SUSTAINABLE **FOREST** MANAGEMENT NETWORK

RÉSEAU DE GESTION DURABLE DES **FORÊTS**

Networks of Centres of Excellence
Réseaux de centres d'excellence

Riparian Areas

Challenges and Opportunities for Conservation and Sustainable Forest Management

Julienne Morissette and Margaret Donnelly

THE SUSTAINABLE FOREST MANAGEMENT NETWORK

Established in 1995, the Sustainable Forest Management Network (SFM Network) is an incorporated, non-profit research organization based at the University of Alberta in Edmonton, Alberta, Canada.

The SFM Network's mission is to:

- Deliver an internationally-recognized, interdisciplinary program that undertakes relevant university-based research;
- Develop networks of researchers, industry, government, Aboriginal, and non-government organization partners;
- Offer innovative approaches to knowledge transfer; and
- Train scientists and advanced practitioners to meet the challenges of natural resource management.

The SFM Network receives about 60% of its $7 million annual budget from the Networks of Centres of Excellence (NCE) Program, a Canadian initiative sponsored by the NSERC, SSHRC, and CIHR research granting councils. Other funding partners include the University of Alberta, governments, forest industries, Aboriginal groups, non-governmental organizations, and the BIOCAP Canada Foundation (through the Sustainable Forest Management Network/BIOCAP Canada Foundation Joint Venture Agreement).

KNOWLEDGE EXCHANGE AND TECHNOLOGY EXTENSION PROGRAM

The SFM Network completed approximately 334 research projects from 1995 – 2008. These projects enhanced the knowledge and understanding of many aspects of the boreal forest ecosystem, provided unique training opportunities for both graduate and undergraduate students and established a network of partnerships across Canada between researchers, government, forest companies and Aboriginal communities.

The SFM Network's research program was designed to contribute to the transition of the forestry sector from sustained yield forestry to sustainable forest management. Two key elements in this transition include:

- Development of strategies and tools to promote ecological, economic and social sustainability, and
- Transfer of knowledge and technology to inform policy makers and affect forest management practices.

In order to accomplish this transfer of knowledge, the research completed by the Network must be provided to the Network Partners in a variety of forms. The KETE Program is developing a series of tools to facilitate knowledge transfer to their Partners. The Partners' needs are highly variable, ranging from differences in institutional arrangements or corporate philosophies to the capacity to interpret and implement highly technical information. An assortment of strategies and tools is required to facilitate the exchange of information across scales and to a variety of audiences.

The KETE documents represent one element of the knowledge transfer process, and attempt to synthesize research results, from research conducted by the Network and elsewhere in Canada, into a SFM systems approach to assist foresters, planners and biologists with the development of alternative approaches to forest management planning and operational practices.

SFM NETWORK PARTNERS AND AFFILIATES AUGUST 2009

GRANTING COUNCILS

- Networks of Centres of Excellence (NCE) Program
    - Natural Sciences and Engineering Research Council of Canada (NSERC)
    - Social Sciences and Humanities Research Council of Canada (SSHRC)

FUNDING PARTNERS

GOVERNMENTS

- Canadian Forest Service
- Environment Canada
- Parks Canada
- Government of Alberta
  Sustainable Resource Development
- Government of British Columbia
  Ministry of Forests and Range
- Government of Manitoba
  Department of Conservation
- Government of Newfoundland and Labrador
  Department of Natural Resources
- Government of Ontario
  Ministry of Natural Resources
- Gouvernement du Québec
  Ministère des Ressources naturelles, de la Faune et des Parcs
- Government of Yukon Territory
  Energy, Mines and Resources

INDUSTRIES

- AbitibiBowater Inc.
- Ainsworth Lumber Co. Ltd.
- Alberta-Pacific Forest Industries Inc.
- Canadian Forest Products Ltd.
- Daishowa-Marubeni International Ltd.
- J.D. Irving, Limited
- LP Canada Ltd.
- Manning Diversified Forest Products Ltd.
- Tembec Inc.
- Tolko Industries Ltd.
- Weyerhaeuser Company Ltd.

ABORIGINAL GROUPS

- Heart Lake First Nation
- Kamloops Indian Band
- Métis National Council
- Moose Cree First Nation
- Treaty 8 First Nations in Alberta

NON-GOVERNMENT ORGANIZATIONS (NGOs)

- Ducks Unlimited Canada

INSTITUTION PARTNERS

- University of Alberta
  (Host Institution; also a Funding Partner)
- Concordia University
- Dalhousie University
- Lakehead University
- McGill University
- Memorial University of Newfoundland
- Mount Royal College
- Royal Roads University
- Ryerson University
- Simon Fraser University
- Thompson Rivers University
- Trent University
- Université de Moncton
- Université de Montréal
- Université de Sherbrooke
- Université du Québec à Chicoutimi
- Université du Québec à Montréal
- Université du Québec à Rimouski
- Université du Québec à Trois-Rivières
- Université du Québec en Abitibi-Témiscamingue
- Université Laval
- University of British Columbia
- University of Calgary
- University of Guelph
- University of Lethbridge
- University of Manitoba
- University of New Brunswick
- University of Northern British Columbia
- University of Ottawa
- University of Regina
- University of Saskatchewan
- University of Toronto
- University of Victoria
- University of Waterloo
- University of Western Ontario
- University of Winnipeg
- Wilfrid Laurier University

AFFILIATES

- Canadian Institute of Forestry
- Forest Ecosystem Science Co-operative
- Forest Engineering Research Institute of Canada
- Lake Abitibi Model Forest
- Manitoba Model Forest
- National Aboriginal Forestry Association

Knowledge Exchange and Technology Extension Program (KETE)
Sustainable Forest Management Network

Riparian Areas

Challenges and Opportunities for Conservation and Sustainable Forest Management

By

Julienne Morissette[1] and Margaret Donnelly[2]

1 Ducks Unlimited Canada Inc., #100 – 17958 106th Ave., Edmonton, AB T5S 1V4; j_morissette@ducks.ca

2 Donnelly Ecological Consulting, PO Box 146, Weymouth, NS B0W 3T0; margdonn@ns.sympatico.ca

Citation: Morissette, J. and Donnelly, M. 2010. Riparian Areas: Challenges and Opportunities for Conservation and Sustainable Forest Management. Sustainable Forest Management Network, Edmonton, Alberta 56 pp.

ISBN# 978-1-55261-271-2
Printed in Canada
Cette publication est aussi disponible en français
Published June 2010

Sustainable Forest Management Network

Abstract

Generally riparian areas are described as the "…interface between aquatic and terrestrial systems." However, definitions pertaining to riparian areas range from simple to complex, and can be ecologically-based or defined in terms of management applications. Regardless of the definition, the management of these highly productive, complex components of the landscape is a challenge to forest managers and policy makers.

The planning and application of riparian guidelines and buffer retention strategies is further complicated since approval for forest management plans for these areas falls under the jurisdiction of both federal and provincial regulatory agencies. Management guidelines provided by these agencies are generally updated infrequently and thus do not incorporate new knowledge or new approaches easily. They are also developed in isolation of other values and resource sectors (*e.g.* private vs. crown land, forestry vs. fisheries concerns) leading to problems with integrated management of multiple resources and values.

In recent years, there has been increased interest in developing alternate management strategies for riparian areas to more fully integrate their management with the rest of the forest. In several jurisdictions, there is interest in applying natural disturbance-based approaches to manage these systems, and potentially integrate landscape-level strategies to minimize cumulative effects to both terrestrial and aquatic components of the forest ecosystem. This has resulted in considerable debate among scientists, policy makers and resource managers regarding the long term consequences of current methods and policies, as well as the development of new policies and practices for managing and conserving riparian areas and water resources.

Related to the interest in alternative management practices, a series of questions regarding the management of riparian areas in the boreal forest were developed through consultation with several SFM Network industrial partners in western Canada. These questions are addressed in this synthesis document through the use of case studies, as well as a review of the literature and guidelines pertaining to riparian systems. Ultimately, we hope to stimulate dialogue and knowledge exchange among forestry companies, governments and other stakeholders to build a stronger riparian management framework for decision making. The challenges faced during the riparian guidelines development, review and implementation process are also discussed as well as some of the potential solutions for the sustainable management of riparian areas.

Acknowledgements

We would like to thank our industry (Weyerhaeuser - Prince Albert Forest Management Agreement Area; LP Canada, Swan River Division; Alberta-Pacific Forest Industries) and government (Alberta, Manitoba, Saskatchewan) partners who willingly shared their challenges and learning experiences relative to the management of riparian areas to strengthen this case study. We also thank our partners and 2 anonymous reviewers for reading earlier drafts of the document and providing constructive recommendations to improve its quality. We would like to recognize the following people individually for their assistance:

LP Canada Ltd.
Donna Kopecky; Vern Bauman; Barry Waito

Alberta Pacific Forest Industries
Elston Dzus; Mark Spafford; Dave Chene

Weyerhaeuser Saskatchewan
Brian Christensen

Alberta Government
John Stadt

Manitoba Government
Phil Keenan, Julie Ringash

Saskatchewan Government
Bob Wynes; Deb Weedon; Gigi Petowello

Ducks Unlimited Canada
Michael Robin; Sean Smyth; Matthew Spearman; Kevin Smith; Chris Smith

Sustainable Forest Management Network
Cynthia Kaufmann; Catherine Rostron; Jane Stewart

TABLE OF CONTENTS

1.0 Statement of Purpose

Riparian areas are habitats that form the interface between aquatic environments and the surrounding upland. In many areas of the world, riparian areas are among the most diverse and productive habitats in a landscape due to the biotic and nutrient exchanges occurring between the surrounding landscape elements. They are also often among the most modified (*e.g.* settlement areas, recreational purposes, industrial needs associated with water). As a result, riparian conservation and management can be contentious issues with the public, First Nations, governments, environmental non-government organizations and industry, and are often a source of conflict among these parties.

Riparian areas are among the most diverse and productive habitats in a landscape; they are also often the most modified.

The planning and application of riparian guidelines and buffer retention strategies is further complicated as approval for forest management plans for these areas falls under the jurisdiction of both federal and provincial regulatory agencies. Management guidelines provided by these agencies are generally updated infrequently and thus do not incorporate new knowledge/ new approaches easily. They are also developed in isolation of other values and resource sectors (*e.g.* private vs. crown land, forestry vs. fisheries concerns) leading to problems with integrated management of multiple resources and values.

A statement of commitment to ecosystem-based management (EBM) is now common in many government and corporate policy documents. The primary goal of EBM is to maintain ecosystem health and function by considering the consequences of activities at a full range of spatial scales, integrating aquatic and terrestrial systems and making changes as required within an adaptive management framework (Franklin 1997). It has been suggested that this can be achieved in part by implementing forest management practices that maintain biodiversity and approximate landscape patterns such as those created by natural disturbances. As a result, a natural disturbance model (NDM) for sustainable forest management (SFM), first proposed to forest managers in the early 1990's (Hunter 1993; Attiwill 1994), is growing in application (Bergeron *et al.* 1998) across terrestrial components of the western boreal forest. In several jurisdictions, there is interest in applying natural disturbance-based approaches to managing riparian areas to more fully integrate management strategies for both terrestrial and aquatic components of the forest ecosystem. The key to a NDM approach is to recognize the dynamic nature of a system and maintain ecosystem processes within the natural range of variability (NRV) as influenced by various natural disturbance agents in the forest.

How can natural disturbance-based approaches be applied to the management of riparian and aquatic ecosystems?

In addition, there is a growing societal expectation that forested landscapes will be managed for all SFM values (ecological, social and economic). Consequently, various forest management guidelines, including those that pertain to riparian areas, are under review throughout the boreal forest region. Guidelines and policies are under review in Saskatchewan and were recently reviewed in Alberta and Manitoba. This climate of change has resulted in some debate among scientists, policy makers and resource managers regarding both the long term consequences of current methods and policies as well as the development of new policies and practices for managing and conserving riparian areas and water resources.

Consultation and interaction with representatives from three western boreal forestry companies that share some common guiding management principles *(Figure 1, Box 1)* identified a series of questions related to the management of riparian areas:

What is a riparian area?

What are the current riparian guidelines in the boreal plain?

What are the objectives of the guidelines?

What research supports these decisions in the boreal plain?

Do current practices fit within the natural disturbance model?

Are we missing opportunities for more effective landscape management?

Are buffers always necessary?

What about public perception?

Do we have the necessary science to change policies?

Based on the questions listed above, this document was developed with several objectives in mind:

- To address the above questions using research, literature and the experiences of government and industry partners to highlight difficulties and potential solutions in riparian management;
- To stimulate and support dialogue and knowledge exchange among forestry companies, governments and other stakeholders regarding the challenges faced during the riparian guidelines development, review and implementation process;
- To encourage the integration of landscape level considerations into forest management planning for the conservation of water resources; and
- To foster knowledge exchange between research scientists and forest managers.

Box 1: Participating industry partners and guiding principles

Alberta Pacific Forest Industries, Boyle, AB

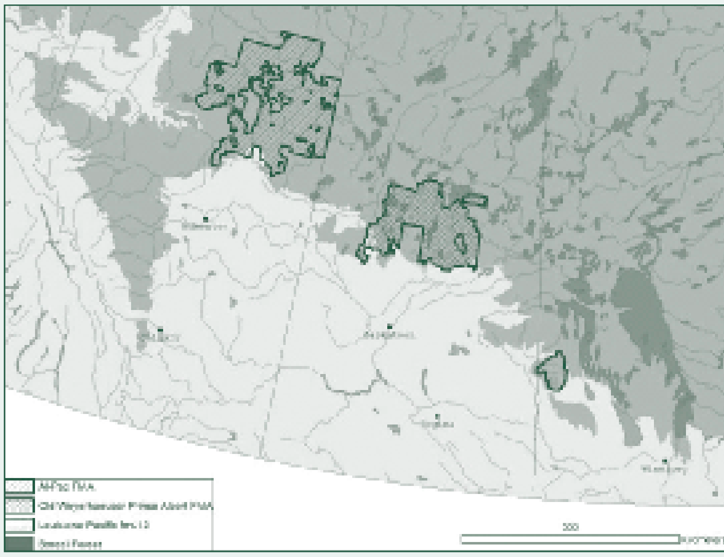
Alberta-Pacific (Al-Pac), a private company in northeastern Alberta owned by Mitsubishi Corporation (70%) and Oji Paper Co. Ltd. (30 %), operates a single-line bleached kraft pulp mill near Athabasca, AB. Alberta-Pacific is responsible for conducting inventories, planning roads, harvesting and silviculture in an area of about 5.8 million hectares under its Forest Management Agreement with the Province of Alberta. Management responsibilities include the harvest of hardwood trees for pulp and the activities of softwood quota holders. Alberta-Pacific is Forest Stewardship Council (FSC) certified.

LP Canada Ltd. Swan River, MB

LP Canada (LP) is part of an international forest products company with operations in Canada, the United States and Chile. The LP facility in the Swan Valley began operating in 1996 and produces Oriented Strand Board. This facility primarily uses aspen harvested from LP's Forest Management License (FML#3) area, including both Crown land and private wood sources. Forest management activities within the FML area are conducted under agreement with Manitoba Conservation, following the approval of a 10 year Forest Management Plan and the issuance of an Environment Act License. The current plan is in effect for ten years and provides strategic direction for operations within the licence area. Annual Operating Plans (AOPs) are created on a yearly basis to provide detailed information on the location of planned forestry activities for the year. In FML #3, LP is also responsible for planning and renewal activities for approximately 34 quota holders. LP is certified by the Sustainable Forestry Initiative.

Weyerhaeuser Prince Albert, Big River, SK

Weyerhaeuser purchased a pulp mill in Prince Albert and sawmill in Big River, Saskatchewan in 1986 to produce dimensional lumber, softwood and hardwood pulp. Aquatic resource uses on the FMA include domestic fishing, commercial fishing, sport fishing, wild rice production, outdoor recreation and tourism including ecotourism. Weyerhaeuser developed a 20 yr plan in 1997 to implement the ecosystem-based approach upheld by the Province of Saskatchewan as the best way to sustainably manage forest resources. Ecosystem based management was interpreted in the plan as an approach to develop forest management practices that emulate natural disturbances and was integrated into the forest harvesting strategy contained in the plan. A public consultation process was also included in the 20 yr plan. General support for implementing approaches in the plan (*e.g.* large harvest blocks, harvesting riparian buffers) that were not contained in provincial management guidelines at the time was obtained because of the inclusion of research and demonstration projects (from 20 yr plan). The forest management plan attempted to introduce forest management initiatives consistent with this approach from 1998 until 2007. At the time of this case study, this FMA area was certified by the Canadian Standards Association. Weyerhaeuser participated in the early stages of this project until 2007, when operations were withdrawn on this FMA due to financial reasons.



