**

**Transportation and Deposition Zones**

For the Clayoquot Sound watersheds, I used traditional terrain stability data to select polygons representing transportation and deposition zones using the surficial material (e.g. $F = \text{fluvial sediments}$), qualifier (e.g. $A = \text{active}$), and surface expression (e.g. $p = \text{plain}$), as outlined by the HPG (CIT 2004b). A complete list of the surficial material combinations I used in querying the database are shown in Table 3. For further information regarding terrain symbols and interpretation see the Ministry of Environment Terrain website at [http://www.env.gov.bc.ca/terrain/](http://www.env.gov.bc.ca/terrain/).

For the Princess Royal watersheds, with no digital terrain stability data available, I queried Predictive Ecosystem Mapping (PEM) for the surficial material information. I chose to use PEM in this case because it had a lower resolution of 1:20,000 as compared to the Terrestrial Ecosystem Mapping (TEM) with a resolution of 1:50,000.
Table 3 Data and Analysis Steps Necessary to Identify Hydroriparian Process Components, no Buffers are Required for these Components

DEM: Digital Elevation Map, TEM: Terrestrial Ecosystem Map, VRI: Vegetation Resources Inventory (the new version of forest cover). PEM: Predictive Ecosystem Map. F = Fluvial, C = Colluvium, O = Organic, ^ = Active, f = fan, p = plain, v = veneer, j = gentle slope, t = terrace(s)

<table>
<thead>
<tr>
<th>Hydroriparian Process Components</th>
<th>Data</th>
<th>Data Analysis</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport and Deposition Zones</td>
<td>Terrain map or TEM</td>
<td>Deposition: Ff, Fp, or F^aP (0-7% slope) Transportation: F^aP, F^af, F^av, F^aj (usually &lt;15% slope) Fp, Ft, Cf, L^aj, L^ap Op, Ov (in combination with Fp) (HPG p.50)</td>
<td>Layer with transportation and deposition zones. All other area assumed to be source zone.</td>
</tr>
<tr>
<td>Stream slope classes &lt; 20% and &gt; 20%</td>
<td>DEM TRIM streams Stream class (if available)</td>
<td>Create slope map using DEM Classify into slope classes Intersect stream layer with slope class layer</td>
<td>Slope layer Layer with streams in slope categories Streams &lt; 20% Streams &gt; 20%</td>
</tr>
</tbody>
</table>

Stream slope classes

For both Princess Royal and Clayoquot Sound watersheds I used a digital elevation model (DEM) layer to create a layer of slope values. I then classified the slope layer into the 4 slope categories identified in the HPG: less than 10% slope, between 10-20%, 20-60%, and greater than 60% (Table 3). Areas with slopes of greater than 20% are generally assumed to be barriers to anadromous fish such as salmon (BC Ministry of Forests 1995). I then intersected the slope polygon layer with the stream layer. The resulting layer contains streams, and each segment of stream is linked to the category of slope in its area (e.g. 0-10%). From this point I could query for stream segments of various slopes.
High Value Fish Habitat Maps

Stream Classification and Upland Streams

Digital stream classification data were not available for the Princess Royal watersheds, and, while they were available for Clayoquot Sound, they used a different classification system than is used province-wide. Therefore, for consistency I used the stream slope classes to select streams with potential to support fish (assumed to be < 20\% slope and less than 400m in elevation) and streams not likely to support fish (>20\% slope and >400m) (BC Ministry of Forests 1995). I created buffers around potential fish habitat streams with 1.5 DTH and streams with no potential fish habitat with 1.0 DTH (summarized in Table 4). The HPG notes that field checking will be used to revise such maps during site level planning as fish habitat is difficult to assess at this scale (CIT 2004b).

Upland streams are defined as class S4-6 streams (BC Ministry of Forests 1995) that have a slope of greater than 5\%. The BC Riparian Management Area Guidebook (BC Ministry of Forests 1995) defines class S4 streams as less than 1.5m in width and containing fish. Classes S5 and S6 have no fish and are greater than 3 m in width and less than 3 m in width, respectively. Classes S1 to S3 are larger streams with fish. Data available for upland streams are incomplete, and with no digital S1 - S6 stream classification data I relied on the potential fish/no fish buffers to capture upland stream buffers since all mapped streams received a minimum buffer of 1.0 DTH. Since upland streams are designated to get a 1.0 x DTH buffer in the HPG land use objectives (ILMB 2007 and Appendix 1) I felt that potential upland streams in the data were adequately addressed. In fact, this method may overestimate buffer area for some streams as the
buffers for upland streams can be harvested up to 30%, while non-fish streams buffers can only be harvested up to 10% (ILMB 2007).
Table 4 Data and Analysis Steps Necessary to Identify High Value Fish Habitat Components and their Associated Buffers. TRIM = Terrain Resources Information Management, DEM = Digital Elevation Map, TEM = Terrestrial Ecosystem Map, VRI = Vegetation Resources Inventory (the new version of forest cover), PEM = Predictive Ecosystem Map, DTH = Dominant Tree Height (30m), BEC = Biogeoclimatic Ecosystem Classification. F = Fluvial, A = Active, f = fan, p= plain, j = gentle slope, t = terrace(s)

<table>
<thead>
<tr>
<th>High Value Fish Habitat Component</th>
<th>Data</th>
<th>Data Analysis</th>
<th>Output</th>
<th>Buffer*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streams with Potential Fish Habitat</td>
<td>TRIM streams</td>
<td>Separate S1-S4 (fish bearing) and S5-S6 (no fish) following BC MoF (1995). If no stream class available, select streams &lt;20% slope and &lt;400m elevation as streams with potential fish habitat.</td>
<td>Streams with expected fish habitat</td>
<td>Potential fish streams: 1.5x DTH Non-Fish: 1.0x DTH (can harvest buffer up to 10%)</td>
</tr>
<tr>
<td>Upland Streams</td>
<td>TRIM streams</td>
<td>Class 4-6 streams that have a slope &gt;5% If no class avail. treat all tributaries &gt;5% as upland streams (encompassed by non-fish streams)</td>
<td>Upland streams</td>
<td>1.0x DTH (can harvest buffer up to 10%) Maintain 70% equivalent to functional riparian forest</td>
</tr>
<tr>
<td>Active fluvial units</td>
<td>Terrain stability Or TEM</td>
<td>Active fluvial units: F^Ap, F^Av, F^Ab, F^Aj, F^Af Floodplain of unknown activity Fp Field names: SURFM_1 = F SURFM_Q1 = A SURF_E1A = p</td>
<td>Active fluvial units</td>
<td>1.5x DTH (can harvest buffer up to 10%)</td>
</tr>
<tr>
<td>Floodplains (includes low-high bench)</td>
<td>Terrain stability TEM or VRI/Forest Cover (BEC site series)</td>
<td>Terrain: Select F^Ap, Fp VRI: Site_S1 = site series number, SiteMC_S1 = site series code, Site_M1a = modifier (site series vary by BEC zone)</td>
<td>Floodplains general from terrain map High, medium, and low bench from BEC site series</td>
<td>Not required</td>
</tr>
</tbody>
</table>
Active fluvial units and Floodplains

Active fluvial units are those influenced by river processes on an on-going basis, such as floodplains. I selected these units from the digital terrain data (or TEM for Princess Royal watersheds where no digital terrain map was available). To select these units I queried for terrain polygons classified as active fluvial units (FAp, FAv, FAb, FAj, FAf, in Table 4) or as floodplains of unknown activity (Fp). Field names in the database I used to query for these terrain classes are listed in Table 4. In the digital terrain data, floodplains are classified with the symbols FAp and Fp which are also part of active fluvial units, therefore I did not query for them separately from active fluvial units.

Floodplains can also be identified by their associated vegetation in BEC site series. I queried for high, medium, and low bench floodplains in either TEM or PEM, whichever was the finest resolution. For the Princess Royal Island floodplains I used PEM since it had better resolution than the TEM (PEM is 1:20,000 while TEM in this area is 1:50,000). I grouped the BEC site series floodplains together with those identified by the terrain units into a layer I called active fluvial units, since the active fluvial units and floodplains overlap. I buffered the active fluvial units layer with 1.5 x DTH (ILMB 2007 and Appendix 1).

