PROTECTION OF MARINE RIPARIAN FUNCTIONS IN PUGET SOUND, WASHINGTON

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Section I. Introduction

Purpose of this document

This document was developed to provide shoreline planners and managers with a summary of current science and management recommendations to inform protection of ecological functions of marine riparian areas (defined in Section III). Washington Administrative Code (WAC 173-26-186(8)) directs that Shoreline Master Programs (SMPs) "include policies and regulations designed to achieve no net loss of those ecological functions." The Washington State Department of Ecology has produced guidelines to help achieve this standard on marine shorelines of Washington (http://www.ecy.wa.gov/programs/sea/sma/guidelines/index.html). In addition, the state's Aquatic Habitat Guidelines (AHG) program developed recommendations for protecting marine riparian functions: Protecting Nearshore Habitat and Function in Puget Sound: An interim Guide (2007) (http://wdfw.wa.gov/hab/nearshore_guidelines/). The AHG program is a partnership of state agencies dedicated to providing science guidance for protection of marine, freshwater, and riparian ecosystems. The AHG program develops guidance documents that can aid local governments updating Shoreline Master Programs (SMP) and Critical Areas Ordinances (CAO).

This information contained in this report will help inform local decisions regarding what is needed to protect ecological functions of marine riparian areas. Specifically, we summarize the range of marine riparian buffer widths (Appendix G) needed to meet particular levels of ecosystem function based on a literature review and input from an expert panel workshop.

Protection of marine riparian areas

Puget Sound's marine shorelines and riparian areas have been altered over the last 160 years by human activities including agriculture, forestry and development. Nearly all of the merchantable timber along the marine shorelines of Puget Sound was harvested or burned by 1884 (Chasan, 1981). Although natural regeneration of riparian vegetation occurred in the years that followed, human manipulation of vegetation continues to influence marine shorelines today.

During the past three decades, an extensive body of research has emerged documenting the importance of riparian areas in providing ecological functions. These functions include:

- Water quality maintenance
- Fine sediment control
- Large woody debris (LWD) delivery and retention
- Microclimate moderation
- Nutrient delivery and retention

- Fish and wildlife habitat creation and maintenance
- Hydrology/slope stability

Most riparian research has focused on stream and riverine ecosystems. Attention to marine riparian processes and functions has only emerged in the literature during the past decade, and research in this area is increasing. Nevertheless, riparian areas provide ecological functions regardless of whether they are adjacent to freshwater or marine water bodies (Desbonnet et al. 1994, 1995; NRC 1996; NRC 2002; Brennan and Culverwell 2004**).**

Organization of document

In addition to the Introduction above, this document contains the following sections:

- Methodology used to compile information.
- Overview of marine riparian areas.
- Description of the seven most ecologically important riparian functions and recommendations for protecting (sustaining?) these functions.
- Impacts to riparian functions from activities associated with development, agriculture and forest practices.
- Recommendations to protect and sustain marine riparian functions.

Section II. Approach/Methods

This document summarizes our literature review and synthesis of scientific and technical information on riparian areas and presents recommendations to help protect marine riparian functions from common human activities. The following seven riparian functions are the focus of this document:

- Water quality
- Fine sediment control
- Shade/microclimate
- Large woody debris (LWD)
- Detritus and nutrients
- Fish and wildlife habitat
- Hydrology and slope stability

We addressed the following questions regarding the seven riparian functions listed above:

- What are the mechanisms or processes by which riparian areas perform each of the seven functions?
- How do human activities (i.e., agriculture, forestry, and development) affect riparian area function?
- What management approaches are most likely to protect each function?
- What data gaps and uncertainties exist relative to each function?

We paid particular attention to buffer-effectiveness research; that is, research focused specifically on the performance of buffers of varying widths at protecting riparian function for both freshwater and marine settings within and outside the Puget Sound region. We examined seven riparian buffer review documents to help determine the buffer widths that have been recommended to protect the seven riparian functions. These seven documents were selected because we identified them as being among the most thorough, frequently cited, and scientifically sound sources available (Appendix B). They were also selected because of their relevance to Washington State (Castelle et al. 1992; FEMAT 1993; Knutson and Naef 1997), the Puget Sound lowlands (Castelle et al. 1992; May 2000), and coastal systems (Desbonnet et al. 1994, 1995). Because some of the review documents did not consider wildlife, we added some pre 2000 references dealing with buffer recommendation for protection of wildlife that we encountered during the literature review.

We reviewed books, journals, online gray literature from government sites (USGS, US EPA, USDA, Washington State Departments of Ecology, Natural Resources, and Fish and Wildlife); online databases [Web of Science, CAB Abstracts, ProQuest, ScienceDirect, Agricola], and bibliographies [most notably one written by David Correll for the Smithsonian Institution, Correll 1999]. A summary of this information is contained in Appendix C, Tables 1-7.

In Appendix G, we summarized buffer width recommendations from Appendix C to achieve 80-100% effectiveness. We did this in three ways. First we report the smallest and largest buffer widths recommended in the literature that achieved a minimum of 80% effectiveness for that function. For example, the buffer width recommendation for the water quality function ranges from 5-600 m (16 -1920 ft) across all water quality studies.

Secondly, we present average values, which are based on the arithmetic mean of all buffer widths recommendations from the literature cited in Appendix C that achieve a minimum effectiveness of 80%. For example, the mean width to achieve a minimum of 80% effectiveness among 11 studies in appendix C for water quality function was 109 m (608 ft). For single studies that offer a range of buffer widths to achieve a minimum of 80% effectiveness, we took the average of that range before including it with data from other studies. For example, for the water quality function, Mayer et al (2006) offer a buffer range of 6-70 m (19 -224 ft) to achieve 91-99% effectiveness for subsurface flows for a grass forest buffer. We used a value of 38 m (122 ft, i.e., the average of 6 and 70 m; 19-224 ft) to represent this study.

Finally we provide buffer width recommendations to meet 80% effectiveness based solely on FEMAT curves. The FEMAT curves plot the relationship between the effectiveness of a mature forests buffer at providing an ecosystem function at various buffer widths. For example, the FEMAT curve for LWD indicates that an approximately 40 m (131 ft) buffer width achieves 80% effectiveness of the LWD function. In some cases, the FEMAT function curves illustrate several parameters e.g., the water quality FEMAT curve shows total suspended solids (TSS), sediment, nitrogen and phosphorus. In this case, a range of widths is reflected in the recommendations, to address each parameter of concern. FEMAT curves did not address hydrology/slope or wildlife functions. FEMAT (1993) uses site potential tree height (SPTH) as a proxy for buffer width where one SPTH = 61 meters (200 ft). FEMAT defines site potential tree as "a tree that has attained the average maximum height possible given site conditions where it occurs" (FEMAT 1993). Like other characteristics of Puget Sound marine shorelines, site conditions and thus site potential tree heights will vary across Puget Sound region.

We found no effectiveness studies for litter fall or hydrology/slope stability and thus do not report on this function in terms of buffer width effectiveness. For all other function, we report on the buffer widths that achieve 80% effectiveness as opposed to other values of effectiveness simply because most of the studies could be summarized at this level. The description of effectiveness at the 80% level does not imply a recommendation for adopting that level of effectiveness.

Because much of the literature was related to freshwater riparian systems, we assembled an interdisciplinary science panel to inform the process of adapting fresh water studies to marine nearshore environments (Marine Riparian Workshop Proceedings 2008; Appendix H). We used FEMAT (1993) curves as a tool to communicate with the science panel. First developed in 1993 for freshwater environments, FEMAT curves depict the relationship between ecological functions and the width of mature riparian forests along a generalized shoreline. Relationships between ecological function and width of riparian zones for specific shorelines may differ from this generalized model due to site-specific factors such as slope, soil, geomorphology, plant community type, disturbances, anthropogenic alterations, etc. A riparian function curve for wildlife was not developed due to the complexity of life history requirements for the wide variety of wildlife found in marine riparian areas, as well as the lack of scientific information on this topic.

The decision to adapt FEMAT-style curves for the marine environment was based on the assumption that studies used as the basis for developing these curves can be generally applied to the marine environment. The rationale for this application relates to the similarities of riparian functions between marine and fresh water systems and the support for this application from a number of publications (e.g., Desbonnet et al. 1994, 1995; NRC 2002; Brennan and Culverwell 2004) and the science panel.

The summary of literature reviews, buffer recommendations and adapted FEMAT curves were provided to the science panel at a workshop to solicit their opinion as to the applicability of the riparian function curves to the marine environment. The workshop was held on November 19, 2008 at the University of Washington. It included 14 scientists representing multiple disciplines relevant to riparian function and processes. A proceedings document entitled *Draft Marine Riparian Review Technical Workshop Proceedings* was produced as a result of this workshop and contains the names, affiliations and expertise of science panel members (Appendix H). The consensus of the science panel is that freshwater riparian buffer research as generally depicted in the FEMAT curves is applicable to the marine environment. Exceptions are noted in the workshop proceeding. The recommendations contained in this guidance document are the result of these efforts.

Section III. Overview: Riparian Areas and Riparian Buffers

Riparian areas

As defined by the National Research Council (NRC 2002):

> Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that influence exchanges of energy and matter with aquatic ecosystems (i.e., zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine–marine shorelines.

Riparian buffers

Riparian buffers are generally recognized as a "separation zone" between a water body and a land use activity (e.g., timber harvest, commercial or residential development) for the purposes of protecting ecological processes, structures, functions) and/or mitigating the threat of a coastal hazard on human infrastructures (National Wildlife Federation 2007). As used here, buffers are defined as separation zones (as above) that are relatively undisturbed by humans and thus represent mature vegetation consistent with the potential of the site.

Why are marine riparian areas important?

Based in large measure on our understanding of fresh water riparian ecosystems marine riparian areas likely play a central role in maintaining the health and integrity of aquatic and terrestrial ecosystems (Desbonnet et al 1994; NRC 2002; Brennan and Culverwell 2004). Many of the functions of freshwater riparian areas are similar to marine riparian areas, although marine riparian areas also provide functions that are unique to nearshore ecosystems due to differences in biogeochemical processes, ocean influences and differences in the biota between fresh and marine environments. Marine riparian areas provide a broad suite of functions, seven of which are the focus of this document. These include water quality (filtration and processing of contaminants); fine sediment control; inputs of large woody debris (LWD); shade/microclimate; litter fall/organic matter input; hydrology and slope stability; and fish and wildlife habitat (see Section IV). There are a number of other functions provided by marine riparian areas which were not reviewed nor discussed here e.g., recreation, cultural and aesthetic resources, carbon sequestration, and providing protection from threats of coastal hazards.

Section IV. Riparian Functions

1. Water quality

a. Technical overview: riparian influence on water quality function

Of the seven riparian functions addressed in this document, water quality is perhaps best understood. Riparian areas provide water quality benefits through a variety of mechanisms including:

- Infiltration and corresponding reduction of surface runoff rates/volumes;
- Intercepting nutrients, fine sediments and associated pollutants from surface water runoff;
- Binding dissolved pollutants with clay and humus particles in the soil;
- Conversion of excessive nutrients, pollution, and bacteria from surface and shallow groundwater into less harmful forms by riparian vegetation; and
- Regulating water temperature.

The water quality function of riparian areas is facilitated by vegetation and soils, which slow the flow of surface and subsurface water and increases retention or "treatment" time. Vegetation, geology, landform, and soil characteristics can affect the manner and rate at which water flows over and through the riparian area and the extent to which groundwater remains in contact with plant roots and soil particles (Klapproth and Johnson 2000). Microorganisms found in riparian soils and sediments, including bacteria, fungi, and other biota, are capable of metabolizing pesticides and transforming nutrients and other chemicals into less toxic forms (Ettema et al. 1999; Klapproth and Johnson 2000). They can also perform chemical reduction reactions such as denitrification (Adamus et al. 1991; Schoonover and Williard 2003; Rich and Myrold 2004). In addition to reducing the pollutant load to receiving waters, microorganisms cycle nutrients including carbon, nitrogen, and phosphorus. Soils high in very fine materials (e.g., clay) tend to be less permeable and may facilitate greater runoff, while sand-dominated soils can facilitate rapid draining and therefore limited sediment retention (Hawes and Smith 2005). Fine mineral soils or soils with high levels of aluminum or iron may be more likely to perform the nutrient removal/transformation function than other soil types (Adamus et al. 1991).

Trees, shrubs and herbaceous plants can trap and retain pollutants from the atmosphere, sediments, surface runoff and groundwater (Correll 1997). Plants also help lengthen the residence time of water by decreasing flow and velocity, which can increase filtration and soil retention potential (Evans et al. 1996; Klapproth and Johnson 2000; Ducros and Joyce 2003). Vegetation can help mediate nutrient and pollutant input into receiving waters by stabilizing banks to reduce erosion, storing runoff, trapping sediment, and transforming nutrients (Omernik et al. 1981; Smith 1992; Osborne and Kovacic 1993; Arthington et al. 1997).

b. Key findings from buffer literature and science panel on water quality

Numerous studies have investigated the role of riparian buffers composed of vegetation such as grass and forest in controlling the transport of sediment, nutrients, pesticides, metals, microorganisms, and other contaminants to receiving waters (NRC 2002). Most research focuses on nonpoint source pollution, particularly nutrients (phosphates/phosphorus, nitrates/nitrogen), TSS, and sediments. To a lesser degree, research has also addressed bacteria and other pathogens along with oils, pesticides, and herbicides. Appendix C, Table 1 provides a summary of water quality buffer recommendations reviewed for this document.

Our review suggests that:

- The range of buffer widths that met a minimum 80% effectiveness for this function was 5 – 600 m (16-1920 ft; Appendix G). This wide range relates to the breadth of water quality issues. See Appendix C to get more specific widths related to specific water quality parameters.
- Minimum buffer widths to achieve 80% effectiveness for different elements of water quality functions can be extrapolated from the literature and are listed in Appendix G.
- Site characteristics and the amount and nature of the contaminant in the water influence the buffer's capacity to ameliorate those contaminants.

A riparian function curve for water quality was developed for review by the science panel to determine its application to the marine environment. Summary data from Desbonnet et al. (1995) (Table 1) were used to generate a series of curves for four commonly studied contaminants including sediment, TSS, nitrogen and phosphorus (Figure 1). These curves, which are similar to those developed by FEMAT (1993), demonstrate function (in terms of % removal of contaminant) based on a number of studies at different locations and under different site conditions. Note that curves are contaminant-specific despite similarity of shape.

Panelists generally agreed that the function curves are conceptually valid for water quality issues originating in marine riparian areas. However the panel distinguished marine riparian from freshwater riparian function on the basis of drainage area and relative contribution to Puget Sound water contamination. Relative to the dynamics affecting water quality in Puget Sound at the watershed and landscape scales, undisturbed marine riparian area's contribution to maintaining water quality is limited to the area that drains directly into Puget Sound. Anthropogenic activities in marine riparian areas include the generation and routing (via water) of pathogens, nutrients, toxics, heat, and fine sediment (above normal background levels) that can affect water quality. However, the marine riparian area is limited in spatial extent; that is, it constitutes a small fraction of the Puget Sound drainage basin. Most contaminants reach Puget Sound via streams or drainage networks discharging into the Puget Sound Basin, or pathways that concentrate rainfall and snowmelt from impervious surfaces associated with human residential and commercial development and transportation infrastructure. Washington State Department of Ecology, United States Environmental Protection Agency, Puget Sound Partnership Publication Number 07-10-079 (http://www.ecy.wa.gov/pubs/0710079.pdf); and waste water entering Puget Sound from municipal and industrial facilities. The panel did not address nutrient or pathogens from agricultural sources or residential septic systems.

Table 1. Summary data adapted from Desbonnet et al. (1994, 1995) used to generate generalized curve for removal effectiveness of various pollutants at different buffer widths. This data is identical to Desbonnet et al (1995) with the exception of the zero point which we added for illustrative purposes.

% Removal	**Buffer Width in Meters (ft)**			
	Sediment	TSS	Nitrogen	Phosphorus
0	0	0	0	0
50	0.5 (1.6)	2 (6.6)	3.5 (11)	5 (16)
60	2 (6.6)	6 (20)	9 (30)	12 (39)
70	7 (23)	20 (66)	23 (75)	35 (115)
80	25 (82)	60 (197)	60 (197)	85 (279)
90	90 (296)	200 (656)	150 (492)	250 (820)
99	300 (984)	700 (2297)	350 (1148)	550 (1804

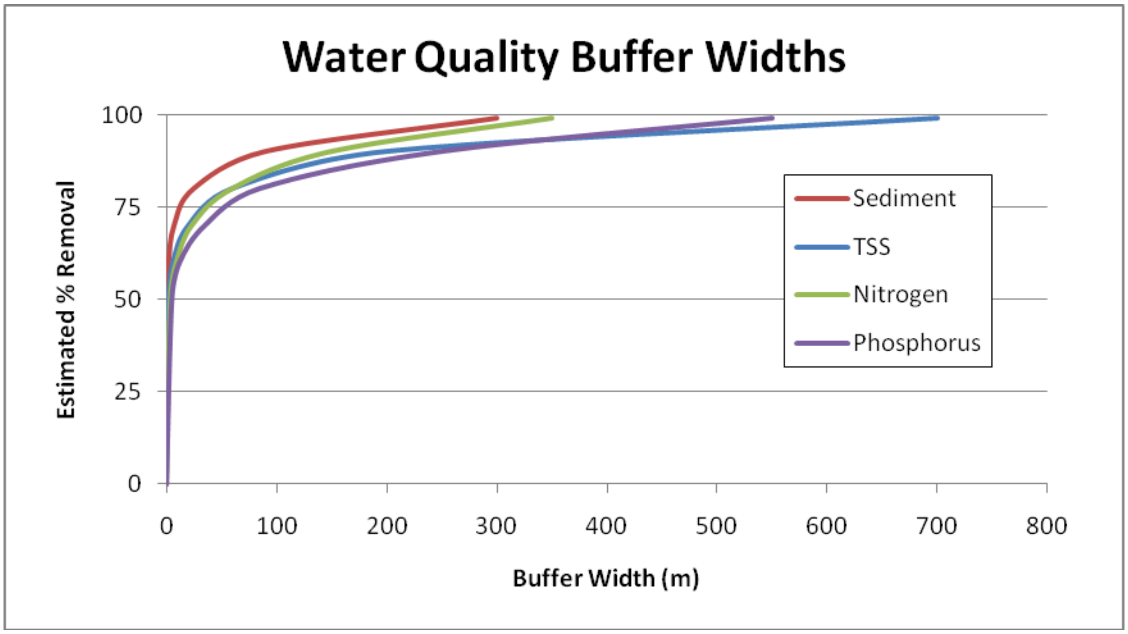

Figure 1. Contaminant removal effectiveness of four water quality parameters at various buffer widths (adapted from Desbonnet et al. 1995).

c. Conclusions and Recommendations for water quality

The literature review (see Appendix C) shows removal effectiveness as a function of buffer widths. In general, the larger the buffer, the greater its effectiveness in performing a water quality function. Long-term studies suggest that contaminant loading can increase over time (depending on the site conditions and type of contaminant), thereby reducing the overall effectiveness of the buffer.

This document focused on four major water quality contaminants that have received the most attention from researchers: nitrogen, phosphorous, total suspended solids and fine sediment. Soil characteristics, slope and vegetation cover type are the most important determinants of buffer effectiveness to protect water quality. To maximize the buffer's effectiveness to remove contaminants, the following actions are recommended in order of priority:

- Retain, restore, or enhance vegetation, particularly native vegetation.
- Manage drainage to ensure that water is moving evenly through the buffer to maximize retention time and infiltration, rather than flowing through pipes, culverts, rills, or other conveyance mechanisms. Avoid routing drainage to adjacent streams that may transect marine riparian areas.
- Avoid the use of pollutants (petroleum, toxics, pesticides, etc) in or near riparian areas.
- Avoid construction of impervious surfaces and septic tank drain fields in riparian areas.

- Manage agricultural and pasture lands to minimally disturb buffers.
- Limit or prohibit the application of pesticides and herbicides in or near riparian areas.
- Avoid disturbance (e.g., grading, compaction, removal) of native soils.

2. Fine Sediment Control

a. Technical overview: riparian influence on fine sediment control function

Riparian areas can play an important role in controlling fine sediment transport into local water bodies (fine sediments include fine-grained particles such as silt, clay, sand, and mud particles). As described previously, fine sediment plays an important role in ameliorating the effect of toxic chemicals and excessive nutrients in water quality. Fine sediment also is important in maintaining soil characteristics necessary for the growth and maintenance of riparian vegetation. However, maintaining natural erosion and sediment transport processes is critical to maintaining Puget Sound beaches and much of the sediment nourishing these beaches originates in marine riparian areas. The delivery of sediment to marine beaches is facilitated by natural driving forces (wind and wave action, bluff saturation, leading to slope failures) and it is very important to maintain these natural sediment inputs. Thus, there is a need to distinguish between “normative” sedimentation rates in marine riparian areas as opposed to human-induced changes to sediment inputs.

Fine sediments originate from a number of terrestrial sources, both natural and anthropogenic, however, the focus of this section is fine sediments originating from development, forestry, and agriculture, which can increase fine sediment delivery beyond normative rates. As used here, normative rate refers to the rate of sediment delivery in riparian areas undisturbed by human activity. Fine sediments become exposed and subject to erosion as a result of vegetation removal, excavation and compaction of soils. Once sediments are suspended in surface water, they can be delivered through run-off to adjacent waterways unless they settle out or become trapped. Undisturbed soils and vegetation in riparian areas act in concert to reduce erosion and slow the transport of fine sediment by the following mechanisms (adapted from Greenway 1987; Gray and Leiser 1992; and Gray and Sotir 1996):

- Riparian vegetation intercepts rainfall energy, helping prevent soil compaction;
- Roots and soils help bind and restrain soil particles and increase sheer strength of the soil;
- Vegetation slows surface runoff allowing for increased localized sediment deposition and decreasing off-site transport;
- Porous and permeable soils improve water absorption reducing surface flow; and
- Transpiring vegetation helps moderate soil moisture levels, which increases infiltration and decreases saturation that leads to increased surface water run-off.

Riparian vegetation can play an even more significant role in sediment and erosion control in steep areas through mechanical reinforcement of sediment via roots and stems and by modifying hydrology through soil moisture extraction (Gray and Sotir 1996). Mature plant communities can be more effective in maintaining slope stability than immature communities. Benefits of vegetation increase in areas with several layers of vegetative cover such as herbaceous growth, shrubs, and trees (Menashe 2001).

b. Key findings from buffer literature and science panel

Most studies include fine sediment control as a component of the water quality function because many contaminants adhere to sediments and increasing inputs of sediments to water bodies can be considered a water quality problem. Appendix C, Table 1 provides a summary of fine sediment control buffer recommendations reviewed for this document.

Our review suggests that:

- The range of buffer widths that met a minimum 80% effectiveness for this function was 25-91 meters (Appendix G).
- Wider buffers are needed in areas with steep slopes.
- Site specific conditions should be considered when determining buffer width (e.g. soils, vegetation type and density, upland/adjacent land uses, and loading).

Two riparian function curves (one for sediment and one for TSS) were developed for review by the science panel (Figure 2) using summary data from Desbonnet et al. (1995) (Table 2). Note that these curves were included in the water quality section. The data were selected because Desbonnet et al's (1995) work was one of the few sources of summary data for fine sediment control at various buffer widths, and represents a number of studies at different locations and site conditions. The data show that roughly 90 percent of sediment can be effectively removed by 30-60 meters (100-200 foot) buffers and roughly 90 percent of TSS can be effectively removed by 200 meter (650 foot) buffers.

There was general consensus by panelists that function curves for sediment control are conceptually valid. Panelists ranked the importance of this function relative to other marine riparian functions as low, largely because of the differences in effects of increased sediment inputs between freshwater and marine systems. Panelists noted that maintaining natural erosion and sediment transport processes is critical to maintaining Puget Sound beaches and much of the sediment nourishing these beaches originates in marine riparian areas. Further, they noted that delivery of this sediment is facilitated by natural driving forces (wind and wave action, bluff saturation, leading to slope failures) and it is very important to maintain these natural sediment inputs. Perhaps the biggest current threat to marine riparian systems from human activity is the reduction of sediment inputs by armoring shorelines and disrupting natural erosion of bluffs.

This is in contrast to freshwater systems, where riparian areas and roads are managed to minimize human-induced fine sediment inputs which can impact habitat and water quality of freshwater streams. Thus, the panel recognized the need to distinguish between "normative" sedimentation rates in marine riparian areas as opposed to human-induced changes to sediment inputs. Further, the panel recognized marine riparian areas should provide for "normative" sediment processes while reducing potentially harmful levels of fine sediments from anthropogenic activities.

Table 2. Summary data adapted from Desbonnet et al. (1994, 1995) used to generate generalized curve for removal effectiveness of various pollutants at different buffer widths. This data is identical to Desbonnet et al (1995) with the exception of the zero point which we added for illustrative purposes. Note that this table is identical to Table 1.

