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Water Quality, Biodiversity and Codes of Practice in Relation to Harvesting Forest Plantations in Streamside Management Zones

Daniel G. Neary[1], Philip J. Smethurst[2], Brenda Baillie[3], and Kevin C. Petrone[4]

August 2011

[1]CSIRO Ecosystem Sciences, Hobart, Tasmania, Australia; and U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona, USA

[2]CSIRO Ecosystem Sciences, and CRC for Forestry, Private Bag 12, Hobart, Tasmania, Australia; Tel: +61 3 6237 5653; Email: Philip.Smethurst@csiro.au

[3]SCION, Rotorua, New Zealand

[4]CSIRO Ecosystem Sciences and Landscape Logic CERF, Perth, Western Australia

Cover Photo: Two types of streamside management zone (SMZ) plantations are shown, both of which include fences to exclude livestock. In the foreground the SMZ was planted with *Acacia melanoxylon* (blackwoods) and not intended for commercial wood production. In the background is an SMZ containing commercial 20-year-old *Eucalyptus nitens* that was harvested and reported in Neary et al. (2010), which is cited in this report. Photo by P. Smethurst.

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Contents

1. SUMMARY

Streamside management zones (SMZs) are special landscape units that include riparian areas and adjacent lands that mitigate the movement of sediment, nutrients and other chemicals from upland forest and agricultural management areas into streams. The size, shape, and management of SMZs are governed by various combinations of economic, ecological, and regulatory factors. Although SMZs used around the world have a wide range of widths, in many cases they are similar at 5-20 m.

Streamside management zones are important barriers or treatment areas that protect water resources from non-point source pollution. Vegetation and the geomorphic characteristics of SMZs result in infiltration, filtering, and deposition from sediment- and nutrient-laden water flowing off intensively managed forestry, agriculture, and urban lands. The effectiveness of SMZs for trapping sediment depends upon the velocity of water flow, size distribution of sediments, slope and length of slope above the SMZ, slope and length of the SMZ itself, depth of water flow into the SMZ, and vegetation characteristics such as type, density, and height. Nutrient removal is a function of SMZ width, runoff water residence time in the SMZ, the vigor of SMZ vegetation, and the amount of runoff water infiltrated into the soil during its transit of the SMZ.

This report examines important SMZ processes and illustrates them with examples from forest management operations and agriculture. A number of international case studies are used to illustrate the effectiveness of SMZs in protecting water quality and biodiversity. The report provides a review of codes of forest practice internationally as they relate to SMZs, with a focus on Australia, New Zealand, and the USA. Some codes from Canada, Europe and Asia are also cited. This report includes an emphasis on an aspect of SMZs that has previously not been reviewed to this extent, i.e. the effects of harvesting forests within SMZs. A literature search on harvesting in SMZs highlighted the limited amount of scientific research on harvesting in SMZs in the farm forestry (agro-forestry) context. Scientific research on harvesting activities in SMZs is largely confined to large plantation forest estates.

Our review indicates that:

1. Harvesting of tree stands within SMZs, if conducted carefully using best management practices (BMPs), can occur without substantial detrimental effects on water quality.

2. Not only can there be a lack of a within-SMZ harvesting effects on water quality, but the establishment of SMZ plantations in an agricultural landscape can provide considerable water quality, biodiversity and other farm benefits.

3. Managers of agricultural landscapes can be reassured that forested and grassed SMZs can be successfully integrated into farming operations for multiple benefits.

4. Use of SMZ plantations are a realistic option for agriculture and forestry, because they can be established and harvested with little risk to water quality.

2. INTRODUCTION

Streamside Management Zones have been used for decades to buffer the potential adverse effects of agricultural and silvicultural practices on adjacent surface water quality (Comerford et al. 1992). The concept is quite old, dating to the 1700s (Porter 1887, cited in Lee et al. 2004). Streamside Management Zones came into common use in the 1960s to improve water quality by functioning as barriers or treatment zones to protect adjoining water resources from disturbances associated with agriculture and forestry (Figure 1). They are one of the most effective tools for reducing nonpoint source pollution from managed landscapes (Phillips 1989b).

In agricultural and forestry landscapes, the concept of an SMZ implies active management during some or all phases the zone's life cycle. Active management includes areas that may be designated as "undisturbed" trees, shrubs, or herbaceous plants. These zones could have management plans that provide for no or infrequent disturbances such as prescribed fire and thinning that are needed to maintain them in a vegetative condition conducive to achieving the overall objectives of the SMZ. The key to the concept of an SMZ is that it is actively managed and not necessarily allowed to exist passively as a "hands off" reserve that develops towards some ecological end-point.

Active management of an SMZ containing a plantation forest entails harvesting and replanting during each plantation cycle. These operations usually include thinning or clearcutting, cultivation and replanting. However, there is concern that these operations might compromise the purpose of the SMZ and put at risk the water quality and other benefits provided by SMZs.

Some of the key points regarding SMZs that are highlighted in this report are:

1. SMZs have been recognised as an effective way to buffer the impacts of various land uses on surface water quality
2. They typically consist of a strip of land of variable width, around the stream, which is actively managed to reduce the transport of non point source pollutants to streams
3. The more that SMZs can be utilised in forestry and agricultural landscapes the better water quality is likely to be (with the exception of some saline landscapes where they may inhibit dilution of salt). There may also be benefits for biodiversity in either retaining native vegetation, or planting species with known value to local wildlife.
4. Impediments to the introduction of SMZs are primarily cost – the opportunity cost associated with setting aside productive land, and the costs of isolating/fencing, planting, managing and maintaining SMZs. If these costs could be offset by wood production, then developing SMZs may have wider appeal – particularly on farmland with resultant benefits for the environment.
5. In both Australia and internationally there are policies, legislation and codes of practice that either prescribe how harvesting may occur within SMZs or may prevent SMZs being used for wood production purposes,
6. There is also significant literature describing the impacts of harvesting on water resources.
7. This document reviews literature to:
    a. Describe the processes by which SMZs buffer nonpoint source pollutants
    b. Describe the effects of harvesting in SMZs on water quality and biodiversity
    c. Review SMZ harvesting guidelines in Australia, NZ, USA and elsewhere

These processes, results, and guidelines are needed by land managers to form conclusions about the potential for SMZs to be specifically designed for a combination of environmental benefits including and timber production. It is hoped that this publication will further the understanding of the benefits of SMZs and guide their incorporation into agricultural, forestry, and urban landscapes.

2.1 Objectives

The objectives of this publication are three-fold:

1. Develop an overview of SMZ buffering functions for nonpoint source pollutants.
2. Review the scientific literature on SMZ harvesting effects on water quality and biodiversity.
3. Review SMZ harvesting guidelines in Australia, New Zealand, the USA, and several other countries.
4. Evaluate water quality and biodiversity effects of harvesting SMZ forest plantations in the context of an agroforestry landscape.

2.2 Definitions

Part of the confusion relative to these special landscape units like SMZs is the terminology associated with them. The objective of this section is to clarify these definitions. Understanding any concept and accompanying literature is ultimately based on knowledge of the descriptive terminology used. Therefore it is appropriate to begin by discussing the terms used in the literature to describe SMZs, since there is a lack of uniformity in how these near-stream landscape units are named. A variety of terms are used to describe SMZs. In this document, an SMZ is synonymous with commonly used terms such as "buffer strips", "filter strips", "riparian zones", "riparian buffers", "riparian management zones", "wetlands", "greenways", "grassed waterways", and "streamside management zones".

2.2.1 Buffer Strips

This term is commonly used to describe the transition between two different land uses where one land use, the buffer, mitigates the effects of the other (Karr and Schlosser 1978, Comerford et al. 1992). Buffer strips allow runoff and its pollutant load to be reduced before reaching surface waters by filtering, deposition, infiltration, adsorption, uptake, and decay.

2.2.2 Filter Strips

This term is often used synonymously with "buffer strips". Its focus is on the function of filtering pollutants that leave upland portions of landscapes. Filter strips are usually viewed as zones to remove (filter) sediment from runoff (Cooper et al. 1987), but will also remove nutrients like nitrate nitrogen if they are wide enough (Lowrance et al. 1984).

2.2.3 Riparian Zones

This terminology has variants in "Riparian Buffers", and "Riparian Management Zones" that imply the same concept. Riparian zones are transition zones between upland and aquatic ecosystems that are under the influence of shallow groundwater (Mitsch and Gosselink 2007). Technically, riparian zones are those that meet the definition of "riparian". They can vary from a few metres wide to hundreds of metres. Often, the term "Riparian Management Zone" is used to broaden the concept beyond that of a buffer (Lowrance et al. 1985).

Figure 1. Streamside Management Zone of the South Esk River, Tasmania, Australia (Photo by Daniel G. Neary).

2.2.4 Greenways and Grassed Waterways

These are specialized grass or herbaceous plant zones along first- and second-order drainage areas in agricultural landscapes (Figure 2, USDA ARS 1987). They are sometimes used in forested areas, but not very frequently. In general, grassed waterways have a high potential for reducing runoff volume and velocity, sediment transport, and chemicals coming from agricultural watersheds (Fiener and Auerswald 2003).

2.2.5 Wetlands

This term is often used interchangeably with riparian. Wetlands are discussed in detail by Mitsch and Gosselink (2007). Although it also describes land that is transitional between terrestrial and aquatic ecosystems, there are a number of distinctions which really set wetlands apart from other landscape units. Cowardin et al. (1979), in their classification of USA wetlands, defined the term as referring to lands where the water table is at or near the surface or the land is covered by shallow water. For the classification system that they used, wetlands have the following distinct attributes: (1) they support hydrophytic plants, (2) they contain predominantly hydric soils, and (3) they are water saturated or covered by water during part of the growing season (Figure 3). In the complete absence of active land management (e.g. wilderness, National Parks, special reserves, etc.), wetlands and riparian areas provide the functions that SMZs do in managed landscapes.

2.2.6 Streamside Management Zones

The size, shape, and management of these landscape units are determined by various combinations of economic, ecological, and regulatory factors (Williams et al. 2003). It can include riparian as well as upland areas (Phillips et al. 1999). The term encompasses all potential functions and management objectives for landscape units adjacent to streams. Thus, it is not tied to the hydrologically functional area of the riparian zone since it can include parts of upland areas, and it includes functions other than buffering. For these reasons, it is a preferable term to define the managed landscape units along streams (Figure 4).

2.3 Components of SMZs

An SMZ consists of a stream channel, perennial or intermittent, and parallel bands or zones moving outward from the channel onto the adjacent uplands (Figure 5). *Perennial* streams have a well defined channel and flow year-round, except during periods of extreme drought. *Intermittent* streams have a seasonal flow and a continuous well-defined channel. *Ephemeral* streams flow during and for a few hours or days after periods of heavy rain, and the stream channel is less recognizable than either perennial or intermittent streams.

Streamside Management Zones can consist of forest or herbaceous vegetation. A *"Three-Sub-zone Concept"* provides a framework for planning, establishing, and maintaining a long-term riparian forest SMZ (Welsch 1991). The first sub-zone out from the stream might be an undisturbed zone of varying width or it might be absent. An important part of the concept of an SMZ is that an informed management decision is made to include or exclude this first sub-zone as a component of the SMZ depending on site conditions, waterway conditions, or management objectives. It is not an "automatic" component. The important structural component in Sub-zone 1, adjacent to the water's edge, is a mixture of fast- and slow-growing native trees, including both overstory and understory species. If the stream is narrow, at maturity the tree canopy from both sides of the stream will meet or nearly meet. However, this first zone can be composed of sedges and other hydrophilic plants and still be fully functional. Trees are not an absolute necessity, because they might not be part of the natural condition, and they do not necessarily have to overhang the stream. However, this sub-zone should be free of weed species that might colonize the site. The second sub-zone, the most important vegetation band, consists of the managed tree vegetation of variable width depending on slope or management objectives. Sub-zone 2 can be designed for uses such as wood production (pulpwood or sawtimber), outdoor recreation, wildlife habitat, or alternative forestry products (ginseng, mushrooms, nuts, etc.). Livestock may or may not be excluded from this sub-zone depending on the SMZ objectives. Sub-zone 2 may or may not be followed by a managed grass strip (sub-zone 3) which functions as a lower gradient runoff control zone. Catchment slope limits the potential size and configuration of sub-zone 3. Dense grasses and/or *forbs* (broad-leaved herbaceous plants and wildflowers) often occupy sub-zone 3. Vegetation must be managed to promote nutrient uptake and sediment filtering. Conservation reserves are often placed in sub-zone 3 (Schultz et al. 2009). Managed grassland, pasture, cropland, or forest occupies the remainder of the landscape.

Figure 2. Grassed waterway in: a) Marshall County, Iowa, USA (Photo courtesy of USDA Natural Resources Conservation Service) and b) central Tasmania (Photo by Daniel G. Neary).

a)

b)

Streamside management zones can encompass stream, riparian zone and upland areas (Figure 6). The size and boundaries are governed by stream, riparian, and landscape configurations as well as management goals and desirable functions. Although there are general guidelines on SMZ sizes, they do not need to follow rigorous size prescriptions. Management objectives and desired functions should guide the sizing of SMZs. Some Codes of Forest Practice and regulatory guidance do employ strict size requirements.

3. SMZ FUNCTIONS, PROCESSES AND LIMITATIONS

3.1 Functions

Streamside management zones provide a number of important functions in ecosystems (Welsch 1991, Table 1). They fall into the broad categories of water quality protection, streamflow maintenance, geomorphic stability, flora and fauna habitat, and social and economic benefits. These zones are more frequently viewed and valued in terms of their water quality benefits. While those functions are important, SMZs in an agricultural and forestry landscape provide important socio-economic functions which are important for their incorporation as a BMP.

The main water quality functions provided by SMZs are maintenance of low temperatures where vegetation is tall enough to generate shade, filtration and deposition of sediments, nutrient and chemical processing, detention of contaminants, plant uptake of nutrients, transformations of nitrogen compounds, and reduction of macrophyte growth (Table 1, Schultz et al. 2009). Sediment detention is the most commonly sought after function of SMZs. Streamside management zones are viewed as a good practice to prevent contamination of streams with pesticide residues although they are not 100% effective (Neary et al. 1993, Neary and Michael 1996, Maltby and Hills 2008)

Streamside management zones have important hydrologic and geomorphic functions. Although SMZ vegetation uses water, it is important for storing water for release later as baseflow (Schultz et al. 2009). Over-bank flows are important for reducing flood peaks. Vegetation in SMZs reduces channel erosion by stabilizing banks. However, there are some conditions where vegetation along the edge of channels can contribute to excess bank scour and erosion (Ffolliott et al. 2003).

An important function of SMZs is providing habitat for both floral and faunal species. This function can be provided by both forested and herbaceous SMZs. It contributes greatly to landscape biodiversity, especially in semi-arid environments (Baker et al. 2004). Streamside management zones provide important landscape connections and cover for terrestrial wildlife as well as habitats for aquatic species.

The social and economic benefits of forested SMZs in agroforestry landscapes have been recognized as very important for agriculture (Correll 2005, Specht and West 2003, Reid and Burk 2002, Table 1). Some of the key functions are:

- Improved aesthetics and property values
- Improved stock safety and management of gullies
- Provision of shelterbelts for stock protection
- Certification of farm products for environmental standards
- Wood sales

- Carbon and other greenhouse gas credits
- Improved water quality for stock and human contact
- Soil conservation
- Increased native habitat

The function of providing a future wood supply and source of income for farmers is one of several incentives for farmers to establish tree plantations along drainages, streams, lakes, and wetlands. At some point in time these plantations will need harvesting, but in an environmentally sound manner. Existing BMPs are designed to achieve that goal.

Figure 3. Two Australian wetlands (Photos courtesy of CSIRO).

a)

(b)

Figure 4. Streamside Management Zone in New Zealand (Photo courtesy of SCION).

Figure 5. A typical 3-zone SMZ design for agroforestry (adapted from University of Missouri Center for Agroforestry 2006). Zone 1 contains native species suitable for bank stabilisation and ecosystem functions. Zone 2 contains trees and shrubs to be managed for multiple benefits including wood and other values. Zone 3 contains grasses that filter sediment. If the farm includes livestock, a fence is required on the outside of zone 3.

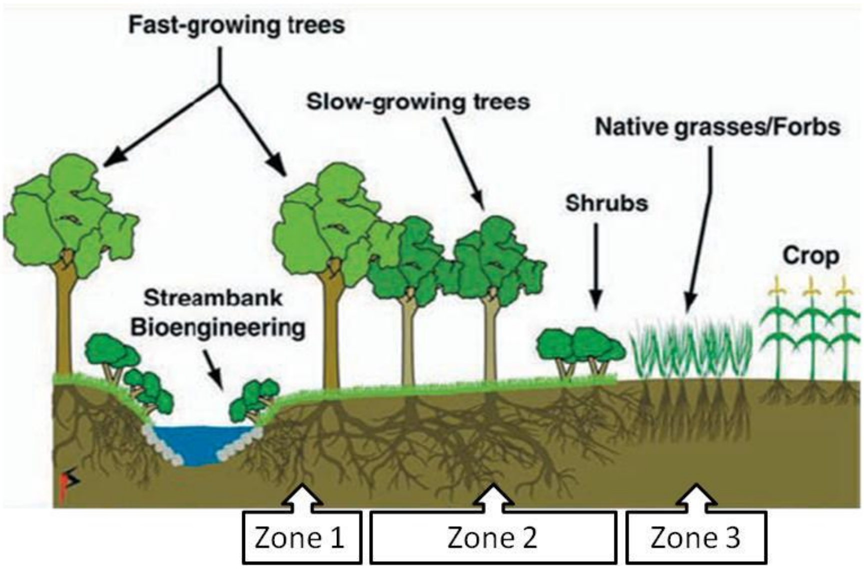


Figure 6. Hypothetical SMZ design (from Neary et al. 2010).

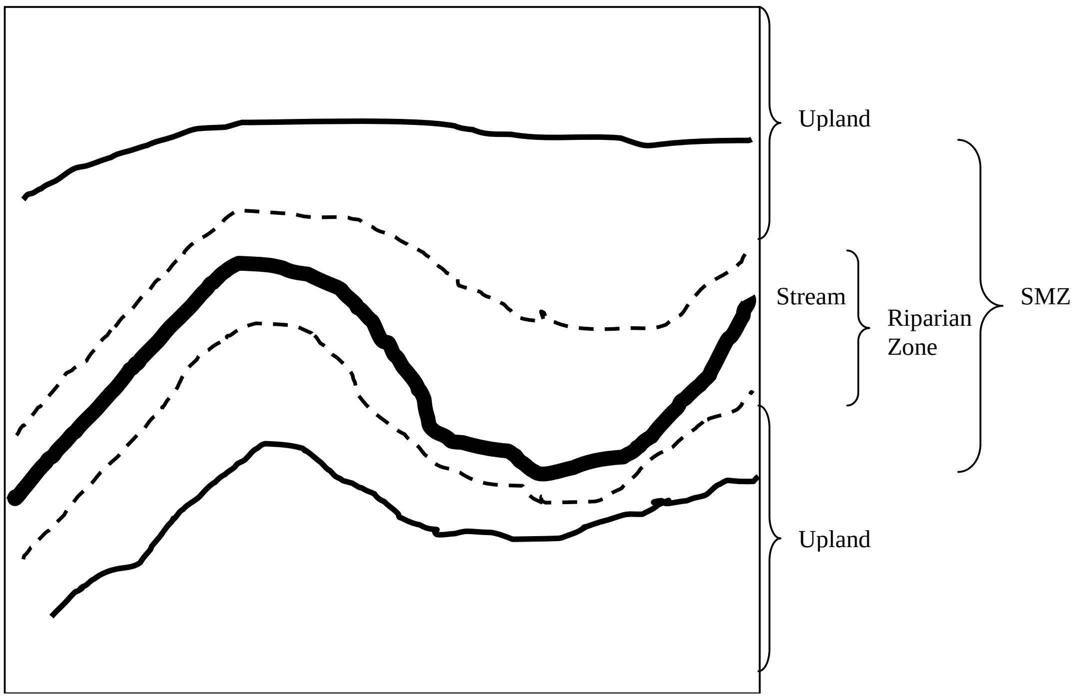


Table 1. Streamside Management Zone functions (Neary et al. 2010; adapted from U.S. Army Corps of Engineers 1991, Comerford et al. 1992, Lowrance et al. 1997, Corell 2005, Mander et al. 2005).

Category	Component	Function
Water Quality Protection	Temperature	Low temperature maintenance
	Sediment	Filtration and deposition
	Contaminants	Detention, adsorption, degradation
	Nutrients	Detention in sediments
		Plant uptake
		Transformations
	Macrophytes	Reduce growth
Streamflow Enhancement	Baseflow	Water storage
		Flow maintenance during dry periods
	Floods	Water storage
		Peakflow reduction
Geomorphic Stability	Streambanks	Bank stabilization
		Stream erosion reduction
	Streambeds	Scour reduction
	Uplands	Wind erosion reduction
Flora and Fauna Benefits	Terrestrial Habitat	Provide productive habitat
		Provide movement corridors and connectivity
		Enhance landscape biodiversity
		Create new habitats
	Aquatic Habitat	Moderate temperature
		Provide stable substrates
		Maintain streamflow
		Create new habitats
	Food Webs	Provide organic energy source
Atmosphere Improvement	Air Quality	Filter pollutants and odors
		Improve adjacent microclimate
Social / Economic Benefits	Floods	Reduce damaging peakflows
	Aesthetics	Provide “greenbelt” and vegetation screens
	Real Estate	Improve farm property values
	Environment	Increase carbon sequestration
	Recreation	Provide recreational sites
	Agriculture	Provide livestock shelter
		Provide forage and water
		Provide livestock security
		Aid certification of farm products
		Provide a source of wood products and income
		Conserve soil resources
		Provide farm carbon credits

3.2 Processes

There are a number of physical, chemical, and biological processes in SMZs that provide the desired functions for land managers (Table 1). The following discussion in this section focuses on those processes that contribute to maintaining water quality and providing landscape biodiversity.

3.2.1 Surface Roughness

Surface roughness features include coarse-woody debris, live woody and herbaceous vegetation, emergent wetland vegetation, the soil organic horizon (litter), boulders, rock outcroppings, surface depressions and ridges, and parts of land that slope away from the stream edge. In an agroforestry landscape, SMZs usually increase surface roughness compared to adjacent tilled fields and pasture, which in turn reduces runoff velocity and thus enhances deposition of sediment and increases the opportunity for runoff to infiltrate into SMZ soils. Sufficient contact time between water, vegetation and soil is important to obtain a decrease in runoff velocity. Some of the other factors that interact with surface roughness and affect trapping efficiency include the width of the SMZ, vegetation type (density, stiffness and height), and slope (Schultz et al. 2009).

Johnson and Buffler (2008) proposed a simple but useful classification system for SMZ surface roughness based on easily measurable or observable features (Table 2). The initial screening factor for their classification system is the percentage of the SMZ that contains recognizable surface roughness features. Examples of the three categories (low, moderate, and high) are shown in Figures 7-9. Johnson and Buffler (2008) recognized that SMZ roughness is not necessarily uniform and can be recognized and mapped. Figure 10 shows an example of an SMZ with sections characterized by variable surface roughness. This feature of SMZs can be fairly uniform or highly variable, as shown in Figure 10.

3.2.2 Water Velocity and Depth

Water velocity is an important concept for SMZ functioning. Sediment transport in water is a function of water velocity and described in detail by Yalin (1977) and Haan et al. (1994). Any SMZ feature that reduces the velocity of water flowing into the buffer area will increase deposition of sediment. It will also provide additional time for infiltration of upland runoff into the soil, facilitating nutrient uptake and transformations (Schultz et al. 2009). Excessive water depths, especially in areas of concentrated flow, will reduce SMZ filtration functions since the water column will not interact with SMZ surface features and move directly into stream channels (Dosskey et al. 2002).