<table>
<thead>
<tr>
<th>Estuaries</th>
<th>TRIM streams TEM (BEC site series)</th>
<th>TEM: CWH vh2 00/HP – marine estuary CWH vh2 00/TM – tidal marsh, mid-bench floodplain CWH vm1 00/HP</th>
<th>Estuaries</th>
<th>Not required</th>
</tr>
</thead>
</table>

*Buffer as required by the HPG and land use objectives (ILMB 2007 and Appendix 1)
Estuaries

I was able to find very little specific data available for estuaries. I was able to query within the Vegetation Resources Inventory (VRI), Terrestrial Ecosystem Mapping (TEM), and Terrain Resource Information Mapping (TRIM) for BEC site series classed as marine estuaries or tidal marsh but this did not result in identifying any estuaries (Table 4). I recognize that there are likely estuaries associated with some of the study watersheds that are not identified in the data. Site level assessments in the field would address this gap.

Hydroriparian Ecosystem Maps

Floodplains and Alluvial Fans

Both floodplains and alluvial fans are encompassed by the query of active fluvial units and floodplains for the high value fish habitat map (Table 4). Rather than create a second floodplain and fan map, I felt it was more efficient to consider the floodplains and alluvial fans identified and buffered as part of the high value fish habitat map. The redundancy of creating these maps twice was also identified in Price (2003).

Forested Swamps, Sedge Fens, Bogs, Marshes, and Wetlands

I identified forested swamps, sedge fens, bogs, marshes and wetlands using BEC site series using the finest resolution terrestrial vegetation information I had available (TEM or PEM). In the Clayoquot Sound watersheds TEM was the finest resolution at 1:20,000 and in the Princess Royal watersheds PEM was the finest resolution at 1:20,000. I first identified sedge fens, bogs, marshes, and wetlands in two separate layers: large
wetlands (>1.0 ha) and small wetlands (0.25-1.0 ha). Next I applied a buffer of 1.5 DTH to the large wetlands and 1.0 DTH to the small wetlands (Table 5).
<table>
<thead>
<tr>
<th>Hydroriparian Ecosystem Component</th>
<th>Data</th>
<th>Data Analysis</th>
<th>Output</th>
<th>Buffer*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floodplains</td>
<td>Same as in HVFH</td>
<td>Same as in HVFH</td>
<td>Same as in HVFH</td>
<td>Not required</td>
</tr>
<tr>
<td>Alluvial fans</td>
<td>Terrain stability or TEM</td>
<td>Active fluvial units = F_A^p (included in floodplains query)</td>
<td>Floodplains and alluvial fans captured in active fluvial units</td>
<td>Not required</td>
</tr>
<tr>
<td>Forested Swamps</td>
<td>TEM PEM (BEC site series)</td>
<td>Query site series for: CWH vh1 13/RC CWH vh2 13/RC CWH vm1 14/RC CWH vm2 11/RC MH mm1 09/SC MH wh 09/YC</td>
<td>Forested Swamps</td>
<td>Reserve if &gt; 0.25ha Buffer: 1.0x DTH (retain 70% of buffer)</td>
</tr>
<tr>
<td>Sedge Fen</td>
<td>TEM PEM (BEC site series)</td>
<td>Query site series for: CWH vh2: 00/FS (used to be CF) CWH vm1: 14/RC (used to be BS), 00/FS, 00/HF, 00/SF CWH vm2: 00/FS, 00/SB, 32 MH mm1 00/SC MH mmp2 00/FE CWH vh, vm, ws, wn: 31</td>
<td>Small and large sedge fens</td>
<td>If 0.25-1.0 ha, buffer = 1.0x DTH If &gt; 1.0 ha, buffer = 1.5x DTH</td>
</tr>
<tr>
<td>Bog</td>
<td>TEM PEM (BEC site series)</td>
<td>SSL field: CWH vh1: 00/SM, 11/YG, 12/LS CWH vh2: 00/TS, 12/LS CWH vm1: 00/BC, 00/SG, 00/TS, 12/YG, 13/LS</td>
<td>Small and large bogs</td>
<td>If 0.25-1.0 ha, buffer = 1.0x DTH If &gt; 1.0 ha, buffer = 1.5x DTH</td>
</tr>
<tr>
<td>Lakes</td>
<td>TRIM Stream classification PEM TEM</td>
<td>TRIM: FCODE = GB15300000 PEM: FULSS, ECP_LBL, SITE_S = LA TEM: CWH vh2 00/WF (riparian fringe of small lakes)</td>
<td>Small and large lakes</td>
<td>If 0.25-1.0 ha, buffer = 1.0x DTH If &gt; 1.0 ha, buffer = 1.5x DTH</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>Marsh</td>
<td>TEM PEM (BEC site series)</td>
<td>CWH vh1 00/SB</td>
<td>Small and large marshes</td>
<td>If 0.25-1.0 ha, buffer = 1.0x DTH If &gt; 1.0 ha, buffer = 1.5x DTH</td>
</tr>
<tr>
<td>Wetland</td>
<td>TEM PEM (BEC site series)</td>
<td>CWH vm1 00/BS CWH vm2 00/HG MH mm1: 00/CA - wetland, 00/TS or 31 - non-forested wetland</td>
<td>Small and large wetlands</td>
<td>If 0.25-1.0 ha, buffer = 1.0x DTH If &gt; 1.0 ha, buffer = 1.5x DTH</td>
</tr>
</tbody>
</table>

*Buffer as required by the HPG and land use objectives (ILMB 2007 and Appendix 1)

Lakes

I identified lakes using the TRIM streams layer. I then separated the lakes into large lakes (>1.0 ha) and small lakes (0.25-1.0 ha) layers, buffering large lakes with 1.5 DTH buffers, and small lakes with 1.0 x DTH buffers (Table 5 and ILMB 2007).

Objective 1 Methods Summary

There are a variety of data sets required to identify the hydoriparian ecosystem network. The data sets I used are a combination of DEM, TRIM, Terrain Stability, VRI,
TEM, and PEM. I have listed which data sets I used for each of the four mapping processes (unstable terrain, hydoriparian process zones, high value fish habitat, and hydoriparian ecosystems) in Table 6. When there is more than one option for a data set the preferred data set is noted with an asterisk. Further options for data include hard copy data, such as forest cover maps, terrain data, and aerial photos, which may increase the accuracy of identifying these hydoriparian ecosystem components. These hard copy data sets are available for only some areas and require professional interpretation. Such data were not available across my study area and their interpretation was outside the scope of this study.
### Table 6 Summary of Data Used to Identify Hydroriparian Ecosystem Network

DEM = Digital Elevation Model, TRIM = Terrain Resource Inventory Mapping, VRI = Vegetation Resources Inventory, TEM = Terrestrial Ecosystem Mapping, PEM = Predictive Ecosystem Mapping. *indicates preferred data set

<table>
<thead>
<tr>
<th>Unstable Terrain</th>
<th>Hydroriparian Processes</th>
<th>High Value Fish Habitat</th>
<th>Hydroriparian Ecosystems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process and Deposition Zones</td>
<td>Stream Slope</td>
<td></td>
</tr>
<tr>
<td>DEM</td>
<td>x (with SinMap)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>TRIM</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Terrain Stability</td>
<td>x*</td>
<td>x*</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRI</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEM</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>PEM</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4 Objective 2:

The second objective of this study is to compare hydoriparian reserve areas across study watersheds according to watershed characteristics and to look for relationships between reserve area and watershed characteristics (e.g. watershed area and gradient). The small sample size of this study (6 watersheds) is such that it is difficult to
achieve statistical significance, however, some basic statistics and analyses can indicate where relationships may occur and provide guidance for future research.