% Removal	**Buffer Width in Meters (ft)**			
	Sediment	TSS	Nitrogen	Phosphorus
0	0	0	0	0
50	0.5 (1.6)	2 (6.6)	3.5 (11)	5 (16)
60	2 (6.6)	6 (20)	9 (30)	12 (39)
70	7 (23)	20 (66)	23 (75)	35 (115)
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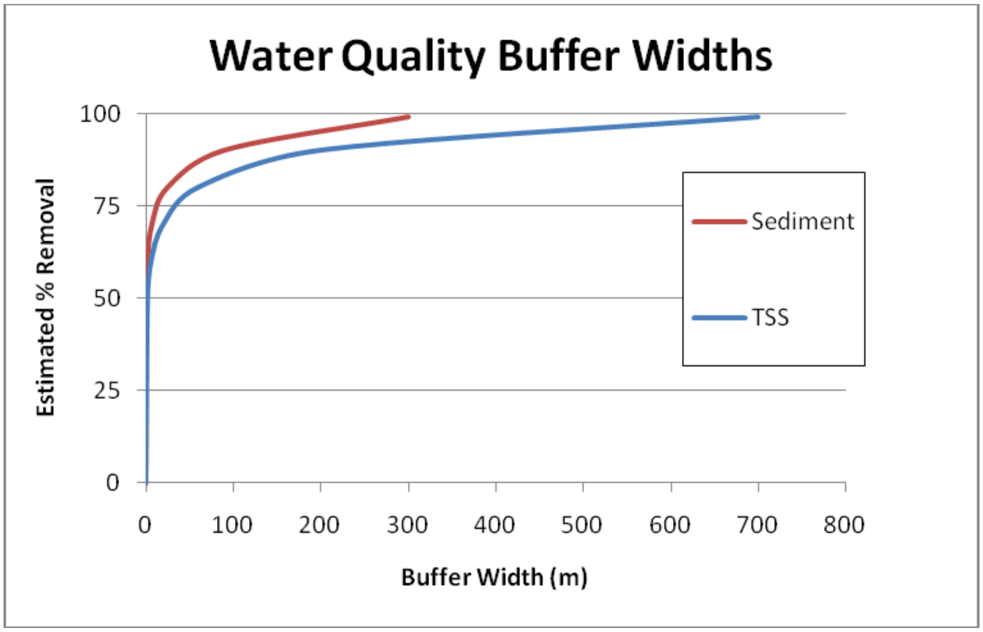

Figure 2. Sediment and total suspended sediment (TSS) removal effectiveness of two water quality parameters at various buffer widths (adapted from Desbonnet et al. 1995).

c. Conclusions and Recommendations for sediment

The literature reviewed for this document (see Appendix C) indicates a range of buffer width recommendations. In addition to buffer width, sediment transport through riparian areas is highly dependent on slope, land use, rainfall, and vegetation and soil type (Hawes and Smith 2005).

Based on the FEMAT-style figure presented in this section, to achieve 100% effectiveness of the buffer to control total suspended solids (TSS) requires a nearly 700 meter (2300 ft) buffer width, but will vary depending upon site specific conditions and fine sediment loading.

To maximize the buffer's effectiveness to control sediment transport, the following actions are recommended:

- Maintain native vegetation cover.
- Minimize soil disturbance including compaction, plowing, grading and soil removal activities.
- Manage drainage and hydrologic conditions as described for other water quality functions.

3. Shade/Microclimate

a. Technical overview: riparian vegetation influence on shade function

Riparian areas can have microclimates that differ from upland areas and which influence physical and biological conditions at a local scale. Marine riparian areas are strongly influenced by marine water temperatures during both summer and winter months (warmer in the winter and cooler in the summer than upland areas). Living riparian (overstory trees, understory shrubs, and ground) vegetation, in turn, can intercept solar inputs and affect microclimate conditions such as soil and ambient air temperature, soil moisture, wind speeds, and humidity (FEMAT 1993; Knutson and Naef 1997; May 2003; Parkyn 2004). Terrestrial and aquatic microclimates are influenced by shade, and temperature fluctuations that can negatively impact both aquatic and terrestrial organisms, particularly those that can only survive within a relatively narrow range of temperature and moisture conditions.

Solar radiation has long been considered an important limiting factor for organisms in the upper intertidal zone of marine environments. Solar radiation affects distribution, abundance, and species composition (e.g., Ricketts and Calvin 1968; Connell 1972). Although research is limited, studies have quantified the influence of shade on marine organisms such as surf smelt (eggs) and talitrids (amphipods) on Puget Sound beaches. In their literature review of causes of spatial and temporal patterns in intertidal communities, Foster et al. (1986) found that desiccation is the most commonly reported factor responsible for setting the upper elevational limits of survival for intertidal animals. More recent studies (Pentilla 2001; Rice 2006) showed that a lack of shade on surf smelt spawning beaches results in higher temperatures, drier conditions, and increased egg mortality.

b. Key findings from buffer literature and science panel

Recommended buffer widths for the shade function in forested riparian areas include a range of values. Appendix C, Table 3 provides a summary of shade buffer recommendations that were derived from seven review documents and other literature.

Our review suggests that the range of buffer widths that met a minimum 80% effectiveness for this function was 17-38 meters (56 – 125 ft; Appendix G).

The FEMAT curve was selected to represent the shade function because it was the only data that depicted shade effectiveness as a continuous function of forested riparian buffer width. The values in Table 3 generally agree with values provided by other riparian review and synthesis reports. One method for comparing different recommendations among authors is to describe the buffer width at a given effectiveness level, such as 80 %. For example, the FEMAT curve suggests approximately 80 percent effectiveness at about 37 meters. Other recommendations for achieving 80 percent effectiveness include Wenger (1999) (10-30 meters); Castelle et al. (1992): (30 meter minimum); May (2000): (30 meter minimum); and Knutson and Naef (1997) (11-46 meters to achieve 50-80 percent (Table 3).

Science panelists agreed that shade is an important function for a number of organisms in the upper intertidal areas during low tide (when exposed upper intertidal areas are subject to heating; see above). On the other hand shade in marine environments is potentially less important in moderating water temperature than shade in freshwater systems. Puget Sound water temperatures as a whole are unlikely to be affected much by shade cast by riparian vegetation, given the mass of water and the exchange rates with water from the Pacific Ocean, primarily through tidal actions. Further, shade from riparian areas is likely to cover only a small fraction of the upper intertidal area given the shallow gradients on many beaches and mudflats. Panelists noted that while increases in solar radiation due to loss of riparian shade could warm shallow intertidal waters, particularly pocket estuaries, the amount of warming and effects on biota have not been quantified.

Table 3. Data used to create generalized curve in Figure 3 indicating percent of riparian shade function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993).

Effectiveness (%)	Buffer Width (SPTH)	Buffer Width SPTH m (ft)
0	0.00	0 (0)
10	0.07	4 (14)
20	0.15	9 (30)
30	0.22	13 (44)
40	0.29	18 (58)
50	0.36	22 (72)
60	0.42	26 (84)
70	0.50	31 (100)
80	0.60	37 (122)
90	0.73	45 (146)
93	0.80	49 (160)
95	1.00	61 (200)

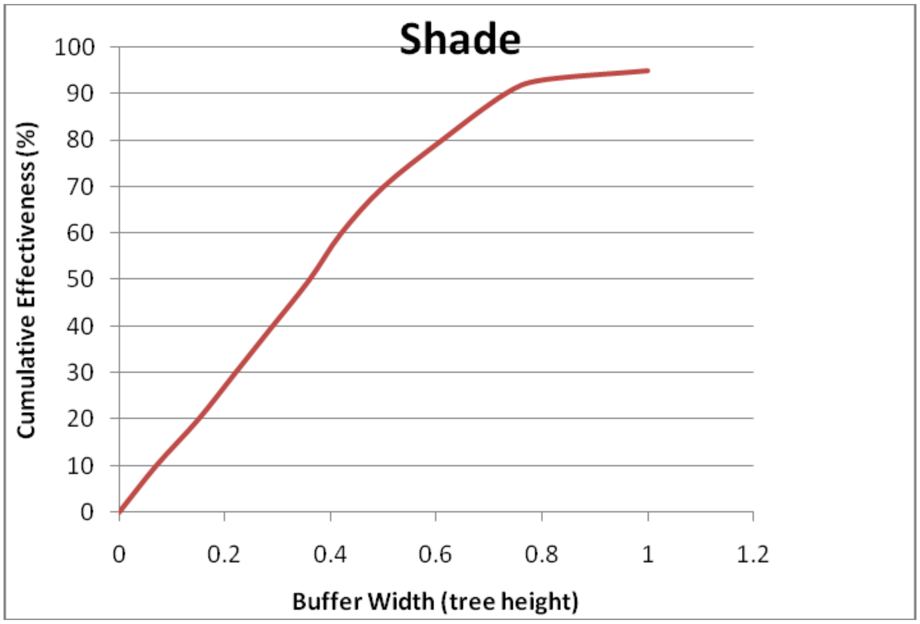

Figure 3. Generalized curve indicating percent effectiveness of riparian shade occurring within varying distances from the edge of a forest stand. Tree height (SPTH) is used to indicate buffer width where one SPTH = 61 meters (200 ft) (adapted from FEMAT 1993).

c. Conclusions and Recommendations

The literature review (see Appendix C) indicates a range of buffer width recommendations for protecting the shade function. Based on the FEMAT curve reported in this section of the report, approximately 1 SPTH (estimated at 61 meters or 200 ft) will provide nearly 100 percent effectiveness of the buffer to protect the intertidal from desiccation, elevated temperatures, and other shade-related functions. Of course, in nonforested community types (e.g., prairie and grasslands) the shade function from overstory trees may be unattainable.

To maximize the buffer's effectiveness to provide the shade function, the following actions are recommended:

- Avoid disturbance to native vegetation in riparian areas, especially nearer the water's edge.
- Retain, restore, and enhance mature trees and a multi-layered canopy and understory of native vegetation at sites that support these types of plant communities.
- Ensure that riparian areas can be maintained in mature, native vegetation through time.
- Prevent modifications to banks and bluffs (e.g., armoring) that could disrupt natural processes (such as soil creep, development of backshore and overhanging vegetation, recruitment of wood and other organic matter to riparian area including beaches and banks.)
- Prohibit cutting and topping of trees and avoid "limbing" (selective branch cutting to enhance views) of trees for view corridors and other purposes within buffers.

4. Large Woody Debris

a. Technical overview: riparian influence on large woody debris function

Forested riparian areas are a significant source of large woody debris (LWD) in freshwater systems (Harmon et al. 1986; Sedell et al. 1988; Bilby and Bisson 1998; Hyatt and Naiman 2001). In marine environments, LWD (also known as 'driftwood') originates from both freshwater and marine riparian sources. Marine riparian areas contribute LWD to shorelines through natural recruitment processes, including windstorms, fires, wave action, and landslides (NRC 1996). Most of Puget Sound's bluffs are naturally unstable and landslides are a common occurrence throughout the region (Johannessen and MacLennan 2007).

Large woody debris provides numerous benefits to shorelines and riparian areas including:

- Moderation of local water temperature and soil moisture;
- Accumulation of detritus serving as a food source and habitat for invertebrates;
- Support of terrestrial vegetation (such as nurse logs);
- Structural complexity that provides habitat for fish and wildlife;
- Sediment trapping and bank erosion control.

Recent research in the Puget Sound region has shown that marine LWD serves similar functions including provision of structural complexity; moderation of local water and soil temperatures; and habitat creation. An overview of the marine research by topic area follows.

LWD and Substrate Temperature: Several studies conducted in Puget Sound have shown that LWD has a significant effect on substrate temperatures (Higgens et al. 2005; Rice 2006; Tonnes

2008). For example, in a study conducted in north Puget Sound, Tonnes (2008) found that mean sediment surface temperatures under LWD on accretionary beaches were 7.7° C cooler than beach sediments lacking LWD. Mean surface temperatures under driftwood on bluff-backed beaches were 2.4° C cooler than nearby sediment. LWD influences sediment temperatures below the surface. Mean temperatures were cooler at depths of 5 centimeters and 15 centimeters under LWD on both accretionary and bluff-backed beaches (Tonnes 2008).

Detritus: Driftwood accumulates detritus from both marine and upland sources, which is consumed by invertebrates, birds and other organisms (Polis and Hurd 1996; Pank 1997; Dugan et al. 2003; Rodil et al 2008).

Invertebrate biomass: Detritus entrained in driftwood has been linked with increased invertebrate biomass which, in turn, supports higher level prey for species such as shorebirds. Amphipods (Talitridae) are the most abundant macroinvertebrate on Puget Sound beaches. In a study of north Puget Sound beaches, Tonnes (2008) found that amphipods represent the predominant biomass of invertebrates within the supratidal zone (e.g. within driftwood). Amphipods are strongly associated with driftwood, where they find refuge from predators, favorable temperature and moisture conditions, and organic matter for consumption. Higher densities of amphipods have been found associated with wood than bare sediment.

Structural support: Marine LWD also provides structural support for vegetation similar to nurse logs in upland settings. In a survey of >1 meter (3.28 ft) diameter wood along 3.9 kilometers (2.3 miles) of Puget Sound beaches, Tonnes (2008) found that 71 percent supported at least one species of terrestrial vegetation. In addition, large wood supported a mean of 2.4 species of vegetation with up to 11 species on a single log. Backshore areas can be relatively dry, exposed and nutrient deficient, and driftwood may play an important role in providing structural stability, moisture and nutrients for establishment of other plant species.

Habitat: Increased vegetation provided by driftwood also increases primary productivity and increases structural complexity for fish and wildlife. May et al. (1997) found wood to be one of the most important factor in determining habitat for salmonids in fresh water systems. Driftwood embedded in beach berms and/or at the toe of banks helps dissipate wave energy and retain sediments that, collectively, act to buffer the effects of storm waves and longshore currents by moderating or reducing bank erosion. It also provides potential roosting, nesting, refuge and foraging opportunities for wildlife; foraging, refuge and spawning substrate for fish; and foraging refuge, spawning attachment substrate for aquatic invertebrates and algae.

b. Key findings from buffer literature and science panel

Numerous studies have investigated the role of riparian areas in providing LWD to adjacent water bodies. Appendix C, Table 4 provides a summary of LWD buffer recommendations that were derived from seven review documents and other research. Most studies find that LWD originates from within one site potential tree height of the riparian area, although steeper slopes may provide LWD from greater distances. Establishing appropriate buffers to maintain the LWD function must therefore account for processes affecting the potential for the land-water interface to change through time such as sea level rise.

A number of studies and reviews of riparian buffers note that, in addition to considering the benefits of LWD in adjacent water bodies, it is important to consider LWD benefits within the terrestrial environment, specifically for its contribution of ecological functions e.g., nurse logs, habitat, nutrient recycling, and helping maintain soil moisture. Appendix C, Table 1 provides a summary of fine sediment control buffer recommendations reviewed for this document.

Our review suggests that:

- The range of buffer widths that met a minimum 80% effectiveness for this function was 17-38 meters (Appendix G).
- Buffer width effectiveness is strongly influenced by site conditions (such as slope) and potential height of mature trees.

The curve adapted from FEMAT (1993) (Appendix D) generally agree with values provided by other riparian review and synthesis reports. The FEMAT curve reveals approximately 80% effectiveness at about 40 meters; the science panel generally agreed that the curve is conceptually valid.

Table 4. Approximated data used to create generalized curve (Figure 4) indicating percent of LWD recruitment function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993).

Effectiveness (%)	Buffer Width (SPTH)	Buffer Width m (ft)
0	0.00	0 (0)
10	0.07	4 (14)
20	0.15	9 (30)
30	0.22	13 (44)
40	0.29	18 (58)
50	0.36	22 (72)
60	0.42	26 (84)
70	0.50	31 (100)
80	0.61	37 (122)
90	0.73	45 (146)
93	0.80	49 (160)
95	1.00	61 (200)

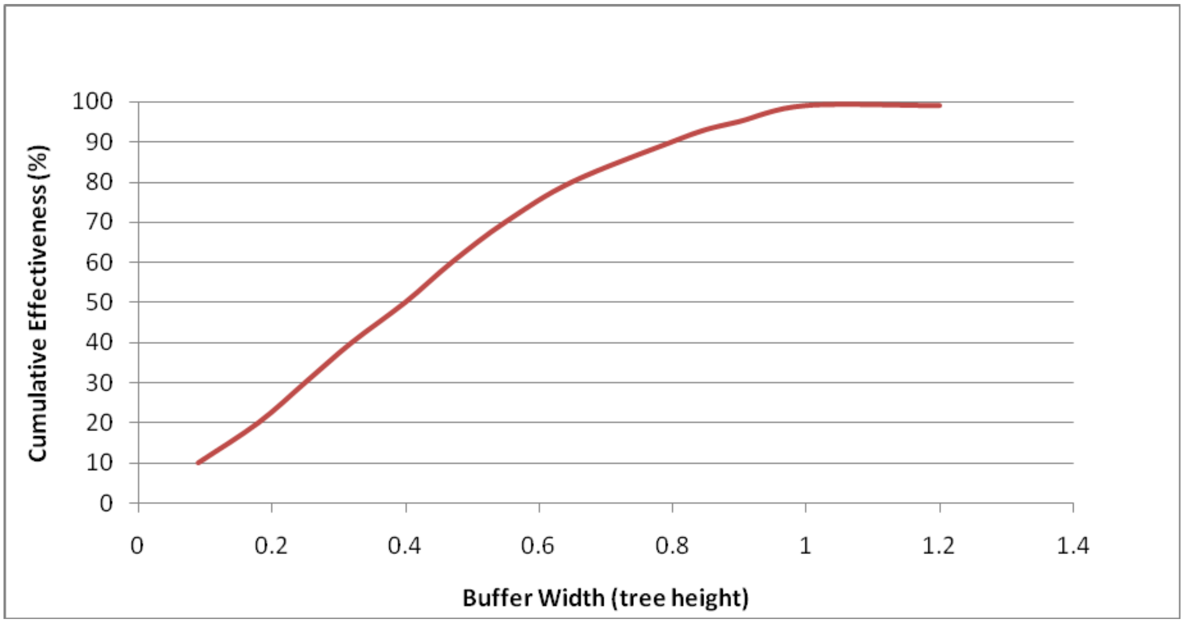

Figure 4. Generalized curve indicating percent effectiveness of LWD recruitment from riparian areas occurring within varying distances from the edge of a forest stand. Tree height (SPTH) is used to indicate buffer width. One SPTH = 61 meters (200 ft) (adapted from FEMAT 1993).

c. Conclusion and Recommendations

The literature reviewed for this document (see Appendix C) indicates a range of buffer width recommendations for protecting the LWD function. Buffer width effectiveness is strongly influenced by site conditions (such as slope, vegetation type and age structure, and natural disturbance regimes).

There are a range of buffer widths for achieving high levels of effectiveness based on the literature in Appendix C ranging from 10 to 130 m (33 – 427 ft). The FEMAT (1993) riparian function curve indicates 100 percent effectiveness of the LWD function at approximately 60 meters (200 ft).

To maximize the buffer's effectiveness to provide the LWD function, the following actions are recommended:

- Avoid human disturbance in riparian areas.
- Allow for the accrual of drift wood and other upland sources of LWD on beaches and shorelines.
- Protect, restore, and enhance marine riparian trees to help ensure a long-term source of LWD.
- Provide buffers that allow for long-term source and recruitment of trees (LWD) as shorelines retreat, or as a result of soil creep and landslides, and increasing sea levels.

5. Litter Fall/Organic Matter

a. Technical overview, riparian influence on litter fall/input of organic matter

Riparian vegetation provides litter that serves as habitat and food for fishes and aquatic invertebrates (Adamus et al. 1991; Levings and Jamieson 2001; Vigil 2003; Lavelle et al. 2005) and influences the amount and type of terrestrial invertebrates that fall into aquatic systems. Terrestrial invertebrates serve as a major food source for fishes (including salmon) birds, mammals, reptiles, and amphibians. Terrestrial insects have recently been shown to be a large component of the diet of juvenile salmonids residing in nearshore waters of Puget Sound. In addition, some fish and invertebrates feed directly on vegetative detritus (McClain et al. 1998; King County DNR 2001; NRC 2002; Vigil 2003; Brennan et al 2004; Lavelle et al. 2005; Fresh 2007; Duffy et al *in review*). Nutrient exchange occurs in two directions from the terrestrial to aquatic systems and vice versa. Examples of nutrient-energy exchange (marine to terrestrial and terrestrial to marine) include:

1. Atmospheric input via wet or dry deposition, which can occur through fires, intensive farming and agricultural activities, and wind erosion (Lavelle et al. 2005).
2. Lateral transfers of nutrients through tidal and wave action, including microalgae and macroalgae washed ashore (Adamus et al. 1991).

3. Decomposing secondary consumers, such as juvenile Pacific herring, Pacific sand lance, longfin smelt, surf smelt, sole, salmon, seabirds, and marine mammals, which also contribute nutrients. For example, Pacific salmon nutrients are deposited by predators and scavengers in excreta, or as carcasses and skeletons (Cederholm et al. 1999; Naiman et al. 2002; Drake et al. 2006).
4. Secondary consumers can transport nutrients to upland areas, facilitating nutrient and energy exchange between terrestrial and aquatic food webs (Ballinger and Lake 2006). For example, Elliott et al. (2003) examined the relationship between bald eagles and Plainfish Midshipman, a demersal fish and intertidal spawner. Between May and June of 2001, the authors found that eagles consumed about 22,700 ± 3,400 midshipman, representing large transfers of nitrogen into upland areas, and the potential to enhance community productivity along the shoreline.

b. Key findings from buffer literature and science panel

A number of references identify the contributions of organic matter (e.g., forest litter, terrestrial insects, woody debris) and food web linkages between freshwater and marine riparian areas and adjacent water bodies (Appendix C, Table 5). Most studies conclude that the delivery of leaf and other organic matter declines at greater distances away from the water's edge, and that most contributions are made within 30-60 meters (100-200 ft) of the shoreline. Appendix C, Table 5 provides a summary of litter fall buffer recommendations that were derived from seven review documents and other research.

Our review suggests that:

- The range of buffer widths that met a minimum 80% effectiveness for this function was 17-38 meters (Appendix G).
- Most litter contributions are made within 30-60 meters (100-200 ft) of the shoreline.
- As in fresh water riparian systems, the delivery of leaf and other organic matter delivered to the marine intertidal areas declines with distance away from the water's edge.

A riparian function curve for litter fall was adapted from the original FEMAT curve (Appendix D). The FEMAT curve reveals approximately 80 percent effectiveness at about 25 meters. The science panel generally accepted that the litter fall curve is a valid representation of marine riparian environments. Panelists also generally agreed that riparian areas are likely to produce insects that fall into the adjacent waters

Table 5. Approximated values for cumulative effectiveness of buffer width for litter fall/organic matter inputs used to create Figure 5, based on the original FEMAT curve.

Effectiveness (%)	**Buffer Width (SPTH)**	**Buffer Width m (ft)**
0	0	0
10	0.04	2.4 (8)
20	0.08	4.9 (16)
30	0.12	7.3 (24)
40	0.17	10.3 (34)
50	0.22	13.4 (44)
60	0.27	16.5 (54)
70	0.33	20.0 (66)
80	0.40	24.4 (80)
90	0.50	30.5 (100)
95	0.65	40.0 (130)
98	0.90	55.0 (180)

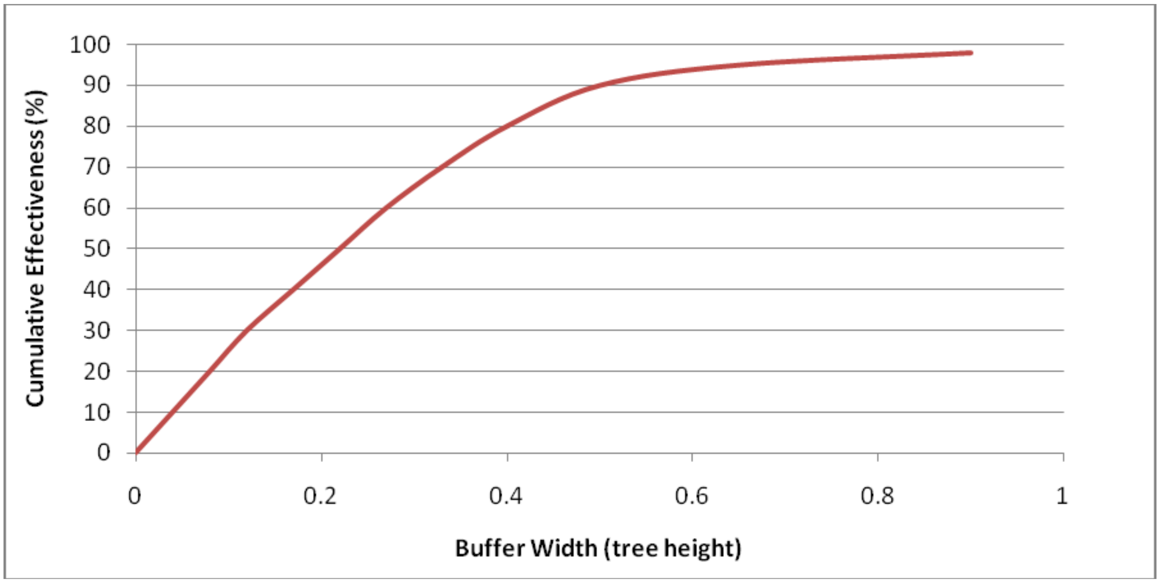

Figure 5. Effectiveness of riparian litter fall/organic matter input as a function of distances from the water’s edge (adapted from FEMAT 1993) where one site potential tree height is approximately 60 meters or 200 ft.

c. Conclusion and Recommendations for litter fall/organic matter inputs

The literature reviewed for this document (see Appendix C) indicates a range of buffer widths to achieve this function. In addition, the function curve derived from FEMAT indicates that approximately 100 percent of the litter fall function is achieved at 60 meter (200 ft).

To maximize the riparian function for litter fall/organic matter inputs the following actions are recommended:

- Maintain native riparian vegetation in the riparian area.
- Avoid human disturbance to vegetation.
- Allow for natural succession of plant communities and maintain sources and accumulations of organic matter within riparian areas and on beaches.

6. Hydrology/Slope Stability

a. Technical overview: riparian influence on hydrology/slope stability function

The role of vegetation in protecting hydrologic processes and slope stability is well documented. The information generally falls into two areas: research focusing on the impacts of sediment inputs to streams and wetlands; and research focused on protecting human infrastructure from anthropogenic disturbances such as logging, agriculture and development.

Sidle et al. (1985) found that tree and shrub root strength contributes to slope stability, and loss of root strength following tree death or removal may lead to increased incidence of erosion and slides. Vegetation also helps lengthen the residence time of soil moisture by decreasing runoff volume and velocity. This in turn can increase filtration and soil retention potential (Evans et al. 1996; Klapproth and Johnson 2000; Ducros and Joyce 2003) and slope stability (Williams and Thom 2001).