3.2.3 Sediment Size

The size of sediment transported into SMZs is a function of water velocity, which is in-turn affected by surface roughness. Sand-sized fractions of suspended sediment will usually deposit quite rapidly as velocity drops off (Figure 11). Silt-sized sediment is able to settle out if runoff water is detained in the SMZ and velocities are dropped to near or <1 m sec^{-1} (Hjulström 1939). Clay-sized sediment fractions in soils do not readily settle out of a water column in even still water. The wider the SMZ buffer and the higher the surface roughness, the more likely that sediment trapping efficiencies will be high (Dosskey et al. 2002).

3.2.4 SMZ Width

The widths of SMZs reported in the literature are quite varied. There is no one-size-fits-all although many are in the 10 to 15 m range. The important feature of SMZ width is that it is flexible enough to meet the objectives of land managers (Minnesota Forest Resources Council 2005). An SMZ width is functionally adequate if it allows sufficient time for water draining off uplands to contact vegetation, litter, and soil and decrease velocity, allowing for deposition of sediment. The SMZ width is important also for providing sufficient space for upland runoff entering as concentrated flow to convert to sheet flow (Schultz et al. 2009). When considering biodiversity, wider SMZ widths may be needed (Stauffer and Best 1980).

There are a number of variables that affect SMZ buffer functions (Comerford et al. 1992, Wenger 1999, Schultz et al. 2009). They include slope gradient, slope length, presence of converging slopes, floodplain width, soil infiltration rate, soil moisture content, sediment size distribution, catchment area, presence of impervious surfaces, vegetation, litter, coarse woody debris, inflowing water depth and rainfall. Questions have been raised if it is possible to incorporate these factors into models to predict needed SMZ widths.

A review by Wenger (1999) of several efforts provides some insights into the modelling approach to SMZ width. Phillips (1989a, 1989b) developed a Hydraulic Model and Detention Model whose key components were saturated hydraulic conductivity, slope, Manning's roughness coefficient, and soil moisture storage capacity. These models were highly dependent on existing data from a "reference" SMZ and were never verified, experimentally field tested or calibrated (Muscutt et al. 1993). However, the Phillips (1989a, 1989b) models have been used in Geographic Information Systems (GIS)-based efforts to delineate buffers (Xiang 1993, 1996). GIS applications to SMZ management are few in number and limited by the spatial resolution for small catchments and sub-basins of larger ones (Mander et al. 1997, Corell 2005). For larger rivers and forested flood plains this is less of a problem. Other simple models for designing SMZ width have been proposed by Flanagan et al. (1989), while others have incorporated the more complex CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Williams and Nicks 1988) or WEPP (Watershed Erosion Prediction Project) (Williams and Nicks 1993) models.

Wenger (1999) reviewed two other methods to determine SMZ width. Mander et al. (1997) developed an SMZ width model more simplified than that Phillips (1989a). However it has seven components; conversion constant, mean intensity of overland flow, distance from stream to watershed boundary or the ratio of catchment area to stream segment length, slope, roughness coefficient (not Manning's), water infiltration rate, and soil adsorption capacity. Not all of these are easily obtainable or available. Nieswand et al. (1990) developed a much simpler model based on a modified Manning's equation:

$$W = k(s^{1/2})$$

Where: W = width of SMZ (buffer) in meters

k = constant size (e.g. 5, 7, 10, 15 etc. m)

s = percent slope expressed as a whole number (e.g. 5, 10, 15 etc.)

The Nieswand et al. (1990) equation is slope limited at 15%. Similar equations were among several referenced by Comerford et al. (1992):

$W = 8 - 9\ m + 0.6\ m\ (s)$ Trimble and Sartz (1957)

$W = 13\ m + 0.42\ m\ (s)$ Swift (1986)

$$W = 9\,m + 0.46\,m\,(s) \qquad \text{USDA Forest Service 1989b}$$

Where: W = width of SMZ (buffer) in metres

s = percent slope expressed as a whole number (e.g. 5, 10, 15 etc.)

Dosskey et al. (2008) reported on simulations using the process-based VFSMOD model to illustrate the effectiveness of SMZ filter strips from site to site and between individual nonpoint source pollutants. They noted that slope and soil texture are the most influential site factors that determine the necessary SMZ width needed to achieve adequate retention of pollutants. A graphical design tool developed with the VFSMOD model enables resource planners to designate appropriate design widths. The graphics tool is simple to use, accounts for several major variables that determine SMZ filter performance, and is based on a validated, process-based, model (Tomer et al. 2008). This SMZ design tool fills a large gap between existing complex assessment-type models and simple design guides. It can be applied quickly in a broad range of agroforestry settings with greater accuracy than existing design guides (Tomer et al. 2005). Furthermore, the model design logic is clear and sufficiently flexible that landscape planners can incorporate changes based on their expertise and local familiarity. While modeling simplifications inherent in this model limit its accuracy, the SMZ width tool provides a better and more quantitative method for selecting the appropriate SMZ width than other methods currently in use.

Using 73 published studies, only two of which were the same as those used by Mayer et al. (2007) for nitrate, Zhang et al (2010) found that SMZ width explained 44% of the variation in nitrogen removal efficiency that included three forms of nitrogen (total N, ammonium and nitrate), and that treed systems were more effective than those containing grass only or grass and trees. A buffer width of 15 m was predicted to remove 80% of N entering the up-slope side of the buffer.

3.2.5 Key Nutrient Transformations

Streamside management zone soils are critical for transforming nitrogen and detaining phosphorus on organic matter and mineral exchange sites (Lowrance et al. 1984, 1985; Hubbard and Lowrance 1994, 1996; Schultz et al. 2009). The ability of SMZs to reduce waterborne pollutants is a function of the physico-chemical conditions of the water, chemical and soil in the SMZ, and the types of plants, animals, and microbiological communities present (Comerford et al. 1992).

Nitrogen, in the form of a solute, can be removed from water flowing through an SMZ by at least two abiotic processes or by several biotic processes. The abiotic processes are volatilization as ammonia and sorption on the soil solid phase. The key nitrogen transformations are mineralization of organic nitrogen, nitrification, and then denitrification via the pathway NO_3-N to NO_2-N to N_2O-N to N_2 gas (Hubbard and Lowrance 1994, Smethurst et al. 2011). Denitrification occurs under anaerobic conditions in the presence of facultative anaerobic bacteria (e.g. *Thiobacillus denitrificans, Micrococcus denitrificans, Paraoccus denitrificans and Pseudomonas spp.).* Denitrification rates are affected by soil pH, temperature, degree of water saturation, soil texture, and soil organic matter content.

Figure 7. Examples of landscapes and SMZs with low surface roughness: a) Yan Yan Gurt Catchment, Victoria, Australia; and b) Pet River Catchment, Northwest Tasmania, Australia (Photos by Daniel G. Neary, CSIRO and USDA Forest Service)

a)

b)

Figure 8. Examples of landscapes and SMZs with moderate surface roughness: a) *Eucalyptus nitens* stand, and b) Pet River riparian area, Northwest Tasmania, Australia (Photos by Daniel G. Neary, CSIRO and USDA Forest Service).

a)

b)

Table 2. Streamside Management Zone surface roughness classification system of Johnson and Buffler (2008)

Degree of Surface Roughness	Description
Low	• Less than 35% of the land surface contains surface roughness features. • SMZs with exposed mineral soils as a result of human use automatically have a low degree of surface roughness, as do managed areas (e.g. areas that are intensively grazed, mowed, or used for agriculture).
Moderate	• Between 35 and 65 percent of the land surface contains surface roughness features • For an open (non-forested) system, such as shrub-steppe or wet meadow, it must not be intensively grazed, mowed, hayed, or intensively managed • Usually, there will be clumps of woody vegetation establishing due to lack of mowing • Vegetation must be rough and dense. • There must be surface roughness features other than herbaceous vegetation, such as woody debris, boulders, or hummocky topography, over at least 5% of the land surface by aerial coverage. • The surface organic horizon (duff layer) is intact throughout the buffer unit.
High	• Greater than 65 % of the land surface contains surface roughness features. • The microtopography is complex with undulating topography resulting from previous geologic and hydrologic events. The land surface does not slope smoothly and consistently toward the stream. • The SMZ unit is forested or covered with dense stands of riparian scrub, shrub-steppe vegetation, or dense rush/sedge vegetation. • The surface organic horizon (duff layer) is intact throughout the buffer unit. Natural occurrences of mineral soils, such as tip-ups (trees that fall over bringing the root crown and attached mineral soils to the soil surface), may be present. In natural shrub-steppe plant communities, 35 percent exposed mineral soil is common and undisturbed sites may be covered with cryptogamic crust. • In forested areas, dead-and-down wood and rotting logs and stumps are common. Specifically, coarse woody debris (>25 mm.) is scattered about and older woody debris is being incorporated into the organic horizon. • There is a well-developed grass and forb layer. However, in shaded SMZ woodlands this will not always be the case. A dense grass-forb layer is not necessary, although it remains important for a high degree of surface roughness as long as other factors are present. • Boulders and exposed bedrock are common and, where present, add microtopographical complexity. This feature is not required and may not be present in some cases.

Figure 9. Examples of landscapes and SMZs with high surface roughness: a) Uncut SMZ plantation, and b) recently harvested SMZ plantation. Pet River Catchment, Northwest Tasmania, Australia (Photos by Daniel G. Neary, CSIRO and USDA Forest Service).

a)

b)

Figure 10. Example of a surface roughness map for a hypothetical SMZ (Adapted from Johnson and Buffler 2008).

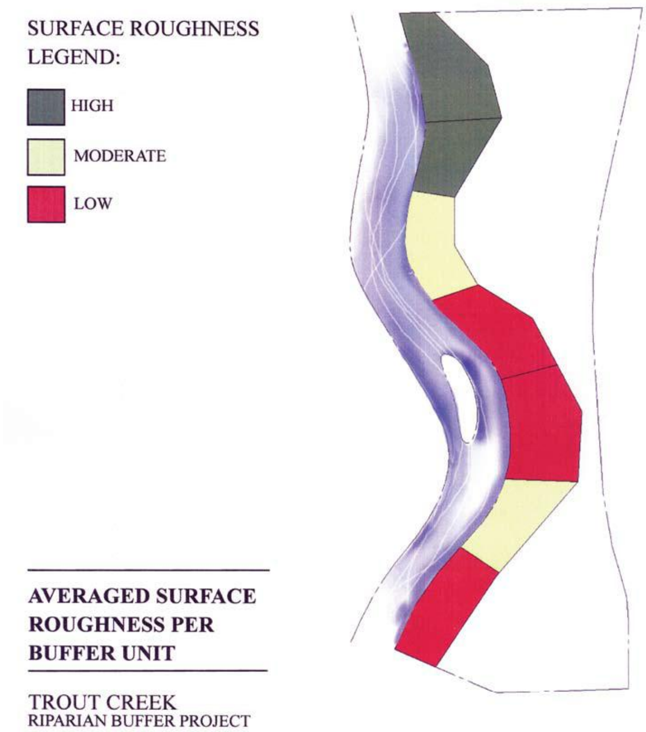
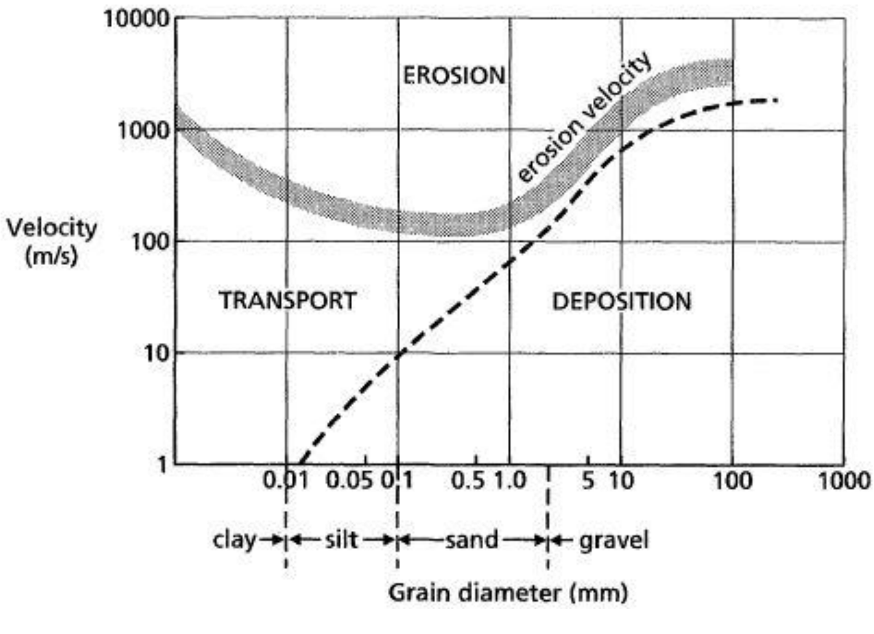


Figure 11. Relationship of suspended sediment size and transport velocity to erosion, transport, and deposition (Adapted from Hjulström 1939).



Phosphorus detention in SMZs is a function of the ratio of dissolved to particulate PO_4-P, and the ratio of overland to sub-surface flow pathways, as PO_4-P is readily adsorbed onto most organic and mineral soil surfaces, whether or not it is suspended in the water column (Schultz et al. 2009). There is greater sediment-bound phosphorus filtering when there are higher amounts of sediment detention in SMZs. As for nitrogen, plant uptake of phosphorus is important for nutrient filtering in SMZs (Lowrance et al. 1984).

3.2.6 Vegetation Uptake of Nutrients

Another key process in the filtering function of SMZ vegetation is nutrient uptake (Lowrance et al. 1985, Schultz et al. 2009). Herbaceous and woody plants found in SMZs are adapted to and effectively function as nutrient filters and storage components of these ecosystems as long as they are growing. Once annual biomass accretion has ceased or vegetation reaches a natural state of senescence, then nutrient filtering via uptake into biomass ceases. Keeping SMZ vegetation in a rapidly growing state is important for maintaining this function. Plants influence nutrient assimilation by several mechanisms. Firstly, they use water for transpiration, which reduces the flow rate of water through an SMZ, thus increasing the residence time of water in the SMZ and allowing for more solutes to be incorporated in biomass or transformed into fixed or volatile forms (Lowrance and Leonard 1988). Secondly, roots of some plants that are adapted to low soil oxygen conditions have the ability to transport oxygen to their roots and effectively aerate their rhizosphere. The oxidized rhizosphere within the anaerobic bulk soil then increases the rate of denitrification (Fisher and Stone 1991). Thirdly, and most obviously, plant roots absorb N (either as nitrate or ammonium ions), phosphate ions, and cations, and then incorporate these ions into biomass. The rate of nutrient uptake depends on a wide variety of conditions and root distributions, but it is also strongly affected by the type of plant and its vigour (Comerford et al. 1992). Periodic removal of vegetation may be necessary to maintain or renew its uptake function.

3.2.7 Habitat

The role of SMZs and their aquatic and riparian components in providing habitat for terrestrial and aquatic organisms is well known (National Academy of Science 2002, Baker et al. 2004). The habitat requirements of many resident and migratory species are met by SMZs and their components. In many instances, the contributions of SMZs to species habitat requirements greatly exceed the small part of the landscape that they occupy (Naiman et al. 1993). In semi-arid landscapes riparian components of SMZs are critical to 80% or more of the threatened, endangered, and sensitive species. But even in mesic environments these landscape units are critical. Although SMZs have natural disturbances like floods, windthrow, and fire, many of the species that inhabit or temporarily use SMZs have evolved to be disturbance tolerant.

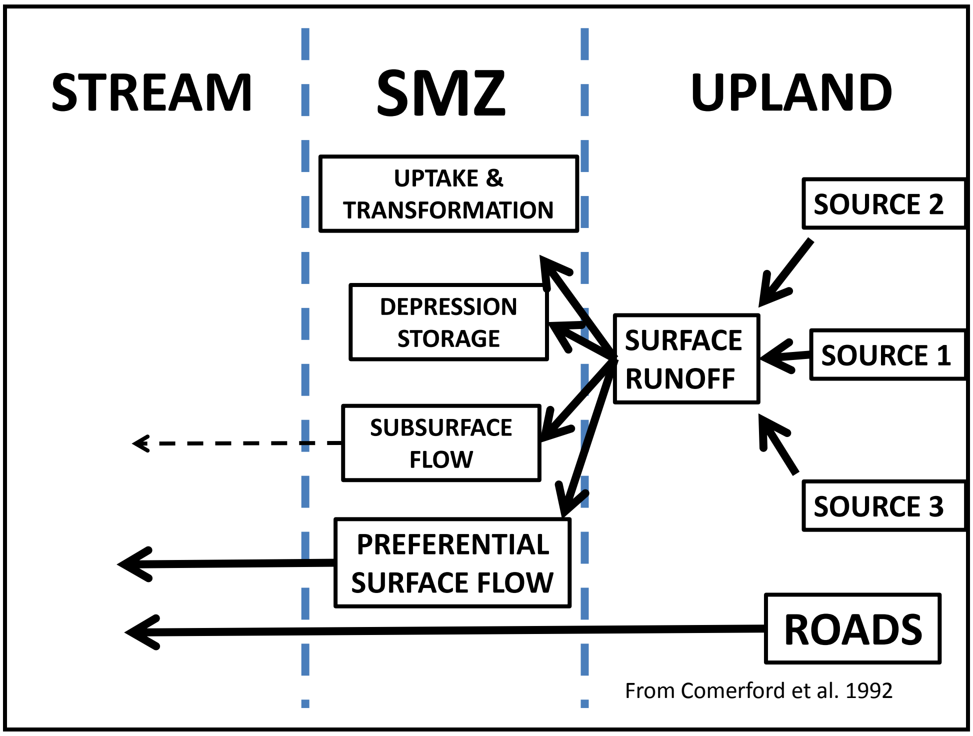
3.3 Function-Limiting Factors

There are a number of conditions where SMZ functionality declines. These conditions are usually related to physiographic, edaphic, hydrologic, or management influences that result in water moving rapidly into and through the SMZ (Comerford et al. 1992). An SMZ functions in reducing sediment and nutrient inputs into streams by providing depression storage, incorporating nutrients into biomass, transforming nutrients to other forms that are either locked up in SMZ biomass or lost to the atmosphere, and routing water into slowly moving subsurface pathways (Figure 12, adapted from Comerford et al. 1992). Changes in flow pathways, volumes of water, surface roughness, SMZ width, and the presence of pathways that bypass SMZs contribute to functionality decline.

3.3.1 Hillslope Uniformity

Conceptually, upland slopes are viewed as providing uniform inputs into SMZs (Source 1 in Figure 12). When slopes are not uniform and create converging flows (Sources 2 and 3 added to Source 1 in Figure 12), inflows to SMZs can overwhelm functions that delay sediments or transform nutrients flow. Water velocities often increase in these situations leading to preferential (channelized) surface flow directly entering streams or lakes, i.e. similar to point sources of water pollution.

Figure 12. Water flow from upland source areas through SMZs and into streams (Adapted from Comerford et al. 1992).



3.3.2 Surface Roughness

Surface roughness was discussed in Section 2.2.1. Lack of or reduced surface roughness contributes to shorter residence times of upland water flows in SMZs. This reduces detention, uptake, and transformation processes.

3.3.3 Flow Conditions and Floods

Streamflow during floods often expands to incorporate SMZ areas. During these conditions water flowing off upland areas goes directly into streams rather than through an SMZ, making many SMZ functions that contribute to improve water quality inoperative. On the other hand, flood flows through SMZs are usually reduced due to structural diversity caused by woody stems and vegetation, producing sediment deposition out of flood flow and into the SMZ area.

3.3.4 Surface Runoff versus Subsurface Flow

Water flow from uplands that enters an SMZ can be routed into depressions for temporary storage, infiltrated into the soil, or shunted via preferential flow directly into the aquatic environment (Figure 12). Preferential surface flows through drainage channels bypass the buffering functions of SMZs (Comerford et al. 1992).

3.3.5 Slope

Slope affects the velocity at which upland water moves into an SMZ. The steeper the slope the wider the SMZ needs to be to provide the same water quality functions. High velocity results in more flows going via the preferential surface flow pathway directly into the waters that SMZs are designed to protect. Excessive slope can greatly limit the effectiveness of an otherwise well-designed SMZ.

3.3.6 SMZ Width

Some aspects of SMZ width and how they affect SMZ functions were addressed in section 2.2.4. Here it remains to be stressed that a minimum SMZ width, tailored for site-specific conditions, is needed for it to function as required, but different functions require different widths. For example, one meter might be adequate to exclude livestock from a stream and dramatically decrease bacteria delivery, but hundreds of meters might be needed to fulfil some habitat or aesthetic functions. Further, the effect of width is strongly influenced by several other attributes, e.g. slope and surface roughness.

3.3.7 Roads

Roads are a special case in that they are the most common cause of an SMZ not working to protect water quality (Swift 1986). Roads create an expansion of effective catchment area and can deliver large amounts of sediment-laded water through SMZs or directly into streams at stream crossing points. Roads within SMZs also produce preferential surface flow paths that increase sediment delivery into streams (Gomi et al. 2006a, Keim and Schoenhotz 1999).

4. POLICY, CODES OF FOREST PRACTICE, AND FARM FORESTRY

National and State policies regulating SMZs in Codes of Forest Practice vary from the very prescriptive to general guidance. These policies provide insight into rationale behind their use in different jurisdictions. Some are based on local scientific investigations and others are founded on recommendations from the general literature that have not been validated for local or regional conditions. Policy promulgation regarding SMZs and other BMPS should be a dynamic process based on the most current information or scientific analyses. Most Forest Practice Codes have inherent review processes and schedules to provide updates and improvements. This section briefly examines the SMZ policy context in Australia and New Zealand.

4.1 Australian Regulatory and Policy Context

The total area of native forest in the latest Australia's State of the Forests Report is estimated to be 162.7 million ha, which is about 21% of Australia's land area (National Forest Inventory 2008). Some 75% of the native forest estate is on public land; the remainder is on private land or unresolved tenure. Australia's plantation estate continues to expand, reaching 2.0 million ha in 2009 (Gavran and Parsons

2010). These areas are in comparison to 460 million ha as agricultural land, of which 74% is pastoral grazing land (Table 3).

Forest practices in Australia are primarily regulated by state governments that legislate for forestry operations to be conducted according to a state-based code of forest practice. Codes were first implemented in Australia in the Australian Capital Territory in 1978. Other jurisdictions followed during the 1980s along with several subsequent revisions (McCormack 1996). The prime motivation for implementing a code of forest practice was to protect environmental values during forestry operations, particularly as native (natural) forests were harvested and regenerated. Current codes include provisions for plantations that were first developed with the assumption that plantations were replacing native forest on a broad-scale. The same provisions have generally been applied where broad-scale plantations replace pasture or other farming enterprises. Since the earliest use of these codes, streamside reserves and machinery exclusion zones have been used to protect soil, water, and biodiversity values. Streamside reserves preclude most harvesting operations and extend 5 to 100 m out from each stream bank, depending on stream size. Machinery exclusion zones are used to protect intermittent streams and drainage ways, but in some areas trees can be carefully harvested within them.

Another type of plantation development that has not received very much attention during code revisions occurs where plantations are established within SMZs on farms while other farming enterprises are maintained on the rest of the landscape. These plantations usually replace pasture, and in such cases are usually fenced to exclude stock. A few farmers have already adopted this practice with the expectation of capturing the range of benefits already mentioned in the previous section (Smethurst et al. 2009, Smethurst and Petrone 2010, Smethurst and Neary 2010).

Tree plantations on farms are a large potential resource for achieving a variety of catchment functions and benefits. The farm area in Australia amounts to over 460 million ha (Table 3). Utilizing 5% of that area for future tree plantings would add 23 million ha to the nation’s forest estate and provide the space needed for national commitments to carbon sequestration (Department of Sustainability and Environment 2008).