Comparing Watersheds and their Reserves

The results of Objective 1 provide reserve areas for the hydoriparian ecosystem network for each study watershed. Using these reserves, I calculated the percentage of each watershed comprised of each hydoriparian feature (unstable terrain, hydoriparian process zones, high value fish habitat, and hydoriparian ecosystems). Each of the study watersheds is classified by EAU BC into a river ecosystem type according to four characteristics (gradient, hydrology, temperature, and nutrients). I plotted the percentage of each hydoriparian feature against the watershed mainstem and tributary gradient because across the six study watersheds the characteristic with the greatest representation of its range was gradient (Table 1). There was some variation among the other three characteristics but over a limited range, whereas the range of gradients represents 6 of 9 possible classes. Ciruna et al. (2007) identified that gradient has the largest influence on watershed features and processes. Therefore, I chose to focus the comparison on the relationship between the area of each watershed reserved and gradient. I did not attempt comparisons with hydrology, temperature, or nutrient classes because I felt that the limited range would make it difficult to determine any potential relationships.
CHAPTER 4: RESULTS

4.1 Objective 1: Map Hydroriparian Ecosystem Network

The focus of the first objective for this study is to map hydoriparian ecosystem networks according to the HPG and accompanying land use objectives. The results of this process are four maps for each study watershed: unstable terrain, hydoriparian process zones, high value fish habitat, and hydoriparian ecosystems. Maps for the watershed on Flores Island, located in Clayoquot Sound, will be used throughout this section to provide an example of the results as this watershed contains a good diversity of hydoriparian features. Bar graphs and tables display the results for all 6 watersheds. Maps for the remaining five watersheds can be found in Appendix 2.

Unstable Terrain

The map of unstable terrain (Figure 5) includes polygons identified as Class 4 and Class 5 terrain stability (Howes and Kenk 1997). Class 4 terrain stability indicates areas with a moderate likelihood of landslide initiation as a result of disturbances such as timber harvesting or road construction (Howes and Kenk 1997). Class 5 is the most unstable class and indicates areas of high likelihood of landslide initiation as a result of disturbance (Howes and Kenk 1997). My results show that the unstable terrain polygons are primarily at the high elevation and high gradient areas near the watershed boundaries, which is to be expected as these are likely the steeper areas with potentially unstable soils. The proportion of unstable terrain for each of the six study watersheds is shown in Figure 6. Across the six study watersheds there is not much difference in the proportion of Class
5 terrain. However, there seems to be a difference in the proportion of Class 4 terrain between the Clayoquot Sound Watersheds and the Princess Royal Watersheds. Some of this difference can be explained by the methods I used to determine unstable terrain in each area: traditional terrain stability mapping in Clayoquot watersheds and the ArcGIS extension SinMap in Princess Royal watersheds.

To explore the effect of the different methods I was able to compare both methods in the Whalen Lake watershed on Princess Royal Island, the only watershed of my 3 study watersheds in Princess Royal Island to have both types of data. Figure 6 shows the similarity between the proportion of Class 5 terrain identified by each method and the large difference in the proportion of Class 4 terrain identified. From the comparison of SinMap to traditional terrain stability mapping in the Whalen Lake watershed it appears that the SinMap method identifies approximately twice as much Class 4 terrain as the traditional terrain stability mapping. This overestimation of Class 4 terrain was unexpected as the resolution of the digital elevation model (the main data used for SinMap calculations) data is extremely good, having a resolution of 10m when most of the province is mapped at 25m resolution. The difference in the amount of Class 4 terrain between the Princess Royal and Clayoquot watersheds is more than double (2.6x). The higher proportion of Class 4 terrain in the Princess Royal watersheds may indicate a true difference in the two areas. It is possible that the Princess Royal watersheds have steeper gradients and therefore more unstable terrain than Clayoquot Sound watersheds or it may be that the difference detected is simply a result of the SinMap methods. A comparison of the two areas with the same type of terrain data would be needed to tell if there really
is a difference. For the purposes of this study, there remains some uncertainty in the values for class 4 terrain reserves.

Figure 5 Flores Island Watershed: Unstable Terrain
Figure 6 Unstable Terrain for all Six Study Watersheds. Whalen watersheds are on Princess Royal Island, Cypre and Flores watersheds are in Clayoquot Sound.

Figure 7 Comparing SinMap and Traditional Terrain Stability in the Whalen Lake Watershed.

Hydroriparian Process Zones

Hydroriparian process zones are areas within a watershed that reflect how sediment moves throughout the watershed. Deposition zones are areas in the watershed where sediment is deposited and are usually found at the outlet of a watershed (Naiman et
al. 2005), as seen in Figure 8. Transportation zones are areas where sediment is transported by the river system, typically found along valley bottoms (Naiman et al. 2005). The final process zone is the source zone, which is assumed to be everywhere within the watershed not identified as either a transportation or deposition zone (Naiman et al. 2005). According to the HPG, the process zones to be identified for reserves are the transportation and deposition zones (CIT 2004b). Transportation and deposition zones in the Flores Island watershed are shown in Figure 8 and the proportion of each process zone in each study watershed is shown in Figure 9.

The area of mapped transportation and deposition zones varied. Deposition zones were only identified in the Clayoquot Sound watersheds. Transportation zones were identified in each Clayoquot Sound watershed and in one Princess Royal watershed, Whalen South. Generally less area of process zones were identified in the Princess Royal watersheds than the Clayoquot Sound watersheds. This result may be a reflection of the variation in coastal watersheds, in that the northern study watersheds may have less area of process zones, or the difference may be because of the different data sets used to identify these zones. In Clayoquot sound traditional digital terrain data were used, while in the Princess Royal watersheds no digital terrain data was available so I used Predictive Ecosystem Mapping (PEM). While the resolution of the two data sets are the same, the collection of PEM data serves a broader purpose than the terrain data and perhaps fine scale terrain polygons were not as well integrated. Larger polygons, like the transportation zone in Whalen South may still have been recognized. I was not able to find any information regarding comparisons or levels of accuracy of the PEM or digital terrain data sets. Although not very visible in the data, transportation and deposition
zones are ‘protected’ by buffering the river system (where sediment transportation occurs) and floodplains (where deposition is likely to occur) as is done in the high value fish habitat map.
Figure 8 Flores Island Watershed: Hydoriparian Process Zones

Legend
- Lakes
- Rivers
- Deposition Zone
- Transportation Zone
High Value Fish Habitat

High value fish habitat as identified in the HPG consists of river reaches with potential fish habitat (<20% slope), river reaches with no potential fish habitat (>20% slope), active fluvial units, and floodplains. River reaches identified through this process as having ‘no potential fish habitat’ are reaches with sections of greater than 20% slope, a generally agreed barrier to migrating fish (BC Ministry of Forests 1995). However, these steeper stream reaches still contribute to the quality of fish habitat further downstream and may support resident populations of fish (Alexander et al. 2007, Meyer et al. 2007). Headwater and small streams may have barriers to anadromous fish passage, but they are extremely important components contributing to watershed health (Alexander et al. 2007, Meyer et al. 2007). High value fish habitat components for the Flores Island study watershed are shown in Figure 10. Figure 11 summarizes the proportion of each
watershed comprised of potential high value fish habitat in the two river types and Figure 12 the proportion of active fluvial units and floodplains.

Figure 10 Flores Island Watershed: High Value Fish Habitat. High value fish habitat in this watershed is represented by lakes, active fluvial units and their buffers, and rivers with buffers for reaches with potential fish habitat and no potential fish habitat.
The results show that there is greater variation between watersheds than between the Clayoquot Sound and Princess Royal watershed groups. In five out of six watersheds there is more reserve area for river reaches with ‘no potential fish habitat’ than reaches with ‘potential fish habitat’. This greater proportion of rivers with ‘no potential fish habitat’ follows expectations because these smaller rivers and streams compose the majority of river length within a watershed (Freeman et al. 2007). There is also variation in the amount of active fluvial units and floodplains with no discernable pattern among the study watersheds.