Vegetation plays an important role in affecting hydrologic processes and slope stability in the following ways (adapted from Gray and Leiser 1982):

Interception: Foliage and plant litter absorb the energy of precipitation, reducing direct impacts on soil.

Restraint: Root systems bind soil particles and blocks of soils, and filter sediment out of runoff.

Retardation: Plants and litter increase surface roughness, and reduce runoff volume and velocity, thereby reducing channelization.

Infiltration: Roots and plant litter help maintain soil porosity and permeability.

Transpiration: Plants absorb moisture, delaying the onset of soil saturation and surface runoff.

Root Reinforcement: Roots mechanically reinforce soil by transferring shear stresses in the soil to tensile resistance in the roots.

Soil Moisture Depletion: Interception of raindrops by foliage and evapotranspiration limit buildup of soil moisture.

Buttressing and Arching: Tree trunks can act as buttress piles or arch abutments in a slope, counteracting shear stresses.

Surcharge: The weight of vegetation on a slope may exert a destabilizing down slope stress and a stress component perpendicular to the slope that increases resistance to sliding.

Root wedging: Roots invade cracks and fissures in soil or rock that could add restraint stability or cause local instability by wedging action.

Wind throw: Strong winds cause trees to blow down that can disturb slope soils

Soil saturation strongly influences erosion potential on a slope. The more water that can be intercepted, absorbed, or otherwise controlled by vegetation, the greater the slope stability. Soil composition and slope geometry (slope height and angle) are also major factors determining slope stability. Studies have shown that decreasing vegetation cover results in increased soil saturation and slope failure during rainfall events. Some slope failures are unrelated to vegetation cover, usually as a result of unusually high precipitation, undercutting, strong winds, or other factors. However, in studies of slope failures in urbanized areas such as Seattle, over 80 percent of slope failures were attributed to human influence such as vegetation removal and poor drainage management (Tubbs 1975; Laprade et al. 2000).

b. Key findings from buffer literature and science panel

None of the buffer research reviewed for this paper provided buffer recommendations for maintaining slope stability and natural hydrologic processes see Appendix C, Table 6). However, two documents include some analysis that could be helpful in determining buffer widths to protect hydrologic functions. Knutson and Naef (1997) include relevant discussion regarding erosion control. Additionally, FEMAT (1993) identified the relationship of tree root strength to slope stability and provides a generalized effectiveness curve for root strength.

Since a riparian function curve for hydrology and slope stability was not found in the literature, data from Griggs et al 1992 as cited in Macdonald and Witek (1994) were used to describe setbacks on bluffs or other unstable slopes to protect against property loss. The minimum setbacks for different bluff heights and various levels of stability are illustrated in Table 6 and Figure 6. These setbacks do not account for ecological functions but rather focus solely on protection against property loss. The FEMAT curve developed for this function is estimated based on extent of root systems adjacent to a slide scar margin, or “soil stabilizing zone of influence” (equal to slide scar width plus half a tree crown diameter). Such information is not easily interpreted into a buffer width or under the variable site conditions existing on marine shorelines. It appears that neither FEMAT (1993) nor other literature makes buffer recommendations. Much of the shoreline in Puget Sound is composed of bluff-backed beaches, which are naturally eroding. Buffers should be based on site-specific slope conditions, with steeper slopes having wider buffers. This approach is similar to establishing stream buffers from the outside edge of the 100-year floodplain. However, the variability and multitude of factors that need to be considered in determining slope stability in the marine shoreline make it difficult to develop specific buffer width recommendations for this function. We offer information from Griggs et al 1992 as a way of conceptualizing the idea of maintaining riparian function on unstable slopes.

All science panel members agreed that the hydrology/slope stability curve developed with data from Griggs et al. 1992 as cited in Macdonald and Witek (1994) is applicable in the marine environment. Panelists discussed the importance of hydrology, geomorphology, soil type, and vegetation type in supporting slope stability functions in Puget Sound, in addition to the human safety concerns about slope stability in the region.

Geomorphology

- Landforms and geology can be more important here than buffer width. For example, in the San Juan Islands, there can be a 45° slope on basalt form that can be very stable.
- Geomorphic shore form is an important consideration – geologic legacy, landscape position, density, slope, etc. Use of Shipman (2008) geomorphic classification system may be useful (Appendix F).

Soil and Vegetation

- Riparian areas can increase slope stability (through root structure) and increase water interception and absorption. Protecting natural rates of sediment delivery and protecting processes and functions of nearshore ecosystems may be achieved by establishing and maintaining adequate riparian buffers.
- Upslope alterations can be contributing factors to slope instability.
- It is important to consider flow paths; for example, slope stability may be associated more with altered upland drainage patterns or precipitation patterns. Buffer width versus landform may be the most important factor. For example, steeper slopes, particularly those with underlying geologic instability, require wider buffers.

Table 6. Setback distances (in ft) from Griggs et al 1992 as cited in Macdonald and Witek (1994) for different bluff heights at various levels of stability where geologic stability for 50-years cannot be demonstrated.

Bluff Height (ft)	**Stable (1:1)(45^0)**	**Moderately Stable (2:1)(30^0)**	**Unstable (1:1)(45^0)+ (2:1)(30^0)**
20	20	40	60
40	40	80	120
60	60	120	180
80	80	160	240
100	100	200	300
120	120	240	360
140	140	280	420
160	160	320	480
180	180	360	540
200	200	400	600

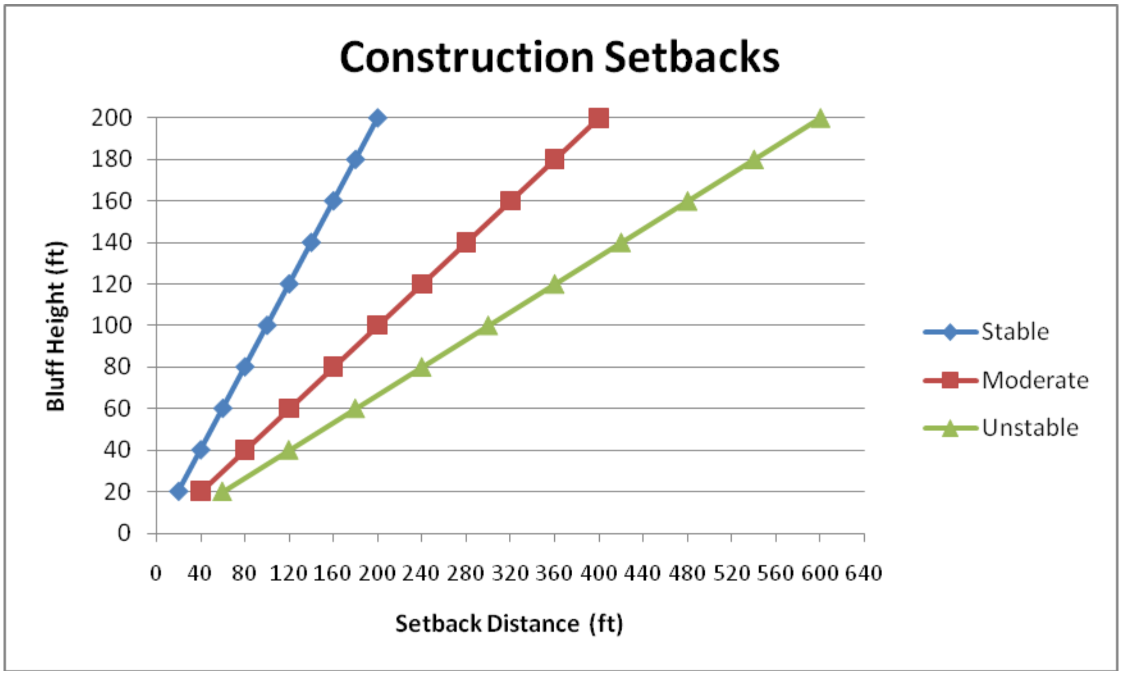

Figure 6. Construction setbacks for different bluff heights at various levels of stability, where geologic stability for 50-years cannot be demonstrated (after Griggs et al 1992 as cited in Macdonald and Witek 1994).

c. Conclusion and Recommendations

No riparian function curve was developed for this section, due to the high variability of site specific conditions that may be encountered and the lack of summary data that could be generally applied.

To maximize the buffer's effectiveness to maintain hydrologic functions and slope stability, the following actions are recommended:

- Avoid development near naturally eroding bluffs.
- Avoid engineering approaches that encroach on buffers to create more stable slope conditions.
- Avoid impervious surfaces and compacted soils.
- Maintain riparian vegetation especially on steep slopes to prevent excessive erosion and allow for evapotranspiration.
- Avoid 'loading' of bluffs whereby excessive moisture (from irrigation, septic fields, impervious surfaces, and other sources of water) can exacerbate the instability and erosion potential of the site.

7. Fish and Wildlife Habitat

a. Technical overview, riparian influence on wildlife function

Provision of wildlife habitat has been well documented for freshwater riparian systems (e.g., Knutson and Naef 1997; Cederholm et al 2000; NRC 2002, Buchanan et al. 2001). Riparian areas provide the resources and structure to meet important life history requirements such as feeding, roosting, breeding, refuge, migration corridors and clean water for a variety of wildlife species. Knutson and Naef (1997) report that riparian areas contribute to the high productivity and species diversity in aquatic and upland areas.

The wildlife function of marine riparian areas is not well documented, although Buchanan et al. (2001) Brennan and Culverwell (2004) described a wide variety of fish and wildlife associations for marine riparian areas of Puget Sound. Wildlife species have adapted to the natural processes, structure, and functions of marine riparian areas and have also played an important role in shaping the structure and character of riparian areas. For example, many birds and mammals that breed and rear in upland areas forage in intertidal areas. Thus, these species provide marine derived nutrients to uplands in the form of feces and carcasses. These marine derived nutrients play an important role in forest ecosystem health (Cederholm et al 2000).

b. Key findings from buffer literature and science panel

A number of studies have examined the role of riparian buffers in supporting wildlife. All studies reviewed for this document report that marine riparian areas function as important wildlife habitat. Appendix C, Table 7 provides a summary of wildlife buffer recommendations that were derived from seven review documents and other research.

Our review suggests that buffer requirements for fish and wildlife depend on different species' individual habitat requirements and may be influenced by season, upland habitat quality and connectivity with other habitat areas.

The science panel generally agreed that marine riparian areas provide habitat for many wildlife species. Some participants pointed out that without buffers, numerous species would not utilize marine nearshore areas or cross onto beaches from upland areas. Perhaps more importantly, riparian buffers and other nearby relatively undisturbed areas provide habitat for riparian obligates (i.e., those that require habitat in close proximity to water bodies such as great blue heron). All panel members agreed that marine riparian areas provide a suite of important services for wildlife. Pertinent information from that discussion follows.

> ***Obligate/Optimal Use Species:*** The science panel was uncertain if obligate species in Puget Sound's marine riparian areas had been identified (but see Buchanan et al. 2001). They suggested that most wildlife in marine riparian areas are probably generalists in their habitat use, and the marine riparian environment supports a number of important functions and processes that create and maintain wildlife habitat. Larger buffers would increase the number of wildlife species using the area and benefit animals with larger home ranges.
>
> ***Invasive species*** within riparian areas may reduce buffer effectiveness. Buffers can harbor nuisance wildlife species which is a cause for concern with respect to local wildlife and human populations.

c. Conclusion and Recommendations

The literature (see Appendix C) provides a range of buffer width recommendations, although few report 100 percent effectiveness. Relative to the other riparian functions discussed in this guidance document, wildlife needs are widely variable.

The ability to recommend a buffer width that would provide 100 percent effectiveness for wildlife is limited at this time because inventories of marine riparian wildlife species and their habitat requirements are lacking. Based on the literature surveyed for this guidance document, a buffer width greater than 200 meters (660 ft) will protect some wildlife habitat functions. Buffer requirements for fish and wildlife depend on the species' individual requirements and these may change or be influenced by season, upland habitat quality and connectivity with other habitat areas. To maximize the buffer's effectiveness to support wildlife, the following actions are recommended:

- Ensure that wildlife habitat connectivity is maximized though maintenance of riparian corridors.
- Ensure native vegetation diversity is maintained (both species composition and age structure) along buffers to offer maximum habitat opportunities to the broadest range of species.
- Allow for natural disturbances such as floods, wind throw and landslides to provide snags, LWD and other complex habitat structural features in the buffer.
- Understand which local species use marine riparian areas by consulting with WDFW Priority Habitat and Species lists or other sources so that buffers can be designed with those species' habitat needs in mind.

Section V. Impacts to Marine Riparian Functions

1. Introduction

Riparian and aquatic ecosystems are currently being altered, impacted, or destroyed at a greater rate than at any time in history (Good et al. 1998). Although no comprehensive study has been conducted to document the rate and extent of marine riparian loss across the Puget Sound basin over time, three studies conducted between 1980 and 2006 provide some perspective on the region's riparian losses. Bortelson et al. (1980 *in* Levings and Thom 1994) studied eleven major river deltas in Washington and documented a 76 percent loss in tidal marshes and riparian habitat during the preceding century. The major losses were within highly developed estuaries including the Puyallup and Duwamish River deltas (Bortelson et al. 1980 *in* Levings and Thom 1994). In 1995, scientists with the Puget Sound Assessment and Monitoring Program (PSAMP) found that approximately 33 percent (or 800 miles) of Puget Sound shoreline had been physically altered by bulkheads, docks, or other structures. These structures typically impact riparian areas through vegetation removal, soil removal and compaction. MacLennan and Johannessen (2008) conducted geographically-focused research in the San Juan Islands and found an average 25% loss of marine riparian forest cover on San Juan, Orcas, Lopez and Stuart islands between 1977 and 2006.

Impacts to riparian function from activities associated with development, agriculture and forestry are well documented in the literature and are summarized in Appendix E, Tables 1-2. As described in Section IV, the level of disturbance to riparian soils and vegetation are key factors determining riparian function. A more detailed description of each of these activities and its impact on riparian function is included in the next three sections.

2. Development

Modern development along marine shorelines usually involves the removal of native vegetation, topsoil and organic matter and the compaction of soils which result from clearing and grading, construction of buildings, pavement, and roads. Additional impacts include the introduction of nonnative plant species associated with landscaping. Loss of natural vegetation in riparian and stream habitats in developed areas is usually permanent, (Booth 1991 *in* Knutson and Naef 1997) and activities associated with development impact all riparian functions (See Appendix E, Tables 1-2). Thus riparian areas are more highly altered in developed landscapes than in agricultural and forested landscapes on a per acre basis (Booth 1991 *in* Everest and Reeves 2006) although agriculture and forestry typically occur over a larger proportion of the landscape than develop areas do. Below we provide a summary of literature addressing development activities and their impacts on riparian function.

a. Water quality

Development activities within riparian areas can affect water quality. Alteration within the riparian areas causes “changes in loading of nutrients, organic matter, and sediments (Valiela et al. 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003); increased loading of contaminants and pathogens (Siewicki 1997; Inglis and Kross 2000; Mallin et al. 2000); and changes in water flow (Hopkinson and Vallino 1995; Jones et al. 2000)” (*in* Hale et al. 2004). The shoreline and upland development of residential, business, and industrial facilities and utilities can result in altered topography, removal of vegetation, soil compaction and grading, and rerouting of surface and groundwater flows (Knutson and Naef 1997; NRC 2002; Ekness and Randhir 2007; Schiff and Benoit 2007). In general, habitat alteration and development creates impervious surfaces, which prevents water from infiltrating into the ground and thus the ability of soil to intercept toxic substances; increases the volume of surface water; increases the magnitude of local flooding (Montgomery et al. 2000 *in* Johannessen and MacLennan 2007); and increases flooding potential (Glasoe and Christy 2005).

b. Fine sediment control

Development impacts to the fine sediment/erosion control function of riparian areas are well documented. Concentration/ channelization of surface runoff can lead to increased soil erosion along and downslope of the path of concentrated flow. Clearing of land for development produces the largest amount of sediment to aquatic resources (U.S. EPA 1993 *in* Stanley et al. 2005), and developed areas can produce 50-100 times more sediment than agricultural areas (Jones and Gordon 2000 *in* Stanley et al. 2005) on a per acre basis. Direct alteration of soils and vegetation within riparian areas can change nutrient loading rates, amounts and types of organic matter, and sediment dynamics (Valiela et al. 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 *in* Hale et al. 2004). In sloped areas, these activities can also result in higher frequencies of slope failure, a relationship demonstrated through many field and laboratory studies (Gray and Sotir 1996; OSB 2007). Permanent loss of vegetative cover increases soil saturation and surface water runoff, causing increased loading of fine sediments. While undisturbed mature native vegetation on slopes provides erosion control and slope stabilization benefits, disturbed or degraded sites can undergo continual erosion, which may hinder the development of effective vegetation cover. Competition by invasive, exotic plants, such as Himalayan blackberry, can also retard or preclude natural establishment of "effective" vegetation (Menashe 2001).

c. Shade/microclimate

The shade function of riparian areas is affected by many activities in the riparian area, particularly those occurring near the water's edge. Vegetation removal can decrease shade (Macdonald et al. 1994; Thom et al. 1994; Macdonald 1995; Penttila 1996; Williams and Thom 2001) and increase water and beach substrate temperatures (Beschta et al. 1987; Williams and Thom 2001; Bereitschaft 2007). Rice (2006) and Sobocinski et al. (2003) demonstrated that shoreline modifications (such as boat ramps, bulkheads, roads, and parking lots) that involve vegetation removal close to the water's edge not only reduce shade but also lower species diversity and abundance. Maintaining native vegetation in the form of mature trees in riparian areas can provide more shade than low-lying shrubs and grasses. Decreased shade, via removal of trees can result in increased egg mortality of beach-spawning forage fishes (Pentilla 2001; Rice 2006) and reductions in diversity and abundance of invertebrate species, as well as loss of habitat structure that supports climate sensitive species (Sobocinski et al. 2003; Brennan and Culverwell 2004; Tonnes 2008).

d. Large Woody Debris (LWD)

The reduced supply of LWD to nearshore ecosystems from marine riparian areas is largely the result of historic activities; however, impacts from ongoing development activities also affect this riparian function. Activities linked to development that affect marine LWD provision include tree removal for development within riparian areas (including shoreline armoring); wood removal (e.g., for fire fuel, landscaping, artwork, furniture); controlled and uncontrolled beach fires; salvage logging; drift log removal from open water; and vegetation removal.

Shoreline armoring can reduce or eliminate the upper intertidal and supratidal zones. This is turn may mobilize LWD and prevent it from settling on the shore. Low levels of LWD have been found on armored beaches compared to unaltered beaches (Sobocinski et al. 2003; Higgins et al. 2005; Dugan and Hubbard 2006; Defeo et al. 2009). Changes in wood abundance and elevated beach temperatures have been documented in several studies around Puget Sound (Higgins et al. 2005; Rice 2006; Tonnes 2008).

e. Litter fall/organic matter inputs

Alteration of riparian habitats can cause changes in nutrient loading, organic matter, and sediments (Valiela et al. 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 *in* Hale et al. 2004). In freshwater systems, dams and other water control structures have caused changes in nutrient cycling (Knutson and Naef 1997) through vegetation removal and soil compaction. Studies in marine systems show lower levels of terrestrially derived organic litter on armored versus unarmored beaches (Sobocinski et al. 2003; Higgins et al 2005; Dugan and Hubbard 2006; Defeo et al. 2009).

f. Wildlife

Shoreline modifications can have direct and indirect impacts on wildlife including interfering with species behavior, lowering survival, and decreasing habitat quality and quantity.

Habitat Loss/Quality

Shoreline modifications result in habitat loss, reduction, and or alteration (Paulson 1992; Levings and Thom 1994; Williams and Thom 2001; Toft et al. 2004), lower bird biodiversity (Donnelley and Marzluff 2004), altered food webs and benthic community composition (Dauer et al. 2000; Lerberg et al. 2000 *in* Hale et al. 2004), creation of passage barriers for salmon and other aquatic species (Williams and Thom 2001), and fragmented habitat (Williams and Thom 2001). The installation of shoreline armoring structures reduces beach width (decreases habitat), and can impede wildlife migration through shoreline corridors (NRC 2002). A reduction in habitat can lower diversity and abundance of wildlife, especially in upper intertidal areas. This can in turn cause change trophic relationships (Sobocinski et al. 2003; Defeo et al. 2009); for example, changes in the nearshore habitat can reduce potential spawning grounds for surf smelt and sand lance, which are a main component of the Pacific salmon diet (Johannessen and MacLennan 2007), and a primary food source for marine bird and marine mammals.

e. Hydrology/Slope Stability

Impacts to the hydrology/slope stability function of marine riparian areas have been widely documented in Puget Sound. Urbanization often causes compaction or removal of top soil, reducing infiltration and soil storage and increasing runoff. Erosion may increase downslope of concentrated flow outlet (e.g., pipe outfalls, impervious surface runoff) and may increase slope failure when this flow discharges to the top of the slope. Vegetation is a critical component in maintaining stable slopes (Morgan and Rickson 1995 *in* Parker and Hamilton 1999; Menashe 1993), and trees above the top of the slope contribute significantly to the geotectonic stability of the slope below (Parker and Hamilton 1999). Tree roots often anchor thin layers of soil to the bedrock or provide lateral stability through intertwined roots (Sidle et al. 1985 and Chatwin et al. 1994 *in* Stanley et al. 2005). In addition, changes to hydrology from the installation of onshore and offshore modifications affects sediment conditions.

3. Agriculture

Agriculture practices like other land use activities can result in the removal of riparian vegetation, addition of pesticides, soil disturbance and thus altered riparian functions. Many riparian areas became disconnected from the aquatic environment when tidelands and wetlands/salt marshes were diked and filled to create farmland. In addition, agricultural sources of bacterial contamination, fertilizers and pesticides can threaten local water quality.

a. Water Quality

Water quality problems associated with agricultural activities include fecal coliform pollution, higher water temperatures, and nutrient and pesticide loading from surface and groundwater flows (Hashim and Bresler 2005). In some cases, excessive fertilizer use has led to increased nutrient levels in aquatic environments, causing algal blooms and eutrophication (Caffrey et al. 2007). Studies in the Puget Sound region show that agricultural activities can increase phosphorus levels in soils and surface runoff (Carpenter et al. 1998 *in* Stanley et al. 2005) and contribute 40 times the amount of nitrogen than forested areas and twice the nitrogen levels of developed areas (Ebbert et al. 2000 *in* Stanley et al. 2005). Agricultural activities that occur within, or drain to, riparian areas can negatively impact riparian soils and sediments by causing soil loss and erosion (Hashim and Bresler 2005), reductions in native vegetation (Spence et al. 1996), and altered flow paths leading to increased sediment, nutrient, pathogen, and pesticide loading (Sedell and Froggatt 1984). In addition, studies have shown that the conversion of riparian areas to cropland has decreased the infiltration potential of riparian soils (NRC 2002).

b. Fine sediment control

Agricultural activities can negatively affect the soil and sediment stability of marine riparian areas. Agricultural activities along Puget Sound shorelines typically result in a loss of native vegetation close to the water's edge because the land is valued for crop production. This loss of vegetative cover and root structure can increase erosion rates into receiving waters (Seddell and Froggatt 1984).

c. Shade/Microclimate

Removal of trees within marine riparian areas reduces the amount of shade available (Hashim and Bresler 2005). Shade and temperature influence photosynthesis rates of plants and metabolic rates of animals. Fluctuations in temperature can alter fish community structure and composition (Baltz et al. 1987; Dambacher 1991; Hillman 1991; Reeves et al. 1987). High water temperatures can cause behavioral changes in fish by affecting migration timing and patterns (Spence et al. 1996).

d. Large Woody Debris

Agricultural activities within riparian areas have resulted in a loss of native vegetation and large woody debris, bank instability, and loss of flood-plain function (Spence et al. 1996).

e. Litter fall/organic matter inputs

Agricultural practices have impaired nutrient regulation in riparian areas. For example, the conversion of riparian areas to cropland has decreased the infiltration potential of riparian soils (NRC 2002), and agricultural activities often require vegetation removal (Everest and Reeves 2006). Excessive fertilizer use has led to increased nutrient levels in aquatic environments, causing algal blooms and eutrophication (Caffrey et al. 2007).

f. Hydrology/slope stability

Land clearing, tillage, wetland drainage, irrigation and grazing can lead to increased surface runoff and greater sediment delivery. Changes in hydrology as a result of agricultural activities can result in altered flow regimes, increased sedimentation, and modified and consolidated stream channels (Sedell and Froggatt 1984), as well as bank instability (Spence et al. 1996).

Permanent loss of vegetation cover, or replacement by monocrops or other non-native vegetation increases soil saturation and surface water runoff. While undisturbed mature native vegetation on slopes provides erosion control and slope stabilization benefits, disturbed sites (such as tilled or over-grazed land) can undergo continual erosion, and may not establish an effective cover. Competition by invasive, exotic plants such as Himalayan blackberry can also retard or preclude natural establishment of effective riparian vegetation (Menashe 2001).

g. Wildlife

Agricultural activities within riparian zones have simplified aquatic and riparian habitats (Spence et al. 1996) and may result in lower biodiversity within these areas.

Grazing practices in riparian areas can damage aquatic habitat through shoreline erosion, disturbance (when large animals disrupt stream channels and pools), and deposition of excess nutrients and fecal coliform.