In the Yan Yan Gurt catchment in Victoria, a large proportion of farmers have adopted agroforestry practices during the past two decades (Reid and Burk 2002) and harvesting has recently commenced (Reid 2008). This model merits consideration nationally as the country attempts to treble its forest plantation estate between 1997 and 2020 to meet wood production and carbon sequestration goals (Thompson 2008, Bureau of Rural Sciences 2009). Streamside management zones on farmland using commercial or non-commercial trees and other vegetation are also encouraged for improving soil, water and biodiversity values (Robins 2002). However, water use by plantations is increasingly under scrutiny and it is a deterrent in some cases where other uses of a scarce water resource have a real or perceived higher value. This interest in plantation development comes at a time when there is also a need to increase food production to meet the demands of population growth (Food and Agriculture Organization 2008). Hence, the benefits of plantations need to be weighed against their potential to compromise water resources and food production.

Although codes of forest practice in some jurisdictions apply to commercial forestry operations on all land tenures, e.g. in the state of Tasmania, their applicability to SMZs on cleared farmland is not clearly laid out, or in some cases is discouraging because harvesting is not permitted (Smethurst 2008). In most jurisdictions this practice is exempt from code provisions if annual areas or harvest volumes are very small, e.g. less than 1 ha. There is recognition in at least one code of forest practice that these provisions may change as new knowledge becomes available (Forest Practices Board 2000, p. 84) and most codes have a 5- to 10-yearly review cycle.

Table 3. Australia and New Zealand agricultural and non-agricultural land areas (New Zealand: Ministry of Agriculture and Fisheries 2009, Australian Bureau of Statistics 2009).

State	Pastoral Land	Cropping Land	Non-Agricultural
	……………………………... (10^6 ha) …………………..………….		
AUSTRALIA:	340.5	119.5	331.5
New South Wales	58.6	6.7	15.0
Northern Territories	61.2	<0.1	73.7
Queensland	143.9	2.3	34.0
South Australia	54.1	4.3	44.2
Tasmania	1.8	<0.1	5.1
Victoria	13.3	3.3	9.3
Western Australia	7.6	102.7	150.2
NEW ZEALAND:	8.0	3.3	12.1

In a plantation cycle, most concerns about potential effects on water quality arise during establishment, harvesting, or tending operations that include major soil disturbance or the application of fertilisers, herbicides or pesticides. Hence, these operations are foci within codes of practice. For example, in the Tasmanian code in relation to reafforestation of pastures (Forest Practices Board 2000, p. 81-84; currently being revised), plantation establishment in streamside reserves is permitted subject to:

- no establishment within 2 m of a stream bank,
- machinery exclusion provisions,
- restrictions on cultivation,
- restrictions on the use of chemicals, and
- prohibition of tree harvesting within 10 m of a bank of a permanent stream.

4.2 New Zealand Regulatory and Policy Context

Prior to human settlement (*c*. 1000 yr Before Present), approximately 85-90% of New Zealand was in forest cover. The initial use of fire by Polynesians and later European settlers cleared large tracts of forest for agriculture and settlement. This initial pioneering stage was followed by an intensification of farming with the introduction of fertilizer, new technologies and Government subsidies. Subsequent degradation of resources such as soil and water, and the need to address the complexity of associated environmental issues in the wider catchment, landscape and community level has seen an increasing emphasis in statutes, policies and codes of practice on sustainability and public accountability (McGlone 1989; Valentine et al. 2007).

The principal statute determining the rules and regulations relating to forestry practices in SMZs is the New Zealand Resource Management Act (New Zealand Government 1991), which replaced a number of pre-existing statutes. The purpose of this Act is 'To promote the sustainable management of natural and physical resources' and 'to manage the use, development and protection of natural and physical resources in a way, or at a rate, which enables peoples and communities to provide for their social, economic, and cultural well being and for their health and safety while:

1. Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

2. Safeguarding the life supporting capacity of air, water, soil, and ecosystems; and

3. Avoiding, remedying or mitigating any adverse effects on the environment.'

The Resource Management Act (1991) delegates much of the governmental environmental management responsibility to sixteen regional government authorities. Regulatory rules in regional and unitary authority plans vary across New Zealand for forestry activities with some plans promoting non-regulatory practices of education and advocacy, guidelines and industry codes of practice. Generally, plantation forest activities within SMZs are permitted throughout New Zealand as long as the land manager adheres to a suite of rules designed to minimize any adverse effects on the aquatic environment. These rules are usually more rigorous than those applying to less sensitive areas.

The width of SMZs is often determined by slope, erosion risk, and the size and sensitivity of the receiving water body. For example, the Bay of Plenty Regional Water & Land Plan (Bay of Plenty Regional Council, 2008) uses slope thresholds to define the width of SMZs for earthwork activities. These range from 0-5 m for slopes <7° and up to 40 m for slopes >35° for accredited forestry operators, extending to wider distances for the Rotorua lakes and for non-accredited forestry operators. Table 4 summarizes the most common operational rules pertaining to forestry activities in SMZs. Plans usually allow the harvesting of historical forest plantings up to the stream edge but specify planting set-back distances usually of 5 m from a water body and up to 20 m in some cases. Therefore, in many parts of New Zealand, farmers wanting to plant in SMZs for timber purposes will need to do so outside these 'no planting' zones.

In addition to the Resource Management Act of 1991, there are a number of other key agreements and codes of practice that influence farm forestry practices in SMZs in New Zealand. These include the Environmental Code of Practice for Plantation Forestry (New Zealand Forest Owners Association 2007), the Forest Accord of 1991, and Principles for Commercial Plantation Forest Management in New Zealand (1995), all endorsed by the New Zealand Farm Forestry Association. The Dairying and Clean

Stream Accord (Ministry of Agriculture and Fisheries 2003) between the Fonterra Co-operative Group and Government Agencies targets the exclusion of dairy cattle from water bodies and management of farm nutrients to minimize environmental impacts on receiving water bodies. As an OECD (Organisation of Economic Cooperation and Development) member, New Zealand is also participating in the development of 49 agri-environmental indicators (Manderson et al. 2007).

As a result, in New Zealand, there is a strong emphasis on the management of SMZs in the agricultural landscape for mitigating nutrient and sediment run-off and for protection and conservation purposes using indigenous plant species. Planting exotic or indigenous species for timber purposes is generally not a priority consideration (Cornell 2003), even though in appropriate areas, they can be established more cost effectively than indigenous plants, (Cornell 2003; Ministry for the Environment 2001) and provide a potential opportunity for carbon sequestration.

5. INTERNATIONAL SMZ EXPERIENCES AND GUIDELINES

There is a wide range of SMZ sizes in use both within and between countries. This is a function of physical and biological factors, regulatory environment, and specific functions desired for these landscape management areas. In some cases the sizes are based on effectiveness experience, while others have been selected by modelling approaches, incorporation of recommendations from published literature, or decisions by regulatory agencies.

The following analysis demonstrates that trend in SMZ determination is towards more flexibility based on site characteristics and function requirements with less emphasis on rigid, regulatory selection of sizes. A lot of emphasis is placed on planner experience and research and monitoring results, but models can serve to guide the selection of SMZ widths.

5.1 Australia

Australian Codes of Forest Practice for both plantations and other commercial forests designate SMZs that either exclude harvesting, and are called reserves, or buffers. There exists a lot of variation across Australia as to the makeup and size of SMZs (Bren 1993). Some include harvesting with conditions that are more restrictive than for general forest areas at greater distances from the stream. An example of a restriction is machinery traffic exclusion, where harvesting can proceed by using mechanical arms that reach from outside this zone (where the machine is parked) into the zone to conduct operations, e.g. tree cutting followed by lifting of cut trees outside the zone to complete delimbing and debarking. Various types of SMZs are of prescribed widths that depend on stream size, soil type (which particularly considers erodibility), slope or other factors that are a risk to water quality. These widths are summarised in Table 5 for Australian states. There are also two Australian territories, but the Northern Territory has only a preliminary description of salient BMP principles, and the Australian Capital Territory has a code similar to that for the state of New South Wales. Small stream sizes (e.g. up to 1st order perennial streams) commonly attract a 0-10 m no-harvest zone, a 5-20 m modified harvest zone, or both. Larger streams commonly lack a modified harvest zone, but require a wider no-harvest zone, ranging up to 40 m for some streams in Tasmania and Victoria.

Table 4. A summary of the more common vegetation clearance and roading rules in regional plans for permitted forestry activities in, or relating to SMZ's in New Zealand. For exact wording, and full details of the rules, refer to the individual regional plans.

Part	General Activity	Rules
1.	Vegetation Clearance or Disturbance	Harvesting of plantation forest in SMZ's planted prior to the date of the plan becoming operational is permitted subject to conditions.
		Trees are to be directionally felled or pulled back from a water body, unless it is unsafe to do so
		In cable harvesting operations, stems butts are to be raised above the ground to minimize disturbance to vegetation, no logs or trees shall be dragged through the bed of a water body.
		No material can enter, or be in a position to enter a water body that may result in diversion or damming, bed or bank erosion, impeding flood flows, preventing fish passage, or more than minor adverse effects on ecosystems. In some plans vegetation >75-100 mm in diameter must be removed.
		Ground cover to be re-established on disturbed areas within a certain time frame from the completion of the operation (6-18 months)
		Effective water run-off, erosion and sediment control measures to be in place to minimize erosion and sediment discharge and adverse impacts on water bodies
2.	Roading and Earthworks	The volume or area of earthwork activities permitted within SMZ's varies through out New Zealand
		Machinery operations may operate within a restricted distance (i.e. 10 m) of a water body
		Roading, tracking and trenching operations are usually restricted to a certain length over a given time period for range of slope categories
		Disturbed areas are to be revegetated or stabilized as soon as practicable to minimize erosion and contamination of water bodies
		Installation of appropriate storm water or runoff controls to limit sediment discharge to water bodies
		Stream crossings including culverts & bridges are to be aligned at right angles to the flow, with minimal associated earthworks, and to be stabilized and revegetated as soon as possible afterwards. Stream crossings should not to obstruct flow, cause flooding or impede fish passage.

Table 4 (continued). A summary of the more common land preparation and water quality rules in regional plans for permitted forestry activities in, or relating to SMZ's in New Zealand. For exact wording, and full details of the rules, refer to the individual regional plans.

Part	General Activity	Rules
3.	Land Preparation	Only approved agrichemicals are to be applied by approved operators, following manufacturer's instructions.
		All reasonable steps are taken to ensure that agrichemicals are applied in a manner that ensures the agrichemical does not enter the water; only approved agrichemicals can be used near or adjacent to water bodies.
		No storing, refuelling or mixing of fuels, oils, or agrichemicals shall take place in the SMZ or within a set distance of a water body or where deliberate or inadvertent discharge is likely to enter a waterway.
		Fertiliser application is permitted as long as all practical steps are taken to apply the fertilizer accurately, there is no direct discharge to water bodies, and all practical measures are taken to avoid run-off into water ways.
		Burning, when defined as vegetation clearance, comes under the same rules; there are few additional rules, mainly pertaining to the South Island high country.
		No replanting within a certain distance of a water body (commonly 5 m).
4.	Water Quality	Discharge originating from the activity is managed to ensure that after reasonable mixing there is (a) no production of conspicuous oil or grease films, scums or foams, or floatable or suspended materials, (b) no conspicuous change in the colour or visual clarity, (c) no emission of objectionable odour, (d) no rendering of fresh water unsuitable for consumption by farm animals, (e) any adverse affects on aquatic life (RMA, 1991). Some plans provide additional water quality rules.

5.1.1 New South Wales

In New South Wales, SMZs are called Drainage Feature Protection Areas (DFPAs) and are required next to wetlands, streams, drainage lines, and drainage depressions (Figure 13, Forests New South Wales 2005). The DFPAs are based on water resource type and perennial stream order (Table 5). They have two sub-zones, a *buffer zone* and a *5-m zone*. The buffer zone is an area where harvest operations are modified to meet water resource protection values. Trees may be cut if the harvesting operator believes the upper 20 cm of soil is dry enough to avoid erosion. Machinery operating in this zone must not create ruts that become drainage channels, and minimize mineral soil exposure by utilizing slash, understory vegetation, or litter to protect the soil. Skidding tracks must be designed and the leading edges of skidded logs elevated to prevent soil scour. In the 5-m zone no processing or extraction machinery is allowed except on harvest plan-designated crossings. Felling machinery is allowed if the soil is not saturated. Trees can be felled into this zone and adjacent waters if substantial crowns, logs, and other slash can be removed with minimal disturbance. Water crossings must be planned and approved. The SMZ (DFPA) widths can be wider than specified depending on stream ordering and the harvest plan.

5.1.2 Northern Territory

The Northern Territory does not have any specific guidance on SMZ dimensions (McCormack 1996). It provides a list of general BMPs in its Forest Code (Table 6). Its focus is on minimizing inputs of sediment from roads, stream crossings, and skid tracks. It recognizes the potential impacts of roads by concentrating on minimizing harvest-associated roads, designing stream crossing, conducting construction with BMPs, and doing adequate maintenance. Wet weather is recognized as higher hazard periods.

5.1.3 Queensland

Queensland's code of forest practices for native forestry defines four areas in its stream protection system SMZs (Department of Natural Resources and Water 2007). The *protected feature* encompasses the water area from normal levels to the usual seasonal high water line and defining bank (Figure 14). The next area is a *buffer zone* ranging from 2 to 10 m in width either side of the stream area depending on stream order (Table 7). If the protected feature's defining high bank is unstable then the buffer zone is extended out three times the height of the instability. No felling of trees is allowed into streams, unstable drainage lines, within buffer zones, or into buffer zones from the next SMZ are, the *filter zone*. The filter zone varies from 10 to 50 m depending on stream order. Trees may be harvested within the filter zone based on a low intensity, periodic (10-40 years) system.

Guidelines for Queensland state that trees may not be felled out of the filter zone if the operation would cause instability to stream or drainage line banks. The next zone out from the protected water feature is the general area where harvesting operations may be conducted according to general conditions specified in the forest harvesting field guide (Department of Natural Resources and Water 2007).

In the Queensland Code, drainage lines refer to naturally occurring hydrologic features that convey overland surface flow but do not appear on 1:250,000 topographic maps. These landscape features have their own guidelines for buffer and filter zone sizes within the SMZ (Table 8). Buffer widths of drainage lines established for unstable sections must be applied above and below the instability for the same distance as the buffer is wide. Trees within the filter zone may not be felled if this action would destabilize a portion of a stream or drainage line.

Wetlands are another category of protected water features in the SMZ concept that have separate guidelines for buffer and filter zones based on size (Table 9, Department of Natural Resources and Water 2007).

5.1.4 South Australia

South Australia uses some of the same terminology and SMZ width distances as Queensland but there are variations on the terminology and SMZ sizes (Primary Industries and Resources South Australia Forestry 2009). A *filter zone* is an undisturbed and vegetated area adjacent to drainage lines established to minimize soil disturbance and erosion. Trees may be planted and harvested within filter zones providing risk analyses are conducted for the protection of soil and water quality. Machinery access is limited to conducting spot treatments for cultivation, weed control, and planting. The minimum width is 5 m (Table 10). A *buffer zone* is a non-plantation area established for providing an undisturbed zone between water resources and managed forests to protect water quality. Machinery access is limited to fire suppression and management equipment. The SMZ size that constitutes the buffer is 10 m for 1st and 2nd order streams and 20 m for 3rd and 4th order waters. The filter zone concept is not applied to perennial waterways where buffer zones are used (Primary Industries and Resources South Australia Forestry 2009). In cases where forest plantations were established in buffer zones, trees may be felled using caution to protect the soil resource and water quality.

5.1.5 Tasmania

In a plantation cycle, most concerns about potential effects on water quality arise during establishment, harvesting, or tending operations that include major soil disturbance or the application of fertilisers, herbicides or pesticides. Hence, these operations are focal points within the Code of Practice. Streamside Management Zone sizes are based on stream class, not stream order as in other Australian States. The sizes of the Tasmanian SMZs increase (10 to 40 m either side of a waterway) as catchment area increases or special water uses like water supply are factored in (Table 11).

In relation to reforestation of pasture land (Forest Practices Board 2000, p. 81–84; currently being revised), plantation establishment and harvesting in SMZs is permitted subject to:

- No establishment planting within 2 m of a stream bank
- Machinery exclusion within 10 m of streams
- Restrictions on cultivation
- Restrictions on the use of fertilizers and herbicides
- Prohibition of tree harvesting within 10 m of a bank of a permanent stream.

The latter restriction, meant for broad-scale plantation forestry, is problematic in an agroforestry system where SMZ forests are smaller. Farmers might prefer to establish plantations next to streams, but restrictions such as prohibition of tree harvesting within 10 m of a bank could decrease the attractiveness of this option. The 10 m exclusion in the Tasmanian Code (Forest Practices Board 2000) was based on practical considerations and conservative estimates of a distance needed to assure adequate water quality. Actual field monitoring of water quality during and after tree harvesting using

BMPs in within SMZs has been scarce, but has been recently augmented by a harvesting study in Northwest Tasmania (Neary et al. 2010).

Table 5. Summary of prescribed minimum SMZ widths for plantations in Australian states (Forests New South Wales 2005, Department of Natural Resources and Water 2007, Primary Industries and Resources South Australia Forestry 2009, Forest Practices Board 2000, Department of Sustainability and Environment 2007, Forest Industries Federation 2006). Due to variation between states in stream definitions and other aspects of codes, SMZ widths provided here should be considered only indicative. Where current specifications were unclear, those provided by McCormack (1996) are indicated.

Stream Size	SMZ Width (m, each side) by State**					
	Qld	New South Wales	Vic	Tas	SA	WA
Drainage depression*	5	5-10	15	10	5	6
Drainage line*	5	5-15	15	10	5	6
Intermittent stream	5	5-20	15	10-20	5	6
Perennial stream order:						
1	12	5-20	20-40	10-20	5	6
2	17	5-20	20-40	20	5	6
3	25	5-20	20-40	20	20	6
4	30	5-20	20-40	30	20	6
5	45	5-20	20-40	40	20	6
6	60	5-20	20-40	40	20	6
Wetland or lake	40	5-20	20-40	40	20	6

* Drainage depressions and lines occur where water flows after significant rainfall, but channel features are absent or not well developed.

** Variations take into consideration erodibility as indicated by geology, soil type, or other indicators of water quality risk.

Figure 13. New South Wales water drainage features (Forests New South Wales 2005)

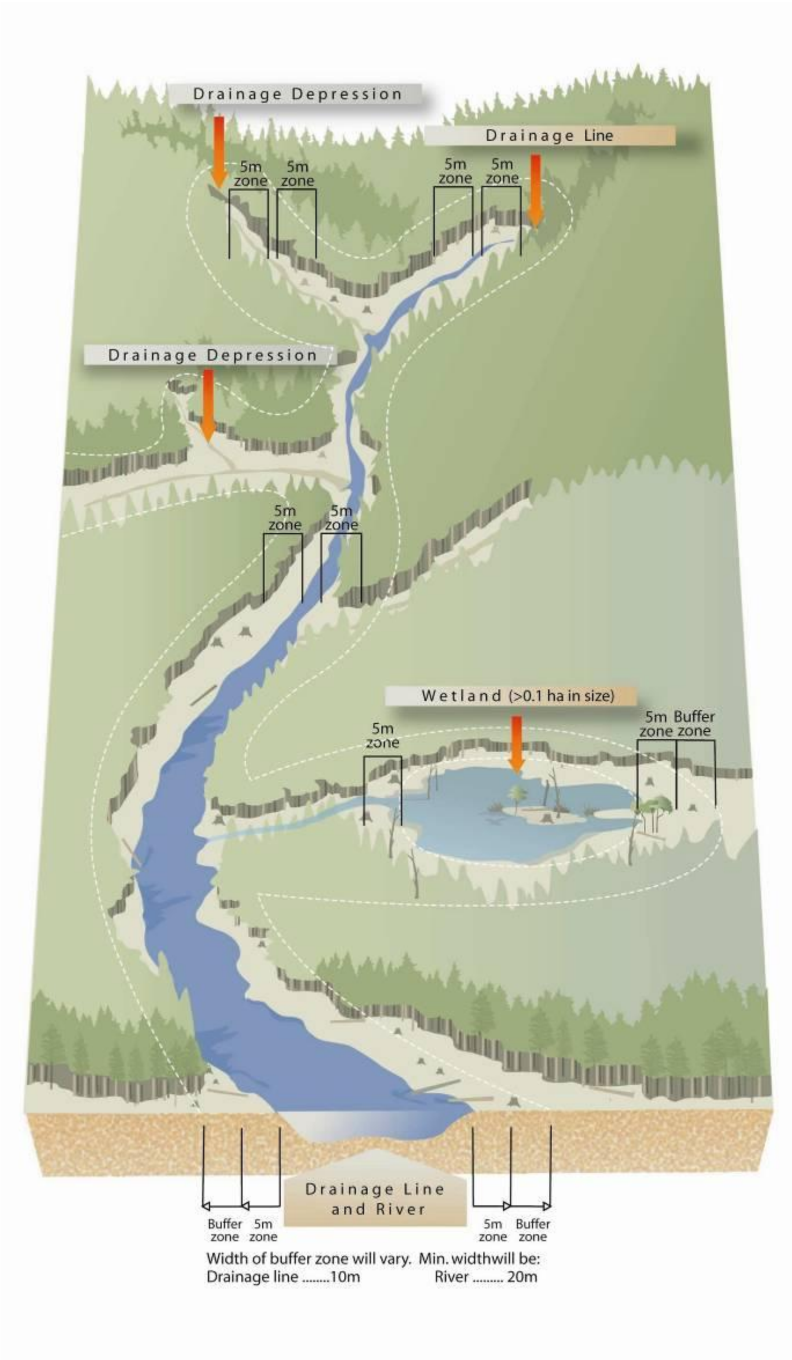


Table 6. Northern Territories Codes of Practice for plantations (From McCormack 1996).

Code Item	Description
7	Water quality, stream stability and habitat values will be maintained in the forest environment including the development area and adjoining lands.
9	The threat to water quality will be minimised by controlling the extent of road construction, and the number of stream crossings to that required for efficient plantation operations. Roads will be located and designed to minimise run-off and to facilitate effective construction and maintenance.
10	Permanent watercourse crossings will be located, designed, constructed and maintained so as to minimise disturbance during construction and to ensure stability in the long-term in order to minimise risks of degrading water quality and aquatic habitat.
12	Roads and their associated drainage systems will be maintained in effective functioning order to minimise risk of degradation of water quality.
22	The risk of water pollution caused by run-off from areas disturbed by harvesting machinery traffic, will be minimised during and after operations. The extent of adverse impacts on soils such as compaction caused by machinery traffic during wet weather will be minimised.
23	Turbid run-off from roads causing water pollution will be minimised.

Table 7. Queensland minimum buffer and filter zone widths for streams* (Department of Natural Resources and Water 2007).

Stream Order	Minimum Buffer Zone	Minimum Filter Zone
	……………………………m……………………………	
1	2	10
2	2	15
3	5	20
4	5	25
5	5	40
6	10	50

*Streams are defined as a gully, creek or river that is represented on a 1:250,000 topographic map.

Figure 14. Queensland stream protection system schematic and operational definitions (Department of Natural Resources and Water 2007).

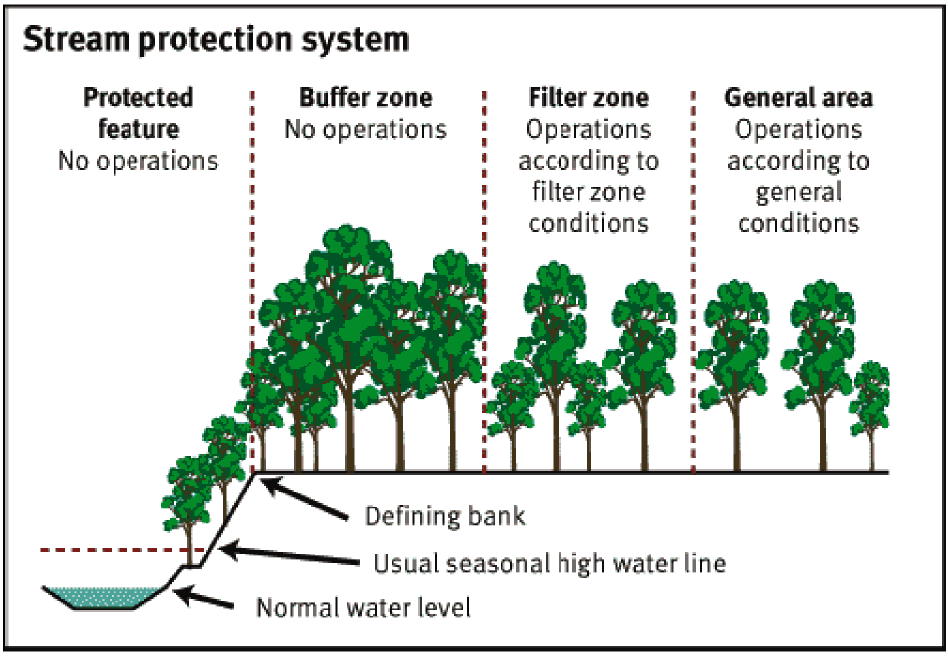


Table 8. Queensland minimum buffer and filter zone widths for drainage lines (Department of Natural Resources and Water 2007).