Ecosystem based management

Economic, ecological and social sustainability

Adaptive management

Approximating natural forest patterns

Figure 1 Map of western Canadian provinces outlining the Forest Management Areas of industry partners providing perspective in this report. Only the boundaries for Forest Management Unit 13 of FML Area #3 are shown for LP Canada, Swan River Division. Several guiding principles common to the Forest Management Plans or corporate policy documents of the 3 companies are listed.

2.0 Defining the terms

2.1 What does "riparian" mean?

Riparian systems are transitional semi-terrestrial areas regularly influenced by freshwater, usually extending from the edges of water bodies to the edges of upland communities.

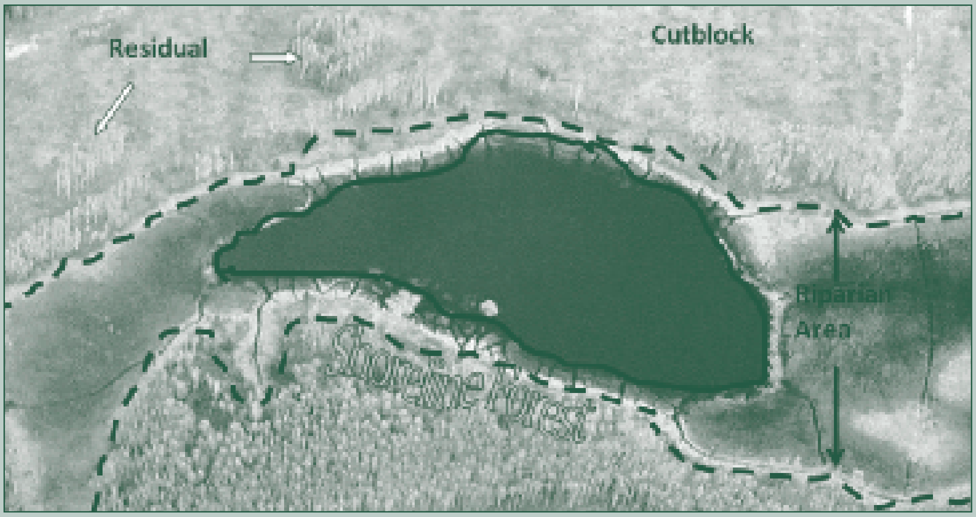
There can be substantial ambiguity surrounding the term "riparian". The Latin roots of the term (Riparius: of or belonging to the bank of a river) presuppose that flowing water (lotic) be involved in the definition however the term has evolved to also be used to describe areas adjacent to lentic or non-flowing systems. For example, the American Society of Fisheries defines riparian areas as "complex assemblages of organisms and their environments existing adjacent to and near flowing water" (Lowrance *et al.* 1985). A more general definition simply defines riparian areas as "…interfaces between aquatic and terrestrial systems" (Gregory *et al.* 1991). The variety of existing definitions can also be attributed in part by whether the definition is intended for application in an ecological *(Box 2)* or a management context *(Box 3).*

Box 2: Examples of ecological definitions for riparian areas

Riparian Area: (Ecological definition)

- A 3-dimensional ecotone of interactions that include terrestrial and aquatic ecosystems, that extend down to the ground water, up above the canopy, outward across the floodplain, up the near slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at variable width (Illhardt *et al.* 2000)
- A strip of land of variable width adjacent to and influenced by a body of freshwater (Canadian Council of Forest Ministers 2006).
- A transitional semi-terrestrial area regularly influenced by freshwater usually extending from the edge of a water body to the edge of upland communities (Naiman 2005).

The figure below illustrates an ecological definition (Illhardt *et al.* 2000) applied in a management context. The dotted line represents the area where probabilistic approaches become applicable. As distance to water increases, the probability that a habitat is considered riparian decreases.



Box 3: Definitions used in the management of boreal riparian areas and shoreline forests

Riparian Management Area: (Management definition)

Definitions used to delineate riparian areas and the boundaries for management from federal and provincial governments (3) are described below. Provincial definitions in particular provide examples of regional variation in using definitions to guide management decisions.

Federal Definition

Riparian Area: A strip of land of variable width adjacent to, and influenced by, a body of freshwater (Canadian Council of Forest Ministers 2006).

Alberta (Alberta Timber Harvest Planning and Operating Ground Rules 2006)

Riparian Zone

(1) The band of land that has a significant influence on a stream ecosystem or is significantly affected by the stream. It often has specialized plant and animal communities associated with it. [Anon]

(2) Terrestrial areas where the vegetation complex and microclimate conditions are products of the combined presence and influence of perennial and/or intermittent water, associated high water tables, and soils that exhibit some wetness characteristics. Normally used to refer to the zone within which plants grow rooted in the water table of rivers, streams, lakes, ponds, reservoirs, springs, marshes, seeps, bogs and wet meadows. The riparian zone is influenced by, and exerts an influence on, the associated aquatic ecosystem (measured from the high water mark). [Dunster]

Saskatchewan (Weyerhaeuser FMA Standards and Guidelines definition)

Riparian Management Areas have distinct spatial boundaries designated to achieve specific management goals for riparian areas and may contain zonation or elements including aquatic or terrestrial environments associated with or outside the riparian ecotone (delineated from merchantable species).

Riparian Reservation is a strip of undisturbed vegetation along a stream or lake left to protect the water body from the effects of road construction on adjacent land. Reservation width is measured on each side of the stream from the top of the actual streambed bank, or on lakes from the lakeward edge of the terrestrial vegetation. (Fish Habitat Protection Guidelines, Road Construction and Stream Crossing, SERM/DFO 1995)

Box 3, continued

Manitoba (Forest Management Guidelines for Riparian Management Areas 2008)

Riparian Area (RA) - Riparian area refers to an area of land on the banks or in the vicinity of a waterbody, which due to the presence of water supports, or in the absence of human intervention would naturally support, an ecosystem that is distinctly different from that of adjacent upland areas (The Water Protection Act 2005). For operational purposes, the RA will end at the edge of the merchantable forest. No forestry activity will be permitted within the RA.

Riparian Management Area (RMA) - The RMA is the forested area adjacent to the RA in which forest management activities can take place. A RMA can be comprised of the following zones: machine free zone (MFZ), MFZ and management zone (MZ), reserve zone (RZ), RZ and MZ, or in some cases only best management practices (BMPs) may be applied.

From an ecological perspective, riparian systems are transitional semi-terrestrial areas regularly influenced by freshwater, usually extending from the edges of water bodies to the edges of upland communities (Naiman *et al.* 2005). Thus, in general terms, riparian areas can be adjacent to lakes, rivers and wetlands and are generally considered transition areas between two different ecological areas referred to as "ecotones"(*e.g.* Gregory *et al.* 1991; Naiman and Décamps 1997). Ilhardt *et al.* (2000), define the riparian area as,

> *"…3 dimensional ecotones of interactions that include terrestrial and aquatic ecosystems, that extend down to the ground water, up above the canopy, outward across the floodplain, up the near slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at variable width."*

This approach to defining riparian areas includes several important attributes of riparian habitats such as proximity to a water body, temporal and spatial (horizontal and longitudinal) variability and the probabilistic nature of delineating their width. That is, the probability of an area being considered riparian generally decreases with increasing distance from water but is location and species specific.

The temporal and spatial variability of boreal forest ecosystems is well documented and is the result of complex interactions between natural disturbance regimes, soils, topographic setting and hydrologic features. This variability is also manifested in a wide range of aquatic and semi-aquatic habitat types (*e.g.* rivers, lakes, marshes, bogs, fens and swamps) which support a diverse vegetation community. The vegetation communities and species assemblages associated with specific hydrologic features also vary with respect to interactive factors such as topographic setting, soils, and climate (Gregory *et al.* 1991). Additionally, riparian areas are subject to drying events and flooding events that vary in space and in time, thus creating a complex series of habitat types across landscapes. These factors considered, riparian areas are not restricted to any particular vegetation class but can generally be identified by their proximity to a water body.

Vegetation communities and species assemblages associated with specific hydrologic features vary with respect to interactive factors such as topographic setting, soils, and climate.

Attempts to delineate riparian areas based on set distances may be unsuitable because the same boundary does not apply at all scales, to all ecosystem functions, ecosystem types or to all species.

A probabilistic approach to delineating riparian areas is particularly suitable because it addresses the difficulty of delimiting these areas on the landscape using broadly applicable criteria (Lee and Smyth 2003). Thus, rather than assigning a set distance at which ecosystems cease to be considered riparian, the probabilistic approach suggests that habitats closer to water are more likely to be riparian. From an ecological standpoint, attempts to delineate riparian areas using hard fast boundaries based on set distances may be unsuitable because the same boundary does not apply at all scales, to all ecosystem functions, ecosystem types or to all species. For example, at a stand scale, Harper and MacDonald (2001) found that vegetation communities in the riparian mixedwood forest understory showed edge-effects for a distance of up to 40-60 m into the forest. While examining a similar question at a different scale, Macdonald *et al.* (2003) found there was very little difference between the overall stand composition of riparian forests and that of the surrounding landscape. The limitations of the varied ecological approaches to defining riparian areas become immediately apparent if attempts are made to use it in a forest management or regulatory context where consistency and ease of enforcement are necessarily as much a concern as minimizing effects.

`Riparian management area' refers to the area near water in which special management practices by forestry or other industry can occur.

Thus, in a forest management or regulatory context, the term 'riparian' is inevitably used in a slightly different way. Generally 'riparian' still refers to an area or vegetation community proximal to water. However, in forestry, it is sometimes further defined to refer to a `riparian management area' - the area near water in which special management practices by forestry or other industry can occur (*e.g.* 100% exclusion, partial harvest). Examples of other terms used to describe this area include special management zones, areas of concern and shoreline forest (*e.g.* Ontario), or riparian management zone (*e.g.* Manitoba). Although a variety of regulations governing industrial forestry in riparian areas on Crown lands exist in all provinces, all include the provision that a strip of forest of specified width be left unharvested (buffer strip or reserve zone) adjacent to a water body. Nova Scotia is the only province or territory where riparian buffers are currently required on privately owned woodlots.

In some jurisdictions the measurement of the buffer strip width is calculated beginning at the high water mark while in others it is calculated from the edge of merchantable timber (determined by size and/or by species) located nearest the water. Thus, a reserve zone (buffer strip) may not always contain entirely mature forest. Regardless, enforcement and compliance monitoring to ensure forestry companies are meeting license and legal requirements necessitates definite boundaries, despite these being less consistent with the variability inherent in these systems *(Box 3)*.

The Canadian Council of Forest Ministers (CCFM) has developed a working definition of the term 'riparian area': "a strip of land of variable width adjacent to and influenced by a body of freshwater" (Canadian Council of Forest Ministers 2006). This simple definition is less cumbersome than the above definition put forward by Ilhardt *et al.* (2000), but also makes no attempt to delimit a definitive riparian boundary on the landscape. To help eliminate some ambiguity with related terminology, *in this document upland forests associated with a body of water will be termed* ***shoreline forests****, reserving the term* ***buffer strip*** *for the management context.* Riparian areas will be used in the general sense provided by the CCFM.

2.2 Functions of riparian areas

Although a detailed description of riparian area functions is not a major objective of this synthesis document a brief consideration of functions provides context for later discussion points *(*Note: Gregory et al. 1991;Naiman and Descamps 1997 and Naiman et al. 2005 provide detailed reviews of the functions of riparian areas).*

The inherent variability associated with boreal riparian systems challenges our understanding and consequently our management of these areas across the landscape.

The inherent variability associated with boreal riparian systems challenges our understanding and consequently our management of these areas across the landscape. Known functions of riparian areas are extensive but include regulating:

a) flows of water, nutrients and energy between uplands and aquatic habitats,

b) erosion and sedimentation, and

c) light and temperature regimes (Naiman *et al.* 2005).

Riparian areas tend to have higher productivity, higher species diversity and contain species not found in other areas.

They also act as a source of large and fine woody debris (Naiman and Décamps 1997; Andison and McCleary 2002) and serve as dispersal habitat and corridors for flora and fauna (*e.g.* Gregory *et al.* 1991; DeGraaf and Yamasaki 2000; Holmes, unpubl. data). These functions are in turn influenced by biophysical characteristics of riparian areas such as landscape context (*e.g.* climate, landforms, topography), soil type and vegetation composition.

Riparian areas are identified as important habitats in a suite of geographic regions because they tend to have higher productivity (Whitaker *et al.* 2000), higher species diversity (*e.g.* Naiman and Décamps 1997; Bedford 1999) and also contain species not found in other areas on the landscape (Sabo *et al.* 2005). Raedecke (1988) estimated that 70% of all vertebrate species use riparian habitat at some point during their lifecycle (based on research in northwestern US). Similar figures for the boreal are expected. However, the boreal forest may be fundamentally different from other areas. Whereas riparian areas often represent a concentration of moisture in an otherwise relatively arid landscape; in the boreal forest, edges and ecotones are abundant features and moisture gradients are typically less steep than in more arid ecosystems.

Testing assumptions provides an opportunity to expand our understanding of boreal riparian areas, especially where it may not be appropriate to assume riparian functions typical of other regions.

A brief consideration of assumptions regarding the functions of riparian areas and possible alternate explanations is appropriate, especially when considering management strategies. Testing assumptions represents an excellent opportunity to expand our understanding of boreal riparian areas, particularly for the western boreal forest where it may not always be appropriate to assume riparian functions typical of other geographic regions.

For example, one such assumption is that riparian areas, including shoreline forests, are ecologically unique relative to upland habitats. While in some regions, studies have indeed found patterns in plant or animal species composition and abundance that support this tenet (*e.g.* Stauffer and Best 1982; LaRue *et al.* 1995) other studies have found the opposite (McGarigal and McComb 1992; Whitaker and Montevecchi 1997). In the western boreal forest, recent work in Alberta

One assumption is that riparian areas, including shoreline forests, are ecologically unique relative to upland habitats.

examined plants, amphibians, small mammals and birds and found that only bird communities exhibited higher richness and abundance at forests sites adjacent to lakes (MacDonald *et al.* 2006). Amphibians were also more abundant in shoreline forests however this pattern was attributed to life cycle requirements for both terrestrial and aquatic habitats and thus immigration and emigration patterns of individuals across the landscape.

While this pattern highlights the importance of sufficient terrestrial habitat alongside aquatic habitat for some species, the idea that shoreline forests are ecologically unique was not supported for all groups studied (MacDonald *et al.* 2006). This is just one example that supports the idea that perceived functions of riparian areas are often assumptions or tenets and that alternate explanations for these functions are possible, warranting further study (Table 1; Naiman *et al.* 2005).

Table 1 Some examples of assumptions regarding riparian areas and potential alternate explanations (Modified from Table 1.1, Naiman *et al.* 2005).

Assumption/Tenet	Possible alternate explanation
Riparian areas have high biodiversity and production	Biota of riparia are transitional assemblages, mostly outside their optimal location along regional gradients; local gradients in riparia are so steep that production is extremely variable and not very high overall.
Riparian areas act as nutrient filters through interception of pollutant laden runoff	Riparian areas provide nutrient inputs to the river, owing to decomposition of leaves and other organic matter (as well as from lateral erosion).
Riparian areas are corridors for wildlife	Birds and other animals may simply move through riparian areas in relation to spatial orientation.
Floodplains and riparian areas harbor the most endangered ecological systems on earth	Ecological systems associated with floodplains are highly resilient and display a great adaptive capacity.

3.0 Riparian Guidelines: brief history and current context

3.1 Where do riparian guidelines come from?

Historically buffers were used to prevent sedimentation and stabilize stream banks; recently objectives have broadened to include providing habitat for terrestrial and aquatic biota.