4. Forest Practices

Coniferous forests are the dominant forest type throughout the Puget Sound basin, with the exception of areas with relatively frequent natural disturbance (e.g., landslides, wind stress), or soils that would not support conifers (e.g., rocky headlands, shallow soils). The age structure, density, diversity, and connectivity of existing riparian forests are important characteristics that determine the types and level of functions provided.

a. Water Quality

Industrial forest practices, including the use of fertilizers and pesticides, timber harvesting, and road construction and maintenance, can degrade water quality and cause changes in hydrology and riparian vegetation (Jones et al. 2000). Forestry activities within riparian areas negatively affect that area’s ability to perform its water quality functions in much the same way that agricultural practices do. Specifically, the removal of riparian vegetation may limit the ability of riparian areas to decrease flows and filter, break down, and slow the flow of pollutants. Pesticides can be transported to riparian areas via surface and groundwater flows.

b. Shade/Microclimate

The removal of canopy through logging and thinning practices opens the understory and ground to increased light and air flow. The resulting microclimate changes can change the character of the plant species, expose soils and beach sediment to desiccation, and/or alter the temperature of water bodies below through the removal of shade-inducing foliage. Timber harvesting within riparian areas reduces shade and can increase water temperatures (Hashim and Bresler 2005).

c. Large Woody Debris

Large old-growth trees within marine riparian areas were historically among the first harvested in the region because of their close proximity to water and low transport costs (Prasse 2006; Brennan 2007; Chiang and Reese undated). Along Puget Sound shorelines and rivers, the number, size and species composition of trees has changed dramatically since the mid 1800s due to tree harvest, levee construction, development and invasive species colonization (Spence et al. 1996; Collins et al. 2002; Brennan 2007). As a result, the composition and volume of LWD on beaches has changed, with larger, mature logs occurring with less frequency. In a survey of 3.9 kilometers of beaches in north Puget Sound, fewer than 5 percent of large logs documented were considered ‘new’ recruits to the beach. The remaining 95 percent were severely weathered, and carbon dating revealed that many were delivered to the aquatic environment between 1700 and 1920 (Tonnes 2008).

The amount of new wood, especially large logs, delivered to beaches appears to be declining (Gonor et al. 1988; Maser and Sedell 1994; MacLennan 2005; Tonnes 2008), Old growth logs are decomposing and gradually disappearing from beaches. In addition, much of the wood currently being recruited to beaches consists of end-cut logs, which are more mobile (due to their smaller size and lack of a root wad and branches) and therefore provide somewhat different functions over shorter temporal and spatial scales (Tonnes 2008).

e. Fine sediment control

Road construction in forested areas increases sedimentation and reduces bank stability (Everest and Reeves 2006). Construction and maintenance activities can increase fine sediment loads and mass wasting processes (e.g., debris avalanches, debris flow, and debris torrents), which in turn can cause erosion and changes in stream channel (or beach) morphology (Hashim and Bresler 2005; Everest and Reeves 2006). Logging and burning can destabilize soils, increase the frequency and magnitude of erosion, and cause sedimentation (Knutson and Naef 1997).

f. Wildlife

Forest composition, structure and age class strongly influence type of wildlife habitat available and the diversity of wildlife that utilize the habitat. Old-growth rain forests of the Olympic Peninsula are among the most productive ecosystems in the world (Franklin and Dryness 1973), while younger second and third-growth forests provide fewer habitats and harbor a fewer numbers of species (Ruggiero et al 1991). Removal of forest cover and associated structure (such as snags and downed logs) can lower the habitat quality in riparian areas, reduce the input of nutrients into waterways (an essential food source for aquatic invertebrates) and eliminate important wildlife migration corridors.

Forestry practices can cause changes in the abundance and diversity of wildlife in riparian areas. This occurs through the loss of LWD, canopy and shrub cover, interior forest habitat within and adjacent to the riparian zone, sedimentation of the aquatic habitat, and habitat fragmentation (Knutson and Naef 1997).

g. Hydrology/Slope stability

Intact coniferous forests provide a perennial canopy and extensive root structure, which intercepts substantial amounts of precipitation, moderates surface and subsurface flows, and reduces erosion potential. Removal of forest cover and structure changes the character of the surface flow, particularly on steeper slopes where surface run-off accelerates and erosion and flash-flooding of small streams can occur.

5. Other Impacts of Concern

Development, agriculture and forest practices are only three of numerous potential impacts to riparian ecosystems. Additional impacts that were outside the scope of this guidance document include:

- Atmospheric deposition of pollutants.
- Harmful Algal Blooms (HABs) and other marine-borne pathogens and diseases.
- Non-native/nuisance Species.
- Recreation (harvest/collection of organism, trampling, wildlife disturbance).
- Climate change (changes in air/ocean temperature, sea level rise, changes in hydrology. and erosion from increased wave action, shoreline retreat, inundation, flooding).
- Oil and fuel spills from commercial shipping and tanker traffic.

Section VI. General Conclusions and Management Recommendations for Protecting Marine Riparian Function

This section is divided into three categories: (1) general conclusions adapted solely from the NRC (2002); (2) overarching recommendation; s; and (3) impact-specific recommendations adapted from the literature review with input by the science panel as described above. These recommendations are intended to offer guidelines and approaches for protecting marine riparian functions addressed in this guidance document.

1. General Conclusions Adapted Solely from the NRC (2002)

- Riparian areas perform important hydrologic, geomorphic, and biological functions. These areas encompass complex above- and below-ground habitats created by the convergence of biophysical processes in the transition zone between aquatic and terrestrial ecosystems.
- Riparian areas cannot be thought of in isolation from associated water bodies. The characteristic geomorphology, plant communities, and associated aquatic and wildlife species of riparian and marine systems are intrinsically linked.
- Natural riparian systems have adapted to specific disturbance regimes. Managing riparian areas without regard to their dynamic patterns and influences of adjacent water bodies ignores a fundamental aspect of how these systems function.
- Riparian areas, in proportion to their area within a watershed, perform more biologically productive functions than do uplands. Riparian areas provide a wide range of functions, such as microclimate modification and shade, bank stabilization and modification of sediment processes, contributions of organic matter and large wood to aquatic systems, nutrient retention and cycling, wildlife habitat, and general food web support for a wide range of aquatic and terrestrial organisms.
- Riparian areas are effective in filtering and transforming materials (such as dissolved and particulate nonpoint source pollutants) from hill slope runoff.
- Because riparian areas are located at the convergence of terrestrial and aquatic ecosystems, they are regional hot spots of biodiversity and often exhibit high rates of biological productivity in marked contrast to the larger landscape.
- During the last decade, a patchwork of federal, state, and local laws and programs has come to acknowledge the importance of riparian areas and to require or encourage special management to restore or protect their essential functions, although the degree of protection, the focus, and the spatial coverage of these laws and programs are highly variable among federal, state, and local levels.

2. Overarching Recommendations

This section contains general management recommendations that broadly address riparian areas.

- Protect marine riparian soils and vegetation – prevent damage to native riparian soils and vegetation, including clearing and grading, compaction, covering (paving) and removal.
- Restore damaged marine riparian habitat – restore vegetation, soil characteristics.

- Account for scale issues (temporal and spatial) when evaluating riparian condition, current functions and potential for future functions, and cumulative effects of alterations. The dynamic nature and connectivity of riparian areas and linkages between riparian and aquatic systems operate at multiple scales.
- Exclude all major sources of contamination from the riparian buffer, including construction, impervious surfaces, mining, septic system drain fields, agricultural activity, clear cutting and application of pesticides and herbicides.
- Manage riparian areas for the long-term. For many sites, substantial time, on the order of years to decades, will be required for vegetation to become fully functional (NRC 2002).
- Require additional structural setbacks (10-30 ft) landward of buffers will allow routine maintenance of structures without compromising buffer function integrity.

3. Recommendations to Avoid or Minimize Specific Impacts

The following recommendations are directed at protecting riparian functions from activities associated with development:

- Avoid vegetation removal on shorelines and bluffs. If vegetation must be removed, minimize the area and amount removed and locate the disturbed area as far from the water as possible. Minimize ground disturbance, removal of mature trees, and introduction of nonnative vegetation, especially invasive species such as English Ivy.
- Avoid locating impervious surfaces in riparian buffers. If impervious surfaces must be located in riparian areas, minimize footprint, and mitigate impacts through techniques including pervious surfaces such as pervious pavers and concrete; bioretention facilities such as rain gardens; green roofs, cisterns, etc. Promote infiltration and implement approved methods/designs for controlling rates of surface runoff and pollutant loading. Caution should be taken when designing and installing bioretention and other facilities that infiltrate water along slopes and bluffs so as to not increase the likelihood of mass failures or erosion.
- Avoid shoreline modification**;** maintain existing native vegetation, particularly at and near the land-water interface. If shoreline alterations must occur they should be done in a way that minimizes potential negative impacts to natural functions and should use the least intrusive methods including bioengineering or relocating structures where feasible and practicable. All adverse impacts should receive full compensatory mitigation to ensure no net loss of ecological functions.
- Remove invasive plant species from marine riparian areas; Purple Loosestrife, Himalayan blackberry, English Ivy and other invasive plants compete with native species, particularly in disturbed sites along marine bluffs and shorelines.
- Restore and replant marine riparian areas with native vegetation to improve the connectivity of upland and marine riparian habitat, and to restore functions that benefit the nearshore and beach ecosystems. Ensure that replanted marine riparian areas are properly maintained to improve plant survival.

- Avoid building in the riparian buffers. If building must occur, then minimize footprint, site disturbance and locate structures far enough back from the water's edge to ensure maintenance of functional riparian areas.
- Avoid locating septic and waste water systems in the riparian area. If they must be located in the riparian area, then they should be designed, maintained, and operated in such a way that that human waste and nutrients are prevented from leaching into local water bodies.
- Avoid disturbance to native vegetation in the riparian area, especially near the water's edge, with the goal of maintaining vegetation communities that are resilient to disturbance from surrounding land uses and able to regenerate with minimal human intervention; and to help ensure that nutrients, pathogens, toxics, and fine sediments associated with land-use practices are prevented from entering water bodies.
- Avoid land use practices in riparian areas that involve the use or generation of nutrients, pathogens, and toxics. Avoid salvage or removal of downed trees, LWD or snags in riparian areas and on beaches. Maintain complex, multi-aged riparian forest cover and wide buffers to allow natural recruitment of LWD over long time frames.

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APPENDIX A. Researchers who conducted technical and scientific literature review on riparian buffers and functions

Section	Name	Affiliation
Slope stability/erosion control Hydrology	Jessi Kershner	UW School of Marine Affairs
Water quality Litter fall/organic matter inputs	Rachel M. Gregg	UW; Washington Sea Grant
Large Woody Debris	Dan Tonnes	UW School of Marine Affairs, NOAA-NMFS
All Functions	Jim Brennan	UW; Washington Sea Grant

APPENDIX B. Brief descriptions of seven buffer review documents

FEMAT 1993
The Forest Ecosystem Management Assessment Team (FEMAT) was formed in 1993 with a directive to assess management options for managing federal lands within the range of the Northern Spotted Owl along the west coast of the United States. The forest plan presents buffer effectiveness curves that were created to represent the relationship between buffer width and ecosystem function.

Castelle et al. 1992
This report focuses on the role of wetland buffers and their effectiveness in protecting ecosystem functions, and was developed for Washington State agencies to consult when creating policies for wetland protection. The report contains a literature review, an agency survey of buffer requirements of areas throughout the United States, and a field study of buffers in King and Snohomish counties.

Knutson and Naef 1997
This review of fish and wildlife habitat requirements was written for the Washington Department of Fish and Wildlife. The authors review freshwater riparian habitat functions (e.g., vegetation, litter fall, large woody debris, water quality) and assess the vulnerabilities of riparian habitats to human activities. The report provides recommendations using riparian habitat area (RHA) widths.

May 2000
This report covers buffers as means of protection for riparian habitat functions for stream systems in Kitsap County. The author summarizes buffer-related research and pays special attention to the preservation of salmonid habitat, including riparian wetlands, and instream spawning and rearing areas.

Desbonnet et al. 1994, 1995
Both papers focus on the role of vegetated buffers in coastal areas and provide recommendations. These papers review the benefits of vegetated buffers, their effectiveness in protecting ecosystem functions, and the variables that affect buffer effectiveness, including possible impacts from human activities and land use.

Wenger 1999
The authors reviewed about 140 articles and books for guidelines on riparian buffers with regards to their width, extent, and composition. This review was created to provide guidelines for local officials and natural resource managers in Georgia.

APPENDIX C. Literature cited for seven buffer functions

Study	Year	Study type	Review or original research	Pollutant of focus	Buffer Composition	Buffer range	Minimum Width Recommendation[1]	Key findings and comments
City of Boulder PDS and Biohabitats, Inc.	2007	Wetlands and streams	Review of science and regulatory approaches to buffers	Phosphorus	Not specified	Not specified	30 m (100 ft) for steep slope, 50 ft for shallow slope	Base minimum recommendations on CWP/EPA 2005. Buffer composition not specified, but recommends grass and trees (best for sediment- bound nutrients, pesticides, and pathogens).
				Nitrogen			30 m (100 ft)	
				Biocontaminants, pesticides			15 m (50 ft)	
Goates	2006	Freshwater streams	Review of adequacy of standard 30m buffers in protecting wildlife	Not specified	Not specified	15-40 m (49 – 131 ft) (Phillips 1989)	Not specified	
				Soluble nitrogen	Forest	30m (98 ft) to remove 97-100% (Doyle et al. 1975; Pinay and Decamps 1988)		
				Nitrogen and phosphorous	Not specified	36 m (118 ft) to reduce nutrients (Young et al. 1980)		
Mayer et al.	2006	Freshwater and wetlands	Summary of 14 regional reviews of riparian buffer literature	Nitrogen	Grass	4.6 – 27m (15 – 89 ft)– surface flow, -27-76% effective 10 – 100 m (33 – 328 ft) subsurface flow, 60-100% effective	>30 m (>98 ft) for effective reduction	Soil type, hydrology (flow paths), and subsurface biogeochemistry (e.g., organic carbon supply, high nitrate inputs) influence nitrogen removal in subsurface flows. Surface flows primarily remove nitrogen effectively when buffers are wide enough and sufficiently vegetated to control erosion and filter particulate nitrogen forms. Vegetation type (e.g. grass, trees, etc.) influences interception potential; for example, grass buffers are better at trapping sediment, filtering sediment-borne nutrients, and reducing sheet flow.
					Grass forest	7.5 – 15 m (25 – 49 ft) – surface flow, 28-41% effective 6 – 70 m (20 – 230 ft) – subsurface flow, 91-99%		
					Forest	30 – 70 m (98 – 230 ft) – surface flow, 78-79% 10 – 220 m (33 – 722 ft) subsurface flow, 58-100%		
					Forest wetland	5.8 – 38 m (19 – 125 ft) – subsurface flow, 59-100%		
					Wetland	20 m (66 ft) – surface flow, 12-74% 1 – 200 m (3.28 – 656 ft) – subsurface flow, 52-100%		
Hawes and Smith	2005	Freshwater streams		Nitrogen and phosphorus		4.9 – 50 m (16-164 ft)	5-30 m (16 – 98 ft) of dense grassy or herbaceous buffers on gradual slopes	Wider buffers will be able to provide longer-term storage. Nitrogen is more effectively removed than phosphorous. Greater widths necessary for steeper slopes
				Pesticides		15 – 100 m (49-328 ft)		

Parkyn	2004	Freshwater and wetlands	Summary review of published research on efficiency and management of riparian buffer zones	Solids, phosphorus, and nitrogen	Vegetated filter strips, usually consisting of rank paddock grasses	4.6 - 9.1 m (15 – 30 ft) for removal of 74-84% of solids, 61-79% of phosphorus, 54-73% of nitrogen (Dillaha et al. 1989)	Not specified	
May	2003	PNW streams	Review and summary of stream buffer literature and evaluation of Puget Sound lowland streams.	Sediment and erosion control	Not specified	8 – 183 m (26 – 600 ft)	Not specified	
				Pollutant removal		4 – 262 m (13 – 860 ft)		

Summary of water quality buffer recommendations from selected review documents.

Study	Year	Study type	Review or original research	Pollutant of focus	Buffer Composition	Buffer range	Minimum Width Recommendation[1]	Key findings and comments
Schoonover and Williard	2003	Stream buffer	Original	Nitrate	Not specified	0 – 10 m (0 – 33 ft) (at 3.3 m (11 ft), 61-90% nitrate reduction)	Not specified	Limited samples in original research along cane and forested buffers. In 10 m(33 ft) cane buffer, about 40% of observed 99% nitrate reduction may be related to dilution by upwelling groundwater. Denitrification and plant assimilation – most likely reasons for reduction. Results varied based on Nitrate-N input (mg/L) and water table depth.
			Review of groundwater nitrate removal by forest riparian buffer zones	Nitrate	Deciduous forest	19 m – 55 m (62 – 181 ft) for 90 – 94% removal		
					Forest	16 m – 90 m (53 – 296 ft) for >90% removal		
					Pine forest	5 m (16 ft) for 98% removal		
					Alder forest	50 m (164 ft) for 98% removal		
					Pine/deciduous forest	8 m – 15 m (26 – 49 ft) for 21-93% removal		
GEI Consultants Inc.	2002	Freshwater	Review of riparian buffers on WA agricultural lands	Fecal coliform	Not specified	Not specified	3.8 m (12.5 ft) (Doyle et al. 1975 and Oskendahl 1997)	
Borin and Bigon	2002	Stream buffers	Original	Nitrate	Grass and trees	6 m (1.8 ft) for 47-74% reduction	6 m (1.8 ft)	Subsurface flow 5m grass strip and 1m wide row of trees
Kuusemets et al.	2001	Stream buffers	Original	Nitrate	Meadow/Alder forest	31 – 51 m (102 – 167 ft)	31 m (102 ft) for 40% removal 51 m (167 ft) for 85% removal	
				Phosphorus			31 m (102 ft) for 78% removal 51 m (167 ft) for 84% removal	
Christensen	2000	Freshwater streams and rivers	Literature review of studies on freshwater buffers	Nitrogen	Vegetated	7-60 m (23 – 197 ft) range for removal	30 m (100 ft) most recommended minimum width to reduce inputs	Wide range of effectiveness due to slope, vegetation composition, and time of year
				Phosphorus		5-50 m (16 – 164 ft) range for removal/reduction		
USDA	2000		Review of studies evaluating buffer effectiveness for pesticides	Not specified	Not specified	4.6 – 9 m (15-30 ft), up to 50 m (164 ft) for multipurpose buffers 4.8 – 18 m (16-59 ft) to filter chemicals 5-262 m (16 – 860 ft) (soluble)	Not specified	
Wenger	1999	Stream buffers	Review and summary of the primary buffer literature and evaluation of several models for evaluating riparian function	Sediment	Not specified	15 – 30 m (49 – 98 ft)	*3 options:* 30.5 m (100 ft) + 0.61 m (2 ft) per 1% slope 15.2 m (50 ft) + per 1% slope 30.5 m (100 ft) fixed buffer width (recommended for governments that find it difficult to implement variable width buffers)	Slopes > 25% does not count toward buffer width. Long-term studies suggest the need for wider buffers. All major sources of contamination should be excluded from the buffer, including construction, impervious surfaces, mining activities, septic tank drain fields, agricultural fields, waste disposal, livestock, clear cutting, application of pesticides and herbicides. Buffer effectiveness declines over time, primarily due to loading. Must control sources of contaminants.
				Nitrate		15 – 30 m (49 – 98 ft)		
				Phosphorus		15 – 30 m (49 – 98 ft)		
				Other contaminants		9+ – 15+ m (30+ – 49+ ft)		

Knutson and Naef	1997	Freshwater systems	Review and summary of riparian and buffer literature	Sediment filtration	Not specified	8 – 91m (26 – 300 ft)	42m (138 ft) for sediment filtration	
				Other pollutant removal		4 – 184m (13 – 600 ft)	24 m (78 ft) for pollutant removal	
Desbonnet et al.	1994, 1995	Coastal vegetated buffers	Review and summary of functions and buffer studies conducted at different locations and under different conditions	Sediment TSS Nitrogen Phosphorus	Not specified	25 – 700m (82 – 2300 ft) for all contaminants	60 m (197 ft) buffer width for 80% contaminant removal (ultimately recommend variable widths to accommodate small coastal lots)	Authors provide gradient of effective sediment and pollutant removal by m/ft and percentage: 5 m (16 ft) 50% or > 10 – 15 m (32-49 ft) 60% or > 20 – 30 m (66-98 ft) >70% 50m (164 ft) 75% or > 75 – 100 m (246-328 ft) 80% or > 200 m (656 ft) 90% or > 600 m (1968 ft) 99% or >
FEMAT	1993	Streams and rivers	Based recommendation primarily on literature review by Castelle et al (1992)		Not specified	3.7 – 262m (12 – 860 ft)	61 m (200 ft) (logging operations) 91 m (300 ft) slope distance for fish bearing streams	Widths vary as a function of geomorphic characteristics such as slope and soil type and by vegetative structure and cover
Castelle et al.	1992	Wetland buffers	Review and summary of literature, agency survey, and a field study on wetland buffer use and effectiveness		Not specified	3.7 – 262m (12 – 860 ft) 19 – 88m (62 – 288 ft) to achieve 50-92% pollutant removal effectiveness	30.5 m (100 ft) or greater	Buffer effectiveness increases with buffer width. Slope and vegetation cover are most important factors for reducing water quality impacts (<15% slope and dense vegetative cover are most effective). Buffers less than 15m (50 ft) are generally ineffective in protecting wetlands.

[1] Unlike some other authors, Knutson and Naef (1997) does not offer minimum buffer width recommendations based on individual functions, but instead recommend Riparian Habitat Area (RHA) widths based on stream type. Authors note that WDFW does not identify minimum (RHA) widths because minimal conditions do not offer adequate habitat to support healthy fish and wildlife in the long run.

Summary of fine sediment control buffer recommendations from selected review documents.

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
City of Boulder PDS and Biohabitats, Inc.	2007	Wetlands and streams	Review of science and regulatory approaches to buffers	Not specified		3 m (100 ft) for steep slope (5-15%) 15 m (50 ft) for shallow slope (<5%)	Base recommendations on CWP/EPA 2005
Hawes and Smith	2005	Freshwater streams		Not specified	10 – 45 m (33-148 ft) (Army Corps 1991) 9 – 61 m (30-200 ft) (Fisher and Fischenich 2000) 15 – 65 m (49-213 ft) (Broadmeadow and Nisbet 2004)		Depends on soil type, slope, land use, rainfall, the rate at which water can be absorbed into the soil, type of vegetation in the buffer, the amount of impervious surfaces, and other characteristics specific to the site. Mixed buffers of trees, shrubs, and grasses are more effective than single buffer vegetation type.
May	2003	PNW streams	Review and summary of stream buffer literature and evaluation of Puget Sound lowland streams	Not specified	8 – 183 m (26 – 600 ft) for sediment removal/erosion control	30m (98 ft)	
Pentec Environmental	2001	Freshwater in City of Everett	Review	Not specified	15 – 91 m (50-300 ft)	15 m (50 ft) for 60% removal 30 m (98 ft) for 70% removal 91 m (300 ft) for 80%+ removal	
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Not specified	9-90 m (30 – 295 ft)	30-90 m (98 – 295 ft)	Ability of buffers to remove sediment varies depending on vegetation type and density, type of soil, slope and placement of the filter. Grass more effective at removing coarse sediments. Non-linear relationship between buffer width and % sediment removal.
USDA	2000		Review of studies evaluating effectiveness of buffers to trap pesticides entering water	Not specified	4.6 – 15 m (15-50 ft)	4.6 – 9 m (15-30 ft) cited as adequate, but for sedimentation and erosion, wider buffers are recommended	

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
Christensen	2000	Freshwater streams and rivers	Literature review of studies on freshwater buffers	Not specified	3 – 122 m (10-400 ft)	31 m (100 ft)	
Wenger	1999	Stream buffers	Review and summary of the primary buffer literature and evaluation of several models for evaluating riparian function	Not specified	18-30 m (49-98 ft)	15 – 30m (49 – 98 ft)	Ability to trap suspended solids is negatively correlated with slope. Significant evidence from long-term analysis that wider buffers are necessary to maintain sediment control. Buffers are less effective in stopping sediment transported by concentrated or channelized flow.
Knutson and Naef	1997	Freshwater systems	Review and summary of riparian and buffer literature	Not specified	8 – 91m (26 – 300 ft) for sediment filtration 31 – 38 m (100-125 ft) erosion control	42 m (138 ft)	
Desbonnet et al.	1994, 1995	Coastal vegetated buffers	Review and summary of riparian functions and buffer studies conducted at different locations and under different conditions (composite of data).	Not specified	0.6 – 304 m (1.98 – 997 ft) for 4 – 99% removal of TSS and sediment	25m (82 ft) for 80% removal efficiency	For TSS removal, an approximate increase in buffer width by a factor of 3.0 provides a 10% increase in removal efficiency; buffer width must increase by a factor of 3.5 to achieve a 10% increase in sediment removal. TSS and sediment removal values high in forested buffers. Application of vegetated buffers for residential and other developing lands has not been adequately addressed in existing implementation efforts. Much of the coast is developed (or developing) to the water's edge, providing little means for long-term protection of coastal water quality, shoreline and aquatic habitat, and visual appeal. Mechanisms that apply to inland riparian buffers should similarly apply to coastal buffers.
FEMAT	1993	Streams and rivers		Not specified	3.7 – 262 m (12 – 860 ft)	None offered specific to sediment removal/ water quality, other than the following: 61 m (200 ft.) (one site potential tree height to control sediment from logging operations) two site potential	

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
						trees, or 91 m (300 ft) slope distance for fish bearing streams (for maintaining general riparian functions)	
Castelle et al.	1992	Wetland buffers	Review and summary of literature review, agency survey, and a field study on wetland buffer use and effectiveness Sediment/soil erosion control recommendation is part of general water quality buffer recommendation	Not specified	3.7 – 262 m (12 – 860 ft) 19 – 88m (62 – 288 ft) to achieve 50-92% pollutant removal effectiveness	30.5 m (100 ft) or greater	Buffers are essential for wetlands protection. Buffer effectiveness increases with buffer width. Slope and vegetation cover are most important factors for reducing water quality impacts (<15% slope and dense vegetative cover are most effective). Buffers less than 15 m (50 ft) are generally ineffective in protecting wetlands. Buffer widths effective in preventing significant water quality impacts to wetlands are generally 30.5 m (100 ft) or greater.

Summary of shade buffer recommendations from selected review documents.