Drainage Lines	Minimum Buffer Zone	Minimum Filter Zone
	……………………………….m……………………………..	
Stable	0	5
Unstable	3 times the maximum height of the instability	5

Table 9. Queensland minimum buffer and filter zone widths for wetlands (Department of Natural Resources and Water 2007).

Size of Wetland, Lake or Spring	Minimum Buffer Zone	Minimum Filter Zone
	……………………………….m……………………………..	
<1,000 m^2	10	10
>1,000 m^2	20	20

Table 10. South Australia minimum buffer and filter zone widths for drainage lines, streams, wetlands, and sinkholes (Primary Industries and Resources South Australia Forestry 2009).

Water Resource Type	Description	Filter Size	Buffer Size
		m	m
Drainage Line	Edge of saturated zone or centre of drainage line	5	--
Water Course (1st & 2nd Order)	Bank of water course or sinkhole (no aquifer connection)	--	10
Water Course (3rd & 4th Order)	Bank of water course, lake, or reservoir, and edge of wetland or sinkhole (direct aquifer connection)	--	20

Table 11. Tasmanian SMZ minimum reserve widths (Forest Practices Board 2000).

Stream Class	Description	Width Either Side	Total Width
		……………………..m.	…………………..
1 (large permanent stream)	Rivers & Lakes Water Supply	40	80
2	Creeks, etc Catchment >100 ha	30	60
3 (small permanent stream)	Other Watercourses Catchment 50-100 ha	20	40
4 (temporary stream draining < 50 ha)	Other Waters, Wet Part of the Year	10*	20

*No logging machinery within 10 m of the streambank except at defined crossings

5.1.6 Victoria

The SMZs within the State of Victoria's code of forest practices vary according to the importance of factors such as water resource type, water quality risk, and slope (Table 12, Department of Sustainability and Environment 2007) and forest type (native forests or plantations) . A risk assessment for water quality includes consideration of soil erodibility, soil permeability, rainfall erosivity, topography, and location of infrastructure like roads, log decks, and debarking and sizing landings. The size guidelines for buffer and filter SMZs in native forests vary from 10 to 40 m depending on the previously mentioned factors and location within a *filter strip* or *buffer strip*. In the Victorian code, filter strips are located along temporary streams and drainage lines. The filter strip is defined as a zone of vegetated soil adjacent to a intermittent waterway with any merchantable overstory removed. Trees may be felled within the filter strips under conditions that the felling and extraction will not produce soil compaction, erosion, or undue disturbance. However, harvesting machines are excluded from the filter strip (Department of Sustainability and Environment 2007). Filter strip widths vary from 10 to 15 m either side of the drainage feature of concern. The term buffer strip refers to a protective vegetation zone adjacent to a waterway or other special ecological feature where all harvesting activities are excluded. Additional widening of filter strips or buffer strips may occur where risks to water quality are elevated due to local topography, the intensity and magnitude of the harvesting, and the presence of special water supply catchments.

Special considerations in the Victorian code allow some harvesting operations in buffer and filter strips when documented in the forest coupe plan. These include removal of trees for safety reasons, access for planned drainage and stream crossings, pushing fill and logging slash into these areas for designated stream crossings, and construction of temporary culverts and bridges. Felling of trees within filter strips is allowed but routine felling from the general harvest area into filter strips is prohibited. Measures to reduce the impact of timber harvesting on water quality and aquatic ecosystem river health must take into account other requirements set out in Special Area Plans made under the Catchment and Land Protection Act 1994.

For plantations, forest management needs to achieve adequate environmental outcomes, but harvesting and other operations are not necessarily disallowed.

Table 12. Victoria minimum width (m) for buffer strips (B) and filter strips (F) on each side of streamside reserves in native forests (Department of Sustainability and Environment 2007).

Waterway Class	Sites With Low or Moderate Water Quality Risk	Sites With High or Very High Water Quality Risk	
Slope:	0 - 30°	0 - 20°	21 - 30°
1. Pools, permanent streams & wetlands	20 B	30 B	40 B
2. Temporary streams	10 F	10 B + 10 F	20 B
3. Drainage lines	10 F	10 F	15 F
B = Buffer strip , F = Filter Strip			

5.1.7 Western Australia

The SMZ sizes used by Western Australia are also based on stream order but are considerably larger (30 to 200 m), than those mandated by other States (Table 13; McCormack 1996, Forest Industries Federation 2006). The intent of the Western Australia Code is the protection of water quality. This is done through careful planning and control of machinery operations and timing. The Code of Practice does not go into specific definitions of SMZ components. Non planted buffers of 6 m from watercourses are recommended (Forest Industries Federation 2006). Following this prescription, future harvesting and machinery operation would not occur within the 6 m buffer. Guidelines provided for harvesting mandate that felling across wetlands, water courses, riparian, zones, and drainage lines should be avoided.

Table 13. Western Australian SMZ reserves (Food and Agriculture Organization 1996, McCormack 1996, Forest Industries Federation 2006.)

Stream Order	Width Either Side	Total Width	Minimum Width
	………………………………..m…………………………………..		
1st	30	60	20
2nd	30	60	20
3rd	30	60	20
4th	75	150	50
5th+	200	400	100

5.2 New Zealand

In New Zealand, the management and protection of SMZs is the responsibility of local government via 12 regional councils, and 4 unitary councils that have the responsibilities, duties and powers of a regional council. Rules and regulations pertaining to forestry related activities in SMZs are contained in various regional and unitary authority plans, most commonly in the Regional Soil and Water Plan. Table 4 provides a summary of the common rules for forestry activities relating to SMZs in New Zealand. Depending on the type of activity (definitions of the different types of activities are in the Resource Management Act, Part 5, 77B,), some forestry activities are permissible without a resource consent from the local authority as long as they comply with any standards, terms or conditions specified in the plan (permitted activity). Other forestry activities require a resource consent that may also involve public consultation as part of the resource consent process. The rules contained in these plans and resource consents form the basis of BMPs in SMZs in plantation and farm forestry in New Zealand.

Because of the variable way in which Regional and Unitary Councils control forestry operations (Baillie 2010), the New Zealand Forest Owners Association is proposing the establishment of a National Environmental Standard for Plantation Forestry and this process is being managed by the Ministry for the Environment (Ministry of the Environment 2010). The intent of the proposed standard is to improve national consistency and definitions in local authority plan rules relating to plantation forestry. For instance, adoption of definitions and management guidelines for streams and coastal areas, like those used by the Northland Regional Council (Figures 15 and 16), will go a long way to improve national consistency and communications between local governments and forestry operators (Northland Regional Council 2005). At the time of this, the proposed National Environmental Standard for Plantation Forestry has been available for public comment, and submissions were being analysed by the Ministry for the Environment. Proposed rules for permitted forestry activities relating to SMZs include a minimum planting setback of 5 m from wetlands, and perennial rivers and streams with a channel width less than 3m; a 10 m setback from perennial rivers and streams with a channel width greater than 3m and lakes larger than 0.25 hectares; and up to a maximum of a 30 m setback from a coastal Marine area. Similar setbacks are proposed for permitted mechanical land preparation and earthwork activities. Proposed harvesting rules require a detailed assessment and mapping of water-body and riparian areas to identify values and risks included in the harvest plan. Other proposed harvesting rules aim to minimize soil erosion, sediment discharge, entry of logging slash and operational disturbance in riparian areas and water bodies. Local authorities would still have the option to apply more stringent conditions for any forestry activities that fall outside the permitted activity threshold.

Other documents that influence BMPs in SMZs in NZ include the Principles for Commercial Plantation Forest Management in New Zealand (New Zealand Forest Managers 1995) and the New Zealand Environmental Code of Practice for Plantation Forestry (New Zealand Forest Owners Association 2007). The central objective of the New Zealand Environmental Code of Practice for Plantation Forestry (New Zealand Forest Owners Association 2007) is to ensure compliance with the Resource Management Act 1991, and to avoid, remedy, or mitigate adverse or potentially adverse on- and off-site environmental impacts produced by forestry activities, particularly harvesting and earthworks. A central tenet of the Code of Practice is planning, supervision, and execution of harvest plans by trained personnel who understand the goals of the Resource Management Act and the appropriate best management plans needed to achieve those goals. The Code of Practice includes a minimum horizontal setback of 5 m each side of all perennial streams and contains a comprehensive suite of rules and guidelines for forestry operations. In addition, most forest companies, have their own in-house rules, standards, guidelines and BMPs relating to forestry activities in SMZs that are often more stringent than regulatory requirements.

5.3 USA

5.3.1 SMZs as Best Management Practices

The U.S. Environmental Protection Agency (US Environmental Protection Agency) coined the term ‘‘Best Management Practices’’ (BMPs) in the mid-1970s as the agency developed guidance for achieving nonpoint pollution control objectives of the 1972 Amendment of Water Pollution Control Act (known as the Clean Water Act). Best Management Practices are generally successful, because of the improved understanding of the actual linkages between soils and water that Stone (1973) elucidated in his analysis of the linkages between forest harvesting and water quality. Singer and Maloney (1977) first defined BMPs as operational practices that prevent or reduce the amount of nonpoint source pollution in keeping with water quality objectives. Best Management Practices are relatively low cost measures to reduce nonpoint pollution developed from science and professional judgment. Binkley and Brown (1993) updated Stone’s (1973) analysis of the problem and clearly pointed out that BMPs, including SMZs, may effectively prevent significant increases in stream sediment concentrations. They also noted that concentrations of suspended sediment, even in undisturbed forest watersheds, differ substantially from watershed to watershed depending upon site specific soils, geology, climate, and stand treatment details such as amount of road distance, layout, and construction quality, harvesting system used, vegetation recovery, use of SMZs, and timing.

Singer and Maloney (1977) discussed SMZs as planning features that could minimize nonpoint source pollution of streams, lakes, and wetlands. They viewed these areas as management areas and not “hands off” reserves since they stipulated operational procedures that could be appropriate within zones. These included maintaining natural ground cover and density of trees and other vegetation to protect against water temperature changes, streambank erosion, and direct movement of sediments and other pollutants into stream channels. Singer and Maloney (1977) stated the importance of locating landings, skid trails, and haul roads within SMZs to avoid paralleling channels for long distances or creating excessive numbers of stream crossing. Other BMPs recommended in the document included felling away from perennial and intermittent channels, avoiding skidding down drainage ways, preventing creation of artificial drainage lines, preventing excessive woody debris piling in channels, and utilizing adequately sized culverts.

Figure 15. A definition of the waterway margin for rivers, streams, lakes, and wetlands.

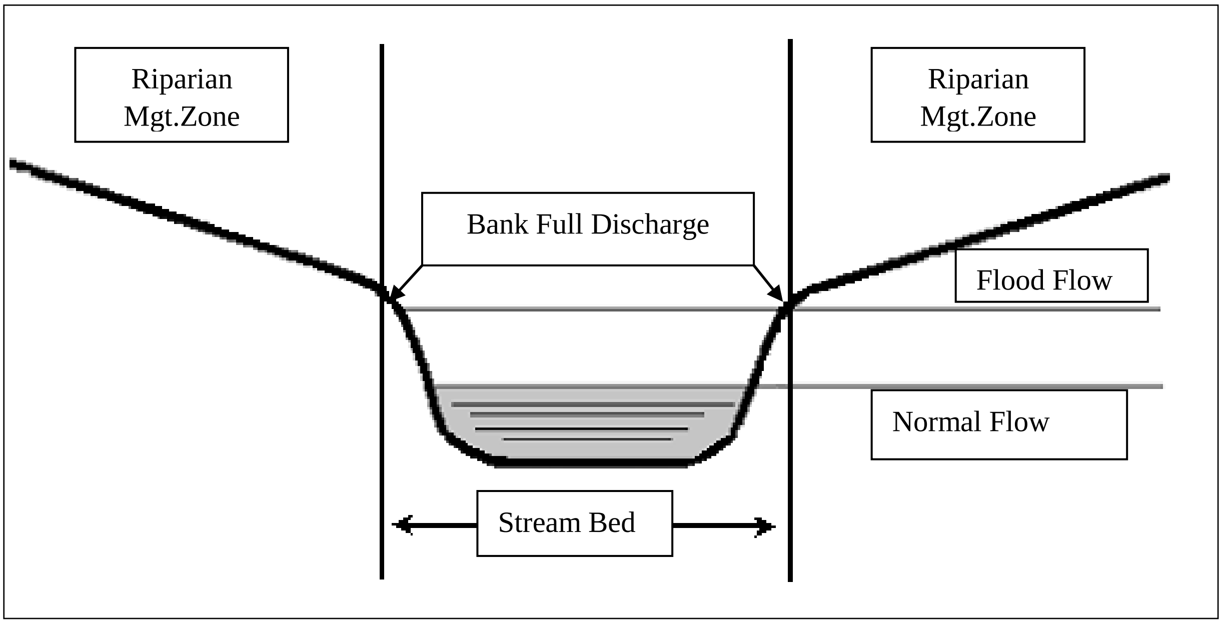
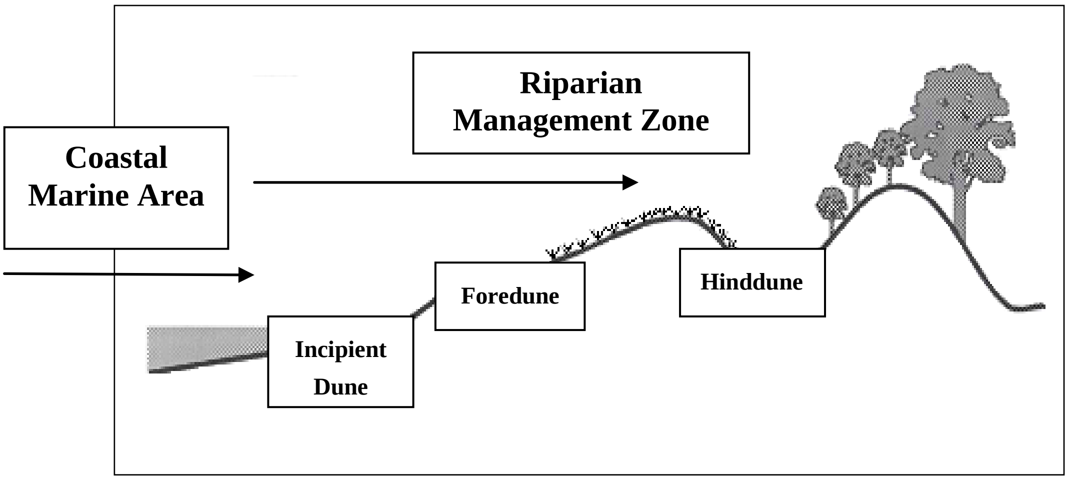


Figure 16. A riparian management zone definition in relation to a coastal marine area.



State-based SMZ widths adopted in the eastern USA are listed in Table 14. On perennial streams they range from 7.6 m in states with low relief to 30.5 m in those with greater relief. Michigan and Wisconsin have larger SMZ width recommendations, but much lower relief than West Virginia due to many freshwater lakes. Only two states (Georgia and West Virginia) have recommended SMZ widths for ephemeral streams. In most of the states in Table 14, SMZ widths for intermittent streams are the same as perennial water courses.

Table 14. Minimum SMZ width recommendations for silvicultural chemical applications in the eastern USA (From Michael 2004).

State	Stream Classification		
	Ephemeral*	Intermittent	Perennial
	..................m..................		
Alabama	NR	10.7	10.7
Arkansas	NR	10.7	10.7
Connecticut	NR	7.6	7.6
Delaware	NR	15.2	15.2
Florida	NR	NR	10.7
Georgia	6.1	6.1	12.2
Illinois	NR	7.6	15.2
Indiana	NR	7.6	15.2
Iowa	NR	NR	15.2
Kentucky	NR	7.6	7.6
Louisiana	NR	10.7	15.2
Maine	NR	22.9	22.9
Maryland	NR	10.7	10.7
Michigan	NR	30.5	30.5
Minnesota	NR	NR	15.2
Mississippi	NR	9.1	9.1
Missouri	NR	7.6	7.6
Nebraska	NR	NR	15.2
New Hampshire	NR	15.2	15.2
New Jersey	NR	7.6	7.6
New York	NR	15.2	15.2
North Carolina	NR	15.2	15.2
Ohio	NR	7.6	7.6
Pennsylvania	NR	NR	7.6
South Carolina	NR	12.2	12.2
Tennessee	NR	7.6	7.6
Texas	NR	15.2	15.2
Vermont	NR	15.2	15.2
Virginia	NR	15.2	15.2
West Virginia	7.6	30.5	30.5
Wisconsin	NR	10.7	30.5

*NR = No Recommendation or Requirement

5.3.2 Southern USA

Comerford et al. (1992) concluded that SMZs (i.e. *buffer strips*) have the potential to protect streams and riparian areas from the adverse effects of forest management (i.e. nonpoint source pollutions). They noted that the utility and size of an SMZ will depend not only on local geomorphic conditions, but also on soil physico-chemical properties, vegetation characteristics, and climate. Streamside management zone widths are a commonly used metric to define the functional zones of these management areas. However, Comerford et al. (1992) distinctly pointed out that sizes should be prescribed based on a flexible system that can account for individual site variation and not rigid, uniform guidelines. The generally recommended size range, either side of streams, reported by Comerford et al. (1992) for water quality protection, is 7 to 9 m, but operational applications of SMZs for sediment mentioned in their review ranged from 2 to 125 m for sediment (Table 15) and 9 to 91 m for herbicides (Table 16). These ranges of SMZ widths are similar to those indicated by Zhang et al. (2010) for effectively filtering sediment, nutrients and pesticides. Comerford et al. (1992) mentioned the importance of slope and reported several approaches to factoring in slope (Table 17). However they did not recommend any as being a “better” choice.

It should always be remembered that SMZs cannot be expected to completely mitigate poorly planned and executed upslope forest and agricultural management (Nutter and Gaskin 1988). The emphasis for protection of water quality should be on pre-operational planning and implementation of BMPs within the SMZs and adjacent upland areas, not after-the-fact impact mitigation.

Wenger (1999) reviewed SMZ sizes reported at the time for a variety of functions (Table 18). Sediment detention width recommendations or usage were the smallest (5 – 30 m), temperature maintenance and nutrient detention functions had intermediate sizes, and wildlife zones were the largest (up to 100 m). Wildlife SMZs are typically larger because of the need to provide adequate animal movement corridors.

Hodges (2006) summarized SMZ widths for 11 states in the southern USA (Table 19), as well as equipment and vehicle restrictions (Table 20). Most State regulations allow harvesting in SMZs if it is done carefully.

Table 15. Streamside Management Zone widths in the literature for sediment filtering and detention reported by Comerford et al. (1992).

SMZ Purpose	SMZ Width (m)	Reference
General Forest Management	7 – 50	Trimble and Sartz 1957
Municipal Watershed Management	14 - 100	Trimble and Sartz 1957
Slight Erosion Hazard Soils	9 - 64	Swift 1986
Moderate Erosion Hazard Soils	12 - 83	Swift 1986
Severe Erosion Hazard Soils	15 - 103	Swift 1986
Roads With Brush Barriers	10 - 19	Swift 1986
Developed Upland Areas	25 – 125	Brown et al. 1990
Equipment Operation	2 – 9*	USDA Forest Service 1989ab
*Width = 9 m + (0.46 x % Slope)		USDA Forest Service 1989b

Table 16. Streamside Management Zone widths in the southern USA for herbicide filtering and detention reported by Comerford et al. (1992).

SMZ Purpose	Width (m)	Reference
Normal Aerial Application	30	USDA Forest Service 1989a, 1989b
Normal Ground Application	9	
Water Supply Protection	30	
Residence Protection	91	

Table 17. Streamside Management Zone slope corrections to detain sediment (Comerford et al. 1992).

Streamside Situation	Slope Correction Formula	Reference
Stream Protection	W = 8 - 9 m + (0.6 m x Slope %)	Trimble and Sartz 1957
Municipal Watersheds	W = 16 - 17 m + (1.2 m x Slope %)	Trimble and Sartz 1957
Below Roads, No Barrier	W = 13 m + (0.42 m x Slope %)	Swift 1986
Below Roads, Brush Barrier	W = 13 m + (0.12 m x Slope %)	Swift 1986
Stream Protection	W = 9 m + (0.46 m x Slope %)	USDA Forest Service1989b

Table 18. Georgia, USA, review of SMZ (riparian buffer) widths and recommendations for key functions (Adapted from Wenger 1999).

Streamside Management Zone Function	Width Range (m)	References
Sediment Detention	05 - 30	Peterjohn and Correll 1984, Castelle et al. 1994
Phosphorous Filtering	15 - 30	Vought et al. 1994, Mander et al. 1997
Nitrogen Removal	15 - 30	Lowrance 1992, Osborne and Kovacic 1993
Pesticide and Metal Filtering	15 - 30	Neary et al. 1993, Lowrance et al. 1997
Biological Contaminant Filter	09 - 60	Young et al 1980, Coyne et al. 1995
Temperature Maintenance	10 - 15	Barton et al. 1985, Osborne and Kovacic 1993
Woody Debris Input	15 - 30	Collier et al. 1995a 1995b, Murphy et al. 1986
Wildlife Habitat - Birds	15 – 100	Triquet et al. 1990, Kinley and Newhouse 1997
Wildlife Habitat - Mammals	67 - 100	Cross 1985, Naiman and Rodgers 1997,
Wildlife Habitat – Herpetofauna	75 - 100	Gomez and Anthony 1996, Burbrink et al. 1998

Table 19. Comparison of recommended SMZ widths (m) in the southeastern USA region, 2004 (Adapted from Hodges 2006).

State	Perennial Stream			Intermittent Stream	Cold Water Fish	Wetlands	City Water Supply
Widths:	All	0-20	20-40				
Alabama	10.7			10.7			
Arkansas	10.7-24.4			10.7-24.4			
Florida		10.7	22.9-30.5	10.7-91.4		15.2	61.0
Georgia	12.2-30.5			7.6-15.2	30.5		15.2-45.7
Kentucky	7.6-16.8				18.3	15.2	
Louisiana		15.2	30.5	10.7			
Mississippi	9.1-18.3			10.7			
N.Carolina	15.2			15.2	15.2-38.1		
S.Carolina	12.2-48.8			12.2-48.8	12.2-61.0		
Tennessee	7.6-44.2			7.6-44.2			
Virgina	15.2			15.2	18.3-36.6	15.2	30.5-61.0

Note: Bold widths indicate that the SMZs are slope dependent

Table 20. Comparison of the harvesting equipment allowed in SMZs in the southeastern USA according to State BMP manuals (Adapted from Hodges 2006).