Riparian buffers were first utilized in the United States in the 1960's (Calhoun 1988) but date back to the 1700's in European forest management where treed corridors were retained along streams (Porter 1887 *in* Lee and Smyth 2003). Historically, the primary reason for requiring the use of riparian buffers was to prevent sedimentation and stabilize stream banks (Lee and Smyth 2003). More recently objectives have broadened to include providing habitat for terrestrial and aquatic biota. An examination of references contained within guidelines and policy documents reviewed for this case study revealed many of the guidelines developed for boreal Canada appear to be modeled after practices and research in temperate and mountainous zones. This is likely due to the absence of similar research for boreal systems at the time guidelines were initiated.

In general buffer widths prescribed in boreal regions are amongst the widest in Canada.

Lee *et al.* (2004) and Lee and Smyth (2003) provide an extensive review and evaluation of riparian management guidelines in North America. They found the factors used to determine buffer width include topography, fish presence, waterbody size and type, aesthetic or recreation value and potential for downstream impacts. Lee *et al.* (2004) found that just over half of North American jurisdictions use 2 or less factors to establish a buffer width. However, most jurisdictions use a "one or few sizes fits all" approach (Lee and Barker 2005). While most guidelines consider rivers separate from open water such as lakes, very few consider wetlands separately or use an ecologically based wetland classification system (NCASI 2007). Guidelines are typically applied on the basis of waterbody size rather than a hydrological or ecological classification which would be expected to better reflect function and other associated values. In general buffer widths prescribed in boreal regions are amongst the widest in Canada (Lee *et al.* 2004).

Since most of the current guidelines were developed, forest management in Canada has moved from a sustained yield, timber focus to an SFM approach.

Another important factor when evaluating riparian management practices is the overall forest management paradigm or direction under which riparian strategies are implemented. Since most of the current guidelines were developed, forest management in Canada has moved from a sustained yield, timber focus to a sustainable forest management (SFM) approach. One of the key objectives of SFM is the maintenance of a diverse set of forest values, including ecological, social and economic elements, and the provision of forest-derived goods and services for current and future generations. Forest management strategies to achieve SFM have changed considerably including;

- a shift in focus from minimizing impacts predominantly at the stand level to including considerations at a watershed or landscape scale (Donnelly 2003),
- growing implementation and application of natural disturbance models (Hunter Jr. 1993; Attiwill 1994; Bergeron *et al.* 1998),
- a recognition of the need to develop a systems approach and integrate management of both terrestrial and aquatic resources (Franklin 1997; Kimmins 2004), and
- improved access to advanced technology for planning (*e.g.* GIS, models), inventory (*e.g.* remote sensing, high resolution imagery) and operations (GPS, better equipment).

Below, we provide a focused description of riparian guidelines in three different provinces with emphasis on three boreal plain FMAs which serve as examples of some contemporary approaches to forest management.

3.2 Regulations and guidelines governing the management of boreal plain riparian areas

Federal, provincial/territorial and municipal levels of government are involved in managing the use of forest resources around water. Each province has developed its own interagency arrangements for managing these natural resources, with sometimes patchy coordination between levels of government and with companies. Engagement processes are sometimes formal but informal processes are not uncommon.

Federal legislation influencing operational practices in and near riparian areas includes the *Federal Fisheries Act* (Department of Fisheries and Oceans 1986) enforced by the Department of Fisheries and Oceans. Companies are legally responsible for the "harmful alteration, disruption or destruction" of fish habitat (HADD) which includes any meaningful change in one or more habitat component, that can reasonably be expected to cause a real reduction in the capacity of the habitat to support the life requisites of fish including, but not limited to, water quality. The department has been quite clear in its mandate to enforce infractions but at this time, does not provide recommendations regarding the best management approaches for these areas. While these regulations are clearly applicable to bridge and culvert installations they are also considered for riparian buffer widths, and approval of forest management and access plans, where water quality effects may be of concern.

Federal and provincial fisheries agencies may be involved in the review of strategic level forest management plans to ensure that harvest and access management activities will not adversely affect water resources and regulatory requirements are met. The degree of involvement varies by province and sometimes by Forest Management Agreement (FMA) area.

A review of the guidelines and standards for three of the provinces with forested areas in the boreal plains indicates that, historically, factors considered for characterizing water bodies and making decisions about the width of buffers tended to be limited to size, permanency and presence or absence of fish (Table 2). Recently, Manitoba Conservation developed new guidelines designed to identify opportunities where forest harvest may be integrated with the conservation of other resource values and to align riparian policy more closely with SFM approaches (Manitoba Conservation 2008). However, in general, objectives for riparian management tend to be broadly stated such as “maintaining aquatic biodiversity, wildlife habitat, and water quality”. The use of the term “maintaining” here seems to mean relative to the pre-harvest condition but this is not always explicitly stated in guidelines.

Table 2 Overview of provincial forest management guidelines for riparian areas and shoreline forests on the boreal plains.

Province	Terminology	Delineation (buffer measured from…)	Water Body Type	Width (m)	Factors Considered	Selective harvest permitted in buffer
Alberta	Riparian area or Management Zone	High water mark	Lakes, ponds, streams and rivers	30-100	Size and permanency of water feature; presence of fish	No - except where specifically described in an AOP or by approval of forest superintendent[i]
Saskatchewan	Riparian Buffer	Presence of Overstory Species	All	15, 30 or 90	Slope, fish	No - Only Weyerhaeuser FMA uses variable retention harvesting.[ii]
Manitoba[iii]	Riparian Area (RA) Riparian Management Area (RMA) Reserve Zone (RZ) Machine Free Zone (MFZ)	RA – includes area from water's edge to merchantable trees (ie. of harvestable size) RMA – adjacent to RA; starts at merchantable trees, and extends inland; includes a Machine Free Zone (MFZ) and a management zone where limited harvest is permitted based on decision keys. RZs (no harvest permitted)- decision keys are used as a guideline for making decisions about whether an RZ is required, and its width	All	variable[iv] Reserve zones up to 200 m wide are possible	Slope, forest health, cultural features, fish, wildlife, water quality	Yes – based on regulatory approval but a machine free zone is always required (7m based on reaching capabilities of machinery)

i. Examples of exceptions may include considerations of local topography, wildlife use and salvage logging.
ii. Adapted for Prince Albert FMA area to accommodate timber requirements under 20 Year Forest Management Plan (1999).
iii. Based on riparian management area guidelines approved in September 2009.
iv. Buffer width varies based on decision support keys and agreement with a regionally based government integrated resource management team.

Alberta

In Alberta, guidelines for forest management activities near waterbodies are outlined in the *Alberta Timber Harvest Planning and Operating Ground Rules* (Alberta Sustainable Resource Development 2006). The operating ground rules address two main areas related to riparian management:

1) minimizing the impacts of harvest operations on water yield, regime and quality, watercourse structure, soils, cover and provision of riparian habitat for fish and wildlife during harvest block planning; and

2) minimizing effects on soils, debris inputs into watercourses, future forest productivity and other resources during operations (Alberta Sustainable Resource Development 2005).

Although specific guidelines vary by FMA, buffers are required in all regions of Alberta to serve as a filter strip and slow surface runoff, reduce erosion hazard and water sedimentation.

There is provision for region specific ground rules in the current policy and though specific guidelines may vary by Forest Management Agreement (FMA) area, a common element across regions includes the requirement for riparian management in the form of buffers. Riparian buffers are intended to serve as a filter strip around lakes and streams and slow surface runoff from adjacent harvested areas thereby reducing erosion hazard and water sedimentation (The Forestry Corps 2004). Strips of timber and/or vegetation are not disturbed during harvest with the expectation post-harvest effects on wildlife, quality and quantity of water, and aesthetics will be buffered or minimized.

In 2005 the Alberta government conducted a review of current riparian management policy in Alberta's forests. Upon completion of the review, the policy and associated guidelines were thought to be adequate for conserving water values based on the current Alberta forest management standards. They further outlined a series of management goals for riparian areas along with supporting strategies (Alberta Sustainable Resource Development 2005). The goals are centered on ecological functions of riparian areas and include maintaining:

- water quality (water chemistry, sedimentation, temperature),
- water quantity,
- coarse woody debris and organic inputs,
- terrestrial and aquatic habitat and biodiversity,
- landscape connectivity, and/or
- minimizing cumulative effects.

Although a broad series of factors are considered as part of these goals, some additional objectives could include: socio-economic objectives (traditional values, subsistence living, recreational), natural disturbance approximation and forest health (disease, insect pests and stand renewal).

For example, operating ground rules on the Alberta Pacific Forest Industries (Al-Pac) FMA area in northeastern Alberta require the use of 30, 60 and 100 m buffers as per provincial requirements (Table 2). In addition, Al-Pac developed their own operating practices based on company directives which calls for the provision of 10 m wide riparian buffers for intermittent/ephemeral water bodies where fish or fish habitat is known to be present and a 10 m machine free zone (equipment can reach 8 m thus leaving a 2 m buffer) where no fish are known to be present. Further, certain water features identified by the company's Integrated Resource Plan as "special water features" require an 800-1000 m buffer because they contain cultural and/or wildlife attributes. Al-Pac typically does not deviate from these operating guidelines, but under special circumstances (disease control, some salvage operations) permits to harvest riparian areas can be obtained.

Saskatchewan

Saskatchewan currently manages riparian guidelines on an FMA by FMA basis. At the time of writing, all forest management areas except one apply a 15, 30 or 90m Riparian Management Area width depending on the size of water body and presence or absence of fish.

Saskatchewan currently manages riparian guidelines on an FMA by FMA basis.

Buffers are not currently managed in Saskatchewan except for the Weyerhaeuser FMA where variable retention harvest is permitted.

The exception to the provincial standard riparian buffer width (15, 30 or 90 m) requirements is the Weyerhaeuser Prince Albert FMA, located south of Prince Albert, SK (currently inactive due to closure of facilities associated with the FMA in April 2006). In the last 20 year strategic Forest Management Plan developed by Weyerhaeuser Saskatchewan (Weyerhaeuser 1999) the preferred management scenarios included a variable retention harvesting prescription on all water bodies.

The Weyerhaeuser Prince Albert FMA objectives for riparian area management included:

1) protecting riparian dependant resources and aquatic ecosystems by maintaining the diversity of ecological structures and functions in the riparian areas; and

2) adopting a landscape perspective to

    (a) provide habitat connectivity and environmental requirements for riparian communities of plants and animals; and

    (b) minimize impacts on watershed hydrology.

Landscape-based categories of riparian management areas were developed with applicable standards for each category (Table 3) as well as a suite of general standards for all categories that address:

- forest health and blowdown (site inspection required),
- tree retention volumes (25% average volume within minimum harvest zone, 20% within a harvest block),
- soils and site disturbance (rutting <12 cm deep and 5 m long, limited to <1% of the harvest zone area),

- roads and landings (avoid),
- landscape harvest block planning (layout to minimize wind damage on buffer, plan retention of structure, minimize stream crossings, harvest riparian area in conjunction with harvest of adjacent non-RMA block),
- water quality (maximum allowable change in turbidity 25 units),
- renewal (within 2 growing seasons),
- overlapping RMA categories (category with greatest buffer width or least amount of disturbance takes precedence), and
- skid trails and topographic constraints (not allowed in no harvest/no machinery zones except with approval).

Table 3 Standards for riparian buffer requirements by riparian management category and waterbody type in the Weyerhaeuser Prince Albert FMA, Saskatchewan (Weyerhaeuser 1999).

Riparian Management Category	Waterbody type	Standards
1	Large lakes (>5 ha), rivers & streams[1]	10 m no harvest zone once overstory trees encountered, with 30 m limited harvest zone upslope
2	High slope areas (>15%) on small lakes or ponds (0.5-5.0 ha in size)	Limited harvest zone[2] to maximum distance of 30 m or top of slope; includes a 10 m machine free zone on downslope edge of buffer
3	Low slope areas (<15%) on small lakes or ponds	10 m limited harvest/machine free zone at start of overstory trees
4	Intermittent streams[1]	Ensure no impediments to surface or subsurface flow; leave residuals in clumps and single trees. Keep machinery out of channel unless frozen
5	Ephemeral streams and wetlands	Ensure no impediments to surface or subsurface flow

1 Streams and ephemeral/intermittent drainages included are those discernible at 1:15 000 scale on aerial photographs or during pre-harvest surveys or harvesting operations.

2 A minimum average volume retention level of 25% per operating year across the FMA is required within limited harvest zones, with a 20% minimum volume per block. The volume within the no harvest zones is not included in the volume for the limited harvest zone.

The development of the riparian area harvest prescription was challenging. Though both the government and industry agreed that harvesting shoreline forest was potentially beneficial in many cases, reaching agreement on the best way to harvest these areas was not as straightforward. There was extensive consultation between Weyerhaeuser, the Province, and science advisors. Adverse effects from harvest activities within riparian areas were a great concern of both the public and the government. This led to consultation about the appropriate practices to be implemented as well as the effects monitoring required. It was agreed to leave a 10m no harvest zone adjacent to a 30m zone where 25% of the volume was retained (Figure 2). The width of the no harvest zone was measured from the point where vegetation shifts to overstory trees. Effects assessment (*e.g.* benthic invertebrates, regeneration) was an approval condition of the FMP. The policy is intended to reflect a commitment to continual improvement and the incorporation of the most recent scientific knowledge during future revisions of these standards and guidelines (adaptive management).

The policy reflects a commitment to continual improvement and the incorporation of the most recent scientific knowledge during future revisions of the guidelines.

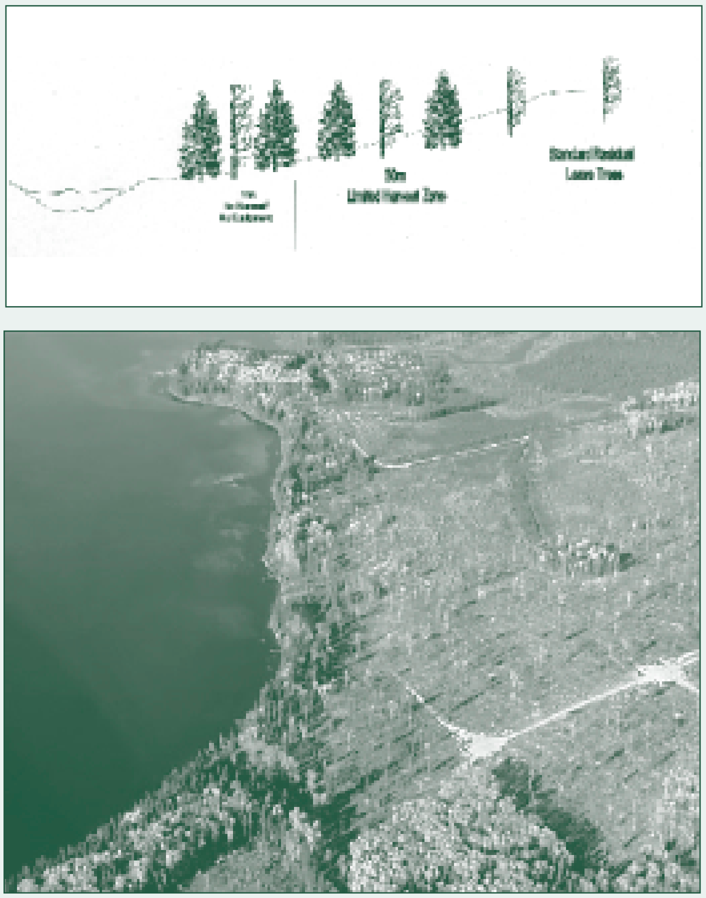


Figure 2 Schematic and photograph illustrating a 10m no harvest zone adjacent to a 30m zone where 25% of the volume was retained for a riparian management area in the Weyerhaeuser Prince Albert FMA. Standard practices are applied in the remainder of the cutblock. (Photo and diagram courtesy of Weyerhaeuser Saskatchewan Ltd., Prince Albert Forest Management Area)

In Saskatchewan, including the Weyerhaeuser FMA, additional provisions are made for sites (including lakes) designated as visually sensitive due to factors such as recreational values or other issues of public concern. Standards pertaining to visually sensitive lakes, including both planning and harvest activities, are found in the Visual Resource Management Standard *(See Box 7 on page 43)*. These guidelines take precedence over the riparian management guidelines and demonstrate that under some circumstances social values are deemed more important than ecological or economic values. If a site is identified as visually sensitive then a long term plan to address the visual landscape must be developed.

More recently, province-wide standards and guidelines are being developed in an effort to move towards a results-based regulatory system.