Study	Year	Study focus	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and Comments
Hawes and Smith	2005	Freshwater streams		Not specified	9 – 70 m (30 ft – 230 ft)	9 m (30 ft) – adequate, may need 70 m (230 ft) to completely control temperature	" The amount of shade required is related to the size of the channel. The type of vegetation in the buffer regulates the amount of sunlight reaching the stream channel. Generally, a buffer that maintains 50% of direct sunlight and the rest in dapple shade is considered preferable."
Parkyn	2004	Freshwater and wetlands	Summary review of published research on efficiency and management of riparian buffer zones	Vegetated filter strips, usually consisting of rank paddock grasses	5 – 30 m (16- 98 ft) (for reduced air temperatures – Meleason and Quinn 2004)	5 m (16 ft) reduced air temp by 3.25ºC 30 m (98 ft) reduced air temp by 3.42ºC	Narrow buffers can maintain cool air temperatures
					>10 m (33 ft) (for water temperature moderation – Davies and Nelson 1994)	10 m (33 ft) or greater	
					45 m (148 ft) or > (to maintain natural microclimate following timber harvest – Brosofske et al. 1997)	45 m + (148+ ft)	
May	2003	Freshwater streams	Literature review of freshwater riparian buffers	Not specified	11 – 43 m (36 – 141 ft) for water temperature moderation	30 m (98 ft)	Buffer width recommendations should be qualified with vegetation type and SPTH of trees. "For example, 30 m (98 ft) of mature forest may provide a natural level of shade, but the same width of deciduous trees (willow, alder, etc.) or shrubs may not. With respect to shade and temperature control, a buffer composed of grasses, shrubs, and/or small trees is not equivalent to a natural riparian forest of mixed, mature coniferous and deciduous trees. Buffer quality is as important as buffer quantity."
					45 – 200 m (148 – 656 ft) for microclimate	100 m (328 ft)	
Eastern Canada Soil and Water Conservation Centre	2002	Freshwater streams and rivers	Literature review of buffer strips	Not specified	17 – 24 m (56 – 79 ft)	24 m (79 ft) with dense trees will maximize shading and 17 m (56 ft) will supply 90% of shade (Belt et al. 1992)	Loss of vegetation may increase water temperature by 2 to 100C(Belt et al. 1992). Recommend large dense trees and bushes (based on Carlson et al. 1992). The amount of shade is more dependent on the height and density of the buffer than actual width.
Christensen	2000	Freshwater streams and rivers	Literature review of studies on freshwater buffers	Not specified	11 – 43 m (36 – 141 ft)	30 – 43 m (98 – 141 ft) for 50-100% temperature moderation 11 – 24 m (36 – 79 ft) and 15 – 30 m (49 – 98 ft) (36 – 141 ft) for 60-	11 – 43 m (36 – 141 ft): ranges represent between 60 and 100% of shading that is similar to levels of light below the canopy of old-growth riparian trees 22 – 46 m (72-150 ft) range of effective buffers, 31 m (100 ft) min buffer width. "provide shade equivalent to mature forest

Study	Year	Study focus	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation¹	Key findings and Comments
						80% temperature moderation 23 – 38 m for 80% temperature moderation	conditions, and maintian background water temperatures"
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Not specified	15 – 30 m (49 – 98 ft) (for water temperature moderation)	15 m (49 ft)	Not specific, but use Dosskey et al. (1997) to recommend shrub and trees to yield high level of effectiveness for temperature moderation. Grass ranks low.
Wenger	1999	Stream buffers	Review and summary of the primary buffer literature.	Not specified	10 – 30 m (33 – 98 ft)	10 m (33 ft) (based primarily on review by Osborne and Kovacic 1993)	Must be forested and continuous along all stream channels Forested buffers of native vegetation are vital to the health of stream biota
Knutson and Naef	1997	Fish and wildlife associated with freshwater systems	Review and synthesis of riparian and buffer literature.	Not specified	Temperature Control: 11-46 m (35-151 ft) for 50-80% shading Microclimate Maintenance: 61 - 160 m (200 – 525 ft)	Temperature 27 m (90 ft) Microclimate: 126 m (412 ft)	Perpendicular distance from stream NOTE: Authors (WDFW) do not identify minimum Riparian Habitat Area (RHA) widths because minimal conditions do not offer adequate habitat to support healthy fish and wildlife in the long run.
FEMAT	1993	Streams and rivers	Based recommendation primarily on Beschta et al. 1987; Steinblums 1977; Chen 1991.	Not specified	3.7 – 262 m (12-860 ft)	None offered specific to shade/microclimate, other than the following: - 100 ft.+ to provide as much shade as undisturbed late successional forest (Steinblums 1977) -	Buffer width correlates well with degree of shade (citing Beschta et al. 1987). Temperature and microclimate characteristics are influenced by season, time of day, aspect and extent of tree removal. Few reported field observations of microclimate in riparian zones, but Chen (1991) documented change in soil and air temperature, soil moisture, relative humidity, wind speed, and radiation as a function of distance from clear-cut edge into upslope forest.
Castelle et al.	1992	Wetland buffers	Review and summary of literature, agency survey, and a field study on wetland buffer use and effectiveness.	Not specified	15 – 30 m (50-98 ft) (Broderson 1973; Lynch et al. 1985 and Brazier and Brown 1973)	30.5 m (100 ft) or greater for multiple functions; no recommendation specific to shade	Buffers are essential for wetlands protection Buffer effectiveness increases with buffer width Slope, exposure, and canopy cover are considerations for establishing buffers on a case-by-case basis.

Summary of large woody debris (LWD) buffer recommendations from selected review documents.

Study	Year	Study type	Basis for Buffer Recommendation	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key comments and findings
May	2003	Freshwater streams	Review and summary of stream buffer literature and evaluation of Puget Sound lowland streams	Not specified	10 – 100 m (33 – 328 ft) 20-30 m (Murphy and Koski 1989) 15-46 m (McDade et al. 1990) 45 m (148 ft) (Harmon et al. 1986) 46 m (151 ft) (Robison and Beschta 1990) 50m (Van Sickle and Gregory 1990; Collier et al. 1995) 55m (Thomas et al. 1993) 200 m (656 ft) Hennings 2001 (required to minimize non-native veg. intrusion)	50 m (164 ft)	Approximates one site tree height and is based on long-term, natural levels of LWD
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Not specified	5-100 m (16 – 328 ft)		
Christensen	2000	Freshwater streams and rivers	Literature review of studies on freshwater buffers	Not specified	10 – 100 m (33 – 328 ft) provides approximately 80-90% LWD 30 m (98 ft) (Murphy and Koski 1989) 31 m (102 ft) (Bottom et al. 1983) 30-46 m (98 – 151 ft) (Mc Dade et al. 1990) 45 m (148 ft) (Harmon et al. 1986) 50 m (164 ft) (Collier et al. 1995; Robison and Beschta 1990; Van Sickle and Gregory 1990)	46 m (150 ft)	
Wenger	1999	Stream buffers	Review and summary of the primary buffer literature	Not specified	15 – 130 m (49 – 427 ft) (Murphy et al 1986) 1 SPTH for LWD input – 3 SPTH for stability (allow for wind throw) (Collier et al 1995)	No specific recommendation	LWD is the most important factor in determining habitat for salmonids and related fish (May et al. 1997) Of all the ecological functions of riparian areas, the process of woody debris loading requires the longest time for recovery after harvest (Gregory and Ashkenas 1990)
Knutson and Naef	1997	Freshwater systems	Review and synthesis of riparian and buffer literature. Used average of reported widths	Not specified	30.5 – 61 m (100 – 200 ft)	45m (147 ft)	Perpendicular distance from stream

Study	Year	Study type	Basis for Buffer Recommendation	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key comments and findings
FEMAT	1993	Streams and rivers	Based recommendation on the probability that a falling tree will enter the stream is a function of slope distance from the channel in relation to tree height (citing multiple authors). Note: does not account for steep and unstable slopes that would increase the likelihood of delivery from greater distances.	Not specified	No range provided	None offered specific to LWD, other than the following: Estimation of values provided in generalized curves indicates approximately 70% cumulative effectiveness for LWD at 0.5 SPTH (30.5 m; 100 ft) Delivery of wood is low at distances greater than approximately one tree height away from stream channel	

Summary buffer recommendations for input of litter fall/organic matter from selected review documents.

Study	Year	Study type	Basis for Buffer Recommendation	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key comments and findings
Hawes and Smith	2005	Freshwater streams	Review of buffer recommendations	Not specified	3 – 100 m (10-328 ft) Majority of studies reviewed fall within 15 – 31 m (50-100ft)	3-10 m (10 – 33 ft)	Use general rec widths of Jontos 2004 (modified from Fisher and Fischenich 2000)
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Not specified	5-100 m (16 – 328 ft)		
Wenger	1999	Stream buffers	Citing primary literature, specifically Davies and Nelson (1994)	Not specified	15 – 130 m (49 – 427 ft) (Murphy et al. 1986) as part of combined discussion of litter and LWD	30m (98 ft)	Removal of riparian forests has a profoundly negative effect on stream biota. Results in significant decrease in macroinvertebrate and fish abundance Forested buffers of native vegetation are vital to the health of stream biota.
Knutson and Naef	1995	Freshwater systems	Review and synthesis of riparian and buffer literature Discussed as "contributions to the food web" and in relation to LWD Used average of reported widths	Not specified	30 – 61 m (100 – 200 ft) (same as LWD)	45m (147 ft) – none offered specific to this function, but discussed along with LWD/Structural Diversity	Riparian areas are the dominant contributor to the aquatic food web (approximately half dissolved compounds, half particulate matter)
Desbonnet et al.	1994, 1995	Coastal vegetated buffers		Not specified	This function not reviewed by these authors	Not specified	
FEMAT	1993	Streams and rivers	Based recommendation primarily on Erman et al. (1977) and "best professional judgment." Erman et al. reported that composition of benthic invertebrate communities in streams with riparian buffers greater than 30.5m (100 ft.) were indistinguishable from streams flowing through unlogged watersheds.	Not specified	No range offered, but produced effectiveness curve consistent with Erman et al (1977) and "best professional judgment"	30.5 m (100 ft) or more (one-half site potential tree height, or more) to maintain biotic community structure in stream	Distance from which litter originates depends on site-specific conditions Delivery of leaf and other particulate organic matter declines at distances greater than approximately one-half tree height from stream channel Riparian forests of widths equal or greater than 30.5 m (100 ft) retained sufficient litter inputs to maintain biotic community structures in the stream.
Castelle et al	1992	Wetland buffers	Review and summary of literature review, agency	Not specified	This function not reviewed by these authors	30.5 m (100 ft) or greater for multiple functions; no	Vegetation provides a food source through leaf litter and insect drop and provides cover

Study	Year	Study type	Basis for Buffer Recommendation	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation¹	Key comments and findings
			survey, and a field study on wetland buffer use and effectiveness			recommendation specific to inputs of organic matter	through deposition of large organic debris. Buffer effectiveness increases with buffer width. Slope, exposure, and canopy cover are considerations for establishing buffers on a case-by-case basis. Cite Erman et al. (1977) and Newbold (1980), who found that a 30 m (98 ft) buffer was successful in maintaining background levels of benthic invertebrates in streams adjacent to logging activity

Summary of hydrology/slope stability buffer recommendations from selected review documents.

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
City of Boulder PDS and Biohabitats, Inc.	2007	Wetland and stream	Review of science and regulatory approaches to buffers	Not specified	Not specified	Not specified	Best vegetation type: shrubs and trees
Hawes and Smith	2005	Freshwater	Review	Not specified	9 – 30 m (30-98 ft)	10-20 m (based on Jontos 2004)	
May	2003	PNW streams	Review and summary of stream buffer literature	Not specified	Not specifically reviewed by this author. Some information may be derived from summary of sediment removal and streambank erosion control: 8-183 m (26-600 ft) for sediment control	30 m (98 ft)	
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Not specified	5-125 m (16-410 ft) for stabilization of bank erosion	5 m (16 ft) (of vegetated buffer required to protect riverbank stability)	"The *Guidelines for Queensland Streambank Stabilisation with Riparian Vegetation* recommend a naturally diverse and dense vegetation community within a buffer zone width determined by the minimum width of 5 m (16 ft) (the *basic allowance*) plus the *height allowance* and the *establishment allowance.* An example of a 'decision tree' is provided in the guidelines to assist the determination of riparian zone widths. It should also be acknowledged that erosion processes are natural and even healthy vegetated streambanks are not static, and should not be expected to remain unchanged by erosive forces over time."
Christensen	2000	Freshwater	Review	Not specified	Not specified	31 m (100 ft)	
Wenger	1999	Stream buffers	Review and summary of the primary buffer literature and evaluation of several models for evaluating	Not specified	Author did not review these functions specifically. However, the review of sediment and	30 m (98 ft) (general buffer recommendation)	Buffer effectiveness increases with buffer width Long-term studies have suggested that much wider buffers (than those recommended) are necessary for sediment control. Efficiency of buffers can be expected to vary based on

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
			riparian function		surface runoff is relevant to these topics.		slope, soil infiltration rate, and other factors. Width may be extended to account for steep slopes and land uses that yield excessive erosion. One of the most important roles of protected riparian buffers is to stabilize banks.
Knutson and Naef	1997	Freshwater systems	Review and summary of riparian and buffer literature.	Not specified	Authors provide some relevant review, but no recommendations specific to these topics. However, discussion and recommendations for erosion control are relevant. 30 – 38 m (98-125 ft) for erosion control	34 m (12 ft) NOTE: Authors (WDFW) do not identify minimum Riparian Habitat Area (RHA) widths because minimal conditions do not offer adequate habitat to support healthy fish and wildlife in the long run.	Riparian areas assist in regulating stream flow by intercepting rainfall, contributing to water infiltration, and using water via evapotranspiration – vegetation helps to trap water flowing on the surface, storing it in the soil and later releasing it to streams, moderating peak stream flows. Used average of reported widths. Note that larger buffer in range is for controlling mass wasting.
Desbonnet et al	1994, 1995	Coastal vegetated buffers		Not specified	These functions not reviewed by these authors	Not specified	
FEMAT	1993	Streams and rivers		Not specified	No range offered, but produced effectiveness curve for slope stability based on an estimate of tree root strength.	Not specified	Based recommendation on the width of a slide scar plus half a tree crown diameter, which is an estimate of the extent to which root systems of trees adjacent to the slide scar margin affect soil stability. Steep hill slope areas are common initiation sites of debris slides and debris flows (Dietrich and Dunne 1978). Root strength provided by trees and shrubs contribute to slope stability; and loss of root strength following tree death by harvest or other causes may lead to increased incidence of slides (Sidle et al. 1985)
Castelle et al.	1992	Wetland buffers	Summary of literature review, agency survey, and a field study on wetland buffer use and effectiveness	Not specified	This function not specifically reviewed by these authors	30.5 m (100 ft) or greater for multiple functions; no recommendation specific to hydrology and slope stability.	Buffers play a role in moderating water level fluctuations…vegetation impedes the flow of runoff and allows it to percolate into the ground. The soil then yields this water to the wetland over an extended period of time, resulting in stable, natural ecosystems. Buffer effectiveness increases with buffer width Slope, exposure, and canopy cover are considerations for establishing buffers on a case-by-case basis. The best functioning buffers were the most stable, and buffer stability was in turn enhanced by high percentage vegetative cover and dense stands of trees,

Study	Year	Study type	Review or original research	Buffer Composition	Buffer Range	Minimum Buffer Width Recommendation[1]	Key findings and comments
							rather than by sparse vegetation or individual trees protruding above an understory (citing Darling et al 1982).

[1] Unlike some other authors, Knutson and Naef (1997) do not offer minimum buffer width recommendations based on individual functions, but instead recommend Riparian Habitat Area (RHA) widths based on stream type. Authors do not identify minimum (RHA) widths because minimal conditions do not offer adequate habitat to support healthy fish and wildlife in the long run.

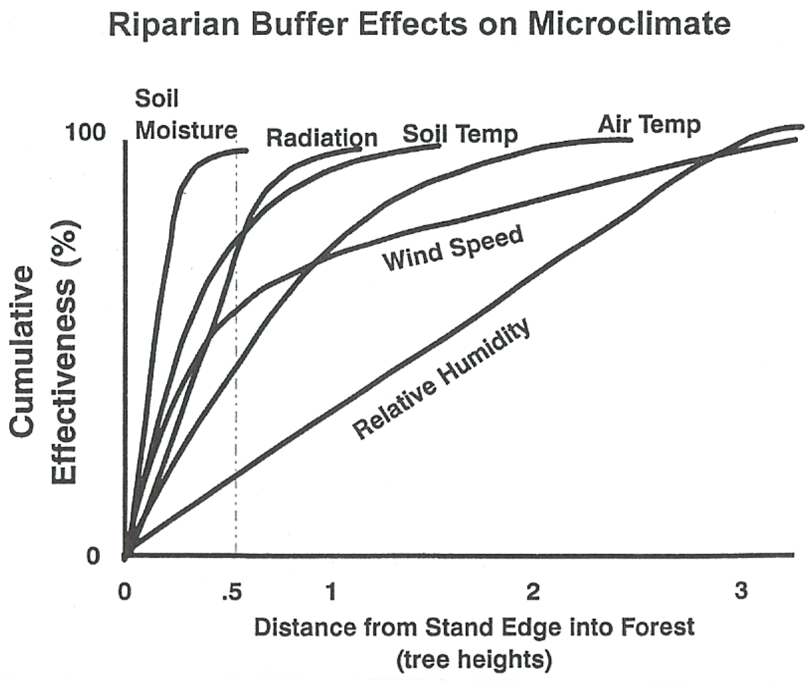
Summary of wildlife buffer recommendations from selected review documents. Buffer composition was not specified.

Study	Year	Study type	Review or original research	Review of Multiple Wildlife Types	Buffer Range	Minimum Buffer Recommendation	Key comments and findings
City of Boulder PDS and Biohabitats, Inc.	2007	Wetland and streams	Review of science and regulatory approaches to buffers			31 m (100 ft) for unthreatened species 61 – 91 m (200-300 ft) for rare, threatened and endangered 15 m (50 ft) for species diversity in rural areas; 31 m (100 ft) for species diversity in developed areas	Base recommendations on CWP/EPA 2005
Goates	2006	Freshwater streams	Review of adequacy of standard 30m buffers in protecting wildlife		30.5 m (only 44% of nests and hibernation burrows of turtles in South Carolina (Burke and Gibbons 1995) 30 m (98 ft) buffer inadequate to maintain bird species in logged areas of western WA (Pearson and Manuwal 2001)	73 m (240 ft) required to protect 90% of hibernation and nesting; 275 m (902 ft) to protect 100% (Burke and Gibbons 1995) 45 m (148 ft) buffer required to maintain bird community (Pearson and Manuwal 2001)	30m minimum protect from timber harvests (Castelle et al. 1994; Semlitsch and Bodie 2003; Lee et al. 2004) Recommend that managers consider temporal constraints, long-term analyses, sex, and location.
Hawes and Smith	2005	Freshwater	Review		10 – 50 m (33-164 ft)		
Parkyn	2004	Freshwater and wetlands	Summary review of published research on efficiency and management of riparian buffer zones		3-107 m (10 ft - 351 ft) (depending on particular resource needs of invidiual species – Castelle et al. 1994)		Will differ depending on needs of species
May	2003	PNW streams		Yes	15-100 m (49 – 328 ft)	100 m (328 ft)	Compiled different recommendations from authors, including: 30m for macroinvertebrates, Chinook salmon, Cutthroat trout >30m for macroinvertebrates and salmonids 30-70 m (98 – 230 ft) for salmonids 30-70 m (98 – 230 ft) and 67-93 m (220 – 305 ft) for small mammals 100 m (328 ft) min for migration corridor for large mammals and for interior habitat and migration corridor 50-125 m (164 – 410 ft) for nesting, migrating, and feeding habitat for birds

Study	Year	Study type	Review or original research	Review of Multiple Wildlife Types	Buffer Range	Minimum Buffer Recommendation	Key comments and findings
							200 m (656 ft) for eagle nest and heron rookery, deer and elk habitat
Bavins et al.	2000	Fish habitat (freshwater and marine)	Summary of buffer recommendations for fish habitat	Yes, but primarily limited to fish	5-106 m (16 – 348 ft) for species diversity and distribution (e.g., connectivity between marine and freshwater environments; continuous lines of vegetation; migration pathways) 15-45 m (49 – 148 ft) for provision of other wildlife habitat (wildlife corridors) 5-100 m (16 – 328 ft) for provision of remnant vegetation 30 m (98 ft) or > for salmonid eggs to develop normally	Not specified, but recommend vegetated buffers	
Wenger	1999	Stream buffers		Yes	Ranges reported for different wildlife types Generally: 15-100+m (49 – 328+ ft)	100m (328 ft)	While not practical on all streams, there should be some with 90-300m riparian corridors, along with large blocks of upland forest targeted for preservation.
Knutson and Naef	1997	Freshwater systems		Yes	8-300 m (26 – 984 ft)	88m (average of reported widths)	"Buffers" described as "Riparian Habitat Area" widths
Desbonnet et al	1994, 1995	Coastal vegetated buffers		Yes	15-200 m (49 – 656 ft)	No single buffer recommendation offered	Reported buffer widths were intended as minimum values to meet desired objective 5 m (16 ft) poor habitat value; useful for temporary use by wildlife 10 m (33 ft) minimal protection for stream habitat, useful for temporary use by wildlife 15 m (49 ft) minimal wildlife and avian value 20 m (66 ft) minimal value for habitat, some for avian habitat 30 m (98 ft) maybe useful as travel corridor for wildlife and avian habitat 50 m (164 ft) minimal habitat value 75 m (246 ft) fair to good wildlife and avian habitat value 100 m (328 ft) good wildlife habitat, may even protect significant wildlife habitat 200 m (656 ft) excellent wildlife value, likely to support a diverse community 600 m (1968 ft) excellent wildlife habitat value, supports diverse community, protects significant species
Castelle et al.	1994	Wetland buffers		Yes	2-110 m (7-361 ft) wildlife		
Johnson and Ryba	1992	Stream buffers		Yes	10-200 m (33-656 ft)		Birds require larger buffers than other wildlife groups. Salmonids require ~30 m (100 ft) buffer.

Study	Year	Study type	Review or original research	Review of Multiple Wildlife Types	Buffer Range	Minimum Buffer Recommendation	Key comments and findings
Castelle et al	1992	Wetland buffers		Yes	Ranges varied by wildlife type	33-98 m (108 – 321 ft)	Draws conclusion from WA Dept. of Wildlife (1992) Buffer needs of wetland wildlife.
Groffman et al	1990			Yes	32-100 m (105 – 328 ft) (or more)	No single buffer recommendation offered. 32-100 m (or more in case of threatened or endangered species)	Buffer model is offered, based on 4 factors: 1) habitat suitability; 2) wildlife spatial requirements; 3) access to upland and/or transitional habitats; 4) noise impacts on feeding, breeding, and other life functions.

APPENDIX D. Original FEMAT curves.