Figure 11 Percentage of River Reaches with Potential Fish Habitat and No Potential Fish Habitat for all Six Study Watersheds. Area Reserved = Percent of Watershed Area
Hydroriparian Ecosystems

Hydroriparian ecosystems listed in the HPG include small steep streams, fans, floodplains, karst landscapes, forested swamps, sedge fens, wetland ponds, lakes, shoreline saltspray forests, and estuaries. Hydroriparian ecosystem components I identified in the Flores Island watershed were lakes, rivers, and bogs (Figure 13). Figure 14 illustrates the proportion of each watershed comprised of these hydoriparian components. Overall the hydoriparian ecosystems themselves make up a small proportion of watershed reserves (<10%). The exception to this is large dominating features such as Whalen Lake in the Whalen Lake watershed (over 25% of watershed area) and the complex of bogs in the Flores Island watershed (over 20% of watershed area).
Figure 13 Flores Island Watershed: Hydroriparian Ecosystems

Legend

- Lakes
- Rivers
- River Buffer
- Active Fluvial Units
- Active Fluvial Units Buffer
- Large Lakes Buffer
- Small Lake Buffer
- Bogs
- Bogs Buffer

Figure 14 Hydroriparian Ecosystems Reserve Area

Legend

- Forested Swamp
- Sedge Fen
- Bogs
- Lakes
- Wetlands
Synthesis

To calculate the total proportion of each watershed identified as hydoriparian reserve network I eliminated the overlap between hydoriparian features using the overlay function in ArcGIS to show the final ‘footprint’ of reserves (Figure 15). The alternative would be to add the proportions of reserve of each reserve type together, however many of the reserved area overlap so the overlay or ‘footprint’ approach is the most meaningful to determine the overall area of each watershed identified as a reserve. The proportion of watersheds identified as part of the hydoriparian reserve network ranged from a low of 37% in a Clayoquot Sound watershed to a high of 83% in a Princess Royal watershed (Table 7 and Figure 16).

The high amount of hydoriparian reserve area in the Princess Royal watersheds may partly be explained by potential errors associated with using the SinMap method to map unstable terrain. From comparing the SinMap method to traditional terrain stability mapping in the Whalen Lake watershed on Princess Royal Island I know that SinMap can overestimate Class 4 terrain by approximately 100%. Without field validation I cannot conclude that SinMap is wrong, particularly as a study done by Terratech Consulting (1998) found that when data quality is high (as was the case here with a DEM of 10m resolution) SinMap results were superior to those of traditional terrain mapping.

Within the Whalen Lake watershed I was also able to use the traditional terrain stability mapping to see what the ‘footprint’ of reserves would be using that method of identifying unstable terrain (69%). A footprint of 69% with traditional stability mapping means the SinMap method results in an overestimation of overall reserve area of about 20%. When I adjusted the Whalen North and Whalen South watersheds footprint by 20%
it resulted in reserve networks of 59% and 62% (Table 7 and Figure 16). Across all watersheds, Class 4 terrain was the largest contributor to reserve area. Given this large influence I would recommend that high quality terrain data with field checking combined with aerial photo checking would be essential for accurate reserve mapping. I also recommend more effort focused on calibrating and testing SinMap in different areas of the province.

**Figure 15 Flores Island Watershed: All Hydroriparian Reserves**
Table 7 Summary of Study Watershed River Ecosystem Type and Total Reserve Area

<table>
<thead>
<tr>
<th>Study Area</th>
<th>River Ecosystem Type (EAU BC)</th>
<th>Area (ha)</th>
<th>Reserve Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Princess Royal Watersheds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whalen North</td>
<td>C2b</td>
<td>12,568</td>
<td>73 (59)</td>
</tr>
<tr>
<td>Whalen Lake</td>
<td>C2b</td>
<td>8,852 (6,091)</td>
<td>83 (69)</td>
</tr>
<tr>
<td>Whalen South</td>
<td>C2b</td>
<td>2,957</td>
<td>78 (62)</td>
</tr>
<tr>
<td><strong>Clayoquot Sound Watersheds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cypre West</td>
<td>C1a</td>
<td>59,195</td>
<td>59</td>
</tr>
<tr>
<td>Flores Island</td>
<td>H1b</td>
<td>1,651</td>
<td>55</td>
</tr>
<tr>
<td>Cypre East</td>
<td>C2b</td>
<td>4,612</td>
<td>37</td>
</tr>
</tbody>
</table>

Values in brackets for the Princess Royal watersheds are results of conventional terrain stability, the rest of the Princess Royal watershed results use SinMap to estimate terrain stability classes.

Figure 16 Total Reserve Areas in all Six Study Watersheds

4.2 Objective 2: Relationships Between Reserve Areas and Stream Gradient

As I compare results between watersheds, recall that all watersheds are classified according to their gradient, hydrology, temperature, and nutrient class in the EAU BC aquatic classification (Ciruna et al. 2007). All three of the Princess Royal watersheds and
one of the Clayoquot Sound watersheds are classed as C2b: *Lower Inner Coast and Fjord Coastal Rivers* (Table 1). The other two Clayoquot Sound watersheds are classed as C1a: *Exposed Outer Coast and Island Coastal Rivers* and H1b: *Lower Relief Coastal Headwaters*. The hydrologic regimes of the six study watersheds differ in winter with greater flow in the southern watersheds than the north, but flows for the rest of the seasons are similar. While the temperature and nutrient values did vary, the range of possible variation was not well represented within the study watersheds. Stream gradient is the characteristic which varied the most across watersheds (Table 1) and has the greatest influence on watershed characteristics (Ciruna et al. 2007). Therefore, in comparing reserve areas between watersheds I chose to focus on potential relationships with mainstem and tributary gradient.

Of the plots for unstable terrain and hydoriparian process zones (Figure 17), the strongest potential relationships seem to be between Class 5 terrain and transportation zones and tributary gradient. The results show that there is more Class 5 terrain present when the tributary gradient is steep; a logical result considering that a steep tributary gradient indicates steeper watershed topography where more soils could be unstable. There are also more transportation zones when the tributary gradient is steep; perhaps steep valley walls direct more flow and sediment into recognizable transportation zones than in wider valleys where transport zones may be smaller.

The plots showing high value fish habitat components and gradient (Figure 18) indicate that there may be more ‘no fish habitat potential’ streams when the mainstem or tributary is steep. This is reasonable since a steeper gradient means more of the stream is
likely to be greater than 20% and therefore classed as a ‘no fish habitat potential’ stream. The results also showed a potential relationship between floodplains and gradient, as there seems to be more floodplains when the tributary is steep. It may be possible that steep tributaries facilitate faster flows that create more floodplains in the valleys when substrates allow for an unconstrained channel.

The plots of hydoriparian ecosystems and gradient did not indicate any obvious potential relationships with mainstem or tributary gradients. The representation of hydoriparian ecosystem components may be due to other factors such as past glacial activity or smaller local factors like precipitation. A study with more variation in watershed characteristics may be able to find some relationship to other attributes such as hydrology, temperature, or nutrients.
Figure 17 Graphs of Unstable Terrain and Hydoriparian Process Zones vs. Gradient 1 = shallow, 2 = Moderate, 3 = Steep
Figure 18 Graphs of High Value Fish Habitat and Gradient. Gradient 1 = shallow, 2 = Moderate, 3 = Steep
Figure 19 Graphs of Hydroriparian Ecosystems and Gradient. 1 = shallow, 2 = mod, 3 = steep
CHAPTER 5: DISCUSSION

Identifying hydoriparian reserves according to the Hydoriparian Planning Guide resulted in substantial portions of study watersheds being classified as hydoriparian reserves (37-69%). My results also indicate that Class 4 terrain comprised a large part of the reserve area (22-25% of Princess Royal watersheds are Class 4 and 14-21% of Clayoquot Sound watersheds are Class 4) and that the proportion of Class 4 terrain may be greater in the Princess Royal watersheds than in Clayoquot Sound watersheds. Though Class 4 terrain comprised a large part of the reserve area, I was able to show that there is potential for substantial overestimation of the amount of Class 4 terrain when using the SinMap terrain classification method. This emphasizes the importance of obtaining high quality data on which to base such analyses. My results suggest that that there are more relationships between tributary gradient and hydoriparian features than between mainstem gradient and hydoriparian features. For example, Class 5 terrain, transportation zones, ‘no potential fish habitat’ stream reaches, and floodplains all increased their proportional area in watersheds with steep tributary gradients. The only relationship between mainstem gradient and hydoriparian features was with ‘no potential fish habitat’ stream reaches.