More recently, province-wide standards and guidelines for forest management are being developed in an effort to move towards a results-based regulatory system (SK Environment pers. comm, February 2009, May 2010). As the provincial standards and guidelines are developed and approved, the FMA standards and guidelines will be superseded. This change in management model will require government agencies to become more involved in monitoring results and outcomes of practices, with the companies responsible for meeting management objectives and following approved strategic and operating level plans.

Manitoba

Manitoba guidelines require buffer zones around all lakes, rivers, streams, and wetlands as a method to reduce or eliminate impacts resulting from forest management activities.

The potential for adverse effects resulting from forest management activities near water bodies in Manitoba are also typically mitigated at the stand level. The current regulatory framework and guidelines are centered on the establishment of riparian buffer zones around all lakes, rivers, streams, and wetlands as a method to reduce or eliminate impacts resulting from forest management activities.

Riparian buffer zone requirements are outlined in the *Forest Management Guidelines for Riparian Management Areas* (Manitoba Conservation 2008) recently adopted as a provincial standard. They replace the former guidelines developed in the mid 1990's that required a 100 m no harvest buffer on all waterbodies (*Consolidated Buffer Management Guidelines*, Manitoba Natural Resources 1996). In Manitoba, under the Consolidated Buffer Management Guidelines, forest managers were sometimes allowed to deviate from the standard 100m guideline with government approval. These decisions were made by the province's District Integrated Resource Management Team (IRMT) following a review of rationale, site inspections and an effects assessment for many values. The new riparian guidelines were developed with the intention of reflecting the range of values being considered during these mitigation discussions.

The guidelines incorporate a decision support framework to identify potential areas where it is possible to harvest within riparian areas without adversely affecting other values.

The guidelines incorporate a decision support framework to identify potential riparian areas where it is possible to harvest without adversely affecting other values. The framework, developed using a series of 6 decision keys, is based on factors that influenced buffer width decisions in the past. These factors include social and recreational values, fish and wildlife values, water quality, slope, soils and forest health.

The new riparian management area guidelines were developed by the Manitoba Forest Practices Guidelines Committee, an advisory committee with representatives from the forest industry, non-government organizations and the government, under the direction of Manitoba Conservation. They are designed to identify opportunities where forest harvest can be integrated with the conservation of other resource values.

Forest managers may develop harvest prescriptions within the management zone (MZ) of the designated riparian management area (RMA) dependent upon regulatory approval (Table 2). These decisions are made at a stand level, on a case by case basis, and are based on a review of rationale, site inspections and an assessment of the potential for adverse effects by the province's District Integrated Resource Management Team (IRMT).

Forest managers may develop harvest prescriptions within the management zone of the designated riparian management area dependent upon regulatory approval.

The new RMA guidelines were reviewed following an implementation phase (2008-2009) and will be formally reviewed again in January 2013. Landscape design guidelines are also under development by the Committee with the intention of eventually reviewing the riparian management guidelines to integrate both stand level and landscape level objectives.

Within Manitoba, LP Canada Ltd., Swan Valley (LP) is responsible for forest planning and management on crown lands within the Duck Mountain Provincial Forest. The company and Manitoba Conservation, Forestry Branch have established a process where they mitigate potential forestry effects and discuss buffer management strategies collaboratively through a series of annual meetings. This process has enabled the company to implement variable width buffer strips that range from 0 to 100 m wide along water features. Riparian buffers within the LP license area are established from the edge of the merchantable tree line (based on size) into the upland forest. The determination of variable buffer widths is based on traditional knowledge, local experience, reconnaissance surveys and information collected during intensive pre-harvest surveys or research studies.

The determination of variable buffer widths is based on traditional knowledge, local experience, information collected during intensive pre-harvest surveys or research studies.

All riparian buffer strips retained within LP's operating areas are 'no harvest buffers' meaning these areas will not be managed unless otherwise directed by the provincial government. However, the harvesting of larger riparian buffers is considered an acceptable practice as long as the area adjacent to the buffer has forest cover that has reached a sufficient height (2 m high for softwood and 3 m high for hardwood). This requirement is primarily based on considerations that attempt to reduce hunting pressure on wildlife by reducing the line of sight to less than 400 m. In practice, forest planners generally avoid returning to harvest a riparian buffer due to the cost of harvesting small areas or low volumes.

3.3 Are the guidelines working?

Guideline effectiveness is a multifaceted issue that should also consider the question "Would different guidelines work just as well?" A detailed and thorough overview of the efficacy of riparian guidelines for conserving a range of functions and biota exists in Lee and Smyth (2003). The objectives reviewed by Lee and Smyth (2003) included preventing or reducing runoff, water yields and sedimentation, maintaining stream temperatures and woody debris inputs, and achieving biodiversity (terrestrial and aquatic) objectives including habitat and connectivity. The results of this review are briefly summarized below, with a particular focus on the provision of riparian buffers in boreal regions, to provide context for subsequent sections of this document. Results from other studies published since the review by Lee and Smyth (2003) are also included where relevant.

Guideline effectiveness is a multifaceted issue that should also consider the question "Would different guidelines work just as well?"

Water Yields, Runoff, Nutrients and Sedimentation

Research regarding the efficacy of buffers in preventing runoff and increases in water yields is limited for boreal regions.

Research regarding the efficacy of buffers in preventing runoff and increases in water yields is limited for boreal regions though research that looks at the general effects of harvesting on these factors does exist. However, Buttle *et al*. (2000), in a review of hydrologic research in Canada (1995-1998), noted that a basic understanding of the potential effects of forest disturbance on hydrological processes and their recovery is lacking, and within and between region extrapolation of results from a single basin to an entire region may not be appropriate due to local sources of natural variation. For instance, interactions between surface and subsurface water systems are far more complex on the boreal plain compared to the boreal shield ecozone. Furthermore, forest management policies are developed for application at a regional scale and assumed to be relevant based on these interpretations of basin-level research. Devito *et al.* (2005b) developed a framework for broad-scale classification of hydrologic response units on the boreal plains as a means to unify hydrologic concepts, integrate surface water and groundwater processes and assess the susceptibility of surface waters to disturbance. The hierarchical classification provides a conceptual framework based on factors (climate, bedrock and surficial geology, soil type and depth) that control water cycling at the appropriate spatial scale and can be used to design effective mitigative measures in forest management planning (Buttle *et al.* 2000) .

Water yields, peak flows, and nutrient yields increase immediately after disturbance and decline thereafter until hydrologic recovery is achieved.

In the boreal shield region, timber harvest results in increased base and peak flows due to decreases in snow and rainfall interception, reductions in evapotranspiration and increasing infiltration (Buttle *et al.* 2000). Increased water inputs result in greater soil water content and increased ground water recharge which leads to a rise in water table levels and a greater potential for lateral flow above bedrock surfaces or less-conductive horizons. These post-disturbance increases in soil water and enhanced potential for lateral flow translate into increased annual streamflow. Increased water yield has been associated with the removal of forest canopy in both coniferous and deciduous forest types (Buttle and Murray 2007). However, a study in northwest Ontario on the boreal shield found no difference in water yield between two lakes; one with extensive watershed and shoreline harvest, and the other with moderate watershed harvest and retained buffer (Steedman and France, 2000). Water yields, peak flows, and nutrient yields increase immediately after disturbance (harvesting and wildfire) and decline thereafter (Lee and Smyth 2003) until hydrologic recovery is achieved generally 20-30 years.

Hydrologic recovery varies widely depending on site characteristics, level of harvest and the effect under consideration.

In north-central BC, Macdonald *et al.* (2003) examined clearcut effects on streamflow and suspended sediments in sub-boreal B.C. and found that the total runoff and peakflows increased for up to five years post-harvest, with a reduction in sediment concentrations within three years. Sediment sources were associated with stream crossings and landings located near streams rather than erosion of stream banks. However, hydrologic recovery varies widely depending on site characteristics, level of harvest and the effect under consideration (Buttle and Murray 2007).

On shallow or bedrock soils, soil moisture storage capacity can be exceeded and the impacts of forest harvesting such as increased runoff may be exacerbated resulting in lateral runoff (Buttle *et al.* 2000; Devito *et al*. 2005a; McDonnell 2003). Forest harvest can affect soils through compaction, erosion, rutting, loss of organic matter, etc. These effects may last 10 – 21 years before returning to pre-harvest conditions (National Research Council 2008). In contrast, on the boreal plain where a drier climate and deep glaciated substrates prevail, surface–groundwater interactions are likely complex and dominated by soil water storage and evapotranspiration (Devito *et al.* 2000) resulting in a low risk of runoff due to harvesting (Devito *et al.* 2005a). In Saskatchewan, on the boreal plain, Pomeroy *et al.* (1997) found that cutover sites had greater water storage compared to regenerating or mature forests likely due to less interception and smaller evapotranspiration fluxes following harvest.

Buffers are relatively ineffective at mitigating increases in water yields since these effects are a function of the overall proportion of disturbance in the catchment rather than in any particular riparian area.

Lee and Smyth (2003) suggest that riparian management areas are not likely to mitigate water yield increases following harvest due to their relatively small size (~2% of watershed area for boreal forests) and buffers are relatively ineffective at mitigating increases in water yields because these catchment-level effects are a function of the overall proportion of disturbance in the catchment rather than in any particular riparian management area. Devito *et al.* (2005a) suggested that valley-bottom ephemeral draws and wetland areas have the greatest risk of impacts due to harvesting. Lee and Smyth (2003) suggest that water yield effects could be minimized by avoiding these areas and designing roads to avoid the creation of hydrologic connections.

"Riparian energy and nutrient inputs are probably more important on small lakes or lakes with complex shorelines where the ratio of shoreline length to lake surface area is relatively large" (Gunn *et al.* 2004). Forest disturbance has been linked to increased nutrient fluxes from terrestrial areas to receiving waters however the extent of these effects differs between landscapes and nutrient types (Buttle and Murray 2007). Disturbance by wildfire can increase the availability of water-soluble nutrients due to the mineralization of organic nutrients contained in vegetation and the exposure of mineral soil that takes place in severe fires (Bayley *et al.* 1992). These nutrient pulses are likely important however it is unknown whether harvesting results in similar nutrient pulses.

Buffers are effective at reducing sediment flow into water bodies from overland flows created by disturbance of the forest floor but were less effective in preventing sediment transport through channelized flow. Nitschke (2005), in a meta-analysis of Canadian and American research comparing fire versus harvest effects, found roads associated with harvest activities provide a long-term sediment source that deserves attention from forest managers. Lee and Smyth (2003) suggested that buffers were not needed to control sediment when soil disturbance during harvest was minimized. Furthermore, they identified skid trails, landing areas, and roads as the more dominant sources for sediment from harvesting. In recent years, efforts on the part of forest management companies to reduce harvest-related water effects through the use of best management practices for harvest operations, road construction and stream crossings, along with training and education, have enhanced the mitigation of site disturbance and reduced the potential for sediment inputs to aquatic systems (NCASI 2009). Shoreline harvesting along coldwater lakes in the boreal shield of Canada resulted in no significant sediment deposition (Steedman and France 2000).

Best management practices for harvest operations, road construction and stream crossings, along with training and education, have reduced the potential for sediment inputs to aquatic systems.

In summary, some hydrological research demonstrates that buffers may not always be necessary along receiving waters, while in some cases (*e.g.* source waters) the use of much wider buffers may be required (Devito *et al.* 2000). More research in the boreal plain is needed to understand where buffers are necessary to meet objectives and where these objectives might be better addressed with alternative riparian management strategies in combination with other stand retention practices.

Buffers may not always be necessary along receiving waters, while in some cases (e.g. source waters) the use of much wider buffers may be required.

Regulating stream temperature and maintaining allochthonous organic inputs

Canopy cover from treed buffers provides significant modulation of stream temperatures in the boreal and other ecoregions. Treed buffers are unlikely to be effective for maintaining temperatures of boreal lakes and wetlands as the canopy only occasionally provides direct cover to these types of shorelines (Steedman *et al.* 2001).

Treed riparian buffers also provide a significant amount of allochthonous organic debris into streams. The removal of shoreline forest has clearly been shown to create a loss of habitat and food sources in stream systems (Lee and Smyth 2003). In addition, France *et al.* (1996) found that harvesting shoreline forest around boreal shield lakes reduced inputs of small woody debris by up to 90%. Lee and Smyth (2003) suggest that a lack of treed buffers around medium to large lakes is less likely to impact organic inputs relative to smaller lakes. However, it is important to consider that seemingly small changes in an ecosystem can occasionally lead to bigger than expected changes. For example leaf exclusion experiments have shown that the entire food chain can be affected when woodland streams are deprived of leaf litter inputs, even for a short time (Naiman *et al.* 2005).

Biodiversity Objectives

Riparian areas contribute significantly to biological diversity and wildlife habitats (Sabo *et al.* 2005). They are biologically diverse areas in terms of vegetation communities and the species that live within them, with soil and moisture conditions that are usually different from upland areas. Riparian areas provide important habitat elements (core areas and refugia) and are utilized as travel corridors by many species of wildlife (Lindenmayer and Franklin 2002). Although riparian buffer strategies were originally developed to address water issues, biodiversity objectives such as wildlife habitat, connectivity and travel corridors are now key components of riparian management strategies (Manitoba Conservation 2009; Ontario Ministry of Natural Resources 2010).

Although riparian buffer strategies were originally developed to address water issues, biodiversity objectives such as wildlife habitat, connectivity and travel corridors are now key components of riparian management strategies.

Though specific biodiversity objectives can be difficult to measure, several studies have examined the suitability of various buffer widths for maintaining flora and fauna in North America. Results are generally mixed but this is not surprising given the range of forest types, and forest practices. In addition, it is challenging to distinguish human impacts from natural fluctuations, particularly in animal populations. Results are also mixed depending on whether species habitat requirements or preferences include riparian, aquatic, or terrestrial areas. For some groups, including terrestrial invertebrates and reptiles, little data is available on the effects of riparian harvest activities in boreal ecoregions and in the western boreal forest studies are particularly limited (but see results of Terrestrial Riparian Organisms, Lakes and Streams- TROLS; Northern Watersheds study-Alberta Conservation Association). This could be an important limitation to effective riparian management for forest wildlife as habitat associations and behaviors can vary from one region to the next, even for the same species (Hannon *et al.* 2002).

Little data is available on the effects of riparian harvest activities on terrestrial invertebrates and reptiles in boreal ecoregions.

Riparian areas have a relatively high diversity of non-vascular and vascular plants because of the relatively close spatial proximity of varying abiotic conditions and the complex interaction of disturbance and succession (Harper and MacDonald 2001; Sabo *et al.* 2005). The impact of tree removal in riparian areas through harvesting and disturbance is unclear for plant communities in and around boreal water bodies (Lee and Smyth 2003). Short term studies have shown little response by plants to buffer width (Macdonald *et al.* 2006).

Evidence suggests that distribution and/or abundance of mammals and amphibians is positively affected by the presence of water. However, it is unclear whether disturbance of treed riparian zones alters this distribution (Lee and Smyth 2003). On the boreal plain, small mammal and amphibian communities do not exhibit drastic changes in response to various buffer widths (2–100m). In other boreal regions, anuran or mammal communities did not vary in relation to different width buffers (Darveau *et al.* 1995; Whitaker and Montevecchi 1997). For most large mammals, the riparian buffers retained are not wide enough to provide core reproductive habitat, however, they may provide sufficient cover to feed and travel (Lee and Smyth 2003). For some mammal species such as moose, there is a preference for treed riparian areas. However these areas do not appear to be important habitat for many small- and medium-sized species. Thus for some landscapes and for some species assemblages the buffer size required may be very small (Hannon *et al.* 2002).

For some landscapes and for some species assemblages the buffer size required may be very small.

The TROLS study also evaluated the response of the terrestrial bird community to buffers of different widths. Results indicated several bird species considered to be habitat generalists, or edge associated, did not show a decrease in abundance in response to variation in buffer widths (Hannon *et al.* 2002). However, traditional buffers were deemed insufficient for maintaining interior forest bird species and led to the recommendation that riparian buffer widths should be a minimum of 200 m to maintain these bird communities (Hannon *et al.* 2002). Some studies have noted increased densities and species richness in buffers immediately after harvest due to a crowding effect, however, this condition declines in subsequent years as birds disperse (Darveau *et al.* 1995). Finally, little research has been done on bird species (*e.g.* some species of ducks) whose life histories are dependent on the presence of trees close to water (but see Pierre *et al.* 2001). As most individuals typically nest within 200 m of water, it is expected these species would be negatively impacted by removal of large trees from shoreline forests but these effects have not been clearly demonstrated (Pierre *et al.* 2001).