Riparian Buffer Effects on Microclimate

APPENDIX E: Literature summary documenting the impacts of development, agriculture and forest practices on riparian functions

Land use impacts on riparian function (Development, Agriculture and Forestry)

Land use	Riparian function impaired							Specific activities associated with land use category	Impact findings on function	Literature cited
	Water Quality	Shade/Microclimate	LWD	Litter fall	Fine sediment control	Wildlife	Hydrology/slope stability			
Development	**X**	**X**	**X**	**X**	**X**	**X**	**X**	Clearing and grading/vegetation removal Construction of homes, buildings, roads/Impervious surfaces Shoreline armoring (docks, bulkheads, etc.) Landscaping (non-native plants) Recreational activities (hiking, biking, beachcombing, etc.)	Riparian areas are more highly altered in developed landscapes than in agricultural and forested landscapes	Booth 1991 *(in* Everest and Reeves 2006)
									Direct alteration within the riparian area (vegetation removal/reduction, soil compaction, grading) causes changes in loading of nutrients, organic matter and sediments; reduces capacity of riparian area to filter/absorb pollutants; increases sediment loading	Valiela et al 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 (*in* Hale et al. 2004)
									Creation of impervious surfaces (e.g., parking lots, paved streets, sidewalks, roads), vegetation removal, and soil compaction cause surface water to increase in volume and magnitude. Increased runoff decreases the ability of soils and vegetation to infiltrate and intercept pollutants , increases flooding potential.	Knutson and Naef 1997; Montgomery et al. 2000 (*in* Johannessen and MacLennan 2007); Glasoe and Christy 2005; Hashim and Bresler 2005; Ekness and Randhir 2007; Schiff and Benoit 2007
									Construction of boat landings, docks, and piers creates increased slopes, causing increased and concentrated water flows; construction of domestic, residential and industrial facilities and utilities in and near riparian areas can result in altered topography, removal of vegetation, and rerouting of surface and groundwater flows	Knutson and Naef 1997; NRC 2002; Ekness and Randhir 2007; Schiff and Benoit 2007
									Construction close to the water's edge (bulkheads, docks, etc.) reduce shade as well as species diversity and abundance	Sobocinski et al. 2003; Rice 2006
									Areas with high levels of impervious surface coverage (>50%) correlated with low macrobenthic diversity and abundances	Lerbert et al. 2000
									Vegetation removal causes decreased shade and increased temperatures	Beschta et al. 1987; Macdonald et al. 1994; 1995; Thom et al. 1994; Penttila 1996; Williams and Thom 2001; Bereitschaft 2007
									Removal of vegetation cover also reduces LWD and canopy cover, which serve to dissipate flow energy and control temperature by shading	Booth et al. 2006
									Increases of light levels in the upper intertidal zone results in higher levels of mortality and dessication of insects, invertebrates, and the eggs of intertidal spawning fish like Pacific sand lance and surf smelt.	Pentilla 1996, 2000; Rice 2006
									Low levels of organic litter and LWD have been found on armored beaches	Sobocinski et al. 2003; Dugan and Hubbard 2006; Defeo et al. 2009
									Increased surface runoff of toxins Toxins can affect wildlife through physiological and behavior changes,	Klapproth and Johnson 2000; Krebs and Bums 1977; Krebs and Valiela 1978; Moore et al. 1979

									reduced density and species richness	(*in* Adamus et al. 1991); Firehock and Doherty 1995 (*in* Klapproth and Johnson 2000); Hashim and Bresler 2005; PSAT 2007
									Vegetation is a critical component in maintaining stable slopes . Roots anchor thin layers of soil to the bedrock or provide lateral stability through intertwined roots.	Morgan and Rickson 1995 (*in* Parker and Hamilton DATE); Sidle et al. 1985 and Chatwin et al. 1994 (*in* Stanley et al. 2005).
									Decreased wood abundance and elevated beach temperatures have been documented in several studies around Puget Sound.	Higgens et al. 2005; Rice 2006; Tonnes 2008
									Low levels of LWD and organic litter have been found on armored beaches as compared with unaltered beaches	Sobocinski et al. 2003; Dugan and Hubbard 2006; Defeo et al. 2009
									Dams and other water control structures have caused changes in nutrient cycling	Knutson and Naef 1997
									Offshore structures (e.g., breakwaters, jetties) can cause increased deposition of beachwrack .	Martin et al. 2005 *in* Defeo et al. 2009
									Shoreline modifications result in 1. wildlife habitat loss, reduction, and or alteration 2. lowered bird biodiversity 3. altered food webs and benthic community composition 4. creation of passage barriers for salmon and fragmented habitat connectivity 5. lowered abundance of wildlife which can cause harm to upper trophic levels, like Pacific salmon	1. Paulson 1992; Levings and Thom 1994; Williams and Thom 2001; Toft et al. 2004; Griggs 2005 2. Donnelley and Marzluff 2004 3. (Dauer et al. 2000; Lerberg et al. 2000 *in* Hale et al. 2004), 4. Williams and Thom 2001). 5. Sobocinski et al. 2003; Johannessen and MacLennan 2007; Defeo et al. 2009
									Habitat alteration can cause increased loading of contaminants and pathogens	Siewicki 1997; Inglis and Kross 2000; Mallin et al. 2000 (*in* Hale et al. 2004)
									Habitat alteration can cause changes in water flow	Hopkinson and Vallino 1995; Jones et al. 2000 (*in* Hale et al. 2004)
									Clearing of land for development produces the largest amount of sediment to aquatic resources; developed areas can produce 50-100 times more sediment than agricultural areas	U.S. EPA 1993 (*in* Stanley et al. 2005); Jones and Gordon 2000 (*in* Stanley et al. 2005
Agriculture	**X**		**X**		**X**	**X**	**X**	Clearing and grading/vegetation removal Application of pesticides/fertilizers Tillage/irrigation practices	Loss of native vegetation and LWD, bank instability and loss of floodplain function	Spence et al. 1996 *(in* Everest and Reeves 2006)
									Increased phosphorus and nitrogen levels in soils and surface runoff; 40 times the amount of nitrogen in agricultural land than forested areas and two times the nitrogen levels of urban areas in Puget Sound	Carpenter et al. 1998 (*in* Stanley et al. 2005); Ebbert et al. 2000 (*in* Stanley et al. 2005
									Excessive fertilizer use has led to increased nutrient levels in aquatic environments, causing algal blooms and eutrophication	Caffrey et al. 2007
									Activities can cause soil loss and erosion	Hashim and Bresler 2005
									Loss of vegetation cover, changes in hydrology cause altered flow regimes; increased sedimentation	Seddell and Froggatt 1984 *(in* Everest and Reeves 2006)
									Activities within riparian areas have simplified aquatic and riparian habitats	Spence et al. 1996 *(in* Everest and Reeves 2006)

								Direct alteration can cause increased loading of contaminants and pathogens	Inglis and Kross 2000 *(in* Hale et al. 2004)
								Conversion of riparian areas to cropland can decrease the infiltration potential of riparian soils	NRC 2002
Forestry	**X**	**X**			**X**	**X**	**X**	Introduction of pesticides and fertilizers Impervious surfaces (roads etc) Vegetation removal (timber harvesting)	Timber harvesting within riparian areas reduces shade	Hashim and Bresler 2005
									Timber harvesting within riparian areas increases sedimentation	Everest and Reeves 2006
									Timber harvesting within riparian areas reduces bank stability	Everest and Reeves 2006
									Road construction and maintenance activities can increase fine sediment loads and mass wasting processes, and can reduce bank stability	Hashim and Bresler 2005; Everest and Reeves 2006
									Forestry practices can cause changes in the abundance and diversity of wildlife in riparian areas. This occurs through the loss of LWD, canopy and shrub cover, interior forest habitat within and adjacent to the riparian zone, sedimentation of the aquatic habitat, and habitat fragmentation.	Knutson and Naef 1997
									Removal of trees within marine riparian reduces available shade (thereby increasing water temperatures); temperature changes affect water quality and changes in fish/wildlife behavior, structure, and composition.	Hashim and Bresler 2005 Vigil 2003; Everest and Reeves 2006
									Forestry practices, including use of fertilizers and pesticides, timber harvesting, and road construction and maintenance, degrade water quality and can cause extensive changes in hydrology and riparian vegetation	Jones et al. 2000

Impact of specific activities on riparian function

Specific activities	Typically associated with land use	Riparian function impaired							Finding	Literature cited
		Water quality	Shade/Microclimate	LWD	Litter fall	Fine sediment control	Wildlife	Hydrology/slope stability		
Clearing and grading/ vegetation removal (including timber harvesting)	Development Agriculture Forestry	X	X	X		X	X	X	Can lead to an increase in contaminated runoff	Ekness and Randhir 2007
									Common development practices can result in conditions that produce unhealthy plants that require excessive fertilizers and pesticides	WDOE 2007
									The reduction or removal of slope vegetation can result in either increased rates of soil erosion or higher frequencies of slope failure.	OSB 2007
									Permanent loss of vegetation cover or replacement by ineffective vegetation increases soil saturation and surface water runoff. Disturbed or degraded sites undergo continual erosion and may not establish an effective cover.	Menashe 2001
									Vegetation removal decreases shade, leading to increased temperatures that can impact wildlife survival	Macdonald et al. 1994; Thom et al. 1994; Macdonald 1995; Penttila 1996, 2000; Williams and Thom 2001; Rice 2006; Bereitschaft 2007
									Can cause extensive changes in hydrology and riparian vegetation.	Jones et al. 2000
									Timber harvesting within riparian areas reduces shade; agricultural activities can degrade water quality by increasing fecal coliform levels, temperatures and nutrient/pesticide loading.	Hashim and Bresler 2005
									Timber harvesting within riparian areas reduces bank stability	Everest and Reeves 2006
									Agricultural activities within riparian zones have resulted in a loss of native vegetation and LWD, bank instability, and loss of floodplain function.	Spence et al. 1996 (*in* Everest and Reeves 2006)
									Agricultural activities within riparian areas have simplified aquatic and riparian habitats	Spence et al. 1996 (*in* Everest and Reeves 2006)
Construction and maintenance of impervious surfaces (e.g. roads, homes and buildings)	Development Agriculture Forestry	X				X	X	X	Can lead to an increase in contaminated runoff	Ekness and Randhir 2007
									Can degrade water quality (including increased temperatures) and cause extensive changes in hydrology	Jones et al. 2000
									Direct alteration can cause increased loading of contaminants and pathogens	Mallin et al. 2000 (*in* Hale et al 2004)
									Can increase fine sediment loads and mass wasting processes, which can cause erosion.	Hashim and Bresler 2005
									Direct alteration within the riparian area causes changes in loading of nutrients, organic matter and sediments	Valiela et al 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 (*in* Hale et al. 2004)
									Areas with high levels of impervious surface coverage (>50%) correlated with low macrobenthic diversity and abundances.	Lerbert et al. 2000

									Impervious surfaces cause increased volume and magnitude of surface water runoff, decreasing the ability of soil and vegetation to absorb/intercept pollutants	Montgomery et al. 2000 (*in* Johannessen and MacLennan 2007)
									Impervious surfaces increase flooding potential	Glasoe and Christy 2005
									Increased sedimentation has also been shown to affect juvenile and filter-feeding fish.	Williams and Thom 2001
Shoreline armoring (e.g. docks, bulkheads, etc)	Development	X					X		The construction of boat landings, docks, and piers often creates increased slopes, which causes increased and concentrated water flows. Shoreline armoring structures, such as rip-rap, concrete, and bulkheads, can require the removal of vegetation and can also impede the movement of wildlife that utilize the shoreline as migration corridors.	NRC 2002
									The installation of shoreline armoring structures reduces beach width, resulting in the loss of wildlife habitat (in upper intertidal areas)	Griggs 2005
									Associated with low levels of organic litter and LWD	Sobocinski et al. 2003; Dugan and Hubbard 2006; Defeo et al. 2009
									Alters hydrologic processes, which affects sand transport rates, erosion and beach accretion processes	Defeo et al. 2009
									Shoreline modifications result in habitat loss, reduction, and or alteration* lowered bird biodiversity** (altered food webs and benthic community composition*** creation of passage barriers for salmon and fragmented habitat connectivity****	*Paulson 1992; Levings and Thom 1994; Williams and Thom 2001; Toft et al. 2004 ** Donnelley and Marzluff 2004 ***Dauer et al. 2000; Lerberg et al. 2000 *in* Hale et al. 2004 ****Williams and Thom 2001
Construction and maintenance of impervious surfaces (e.g. roads, homes and buildings)	Development Agriculture Forestry	X				X	X	X	Can lead to an increase in contaminated runoff	Ekness and Randhir 2007
									Can degrade water quality (including increased temperatures) and cause extensive changes in hydrology	Jones et al. 2000
									Direct alteration can cause increased loading of contaminants and pathogens	Mallin et al. 2000 (*in* Hale et al 2004)
									Can increase fine sediment loads and mass wasting processes, which can cause erosion.	Hashim and Bresler 2005
									Direct alteration within the riparian area causes changes in loading of nutrients, organic matter and sediments	Valiela et al 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 (*in* Hale et al. 2004)
									Areas with high levels of impervious surface coverage (>50%) correlated with low macrobenthic diversity and abundances.	Lerbert et al. 2000
									Impervious surfaces cause increased volume and magnitude of surface water runoff, decreasing the ability of soil and vegetation to absorb/intercept pollutants	Montgomery et al. 2000 (*in* Johannessen and MacLennan 2007)
									Impervious surfaces increase flooding potential	Glasoe and Christy 2005
									Increased sedimentation has also been shown to affect juvenile and filter-feeding fish.	Williams and Thom 2001
Shoreline armoring (e.g. docks, bulkheads, etc)	Development	X					X		The construction of boat landings, docks, and piers often creates increased slopes, which causes increased and concentrated water flows. Shoreline armoring structures, such as rip-rap, concrete, and bulkheads, can require the removal of vegetation and can also impede the movement of wildlife that utilize the shoreline as migration corridors.	NRC 2002

									The installation of shoreline armoring structures reduces beach width, resulting in the loss of wildlife habitat (in upper intertidal areas)	Griggs 2005
									Associated with low levels of organic litter and LWD	Sobocinski et al. 2003; Dugan and Hubbard 2006; Defeo et al. 2009
									Alters hydrologic processes, which affects sand transport rates, erosion and beach accretion processes	Defeo et al. 2009
									Shoreline modifications result in habitat loss, reduction, and or alteration* lowered bird biodiversity** (altered food webs and benthic community composition*** creation of passage barriers for salmon and fragmented habitat connectivity****	*Paulson 1992; Levings and Thom 1994; Williams and Thom 2001; Toft et al. 2004 ** Donnelley and Marzluff 2004 ***Dauer et al. 2000; Lerberg et al. 2000 *in* Hale et al. 2004 ****Williams and Thom 2001
Tillage and irrigation practices	Agriculture	X							Can result in soil loss and erosion as well as the transport of pesticides and fertilizers to surface and groundwater	Hashim and Bresler 2005
Introduction of pesticides and fertilizers	Development Agriculture Forestry	X							Can degrade water quality and cause extensive changes in hydrology and riparian vegetation	Jones et al. 2000
									Agricultural activities result in fecal coliform pollution, and nutrient and pesticide loading	Hashim and Bresler 2005
Recreational activities (trails, etc)	Development							X	Trampling of riparian soils leads to compaction, erosion and the destruction of soil microbial communities	NRC 2002

APPENDIX F. Puget Sound Shore Form Tables (adapted from Shipman 2008)

Shoreline Type	Landforms	Characteristic Regional Location(s)	Characteristic Human Modifications
Rocky Coasts (resistant bedrock with limited upland erosion)	Plunging (rocky shores within minimal erosion/deposition and no erosional bench or platform)	San Juan Islands Strait of Juan de Fuca	Intertidal fill Armoring of pocket beaches
	Platform (wave-eroded platform/ramp, but no beach)		
	Pocket Beaches (isolated beaches contained by rocky headlands)		
Beaches (shorelines consisting of loose sediment and influenced by wave action)	Bluffs (formed by landward retreat of the shoreline)	Main Basin, most of Puget Sound Whidbey Basin Northern Straits South Sound San Juan Islands	Armoring Intertidal and backshore fills Groins and jetties Overwater structures Slope stabilization Fill at base of bluff Upland hydrologic changes Inlet stabilization
	Barriers (formed where sediment accumulates seaward of earlier shoreline)		
Embayments (protected from wave action by small size and sheltered configuration)	Open coastal inlets (small inlets protected from wave action by their small size or shape, but not extensively enclosed by a barrier beach)	Northern Straits Main Basin South Sound Kitsap bays and inlets Hood Canal Includes Port Madison, Discovery Bay, Eld Inlet, Kala Point, Point Monroe, Foulweather Bluff, Beckett Point	Watershed modifications: hydrology, sediment loading Fill Bank armoring Inlet modifications: relocation, stabilization, closure, dredging Wetland and intertidal fill Barrier modification
	Barrier estuaries (tidal inlet largely isolated by a barrier beach and with a considerable input of freshwater from a stream or upland drainage)		
	Barrier lagoons (tidal inlet largely isolated by a barrier beach and with no significant input of freshwater)		
	Closed lagoons and marshes (back-barrier wetlands with no surface connection to the Sound)		
Large Deltas (long-term deposition of fluvial sediment at river mouths)	River-dominated (extensive alluvial valleys with multiple distributaries and significant upstream tidal influence)	Strait of Juan de Fuca Stilliguamish River Elwha River Dosewallips River Hood Canal (South of Foulweather Bluff)	Diking Draining Cultivation Watershed changes Dredging

	Wave-dominated (deltas heavily influenced by wave action, typically with barrier beaches defining their shoreline)		
	Tide-dominated (deltas at heads of bays where tidal influence is much more significant than fluvial factors, typically with wedge-shaped estuary)		
	Fan deltas (steep, often coarse-grained deltas with limited upstream tidal influence)		

APPENDIX G. A summary of buffer width recommendations from Appendix C.

See Section II for a description of how this table was created.

Function	Buffer width recommendation to achieve ≥ 80% effectiveness	Literature cited	Average of all literature (to achieve ≥ 80% effectiveness)	Minimum buffer width (approximate) based on FEMAT curve to achieve ≥ 80% effectiveness
Water quality	5-600 m (16 – 1,968 ft) (Appendix C contains specific buffer widths for different water quality parameters)	5 m (16 ft): Schooner and Williard (2003) for 98% removal of nitrate in a pine forest buffer 600 m (1969 ft): Desbonnet et al (1994/1995) for 99% removal	109 m (358 ft)	25 m (82 ft) sediment 60 m (197 ft) TSS 60 m (197 ft) nitrogen 85 m (279 ft) phosphorus
Fine sediment control	25-91 m (92 – 299 ft)	25 m (82 ft): Desbonnet et al (1994/1995) for 80% removal 91 m (299 ft): Pentec Environmental (2001) for 80% removal	58 m (190 ft)	25 m (82 ft) (sediment) 60 m (197 ft) (TSS)
Shade	17-38 m (56 – 125 ft)	17 m (56 ft): Belt et al 1992 *IN* Eastern Canada Soil and Water Conservation Centre (2002) for 90% 38 m (125 ft): Christensen (2000) for 80% temperature moderation	24 m (79 ft)	37 m (121 ft) (.6 SPTH*)
LWD	10-100 m (33 – 328 ft)	10 m (33 ft): Christensen (2000) for 80-90% effectiveness 100 m (328 ft): Christensen (2000)	55 m (180 ft)	40 m (131 ft) (.65 SPTH*)

		for 80-90% effectiveness		
Litter fall	No studies found	N/A	N/A	24 m (79 ft) (.4 SPTH*)
Hydrology/slope stability	No studies found	N/A	N/A	N/A
Wildlife	73-275 m (240 – 902 ft)	73 m (240 ft): Goates (2006) for 90% of hibernation and nesting	174 m (571 ft)	N/A
		275 m (902 ft): Burke and Gibbons 1995 *IN* Goates 2006 for 100% of hibernation and nesting		

* Tree height (SPTH) is used to indicate buffer width where one SPTH = 61 meters or 200 ft (adapted from FEMAT 1993)

APPENDIX H. Marine Riparian Technical Review Workshop Proceedings

November 19, 2008

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SECTION I: Introduction/Background

The Marine Riparian Technical Review Workshop (riparian workshop) was held on November 19, 2008 at the University of Washington's School of Aquatic and Fishery Sciences. The goal of the workshop was to solicit expert scientific opinion to help the state's Aquatic Habitat Group (AHG) develop management guidelines to protect marine riparian functions. The AHG is a multi-agency panel assembled to provide guidance for local governments updating Shoreline Master Programs and Critical Areas Ordinances to better protect ecological functions, including marine riparian functions. The riparian workshop included a panel of 14 scientists (including three members of the AHG) with expertise in riparian functions and processes. Panelists were asked to help determine how best to apply knowledge about *freshwater* riparian functions to protect *marine* riparian functions and processes. Seven specific riparian functions were addressed during the workshop, including:

A. Water Quality
B. Shade/Microclimate
C. Large Woody Debris (LWD) recruitment
D. Litter Fall/Provision of allochthonous[*] inputs
E. Fine Sediment Control
F. Wildlife
G. Hydrology/Slope Stability

The names, affiliations, and expertise of panelists (including the three members of the AHG who also served as panelists) are included in Appendix A.

The riparian workshop was the second of a three-phase project. Phase I involved a literature review and the development of draft riparian guidance document; Phase II (the riparian workshop) is the focus of these proceedings. Phase III will involve finalizing the guidance document based in part on expert input solicited during Phase II. *Although shoreline managers utilize a variety of tools to protect aquatic and riparian ecosystems, this project is focused on providing guidance on establishing appropriate buffers for protection of marine riparian area functions.*

In preparation for the workshop, the AHG modified the functional effectiveness curves (also known as riparian function curves) designed and used by FEMAT (1993) to characterize the relationship between buffer width and riparian functions in freshwater environments of the Pacific Northwest (see original curves at end of Appendix A). These regenerated riparian function curves are based on the results of function studies conducted primarily in freshwater systems and are presented as analogs for

---

[*] Allochthonous inputs are organic matter brought in from outside a system.

marine riparian areas. The relevance of freshwater riparian functions to marine riparian functions has been recognized and supported in a number of publications (e.g., Adamus et al. 1991; Desbonnet et al. 1994, 1995; NRC 2002; Brennan and Culverwell 2004; Lavelle et al. 2005). The curves plot the relationship between buffer width (X axis) and its relative effectiveness (Y axis) in maintaining or providing a particular function (e.g., pollution abatement/water quality, LWD recruitment, wildlife habitat). These curves are particularly well suited to define tradeoffs between buffer width or size and function loss based on the following assumptions:

1. By virtue of their location, riparian areas mediate important ecological processes and functions that benefit adjacent water bodies (and vice versa).
2. The functional effectiveness of buffers at various widths illustrated by the riparian function curves reflects a generic or typical setting (i.e., a prototypical morphology and physical setting of a relatively undisturbed vegetation community growing adjacent to a water body).

Most studies focus on receiving waters to measure and observe how riparian functions are manifested in the ecosystem, yet many of these ecological functions occur within the riparian area as well. For example, the curve describing LWD recruitment is measured from the middle or edge of the stream, not within the riparian area. For some functions, site potential tree height (SPTH) was used as a proxy for buffer width, whereas other buffer width determinations are provided as simple linear measurements. More details about how the riparian function curves were used to solicit expert opinion during the riparian workshop is included in the following section. *Input gathered from panelists during the workshop on the applicability of riparian research to protect marine riparian functions is intended to meet the state's best available science criteria.*

SECTION II: Workshop Objectives and Approach

The four key objectives for the workshop were to:

1. Solicit expert opinion on the applicability (or fit) of using freshwater riparian function curves to protect marine riparian functions.
2. Solicit expert opinion on the uncertainties associated with the application of buffers in different physical or ecological settings (e.g., geomorphology, vegetation type and cover, exposure, etc.).
3. Identify literature that could help inform the development of buffers for marine riparian areas.
4. Identify data gaps, uncertainties, and research needs associated with marine riparian areas.

To achieve these objectives, the workshop was divided into three facilitated sessions as described below.

***Session I:* Background/context**

Panelists were provided with background information on marine riparian protection efforts in the Puget Sound region. This was followed by an overview and summary of scientific information for each of the seven riparian functions addressed in the workshop. Riparian function curves for six of the seven riparian functions (wildlife was not included, see details in section III d) were presented along with underlying science used to generate the curves, providing a context for how applicable the function curves could be for marine settings.

***Session II*: Riparian function curve review**

Panelists were asked to review the riparian function curve generated for each riparian function and to respond to three questions:

1. Does the riparian function curve "fit" (e.g., is it applicable) in marine settings? The applicability of a particular function curve refers to how well the curve describes the functions of marine riparian areas in a prototypical shoreform/beach type in Puget Sound.

2. How important is this riparian function in marine settings? Panelists were asked to provide their opinion on the capacity of undisturbed marine riparian areas to provide each function or process on a scale of 1 (lowest) to 10 (highest). For example, for the hydrology/slope stability function, participants were asked to assign points based on their understanding of marine riparian areas' ability to protect hydrology and slope stability functions derived from riparian vegetation. This information was used to generate discussion and help the workshop organizers better understand where and why opinion differed among panel members.

3. How should the curve be modified to better characterize the marine riparian environment? If the panelists thought a function curve did not accurately describe a relationship, they were asked how the curve should be modified to better describe it. Panelists were asked to provide supporting information for suggested modifications.

***Session III*: Additional information (caveats, controlling factors, missing literature, and data gaps):**

For each of the seven functions, panelists were asked:

1. Which controlling factors (e.g., shore form, slope, disturbance, vegetation type, aspect, soils, etc) are most important in determining the specific relationship between buffer width and this function?

2. What additional literature would be informative?

3. What data gaps exist?

SECTION III: Overview of Riparian Functions and Key Findings of Science Panel

A. Water Quality

Overview

The water quality function of riparian areas is well understood and widely documented, although much of the literature is focused on freshwater systems. Riparian vegetation and soils bordering both freshwater and marine systems act in concert to intercept and absorb water; absorb and process nutrients, sediments, and pollutants; store and transmit water; and retain or decompose pollutants (Correll 1997; Wenger 1999; Vigil 2003; Brennan and Culverwell 2004; Hawes and Smith 2005). Vegetation and soils decrease surface and subsurface water velocity and flow, thereby increasing the potential for retention, filtration, and/or transformation of sediments and other contaminants. A number of factors have a strong influence on buffer effectiveness for water quality, including vegetation type and density, topography and slope (i.e., geomorphology), contaminant load, amount of impervious surface, ability to provide sheet flow (as opposed to channelized flow), infiltration/absorption capacity, organic and moisture content of soils, and soil texture (permeability).

Riparian function curve for water quality

The data (Table 1) and graph (Figure 1) below were adapted from Desbonnet et al. (1995) to provide a generalized representation of buffer width recommendations for water quality. It is considered a good synopsis of the findings of several buffer review and synthesis papers, and was one of the few sources of summary data for water quality effectiveness at various buffer widths.

Table 1. Summary data used to produce a generalized curve for effectiveness of vegetated buffers to remove various pollutants at different widths (adapted from Desbonnet et al. 1995). TSS = total suspended sediment. We found no information available on composition of vegetation within the buffer.

% Removal	**Buffer Width (m)**			
	Sediment	*TSS*	*Nitrogen*	*Phosphorus*
50	0.5	2	3.5	5
60	2	6	9	12
70	7	20	23	35
80	25	60	60	85
90	90	200	150	250
99	300	700	350	550

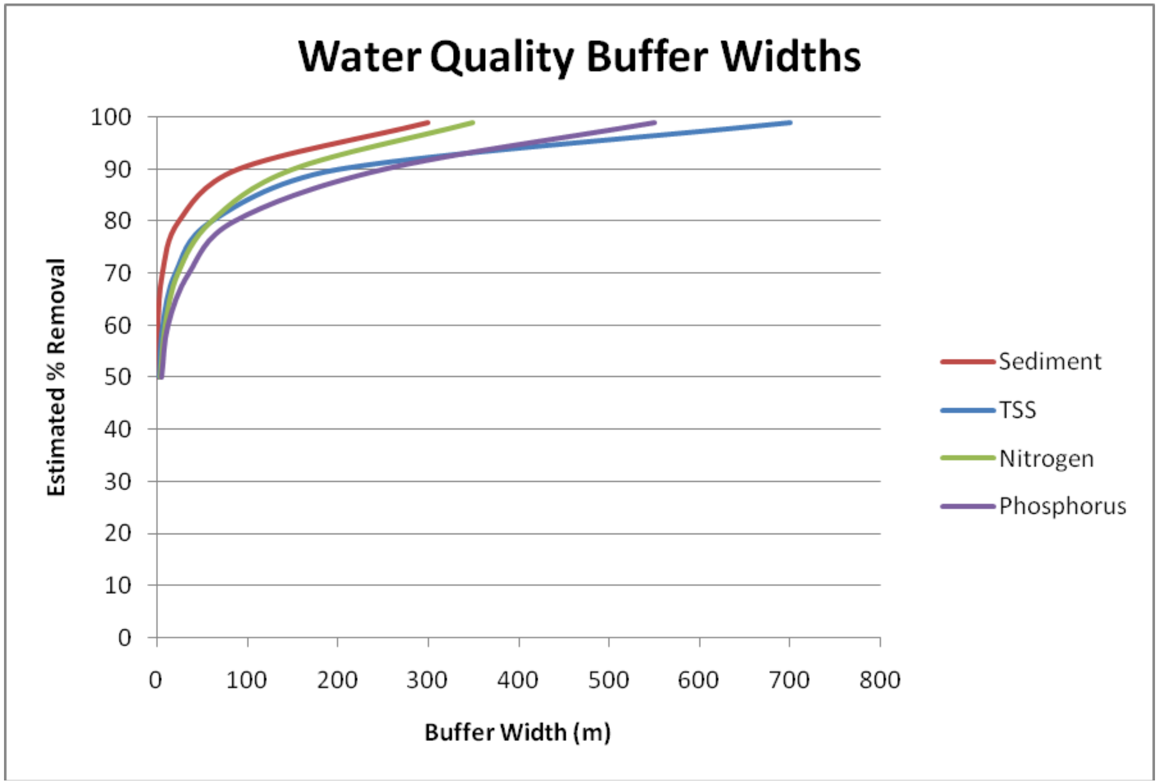


Figure 1. Contaminant removal effectiveness of four water quality constituents at various buffer widths (adapted from Desbonnet et al. 1995).