State	SMZ Harvesting Guidelines
Alabama	Equipment allowed in SMZs, but the forest floor should be protected
Arkansas	Minimize forest floor disturbance
Florida	Equipment allowed in SMZs
Georgia	Equipment allowed in SMZs, no operation within 7.6 m of perennial streams
Kentucky	No equipment or vehicles allowed within SMZ The preferred extraction method is winching. No equipment operation within 7.6 m of perennial streams.
Louisiana	Harvesting equipment allowed in SMZs. Recommended equipment includes wide-tire and tracked skidders & forwarders
Mississippi	Equipment allowed in SMZ
N. Carolina	Equipment or vehicles not allowed within an SMZ that has a stream confluence. Timber should be removed with extreme care to leave the forest floor essentially undisturbed. The preferred method is winching.
S. Carolina	Equipment allowed in SMZs, Secondary zone suggests using wheel or tracked vehicles
Tennessee	No harvesting equipment or vehicles are allowed within SMZ, The preferred extraction method is winching
Virginia	Equipment is allowed in SMZs. The forest floor should remain mostly undisturbed

Williams et al. (2003) reviewed state forestry BMP manuals for SMZ width-slope relationships for the southeastern USA (Table 21). Planning and maintenance of adequate SMZs are essential components for protecting water quality during forest harvesting operations. Most SMZ guidelines in the southeastern USA specify widths that vary according to slope. Although the variable width approach for designing SMZs is beneficial for water quality, it complicates forest operations planning and SMZ delineation in harvest units. Williams et al. (2003) proposed an SMZ modelling process that incorporates accurate stream bottom maps with digital elevation models to accurately map SMZs that vary in width because of side-slope variability.

5.3.3 USA-Canada Regional Reviews

Lee et al. (2004) compared guidelines for SMZs (i.e. *riparian buffers*) amongst jurisdictions in Canada and the USA (Table 22). Streamside Management Zone widths varied from a mean of 45.8 to 12.1 m. They reported that Canadian jurisdictions had the widest buffers due to guidelines for Boreal regions. The Southeast USA has the narrowest SMZs. Incorporation of modifying factors such as waterbody type and size, slope, and the presence of fish has resulted in a shift from a “one-size-fits-all” approach to more complicated guidelines. This trend and the one of expansion of SMZ planning to larger catchments are projected to continue well into the future.

Table 21. Slope variable SMZ widths in State BMP manuals of the Southeast USA (From Williams et al. 2003).

State	Slope - %						
	0	10	20	30	40	50	60
	……………………………SMZ Width – m………………………						
Virginia WW*	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Virginia CW	19.8	19.8	22.9	30.5	30.5	38.1	38.1
Virginia DW	30.5	45.7	45.7	45.7	61.0	61.0	61.0
N. Carolina WW	15.2	15.2	15.2	15.2	15.2	15.2	15.2
N. Carolina CW	15.2	20.1	22.9	30.5	30.5	38.1	38.1
S. Carolina WW	12.2	24.4	24.4	36.6	36.6	48.8	48.8
S. Carolina CW	12.2	36.6	36.6	48.8	48.8	61.0	61.0
Georgia	12.2	12.2	12.2	21.3	21.3	30.5	30.5
Tennessee	7.6	13.7	19.8	25.9	32.0	38.1	44.2
Kentucky	7.6	13.7	19.8	25.9	32.0	38.1	44.2
Mississippi	9.1	12.2	12.2	15.2	15.2	18.3	18.4

*WW = warm water fishery, CW = cold water fishery, DW = Drinking Water Supply

Table 22. Regional differences in total SMZ (i.e. buffer) widths in the USA and Canada for permanent (P) and intermittent streams (Large = > 5m wide, Small = <5m wide) and lakes (Small = < 4ha, large > 4 ha) (Lee et al. 2004)

Waterbody Type	Boreal	Rocky Mountain	Pacific	Northeast	Midwest	South
Jurisdictions:	13	9	6	16	9	11
Size:	……………………………………………m…………………………………..........					
Streams						
Large - P	39.1	24.4	24.3	29.7	25.7	19.4
Small - P	26.3	24.2	22.7	23.7	14.4	17.5
Intermittent	13.9	24.2	21.7	13.1	11.5	12.1
Lakes						
Small	45.8	23.0	22.7	30.6	21.7	17.4
Large	52.2	23.0	22.7	30.2	21.7	17.4

Lee et al. (2004) found that about 80% of the jurisdictions surveyed in their study allowed for the option of tree cutting within the SMZ buffers. The types of cutting allowed included single tree and group selection, and zoned harvest. Although there were differences in SMZ harvesting prescriptions, the restrictions imposed by most guidelines for buffer zone harvesting were similar. They included:

- Retaining >50% of the tree volume, cover, or basal area
- Minimizing or eliminating machinery operations
- Protecting understory species and overstory regeneration

- Preventing harvesting-related streambank or shoreline erosion
- Spatially distributing cutting via single tree or group selections
- Preventing removal of all large or “old-growth” stems

The objectives of harvesting within SMZs stated in various guidelines include economic benefits from tree harvesting, maintaining tree-replacing disturbances, keeping riparian woody vegetation in a vigorous, rapid growth mode, and removing trees susceptible to wind-throw. Palik et al.’s (2000) treatise on riparian silviculture and experiments by Lakel et al. (2010) concluded that partial harvest inside SMZs has relatively little impact on water quality characteristics such as temperature and sediment. Long-term effects on woody debris inputs to streams still need to be evaluated. Lee et al. (2004) noted that some jurisdictions in the USA and Canada are using multiple management zones with increasing intensities of harvest grading from stream channels upslope.

Blinn and Kilgore (2004) produced a regional summary of minimum SMZ widths for perennial and intermittent streams and lakes in the eastern USA (Table 23). They found that 72 to 76% of the States surveyed used SMZs for perennial and intermittent streams that averaged 7.7 to 15.2 m in width. Their survey did not detect a great deal of difference between Northern and Southern USA jurisdictions.

Table 23. Regional summary of minimum SMZ widths for perennial and intermittent streams and lakes in the eastern USA (Adapted from Blinn and Kilgore 2004).

Minimum Width	Perennial Streams		Ephemeral Streams		Lakes	
	North 24 States	South 13 States	North 17 States	South 12 States	North 13 States	South 5 States
m	……………………..………………Number..					
7.6	4	2	4	4	2	1
7.7-15.2	11	10	7	7	5	4
15.3-22.9	1	0	0	0	1	0
23.0-30.5	5	0	4	0	3	0
30.6-39.6	1	0	1	0	1	0
None	2	0	1	0	1	0
Site Specific	0	1	0	1	0	0

5.3.4 USA Agency Guidelines

Other SMZ widths have been suggested as general guidelines by the U.S. Environmental Protection Agency for nutrient filtering (Table 24). The U.S. Fish and Wildlife Service adopted general SMZ width guidelines for specific regions and States (e.g. Oklahoma Region, Table 25). Maryland produced a fact sheet on riparian forest buffers (Tjaden and Weber 1997).

Table 24. U.S. Environmental Protection Agency 2005 review of SMZ (i.e. buffer) widths for nitrogen removal (Mayer et al. 2005)

Vegetation Type	Nitrogen Form	SMZ Width	Effectiveness	Number of Studies
		………..m………..	…….%.........	
Grass	Total N	5 – 91	15 – 38	4
	Nitrate	5 – 100	8 – 100	13
Grass & Forest	Total N	8 - 15	28 – 41	2
	Nitrate	6 - 70	91 – 99	7
Forest	Total N	--------	--------	-------
	Nitrate	10 – 220	58 – 100	22
Forest Wetland	Total N	--------	--------	-------
	Nitrate	6 - 38	59 – 100	8
Wetland	Total N	--------	--------	-------
	Nitrate	1 – 200	12 – 100	7

Table 25. U.S. Fish and Wildlife Service recommendations for primary (ephemeral streams) and secondary (intermittent, braided, and perennial streams, lakes and ponds) SMZs in the Oklahoma Region (US Fish and Wildlife Service 2007).

Stream Width	Slope	Primary SMZ	Secondary SMZ
…..….m…..…	%	………….…m…………...	……….m……….
<6	<7	10.7	0
<6	7 - 20	10.7	15.2
<6	>20	Top of slope or 45.7	22.9
6 - 15.2	<7	15.2	0
6 - 15.2	7 - 20	15.2	15.2
6 - 15.2	>20	Top of slope or 45.7	22.9
15.2	<7	Width of stream or 30.5 maximum	0
15.2	7 - 20	Width of stream or 30.5 maximum	15.2
15.2	>20	Top of slope or 45.7	22.9

5.35 Minnesota SMZ Guidelines

The State of Minnesota has a particularly well-developed set of guidelines for forest management, and SMZs in general (Minnesota Forest Resources Council 2005). These guidelines are worth separate examination since they are well-developed and contained in an easy-to-use and easy-to-update book. The Minnesota guidebook uses the terminology “Riparian Management Zone” (RMZ) which is congruent with the SMZ terminology used in this paper. An RMZ can include areas which are not strictly “riparian”. The Minnesota guidelines recognize that site variability and landowner objectives require a great deal of flexibility in developing forest management plans. The highlights of the flexibility built into the Minnesotan SMZ guidelines are as follows (Minnesota Forest Resources Council 2005):

- Width and residual basal area guidelines are recommendations not mandates
- It is acceptable to vary above and below width and basal area guidelines

- SMZ boundaries can be straight or irregular
- Slope aspect should not govern SMZ locations
- Trees left as residuals should be relatively evenly distributed but can be in even or in gap-bunch distributions
- Cleared areas in the SMZ should be minimized
- The best professional judgment should be used to determine species and distributions of residual trees considering site conditions, tree species, wildlife needs, clumps needed to reduce windthrow hazard, gaps needed for regeneration of shade-intolerant species, needs to retain trees near waterbody banks, and other management objectives needs.
- Distributions of individual trees should consider species distributions and arrangements, regeneration requirements, species-specific crown sizes, windfirmness, the presence of insect and disease stressors, and needs to retain conifers near trout water bodies.
- Tradeoffs need to be recognized.

A number of BMP recommendations are presented by the Minnesota guidebook (Minnesota Forest Resources Council 2005). This is a flexible system that adapts to the needs to protect resources and the practicalities of establishing SMZ (i.e. RMZ) boundaries. The Minnesota system allows straight as well as irregular RMZ boundaries, recognizing that the former may be easier to establish and manage. The recommendations that pertain to SMZ widths are presented in Table 26. Because of its trout and many water resources, Minnesota has segregated its SMZ width recommendations according to the presence of trout, the use of even-aged or uneven-aged forest management within the SMZ, stream or lake size, and the perennial or intermittent nature of streamflow. The recommended SMZ widths are greater for trout waters (45.7 to 61.0 m), larger water bodies (30.5 to 61.0 m), and uneven-aged forest management. No SMZ widths are recommended for intermittent streams and drainages. An example of a hypothetical SMZ is shown in Figure 17 with a straight and irregular boundary as well as varying SMZ widths that follow local topography and other geomorphic features. Skid tracks mark access points for harvesting within the SMZ. Examples of residual stands in both clumped and regular spacing are shown in Figure 18.

5.4 Canada

Forest practices codes and SMZ guidelines in Canada are regulated by each individual Province. General country-wide standards come from the Forest Stewardship Council of Canada, a non-government body which offers environmental certification for land use practices based on a water body classification system (Forest Stewardship Council 2004). Canada

The bulk of the ownership and harvesting of Canada’s 397 million ha of forest land is Provincial (80%), with Federal and private ownership of 11 and 9%, respectively. Harvesting done by the forest industry is on a permit system guided by four regionally-specific forest management standards: National Boreal, British Columbia, Great Lakes St. Lawrence, and Maritimes. A couple of examples are provided here to give an indication of Provincial government direction to the forest industry on SMZs (Forest Stewardship Council 2005).

5.4.1 British Columbia

In this province, the principal SMZ management unit is the *Riparian Management Area* (RMA), and it has been an integral part of SMZ establishment and forest harvesting management since 1995 (Province of British Columbia 1995). A RMA (SMZ) consists of a *Riparian Management Zone* (RMZ) and, sometimes, a no-harvest *Riparian Reserve Zone* located adjacent to water bodies (RRZ; Fig. 19). Within the management zone, constraints to forest practices are applied. The widths of these zones are determined by specific water resource attributes found in the British Columbia riparian classification system or by characteristics of the adjacent terrestrial ecosystem.

Table 26. Minnesota recommended SMZ widths and residual basal areas by water body type (Minnesota Forest Resources Council 2005).

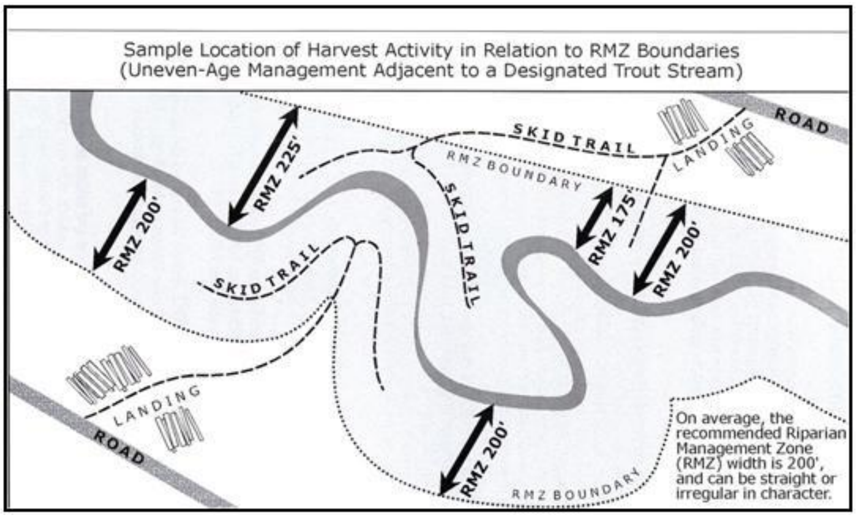
Water Body Type	Forest Management	Minimum SMZ Width	Minimum Residual Basal Area
		…………m………	………m^2 ha^{-1}…….
Trout Streams and Lakes			
	Even-Aged	45.7	13.3
	Uneven Aged	61.0	17.8
Non-Trout Streams			
>3.0 m wide	Even-Aged	30.5	5.6 – 17.8
0.9 – 3.0 m wide	Even-Aged	15.2	5.6 – 17.8
<0.9 m wide	Even-Aged	15.2	5.6 – 17.8
Non-Trout Streams			
Perennial <0.9 m wide	Even-Aged	15.2	5.6 – 17.8
Non-Trout Streams			
Intermittent <0.9 m wide	Even-Aged	Not Applicable	Not Applicable
Non-Trout Lakes/Wetlands			
>4.0 ha	Even-Aged	30.5	5.6 – 17.8
<4.0 ha	Even-Aged	15.2	5.6 – 17.8
Non-Trout Streams			
>3.0 m wide	Uneven-Aged	61.0	17.8
0.9 – 3.0 m wide	Uneven-Aged	30.5	17.8
<0.9 m wide Perennial	Uneven-Aged	15.2	17.8
<0.9 m wide Intermittent	Uneven-Aged	Not Applicable	Not Applicable
Non-Trout Lakes/Wetlands			
>4.0 ha	Uneven-Aged	61.0	17.8
<4.0 ha	Uneven-Aged	15.2	17.8

The riparian classification system that is the basis for British Columbia RMAs for streams, wetlands, and lakes was established in the Forest Practices Code (FPC) and the Forest and Range Practices Act (FRPA) regulations (Province of British Columbia 1995). In this system, streams are classified S1 to S6 based on the presence of fish (S1 - S4) or their absence (S5 - S6), their location within a community water supply watershed, and average channel width (Table 27). The stream classification system is based on the *reach* concept where the reach is understood to be a relatively continuous and homogeneous length of stream with recurring structural characteristics that also correspond to fish habitat types. The key physical factors used to determine reaches in the field are channel pattern, confinement, gradient, streambed, and bank materials. Stream reaches also exhibit general uniformity in geomorphic characteristics and in flow regime.

Riparian classification key for lakes under the FPC and FPRA, the widths of the respective RRZ and RMZ of each lake are listed in Table 27 (Province of British Columbia 1995).The outer edge of the lake is measured from the high-water mark or the edge of an immediately contiguous wetland. Further descriptions of the lake classification system can be found in the Province's "Riparian Management Area Guidebook".

British Columbia has five riparian classes of wetlands (W1 to W5) based on size, biogeoclimatic unit, and delineation of the wetland as a simple or a wetland complex (Province of British Columbia 1995). Classes W1 to W4 are simple wetlands while class W5 is a wetland complex.

Figure 17. Layout of sample SMZ (RMZ) boundaries, tree harvest access skid trails, and variable RMZ widths in feet (Adapted from Figure GG-6, Voluntary Site-Level Forest Management Guidelines, Minnesota Forest Resources Council 2005).



Since 1995, three riparian management approaches have been widely applied in British Columbia. Two of these schemes are the legislated management systems under the original FPC and the current FRPC legislation. The third scheme was developed by the Forest Stewardship Council of Canada, a non-government body that provides environmental certification for land use practices. All three approaches are based on the water body classification system developed for the FPC. The prescriptive FPC and the results-based FRPA differ primarily in that the FRPA provides more explicit latitude to vary riparian standards from the legislated defaults based on site and watershed-level on-the-ground evaluations. The Forest Stewardship Council system is generally a more conservative approach that requires higher levels of riparian tree retention for all water body classes, in particular for small streams (classes S4, S5, and S6). The Forest Stewardship Council system is voluntary, and can be one of the alternative approaches approved under a FRPA Forest Stewardship Plan by Provincial regulators. Small streams included within the S4, S5, and S6 stream categories in British Columbia have been a focus of attention and debate because they are particularly difficult to manage. Within each class, these streams comprise a diverse array of channel sizes, types, hydrologic network linkages, and ecological functions. These three classes may constitute 80 % or more of the total length of the hydrologic network within a given watershed. Because of their abundance and diversity, riparian management strategies for small streams need to be flexible, adaptable and appropriate for each harvesting area and its specific environment. A "landscape-level" conceptual approach to riparian area management and SMZs has been the focus of considerable attention in British Columbia in the past few years (Nitschke and Innes 2008).

Figure 18. Example of residual stand layout within sample SMZ (RMZ) boundaries, (Adapted from Figure GG-7, Voluntary Site-Level Forest Management Guidelines, Minnesota Forest Resources Council 2005).

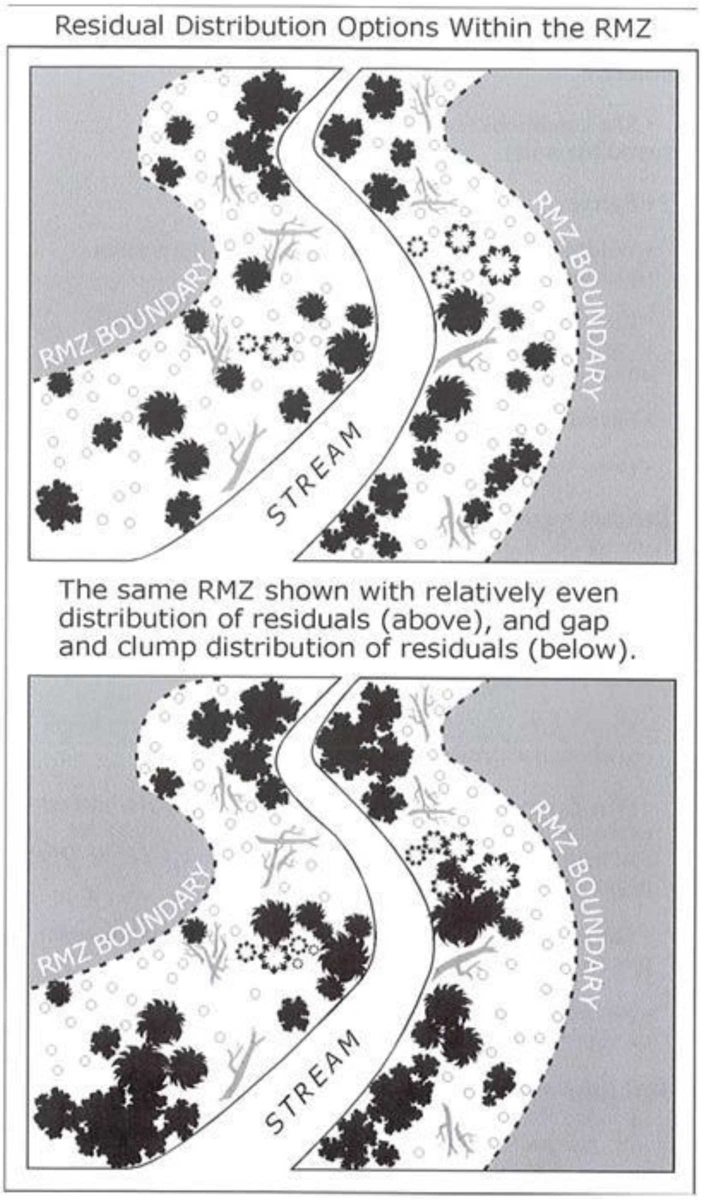
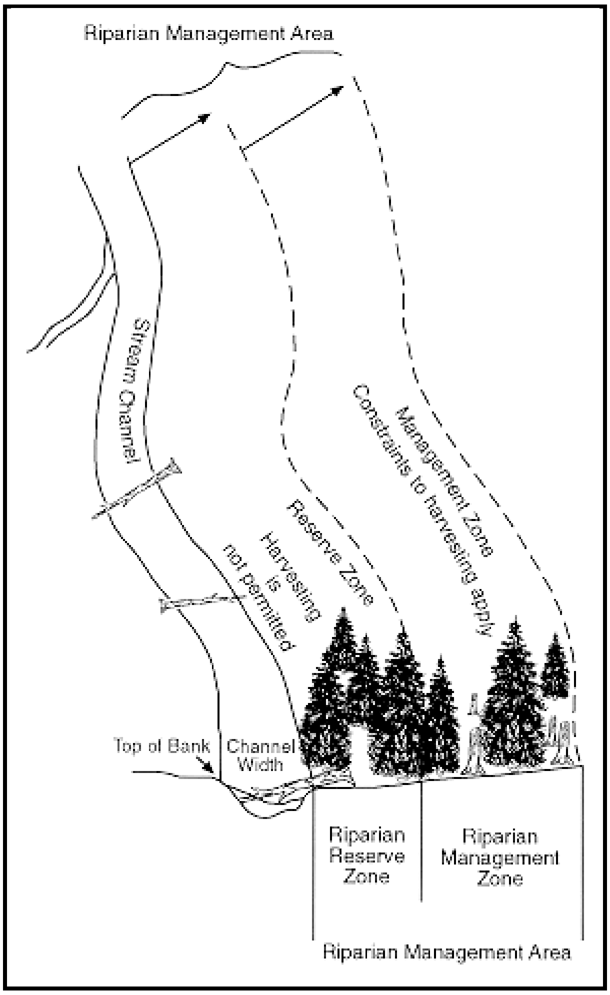


Figure 19. SMZ layout for streams in British Columbia showing a hypothetical layout of a management zone and a riparian reserve zone along a stream channel (From the Riparian Management Area Guidebook, Province of British Columbia 1995).



5.5 Alberta

The Province of Alberta, like all the other Canadian provinces, implemented forest harvesting planning and operations rules to protect watersheds, the primary component of the forest environment that can be protected during harvesting operations through application of BMPS that include SMZs (Province of Alberta 1994). Annual operating plans and specific ground rules are intended to carry out policy and legal directives of the Department of Environmental Protection, the Alberta Forests Act, the Timber Management Regulation, and the Alberta Public Lands Act.

The Alberta standards for watershed protection and harvest planning begin, like many other jurisdictions, with water body classification (Province of Alberta 1994). The water resources classifications (Table 28) have direct connections with fish and wildlife concerns and land use impacts. Roads, landings, protection SMZ, tree felling activities, and equipment operation buffers are outlined in Table 29.

Table 27. British Columbia RMA standards for streams, lakes and wetlands under the Forest Practices Code and Forest and Range Practices Act (Province of British Columbia 1995).