5.1 Objective 1:

The first objective of this study was to test the process of mapping hydoriparian reserves using the Hydoriparian Planning Guide (HPG) and associated land use
objectives. I began the HPG mapping process with a steep learning curve as I identified what data were required and where to find them, acquired these data, and finally interpreted the data to identify hydrioparian ecosystems and reserves. Acquiring data for a larger area with sufficient accuracy and content was difficult. The data I had available let me to focus on northern Princess Royal Island and Clayoquot Sound. Once all of the necessary data were collected, and the query criteria defined, the process of identifying and mapping hydrioparian ecosystems was relatively quick. Each watershed demanded roughly 2 days of work with additional time then spent on analysis of reserve composition and comparison of watershed reserves.

Determining how to identify hydrioparian features was not straightforward. While it is relatively simple to understand what a sedge fen might look like on the ground, learning how to query for it in digital data often collected for other purposes was more difficult. I found this to be particularly true since many of the data sets had limited metadata, and field descriptions reside in data capture methodology or data dictionaries not easily found on government websites. Provincial government links to data capture methodology and data dictionaries were often out of date. The lack of accessible metadata can also result in overconfidence in the data, which is why I explicitly list each data set and its resolution in Table 2. It is important to remember that data layers are never completely accurate, and complex mapping exercises can exacerbate errors and further reduce the accuracy of the data (Burrough and McDonnell 2004).

Once I developed the procedures for how to query for various hydrioparian features, the process of creating the maps and buffering the features became streamlined. To increase the number of study watersheds in future research a GIS analyst could use
modelling software, such as ModelBuilder in ArcGIS, to develop a method to run these queries for multiple watersheds. I found that the mapping process was also slowed because following the complete EBM framework, as outlined in the EBM Handbook (CIT 2004a) and the HPG (CIT 2004b), requires maps to be produced for other planning components such as large ranging carnivore habitat or recreation. Some of these, generally terrestrial focused maps, are then used to assist in hydoriparian planning. For example, the rare ecosystems layer is produced as part of the terrestrial ecosystems layer, but can also be used to identify rare ecosystems in the riparian and floodplain areas. As a case study focused on hydoriparian planning I either had to create these maps myself or do without. The only case where I did without was to not create the terrestrial ecosystems layer.

Overall, I successfully met the first objective; I identified, mapped, and buffered hydoriparian features as necessary. Given reasonable existing data, the HPG and the legal objectives can readily be interpreted by someone familiar with hydoriparian ecosystems and ArcGIS with some additional explanation and a key for querying various datasets.

The largest component of the hydoriparian reserve network was unstable terrain. Through my research I was able to test two methods of identifying unstable terrain: traditional terrain stability mapping and an ArcGIS extension called SinMap. SinMap uses digital elevation models to estimate terrain stability classes. I was able to compare these methods in the Whalen Lake watershed on Princess Royal Island, where both SinMap and traditional terrain stability mapping were available, and found that SinMap quite accurately identified Class 5 terrain (the most unstable terrain) but overestimated
Class 4 terrain by 100% (Figure 7). This is in agreement with the Gordon (2003) study of five north coast watersheds where using helicopter-based visual checks showed that approximately 30% of Class 4 and 5 terrain as identified by SinMap were not unstable. However, another test of SinMap done by Terratech Consulting (1998) found that when the DEM data were of high accuracy, the SinMap results were superior to the traditional terrain stability maps for the same area. Therefore in cases where traditional terrain stability mapping is unavailable, or the DEM data is of high quality, SinMap is an alternate option, particularly if there is the capacity for aerial photo interpretation and field mapping as checks. Over time the calibration of SinMap will also improve, thereby improving the accuracy of the digital results.

Based on the comparison in Whalen Lake watershed I adjusted the Class 4 unstable terrain values in the other two Princess Royal watersheds, decreasing them by 50%. While this adjustment addresses the likely overestimation of Class 4 terrain there still remains some uncertainty, which also affects the estimation of total reserve areas. As the unstable terrain is such a large component of the reserve network it will be important to improve the distribution of available digital terrain stability mapping and testing and calibration of SinMap as a viable alternative. Accurate representation of hydoriparian ecosystems will be very important as there are many demands for resources in these watersheds, and support from a wide range of stakeholders, including industry, will be needed to support EBM implementation.

The largest overall hydoriparian reserve networks were in the Princess Royal watersheds, where the percentage of watersheds identified as hydoriparian reserve ranged from 73-83%, using SinMap alone to identify unstable terrain, and ranging from
59-69% after adjusting the terrain values. Clayoquot Sound watersheds ranged from 37-59% in hydoriparian reserve.

I also found that the proportion of Class 4 terrain seems to be higher, on average, in the Princess Royal watersheds, with an adjusted range of 22-25%, than in Clayoquot Sound watersheds, with a range of 14-21%. Traditional terrain stability mapping for the three Princess Royal watersheds would be needed to ascertain if this really is the case. The EAU BC classification system (Ciruna et al. 2007) shows that river gradients are highly variable along the BC coast, so while there may be a true difference in Class 4 terrain between Princess Royal Island and Clayoquot Sound it is not likely a generalization that could be made in comparison of southern coastal watersheds versus northern coastal watersheds.

**Redundancies and Challenges in the Mapping Process**

As I worked through the mapping process I identified some apparent redundancies in the HPG guidelines. The most obvious of these was the overlap between floodplains, active fluvial units and alluvial fans. In the terrain classification, the definition of active fluvial units includes both alluvial fans and floodplains. The TEM or PEM database can also be queried for floodplains using BEC site series associated with high-, medium-, and low-bench floodplains. Some of the hydoriparian reserves overlap spatially but they are still important to distinguish for future planning purposes as they may have different characteristics which warrant identification (e.g. deposition zones and floodplains).

Some challenges exist where the available data were not able to identify hydoriparian features (such as stream classes, upland streams, and unstable terrain) at the
level of detail required by the HPG. There is limited digital stream classification as defined by the provincial Riparian Management Area Guidebook’s S1-S6 classification (BC Ministry of Forests 1995) available for the province. There is a digital stream classification available for Clayoquot Sound, but it is different than the S1-S6 provincial stream classification and was developed as part of the Clayoquot Sound Scientific Panel recommendations (CSSP 1995). With no provincial stream classification information available, I used a general query of streams < 20% slope and < 400m elevation to identify stream reaches with potential fish habitat (analogous to S1-S4) as used by Price (2003). Stream reaches not identified this way were considered to have ‘no potential fish habitat’ (S5-S6). This approach is a coarse generalization of fish presence in streams. The possible sources of error with this approach are linked to DEM accuracy which is 25m resolution provincially, and 10m on Princess Royal Island. While this resolution is likely adequate for watershed planning, site level plans are needed to refine these classes.

Connectivity is another challenge when mapping hydoriparian ecosystems. I did not adjust stream classes to reflect connectivity between potential fish habitats. For example, if two stream reaches classed as ‘potential fish habitat’ reaches were separated by a reach of ‘no potential fish habitat’ I left the classification for the upstream ‘potential fish habitat’ stream reach as is. I decided not to eliminate potential fish habitat upstream of a high gradient section because of the uncertainty in the data. Just because a reach of stream is classed as greater than 20% slope doesn’t mean it is actually a fish barrier. Instances where potential fish habitat reaches are separated by a higher gradient ‘no potential fish habitat’ reach are an example of how issues can be flagged at the watershed scale for field checking.
Another challenge is that upland streams are frequently missing from digital data, mostly because they are often not visible on air photos (Price 2003). Following the HPG I could have identified tributaries with a slope of > 5% as a proxy for upland streams, but these would either already be identified as potential fish streams (and therefore have a larger buffer than would be assigned to them as an upland stream) or as ‘no fish habitat potential’ streams (with the same buffer as an upland stream). I therefore assumed that upland streams in the data were adequately buffered by identifying potential fish habitat and ‘no fish habitat potential’ stream reaches. What I was ultimately unable to determine, was how to account for streams not identified in the stream data. This is an important gap in the data as increased detection of upland streams could substantially increase the amount of reserve area because these small streams often make up a large proportion of the stream network (Leopold 1964). Price (2003) recommends setting aside some proportion of the land base slated to be harvested to apply upland stream buffers in the field, but I did not have harvest plans for the study watersheds so I addressed upland streams by buffering streams visible in the digital data. Unmapped upland streams would also be partially addressed by the unstable terrain reserves, as these steeper sections of the watershed could contain many streams (Richardson et al. 2005).