Key science panel findings

Water quality is an important function of marine riparian areas, but relative to the dynamics affecting water quality in Puget Sound at the watershed and landscape scales, many panelists concluded that an undisturbed marine riparian area's contribution to maintaining water quality is proportional to the upland area. Anthropogenic activities in marine riparian areas undoubtedly include the generation and routing (via water) of pathogens, nutrients, toxics, heat, and fine sediment (above normal background levels) that can affect water quality. However, the marine riparian area is limited in spatial extent; that is, it constitutes a small fraction of the Puget Sound drainage basin. Most contaminants reach Puget Sound via:

1) Streams or drainage networks discharging into the Puget Sound Basin, or pathways that concentrate rainfall and snowmelt from impervious surfaces associated with human residential and commercial development and transportation infrastructure; and

2) Waste water entering Puget Sound from municipal and industrial facilities (i.e. municipal sewage treatment plants and direct discharge from industrial facilities).

Thus, while minimizing impervious surfaces and controlling harmful inputs into surface and groundwater is as important in marine riparian areas on an acre for acre basis as it is across the entire Puget Sound basin, many panelists believed that relative to the larger watersheds that deliver pollutants to Puget Sound, marine riparian areas contribute a small fraction of the ecological function in mitigating water quality impacts at a landscape scale. However, given their proximity to nearshore development and their role in influencing shoreline habitats and species, the panel generally agreed that marine riparian areas do play a role in protecting water quality (i.e., site specific, along marine shorelines) and contribute to the cumulative watershed influences. One aspect of residential development in marine riparian areas not addressed during the workshop included pollution from failing septic systems including bacteria and nutrients.

Panelists generally agreed that the curve in Figure 1 is conceptually valid for water quality issues originating in marine riparian areas.

B. Shade/Microclimate

Overview

Marine riparian areas have unique natural climate control mechanisms that differ from upland areas and which influence both physical and biological conditions at a local scale. Riparian vegetation can intercept solar inputs and help create microclimate conditions (soil and ambient air temperature, moisture, solar radiation, wind, humidity) in both terrestrial and aquatic environments (FEMAT 1993;

Knutson and Naef 1997; May 2003; Parkyn 2004). Forested buffers have an insulating effect, helping to moderate ambient air, soil, and water temperatures, keeping them warmer in the winter and cooler in the summer (Castelle et al. 1992; FEMAT 1993; Osborne and Kovacic 1993; Knutson and Naef 1997; Chen et al. 1999; Wenger 1999; Bavins et al. 2000; Rice 2006; Tonnes 2008).

Riparian function curve for shade

In order to develop a graphic representation of shade effectiveness (Figure 2), the generalized curve from FEMAT (1993) (Appendix D) was used to generate the data needed (Table 2) to create a plot of buffer width effectiveness at varying distances from the edge of a forest stand.

Table 2. Approximated data used to create a generalized curve (Figure 3) indicating percent of riparian shade function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993) (SPTH = site potential tree height).

Cumulative Effectiveness (%)	Buffer Width (SPTH)	SPTH m(ft)
0	0.00	0(0)
10	0.07	4(14)
20	0.15	9(30)
30	0.22	13(44)
40	0.29	18((58)
50	0.36	22(72)
60	0.42	26(84)
70	0.50	31(100)
80	0.61	37(122)
90	0.73	45(146)
93	0.80	49(160)
95	1.00	61(200)

Figure 2. Generalized curves representing cumulative effectiveness of microclimate attributes as a function of distances of the edge of a forest stand (after Chen 1991). One tree height equals 200ft (61m) (from FEMAT 1993).

Key science panel findings

Panelists unanimously agreed that shade/microclimate is an important marine riparian function. In contrast to freshwater environments, where shade can help moderate stream water temperatures, shade in marine environments was considered less important in moderating water temperature than in moderating temperatures of beach substrates in the supratidal zone and in intertidal zones during low tides, especially during summer months. Panelists noted that while increases in solar radiation due to loss of riparian shade could warm shallow intertidal waters, the effects of this warming have not been quantified. They pointed to studies indicating that riparian vegetation plays an important role in the survival of forage fish spawn (Penttila 2001; Rice 2006) by reducing either heat or desiccation stress. They also noted that solar radiation is an important limiting factor for most rocky intertidal organisms (Ricketts and Calvin 1968; Connell 1972), and that shade may be particularly important for climate-sensitive species. Panelists also noted that ultraviolet radiation is an important consideration because it will persist, even on cloudy days.

Additional panel comments include:

- Overall, vegetation community type is an important consideration for assessing the shade function as some shorelines, even in an undisturbed state, do not support forest community types.

- Important factors that influence marine riparian shade include aspect, SPTH, bank morphology, and other site characteristics that affect plant growth.
- Loss of overstory trees can increase solar radiation to the patch and to the upper beach – an effect that may persist for decades or even longer.
- The continuity of the vegetated community structure over time is an important component of the shade characteristics it provides (as well as other functions) and is influenced by natural processes and disturbances. In the Puget Sound marine environment, where slumping cliffs and erosion are common shoreline characteristics, the shade function depends on a recruitment process. For example, the setback distance of a tree that is 50 feet from the shoreline today will shrink over time as a result of bank erosion, or surface soil creep. This differs from the shade function in freshwater environments, which may be relatively more stable, but is somewhat analogous to a relocation of the stream channel in a floodplain, albeit with somewhat greater predictability because the shoreline only migrates in one direction.

Data gaps

- Limited knowledge exists on survival thresholds for climate-sensitive species, especially in the marine environment.
- Microclimate data are typically derived from upland research. Applying upland climatic data to the marine environment where many buffers are simply one-sided is a large data gap.
- Research is needed on the influence of shade to groundwater (some of which is discharged to beaches via surface flows) on shorelines.

C. Large Woody Debris (LWD) Recruitment and other functions of wood

Overview

The contribution of large woody debris (LWD) into marine environments is considered an important function of marine riparian areas, although the relative proportion of wood delivered from the marine setting compared to river systems is not well documented (Brennan and Culverwell 2004; Tonnes 2008). The role of upland riparian areas in providing LWD in freshwater environments, however, has been very well studied. It is generally believed that LWD provides similar functions in both freshwater and marine systems (Harmon et al. 1986; Sedell et al. 1988; Bilby and Bisson 1998; Hyatt and Naiman 2001; Latterell and Naiman 2007) including:

- Accumulation of organic matter and sediments.
- Habitat structure for periphyton (Coe et al. 2009), invertebrates, fish, and wildlife.
- Bank stability and erosion control.
- Substrate (such as “nurse logs”) for recruitment of plant species.
- Moderation of local benthic temperatures and moisture regimes on beaches.

The source of LWD in streams and rivers is riparian forest growth both adjacent to and upland from the stream channel. Similarly, the natural source of marine LWD (also known as “driftwood”) comes from adjacent marine riparian areas, or is delivered from rivers, streams, and other shoreline areas via marine currents. In recent decades, the volume and quality (wood variety and dimensions) of LWD from natural sources appear to have been reduced due to historic and current logging practices, the conversion of shoreline areas for agriculture and flood control levees, and urbanization (Tonnes 2008). Persistence and residency time of LWD are controlled by decomposition rates of different wood types, size and dimensions of the wood, their ability to become trapped or anchored, and the exposure to hydraulic forces (e.g., river flows, tides, waves, currents).

Riparian function curve for LWD

For the LWD riparian function curve (Figure 3), cumulative effectiveness of LWD recruitment data (Table 3) was plotted as a function of potential tree height (based on the FEMAT 1993).

Table 3. Approximated data used to create generalized curve (Figure 3) indicating percent of LWD recruitment function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993). Note that one SPTH equals 200 feet (61 meters).

Cumulative Effectiveness (%)	**Buffer Width (SPTH)**	**SPTH m(ft)**
0	0	0
10	0.09	6(18)
20	0.18	11(36)
30	0.25	15(50)
40	0.32	20(64)
50	0.4	24(80)
60	0.47	29(94)
70	0.55	34(110)
80	0.65	40(130)
90	0.8	49(160)
93	0.85	52(170)
95	0.9	55(180)
99	1	61(200)
99	1.2	73(240)

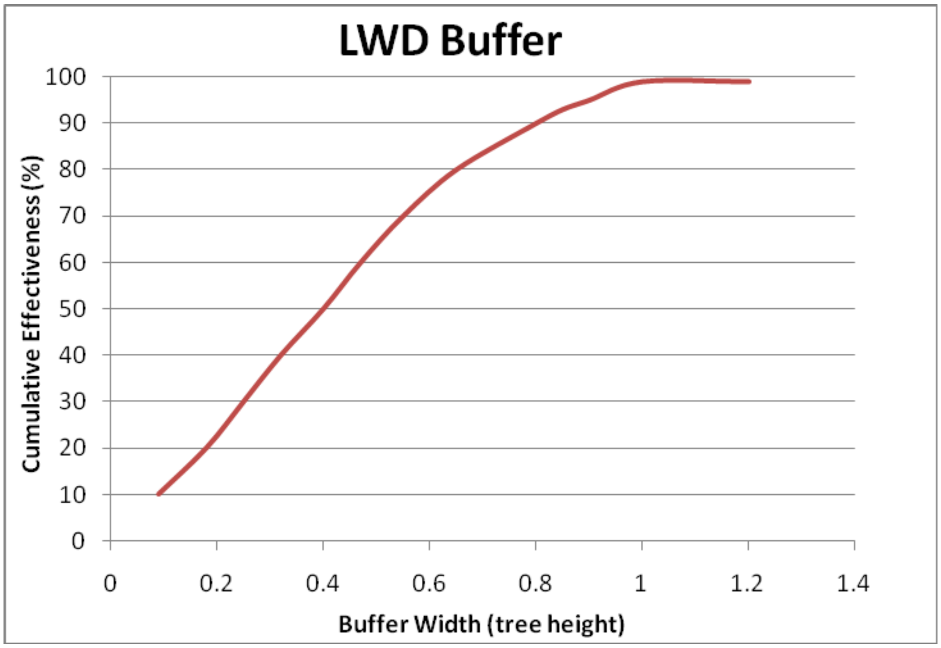


Figure 3. Generalized curve indicating percent effectiveness of LWD recruitment from riparian areas occurring within varying distances from the edge of a forest stand. Tree height (SPTH) is used to indicate buffer width. One SPTH is equal to 200ft (61m) (FEMAT 1993).

Key science panel findings

In general, the science panel agreed that the LWD effectiveness curve is conceptually valid although the proportion of marine LWD entering via shorelines versus river systems is largely unknown. The panel recognized that the quantity and availability of marine LWD is likely to be lower now than historically, particularly in the largest diameter classes, as a result of historic harvest, urbanization, salvage logging, and efforts by the U.S. Army Corps of Engineers to remove floating logs that pose navigation hazards. Wood entering beaches from coastal shorelines may be more stable since this LWD often includes root balls, or may be anchored in the bank, which could reduce its mobility during high tide and storm events. Dan Tonnes discussed his thesis research in Whidbey Basin, where he found that 1.4 percent of the LWD on sediment bluff beaches originated from adjacent unstable bluffs. Additional points raised by the panel included:

- LWD is important for many nearshore organisms that use wood as food and habitat.
- LWD helps stabilize beaches and reduce wave-cut erosion of bluffs.
- The shape of the function curve is primarily based on downhill delivery, within a distance of a single tree height and for more stable and less steep. The shape of the curve would be different under steeper and less stable slope conditions.

D. Litter Fall/Provision of Allochthonous Inputs

Overview

Riparian areas contribute significantly to material creation, cycling, and movement between terrestrial and aquatic systems (Lavelle et al. 2005; Ballinger and Lake 2006). Although the exchange of energy and nutrients between aquatic and terrestrial systems is identified as an important ecological process for maintaining productivity, most studies of these interactions focus on the influence of allochthonous inputs of organic material on stream systems. The contribution of these inputs to marine systems and influence on productivity and other ecological functions is not well understood.

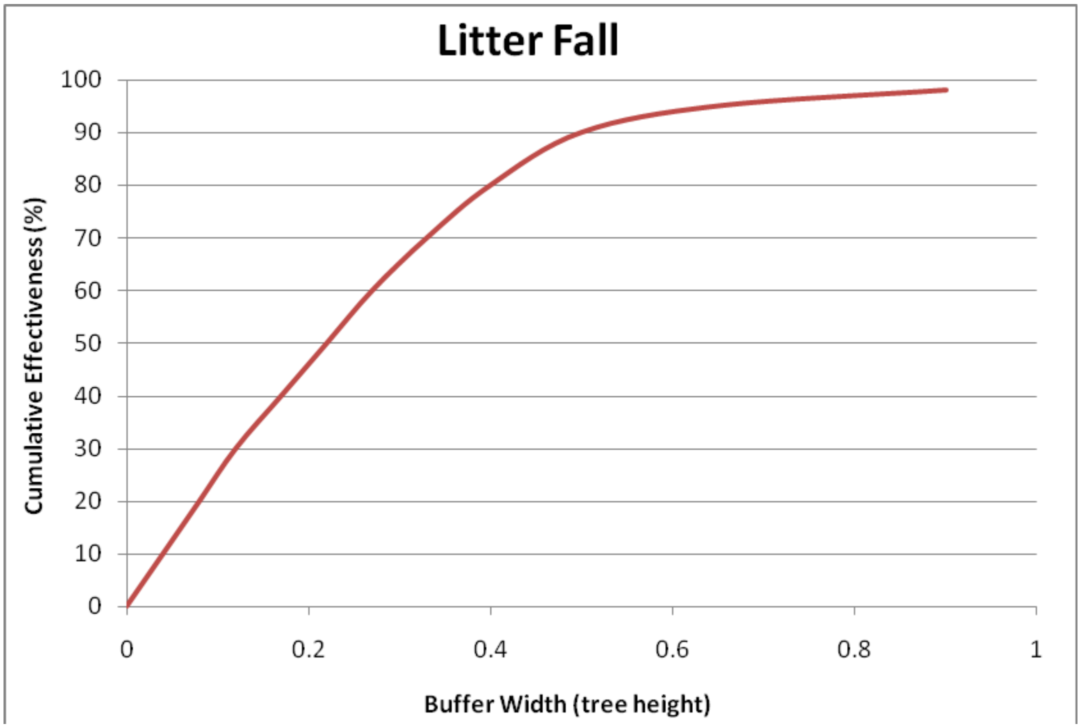
Riparian vegetation provides organic litter that serves as habitat and food for fishes and aquatic invertebrates (Adamus et al. 1991; Vigil 2003; Lavelle et al. 2005;; Ballinger and Lake 2006). Aquatic invertebrates are important components of stream systems and are often used as indicators of stream health (Wenger 1999). Riparian vegetation influences the amount and type of terrestrial invertebrates that fall into aquatic systems which in turn serve as a major food source for freshwater fishes birds, mammals, reptiles, and amphibians (Romanuk and Levings 2003; Sobocinski 2003). Terrestrial insects are an important food source for many salmonids in streams, and have recently been shown to be a large component of the diet in juvenile salmonids while residing in marine nearshore waters of Puget Sound (Sobocinski 2003; Brennan et al. 2004; Duffy et al. 2005; Fresh et al. 2006; Fresh 2007). In addition, some fish and invertebrates feed directly on vegetative detritus (McClain et al.1998; King County DNR 2001; Vigil 2003; Lavelle et al. 2005).

Riparian function curve for allochthonous inputs

The FEMAT (1993) “litter fall” buffer effectiveness curve was used to recreate a generalized graphic representation of allochthonous inputs because data required to generate a graph were not available from other sources.

Table 4. Approximated[*] data used to create generalized curve (Figure 5) indicating percent of riparian allochthonous input function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993).

Cumulative Effectiveness (%)	Buffer Width (SPTH)	SPTH m(ft)
0	0	0
10	0.04	2.4(8)
20	0.08	4.9(16)
30	0.12	7.3(24)
40	0.17	10.3(34)
50	0.22	13.4(44)
60	0.27	16.5(54)
70	0.33	20(66)
80	0.4	24.4(80)
90	0.5	30.5(100)
95	0.65	40(130)
98	0.9	55(180)



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[*] An estimate of values from FEMAT 1993 plotted on an X and a Y axis, or extrapolating from FEMAT graphs to come up with specific numbers to plot on a new graph. See guidance document for more detail.

Figure 4. Generalized curve indicating percent effectiveness of riparian allochthonous input and litter fall occurring within varying distances from the edge of a forest stand. One site potential tree height is equal to 200ft (61m) (adapted from FEMAT 1993).

Key science panel findings

Overall there was a general acceptance that organic nutrient exchange is a relevant function of marine riparian areas and that the conceptual curve is a valid representation of marine allochthonous input functions. In addition, there was a consensus on the following:

- Energy and nutrient exchange is a multi-dimensional characteristic across the aquatic and terrestrial interface. For example, litter fall/allochthonous input is not limited to leaves, but includes other matter such as plant stems, insects, and other organic matter.
- Riparian areas are likely an important area of emergence for insects, and some flying insects may be introduced to marine waters via wind and stream inputs. Panelists noted that some of the insects found on beaches and in the diet of juvenile salmonids do not fly and are not as likely to become airborne and transported via wind.
- Nutrient exchange is not simply unidirectional, but bi-directional. Marine derived nutrients are also transported into the terrestrial environment via multiple pathways including:
    - Atmospheric input via wet or dry deposition, which can occur through fires, intensive farming and agricultural activities, and wind erosion (Lavelle et al. 2005).
    - Lateral transfers of nutrients through water flows, including microalgae and macroalgae washed ashore (Adamus et al. 1991; McLachlan and Brown 2006).
    - Decomposing secondary consumers, such as juvenile Pacific herring, Pacific sand lance, longfin smelt, surf smelt, sole, salmon, seabirds, and marine mammals, also contribute nutrients. For example, in freshwater systems, Pacific salmon nutrients are deposited by predators and scavengers in excreta, or as carcasses and skeletons (Cederholm et al. 1999; Naiman et al. 2002; Drake et al. 2006).
    - Secondary consumers can transport nutrients to upland areas, facilitating nutrient and energy exchange between terrestrial and aquatic food webs (Ballinger and Lake 2006). For example, Elliott et al. (2003) examined the relationship between bald eagles and Plainfish Midshipman, a demersal fish and intertidal spawner. Between May and June of 2001, the authors found that eagles consumed about 22,700 ± 3,400 midshipman, representing large transfers of nitrogen into trees, and the potential to enhance community productivity along the shoreline.

The overall relevance of this function curve was ranked in the middle, likely because many panelists did not feel knowledgeable enough to make an informed ranking due to a lack of empirical studies in marine riparian systems.

E. Fine Sediment Control

Overview

One of most studied functions of riparian areas is fine sediment control. Fine sediments enter waterways from a number of terrestrial sources, both natural and anthropogenic. The human-derived fine sediments originate primarily from construction sites, suburban and urban developed areas, forestry and agricultural practices, and unpaved roads that drain into waterways. Sediments become exposed and subject to erosion as a result of vegetation removal, excavation, road wash from unpaved roads, and compaction of soils. Once sediments are suspended in and moved by surface water runoff, they can be delivered to waterways unless they settle out or become trapped.

Excess amounts of sediment, particularly fine sediments, can have numerous deleterious effects on water quality and aquatic biota. The following list briefly summarizes several major effects from anthropogenically-produced sediment (adapted from Wenger 1999):

- Sediment deposited in rivers and streams can reduce habitat for fish and invertebrates.
- Suspended sediment reduces light transmittance, which decreases primary productivity.
- High concentrations of fine suspended sediments cause direct mortality, or impairment (such as suffocation and/or reductions in food supply) for many fish and invertebrates.
- Excess suspended sediments can interfere with filter feeders' apparatus thus reducing the abundance and diversity of filter-feeding organisms, including mollusks and some arthropods.
- Sediments absorb chemical compounds, serving as a delivery mechanism for contaminants to water bodies.

Riparian buffers composed of dense vegetation can act as a "line of defense" for reducing or eliminating anthropogenic sedimentation of waterways in a number of ways by (adapted from Wenger 1999):

- Displacing sediment-producing activities away from a water body;
- Trapping terrestrial sediments in surface runoff;
- Reducing the velocity of sediment-bearing storm flows, allowing sediments to settle out of water and be deposited on land;
- Creating sheet flow of surface waters, reducing channelization (which can increase conveyance and erosion);
- Stabilizing banks and bluffs, preventing landslides and other erosion;
- Intercepting and absorbing precipitation in the canopy, understory, and ground cover, thereby reducing the amount of water that can displace sediments; and/or

- Contributing LWD, which helps to trap sediments, support vegetation, and reduce erosion from stream flows and waves.

Research on buffer effectiveness has examined both forested buffers (composed of native vegetation) and grass buffers, although results are mixed as to which is most effective at controlling fine sediments. Riparian buffers composed of dense vegetation can reduce the velocity of sediment bearing storm flows, help reduce channelization, and intercept precipitation in the canopy thereby reducing the amount and energy of water that can displace sediments. In addition, composition and density of riparian vegetation (both standing and as LWD) are important elements for controlling surface flows, trapping sediments, and reducing erosion. Riparian soils also play an important role in absorbing water and trapping sediments.

An important factor in determining the sediment removal capabilities of riparian areas is slope. Riparian areas with steeper slopes require wider buffers to provide the same level of sediment removal (similarly with contaminant removal). Capacity is also an important consideration. High levels of sediments can exceed the capacity of riparian areas to trap sediments. If overloaded, riparian effectiveness can be reduced to a point where this function is essentially lost.

Riparian function curve for fine sediment control

To illustrate fine sediment control in generalized curves for riparian buffer effectiveness at various widths, the summary data from Desbonnet et al. (1995) (Table 5) were used to generate a scatter plot (Figure 5) and associated curves, similar to the riparian buffer curves developed by FEMAT (1993).

Table 5. Summary data used to generate generalized curves for sediment control effectiveness at different buffer widths (adapted from Desbonnet et al. 1995).

% Removal	**Buffer Width(m)**	
	Sediment	*TSS*
50	0.5	2
60	2	6
70	7	20
80	25	60
90	90	200
99	300	700

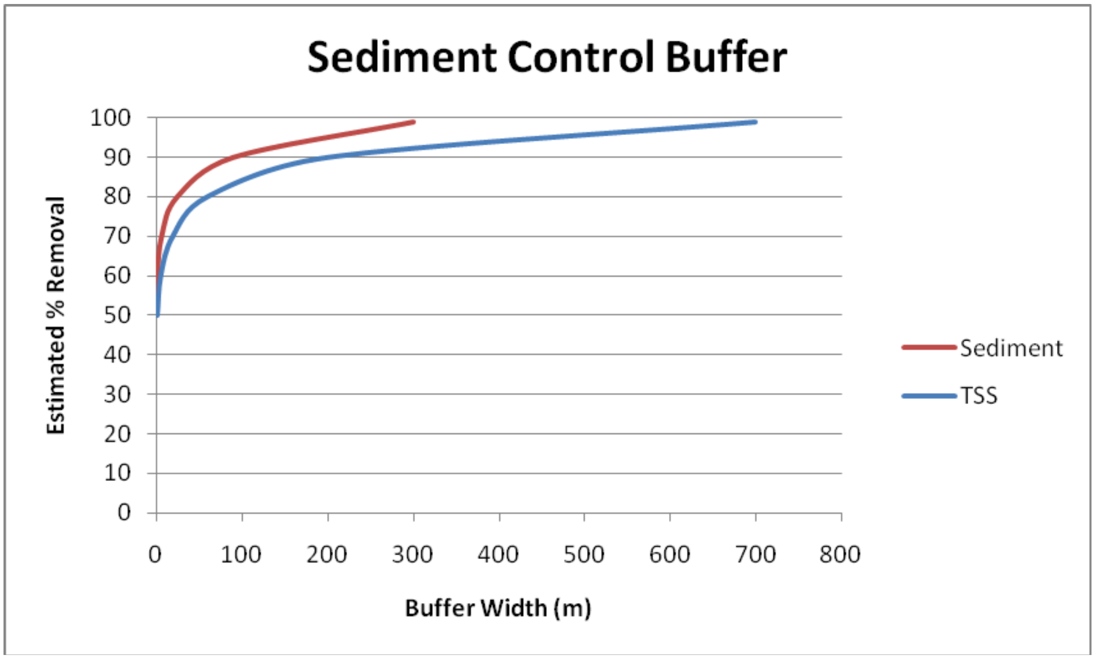

Figure 5. Generalized curve illustrating sediment removal effectiveness at various buffer widths (adapted from Desbonnet et al. 1995).