Traditional buffers were deemed insufficient for maintaining interior forest bird species and led to the recommendation that riparian buffer widths should be a minimum of 200 m to maintain these bird communities.

The response of aquatic invertebrates and fish communities to riparian disturbance has been mixed, with changes usually attributed to secondary effects of harvesting.

The response of aquatic invertebrates and fish communities to riparian disturbance has been mixed, with changes usually attributed to secondary effects of harvesting (*e.g.* temperature changes, channelized flows, sedimentation when they occur). In non-boreal regions, buffers have been shown to minimize adverse effects to aquatic macroinvertebrates and fish, especially in flowing systems. Fish and macroinvertebrates are considered good indicators of ecosystem health and fish in particular resonate with public concerns. Hence many buffer guidelines use the presence or absence of fish to assign a buffer prescription. Sufficient short- and long-term data to evaluate the effects of changes to buffer guidelines on invertebrates and fish communities in open water and lakes in the western boreal forest is lacking.

In many regions, post-harvest increases in stream water temperatures, and associated negative effects on fish, are well demonstrated. However, fish populations have also been found to recover quickly following disturbance if access to source populations is not interrupted (Naiman *et al.* 2005). Thus sedentary species may be more sensitive to habitat changes. Results from research on lakes on the boreal shield have indicated little response of trout to harvesting in shoreline buffer strips of lakes (Steedman 2000, St. Onge and Magnan 2000). Certainly more research and monitoring are required to evaluate alternate riparian management strategies for both fish and macroinvertebrates. Lee and Smyth (2003) recommended that harvest prescriptions for riparian areas might be better assessed on a case by case basis with particular attention paid to watershed scale considerations such as cumulative effects.

Riparian buffers may be an effective way to maintain connectivity on the landscape by acting as movement corridors for some species.

The role of riparian areas as corridors, refugia and core habitat has also been extensively discussed (Fischer *et al.* 2000; Lee and Smyth 2003; Naiman *et al.* 2005). There is some evidence to suggest that riparian buffers are an effective way to maintain connectivity on the landscape by acting as movement corridors for some species (Norton *et al.* 2000). A corridor is a strip of vegetation that connects two or more larger patches of vegetation through which an organism will move over time (Fischer *et al.* 2000). Attributes of corridor suitability vary between species (Lindenmayer *et al.* 2000), but for some species, riparian buffer strips provide suitable wildlife corridors (*e.g.* fisher, marten). Hannon *et al.* (2002) and Machtans *et al.* (1996) demonstrated that buffer strips of shoreline forest were useful for fledgling and dispersing songbirds and served to increase connectivity between two isolated forest fragments, at least in the short term. However, recent research has provided evidence that the persistence and habitat suitability of some of these corridors over time may be in question. Martell *et al.* (2006) found 72% of poplar trees within 30 m of streams studied were removed by beaver foraging and suggest that much wider buffers may be needed to accommodate beaver and other wildlife. Likewise managers should consider that riparian corridors are dynamic systems and will change over time due to succession, aging and natural disturbance processes. Alternatively, relying on riparian buffers exclusively to provide connectivity on the landscape may be a poor strategy and a broader landscape approach to mature forest corridor planning is recommended *(e.g. Box 4).*

Managers should consider that riparian corridors are dynamic systems and will change over time due to succession, aging and natural disturbance processes.

Box 4: Balancing tradeoffs: an economic and ecological corporate reality

"LP recognizes that more information is required to understand the complexities of the biophysical interactions within riparian areas and continues to foster and explore new partnerships related to watershed conservation. LP continues to work through the challenges that arise when trying to balance mill wood requirements, regulatory requirements for wildlife habitat, and company obligations for conserving water resources and biodiversity across the license area. Unfortunately, the results of managing for multiple values without taking into consideration how one requirement affects the other can potentially increase the pressure on the forest ecosystem, i.e. by increasing forest fragmentation and the density of forest road development. For example, the need to employ variable retention harvesting in support of the natural disturbance model, coupled with regulatory requirements to reduce line of sight within cutblocks and the application of buffers around all aquatic features, has resulted in less wood volume per cutblock. This reduction in wood volume necessitates the need for LP to design and potentially access more harvest areas to meet mill requirements and Annual Allowable Cut targets. For this reason, it becomes necessary to design better variable retention strategies recognizing that companies cannot manage for all forest values everywhere and that some tradeoffs need to take place in order to sustain the long-term viability of other biologically and/ or socially significant forest values." LP-Canada Ltd., Swan River, pers. comm.

It has also been suggested that riparian buffer strips might act as refugia or core habitats for some species post-harvest. Refugia refers to

> *"the use of riparian areas as a temporary habitat that facilitates the survival of a species until post-disturbance recovery provides more favourable habitat. Core habitats represent areas capable of supporting long-term sustaining populations of species. Like refugia, core habitats are sources for dispersal into the surrounding post-disturbance habitats. These categories represent points along a continuum of dependence upon riparian areas" (Lee and Smyth 2003).*

Most of the current research regarding shoreline forest and the width of buffer strips is based on presence/absence data and/or relative abundance/density data. More specialized study is needed to gain a clear understanding of the role of riparian areas in the life history and population maintenance of species. Until that time we will continue to have incomplete knowledge about which species need the combination of trees and proximity to water as a critical component of their life history (Lee and Smyth 2003). Larger riparian areas may also be required for temporary refugia for species that will re-colonize disturbed areas or as core habitat for long-term population maintenance. However these objectives need to be evaluated and managed at a broader scale not on a stand by stand basis and should be considered along with other trade-offs being made on the landscape.

More specialized study is needed to gain a clear understanding of the role of riparian areas in the life history and population maintenance of species.

4.0 Forest management on the boreal plain – opportunities to implement a systems approach?

4.1 The natural disturbance model

The primary goal of forest ecosystem management is to maintain the ecological integrity and health of the forest.

The concept of ecosystem management has been incorporated into policy and practice in many areas of Canada. The primary goal of forest ecosystem management is to maintain the ecological integrity and health of the forest (Gauthier *et al.* 2009). Hunter (1993) and others (Perera and Buse 2004; Bergeron and Harvey 1997; Attiwill 1994) have suggested the adoption of forest management practices that result in forest patterns and structure that more closely resemble those derived from natural disturbances as a means to achieve ecosystem-based management. In practice, a common objective of the natural disturbance-based approach is to design forest management practices that fit within a historical range of variability of natural disturbance regimes (Landres *et al.* 1999; Ontario Ministry of Natural Resources 2001; Andison 2003).

Kimmins (2004) outlined the need to manage forest ecosystems as integrated systems, with a conceptual framework designed to maintain ecosystem structure and function and accommodate harvest activities. The concept of a forest ecosystem incorporates the interactions, structures and processes that link biotic and physical elements and are made of several hierarchical levels (Gauthier *et al.* 2009). A systematic approach, at multiple scales, including both terrestrial and aquatic landscape components, is needed as forest managers develop and implement strategies and objectives to achieve ecosystem-based management. Riparian areas are an important component of these forest systems and should be integrated into both strategic and operational planning processes.

> *"However, when pursued out of uncertainty about potential impacts, a no-cut buffer simply limits management options and opportunities. These opportunities include not only management for obvious features, such as desired commercial species and timber products, but also enhancement and restoration of riparian functions. Our point is that no-cut buffers do not accommodate the natural range of variability in riparian forests, including differences in potential composition and productivity. These buffers ignore the fact that disturbance is a natural part of riparian systems and they provide minimal flexibility for meeting diverse management objectives". (Palik et al. 2000)*

Clear methods for applying the natural disturbance model to riparian areas need to be developed.

Clear methods for applying the natural disturbance model to riparian areas need to be developed however only a handful of studies have examined natural disturbance patterns specifically associated with riparian areas. In general, studies examining forest fire dynamics in boreal landscapes can be conflicting. Johnson *et al.* (1998) stated "Fire behaviour should not vary strongly with stand age or with species composition types". However, Quintillio *et al.* (1991) suggest "pure healthy aspen stands are virtually impenetrable by fire except under extreme burning conditions". Cumming (2001) concluded that forest composition influences fire behaviour at both regional and local scales. They demonstrated empirically that black spruce and pine burned most frequently, while aspen forests burned least frequently, with white spruce and wetland forest types falling out in the middle. Although some authors (*e.g.* Andison and McCleary 2002; Everett *et al.* 2003; Macdonald *et al.* 2004) did not find any differences in stand age and composition between shoreline/riparian forests and those of the surrounding landscapes, other studies (Suffling *et al.* 1982; Denneler *et al.* 1999) have demonstrated shoreline/riparian forests may experience a lower frequency or intensity of fire disturbance than other parts of the landscape.

Lee and Smyth (2003) determined that succession patterns following natural disturbance varied with stream type. Large permanent streams tended to have greater amounts of unburned residual than small permanent and intermittent streams. In addition, the amount of unburned residual around permanent streams was greatest in close proximity to the stream and increased further away from intermittent streams. Thus, if forest managers were approximating natural disturbance (fire) Lee and Smyth (2003) suggested that:

1) streamside forest around large permanent and small permanent streams should be removed,

2) forest around intermittent streams should be retained, and

3) forest retention along intermittent, upland streams should exceed current buffer widths.

This strategy could also apply to lakes, pond and wetlands however further research is needed to develop methods for approximating natural disturbance regimes in these types of riparian areas and to forecast their potential ecological and socio-economic consequences using spatially explicit models. Nitschke (2005) recommends the use of partial or selective harvests combined with prescribed burns as the best way to approximate wildfire in headwater streams and reduce negative effects from harvest.

The influence of beaver disturbance on the boreal plain landscape is not well understood spatially or temporally.

Beaver are also considered to be an important natural disturbance on the landscape (Barnes and Mallik 1997; Gabor *et al.* 1999). In many areas, the management of beaver is a trade-off between the importance of the wetland habitats they create and the area of productive land lost to flooding (Naiman *et al.* 1986). However, the influence of beaver disturbance on the boreal plain landscape is not well understood spatially or temporally. Their role in maintaining habitat heterogeneity could be as important as abiotic disturbances such as fire or wind (Wright *et al.* 2002), particularly in wetland- dominated landscapes and during periods of high beaver population densities. In addition, beaver have a clear influence on the vegetation structure and composition of riparian areas (Wright *et al.* 2002). Questions about the spatial and temporal dynamics of beaver activity in maintaining riparian habitats on the boreal landscape over time should be addressed. An evaluation of the opportunity to integrate beaver disturbance into the natural disturbance model is also necessary.

Stand level considerations (e.g. snag and green tree retention) for approximating natural disturbance in riparian areas are important.

Finally, stand level considerations for approximating natural disturbance in riparian areas are also important. For example, the retention of trees with existing cavities and/or trees with the potential to develop them. Retention of trees and snags has been suggested as a strategy to provide old growth characteristics for riparian associated species such as eagles, osprey and cavity nesting ducks (Hanowski *et al.* 2007; Macdonald *et al.* 2006).

Research is needed to address whether the amount of displacement and the rate of recovery of riparian systems subjected to anthropogenic disturbances are comparable to that of riparian/wetland communities subjected to natural disturbance processes. For example, research from other regions has shown that invertebrate communities in lotic systems showed faster than expected recovery post-fire due to the rapid recovery of riparian vegetation (Dwire and Kauffman 2003). However, it appears that no studies have examined the recovery of boreal riparian systems following disturbance.

4.2 Making the most of our forest resources: can we be more strategic?

Riparian habitats are an integral part of the landbase and should be integrated into the strategic planning framework.

It is reasonable to expect that on any given landbase there is a finite capacity to meet the expectations of all resource users and thus some trade-offs are necessary. The question then arises-what are these trade-offs? Similar to upland areas, riparian areas contain a broad range of values ranging from biodiversity to economic and social values. It is unlikely that a single riparian area could address or consist of all values at once. The forest ecosystem must be managed over large spatial scales and long time frames in order to produce desired goods and services in perpetuity. Forest planners should consider riparian habitats as an integral part of the landbase and integrate these areas, along with the terrestrial aspects of the forest system, into the strategic planning framework.

Riparian and wetland areas are often not inventoried or mapped at the level of detail of merchantable stands, and may not be included in ecologically-based classifications making wildlife habitat and other value assessments problematic.

Success in achieving multiple objectives over time requires tactical planning and spatially explicit accounting of forest composition including species, age and size distributions of stands. Models for forest management planning have historically been aspatial due to mapping or technological restrictions. In addition, riparian areas are often netted down (excluded) from Annual Allowable Cut (AAC) calculations due to no harvest buffer requirements and therefore also excluded from the spatially explicit forest management planning models that do exist. These calculations are also often based on limited hydrological data and poor digital elevation models resulting in still greater inaccuracy. Furthermore, riparian and wetland areas are often not inventoried or mapped at the level of detail of merchantable stands, and may not be included in ecologically-based classifications making wildlife habitat and other value assessments problematic. Finally, succession pathways and management responses are also not readily available for riparian areas, which further complicates the forecasting of future forest conditions and predictions related to biodiversity conservation, especially for Species at Risk or regionally important species. As a result of these limitations in many areas, riparian buffers have not been strategically incorporated into a long term vision of future forest condition. This exclusion could have both economic and ecological costs over the long term and is a concern for some companies *(Box 4).*

Strategic planning and landscape design involve "strategic policies, goals and objectives, which are translated into tactical activity schedules, which are then rendered into specific operational actions on the ground" (Andison 2003) . This approach tends to be driven by biodiversity concerns rather than timber harvest scheduling problems –regardless of intent the strategic deployment of forest management effort in space and time is undertaken. The process is facilitated by Geographic Information Systems (GIS) and computer simulation technologies that are now widely available and coincides with a greater emphasis on "coarse filter" management of habitats rather than a single species (Andison 2003).

Landscape approaches provide opportunities to incorporate multiple objectives into an overall design strategy, including the location and design of riparian buffers in order to meet specified management objectives. For instance, riparian buffers and wetland areas along with designated Protected Areas, old forest patches, and inoperable or other non-harvestable areas can be treated as `anchors' in a landscape design to promote biodiversity (Huggard 2004). These anchors become the building blocks of a biodiversity conservation matrix to provide a range of habitat types and ages through time and space, enhance forest connectivity, and link patches of high conservation value forests. Ecosystem representation analyses should be undertaken on the current and projected future forest condition to determine the ecosite type, abundance, distribution and seral class/age for both terrestrial and wetland areas (Bunnell *et al.* 2003). Rare and infrequent ecosites, and habitats for Species at Risk and species of special interest that are located in riparian areas could be deferred from harvest while abundant riparian ecosite types could be considered for management. A habitat matrix that associates plant and animal species with particular ecosite types can then be used as a decision support tool to decide which riparian areas could be considered for management activities (LP Canada 2006).

Landscape approaches can incorporate multiple objectives into an overall design strategy, including the location of riparian buffers to meet specified management objectives.

Riparian buffers are often retained with a secondary objective to conserve old forest areas or high conservation value forests (Lee and Barker 2005; McAfee and Malouin 2005). However, forest modeling scenarios developed by Lee and Barker (2005) indicate that under current forest management practices most old seral stages shift from the operational land base to the riparian land base by 100-140 years into the model. Thus in the long term, species dependent on old forest but for which riparian buffers may not represent suitable habitat (due to configuration or proximity to a water body) could be in jeopardy. This example illustrates that the retention of shoreline forest buffers cannot replace a strategy for maintaining old forest areas on the landscape. Old forest strategies should be designed to ensure both upland and lowland old forest areas are distributed across the landscape.

The amount of merchantable timber located in areas that require buffer strips is another important factor to consider when developing riparian management strategies. Forestry companies that participated in this study estimated approximately 4 to 11 percent of merchantable timber on the landbase was located in riparian areas that would require buffers. Models need to be developed which evaluate whether alternative riparian management practices could provide additional timber within areas scheduled for harvest rather than accessing additional harvest blocks, which would reduce road densities and the amount of landscape in a harvested state. The ability to conduct management activities in riparian buffers could also increase the potential for larger core forest areas while maintaining a suitable patch size distribution *(Box 5).* Alternative management practices may enable more wood to be taken from a smaller area resulting in a smaller overall footprint on the landscape. The question then becomes, if we are to retain mature forest, where should it be retained in order to meet multiple objectives and maintain a full suite of forest values? The retention of forests in riparian areas may not always be the best strategy.