Riparian Class	Water Body Size	Riparian Reserve Zone (RRZ) width	Riparian Management Zone (RMZ) width	Total Width of RMA
		……………………………m.…………………………..		
STREAMS	Channel – m			
Fish Present				
S1 Large	>100	0	100	100
S1	>20	50	20	70
S2	>5 to ≤20	30	20	50
S3	1.5 to ≤5	20	20	40
S4	<1.5	0	30	30
No Fish				
S5	>3	0	30	30
S6	≤3	0	20	20
LAKES	Area - ha			
L1	>1,000	0	0	0
L1	<1,000	10	Set by District	10+
L2	1 to 5	10	20	30
L3	1 to 5	0	30	30
L4	<1	0	30	30
WETLANDS	Area - ha			
W1	>5	10	40	50
W2	1 to 5	10	20	30
W3	1 to 5	0	30	30
W4	0.5 to 1	0	30	30
W5	Complex	10	40	50

The Alberta forest harvesting guidelines are not slope adjusted but harvesting is typically not allowed above slopes of 45%. If special circumstances warrant harvesting above this slope limit then operations must be done during time periods when soil erosion will not be aggravated. In the Alberta system, logging is usually not allowed within the SMZ buffers unless specifically permitted and mitigated by BMPs (Province of Alberta 1994).

Table 28. Alberta water classifications (Province of Alberta 1994).

Classification	Description	Flow Description	Channel Size
Large, Permanent	Major Stream/River	All Year	>5 m
Small Permanent	Permanent Stream	All Year	0.5 to 5 m
Intermittent	Small Channels	Wet Season Only	0.0 to 0.5 m
Ephemeral	Vegetated Draws	Only After Rainfall	0.0 to 0.5 m
Source Areas	Saturated Soils/Seeps	All Year	N/A
Lakes	Permanent Water	Frozen in Winter	N/A

Table 29. Roads, landings, SMZ protection widths, tree felling, and equipment 20 m exclusion zone for forest harvesting near different water classifications in Alberta (Province of Alberta 1994).

Classification	Roads, Landings	SMZ Protections	Operating Conditions within SMZs & Water Where Approved	
			Tree Felling	Equipment Operations
Large Permanent	60 m	60 m unless approved	Not into water	-60 m harvest if approved -20 m machine exclusion
Small Permanent	30 m	30 m unless approved	Not into water	-30 m harvest if approved -20 m machine exclusion
Intermittent	30 m	Variable	Not into water	-machine operation within 20 m during frozen and dry periods
Ephemeral	Not in the water channel	Undisturbed understory	Not into water Slash removed	Skidding only during frozen or wet periods
Water Source Areas	-Must be permitted -No log decks -Stream crosssings minimized -Planned tree harvest only	-20 m tree buffer -No harvest unless approved -Width altered with approval	-Not into water -Machines permitted only during freeze conditions	-Machines allowed during freeze periods if permitted -Use of low impact machinery only
Lakes, No Recreation	100 m	100 m unless approved	Not into water	20 m exclusion zone
Lakes, Recreation	200 m	100 m unless approved	Not into water	20 m exclusion zone

5.5.1 Ontario

The Code of Practice for forest harvesting operations in Ontario was specifically developed to protect water quality (Ontario Ministry of Natural Resources 1991). It was specifically designed to be used in conjunction with the Ontario "Timber Management Guidelines for the Protection of Fish Habitat". The Code is a BMP approach based on common sense and the application on the ground of professional experience. In order to maintain water quality the Code has a focus on minimizing or mitigation soil erosion and compaction.

Harvesting practices in riparian areas are scheduled for routine monitoring in order to determine both compliance and effectiveness of BMP and operations. Should water quality be adversely affected, the normal enforcement occurs through application of relevant legislation which includes the Lakes and

Rivers Improvement Act, the Water Resources Act, the Crown Forest Sustainability Act, the Fisheries Act, and the Environmental Protection Act (Ontario Ministry of Natural Resources 1991).

Some of the features of the riparian Code include both operational and equipment operation guidelines for SMZs. A goal of harvesting is to minimize the removal of residual vegetative material that protects the soil. Slopes in excess of 40% are avoided unless specialized cable yarding equipment is utilized. Conventional ground-based skidders are not allowed on steep slopes. In the 10 to 40% slope zone, erosion is mitigated or avoided by the use of using extra-long winch cables, careful selection of skid trail locations, skidding along the slope contours where safety allows, avoiding repeated use of the same skid trail, and following slope contours when using heavy site preparation equipment. Other operational techniques include prohibition of felling trees into water bodies, removal of slash from stream and lake edges, leaving 3 m buffers of undisturbed forest floor and vegetation, keeping stream crossings to a minimum and then only at planned and designated locations, and prohibiting lubrication and fuelling of equipment in riparian zones.

To protect fish habitat most effectively, SMZ widths for harvesting areas, specified for local slopes, approximates the maximum value recommended by Trimble and Sartz (1957) for slopes. Thus the narrowest SMZ area is recommended at 30 m. Residual timber or other vegetation this wide normally provides effective protection on slopes up to 15%, and also protects standing timber from blowdown. The Ontario guidelines are designed for flexibility of application and are not meant to be rigid. Where better local information is available, widths may be modified in a manner consistent with the protection of fish habitat.

5.5.4 Other Provinces

Most other Canadian provinces have SMZ widths of 20 m (Table 30, Decker 2003). Manitoba is the most conservative with SMZ widths of 100 to 200 m. Saskatchewan's SMZ width is determined by stream class, and in the Yukon Territory the SMZ width varies by stream water use (i.e. general land use or water supply). There is no information from Nunavut on SMZ size requirements. The four Maritime Province Forest Codes require slope adjustments, but none of the others in Table 30 do so. Tree harvesting is allowed in most of the provinces, except for Newfoundland and Labrador. Nova Scotia allows harvesting in the SMZs of small streams. Machinery exclusion zones vary from the width of the SMZ (20 m) to 7 m, except in Saskatchewan and the Yukon Territory where harvesting machinery is allowed to operate in the SMZ if the ground is dry or frozen.

5.5 Europe

The European Union's (EU) percentage of forested land varies greatly between countries, ranging from 1 to 74%. The largest expanses of forests are in the Nordic countries, mountainous regions, and around the Mediterranean. Most EU forest lands are privately owned, although public agencies own and manage significant areas in almost all countries. Some of the new EU members from the former Soviet block have high amounts of public forests, but this is changing as privatization proceeds. Europe's forests are increasing in area slowly (1 x 10^6 ha yr^{-1} or 0.6%) as losses to urbanization are more than counterbalanced by expansion onto agricultural and scrub land.

Table 30. Canadian SMZ statistics for provinces other than Alberta, British Columbia, and Ontario (Adapted from Decker 2003).

Province	SMZ Width (W)	Slope (S) Adjustment	SMZ Harvest Allowed	Machinery Exclusion Zone
	m			m
Newfoundland	20	W+1.5 x S%	No	20+ m for slope
Labrador	20	W+1.5 x S%	No	20+ m for slope
Nova Scotia	20	W+1m/2%S>40%	Streams <50 cm	7
Prince Edward	20	30m if S>9%	Yes	20
Quebec	20	No	Yes	20
Manitoba	100-200	No	Yes	15
Saskatchewan	15, 30, 90	No	Yes	Dry/Frozen
Yukon Territory	30-90	No	Yes	Dry/Frozen
Nunavut	No Info	No Info	No Info	No Info

Almost all forests in Europe are managed with formal or informal management plans for wood production, for biodiversity conservation, recreation or other objectives such as water quality, water supply, and soil protection. Over 10% of Europe's forests are currently being managed just to protect the environmental services produced by watersheds. About 50% of Europe's forest land is predominantly coniferous, while 33% contains mostly broadleaved forests, and the remaining 15% is a mixture of evergreen and deciduous species. The largest areas of "undisturbed" forests are in the Nordic countries (6 x 10^6 ha). Intensively managed plantation forests used for wood production cover 15 x 10^6 ha. Protection forests range in area from 10 to 35% of individual EU countries.

Codes of Forest Practice exist in each country to promote BMPs and the application of SMZs in forest harvesting operations (Syversen 2005). Many forests, particularly industrial ones, are certified by the international Forest Stewardship Council (Cauley et al. 2001). Some forest owners have elected to be certified under the international Program for the Endorsement of Forest Certification (Program for the Endorsement of Forest Certification 2008).

5.5.1 Ireland

The Ireland Code of Best Forest Practice is one element of a series of guides developed to ensure sustainable forestry in the country (Forest Service 2000). The guides for SMZ widths and operation limitations are linked to the national Forestry and Water Quality Guidelines (Ryan 1999, Forest Service 2000) as well as other guides for archeology, landscape values, and biodiversity. Forest harvesting operations are guided by an extensive set of BMPs. Aquatic zones are defined as permanent or seasonal rivers, streams, or lakes shown on Ordnance Survey maps. The Irish Forest Service's Forestry and Fisheries Guidelines have formed the basis for the protection of aquatic areas since 1992

Widths of SMZs in Irish forestry are controlled by slope, and range from 10 to 20 m. These zones are both felling and machinery exclusion zones, except in planned and designated stream crossings (Table 31). Machinery fueling and servicing zones must be located more than 50 m from designated aquatic areas.

Table 31. Ireland's Code of Forest Practice buffer zone width (m) for SMZs (From Forest Service 2000).

Slope Considerations and Special Operations Buffers for the Aquatic Zone	Buffer Zone Width on Each Side of the Aquatic Zone	Buffer Zone Width for Erodable Soils
Moderate (0-15%)	10	15
Steep (15-30%)	15	20
	20	25
Machine Fueling/Maintenance	50	50

5.5.2 Sweden

Forests and other wooded lands occupy nearly 74% of Sweden's total land area (Yrjölä 2008). The largest number of stands (35%) is at the age when thinning operations are conducted. Forests ready for final harvest and young stands make up similar amounts, 21% and 26%, respectively (Skogsstyrelsen 2000, 2008). The majority of forest land is under private ownership and management (51% of Sweden's land base). State and local government forestry makes up the remaining forest land ownership (10%). Agriculture, urban areas, and special uses comprise the rest. Forestry in Sweden is governed by the Forestry Act of 1994 (Yrjölä 2008). It establishes two equal policy goals related to sustainability, environmental protection and wood production. Biodiversity is a key issue and is protected with large reserves in the North of Sweden (610 Million ha) and operations regulations governing timber harvesting in the rest of the country. In 2005, the Swedish Forest Agency augmented the Forestry Act and formally adopted a set of objectives for the nation's forest sector. They include overall legislative policy objectives plus thirteen interim quantitative targets to be fulfilled in the near future. Approval of the objectives culminated a two-year development process involving the Swedish Forest Agency and a wide range of stakeholders. The forest management objectives and the criteria and indicators (C&I) for sustainable forest management adopted by the Ministerial Conference on the Protection of Forests in Europe are very similar. The interim targets of the forestry objectives are similar to indicators of the C&I system for biological diversity.

Many forests in Sweden, particularly industrial ones, are certified by the Swedish Forest Stewardship Council (SForest Stewardship Council) (Forest Stewardship Council 2008). This organization is affiliated with the international Forest Stewardship Council. It promotes environmentally sound and appropriate, socially beneficial, and economically sustainable forest management. At the end of 2001, 33% of Sweden's forests were SForest Stewardship Council cerified as sustainable forestry operations. Some forest owners elected to be certified under the Swedish Forest Certification Scheme, which belongs to the international Program for the Endorsement of Forest Certification (Program for the Endorsement of Forest Certification 2008).

The Forestry Act of 1994, as amended, requires the use of SMZs for "natural streams" but does not mandate standardized widths. The SMZs are established on a site specific basis depending on the environmental concerns appropriate for the site (McDermott et al. 2007).

5.5.3 Finland

Forests in Finland occupy 26.2 Million ha of the land area, about 86% of the total land base (Yrjölä 2008). About 23% of this forestry land area consists mostly of scrublands and wastelands. The first piece of forestry legislation in Finland was the Forest Act of 1886. The principles of sustainable forest development and environmental protection were introduced into later legislation. Initially, sustainable forestry was defined only in terms of timber production. The most recent legislation (Forest Act of 1997) stated the equal importance of ecological and social sustainability to the economic one already recognized in earlier legislation. The Finnish forest legislation revisions of the 1990s ensured legislative compliance with international protocols such as the Helsinki Process and the later Kyoto Protocol. In addition, these changes addressed needs to decrease forest management costs, to increase the multiple-use of forests, and to protect the forest landscapes of Finland. Over-arching all these legislative acts is the requirement in the revised Constitution of Finland that delegates the responsibility for nature, biodiversity, and the environment to all citizens. Thus, a number of forest legislation enactments are applicable to all forest owners and managers, not just government forests. Current biodiversity reserves of 343,000 ha of old growth under the current forest legislation may expand to 2.5 Million ha under the Natura 2000 Network Programme (European Commission 2003).

Like Sweden, Finland is involved in the international Program for the Endorsement of Forest Certification (Program for the Endorsement of Forest Certification 2008). The management of 84% of Finnish forestry land outside protected areas is certified according to the standards of the Finnish Forest Certification System (http://www.pefc.fi/pages/english/finnish-forest-certification-council.ph, Program for the Endorsement of Forest Certification 1999, Finnish Forest Certification System 2004). Finnish Forest Certification System requires a level of forest management which is higher than many other forest management regulations. The Finnish Forest Certification System Certificate has been approved by the international Program for the Endorsement of Forest Certification organization (Program for the Endorsement of Forest Certification 2008), and thus Finland has the right to use a product label informing of Program for the Endorsement of Forest Certification forest certification. A second forest certification system is managed by the Forest Stewardship Council (Forest Stewardship Council) on limited land holdings (Yrjölä 2008).

Like Sweden, the Finnish forestry legislation and the Finnish Forest Certification System require the use of SMZs for “natural streams” but they do not mandate standardized widths. The SMZs are established on a site specific basis depending on the environmental concerns appropriate for the site (McDermott et al. 2007).

5.5.4 Germany, Russia, Latvia, Poland

Like Sweden and Finland, Germany requires SMZs around its water resources in forested landscapes but it does not mandate standardized widths. Widths are determined on a site-specific basis according to environmental values and resource protection needs. Russia, Poland, and Latvia have mandated SMZ widths (Table 32). Except for Poland, the widths are determined by stream length, not width. Russia has the largest SMZs except for Brazil.

5.6 Asia, Africa, Central and South America

A number of countries in Asia, Africa, Central America, and South America have no-harvest SMZs that vary in width from 10 to 500 m, and are determined by stream width or special water resource features such as water supplies, and springs. South Africa and India, like Sweden and Finland, do not have mandated standard widths but instead rely on site-specific evaluations. The large SMZ buffers (200-500 m) shown in Tables 32 and 33 have biodiversity and wildlife habitat as major functions.

Table 32. SMZs for Eastern Europe countries (Adapted from McDermott et al 2007).

Country	SMZ Description	SMZ No Harvest Zone	SMZ TOTAL
		m	m
Latvia	Streams >100 km	10	300
	Streams 25-100 km	10	100
	Streams 10-25 km	10	50
	Streams <10 km	10	10
	Water bodies on islands	10	20
	Artificial waters	10	10
	Urban area waters	10	10
Poland	Rivers in State Forests	0	50
Russia	Rivers >500 km	0	500
	Rivers 200-500 km	0	400
	Rivers 100-200 km	0	300
	Rivers 50-100 km	0	200
	Rivers 10-50 km	0	100
	Rivers <10 km	0	50

Table 33. No harvest SMZ widths for protection of riparian values in some Asian and South American countries (From McDermott et al. 2007)

Country	Description	No Harvest SMZ Width
		…………..…m…………….
Indonesia	Rivers >50 m wide	100
	Rivers <50 m wide	50
Congo	Domestic water supply	100
	Other water resources	50
Chile	Above mountain springs	400
	Flat terrain springs	200
	Other water resources	50
Brazil – Amazon Basin	Stream >600 m wide	500
	Stream 200-600 m wide	200
	Stream 50-200 m wide	100
	Stream 10-50 m wide	50
	Stream <10 m wide	30
	Springs	50
Mexico	Permanent water resources	50
	Natural springs	50
	Temporary streams	10
South Africa	All permanent waters	Site Specific
India	All permanent waters	Site Specific

6. SMZ EFFECTIVENESS FOR PROTECTING WATER QUALITY DURING FOREST HARVESTING AND MANAGEMENT

The water quality objectives and functions of SMZs has been elucidated by a number of publications (U.S. Army Corps of Engineers 1991, Comerford et al. 1992, Lowrance et al. 1997, National Academy of Science 2002, Corell 2005, Mander et al. 2005). The primary objectives are minimizing soil disturbance, sediment filtration and deposition, contaminant detention, adsorption, and degradation, nutrient uptake and transformations, and stream temperature regulation. Additional functions of SMZs which contribute to maintaining water quality include streambank stabilization, channel stabilization, and peakflow reduction. Sediment is the single largest water quality problem produced by forest harvesting because it is readily visible, it degrades municipal water supply value and increases water treatment costs, and it produces a variety of adverse effects on stream biota. Nutrient and contaminant effects are much more subtle and transient in nature. Stream temperature effects are functions of affected biota, forest ecosystem, and climate. Streamside Management Zones are able to mitigate many of the water quality of impacts of forest harvesting. This section reviews some of the results of SMZ effectiveness investigations.

6.1 Sediment

Sediment yields after forest harvesting are highly variable depending on such factors as soils, climate, topography, ground cover, and watershed condition. Although sediment yields increase after harvesting due to the physical disturbance of soil, they are usually transient due to vegetation regrowth and the filtering effects of slash and ground depressions. The largest increases documented in the literature have been associated with post-harvest mechanical site preparation in the absence of SMZs (Beasley 1979), slope instability (O'Loughlin and Pearce 1976), road construction (Swanson et al. 1986), or highly erosive soils (Beasley and Granillo 1988). Best Management Practices are most effective on sediment when properly planned and implemented prior to, during, and after harvesting. Most of these guidelines relate to designing, constructing, and maintaining major access roads, logging roads, skid trails, and landings (Binkley and Brown 1993). These transportation corridors are the primary sources for 90 percent of the sediment generated by harvesting (Reid and Dunne 1984, Swift 1988). The underlying principles of BMP guidelines are to minimize disturbances in SMZs, reduce the erosive power of runoff on bare road surfaces, and to maintain the normally high infiltration capacity of forest soils.

Sediment movement to streams is a constant environmental concern in managed forest watersheds, but is also occurs naturally without management, and it can also be a serious issue for other land uses. Watersheds vary greatly in their natural sediment load characteristics. Both natural and anthropomorphic sediment deposits can be re-entrained after initial deposition in ephemeral or perennial stream channels, and move downstream for long time periods (>100 years) and distances. The cumulative effects of erosion and sedimentation that occurred centuries ago from agriculture or forestry can present land managers with many challenges (Neary 2002, DeBano et al. 2005). Sediment is an important water quality parameter since it can harm aquatic organisms and habitats, and render water unacceptable for drinking water supply or recreation purposes.

Reference sediment yield baselines have been discussed by Neary and Michael (1996), Neary (2002), and DeBano et al. (2005). Natural erosion rates for undisturbed forests in the Western United States of <0.01 to 5.53 Mg ha^{-1} yr^{-1} are higher than Eastern United States yields of 0.1 to 0.2 Mg ha^{-1} yr^{-1}, but don't approach the upper limit of geologic erosion (15 Mg ha^{-1} yr^{-1}, Schumm and Harvey 1982). Australia's geologic erosion rates range from 0.04 to 0.86 Mg ha^{-1} yr^{-1} (Wasson et al. 1996). However, they can be as high as 1,000 Mg ha^{-1} yr^{-1} in small gullied basins and along with channel banks are the main sources of sediment for Australian rivers (Wasson 1994, Prosser et al. 2001). The measured differences at both continental and local scales are due to natural site factors such as soil and geologic erosivity, rates of geologic uplift, tectonic activity, slope, rainfall amount and intensity, vegetation density and percent cover, and fire frequency. Landscape-disturbing activities such as mechanical site preparation (15 Mg ha^{-1} yr^{-1}; Neary and Hornbeck 1994), agriculture (560 Mg ha^{-1} yr^{-1}; Larson et al. 1983), and road construction (140 Mg ha^{-1} yr^{-1}; Swift 1986, Binkley and Brown 1993) produce the most sediment loss and can match or exceed the upper limit of natural geologic erosion.

Suspended sediment concentration variations can be quite large both within and between individual catchments and landscape regions (Binkley and Brown 1993). Most undisturbed forested catchments have suspended solid concentrations <5.0 mg L^{-1} with stormflow peaks >100 mg L^{-1}, but some routinely average higher than 20 mg L^{-1}. Forests in regions with highly erosive soils can have average suspended solids concentrations >2,000 mg L^{-1} in the absence of disturbance. Responses of forested watersheds harvested with no SMZ can be in the range of <2 to 43 times control or pre-treatment conditions (Binkley and Brown 1993).

The concept of sediment trapping in SMZs was elucidated by Comerford et al (1992) and Newham et al. (2005). The actual effectiveness of SMZs in filtering out sediment from storm runoff has been demonstrated by a number of researchers (e.g. Arthur et al. 1998, Dosskey 2001, McKergow et al. 2003, 2006; Helmers et al. 2005). Sediment removals of 90% or more have been measured, and reductions in flow weighted mean suspended sediment concentrations of an order of magnitude have been documented (148 to 13 mg L^{-1}, McKergow et al. 2003).

In Nebraska, USA, Helmers et al. 2005 reviewed the sediment trapping effectiveness of a variety of mixed grass species vegetative SMZ filters in the central USA, the eastern USA, and Europe as part of a study of sediment movement in water flow pathways and convergence (Table 34). Sediment reduction reported in the review was a function of SMZ widths and landscape slopes with mean reductions ranging from 63.8 to 96.3%. In a number of cases 100% reduction in sediment flux was achieved by vegetative buffers. The research in Nebraska's Clear Creek Watershed reported in the Helmers et al. (2005) paper determined that, despite the presence of distinct converging flow pathways, an 80% sediment trapping effectiveness was achieved by the mixed grass species SMZs

Table 34. Sediment trapping effectiveness of a range of vegetative filter widths and slopes (Adapted from Helmers et al. 1995)

Buffer Width	Slope Range Minimum	Maximum	Mean Sediment Reduction	Sediment Reduction Range Minimum	Maximum
m	%	%	%	%	%
<5	2	16	77.5	45	97
5 to 10	2	16	83.3	57	100
10 to 15	2	16	96.3	84	100
15 to 20	6	16	96.2	85	100
>20	2	3	63.8	41	88

In Norway, Syverson (2005) studied the loss of nutrients and sediments from agricultural runoff with the objective of determining SMZ buffer zone design criteria which optimise the effectiveness of buffer zones. The research set out to determine the influence of four criteria: buffer zone width, surface runoff amounts, seasonal variation and vegetation type. The results show significantly higher sediment and nutrient removal efficiency from 10 m-wide SMZs compared to 5m widths, however, the specific retention of sediments (i.e. kg m^{-2}) was higher in the 5 m zones. Sediment in runoff over several days did not produce any significant decrease in their removal level. Retention efficiency between summer and autumn varied depending on the water quality parameter (sediment, phosphorus, and nitrogen), but there were no significant differences in removal efficiency between summer and winter. The results showed no significant differences between forest and grass vegetation SMZs in terms of nutrient retention efficiency. There was significantly higher sediment trapping efficiency in forested SMZs compared to those that were primarily covered in grass. Average sediment removal efficiencies ranged from 81 to 91% for sediment. Nutrient removal efficiencies by the vegetated SMZs were less for phosphorus (60–89%) and nitrogen (37–81%).