Key science panel findings

There was general consensus by panelists that the riparian function curve for sediment control is conceptually valid. The panelists discussed the relationship between sediment delivery and land use, the role of sediment, the definition of sediment (e.g., size, class), and the source and function of natural versus unnatural causes of sedimentation. Panelists ranked the relevancy of this function as it relates to other marine riparian functions as low, largely because there is a strong contrast in natural and anthropogenic sediment issues in freshwater and marine systems. Panelists noted that maintaining natural erosion and sediment transport processes are critical to maintaining beaches in Puget Sound.

They also noted that much of the sediment nourishing Puget Sound beaches originates in marine riparian areas, facilitated by natural driving forces (wind and wave action, bluff saturation, leading to slope failures). The panelists felt strongly that it was very important to maintain natural sediment inputs from marine riparian areas into Puget Sound – that perhaps the biggest threat to marine systems from human activity is the reduction of sediment inputs by armoring shorelines and disrupting natural erosion of bluffs. This is in sharp contrast to freshwater systems, where riparian areas are managed to minimize human-induced fine sediment inputs which substantially impact habitat and water quality of freshwater streams. Thus, the panel recognized the need to distinguish between "normative" sedimentation rates in marine riparian areas as opposed to human-induced changes to sediment inputs. Further, while the risks of human induced inputs of fine sediments into marine shorelines have not been as well studied as freshwater systems, the panel recognized marine riparian areas as important for ensuring "normative" sediment processes and reductions of potentially harmful levels of fine sediments from anthropogenic activities.

Additional key comments and questions raised by the science panel are provided under the following topics:

Definition of Sediment

- Most reviews of the water quality functions in riparian areas incorporate a discussion of sediment control as part of the discussion of other contaminants. Associating sediment control functions with other water quality functions may help reduce the confusion concerning natural sediment delivery and transport processes versus excessive fine sediment inputs from anthropogenic sources.
- How sediment is defined (e.g., size, class) can change the role and function within the ecosystem as a whole. Perhaps identifying "anthropogenically-derived fines" would help clarify this.
- Sediment delivery is critical to sustaining Puget Sound beaches and is part of the natural watershed process that shapes the shoreline.

Land Use

- Land use practices influence the characteristics, timing, and magnitude of sediment input, and can increase annual sediment loads reaching streams by several factors.

Role of Sediment

- The role of sediment in nearshore processes of Puget Sound needs to be acknowledged and not confused with controlling fine sediment (and associated contaminant) delivery to marine waters. The compounds that bind to sediment (such as phosphorus) are delivered to the nearshore aquatic environment (where they may play an important ecological role), thus natural levels of sediment delivery should be an important component of riparian management.

F. Wildlife

Overview

In a review of eight separate reports synthesizing much of the literature on riparian functions and buffers, all include a discussion of the importance of riparian areas to wildlife and offer either a range of reported buffer widths, and/or specific buffer recommendations for protection of wildlife habitat. The provision of wildlife habitat is commonly identified as one of the most important functions of riparian areas by meeting important life history requirements such as feeding, breeding, refuge, and migration corridors.

Riparian function curve for wildlife

FEMAT (1993) did not generate a riparian function curve for wildlife. Although a number of other publications describe the importance of riparian areas for supporting wildlife, functional effectiveness data are specific to individual species life history requirements, so it was not possible to generate a function curve. Some researchers have attempted to use physical criteria (plant community, microclimates) as a surrogate for identifying unique riparian habitat attributes for wildlife.

Key science panel findings

Although no riparian function curve for wildlife was available for panel review, there was general consensus that marine riparian areas provide a suite of functions for wildlife as habitat buffers and migration corridors. Some participants pointed out that there are a number of species that would not utilize marine nearshore areas, or cross onto beaches, if a buffer did not exist, which led to a discussion of obligate versus facultative uses. All panel members agreed that marine riparian areas provide a suite of important services for wildlife and this function was rated high across the panel. Discussion on the wildlife function included:

Obligate/Optimal Use Species

- There are few known marine riparian obligate species and it was unclear if the process of identifying obligate species in marine riparian areas had been carried out. It is believed that most wildlife in these areas are generalized in their use and preference, although few studies have focused on this set of questions for marine riparian areas. The unique aspect about the marine riparian environment is that it supports a number of important functions and processes that create and maintain wildlife habitat. Diversity was mentioned frequently with regard to riparian areas; many wildlife species are generalists in their use of ecotones, so increased local species diversity may or may not lead to high regional diversity. Heightened local diversity occurs because structural diversity and vegetation are linked closely with the aquatic system. Larger buffers would benefit bigger animals with wider ranges, and are important for wildlife sensitive to human disturbances. See Marzluff (2005), Sax and Gaines (2003), and Scott and Helfman (2001).

- Invasive species within riparian areas need to be considered as they may reduce buffer effectiveness. Buffers can harbor nuisance species and any pathogens that are transported along with their introduction, which is a cause for concern with respect to local wildlife and human populations.

Additional Key Comments:

- It may be helpful to provide more information on the functions of ecotones in the guidance document (e.g., define and provide information on multiple functions of ecotones).
- Need to consider obligate versus facultative use species in the buffer. For example, some shorebird species may be obligate users of the marine riparian zone during migration periods.
- Address seasonal variability as it relates to wildlife usage;
- Need to consider supralittoral (i.e. the splash/spray zone above spring high tide line, not submerged by water) use by plovers, seals, otters, deer, and other animals.
- Buffer areas could disrupt or enhance migratory pathways, depending on the species life history requirements and habits.
- Functional connectivity between habitats does not always have to be continuous; some animals can leap-frog areas.
- Some structural elements may need to be considered for specific wildlife needs (may vary with beach and/or buffer type).
- Wildlife may have important roles, through selective feedings and deposition of nutrients, in shaping the structure and productivity of marine riparian areas (Naiman and Rogers 1997).

G. Hydrology/Slope Stability

Overview

Substantial literature exists on the role of vegetation in controlling hydraulic processes and increasing slope stability. Much of this literature addresses the impacts (such as sedimentation, siltation, and excessive flow volumes) of logging, agriculture, urbanization, and other practices to streams and wetlands. A significant portion of the literature on impacts has little to do with maintaining or protecting ecological functions of riparian or aquatic systems, but rather focuses on how these impacts affect human infrastructure. Regardless of the system (freshwater or marine), or the focus of the research and assessment reports (ecological or social implications), the general consensus is that vegetation can play an important role in controlling hydrologic processes and slope stability in the following ways (adapted from Griggs et al. 1992: IN Macdonald and Witek 1994):

- *Interception*: Foliage and plant litter absorb the energy of precipitation, reducing direct impacts on soil.
- *Restraint*: Root systems bind soil particles and blocks of soils, and filter sediment out of runoff.
- *Retardation*: Plants and litter increase surface roughness, and reduce runoff volume and velocity, reducing channelization.
- *Infiltration*: roots and plant litter help maintain soil porosity and permeability.
- *Transpiration*: plants absorb moisture, delaying the onset of soil saturation and surface runoff.

In addition, the influences of woody plants on mass movement may include:

- *Root Reinforcement* – Roots mechanically reinforce soil by transferring shear stresses in the soil to tensile resistance in the roots.
- *Soil Moisture Depletion* – Interception of raindrops by foliage as well as evapotranspiration limit buildup of soil moisture.
- *Buttressing and Arching* – Tree trunks can act as buttress piles or arch abutments in a slope, counteracting shear stresses.
- *Surcharge* – The weight of vegetation on a slope may exert a destabilizing down slope stress and a stress component perpendicular to the slope that increases resistance to sliding.
- *Root wedging* – Roots invade cracks and fissures in soil or rock that could add restraint stability or cause local instability by wedging action.
- *Wind throw* – Strong winds exert an overturning movement on trees causing blow down (usually of aged, diseased, or undermined trees) that disturb slope soils.

Riparian function curve for hydrology and slope stability

No data could be found plotting the functional effectiveness of the hydrology/slope stability function, so data were generated following the model provided by Griggs et al. (1992) (IN Macdonald and Witek 1994) were used to create Table 6 and Figure 6. This study addresses setbacks on bluffs and other unstable slopes to protect against property loss.

Table 6. Setback distances (ft.) for different bluff heights at various levels of stability where geologic stability for 50 years cannot be demonstrated (after Griggs et al. 1992).

Bluff Height (ft)	**Stable (1:1)(45^0)**	**Moderately Stable (2:1)(30^0)**	**Unstable (1:1)(45^0)+ (2:1)(30^0)**
20	20	40	60
40	40	80	120
60	60	120	180
80	80	160	240
100	100	200	300
120	120	240	360
140	140	280	420
160	160	320	480
180	180	360	540
200	200	400	600

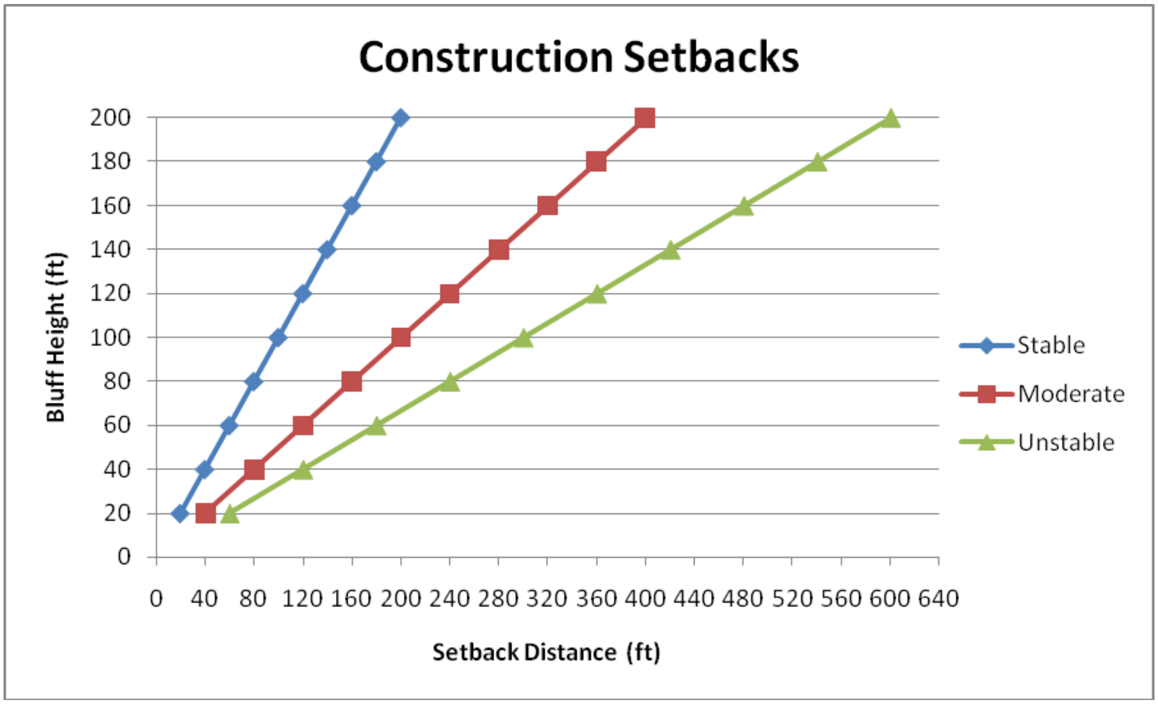

Figure 6. Construction setbacks for different bluff heights at various levels of stability, where geologic stability for 50 years cannot be demonstrated (after Griggs et al. 1992).

Key science panel findings

All participants agreed that the hydrology/slope stability graphic is applicable in the marine environment. Panelists discussed the importance of hydrology, geomorphology, soil type, and vegetation type in supporting slope stability functions in Puget Sound, in addition to the human safety concerns about slope stability in the region.

Geomorphology

- Landforms and geology can be more important here than buffer width. For example, in the San Juan Islands, there can be a 45° slope on basalt form that can be very stable.
- Consider geomorphic shore form (e.g., geologic legacy, landscape position, density, slope, etc.). Use of Shipman (2008) geomorphic classification system may be useful.

Soil and Vegetation

- Soils and vegetation play important roles in slope stability and hydrology.
- The relationship of riparian vegetation and slope stability is very specific to hydrologic and geologic conditions. It is important to consider flow paths; for example, stability may be associated more with altered upland drainage patterns or precipitation patterns. Therefore, this relationship may be site-specific.
- Need to consider the role of vegetation on the slope itself versus above the slope, which would yield different functions. The relative importance of vegetation at each location, given site-specific conditions and methods of protection need to be determined. Similar to the discussion of "sediment" above, management should allow for normative rates of LWD recruitment and erosion to provide sediments and wood to beaches.
- Buffer width versus landform may be the most important factor. For example, steeper slopes, particularly those with underlying geologic instability, require wider buffers.
- Need to maintain normative rates of sediment delivery by using setbacks and buffers – should avoid interfering with natural processes.
- Upslope alterations are large contributing factors to slope instability.
- Home protection and public hazard considerations are likely to garner public support for buffers.
- Riparian areas can increase slope stability (through root structure) and increase water interception and absorption. Protecting natural rates of sediment delivery and protecting processes and functions of nearshore ecosystems may be achieved by establishing and maintaining adequate riparian buffers.

SECTION IV: Summary and Conclusions

The purpose of this workshop was to solicit expert opinion on how best to apply riparian science to protect marine riparian functions and processes with a particular emphasis on buffers. The science panel included fourteen scientists with expertise related to riparian ecosystems. Panelists were asked for input on a variety of questions related to seven specific riparian functions and/or processes.

In general, panelists agreed that findings from studies of freshwater riparian areas are transferable to marine riparian areas, although some processes and functions are unique to marine riparian areas.

A summary of panelist responses to the key questions follows (note: questions were asked for each of seven riparian functions).

1. **Is there general agreement that this function applies in the marine environment? On a scale of 1-10 (low to high), what is the relative importance of this particular function in the marine environment?**

General consensus was reached that each of the seven functions reviewed during the workshop applies in both freshwater and marine riparian environments, although their relative importance varied. For example, three functions (LWD, litter fall, and hydrology) emerged as having higher relative importance to marine environments, based on a subjective ranking process. Many panelists noted that marine riparian science would be greatly improved with additional research. It was also generally agreed these areas should be viewed and managed holistically to address multiple processes and functions at small and large spatial and temporal scales

Water Quality – The panel agreed that while water quality is an important function of marine riparian areas overall, the relative contribution of these areas is minor at a larger scale compared to the freshwater inputs from the Puget Sound drainage basin as a whole. However, water quality functions provided by marine riparian areas may be very important, especially at a site specific level, depending upon land use practices and the integrity of the riparian area.

Shade/Microclimate – According to the panel, shade is of medium relative importance to marine riparian areas in Puget Sound relative to water temperatures in the marine environment, which was judged to be less sensitive to solar inputs than waters in freshwater systems. However, shade has been shown to play a role in survival of upper intertidal organisms in Puget Sound. Additional research is needed to fully understand its role. Erosion and tree removal within and outside the riparian buffer can disrupt the shade function in the marine environment. In addition, the limited knowledge on the survival thresholds for climate-sensitive species in the marine nearshore environment is a major data gap.

LWD Recruitment – LWD in the marine nearshore provides important functions but it was unclear how much of that wood comes from marine riparian areas versus rivers. LWD is known to supply nutrients, stabilize beaches and banks, reduce wave erosion, enhance establishment and growth of vegetation, and provide refuge, nesting and foraging habitat for a variety of species. There is an overall general lack of information specific to the marine environment, but sources of LWD to beaches include freshwater riparian material, logging activity, and marine riparian areas. Recruitment of marine LWD requires buffers that allow for natural erosion and recruitment over extended time periods as banks and bluffs recede.

Litter Fall/Provision of Allochthonous Inputs – These inputs are relevant to both marine and freshwater environments. Terrestrial source nutrients have been shown to be important to the nearshore ecosystem, and some studies have determined that riparian areas serve as emergence habitat for fish prey and support a number of trophic levels in the nearshore food web. Nutrient and energy exchange is not unidirectional and marine derived nutrients find their way to terrestrial environments. Some panelists noted that the contribution of allochthonous inputs to and their influence on productivity in marine systems is a data gap.

Fine Sediment Control/Delivery – This process is important in both marine and freshwater systems. Sediment delivery to the Puget Sound via river systems and eroding marine bluffs (convergence zones) is critical to beach forming processes. Fine sediments originating from anthropogenic sources need to be distinguished from natural sources and background levels. Riparian areas can help control harmful levels of fine sediment and associated contaminant delivery to the aquatic environment while allowing natural processes to continue.

Wildlife – Marine riparian areas provide a suite of habitat functions for wildlife including feeding, breeding, and migration corridors. Some panelists pointed out that there are a number of species that would not cross into the nearshore area if a marine riparian buffer did not exist. Few studies have focused on wildlife utilization of marine riparian areas, but much of what has been studied about the life history requirements in other areas would apply to those species that occur in these areas. Some species may be highly adapted to marine riparian areas and could be considered obligate species, although survey data are lacking.

Hydrology and Slope Stability – Vegetation can play an important role in controlling runoff, maintaining slope stability, and maintaining normative rates of erosion. From this perspective, one function of a riparian area is protecting people from landslides. The safety factors provided by buffers may resonate with people more directly if the argument is framed in terms of the need for normative rates of erosion and sediment delivery to beaches along with protection of human structures.

2. **Does the FEMAT-style curve adapted for this function "fit" for the marine environment? (Yes or No)**

Nearly every panelist agreed that all six of the FEMAT-style curves adapted for riparian processes and functions (a wildlife functional effectiveness graph was not provided) were a reasonable "fit" or conceptually valid for the marine environment, notwithstanding site and scale controlling factors. Several exceptions and caveats were included, such as the LWD function (every panelist felt that the curve's "fit" would vary at a site specific scale); and the shade function (participants pointed to many factors that needed to be considered, including aspect and temporal/spatial variability.

3. **Which controlling factors are most important in determining the specific relationship between buffer width and function (e.g., shore form, slope, vegetation type, aspect, soils)?**

Responses to this question are summarized in Table 7 below. The discussion of these topics was very limited due to time constraints.

Table 7. Controlling factors for riparian buffer functions.

Process/Function	Controlling Factors
Water Quality	▪ anthropogenic activities ▪ flow concentration ▪ slope (highly relevant to flow concentration) ▪ vegetation type and density
LWD	▪ condition of vegetation – species, size, presence, age, structure ▪ landslides ▪ climatic events, wind action, precipitation, ice storms ▪ anthropogenic disturbances: forestry/logging ▪ trigger trees (cause others to fall) ▪ soils ▪ geology ▪ groundwater/hydrology ▪ condition of wood (insects, root rot, disease) ▪ fire (consideration of fine scale disturbances versus catastrophes) ▪ invasive species
Litter	▪ vegetation species, type, age,

Fall/Allochthonous Inputs	structure ▪ vertical diversity (big trees versus understory, ground cover) ▪ climatic events, wind action ▪ slope (degree) ▪ shoreform type ▪ anthropogenic disturbances
Hydrology/Slope Stability	▪ soils ▪ geology ▪ erosion rates ▪ presence of vegetation ▪ groundwater/hydrology ▪ anthropogenic disturbances and upland activities ▪ topography ▪ climatic events, wind and wave exposure, storm severity (climate impacts/change)

Parking Lot Ideas

Throughout the workshop, panelists brought up ideas, issues, concerns, and questions. A number of these topics and considerations were outside the scope of the workshop but were noted as “Parking Lot” issues. They fell into two main topic areas: buffer management and research gaps and needs, and have been grouped by these two categories below.

Guidance on Buffer Management

- Many uncertainties exist in managing marine riparian areas. Using a precautionary approach and adaptively managing these areas is important.
- Management of marine riparian areas must consider a time element. Like many other ecological elements, the processes and functions of marine riparian areas evolve over extended time periods, which need to be considered for developing appropriate management actions. For example, since plants and plant communities (extent, age since last disturbance, composition) are important determinants of riparian functions, managers need to consider the time it takes for large trees to grow and plant communities to become established and maintained through time. Similarly, the time it takes to reestablish following a disturbance event (natural or anthropogenic) should be incorporated into the management strategy (e.g., for protection, enhancement, restoration, recreation).
- Management of marine riparian areas must consider multiple spatial scales. Connectivity is an important characteristic of riparian areas for maintaining ecological functions. Fragmentation and narrowing of buffers can have larger-scale effects. Because shoreline development and permitting typically occur on a site-by-site basis, current management does not account for cumulative and large-scale impacts. In addition, bluffs may continue to erode over time, sea levels will rise and existing buffers will likely become narrower as a result of human or natural disturbance, thereby providing reduced functions. This should be a management consideration for creating sustainable processes and functions.
- In addition to ecological functions, riparian areas have important social, cultural, economic, and recreational values and these should be important management consideration.
- Riparian buffers need to be recognized as being important for human safety in addition to their ecological importance. A large portion of Puget Sound shorelines is naturally eroding, which potentially threatens human infrastructure and safety. The effects of climate change are likely to increase erosion rates and threaten existing infrastructure.
- Sediment (including mass wasting) is important for maintaining beaches in Puget Sound and should not be confused with fine “anthropogenic” sediments that could have adverse environmental effects. One of the key functions of riparian areas is pollution abatement (e.g., trapping fine sediments, treatment of contaminants associated with fine sediments, absorption and treatment of water-borne contaminants). Natural sedimentation and transport processes should be maintained, at normative rates, while also ensuring that riparian functions are protected.

- The term “large wood” has not been precisely defined within the nearshore setting. “Small wood” (i.e. under 1 m long) has been found to moderate beach temperatures and support richer communities of macroinvertebrates.
- Invasive and nuisance species can have a profound effect on riparian functions . Many invasive and nuisance species are well-adapted to disturbance and once established, may alter natural processes and functions, and/or may prevent native species from reestablishing.
- Marine riparian buffers should not be the sole mechanism by which the marine nearshore ecosystems are protected.
- Resiliency of vegetation in marine riparian areas is a function of patch size. As vegetation patches become smaller (thinner) and more isolated by human development, they are more likely to experience disturbances that can change structure and function of that plant community. Isolated patches of relatively undisturbed vegetation may be more susceptible to wind-throw, or invasion of nonnative species, such as English ivy. Further, these patches may become isolated to the point where they suffer from a lack of recruitment of new propagules. They can also be eliminated altogether as a consequence of bluff retreat.

Research Needs and Data Gaps

- Link riparian processes and functions to a geomorphic classification for Puget Sound. A geomorphic classification (e.g., Shipman 2008) may be helpful in developing a riparian classification scheme and may also be informative for identifying important marine riparian functions and processes
- Determine a standard for describing buffer widths. Some investigators have used site potential tree height (SPTH) for determining buffer widths.
- The influence of groundwater on trees and vegetation in the riparian zone.
- Relative contribution of litter fall/allochthonous inputs from the riparian zone versus rivers and other outside areas.
- Value of litter fall/allochthonous inputs and relative food web energetic contribution to the riparian system.
- Identification of priority pollutants in the Puget Sound nearshore system. The panelists noted the need to understand the role of septic systems as likely primary pollutant sources in marine riparian areas; in freshwater systems, septic pollution has been shown to affect fish community structure (Moore et al. 2003).
- Identification of optimal use and obligate species in marine riparian areas
- Classification of the intensity, frequency, and conditions that could give rise to massive slope stability failures in Puget Sound.
- Vegetation dynamics and the effects on riparian function in areas surrounded by human developed lands.

- Riparian condition related to volumes/timing and types of terrestrial insects delivered to nearshore settings.
- The geomorphic functions of driftwood along various Puget Sound shoreline types.

Appendix A. List of Participants

Name	Affiliation	Expertise
Jim Agee	UW	Forest Ecology
Derek Booth	UW, Stillwater Sciences	Geohydrology
Jim Brennan	UW Sea Grant	Marine/Nearshore Ecology
Randy Carman*	WDFW	Marine/Nearshore Ecology
John Marzluff	UW	Wildlife
David McDonald	SPU	Soils Sciences
Bob Naiman	UW	Riparian Ecology
Michael Pollock	NMFS	Riparian Ecology
Tim Quinn*	WDFW	Wildlife
Steve Ralph	Stillwater Sciences, Inc.	Aquatic Ecology
Si Simenstad	UW	Marine/Nearshore Ecology
Kathy Taylor*	WDOE	Marine Ecology /Forest Ecology
Dan	NMFS	Biology

Tonnes		
Steve Toth	Independent Consultant	Geomorphology

* Member of Aquatic Habitat Group

Appendix B. Agenda

TIME	**TOPIC**	**PRESENTER/ FACILITATOR**
8:00-8:20	**Welcome, introductions, agenda review**	Hilary
8:20-8:45	**Background, goals, objectives, terminology**	Hilary
8:45-9:45	**Summary of riparian functions and applicability to marine shorelines**	Jim
9:45-10:00	**Break**	
10:00-Noon	**Detailed discussion of functions** ***Key questions for each function*:** • Does the FEMAT-style buffer curve derived from the freshwater science for this function "fit" for the marine environment? • Why or why not? • How is the relationship between buffer width and this function likely to be different in marine compared with freshwater systems? • What data exists to support each of the differences identified in answer to question the question above?	Hilary/Panel
Noon-1:00	**Lunch**	
1:00-3:00	**Detailed discussion of functions** ***Key questions for each function:*** • Does the FEMAT-style buffer curve derived from the freshwater science for this function "fit" in the marine environment? • Why or why not?	Hilary/Panel

	• How is the relationship between buffer width and this function likely to be different in marine compared with freshwater systems? • What data exists to support each of the differences identified in answer to question the question above?	
3:00-3:15	**Break**	
3:15-4:45	**Controlling factors discussion for functions** • Which controlling factors are most important in determining the specific relationship between buffer width and this function? (e.g., shore form, slope, vegetation type, aspect, soils) • What are the most important data gaps and uncertainties associated with the relationship between buffer width and this function? • How certain are we of the relationship presented?	Hilary
4:45-5:00	**Wrap-up, next steps** • Summarize key thoughts/recommendations • Summarize next steps	

Appendix C. List of Reference Materials

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Appendix D. Original FEMAT curves (FEMAT 1993)