If we retain mature forest, where should it be located to meet multiple objectives and maintain a full suite of forest values?

Landscape variability to promote resilience in ecological communities has been suggested as a risk management strategy in the face of uncertainty.

Implementing a variety of riparian management strategies contributes to landscape variability.

A recent methodology developed to classify conservation lands in Canada's forest landscapes categorized riparian buffer zones as "Environmentally Significant Areas"– ie. areas that permanently protect unique habitat features fundamental to the survival for the species and/or populations (McAfee and Malouin 2005). While this is a broad statement with many assumptions – it does highlight that riparian zones and associated shoreline forest may represent a unique conservation opportunity. This opportunity would also likely be strengthened by the strategic placement of these unique habitat features *(Box 5).*

Finally, landscape variability to promote resilience in ecological communities (Fischer *et al.* 2006) has been suggested by researchers as a risk management strategy in the face of uncertainty. The reasoning is that maintaining the natural range of variability on the landscape (i.e. maintaining patterns and processes) over space and time should ensure the long term sustainability of landscapes. Some of this variability could be enhanced by allowing harvest within some shoreline forests. DeGraaf and Yamasaki (2000) suggest that riparian areas should be actively managed to optimize wildlife habitat quality through time and that actively managed buffers will provide more habitat for more species than unmanaged riparian forests. The current paradigm for riparian management (i.e. fixed buffer widths; often the same width on all systems of a certain type) appears to be out of step with this approach.

5.0 Riparian Guidelines – building a stronger framework for decision making

5.1 How are riparian areas considered in forest planning and operations?

Current riparian buffer guidelines are focused on stand-level decisions for operating around water. While buffers will remain an important part of maintaining the integrity of some aspects of aquatic resources, criteria for establishing where buffers are needed and the appropriate widths should be based on both site- and landscape level-objectives.

One suggestion put forth in a variety of contexts is to develop riparian management policies and guidelines that are based on the most recent applicable science and strategically designed to meet a broader range of SFM objectives (*e.g.* Castelle *et al*. 1994; Fischer *et al.* 2000; Barten 2001; Naiman *et al.* 2005; Sibley and Gordon 2010). This approach is typically referred to as objective-based (riparian) management and can be considered a type of ecosystem management. Ecosystem management methods are used to help account for the full suite of organisms and processes that characterize a system (Dale *et al.* 2000).

Management decisions would be made according to a framework that weighs options while providing a mechanism for resolving issues around competing or conflicting values.

Following this approach, management decisions would be made according to a framework that considers and weighs options while providing a mechanism for resolving issues around competing or conflicting values. These objectives can be set at multiple levels of management (*e.g.* planning vs. operating) and at multiple scales. While some objectives are necessarily addressed at a stand level or operational scale (*e.g.* erodabilty, wind throw, and disease) others (*e.g.* natural disturbance approximation, connectivity) must be incorporated into landscape-level planning and then applied at an operational scale.

Box 5: Strategic and spatially explicit planning: a working example

The width of forested areas or buffer width has typically been studied as the primary metric of importance to biological communities (Rodewald and Bakermans 2006) and therefore is usually the principle focus of management recommendations. The choice of this metric is not unsubstantiated since edge effects may be more pronounced in narrow or small forest stands and there is a positive relationship between area and species diversity. There is some empirical support for these ideas but the paradigm (buffer width) overlooks the importance of the landscape matrix that contains the riparian areas (Rodewald and Bakermans 2006). However, the unusual configuration (relatively narrow linear network) and bias to be near water bodies may not be exactly like interior old forest. There is an opportunity to evaluate reallocating timber volumes that would normally be retained in strips along a riparian zone in order to create larger patches of intact forest on the landscape.

Birds can be used to illustrate how multiple objectives could be considered. Authors have typically found that landscape level variables (*e.g.* woodland area, amount of natural vegetation) are better predictors of bird communities (Groom and Grubb 2002) and species richness (Saab 1999) than local level variables and can influence how species use the landscape (Norton *et al.* 2000). For example, a recent evaluation of shoreline buffer widths in Alberta (Terrestrial Riparian Organisms, Lakes and Streams project- TROLS), found several bird species considered to be habitat generalists or edge associated did not show a decrease in abundance in response to variation in buffer widths (Hannon *et al.* 2002). However, traditional buffers were deemed insufficient for maintaining interior forest bird species and led to the recommendation that riparian buffer widths should be a minimum of 200m (Hannon *et al.* 2002) to maintain these bird communities. In addition, some bird species are typical of those found in early successional habitats. Reallocating timber volumes in one part of the shoreline to create larger patches in another is one way to meet habitat requirements for both types of birds.

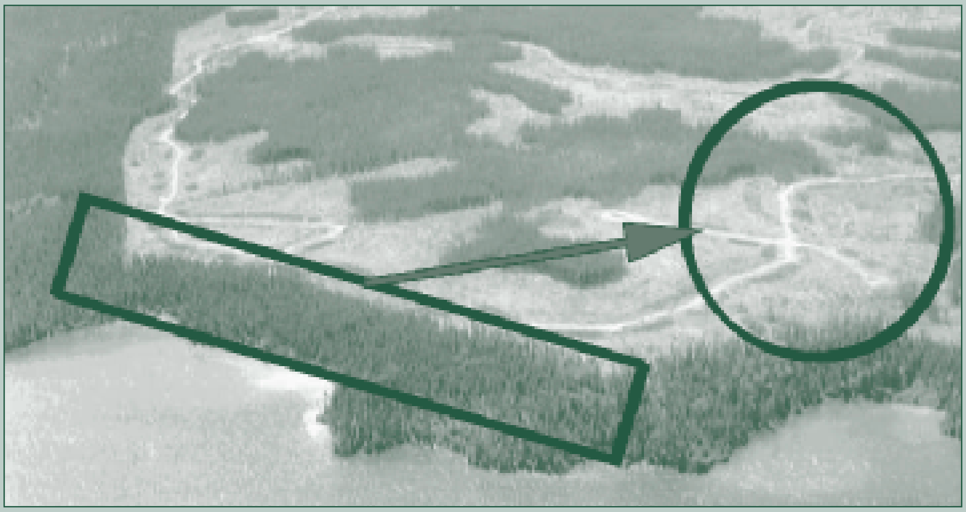


Photo: Courtesy of Tolko Manitoba Inc.

Particular emphasis should be placed on planning for learning through an active adaptive management approach.

Riparian management is not currently integrated into landscape design and strategic planning approaches which have theoretically demonstrated strengths in terms of reducing impacts on the landscape (*e.g.* aggregate harvest scenario). In addition, catchment-level planning should apply a landscape design philosophy. If all types of riparian areas are managed at a landscape scale then the variability of these areas on the landscape should be reflected in the management guidelines and how they are applied. Particular emphasis should be placed on planning for learning through an active adaptive management approach.

5.2 Decision support systems for riparian management

A detailed conceptual framework for a riparian DSS has been developed in a SFM Network synthesis document entitled Managing Riparian Forests: a decision support system *by Sibley and Gordon (2010).*

Clearly, a decision support system, rooted in scientific knowledge and the principles of adaptive management, is needed for riparian areas.

Clearly, a decision support system (DSS) rooted in scientific knowledge and the principles of adaptive management capable of addressing multi-scale issues is needed to manage riparian areas for a suite of SFM values. A riparian DSS should encompass one or more factors such as the hydrological context (*e.g.* climate, surficial geology, and topography), the ecological context (*e.g.* effects on habitat supply, natural disturbance regimes, and functions of riparian areas) and socio-economic factors (*e.g.* value of timber, recreational considerations, and traditional uses). Following landscape level decisions to address objectives, suitable choices based on operational constraints (equipment type, scheduling, silvicultural system) and site-specific characteristics (soil type, slope) are made at the cutblock level (i.e. in annual operating plans, detailed forest management plans) (Table 4).

Devito *et al.* (2000) have proposed that buffer width decisions should:

- be flexible,
- be tailored to local aquatic conditions,
- consider the functional extent of the riparian zone, and
- reflect the landscape context of water bodies.

Some areas on the boreal plain have little surface water flow which significantly reduces the risk of sedimentation and erosion effects in the absence of riparian buffers.

Results of hydrological research (*e.g.* the framework proposed by Devito *et al.* 2005(b), defining a hydrological response unit or catchment in northeastern Alberta) could inform decisions about the suitability of different areas for alternative riparian management practices based on both landscape-level characteristics (*e.g.* hydrological connectivity, surficial geology) and site-level characteristics (*e.g.* permeability, presence/absence of surface and subsurface flows). For example, Devito *et al.* 2005(a) have demonstrated that some areas on the boreal plain have little surface water flow significantly reducing the risk of sedimentation and erosion effects on water quality in the absence of riparian buffers.

Table 4 Examples of landscape-level versus site-level considerations that could be used to set priorities for the management of riparian areas.

Landscape Level	Site Level
• Water quality/Human water Supply	• Water quality
• Landscape position-receiving waters or source waters.	• Waterbody type – wetlands, lakes and streams
• Wildlife habitat considerations	• Waterbody size
• Forest health	• Presence or absence of fish
• Old forest planning	• Wildlife habitat considerations
• Disturbance regime and natural range of variability considerations	• Soils
• Conservation planning	• Slope
	• Forest health
	• Recreation, traditional uses

6.0 Learning opportunities

6.1 Dialogue for creating successful policy instruments, overcoming operational challenges and creating public understanding

Whenever possible managers and conservationists should integrate the results of research into management actions and policies (DeYoe and Hollstedt 2004; Brand and Karvonen 2007). Policy makers and land managers are accountable to the general public and to stakeholder groups potentially making new untested policies much more risky to implement (Stankey et al. 2006). Uncertain ecological, social or economic outcomes must be avoided. Thus the process of developing new policies and regulations can be very complex, particularly when balancing multiple priorities, applying context specific results to a broader application or attempting to account for uncertain outcomes of new policies (Fazey *et al*. 2006). Furthermore, in many cases decisions must also be made in the absence of any research and must be based on professional expertise, "educated guesses", local knowledge or other qualitative information (Fazey *et al*. 2006). Ideally types of information, qualitative and quantitative, are available and function in a complementary fashion- but often this is not the case. Several approaches to overcome these challenges have been tested by participants in this case study while developing and applying riparian guidelines including multi-stakeholder participation, interdisciplinary teams, expert advisory groups or a combination of these.

The process of developing new policies and regulations can be very complex, particularly when balancing multiple priorities, or attempting to account for uncertain outcomes of new policies.

One example is the formation of **interdisciplinary policy or guideline development teams** with key stakeholders at the table (*e.g.* Manitoba Forest Practices Committee). A team is generally formed to achieve a collective and consensus driven approach to a specific aspect of resource management. Advantages of this approach are that operational challenges to new policies and

While it has proven beneficial to have an interdisciplinary team to build guidelines, the process may become longer due to the complexity of interests represented and the need to reach common ground.

Team members in an interdisciplinary setting must be willing to take different perspectives, re-evaluate their own and other's mental models and be open to changing them.

guidelines can be identified early on, and economic and social concerns can be addressed before a policy or guideline is adopted. While it has proven beneficial to have an interdisciplinary team to build guidelines, the process may become longer due to the complexity of interests represented in the negotiating arena and the need to reach common ground. These may arise as a result of intra- and inter-organizational barriers ranging from personal, cultural or technical sources of bias or disagreement (DeYoe and Hollstedt 2004). In addition, the process can be costly and it can be unclear whether the stakeholder should bear these costs (Lynam *et al.* 2002).

The development of new policies is challenging, even within an organization, let alone among multiple stakeholders, as it can be difficult to create and maintain an environment where exchanges are constructive. One obstacle is that people can be very defensive about changing the way they think (Argyris 1985). It may take a long time or particularly significant events before major changes in understanding occur as humans have strong judgmental biases (Hogarth 1987). To further complicate matters, many people are typically weak at learning about dynamic complex systems (Fazey *et al.* 2006). Team members in an interdisciplinary setting must be willing to take different perspectives, re-evaluate their own and other's mental models and be open to changing them. This understandably represents a significant challenge to even the most adventurous in the face of new information, particularly where research may be in conflict with widely held views *(Box 6).* Strategies for knowledge transfer and communication should be developed early in the process, along with new policies or operating procedures. It is important to recognize that a common knowledge base, or opportunities to develop one, facilitates policy development by committee (Stankey *et al.* 2006).

Box 6: Experiential knowledge vs. Research-based evidence

Experiential knowledge and empirical or literature based models can be conflicting. Both have limitations. Often human perception of habitat use can be biased either for or against a particular resource. Likewise models developed from context specific situations may not be widely applicable. One example of such a conflict is illustrated by this example from Lee and Smyth (2003) describing the importance of riparian areas to black bears:

> *"Unsworth* et al. *(1989) recommended that forested buffers along streams, roads, and dense stands on north-facing slopes be retained for bear cover and bedding. However, Clevenger* et al. *(2002) noted that habitat models developed for black bears from expert opinion tended to overestimate the importance of riparian areas relative to empirical or literature-based models. This trend reinforces the widely held view on the importance of riparian areas to wildlife amongst professionals but that the literature may not support the strength of this view."*

As research that questions the importance of buffers becomes more widely available, perceptions of the functions of riparian areas are being challenged.

Another policy development process that has been tested is the formation of a **science advisory committee** to bring experts to the table to provide recommendations to policy makers and forest managers (*e.g.* Saskatchewan, LP-Swan River, Al-Pac). Whenever possible, the recommendations they bring are rooted in empirical data. However, researchers are often called upon to provide their expert opinion in the absence of context specific data and may have a limited understanding of the regulatory or operational aspects of forest management. Furthermore, it can be costly and complicated to coordinate and gather researchers with academic commitments to discuss landscape management challenges. So this approach is not always practical.

Given complexity and the need for immediate action, **experiential knowledge** may be the best evidence available. Because experiential knowledge will always play a significant role in decision making, enhancing the ability to learn from experiences (including research) through work, educational and personal experience is crucial (Fazey *et al.* 2006). A working environment that supports these efforts through access to conferences, workshops and technology is necessary for all resource managers in corporate or public service.

Experiential knowledge will always play a significant role in decision making, enhancing the ability to learn from experiences.

Policy instruments and policy implementation

Following the review and synthesis of current knowledge pertaining to a given guideline, an **adaptive management framework** should be created to guide policy changes, implementation and effectiveness monitoring (Lee 1993; Stankey *et al.* 2006, Rempel and Donnelly 2010). The framework should include:

1) field testing of new guidelines to identify operational feasibility and help provide measurable parameters to evaluate success and calibrate models, and

2) where appropriate, spatial modeling of potential landscape effects at various scales should occur to determine potential outcomes prior to full implementation of guidelines.

Often guidelines are implemented before they can be tested and fined tuned to address operational and planning constraints (Weyerhaeuser SK. pers. com, LP- pers. com, MB-FPC pers. com.) which can be costly (see below).

Overcoming operational challenges

While variability is currently promoted by researchers, both in the context of maintaining the natural range of variability on the landscape and as a risk management strategy in the face of uncertainty, this poses many challenges in an applied setting. First, deviating from a "one size fits all prescriptive approach" could increase the complexity at planning and operational stages and could in turn increase the cost of enforcement and compliance monitoring once implemented (MB-FPC meeting notes; John Stadt pers. comm.). Second, the need for new equipment, better mapping products and the increased risk associated with operating in these areas may lead to a situation where the costs simply outweigh the benefits-ecological or economical. Finally, provincial guidelines for

While variability is currently promoted by researchers, this poses many challenges in an applied setting.

Defined landscape targets and a common vision for future forest conditions would create a better climate for more flexible approaches to riparian management.

desired future forest condition are lacking (J. Stadt pers. comm. SK Forest Service pers. comm., MB Conservation, pers. comm.) adding to the uncertainty of allowing more flexibility in guidelines. Defined landscape targets and a common vision for future forest conditions would create a better climate for more flexible approaches to riparian management.

Public Acceptance

Substantial effort and commitment is often required from government and/or industry to inform and obtain feedback from communities and stakeholders about the potential effects of alternate practices.