There are also some challenges to identifying the appropriate buffer width using dominant tree height (DTH). The land use objectives do not specify how to determine DTH, or at what scale it should account for local variation (watershed, drainage basin, coastal planning unit). I followed Price (2003) and used a 30m DTH. It would be possible to vary this by location using forest cover and leading tree species information. Depending on the differences in leading tree species height the amount of buffer per
watershed could change. My guess is that at the watershed scale increasing or decreasing the DTH in the range of 5-10m would not significantly change the overall reserve area because the change would affect stream buffers most and these are overshadowed by the influence of unstable terrain.

Data quality appears to be better for the south coast watersheds than the north coast watersheds in my sample (Table 1). This discrepancy probably arises because the southern watersheds have experienced greater levels of resource development, with a corresponding increase in the investment in watershed characterization. In particular, the frequency and intensity of data sampling is greater in South Coast watersheds. Clayoquot Sound is the most extreme example of this geographically based sampling difference—because the data for that area are among the most complete in the province because of the Clayoquot Sound Scientific Panel planning process (D. Sirk, pers. comm. 2006).

However, new watershed data such as the recently released digital terrain data for Whalen Lake watershed on Princess Royal Island are still being produced and will improve with time. There are also some new data sets recently released, or soon to be released, such as the provincial corporate watershed base dataset (1:20,000 watersheds, rivers, lakes, etc.), Hectares BC (an online raster tool), and revised BEC data that are all province-wide datasets.

The quality of available data may be responsible for the differences in reserve areas I estimated between Princess Royal Island (59-69%) and Clayoquot Sound (37-59%) watersheds. It appears that the higher quality data for Clayoquot, and more accurate reserves, resulted in less of the total watershed classed as reserve area (Table 7). This also raises the question of whether the HPG could be used in watersheds on the
southern coast, as it is now targeted for the central and north coast. It seems to me that it could, given the good data availability, although it may need some field checking to see if the buffer widths should be adjusted.

**Limitations**

The existence and availability of data dictated where I selected study watersheds, making the sample I obtained far from random. To increase the statistical power of analyses of this type, selecting a larger subsample randomly or systematically from an overall sample of many watersheds (50-60) all along the coast would be preferable. The small study size and non-random approach to watershed selection mean that results of this study likely do not represent the range of watersheds within the two study areas and should not be used to infer outcomes for other watersheds.

While I identified hydoriparian ecosystems and reserves, I did not identify where buffers could be harvested when it was identified as possible within the land use objectives. For example, the land use objectives specify that up to 30% of the buffers around forested swamps can be harvested (Appendix I). I did not attempt to decide where within the forested swamp buffer the 70% retention should be, this would be part of the site level planning. Therefore, there are some instances, such as forested swamp buffers, where some of the area that appears to be unavailable for harvest in the reserve may actually be available for harvest. This ‘extra area’ available is not included in my calculations of the total reserve area per watershed (e.g. I did not determine forested swamp area and then multiply it by 0.7 to reflect 70% retention).
Objective 1 Conclusion

Despite possible errors and data quality issues the HPG, as implemented here, does a reasonable job of identifying hydoriparian ecosystems at the watershed scale. Some characteristics, like fish habitat, may not be best identified at the watershed scale and would benefit from site level assessments (the finest scale of planning in the HPG) for accurate identification. Identifying hydoriparian ecosystems for watershed planning is only one stage in the EBM process, a coarse filter that must be followed by finer filter approaches to watershed classification. The watershed plan does a good job of identifying hydoriparian features, but the site plan will be key to ensuring features on the ground are being protected. Following the EBM framework, the watershed plan would identify likely sites for hydoriparian reserves and flag areas that should be a focus of field checking (e.g. Class 4 terrain). The site plan would include field checking and professional review to refine the spatial delineation of hydoriparian reserves. Adjustments to reserves and buffers should then feed back into the management process and inform decisions for land use at the broader scale.

5.2 Objective 2:

The second objective of this study was to compare resulting reserve areas for each watershed and look for relationships with watershed characteristics. The watershed characteristics on which I focused were mainstem and tributary gradient as these characteristics varied the most among the study watersheds. I graphed the various hydoriparian reserve areas against mainstem and tributary gradient to explore potential relationships between hydoriparian reserve areas and gradient. I noticed more relationships with tributary gradient than mainstem gradient. There seems to be more
Class 5 reserve area, transportation zone, ‘no potential fish habitat’ stream reaches, and floodplains when tributaries have a steep gradient. ‘No potential fish habitat’ stream reaches also seem to be positively related with steep mainstem gradient.

The positive relationship between unstable terrain and tributary gradient makes sense--one would expect that unstable slopes usually occur on steeper terrain. I would also expect more streams classed with ‘no potential fish habitat’ to occur disproportionately in steeper areas as small steep streams are often physically unstable (Richardson et al. 2005). In addition, since I used slope > 20% as the criterion for classifying stream reaches as having ‘no potential fish habitat,’ the correlation between such stream reaches and steeper terrain is not surprising. The potential positive relationship between tributary gradient and transportation zones may indicate that transportation of sediment occurs more in tributaries than in mainstems. More floodplain area also seems connected with steep tributary gradients and floodplains. This relationship is in contrast with Richardson et al. (2005), who note that where steep small streams occur there is little to no floodplain.

I expected to find some relationships between gradient and hydoriparian ecosystems. For example, I expected to find shallower gradients related to increased area of hydoriparian ecosystems as there would be more opportunity for water to pool and maintain water bodies such as lakes and wetlands. Perhaps a study sample with a greater variety of hydoriparian ecosystems is necessary to determine whether this relationship exists. Further applications of the HPG in a wider variety of watersheds would also be needed to confirm the relationships with gradient before predicting proportions of these hydoriparian reserves based on a level of tributary gradient. I did find some results that
were consistent between watersheds, such as unstable terrain comprising the most significant portion of the overall reserve area. ‘No potential fish habitat’ stream reaches were consistently the next largest portion of the reserve area, followed by ‘potential fish habitat’ stream reaches, and then hydoriparian ecosystem components.

To compare my results with other EBM type processes I looked at three sources: the Price (2003) test of the HPG, the Clayoquot Sound watershed plans that follow the Clayoquot Sound Scientific Panel (CSSP 1995) recommendations, and the Forest Ecosystem Management Assessment Team (FEMAT 1993) EBM scenario (Figure 20). From my results I have grouped the Clayoquot Sound watersheds to facilitate direct comparison with the CSSP results. The Princess Royal watersheds are shown twice, first using SinMap values for unstable terrain, and second showing adjusted SinMap values based on the comparison of SinMap and traditional terrain mapping in the Whalen Lake watershed (decreasing the SinMap values by 20%). I have used the average percent of the watersheds designated as hydoriparian reserves, including unstable terrain.

The results from my application of the HPG are very much in line with results from other EBM processes, particularly for my study watersheds in Clayoquot Sound. The area of reserves in the Princess Royal watersheds, even after adjusting for SinMap errors, is higher on average (63%); although the adjusted values are not much more than the Price (2003) results (average of 60%). Whether greater reserves in the Princess Royal watersheds are due to different data sets or more hydoriparian features needing protection is a topic for future research.
Figure 20 Watershed Planning Using EBM. Comparison of my results with other EBM planning processes. Averages for Clayoquot Sound and Princess Royal watersheds shown below. Processes for comparison are the Price (2003) 'Testing the HPG' results (average of Paril and Chambers Creek watersheds), Clayoquot Sound watershed plans based on Clayoquot Sound Scientific Panel (CSSP) recommendations (average of Flores Island, Cypre watershed, and Bedingfield watershed), and the average value from the Forest Ecosystem Assessment Team (FEMAT) EBM scenario.

Limitations and Assumptions to Watershed Comparisons

I did not sample the watersheds randomly. I attempted to select watersheds with as much variation as possible to reflect a wider array of watershed characteristics. Possible implications of this could be that the relationships identified here may not be transferrable to other watersheds. I have also presumed that there is a linear relationship between the variables, which may not be the case. With a larger sample size the relationship between variables would be easier to ascertain in a scatter plot (Triola 1998).