In Virginia, USA, three small watersheds (8 – 10 ha) located in eastern Virginia were monitored to evaluate the impact of forest clearcutting on surface water quality and to evaluate the effectiveness of forestry BMPs for minimizing hydrologic and water quality impacts associated with timber harvesting (Wynn et al. 2000). One watershed (7.9 ha) was clearcut without implementation of BMPs, one watershed (8.5 ha) was clearcut with the implementation of BMPs and a third watershed (9.8 ha) was left undisturbed as a control. Forest clearcutting without BMP implementation reduced storm runoff volume and did not significantly change peak flow rates. Following site preparation, both storm flow volumes and peak flow rates decreased significantly. For the watershed with BMP implementation, storm flow volume decreased significantly following harvest, while peak flow increased. Site preparation did not change storm flow volumes over post-harvest conditions, but did significantly reduce storm peak flow rates. Disruptions in subsurface flow pathways during harvest or rapid growth of understory vegetation following harvest could have caused these hydrologic changes. Harvest and site preparation activities significantly increased the loss of sediment and nutrients during storm events. Storm event concentrations and loadings of sediment, nitrogen, and phosphorus increased significantly following forest clearcutting and site preparation in the watershed with no BMPs. Both the BMP watershed and the Control watershed showed few changes in pollutant storm concentrations or loadings throughout the study. Results of this study indicate forest clearcutting and site preparation can be conducting in the Virginia Coastal Plain without adversely affecting water quality by implementing BMPs before and during harvesting activities.

In West Virginia, USA, a 34-ha gauged watershed on the Fernow Experimental Forest, Parsons, West Virginia, was conventionally clearcut in 1969 to study water yield and water quality impacts of forest harvesting (Aubertin and Patric 1974). Streamflow increased 20 cm during the first year after cutting, but rapid and luxuriant revegetation reduced the flow increase during the second and subsequent years. Clearcutting had a negligible effect on the stream temperature, pH, non-storm turbidity, and concentrations of dissolved solids, Ca, Mg, Na, K, Fe, Cu, Zn, Mn, and NH4+-N. Storm-period turbidity and nutrients exhibited slight increases. Success in avoiding deterioration of water quality was attributed to careful road management, retention of a forested SMZ strip along the stream, and rapid, lush vegetative regrowth after harvesting.

In Western Australia, Australia, McKergow et al. (2003, 2006) studied the effects of grassed SMZ buffers and fencing to reduce sedimentation of streams in agricultural lands of Western Australia. They measured mean suspended sediment reductions from 55 to 7 Mg L^{-1} and 10-fold declines in sediment loads where vegetated SMZs were established and livestock were excluded from stream edges.

Several stream and river buffers were logged in Western Australia to assess the effects on the water quality (Borg et al. 1998). All harvested areas were regenerated to forest soon after logging. Reducing river SMZ (buffer) width from 200 to 100 m, and reducing the width of smaller stream SMZs from 100 to 50 m, had no effect on the watercourses on water quality. The complete removal of stream buffers introduced logging debris into the stream channel and led to minor channel cross-section changes. However, it had no detectable effect on suspended sediment concentrations in the stream. The conclusion of the study was that stream and river SMZs in forests of southern Western Australia can be reduced to half their usual width without any detrimental effects on water quality and stream geometry as long as harvesting is restricted to the dry season, and all roads and temporary harvesting access tracks are built according to BMP principles and located away from stream and river channels. The authors did not recommend complete removal of SMZ buffers as a general practice.

6.2 Temperature

Temperature has been a consideration in establishment of SMZs and no-harvest buffers for a long time (Brown 1969, Beschta et al. 1987, Collier et al. 2001, Davies et al. 2004). It is an important consideration for preserving habitat and oxygen levels for cold water fisheries, and the biota in the food chain that support those fisheries. Some States and Countries specifically identify SMZs for cold- and warm-water fisheries (Table 21). Broadmeadow and Nisbet (2004) summarized SMZ widths reported in the literature needed to maintain temperature regimes. Widths ranged from 15 to 70 m depending on climate, vegetation, and other site factors.

Gomi et al. (2006b) reported on a 6-year study that documented the effects of clear-cut harvesting with and without SMZ riparian buffers (10 m and 30 m wide) on headwater stream temperature in coastal British Columbia. While water temperatures in streams with 10 and 30 m buffers did not show substantial heating, summer daily maximum temperatures increased by 2° to 8°C in the streams with no buffer. Relations between SMZ treatment and daily maximum air temperature suggested that recovery of preharvest temperature conditions was occurring. Recovery rates varied by stream and by season. For 10 m SMZ buffers, warming occurred before and after the harvesting operations, indicating that there are other natural factors besides streamside vegetation removal that influence stream temperatures rises.

Swift and Messer (1971) and Hewlett et al. (1982) described the effects of vegetation removal in the Southeast USA on stream temperatures, and the mitigating effect of forested SMZs. Hewlett et al. (1982) noted that stream temperatures could rise in harvested units with SMZs because of thermal effects of forest harvesting on watershed-scale baseflow temperatures. Rishel et al. (1982) studied the temperature effects of exposing headwater streams in Pennsylvania to direct solar radiation by harvesting the forest overstory. Clearcut harvesting and follow-up herbicide treatment on one watershed produced the highest stream temperatures and greatest diurnal temperature fluctuations. Only slight changes in stream temperature regime were observed on an adjacent commercially clearcut watershed with a 30 m buffer zone along the perennial stream channels.

6.3 Nutrients

The effectiveness of riparian SMZs in removing nutrients from surface and subsurface water flow has been reviewed by a number of authors (Barling and Moore 1994, Castelle et al. 1994, Comerford et al. 1992, Daniels and Gillam 1996, Dillala et al 1989, Mander et al. 1997, Muscott et al. 1993, Parkyn 2004, Peterjohn and Correll 1984, Mayer et al. 2005, Wenger 1999, Zhang et al. 2010). The literature shows a consensus of high nutrient removals from inflows across a range of SMZ widths and vegetation types (Tables 22, 35, and 36). Generally speaking, the wider the SMZ the higher the nutrient removal and retention in the SMZ buffers. Good nutrient retention can be accomplished by both forest and grass and herbaceous plant vegetation in SMZs. There are other reasons for using or not using these different vegetation types in SMZ buffers. Some anomalies exist in the literature results because of variations in vegetation, soils, slopes, inflow concentrations, flow velocity, surface roughness, etc. that are characteristic of SMZs. Some of the reviews have good comparisons of a range of SMZ widths and similar vegetation (Fennessy and Cronk 1997, Table 36). Other reviews utilize the results of studies that often do not have experimental designs that incorporate variability in SMZ width. An example of a study that does incorporate variable SMZ width and treatment was reported by Vaidya et al. (2008) in Nova Scotia.

Table 35. Effect of SMZ vegetation buffers on NO_3-N removal from subsurface flow (Adapted from Muscott et al. 1993)

Source	Location	Vegetation	Buffer Size	Subsurface NO3-N Removal By SMZ	
			m	Conc. mg L^{-1}	Removal %
Peterjohn & Correll 1984	USA	Forest	19	7.4	93
			50	7.4	90
Lowrance et al. 1984	USA	Forest	60	4.4	98
Jacobs& Gilliam 1985	USA	Forest	50	8.0	99
Pinay & Decamps 1988	France	Forest	150	1.3	100
Knauer & Mander 1989	Germany	Grass	Various	22.0	96
Cooper 1990	NZ	Grass	4	1.2	93
Smith 1989	NZ	Grass	13	48.0	77
Haycock & Burt 1991	England	Grass	24	12.0	92

Vaidya et al. (2008) reported on the effects of forest harvesting on stream water quality and effectiveness of three alternative SMZ sizes in eight 64 to 226 ha watersheds in central Nova Scotia, Canada. The SMZs tested were a 20 m no cut, a 20 m select cut, a 30 m select cut, and a control along small intermittent streams. Water quality of eight streams, six in harvested and two in not-harvested watersheds were monitored for two years before and two years after the harvesting of timber. There were significant changes in the concentrations of potassium (6 streams), manganese (5 streams), zinc (2 streams), and total nitrogen (1 stream) after timber harvesting. The water quality results indicated that the effectiveness rankings of the SMZs are 30 m select cut, 20 m no cut, and 20 m select cut. In SMZ buffer zones of similar widths but no harvesting, stream water quality protection was greater than with the select cut SMZs. The extra vegetation in the uncut SMZs zone may have decreased the subsurface and surface runoff flow velocities and increased residence time, thus increasing filtration and retention of minerals in the riparian soil.

Table 36. The effectiveness of nitrogen removal in a range of SMZ buffer sizes and two vegetation types (From Fennessy and Cronk 1997)

Vegetation Type	SMZ Buffer Width	Nitrogen Removal
Forest	m	%
	10	70-90
	20	87-99
	25	68-100
	30	100
	50	95-100
Herbaceous	5	54
	9	73
	16	50
	27	84

There are also a couple of examples where plantation buffers established in SMZs have been credited with reducing the concentrations of nitrogen or phosphorus in headwater streams in agricultural landscapes. For example, Smethurst and Petrone (2010) found a 50% reduction in phosphate concentrations within one year of establishment of a fast-growing eucalypt plantation. The effect on phosphate was probably due to cultivation leading to more surface flow infiltration in the SMZ and the resultant increase in sub-surface flow leading to more phosphate sorption by soil. Newbold et al. (2010) found 26% of annual up-slope nitrate input appeared to be removed by an SMZ plantation buffer in an agricultural landscape.

6.4 Herbicides and pesticides

Comerford et al. (1992) and Lowrance et al. (1992) considered pesticide movement in their syntheses and studies of SMZ buffers to mitigate off-site transport of non-point source pollutants into streams and other water bodies. Comerford et al. (1992) reported that the efficacy of forested buffer strips in maintaining water quality from a pesticide viewpoint was quite varied due to the many factors that can affect chemical movement and transport. These factors include pesticide chemistry, pesticide formulation, application rate, distribution method, buffer size, weather conditions, soils, vegetation, and catchment hydrology. In the 26 cases Comerford et al. (1992) evaluated, the highest streamflow concentrations were a result of the lack of any SMZ buffer, high application rates, and pesticide application into stream channels. The SMZs designed for pesticides in their study ranged in size from 1 to 140 m. They found from their case-limited analysis that 15 m buffer strips or larger were effective in minimizing pesticide residue contamination of streamflow. One SMZ as large as 140 m did not keep herbicide residues out of a stream because of subsurface transport of residues in quickflow (Neary et al. 1985).

Michael (2004) conducted an analysis of the minimum SMZ width recommendations by States in the eastern USA needed to maintain water quality where herbicides and other pesticides are used. Most of the recommendations are within the 15 m one discussed by Comerford et al. (1992). The exceptions are Maine, Michigan, and West Virginia, which require SMZ buffers for herbicides of 22.9 to 30.5 m. Most of the States do not have any recommendations for ephemeral drainages. Michael (2004) noted that most contamination of perennial streams comes from aerial application drift or movement of residues down intermittent or ephemeral channels. He concluded that expansion of SMZ buffers beyond 10 m was not likely to provide much additional protection against water contamination from silvicultural chemicals. Michael (2004) summarized his findings by noting that most "contaminations" of streams are at extremely low levels if applications are done correctly, and that these low levels rarely exceed water quality standards. He pointed out a major information gap in that the minimum amount of ephemeral channel protection required to maximize water quality protection without tying up an excessive amount of upland treatment area is not known.

7. WATER QUALITY EFFECTS OF HARVESTING WITHIN SMZs

Examples provided in previous sections of this report make it clear that SMZs can work well in protecting or improving water quality. However, a big question was: "Can trees in SMZs be harvested without causing a significant deterioration in water quality and other important functions?" There are a limited number of published studies identified that address this question are summarised here.

7.1 Tasmania, Australia

An example of forest harvesting and the effective use of BMPs in an SMZ for the protection of water quality is provided by Neary et al. (2010) and Smethurst and Neary (2010) in Tasmania, Australia. A study was conducted in northwest Tasmania, Australia, to evaluate the water quality benefits of Best Management Practices during tree harvesting in a streamside management zone that would be typical in a farm forestry setting. This case study consisted of harvesting a 20-year-old *Eucalyptus nitens* pulpwood plantation along an intermittent stream in accordance with the Tasmanian code of forest practice (Forest Practices Board 2000). Two main provisions of the code regulated activities within a 10 m zone of the stream. A 5 m machinery exclusion zone immediately adjacent to the stream required tracked harvesters to reach into that zone to harvest trees. An additional 5 m zone, i.e. 5-10 m from the stream, limited machinery traffic to tracked harvesters that were not allowed to turn in this zone. These provisions enabled trees to be cut and extracted with almost no soil disturbance in the 0-10 m zone. Two temporary crossings of the class 4 stream were designated in the forest practices plan and used. Debarking and further processing of stems occurred outside the 0-10 m zone, with retention of woody debris as soil protection (Figure 20). Ground cover and water quality pre- and post-harvesting were measured to identify the major sources of sediment in this headwater catchment, and to determine the effect of tree harvesting.

Tree harvesting in the Tasmanian study produced minimal mineral soil exposure and increased surface roughness responsible for sediment trapping. Post-harvesting turbidity in streamflow was similar to pre-harvest levels (<2.5 Nephelometric Turbidity Units - NTUs) (Figure 21). A road, a dam that was accessible to cattle, and a cultivated paddock were more significant sources of sediment (Smethurst and Neary 2010). These sources led to turbidities of about 300 NTUs in Dam 10 immediately below the road and paddocks and above the harvested stream reach during a storm in late June 2009 and subsequent winter storms through October of 2009. At Dam 13, below the harvest areas, stream turbidities were mostly less than 10 NTUs. The in-stream dams functioned as very effective sediment traps. This study demonstrated how BMPs can be effective in limiting adverse impacts to water quality. This study demonstrates that forest harvesting operations can be conducted without necessarily increasing stream turbidity, if existing BMPs are followed.

7.2 British Columbia, Canada

Macdonald et al. (2003) studied suspended sediment and stream discharge in three sub-boreal streams with mixed conifer species in central British Columbia, Canada, during snowmelt runoff. Two watersheds had 20 m harvesting SMZs established and one was an unharvested control. Harvesting prescriptions required complete removal of merchantable stems >15 cm DBH within the 20 m SMZ of one watershed, and retention of all stems <30 cm in the other harvested watershed. An increase in peak snowmelt runoff discharge was first noted in the second spring following harvest in both treatments and remained above predicted in all subsequent years. Total suspended sediment concentrations also

Figure 20. Tigercat tracked harvester stacking delimbed and debarked *Eucalyptus nitens* stems during an SMZ harvesting study that utilized Best Management Practices. Note the slash coverage remaining in the harvested area. Trees were harvested to the edge of the stream, which flows between the harvested and un-harvested area in this photo. (Photo by Daniel G. Neary)

increased during snowmelt runoff following harvest but they returned to levels at or below preharvest conditions within 2 years in the low harvest intensity watershed, and 3 years in the other harvested watershed. Peak concentrations were in excess of 80 mg L^{-1}, more than twice the predicted concentrations. However, these concentrations occurred in association with some higher stream flows and significant soil disturbance related to the removal during the previous autumn of one culvert in the watershed. The authors concluded that machine-free SMZ areas and limited riparian harvesting treatments provided ample bank protection and reduced sediment delivery to the stream channel. They cautioned that BMPs must be used to ensure that sediment transport from the hillslopes to streams via roads, skid trails, and ditches is minimized.

7.3 Malaysia

Gomi et al. (2006a) studied the effects of logging lowland tropical rainforest in Butik Tarek Experimental Watershed in Malaysia that included 20 m SMZs. Four catchments (14 to 38 ha) included a control no harvest (C1), a 20 m SMZ (C2), a 20 m SMZ with a high road density and close proximity to the SMZ (C2T), and an SMZ partial harvest (C3). Catchment areas outside the SMZs were clearcut and logs extracted by skidders and log trucks. There was no significant difference in sediment delivery to the Butik Tarek stream in catchments C1 and C2. Catchments C2T and C3 produced 6 and 5 times the sediment volume into channels, respectively, than the C1 catchment. Roads and skid trails in C2T and C3 with steep gradients (>20%) and a high degree of connectivity to the catchment channels were responsible for the high sediment delivery to the Butik Tarek stream, not the harvesting operation *per se* (Sidle et al. 2004).

7.4 New Zealand

In New Zealand, most harvesting occurs in the form of clearfelling within broad-scale plantation forests. While some thinning of trees occurs within SMZs as a component of silvicultural treatment, partial harvest of mature crop trees within SMZs at harvest time is rare. Existing crop trees are usually clearfelled and the protection of pre-existing non-merchantable SMZs depends on site conditions and harvest methods used. Clear-felling in SMZs usually results in increased light levels, fine sediment, organic matter, nitrate, stream temperature and algal production and reduced dissolved oxygen levels (Death et al. 2003; Baillie et al. 2005; Thompson et al. 2009). Temporal and spatial factors influence the degree and recovery rate of water quality from harvesting operations (Thompson et al. 2009; Reid et al. 2010). Intact SMZs mitigate many of the adverse impacts associated with up-slope harvesting (Graynoth 1979; Boothroyd et al. 2004; Thompson et al. 2009).

Thompson et al. (2009) measured the effects of harvesting in SMZ’s in five plantation forest streams in the South Island of New Zealand. One site was harvested to the stream edge using ground-based machinery. The remaining four sites were harvested with static skyline cable systems; with harvesting activities occurring within the SMZS of three sites and an intact SMZ, 10 m in width, retained in the fourth. Post-harvest changes in physicochemistry and basal resources were highest in the first year after harvest. These included increases in light availability, fine sediments, nitrate, organic matter and algal production and a reduction in flow velocity with subsequent effects on aquatic invertebrate community composition and functional feeding groups. Harvest impacts were least in the 10 m wide SMZ which provided an effective buffer from most adverse effects associated with harvesting. An interesting aspect of this study was that woody debris suspended across the channel was also effective in mitigating some of the harvesting impacts on water quality.

7.5 Louisiana, USA

Streamside Management Zone widths on either side of stream channels within harvested areas of the Flat Creek Watershed were maintained to the minimum Louisiana State BMP standards, and the effects on water quality were studied during forest harvest operations (Brown 2007). These BMP recommendations included 10.7 m SMZs for intermittent streams, 15.2 m for perennial streams less than 6.1 m wide, and 30.5 m for perennial streams greater than 6.1 m in width. In addition to the BMPs recommended by Louisiana State forest practices guidelines, BMPs were used that address roads, slash, landings, stream crossings, and equipment fluids. Post-harvest total suspended solid concentrations and yields during baseflow and stormflow conditions did not increase at the plot- or the watershed scale. No difference was found between treatment periods for monthly baseflow or stormflow sediment concentrations. Sediment concentrations during the first two years following timber harvesting were toward the lower end of published results for the Gulf Coastal Plain. Sediment fluxes at all SMZ monitoring sites were within the range for undisturbed forested watersheds of the Southeast. Sediment yields during baseflow conditions did not increase post-harvest where SMZs and BMPs were utilized, but increased significantly in streams adjacent to small-scale harvest locations where the SMZs and BMPs were not used.

7.6 Minnesota, USA

Hemstad et al. (2008) reported a study of fish habitat changes after several thinning treatments in a mixed hardwood forest with an SMZ. Control areas had no tree felling at all. Riparian controls had upland areas that were clear-felled with a cut-to-length (CTL) system, but they retained a 30 m no-cut buffer zone (Mattson et al. 2000, Palik et al. 2003). The CTL riparian thinning treatment involved upland clear-felling and SMZ harvesting to a residual basal area of 12.3 m^2 ha^{-1}. The final treatment was a tree-length (TL) harvesting where the adjacent upland was clear felled and the SMZ was thinned to a residual basal area of 12.3 m^2 ha^{-1}. Hemstad et al. (2008) measured a small (15%) increase in fine sediments and gravel embeddedness after harvesting. However, the sediment increase was basin-wide and involved the uncut control reaches as well as the stream reaches that had SMZ harvesting. The largest sources of variability were year-to-year differences and within stream ones. In a number of years the control stream reaches had higher amounts of fine sediments and less stable banks. Downstream reaches were consistently lower in fine substrates indicating considerable variation in within-stream fine sediment levels between reaches. The effect was attributed to roads and stream crossings, not SMZ harvesting. This result points out the role of roads in producing much of the post-harvest sediment yield observed in forested catchments.

7.7 Mississippi, USA

Logging with and without SMZs in twelve mixed hardwood forest catchments with highly erodible loess soils in Mississippi, USA, was evaluated by Keim and Schoenholtz (1999). Treatments consisted of no treatment, cable-only harvesting in an SMZ with a 30 m width, SMZ with no-harvesting and a 30 m width, and unrestricted harvesting. Streams in catchments without SMZs had mean total suspended solids concentrations three times the concentrations of those with SMZs (244.2 vs 83.7 mg L^{-1}). The SMZs did not function in trapping sediment originating in harvest areas outside the buffer. The function of reducing sediment input into streams was achieved by reducing soil disturbance in the SMZ. The authors concluded that SMZ prescriptions should focus on eliminating machine traffic within 10 m of streams.

7.8 North Carolina, USA

A Coastal Plain North Carolina swamp forest was clear-felled in May, 1998, leaving a 10 m-wide uncut portion of the SMZ as a buffer (Ensign and Mallin 2001). The harvested area was along the lower end of a 479 km^2 catchment. A significant increase in total suspended solids from 3 to 10 mg L^{-1}, pre- to post-harvest, was measured in June, July, and August due to rainfall after harvesting. However, extreme rainfall during Hurricane Bonnie in late August, 1998, did not produce a notable effect on total suspended solids. Turbidity in the harvested area was not significantly different from an uncut control catchment although it did rise from 6 to 14 NTUs. One peak of 111 NTUs was measured in the treated catchment the first month after clear-felling.

7.9 Virginia, USA

Lakel et al. (2010) studied the effect on sediment delivery to streams of thinning within a 15.2 m wide SMZ in Virginia, USA. They also studied SMZs of various widths (7.6 – 30.4 m) that were not thinned. All SMZs had up-slope clearcut harvest areas. Without thinning in the SMZ, this range of SMZ widths led to little difference in sediment delivery. Thinning within the SMZ also did not have an effect. Most sediment was produced in the clearcut areas, but traffic areas (decks, roads and skid trails) and cultivated fire lines produced disproportionately more sediment. Hence, thinning within the SMZ resulted in no sedimentation concerns.

8. SMZS AND BIODIVERSITY

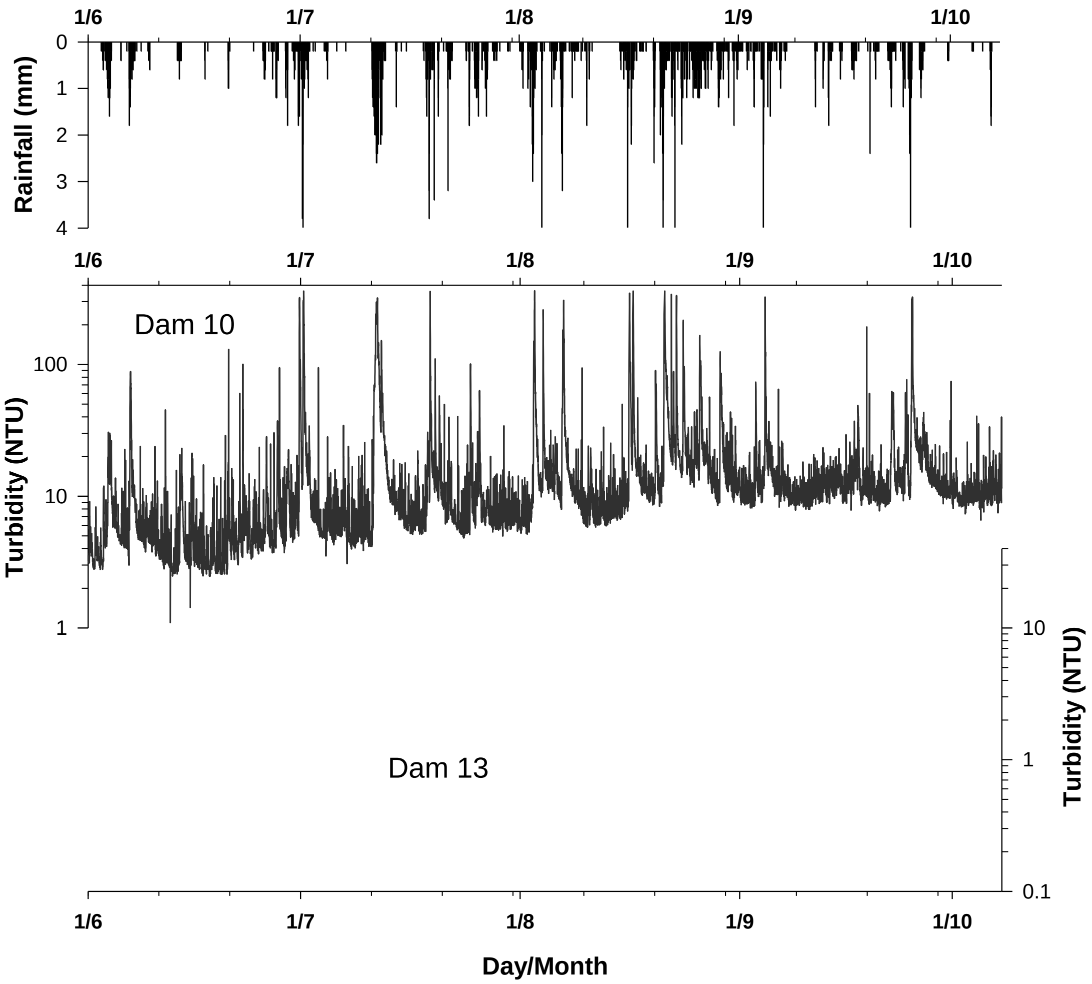
An important function of forested/vegetated SMZs introduced in Section 2 is providing habitat for both floral and faunal species. This function contributes greatly to species and landscape biodiversity, especially in semi-arid environments (Baker et al. 2004). Vegetated Streamside Management Zones provide important landscape connections and cover for terrestrial wildlife as well as habitats for aquatic species. Crawford and Semlitsch (2006) found that there are approximately 173 terrestrial vertebrates in the eastern USA alone that require riparian habitats for some ecological function (26 mammals, 27 birds, 50 reptiles, and 70 amphibians). They concluded that much more data on core terrestrial habitats and SMZ widths are needed to provide land managers with adequate databases to select management options that provided a balance between conservation and sustainable land use.