From a government perspective, new approaches are also perceived to, and occasionally do, carry a high risk especially in terms of political acceptability (MB-FPC- meeting notes; J. Stadt, Pers. comm.; Weyerhaeuser, SK Government pers. com). These concerns are not unsubstantiated. Riparian forests are widely recognized for their social and recreational values (Rodewald and Bakermans 2006). Harvesting in these areas can generate concerns from the public ranging from ecological to aesthetic and/or economic concerns (Hunt and Haider 2004). Substantial effort and commitment is often required from government and/or industry to inform and obtain feedback from communities and stakeholders about the potential effects of alternate practices (Lewis and Sheppard 2006; LP stakeholder committee Meeting 2002). For example, there was public outcry at the application of new guidelines in a visually sensitive area on the Weyerhaeuser SK Prince Albert FMA. As a result, there was substantial investment of time and money to overcome these concerns through public education and the development of a visual standard for these alternate forest management practices (Weyerhaeuser SK pers. comm., *Box 7*). Landscape visualization or mapping exercises have also been successfully used to inform communities and stakeholders involved in forest management planning jurisdictions across Canada (Lewis and Sheppard 2006).

The general public is often not aware of the latest science or forest management strategies that are promoted as the 'best practice' of the day, nor do they necessarily agree with it once they become informed.

The response of the public and stakeholders is not surprising. The principles of the natural disturbance model are not common knowledge even though it is now widely accepted or at least understood amongst academics and forest managers. The general public is often not aware of the latest science or forest management strategies that are promoted as the 'best practice' of the day, nor do they necessarily agree with it once they become informed. For instance, interviews regarding the aesthetics of riparian areas found that the public generally prefer the aesthetics of channels without large woody debris (Gregory and Davis 1993). However, knowledge that large woody debris is important to the health of riparian systems might alter public perception to be more supportive of woody debris in channels (Beckley *et al*. 2005). Similarly, the natural disturbance model has been viewed by the public as controversial due to misunderstandings about the frequency, characteristics and effects of larger disturbance patches (*e.g.* aggregate harvest) described in forest management guidelines (Saskatchewan Forest Service pers. comm. May 2010). Similar public perception issues may arise during attempts to apply natural disturbance patterns to riparian areas. Without public education a natural disturbance approach to riparian management will likely fuel the fire of controversy.

Box 7: Integrating ecological and social aspects of riparian management to address public concerns – Applying a visual standard

Extract from Visual Standard for Weyerhaeuser Prince Albert FMA Standards & Guidelines (Weyerhaeuser Saskatchewan Ltd. 1999)

A riparian management plan is required before harvest blocks can be approved for any visually sensitive lake identified. The 20-year plan will include the following:

1. A map showing the proposed harvest schedule for all blocks adjacent to the shoreline of lakes for the next twenty years. Blocks will be indicated on the map by year of harvest for the first five years. Harvest planned for years 6 to 20 will be identified on the map by five- year periods (6-10, 11-15, 16-20).
2. A minimum of twenty percent of the lakeshore will be maintained in mature, old or very old forest for the entire 20-year period. On lakes smaller than 1000 ha, plans will be assessed on a case-by-case basis and may be approved with less than 20% mature, old and very old forest provided the distribution of ages is acceptable.

Guidelines for Visually Sensitive Lakes

1. Mature, old and very old forest should be representative of species distribution around the lake.
2. Mature, old and very old forest should be well distributed around the lake.
3. There should be a mixture of young and immature forest to ensure diversity of ages around the lake.
4. Design green tree retention within the cutblock to enhance screening and reduce the impact of harvesting on the visual landscape.
5. Planning for visually sensitive riparian areas should take into consideration the recreational and scenic value of these features.
6. Variable width buffers.

Application of variable retention harvest guidelines on a Visually Sensitive Lake in North Western Saskatchewan. *(Photographs courtesy of Weyerhaeuser SK).*

6.2 Research needs and information gaps

There was a pulse of interest in riparian issues by biologists in the mid 90s as questions arose about appropriate buffer widths for shoreline forest. More recently, there has been a lull in this area of research although a number of knowledge gaps remain. Riparian science, particularly in the boreal forest, should continue to grow as these systems are poorly understood. Some gaps are identified below:

- **Ecological functions –**
  - Historically research has been focused on land to water flows. A holistic and integrated approach with increased emphasis on research regarding flows from the water to the land would better reflect a true land-water mosaic and develop an understanding of terrestrial-aquatic linkages (Turner and Carpenter pg 16 in Naiman *et al*. 2005).
  - More research is needed regarding the role of riparian areas in hydrologic processes. We do not have a great understanding of hydrologic processes on the boreal plain and whether the assumption of processes from other areas hold true. Catchments are not clearly identifiable everywhere as geomorphic regions produced by continental glaciation may have no discernable midsized catchments (Omernik and Bailey 1997).
  - More research regarding the ecological function of riparian areas in the life history of many species is necessary (Lee *et al*. 2004).
  - Comparing successional trajectories of shoreline forests under disturbance regimes (harvest, beaver, fire, undisturbed) would add value to the discussion regarding the value of disturbing these areas.

- **Thresholds and cumulative effects –** Research is needed to increase our understanding of threshold responses, whether irreversible changes may occur (Turner and Carpenter pg 16 in Naiman *et al*. 2005) and the cumulative effects of land use practices at broad scales.

- **Range of natural variability –** Research to support the understanding that a variety of management practices balanced with large undisturbed areas may be our best strategy (Lindenmayer *et al*. 2000; Fisher *et al*. 2006;).

- **Spatially explicit landscape models –** Goals such as landscape connectivity, old forest areas, high conservation value forests and core habitats could potentially be achieved without compromising the ecological health of riparian and aquatic areas. Modeling efforts could be used to identify opportunities on the landscape.

- **Mapping and inventory –** The processes that maintain riparian areas often result in rapid vegetation changes at finer scales than the inventory that is currently available in most areas. Better hydrographic maps would assist with the development of models and more accurate planning for these areas. There are often discrepancies between what is planned and what is actually retained post- harvest due to the level of accuracy in stream and topographic maps (Lee and Barker 2005). Often the amount of timber retained on a cutblock is greater than originally anticipated once harvest prescriptions are implemented (LP- pers.com.).

- **Ecological classification** is needed for all components of the landbase including aquatic and terrestrial areas – the availability of ecological attributes, and corresponding level of detail for all forest ecosystems, will provide a common language for planning activities, assist with assignment of SFM values and development of management objectives.

- **Long term evaluation post-treatment –** Research on riparian buffers is usually completed over a short time frame. Long term evaluation of buffers (*e.g.* buffer persistence) and their ecological role on the landscape over time (*e.g.* as refugia or core habitat) is necessary.

7.0 General conclusions and key messages

We provide a series of suggestions and key messages regarding the management of riparian areas and shoreline forests in Canada *(Box 8).* Some authors have suggested that a paradigm shift might be in order to align the management of riparian areas with broader landscape level objectives including habitat availability and natural disturbance-based management approaches (Lee and Smyth 2003; Macdonald *et al.* 2006; Rodewald and Bakermans 2006). The development of a common understanding of the practices that represent movement toward increasingly sustainable practices and the ability to resolve conflicts based on different points of view will be critical to develop forward thinking riparian management strategies.

However, there is a lack of adaptive management experiments to support policy change. Thus a commitment to learning and adopting new knowledge quickly will also be necessary so that managers can implement the best current knowledge as it becomes available (Lindenmayer *et al.* 2000). This commitment will almost certainly require strategies to spread risk. This includes the use of a variety of harvest practices and management approaches for learning, including clear objectives and measures of success (Lindenmayer *et al.* 2000). Interdisciplinary teams should develop specific hypotheses about ecological functions of riparian areas and test these through monitoring and evaluation (Naiman *et al.* 2005) whenever possible.

The results of research, adaptive management experiments and extension activities will promote a common understanding of what constitutes good forestry in the boreal forest as well as promote improvements in “on the ground” forest management and practices. By definition, many of the same issues facing uplands and wetlands, lakes or streams also apply to riparian areas. Without a doubt the use of riparian buffers alone cannot be a substitute for the development of science-based, catchment-level management strategies and land use practices, but should be a component of landscape-level planning. Riparian areas remain one of the most poorly documented habitats on the boreal landscape and reflect the interface between terrestrial and aquatic systems. They are a critical consideration for any effort in integrated landscape management.

Box 8: Key Messages

- Linking ecological definitions to management definitions in riparian areas also increases guideline complexity.
- Guidelines are typically applied on the basis of waterbody size rather than a hydrological or ecological classification which reflects function.
- Flexible riparian guidelines are needed to address multiple, sometimes competing, objectives at a stand level and to address broader landscape scale planning considerations. However, flexibility in one policy arena (riparian guidelines) may require more specific targets in another (landscape level considerations). Policies and guidelines that provide strategic direction for future forest condition are needed.
- Enhanced hydrologic information, digital elevation maps and ecological classifications would facilitate accurate planning of buffer widths.
- The ecological functions of riparian areas used to develop many guidelines are often based on functional relationships from other regions. Further research to test assumptions and effectiveness monitoring is needed, particularly for the boreal plain.
- Although old forest retention strategies linked to riparian areas provide habitat for species that require older forest components, young riparian habitat is also required to maintain biodiversity.
- Biodiversity conservation strategies should ensure patches of upland old forest are distributed across the landscape in addition to older lowland patches in riparian areas. Planning and operational practices in riparian areas should be designed to promote variability in terms of seral class and vegetation communities.
- An adaptive management framework should be developed to assess guideline effectiveness and refine practices as required to meet management objectives.
- A growing body of research indicates it may not always be necessary to buffer riparian areas and disturbance may be beneficial in some cases.

8.0 References

Alberta Sustainable Resource Development. 2005. Review of Riparian Management Policy in Alberta's Forests. Alberta Sustainable Resource Development, Edmonton, Alberta.

Alberta Sustainable Resource Development. 2006. Alberta Timber Harvesting and Operating Ground Rules and Framework for Renewal. Alberta Sustainable Resource Development, Forestry Division, Forest Management Branch, Edmonton, Alberta. http://srd.alberta.ca/forests/managing/manuals

Andison, D.W. 2003. Tactical forest planning and landscape design. Chapter 12. In Towards Sustainable Management of the Boreal Forest. Edited by P.J. Burton, C. Messier, D.W.Smith and W.L. Adamowicz. NRC Research Press, Ottawa, Ontario. pp. 443-480.

Andison, D. W. and McCleary, K. 2002. Disturbance in riparian zones on foothills and mountain landscapes of Alberta. Alberta Foothills Disturbance Ecology Research Series. Foothills Model Forest, Hinton, AB.

Argyris, C. 1985. Action Science, Concepts, methods, and skills for research and intervention. San Francisco: Jossey-Bass.

Attiwill, P.M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. Forest Ecology and Management 63: 247-300.

Barnes, D.M. and Mallik, A.U. 1997. Habitat factors influencing beaver dam establishment in a Northern Ontario watershed. Journal of WIldlife Management 61: 1371-1377.

Barten, P. K. 2001. Riparian area management principles and practice: workshop summary report. Saskatchewan Environment and Resource Management, Forest Ecosystems Branch. Prince Albert, Saskatchewan 50p.

Bayley, S.E., Schindler, D.W., Beaty, K.G., Parker, B.R., and Stainton, M.P. 1992. Effects of multiple fires on nutrient yields from streams draining boreal forest and fen watersheds: nitrogen and phosphorous. Canadian Journal of Fisheries and Aquatic Sciences 49: 584-596.

Beckley, T. M., Parkins, J. R., and Sheppard, S. R. J. 2005. Public participation in sustainable forest management: a reference guide. Edmonton, Alberta, Sustainable Forest Management Network. Knowledge Exchange and Technology Extension Program (KETE).

Bedford, B.C. 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology 80: 2151-2162.

Bergeron, Y. and Harvey, B. 1997. Basing silviculture on natural ecosystem dynamics: an approach to the southern boreal mixedwoods of Quebec. For. Ecol.Manage. 92: 235-242.

Bergeron, Y., Engelmark, O., Harvey, B., Morin, H., and Sirois, L. 1998. Key issues in disturbance dynamics in boreal forests: introduction. Journal of Vegetation Science 9: 464-468.

Brand, R. and Karvonen, A. 2007. The ecosystem of expertise: complementary knowledges for sustainable development. Sustainability: Science, Practice, and Policy 3(1):21-31. http://ejournal.nbii.org/archives/vol3iss1/0601-004.brand.html.

Brosofske, K.D., Chen, J.Q., Naiman, R.J., and Franklin, J.F. 1997. Harvesting Effects on Microclimatic Gradients From Small Streams to Uplands in Western Washington. Ecological Applications 7: 1188-1200.

Bunnell, F., Dunsworth, G., Huggard, D., and Kremsater, L. 2003. Learning to sustain biological diversity on Weyerhaeuser's coastal tenure. Weyerhaeuser Company Ltd., Nanaimo, British Columbia.

Buttle, J.M., Creed, I.F. and Pomeroy, J.W. 2000. Advances in Canadian forest hydrology, 1995–1998. Hydrological Processes14:1571-1558.

Buttle, J.M. and Murray, C.D. 2007. Review of Research on the Forest-Water Interface in Canada. Report prepared for the Canadian Forest Service. Institute of Watershed Science, Trent Univ., Peterborough, ON. 38 p.

Canadian Council of Forest Ministers. 2006. Criteria and indicators of sustainable forest management in Canada: National status 2005. Natural Resources Canada, Canadian Forest Service, Ottawa. 154 p.

Calhoun, J. M. 1988. Riparian management practices of the Department of Natural Resources. Pages 207–211 In Streamside management: riparian wildlife and forestry interactions. K. Raedeke, editor. Contribution No. 59, Institute of Forest Resources, University of Washington, Seattle, Washington, USA.

Castelle, A. J., Johnson, A. W., and Conolly, C. 1994. Wetland and stream buffer size requirements–a review. Journal of Environmental Quality. 23:878-882.

Cumming, S.G. 2001. A parametric model of the fire-size distribution. Canadian Journal of Forest Restoration 31: 1297-1303.

Dale, V. H., Brown, S., Haeuber, R.A., Hobbs N.T., Huntly, N. , Naiman, R.J., Riebsame, W.E., Turner, M.G. and Valone, T.J. 2000. Ecological principles and guidelines for managing the use of land. Ecological Applications 10:639-670.

Darveau, M., Beauchesne, P., Bélanger, L., Huot, J., and Larue, P. 1995. Riparian forest strips as habitat for breeding birds in boreal forest. Journal of Wildlife Management 59: 67-77.

Degraaf, R.M. and Yamasaki, M. 2000. Bird and Mammal Habitat in Riparian Areas. Chpt.8. In Riparian management in forests of the continental eastern United States. Edited by E.S. Verry, J.W. Hornbeck, and A. Dolloff. Lewis Publishers, Boca Raton, Florida. pp. 139-156.

Denneler, B., Bergeron, Y., and Bégin, Y. 1999. An attempt to explain the distribution of the tree species composing the riparian forests of Lake Duparquet, southern boreal region of Quebec, Canada Canadian Journal of Botany 77: 1744–1755.

Department of Fisheries and Oceans. 1986. The Department of Fisheries and Oceans policy for the management of fish habitat. http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/legislation-lois/policies/fhm-policy/index_e.asp?print

Devito, K.J., Creed, I. F., Rothwell, R. L. and Prepas, E. E. 2000. Landscape controls on phosphorus loading to boreal lakes: implications for the potential impacts of forest harvesting Canadian Journal of Fisheries and Aquatic Sciences 57:1977-1984.

Devito, K.J., Creed I.F., Fraser, C. 2005a. Controls on runoff from a partially harvested aspen forested headwater catchment, Boreal Plain, Canada. Hydroogical Processes. 19: 3-25.

Devito, K., Creed, I., Gan, T., Mendoza, C., Petrone, R., Silins, U., and Smerdon, B. 2005b. A framework for broad-scale classification of hydrologic response units on the Boreal Plain: is topography the last thing to consider? Hydrological Processes 19: 1705-1714.

DeYoe, D. and C. Hollstedt. 2004. A knowledge exchange system: putting innovation to work. British Columbia Journal of Ecosystems Management 4 [online]. http:://www.forrex.org/jem/2004/vol4/no1/art4.pdf

Donnelly, M. 2003. Ecologically-based forest planning and management for aquatic ecosystems in the Duck Mountains, Manitoba. Journal of Environmental Engineering and Science 2: S35-S40.