Limitations of this study include having no method to include hydoriparian features that exist on the ground that have not been identified in the datasets, such as
watershed features that are of too small a scale to be captured in the data. Examples include spawning and rearing grounds for salmon. Missing features also depend on data scale and accuracy. For example, wetlands were found in the north coast watersheds, but not in the south coast, which may point to inaccuracy of data from the south coast. This difference could be caused by my using PEM to query in north coast, and TEM in south coast, or a difference in accuracy between the data collectors. Or perhaps there are less wetlands in the south coast watersheds I reviewed; this cannot be determined without ground level assessments. An up-to-date list of existing data sets and how they might be used for hydoriparian mapping purposes would be very helpful to any mapping process like this.

**Objective 2 Conclusion**

The comparison of hydoriparian reserves between watersheds has identified some interesting potential relationships between mainstem and tributary gradients and the proportion of certain hydoriparian reserves. Tributary gradient seems to have the most influence on the proportion of hydoriparian reserve area in a watershed. Steep tributary gradient was identified to have a potential relationship with four reserve types: Class 5 reserve area, transportation zone, ‘no potential fish habitat’ stream reaches, and floodplains. This could allow for some coarse scale screening of watersheds that have steep tributary gradients, identifying them as watersheds where high quality terrain data may be most important as unstable terrain is the largest contributor to overall reserve area. The positive relationship between steep mainstem gradient and ‘no potential fish habitat’ stream reaches also highlights the need for more detailed stream assessment information to validate whether this relationship really exists.
Perhaps most importantly, every watershed is different and has different dominant hydroriparian features, and the resulting hydroriparian reserve composition can be expected to vary as well. The range of reserve area per watershed (37-69%) is quite wide and represents a large proportion of the watershed. Given the current political climate, is a plan with 50% or more reserves likely to be accepted and implemented? In order to be accepted, there would need to be a high quality of data to support the decision and some certainty that these reserves are really all needed to maintain ecosystem function. If such a plan is implemented, how will industry manage the transition to 50% reserves from current practices? We can realistically expect resistance from some resource users and stakeholders, particularly the forest industry, while gaining support from other stakeholders such as environmental groups. As always, careful planning and collaboration with all interest groups will be important. If EBM is going to be accepted and used by the wider resource management community, an implementation strategy supported by all interest groups is going to be the key. Some site level plans that address some of the uncertainty of the watershed plans and refine reserves where appropriate seems a logical next step.

5.3 Considerations for Implementing the Hydroriparian Planning Guide and Ecosystem-Based Management

The HPG is based on an EBM framework, and EBM is a fundamentally different approach from that of traditional resource management, which focuses more on maximising the resources taken from the environment, rather than what is left behind (Swanson and Franklin 1992). EBM forces managers to consider the complexities and interlinkages in both ecological systems and human systems, which many scientists and
researchers consider a benefit to long term resource sustainability, but it also makes strategies difficult to determine (Margerum and Hooper 2001). However popular the concept of EBM has become, there have been few true applications of EBM (Wright et al. 2004). A number of challenges to EBM implementation include political agendas, concepts of land ownership, interdisciplinary conflict, and the difficult shift from anthropocentric to ecocentric values (Wright et al. 2004).

Benefits of EBM include that the collaborative management inherent in the EBM process can build trust between governments and stakeholders (Rigg 2001). In a recent study by McGee (2006) that investigated the process of the North Coast Land and Resource Management Plan (NC LRMP) participants in the process felt that just going through the process alone was beneficial; they agreed that as a result of the process relationships and understanding among participants had improved. Participants also felt that the strengths of using an EBM framework were: that it results in a sustainable land use plan that will support ecosystems many years into the future; that it produces better land management; and that the socioeconomic factors are considered along with ecological integrity (McGee 2006). Participants felt overall that EBM has the potential to be a powerful planning tool, and would be even more useful if there were associated criteria such as a clear understanding of the benefits and impacts, the use of peer reviewed information, and ongoing implementation and funding support (McGee 2006).

The science embodied in the HPG is at a level where we can map hydoriparian ecosystems with a reasonable amount of accuracy, assuming there will be follow-up site level assessments to further refine these maps. The main barrier to EBM implementation in BC is not the science or the data; it is the complex nature of government and
stakeholder relationships. There exists a history of distrust, political posturing, and disagreements between the provincial government, First Nations, environmental non-governmental organizations (ENGOs), and industry (Lertzman et al. 1996). It may be difficult to rebuild a sufficient level of trust between these groups so that they can work together effectively.

Discrepancies in data quality and availability across regions will also necessitate local adaptations to the guidelines based on available data. While this does not mean the HPG should be put on hold to wait for more consistent data, it does mean that there needs to be cooperation in getting the best quality data possible for each watershed and updating the data as new versions become available. This provides many opportunities for research and collaboration between universities, First Nations, ENGOs, and industry.

The HPG will also be a challenge to implement because it is the first large-scale application of EBM in BC (CSSP recommendations were the first, but for a smaller land area). An inherent component of EBM is that it is flexible and adaptive to local conditions, which makes it difficult to monitor implementation in each area, as local environmental and cultural situations will vary. Following the results from other EBM approaches may provide some insight to implementation of EBM and the HPG into the future.
CHAPTER 6: RECOMMENDATIONS AND MANAGEMENT IMPLICATIONS

6.1 Recommendations

After mapping hydoriparian reserves according to the HPG I have some recommendations for future HPG-based mapping exercises and HPG implementation. The first group of recommendations is related to mapping and GIS methods and the second group deals with broader management implications.

Mapping and GIS

I recommend that metadata for provincial data layers need to be improved and/or be more easily accessible. The metadata issue may have improved with more recent provincial layers, but is likely still an issue with older data sets. In particular, the resolution and date of original data collection needs to stay with the data layer. Some of the data sets, such as the provincial DEM have been created by TRIM maps based on air photos. The date of the resulting DEM data layer should carry with it the date of the original air photos to accurately represent the original data.

When mapping hydoriparian ecosystem components, summaries of data queries and field names, as I have included in my methods (Table 4), should be listed clearly. It is possible that even with the same data sets two separate people mapping these components could do so with different data queries and have different results. It might be useful for the EBM Working Group to standardize data queries for each hydoriparian ecosystem component, resulting in more consistent application of the guidelines. Better
recording of mapping methods used to meet the Legal Objectives will also help direct needs for more aerial photographs and site checks.

The issue of missing upland streams in the data is an important gap. These streams may not even be captured by aerial photos (Richardson et al. 2005), and an accurate representation of these streams may only be possible at the site level, a very expensive option. An alternative for watershed level planning is that an extra undefined reserve area could be set aside to add buffer to areas of small and upland streams not captured in the data. In the long-term, increased data collection from on the ground site assessments should be added to the GIS stream layers.

Digital terrain mapping is lacking for many areas across the province and Sin Map is a useful alternative in such areas. However, until there is further research and calibration of SinMap it should probably not be used alone to identify unstable terrain, but should be used in conjunction with aerial photo interpretation and field verification. More research comparing SinMap and traditional terrain stability mapping, along with field verification, may be needed to address the accuracy of the unstable terrain identified by both terrain mapping methods. A particular focus on Class 4 terrain could be included in future research as it was such a substantial proportion of the reserve. To streamline the mapping methods I agree with the recommendation of Price (2003) that the HPG guidelines should note that floodplains and alluvial fans are captured by active fluvial units and review whether they need to be identified separately.
Management Implications

As planning moves from the watershed level to the site level it will be increasingly important to assess the accuracy of the watershed plans, to check whether the hydoriparian ecosystems identified in the watershed plans actually exist on the ground. I recommend that the results of studies like my research be used in future research that includes field ground-truthing to assess how accurate the data are in identifying hydoriparian ecosystem networks.

I also recommend further investigation into whether there really is more Class 4 terrain in northern watersheds, when compared to southern watershed like those in Clayoquot Sound. A relationship such as this could have implications for watershed planning. Further investigation into the relationships between tributary and mainstem gradient with hydoriparian features would also inform the HPG process. If the relationships continue to be identified between some of the hydoriparian features and tributary gradient this may provide justification for more detailed data collection on tributaries and their contributions to hydoriparian ecosystem health and function.