The SMZs and their aquatic components (streams, lakes, ponds, vernal pools, wetlands, etc.) also contribute significantly to aquatic fauna and flora diversity. Biodiversity and wildlife habitat SMZs tend to be larger than those used for strictly water quality purposes (Wenger 1999, Table 37).

Table 37. Several studies on the wildlife habitat function of SMZs (Adapted from Wenger 1999).

Streamside Management Zone Function	References
Wildlife Habitat - Birds	Triquet et al. 1990, Kinley and Newhouse 1997
Wildlife Habitat - Mammals	Cross 1985, Naiman and Rodgers 1997,
Wildlife Habitat – Herpetofauna	Gomez and Anthony 1996, Burbrink et al. 1998

Figure 21. Rainfall in the Pet River catchment, northwest Tasmania, during the 2009 winter, and continuous turbidity measurements at Dams 10 and 13 of the farm in mm per 15-minute intervals from 27 May 2005 to 9 October 2009. Y-axis units for Dams 10 and 13 are in NTUs on different log scales (reprinted with kind permission from Springer Science+Business Media: Journal of Soils and Sediments, Neary, D.G.; Smethurst, P.J.; Baillie, B.; Petrone, K.C.; Cotching, W.; Baillie, C.C. 2010 Does tree harvesting in riparian areas adversely affect stream turbidity – preliminary observations from an Australian case study. 10:652-670, Figure 9).



Ellis (2008) summarized literature recommendations for maintaining biodiversity and wildlife habitat (Tables 38). This synthesis incorporates information from Knutson and Naef 1997, Wenger (1999), and Fischer et al. (2000) (Tables 39-40). Wenger (1999) noted that narrow SMZs offer substantial benefits to many species, but protection of diverse wildlife communities might require buffers of 100 m or more. However, he did recognize that buffers as large as 100 m are not always practical, and a diversity of SMZ sizes as well as large uncut units may be a better approach to solving the wildlife diversity problem than applying large SMZs everywhere.

Table 38. Literature recommendations of minimum SMZ buffer strips to maintain reptile and amphibian habitat (Adapted from Knutson and Naef 1997, Wenger 1999, Fischer et al. 2000, Crawford and Semlitsch 2006).

Riparian SMZ Function	Recommended Width (m)	Reference
General habitat requirements	135-165	Fischer et al. 2000
General habitat requirements	100	Wenger 1999
Riparian dependent species	75-100	Wenger 1999
Riparian dependent species	30-95	Wenger 1999
Full compliment of herpetofauna	30-100	Knutson and Naef 1997
Freshwater turtles	275	Wenger 1999
Amphibian habitat - sediment control	31-88	Knutson and Naef 1997
Amphibian habitat – woody debris	31-55	Knutson and Naef 1997
Salamanders	43	Crawford & Semlitsch 2006

Table 39. Literature recommendations of minimum SMZ buffer strips to maintain bird habitat (Adapted from Knutson and Naef 1997, Wenger 1999, Fischer et al. 2000).

Riparian SMZ Function	Recommended Width (m)	Reference
Full compliment of avian species	125	Knutson and Naef 1997
Maintain avian richness	127	Knutson and Naef 1997
Maintain 90% of bird species	150-175	Wenger 1999
Maintain nesting habitats	100	Fischer et al. 2000
Minimum width for birds	70	Wenger 1999
Maintain bottomland hardwood birds	50-500	Wenger 1999
Sufficient breeding area-sensitive spp.	100	Fischer et al. 2000
Minimum for disturbance-sensitive spp.	25	Knutson and Naef 1997
Minimum for forest-dwelling birds	60	Knutson and Naef 1997
Headwater stream best bird habitat	40	Fischer et al. 2000
SMZ size to reduce nest predation	100	Knutson and Naef 1997
SMZ size to reduce nest predation	150	Fischer et al. 2000
Pheasant, eastern Washington	23	Knutson and Naef 1997
Great Blue Heron	250	Knutson and Naef 1997
Osprey nest, no cut zone	61	Knutson and Naef 1997
Bald eagles	100	Knutson and Naef 1997
Neotropical migrants	100	Knutson and Naef 1997

Table 40. Literature recommendations of minimum SMZ buffer strips to maintain mammal populations (Adapted from Knutson and Naef 1997, Wenger 1999, Fischer et al. 2000).

Riparian SMZ Function	Recommended Width (m)	Reference
Large mammals	100	Knutson and Naef 1997
Small mammals	67-93	Knutson and Naef 1997
Small mammals	67	Wenger 1999
Beaver	30-100	Knutson and Naef 1997
Fisher	100	Knutson and Naef 1997
Deer and elk cover	23-61	Wenger 1999

8.1 Aquatic Organisms

Wilkerson et al. (2010) studied the effect of forest harvesting, with and without two different SMZ widths (11 an 23 m), on water quality and macroinvertebrate and periphyton assemblages in first-order streams in Maine, USA. Water quality did not change for three years after harvesting. Unbuffered and 11 m buffered streams had significantly elevated concentrations of chlorophyll *a* as well as increased abundance of algal feeding Dipterans. The small harvest-induced changes were attributed to an absence of soil disturbance within 8 m stream banks, the small scale of harvesting, and aquatic organism adaptation to disturbance and high resilience.

Quinn et al. (2004) examined the role of native forest SMZ buffers in maintaining invertebrate community diversity and richness in plantation forests of the Coromandel Peninsula of New Zealand. Clearfelled stream reaches with no buffer had the lowest invertebrate diversity and taxon richness. Reaches with 8 – 27 m SMZ buffers did not differ in diversity and richness from reaches with intact native or plantation forest. Castelle et al. (1994) reported that many studies in the USA had the same results with SMZs >30 m.

One of the problems associated with assessing the effects of SMZs on invertebrate communities is that there may be no significant differences between buffered and unbuffered streams at the reach scale, but significant differences at the catchment scale (Collier et al. 2001). In addition, inter-catchment variability can interfere with the interpretation of SMZ buffer studies. Thus, the same BMP techniques (SMZ size, tree retention, machinery exclusion, etc) can have different outcomes in different stream systems.

8.2 Birds

Triquet et al. (1990) studied the effects of SMZ buffers on songbird equitability, richness, and diversity of harvested catchments in Kentucky. Species equitability, richness, and diversity of breeding bird communities were monitored on four watersheds in 1983 and 1986 before and after harvesting. Bird abundance increased 21-23% on two clearcuts during the second growing season after cutting. Bird species richness and bird diversity were highest on an uncut control area of mature forest and a harvest unit with a riparian buffer strip compared to a harvested watershed with no SMZ buffer.

Whitaker and Montevecchi (1999) studied breeding bird assemblages in undisturbed streamside habitats as well as those with 20-50 SMZ buffers alongside timber harvesting units. Total avian abundance was higher in SMZs than in undisturbed habitats. Abundance of forest generalist, interior forest, and riparian forest bird species were similar between SMZ and undisturbed forests. Riparian bird species counts did not increase with wider SMZs (40-50 m). Half of the interior forest bird guilds were never observed in the SMZs. The authors concluded that conservation strategies other than SMZs may be required to maintain both riparian and interior forest bird species.

9. STREAMSIDE MANAGEMENT ZONE DESIGN AND MANAGEMENT

There are a number of models that can aid in the design of variable width SMZs without resorting to time consuming and expensive ground mapping (Williams et al. 2003). The boundaries of SMZs developed in models can then be marked more efficiently in the field using GPS technology. Other SMZ simulation models evaluate hydrologic, water quality, and nutrient cycling aspects of SMZ management (Inamdar 1999a, 1999b)

While the SMZ concept was originally designed for application during the harvesting phase of forestry, there are other issues that need to be considered in the long-term maintenance and management of these areas. Some of these include tree species selection for re-establishment, site preparation, planting operations, invasive weeds, and fire. Once SMZs are established, their use in subsequent silvicultural chemical applications, thinning, fire prevention, and harvesting is much easier.

Bentrup (2008) developed an extensive SMZ design field manual that considers water quality, biodiversity, productive soils, economic opportunities, protection and safety, aesthetics, and outdoor recreation. The objective of his volume was to provide a synthesis of the broad and diverse scientific knowledge base on conservation buffers into an easy to understand and useful field guide.

10. BEST MANAGEMENT PRACTICES

10.1 General Guidelines

There is a huge amount of information in the literature on BMPs for forestry since most State, Province, and Country jurisdictions and land management agencies, and companies, have developed their own sets of BMPs based on either literature recommendations or legislative directions (US Environmental Protection Agency 1973, Collier et al. 1995a, 1995b, Decker 2003, Aust and Blinn 2004, Ice 2004, Minnesota Forest Resources Council 2005, Roebeling and Webster 2007). As stated in the Minnesota publication on BMP guidelines, "*Site-level resource management decisions are based on many different factors, including resource needs, landowner objectives, site capabilities, existing regulations, economics and the best information available at any given time*" (Minnesota Forest Resources Council 2005). The objective of multiple guidelines is to provide land managers with a high degree of flexibility to effectively balance forest management needs, resource sustainability, and the best BMP prescription for the a particular ecological characteristics of each harvest site. The objective should be maximizing BMP effectiveness and ecosystem sustainability, rather than just being able to satisfy the requirements of a "mandated" check-off list.

For example, Roebeling and Webster (2007) listed the current BMPs for forestry harvesting operations in the Tully-Murray Catchment (Table 41). However, not all of these BMPs apply to every harvest unit in the basin, and these general statements are usually qualified by a lot more explicit information than is listed in Table 41. Tasmania's BMP directives are an example.

Table 41. Current BMPs in forestry production within the Tully-Murray Catchment of Australia (From Roebeling and Webster 2007).

Current Forestry BMPs	BMP Description
Drainage	Facilitate drainage by avoiding low spots and planting trees along contour lines
Soil testing and ameliorate	Elemental analysis of soils to assess tree crop nutrient requirements
Minimum tillage	Restrict tillage to localized deep ripping of the plant row when preparing the block for planting
Integrated pest management	Using chemical, cultural, biological and physical control measures for pests, diseases and weeds
Chemical handling and application	Chemical handling and applications by Chem-Cert accredited operators and in accordance with Chem-Cert guidelines
Safe chemicals	Use chemicals that do not persist in the environment
Nitrogen (N) management	Use slow release N fertilizers applied underground close to individual trees
Timing of planting	Trees planted when soil moisture is adequate early in the wet season
Interrow management	Grassed interrows maintained though regular slashing
Pruning and thinning	Pruning and thinning operations carried out when block is dry, leaving waste material in the plant row
Harvest management	Harvesting carried out when block is dry, leaving waste material in the block
Log management	Store harvested logs in designated, hard surfaced areas
Road design	Hard surfacing of roads and preventing water from running over road through establishment of culverts

10.2 Example of Water Quality and Watercourse Protection: Tasmania

The Tasmania code of forest practice has a well-developed listing of BMPs for forest harvesting (Forest Practices Board 2000). A few for water quality, which is a prime consideration in the code, are listed here.

10.2.1 Native Forest Reserves

The BMP directives in the Tasmania code for water quality protection in native forest reserves are listed in Table 42a (Forest Practices Board 2000). The BMPs cover the topics of vegetation retention, boundary marking, tree felling, machinery operations, slash handling, and SMZ tree felling. Table 42b presents BMPs relative to the topic of selective harvesting within SMZs and machinery operations within 10 m of Class 4 watercourses. The key to protecting water quality from a sediment point of view is control of soil and bank disturbance from machinery operations through boundary markings, slope limitations, weather restrictions, stem processing, etc. Additional restrictions are imposed when the harvesting unit is near municipal water supplies. This set of BMPs reflects several important principles:

- BMPs are designed to prevent deterioration of water quality rather than to have to resort to mitigation techniques that might be only partially successful.
- BMPs need to be simple yet effective.
- Two keys to successful implementation are clarity and ease of communication. Overly complex BMPs will invariably have implementation problems.

10.2.2 Plantation Forests

Watercourse protection measures need to be carefully considered in Forest Practices Plans, taking account of past plantation establishment practices, limitations applying to the future harvesting of plantations, and the soil erodibility class (Table 43). This section applies to harvesting of plantations where land has been planted within streamside reserves and machinery exclusion zones. On low to moderate-high erodibility class soils, plantations may be harvested in streamside reserves and within 10 m of Class 4 watercourses, but no trees are to be harvested within 10 m of a Class 1, 2 or 3 watercourse for plantations established after the commencement of the current edition of the Code.

10.2.3 Swampy Ground and Surface Seepage Areas

Wetlands and springs (seeps) are special cases that have some additional BMPs relative to machinery operations, SMZ sizes and harvesting season (Table 44).

10.2.4 Water Supply Catchments

Some additional BMPs are included in the Tasmania code related to water supply catchments, since these are the most important landscape units and the prime reason for implementing BMPs and using SMZs, i.e. the maintenance and protection of water quality (Table 45). These measures relate to the distance from streams that clearfelling can be done within water supply catchment streams, and the area within a catchment that can be harvested in any one year. Again, the goal of these BMPs is to limit soil disturbance and potential adverse impacts on water quality.

11. OVERVIEW OF CURRENT SMZ EXPERIENCE

We make the following observations about the usefulness and limitations of current SMZ experience, and identify several research needs.

- The value of SMZs for protecting water quality and providing biodiversity and other benefits has a strong scientific basis.
- The use of SMZs in landscapes used for food and wood production generally assists in protecting water quality and provides other benefits. Timber harvesting in SMZs can be compatible with environmental objectives if conducted carefully.

Table 42a. Best Management Practices for water quality and watercourse protection for native forest streamside reserves in the Tasmania code of forest practice (Forest Practices Board 2000). Table 42b provides additional provisions for harvesting within an SMZ.

Category	Best Management Practice
Vegetation	Native vegetation will be retained intact in Class 1, 2 and 3 streamside reserves (40 m, 30 m, and 20 m respectively) as defined in Table 8 of the code (page 56 of the code) subject to other provisions in this code permitting watercourse crossings and selective harvesting under certain conditions.
Boundary Marking	Where harvesting adjacent to a Class 1, 2 or 3 streamside reserve is planned, the boundaries of the streamside reserve will be clearly marked before harvesting commences.
Tree Felling	Trees should not be felled into a streamside reserve. Where this accidentally occurs the head should be pulled clear unless unacceptable damage to the reserve is likely to occur. Damage to vegetation, in particular mature myrtles, should be avoided.
Tree Felling	Trees should be felled away from Class 4 watercourses and damage to understorey vegetation should be minimised.
Machinery Operations	Tractors or other harvesting machinery will not enter streamside reserves except at designated watercourse crossings, unless machines such as tracked excavators are specifically approved by a Forest Practices Officer to carry out salvage or restoration works in dry conditions (e.g. removal of slash from watercourses following windthrow).
Slash Handling	Harvesting slash will not be pushed into streamside reserves (including machinery exclusion zones on Class 4 watercourses), and slash heaps should be sufficiently separated from reserves to reduce the risk of burning the reserves.
SMZ Felling	Trees within streamside reserves will only be fallen where authorised in a Forest Practices Plan for road construction or snig track crossings of Class 3watercourses.

Table 42b. Best Management Practices for water quality and watercourse protection for SMZ harvesting in native forest streamside reserves Tasmania Code of Forest Practice (Forest Practices Board 2000).

Category	Best Management Practice
Selective Harvesting	Trees to be fallen will be marked by a Forest Practices Officer.
	Harvesting will take place in dry conditions.
	Trees can be felled without falling into the watercourse, or significantly damaging retained trees.
	No harvesting machine enters the streamside reserve for the purposes of the selective harvesting operation.
	Not more than 30% of the canopy will be removed.
	Trees will not be felled in the 10 m adjacent to a Class 1 or 2 watercourse.
	The selective harvesting is not within 2 km upstream of a town water supply intake.
	Damage to mature myrtles will be avoided.
	Harvesting is not likely to result in unacceptable substantial windthrow.
Tracked Feller Bunchers Harvesting Within 5 m of a Class 4 Water	Use where slopes are less than 20°, and soils are in the low to moderate-high erodibility classes.
	When soils are dry, and where disturbance to the understorey and ground surface are minimized.
	Trees will, wherever practicable, be felled away from watercourses.
	Machines will move in and out of the 10 m machinery exclusion zone by the same path without slewing the machine's tracks.
	Stems will be removed for processing to a site at least 10 m from the streambank.
	All other machinery will be excluded from the machinery exclusion zone except at designated crossing points.
	Class 4 machinery exclusion zone boundaries should be marked where there is dense undergrowth and/or where the watercourse is difficult to define.

Table 43. Best Management Practices for water quality and watercourse protection for SMZ harvesting in plantation streamside forests on low to moderately high and high to very high erodibility class soils, Tasmania Code of Forest Practice (Forest Practices Board 2000).

Category	Best Management Practice
Low to Moderate-High Erodibility Class Soils	Plantations may be harvested in streamside reserves and within 10 m of Class 4 watercourses subject to the following provisions.
	No trees are to be harvested within 10 m of a Class 1, 2 or 3 watercourse for plantations established after the commencement of this edition of the Code.
	Excavator type feller bunchers may enter to within 5 m of a streambank provided slopes are less than 20°.
	Harvesting will only be carried out when soils are dry, or provided measures are taken to minimise soil disturbance.
	Trees will, wherever practicable, be felled away from watercourses.
	Machinery will move in and out of the machinery exclusion zone by the same path without slewing the machine's tracks.
	Remnant native vegetation will be retained.
	Stems will be removed for processing to a site at least 10 m from the streambank.
	Other harvesting machinery will not enter within 10 m of the streambank except at designated crossing points or to remove substantial harvesting debris.
	Where this approach is used, the 10 m machinery exclusion zone will be marked, and the marking responsibility stated in the Plan.
High to Very High Erodibility Class Soils	The Forest Practices Officer will include additional measures to those above in the Forest Practices Plan as considered appropriate.
	Selective harvesting or the felling of the planted streamside reserve at a different time to the remainder of the coupe should be considered on sensitive sites.
	Harvesting debris which results in altered watercourse conditions should be kept out of watercourses.
	Substantial harvesting debris accidentally lodged in permanently flowing watercourses should be removed where authorised by a Forest Practices Officer while causing as little damage as possible to the streambank and reserved vegetation. Machinery is excluded from watercourses.

Table 44. Best Management Practices for water quality and watercourse protection for swampy ground and surface seepage areas, Tasmania Code of Forest Practice (Forest Practices Board 2000).

Category	Best Management Practice
Machinery Operations	Machines will not be taken within 10 m of the border of any swamp or area with obvious surface seepage except at properly corded crossing points Where swamp or surface seepage areas are ill-defined, the edges should be marked prior to the commencement of operations.
Protection	Seepage areas may require additional upslope protection to prevent sediment entering watercourses.
Harvesting Season	Conventional harvesting in production swamp forests (e.g. blackwood swamps) should be in dry conditions.

Table 45. Best Management Practices for water quality and watercourse protection for water supply catchments, Tasmania Code of Forest Practice (Forest Practices Board 2000).

Category	Best Management Practice
Clearfelling	Clearfelling will not be permitted within 50 m of a bank of a Class 1, 2 or 3 watercourse and harvesting will not be permitted within 10 m of a Class 4 watercourse for a distance of 2 km upstream from a town water supply intake, unless approved by the local government authority in whose area the intake is located.
Annual Clearfelling	No more than 5% of a town water supply catchment should be felled annually.

- Practical guidelines (best management practices) on SMZ width and management vary somewhat across the countries and situations examined, which reflects natural differences (topography, soil, climate etc.), management and historical differences, and different processes used to defining and up-dating the regulatory framework.
- A literature search on harvesting in SMZs highlighted the limited amount of scientific research on harvesting in SMZs in the farm forestry (agro-forestry) context. Scientific research on harvesting activities in SMZs is largely confined to plantation forest estates.
- SMZ management is focused on stream protection and nutrient reduction from agricultural activities. As a result, management of SMZs targets stock exclusion and re-establishment of vegetative cover to achieve these goals. There are few examples in the agricultural landscapes of Australia and New Zealand of SMZs being managed for productive purposes such as timber production. Instead, SMZs are planted primarily with indigenous species and retained indefinitely. In the US, it is more common to find active management of SMZs for multiple benefits including timber production, water quality and biodiversity.

- Research and application of SMZ plantation management in relation to water and biodiversity outcomes is not yet complete; while there is enough evidence to encourage the use of SMZ plantations it in many situations, it needs further refinement for other situations, e.g. SMZ harvesting effects and guidelines for situations of moderate and high water quality or biodiversity risk.
- Plantation forests are a desirable land cover in steep, highly erodible soils for protection of soil and water values. However, these sites are a challenge to harvest within environmental constraints, and lack of active SMZ management generally can lead to weed problems. Innovative research in this type of terrain would benefit the forest industry if it explored cost-effective options that enabled harvesting activities around waterways and their riparian areas without leading to adverse environmental outcomes.
- Management of short-term grazing by livestock of pastures in SMZs (sometimes called crash grazing) might be possible without major adverse environmental effects, e.g. if done while surface soils are dry, but no research yet is available to guide this practice.

In our view, SMZs can be successfully established in most landscapes for a combination of environmental, agricultural, and timber production benefits if the regulatory framework allows. Regulations should be dynamic and reviewed periodically to incorporate the best science. Streamside Management Zones are part of an integral Best Management Practices approach to ensuring desired environmental outcomes in forest and agricultural landscapes. We believe that the up-front SMZ and BMP process is the best approach to achieving environmental sustainability of forest and agricultural land management rather than an after-the-fact regulatory approach.

12. ACKNOWLEDGEMENTS

This research was conducted while the senior author was a visitor to CSIRO Australia's Sustainable Agriculture Flagship, and supported by a Sir Frederick McMaster research fellowship. We also thank the Cooperative Research Centre for Forestry and the Landscape Logic Commonwealth Environmental Research Facility Hub for support. The U.S. Forest Service, Rocky Mountain Research Station is acknowledged for its support of the senior author's opportunity to participate in the McMaster research fellowship program. We also thank Jaap and Sue van Dorsser for sharing their experience, knowledge, and philosophy on the rehabilitation of riparian areas along the Awahou Stream in Rotorua, New Zealand.

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Contact Us
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au/flagships

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