Dwire, K.A. and Kauffman, J.B. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178: 61-74.

Everett, R., Schellhaas, R., Ohlson, P., Spurbeeck, D., and Keenum, D. 2003. Continuity in fire disturbance between riparian and adjacent sideslope Douglas-fir forests. Forest Ecology and Management 175: 31-47.

Fazey, I., Fazey, J.A., Salisbury, J.G., Lindenmayer, D.B., and Dovers, S. 2006. The nature and role of experiential knowledge for environmental conservation. Environmental Conservation 33: 1-10.

Fischer, R. A., Martin, C. O., and Fischenich, J. C. 2000. Improving riparian buffer strips and corridors for water quality and wildlife. International conference on riparian ecology and management in mutli-land use watersheds: American Water Resource Association.

Fischer J. Lindenmayer, D.B. and Manning, A.D. 2006. Biodiversity, ecosystem function and resilience: ten guiding principles for commodity production landscapes. Frontiers in Ecology 4:80-86.

France, R., Culbert, H., and Peters, R. 1996. Decreased carbon and nutrient input to boreal lakes from particulate organic matter following riparian clear-cutting. Environmental Management 20: 579-583.

Franklin, J.F. 1997. Ecosystem Management: an overview. In Boyce, M.S. and Haney, A. Eds., Ecosystem Management. Yale University Press, New Haven, CT. Pg 21 - 53.

Gabor, T. S, Murkin, H. R., Ingram, J. W., Clay, R. T., and Maher, R. F. 1999. Beaver pond management assessment program. Institute for Wetland and Waterfowl Research, Ducks Unlimited Canada.

Gauthier, S., Vaillancourt, M.-A., Kneeshaw, D., Drapeau, P., DeGrandpre, L., Claveau, Y. and Bergeron, Y. 2009. Forest ecosystem management : Origins and foundations. In Ecosystem Management in the Boreal Forest. Edited by Gauthier, S., Vaillancourt, M.-A., Leduc, A., DeGrandpre, L., Kneeshaw, D., Morin, H., Drapeau, P., and Y. Bergeron. Les Presses de l'Universite du Quebec, Quebec, Quebec. pp.13-37.

Gregory, K. J., and Davis, R. J. 1993. The perception of riverscape aesthetics: an example from two Hampshire rivers: Journal of Environmental Management 39:171-185.

Gregory, S.V., Swanson, F.J., McKee, W.A., and Cummins, K.W. 1991. An ecosystem perspective of riparian zones focus on links between land and water. BioScience 41: 540-551.

Groom, J.D. and Grubb Jr., T.C. 2002. Bird species associated with riparian woodland in fragmented, temperate-deciduous forest. Conservation Biology 16:832-836.

Gunn, J.M., Steedman, R.J., and Ryder, R.A. 2004. Boreal Shield Watersheds: Lake Trout Ecosystems in a Changing Environment. Lewis Publishers, New York, USA.

Hannon, S.J., Paszkowski, C.A., Boutin, S., DeGroot, J., Macdonald, S.E., Wheatley, M., and Eaton, B.R. 2002. Abundance and species composition of amphibians, small mammals, and songbirds in riparian forest buffer strips of varying widths in the boreal mixedwood of Alberta. Canadian Journal of Forest Research 32: 1784-1800.

Hanowski, J., Danz, N., and Lind, J. 2007. Breeding bird response to riparian forest management: 9 years post-harvest. Forest Ecology and Management 241: 272-277.

Harper, K.A. and MacDonald, S.E. 2001. Structure and composition of riparian boreal forests: new methods for analyzing edge influence. Ecology 82: 649-659.

Hogarth, R. M. 1987. Judgement and choice: The psychology of decision (2nd ed.). Oxford, England: John Wiley & Sons. xii, 311 pp.

Huggard, D. 2004. Establishing Representative Ecosystems within a Managed Forest Landscape: an approach to assessment of non-harvestable areas. Knowledge Exchange and Technology Extension Program (KETE), Sustainable Forest Management Network, Edmonton, Alberta. 31 pp.

Hunt, L.M. and Haider, W. 2004. Aesthetic impacts of disturbances on selected boreal forested shorelines. Forest Science 50: 729-738.

Hunter Jr., M.L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biological Conservation 65: 115-120.

Ilhardt, B.L., Verry, E.S., and Palik, B.J. 2000. Defining riparian areas. In Riparian management in forests of the continental eastern United States. Edited by E.S. Verry, J.W. Hornbeck, and A. Dolloff. Lewis Publishers, Boca Raton, Florida. pp. 23-42.

Johnson, E.A., Miyanishi, K., and Weir, J. M. H. 1998. Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management Journal of Vegetation Science 9: 603-610.

Kimmins, J.P. 2004. Forest ecology: a foundation for sustainable forest management and environmental ethics in forestry. Prentice Hall, Upper Saddle River, New Jersey. 611p.

Landres, P.B., Morgan, P., and Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecol. Appl. 9: 1179–1188.

LaRue, P., Bélanger, L., and Huot, J. 1995. Riparian edge effects on boreal balsam fir bird communities. Canadian Journal of Forest Research 25: 555-566.

Lee, K.N. 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press. Washington, D.C.

Lee, P. and Barker, T. 2005. Impact of riparian buffer guidelines on old growth in western boreal forests of Canada. Forestry 78:263-278.

Lee, P. and Smyth, C. 2003 Riparian forest management: paradigms for ecological management and practices in Alberta. Report produced by the Alberta Research Council (Vegreville, Alberta) and the Alberta Conservation Association (Edmonton, Alberta) for the Northern Watershed Project Stakeholder Committee. Northern Watershed Project Final Report No. 1.

Lee, P., Smyth, C., and Boutin, S. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70: 165-180.

Lewis, J.L. and Sheppard, S.R.J. 2006. Culture and Communication: Can Landscape Visualization Improve Forest Management Consultation With Indigenous Communities? Landscape and Urban Planning 77: 291-313.

Lindenmayer, D.B. and Franklin, J.F. 2002. Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Island Press. Washington. 342 pp.

Lindenmayer, D.B., Margules, C.R., and Botkin, D.B. 2000. Indicators of biodiversity for ecologically sustainable forest management. Conservation Biology 14: 941-950.

Lowrance, R., R. Leonard and Sheridan, J. 1985. Managing riparian ecosystems to control nonpoint pollution. Journal of Soil and Water Conservation 40(1): 87-91.

LP Canada Ltd. 2006. 20 Year Sustainable Forest Management Plan. Swan Valley Forest Division, Swan River, MB.

Lynam, T., Bousquet, F., Le Page, C., d'Aquino, P., Barreteau, O., Chinembiri, F., and Mombeshora, B. 2002. Adapting science to adaptive managers: spidergrams, belief models, and multi-agent systems modeling. Conservation Ecology 5: Article 24.

Macdonald, J.S., Beaudry, P.G, MacIsaac, E.A., and Herunter, H.E. 2003. The effects of forest harvesting and best management practices on streamflow and suspended sediment concentrations during snowmelt in headwater streams in sub-boreal forest s of British Columbia, Canada. Canadian Journal of Forest Research 33: 1397-1407.

Macdonald, E., Burgess, C.J., Scrimgeour, G.J., Boutin, S., Reedyk, S., and Kotak, B. 2004. Should riparian buffers be part of forest management based on emulation of natural disturbance? Forest Ecology and Management 187: 185-196.

Macdonald, S.E., Eaton, B., Machtans, C.S., Paszkowski, C., Hannon, S., and Boutin, S. 2006. Is forest close to lakes ecologically unique? Analysis of vegetation, small mammals, amphibians, and songbirds. Forest Ecology and Management 223: 1-17.

Machtans, C. S., Villard, M-A, and Hannon, S. J. 1996. Use of riparian buffer strips as movement corridors by forest birds. Conservation Biology 10:1366-1379 .

Manitoba Conservation. 2008. Forest Management Guidelines for Riparian Management Areas. Forest Practices Guidebook. Manitoba Conservation, Winnipeg, MB.

Manitoba Natural Resources. 1996. Manitoba Natural Resources Consolidated Buffer Management Guidelines. Manitoba Natural Resources. Winnipeg, MB.

Martell K., Foote A.L., and Cumming, S.G. 2006. Riparian disturbance due to beavers (Castor canadensis) in Alberta's boreal mixedwood forests: Implications for forest management. Ecoscience 13: 164-171.

McAfee, B. and Malouin, C. 2005. Conservation lands: integrating conservation and sustainable management in Canada's forests. Ottawa, Canada, Natural Resources Canada, Canadian Forest Service, Science and Programs Branch.

McDonnell, J.J. 2003. Where does water go when it rains? Moving beyond the variable source area concept of rainfall-runoff responses. Hydrological Processes 17: 1869-1875.

McGarigal, K. and McComb, W. 1992. Streamside versus upslope breeding bird communities in the central Oregon Coast Range. Journal of Wildlife Management 56: 10-23.

Naiman, R.J. and Décamps, H. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28: 621-658.

Naiman, R.J., Melillo, J.M., and Hobbie, J.E. 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). Ecology 67: 1254-1269.

Naiman, R.J., Décamps, H., and McClain, M.E. 2005. Riparia - ecology, conservation, and management of streamside communities. Elsevier Academic Press, Burlington, MA.

National Council for Air and Stream Improvement, Inc, (NCASI). 2007. Synthesis of technical information on forest wetlands in Canada. Technical Bulletin no (38). Research Triangle Park, N.C. National Council for Air and Stream Improvement Inc.

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Effects of Forest Management on Water Resources in Canada: A Research Review. Technical Bulletin No. 0969. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

National Research Council. 2008. Hydrologic effects of a changing forest landscape. Committee on Hydrologic Impacts of Forest Management, National Research Council. National Academies Press, Washington, D.C. 168 pp.

Nitschke, C.R. 2005. Does forest harvesting emulate fire disturbance? A comparison of effects of selected attributes in coniferous-dominated headwater systems. Forest Ecology and Management 214: 305-319.

Norton, M.R., Hannon, S.J., and Schmiegelow, F.K.A. 2000. Fragments are not islands: patch vs landscape perspectives on songbird presence and abundance in a harvested boreal forest. Ecography 23: 209-223.

Omernik, J. and Bailey, R. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association 33:935-949.

Ontario Ministry of Natural Resources. 2001. Forest management guide for natural disturbance pattern emulation, Version 3.1. Ont. Min. Nat. Res., Queen's Printer for Ontario, Toronto. 40 p.

Ontario Ministry of Natural Resources. 2010. Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales. Toronto: Queen's Printer for Ontario. 211 pp.

Palik, B., Zasada, J. and Hedman,C. 2000. Ecological considerations for riparian silviculture. Pages 233–254 in E. Verry, J. W. Hornbeck, and C. A. Dolloff, editors. Riparian management in riparian forests of the continental eastern United States. Lewis Publishers, CRC Press, Boca Raton, Florida, USA.

Perera, A.H. and Buse, L.J. 2004. Emulating natural disturbance in forest management: an overview. Chapter 1. In Perera, A.H., Buse, L.J. and M.G. Weber, editors. 2004. Emulating natural forest landscape disturbances: concepts and applications. Columbia Univ Press NY, NY. USA. pp. 3-7.

Pierre, J.P., Bears, H., and Paszowski, C.A. 2001. Effects of forest harvesting on nest predation in cavity-nesting waterfowl. The Auk 118: 224-230.

Pomeroy, J.W., Granger, R.J., Pietroniro, A., Elliott, J.E., Toth, B., and Hedstrom, N., 1997. Hydrological Pathways in the Prince Albert Model Forest. Final Report to the Prince Albert Model Forest Association. National Hydrology Research Institute, Environment Canada: Saskatoon, SA; 154 + appendices. In Buttle, J.M. and C.D. Murray. 2007. Review of Research on the Forest-Water Interface in Canada. Report prepared for the Canadian Forest Service. Institute of Watershed Science, Trent Univ., Peterborough, ON. 38 pp.

Porter, J.D. 1887. Forestry in Europe: Reports from the Consuls of the United States. United States Government Printing Office, Washington District of Columbia.

Quintillio, D., Alexander, M.E., and Ponton, R.L. 1991. Spring fires in a semi-mature trembling aspen stand in central Alberta Canadian Forest Service, Northern Forestry Center Information Report NOR-X-323 Northern Forestry Center, Edmonton, Alberta.

Raedecke K.J. Ed. (1988). Streamside Management: Riparian Wildlife and Forestry Interactions. Contributed paper Number 59. Forest Resources Institutes, College of Forest Resources, University of Washington, Seattle.

Rempel, R.S. and Donnelly, M. 2010. A Spatial Landscape Assessment Modeling Framework for Forest Management and Biodiversity Conservation. Sustainable Forest Management Network, Univ. of Alberta, Edmonton, AB.

Rodewald, A.D. and Bakermans, M.H. 2006. What is the appropriate paradigm for riparian forest conservation? Biological Conservation 128: 193-200.

Sabo, J.L., Sponseller, R., Dixon, M., Gade, K., Harms, T., Heffernan, J., Jani, A., Katz, G., Soykan, C., Watts, J., and Welter, J. 2005. Riparian zones increase regional species richness by harboring different, not more, species. Ecology 86: 56-62.

Saskatchewan Ministry of Environment. 2009. Weyerhaeuser Prince Albert FMA Area: Standard and Guidelines. 73 pp. http://www.environment.gov.sk.ca/

Sibley, P.K., and Gordon, A.M. 2010. Managing Riparian Forests: a decision support system. Sustainable Forest Management Network. Edmonton, AB.

Stankey, G.H., Bormann, B.T. and Clark, R.N. 2006. Learning to manage a complex ecosystem: adaptive management and the Northwest Forest Plan. U.S. Dept.Agric., Forest Serv, Pacific Northwest Res. Stn, Res.Paper PNW-RP-567. 194 pp.

Stauffer, D.F. and L.B. Best 1982. Nest-site selection by cavity-nesting birds of riparian habitats in Iowa. The Wilson Bulletin 94: 329-337.Steedman, R.J. 2000. Effects of experimental clearcut logging on water quality in three small foreal forest lake trout (Salvelinus namaycush) lakes. Canadian Journal of Fisheries and Aquatic Sciences 57 (Suppl.2):92-96.

Steedman, R.J. and France, R.L. 2000. Origin and transport of Aeolian sediment from new clearcuts into boreal lakes, northwestern Ontario, Canada. Watr Air and Soil Pollution 122: 139-152.

Steedman, R.J., R.S. Kushneriuk, and R.L. France. 2001. Littoral water temperature response to experimental shoreline logging around small boreal forest lakes. Can. J. Fish. Aquat. Sci. 8:1638-1647.

St-Onge, I. and P. Magnan. 2000. Impact of logging and natural fires on fish communities of Laurentian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences 57 (Suppl.2):92-96.

Suffling, R., Smith, B., and Dal Molin, J. 1982. Estimating past forest age distributions and disturbance rates in North-western Ontario: a demographic approach. Journal of Environmental Management 14: 45-56.

The Forestry Corps. 2004. Review of Forest Management Practices for protection of water related resources in the boreal and taiga plain western Canada. Prepared for Ducks Unlimited Canada. Edmonton, AB.

Weyerhaeuser Saskatchewan. 1999. 20 Year Strategic Forest Plan for the Prince Albert, SK Forest Management Area. Weyerhaeuser Sask, Prince Albert, SK.

Whitaker, D.M., Carroll, A.L., and Montevecchi, W.A. 2000. Elevated numbers of flying insects and insectivorous birds in riparian buffer strips. Canadian Journal of Zoology 78: 740-747.

Whitaker, D.M. and Montevecchi, W.A. 1997. Breeding bird assemblages associated with riparian, interior forest, and nonriparian edge habitats in a Balsam fir ecosystem. Canadian Journal of Forest Research 27: 1159-1167.

Wright, J.P., Jones, C.G., and Flecker, A.S. 2002. An ecosystem engineer, the beaver, increases species richness at the landscape level. Oecologia 132: 96-191.

Sustainable Forest Management Network
3-03 Civil Electrical Engineering Building
University of Alberta
Edmonton, Alberta T6G 2G7
CANADA
Phone: (780) 492-6659
Fax: (780) 492-8160
Email: info@sfmnetwork.ca

www.sfmnetwork.ca