Documentation of other EBM initiatives such as the CSSP recommendations (CSSP 1995) and their implementation would be valuable for people working on the HPG implementation. Creation of an online information sharing forum, such as a BC EBM website, to share ideas and results among various applications across the province would also be useful for HPG implementation as well as other EBM initiatives.

Implementation of the HPG, and therefore an EBM approach, is a perfect opportunity to use adaptive management. As identified in the HPG, adaptive management should be a large component of HPG implementation. The degree of
adaptive management will likely range from passive to active, depending on watershed and corresponding social conditions. However, in some high priority watersheds active adaptive management, the use of designed experiments and monitoring, would provide important feedback to the HPG process. Feedback from the monitoring process might help to identify if the level of reserves required are truly needed to maintain hydoriparian ecosystem function, and consequences for adjusting the application of reserves using the flexibility in the Legal Objectives.

A key aspect of adaptive management is monitoring (McLain and Lee 1996, Stankey et al. 2003). I recommend monitoring of key indicators of hydoriparian ecosystem health, perhaps through an effectiveness monitoring framework similar to that used to assess the implementation of the aquatic portion of the Aquatic Conservation Strategy that was an outcome of the FEMAT recommendations (Reeves 2006). Even after a relatively short period of 10 years, Reeves (2006) were able to show that watershed condition scores have increased in many of the watersheds, and that the increase was related to improved riparian conditions.

Since there will need to be trade offs between the many reserves identified for both ecological and human use values, a method to visualize these trade offs would be useful. One such option is the use of spatial optimization software such as Marxan. Marxan has been used by conservation organizations for the last few years to assist in identifying priority conservation areas (Stewart et al. 2003, Carwardine et al. 2007, Klein et al. 2008). Similar analyses could be done to compare different reserve combinations based on the EBM Handbook and HPG.
6.2 Conclusion

In summary, I found that following the HPG guidelines identifies a large area (37-69%) of watersheds as hydoriparian reserve. To ensure that these estimations are as accurate as possible data quality will be important, along with field verification of the results. To connect the data quality with hydoriparian reserves as they are identified in the field, the linkages between watershed level planning and site level planning need to be recognized and emphasized. Data quality is important, however, we are fortunate to have extensive data to work with in BC. Therefore, I don’t see the data or scientific information as the prime limiting factor to HPG implementation; the emphasis should be on commitments to field verification and adaptive management. Recognition of other values, particularly cultural values and the integration of First Nations into the watershed planning teams will also help balance ecological and human values as reserves are determined.
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APPENDIX 1

Central and North Coast Order

December 19, 2007

(http://ilmbwww.gov.bc.ca/slrp/lrmp/nanaimo/cencoast/docs/LegallyestablishedOrderCNC.pdf)

Part 3 - Aquatic Habitats

Objectives for important fisheries watersheds
   1. Maintain an equivalent clearcut area of less than 20% in important fisheries watersheds.

   2. Despite subsection (1), an equivalent clearcut area of more than 20 % may be maintained after:
      (a) information-sharing or consultation with the applicable First Nation;
      (b) a coastal watershed assessment or similar assessment of watershed sensitivity to forest development disturbance is completed to relevant professional standards;
      (c) maintaining an amount, type and distribution of forest cover that is sufficient to sustain natural hydrological and fluvial processes, based on the assessment in subsection (2)(b); and,
      (d) to the extent practicable, an adaptive management plan is developed and implemented to monitor environmental impacts during any primary forest activity.

Objectives for high value fish habitat
   1. Adjacent to high value fish habitat, maintain a reserve zone with a width, on average, of 1.5 times the height of the dominant trees, and do not alter or harvest the forest in the reserve zone unless there is no practicable alternative.

   2. For the purposes of subsection (1), the width of the reserve zone in any one location may be increased or decreased by up to 0.5 tree heights to address site specific values, including reserving critical habitat for species at risk.
3. Where some or all of the forest within the reserve zone required under subsection (1) has been previously altered or harvested, recruit functional riparian forest in that reserve zone, to the extent practicable.

**Objectives for aquatic habitat that is not high value fish habitat**

1. Adjacent to the following riparian habitat:
   (a) S1 to S3 streams;
   (b) lakes greater than 1.0 hectares; and
   (c) marsh and fen wetlands greater than 1.0 hectares in size, retain 90% of the functional riparian forest in management zones with a width, on average, of 1.5 times the height of the dominant trees.

2. Adjacent to lakes and marsh and fen wetlands that are between 0.25 and 1.0 hectares in size, retain 90% of the functional riparian forest in management zones with a width, on average, of 1.0 times the height of the dominant trees.

3. The width of the management zone in subsection (1) and (2) may be increased or decreased by 0.5 tree heights, in any one location, to address site specific values, including reserving critical habitat for species at risk.

4. Despite subsection (1) and (2), the amount of functional riparian forest retained in the management zones for S1 to S3 streams, lakes and marsh and fen wetlands may be reduced to 70% after:
   (a) ascertaining and retaining the amount of functional riparian forest sufficient to maintain stream bank stability and stream channel integrity;
   (b) to the extent practicable, developing and implementing an adaptive management plan and monitoring environmental impacts during any primary forest activity; and
   (c) engaging in information-sharing or consultation with the applicable First Nation.

5. Where some or all of the forest in the management zone required in subsections (1), (2) and (3) has been previously altered or harvested, to the extent practicable, recruit functional riparian forest in that management zone.

**Objectives for forested swamps**

1. Adjacent to forested swamps greater than 0.25 hectares, retain 70% of the functional riparian forest in a management zone with a width, on average, equal to 1.5 times the height of the dominant trees.

2. For the purposes of subsection (1), the width of the management zone in any one location may be increased or decreased by 0.5 tree heights to address site specific values, including reserving critical habitat for species at risk.

3. Despite subsection (1), an additional 10% of the forest in the management zone adjacent to the forested swamp may be altered or harvested where:
a. alteration or removal is required for road access, other infrastructure, or to address a safety concern; or
b. where 70% retention would make harvesting the cutblock economically unviable.

4. Before altering or harvesting the functional riparian forest pursuant to subsection (3):
   a. ascertain and retain the amount of functional riparian forest sufficient to maintain the integrity of the forested swamp;
   b. to the extent practicable, develop and implement an adaptive management plan and monitor environmental impacts during any primary forest activity; and
   c. engage in information-sharing or consultation with the applicable First Nation.

5. Where some or all of the forest in the management zone required in subsection (1) has been previously altered or harvested, to the extent practicable, recruit functional riparian forest in that management zone.

**Objectives for upland streams**

1. Maintain 70% or more of the forest, in the portion of the watershed occupied by upland streams, as functional riparian forest.

2. For the purposes of subsection (1), allocate retention to include upland stream reaches with unique microclimate or other rare ecological or geomorphological characteristics.

3. Despite subsection (1), less than 70% of the forest in the portion of the watershed occupied by upland streams may be maintained as functional riparian forest after:
   a. information-sharing or consultation, with the applicable First Nation;
   b. a coastal watershed assessment or similar assessment of watershed sensitivity to forest development disturbance is completed to relevant professional standards;
   c. maintaining an amount, type and distribution of forest cover that is sufficient to sustain natural hydrological and fluvial processes, based on the assessment in subsection (3)(b); and
   d. to the extent practicable, an adaptive management plan is developed and implemented to monitor environmental impacts during any primary forest activity.

**Objectives for active fluvial units**

1. Adjacent to active fluvial units, retain 90% of the functional riparian forest in a management zone with a width, on average, equal to 1.5 times the height of the dominant trees.
2. For the purposes of subsection (1), the width of the management zone may be increased or decreased by 0.5 tree heights, in any one location, to address site specific values including reserving critical habitat for species at risk.

3. Despite subsection (1), up to an additional 10% of the forest in the management zone may be altered or harvested in accordance with subsection (4).

4. Before altering or harvesting the functional riparian forest pursuant to subsection (3):
   a. ascertain and retain the amount of functional riparian forest sufficient to maintain bank stability and channel integrity on the active fluvial unit;
   b. to the extent practicable, develop and implement an adaptive management plan and monitor environmental impacts during any primary forest activity; and
   c. engage in information-sharing or consultation with the applicable First Nation.