Protection of Riparian Ecosystems:

A Review of Best Available Science

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October 27, 2000

Introduction

The objective of this paper is to provide a review of the current "Best Available Science" (BAS) regarding the requirements for riparian buffers to maintain fisheries and wildlife habitat. The primary focus of this literature review will be on buffers for freshwater streams and rivers. Little research has been completed that has determined appropriate riparian buffers for lakes and marine shorelines, although many researchers have attempted to broaden the scope of findings for riverine ecosystems to include marine and lake shorelines.

The life history of each of several salmonid species is unique, but all spawn in freshwater and share a similar dependence on streams, lakes, wetlands, and nearshore marine areas. Salmonids use streams and rivers for spawning, juvenile rearing and migrating. Estuary and nearshore marine areas provide a vital transition zone for juvenile salmon migrating to the ocean, and for adults migrating back to natal streams to spawn. During these phases of their lives, salmonids are affected by humans through land use impacts on their habitat, as well as from fisheries. The cumulative impacts from human activities have resulted in decline in salmonid populations and threatened or endangered listings of nearly half of the genetically distinct salmonid populations in the Pacific Northwest.

Riparian and floodplain areas are the critical interface between upland and riverine ecosystems, and thus are critical to maintaining proper functioning conditions (PFC). The term "riparian buffer" is the land that is set aside or managed to allow for maintaining PFC. Riparian buffers are determined as the distance measured from the water's edge, and typically are determined by the classification of the waterbody at the location of the riparian buffer.

Regulations have been enacted that specify riparian buffer widths to protect fish and wildlife habitat, reduce the likelihood for landslides, or protect other features. These regulations are required to be based on the "best available science" (BAS). Recently, administrative clarification has been proposed to answer the question of which science is the BAS and why (WAC 365-195-900 through WAC 365-195-925). The proposed criteria are meant to, "assist counties and cities in determining whether information obtained during development of critical areas policies and regulations constitutes the 'best available science.'" Unfortunately, the language in these sections does not lay out specifics about which science can be considered BAS, only how to judge the value of the research.

The BAS for riparian zone management includes scientific literature that has accumulated over the past five decades. Although this review is not exhaustive, it includes and builds on previous literature reviews completed for King County (Johnson and Ryba 1992), Washington Department of Fish and Wildlife (WDFW 1997), the National Marine Fisheries Service (Spence et al. 1998), and Kitsap County (May 1999). Because the literature reviews themselves are not scientific studies, the conclusions within the reviews fall into a different category of BAS. The goal of the multiple literature reviews generally has been to determine appropriate policy for riparian zones. The previous reviews, therefore, are addressed separately in the Riparian Zone Management Recommendations section.

Stream Classification

The following details stream types according to WAC 222-16-030:

TYPE 1	Shorelines of statewide significance
TYPE 2	Waters of high use & importance in water quality
TYPE 3	Waters of medium use & importance in water quality
TYPE 4	Waters with influence on downstream water quality
TYPE 5	Waters not included in types 1 through 4

(1) **"Type 1 Water"** means all waters, within their ordinary high-water mark, as inventoried as "shorelines of the state" under chapter 90.58 RCW and the rules promulgated pursuant to chapter 90.58 RCW, but not including those waters' associated wetlands as defined in chapter 90.58 RCW.

(2) **"Type 2 Water"** shall mean segments of natural waters which are not classified as Type 1 Water and have a high fish, wildlife, or human use. These are segments of natural waters and periodically inundated areas of their associated wetlands, which:
(a) Are diverted for domestic use by more than 100 residential or camping units or by a public accommodation facility licensed to serve more than 100 persons, where such diversion is determined by the department to be a valid appropriation of water and the only practical water source for such users. Such waters shall be considered to be Type 2 Water upstream from the point of such diversion for 1,500 feet or until the drainage area is reduced by 50 percent, whichever is less;
(b) Are within a federal, state, local, or private campground having more than 30 camping units: *Provided,* That the water shall not be considered to enter a campground until it reaches the boundary of the park lands available for public use and comes within 100 feet of a camping unit, trail or other park improvement;
(c) Are used by substantial numbers of anadromous or resident game fish for spawning, rearing or migration. Waters having the following characteristics are presumed to have highly significant fish populations:
(i) Stream segments having a defined channel 20 feet or greater in width between the ordinary high-water marks and having a gradient of less than 4 percent.
(ii) Lakes, ponds, or impoundments having a surface area of 1 acre or greater at seasonal low water; or
(d) Are used by salmonids for off-channel habitat. These areas are critical to the maintenance of optimum survival of juvenile salmonids. This habitat shall be identified based on the following criteria:
(i) The site must be connected to a stream bearing salmonids and accessible during some period of the year; and
(ii) The off-channel water must be accessible to juvenile salmonids through a drainage with less than a 5% gradient.

(3) **"Type 3 Water"** shall mean segments of natural waters which are not classified as Type 1 or 2 Water and have a moderate to slight fish, wildlife, and human use. These are segments of natural waters and periodically inundated areas of their associated wetlands which:

(a) Are diverted for domestic use by more than 10 residential or camping units or by a public accommodation facility licensed to serve more than 10 persons, where such diversion is determined by the department to be a valid appropriation of water and the only practical water source for such users. Such waters shall be considered to be Type 3 Water upstream from the point of such diversion for 1,500 feet or until the drainage area is reduced by 50 percent, whichever is less;
(b) Are used by significant numbers of anadromous fish for spawning, rearing or migration. Waters having the following characteristics are presumed to have significant anadromous fish use:
(i) Stream segments having a defined channel of 5 feet or greater in width between the ordinary high-water marks; and having a gradient of less than 12 percent and not upstream of a falls of more than 10 vertical feet.
(ii) Ponds or impoundments having a surface area of less than 1 acre at seasonal low water and having an outlet to an anadromous fish stream.
(c) Are used by significant numbers of resident game fish. Waters with the following characteristics are presumed to have significant resident game fish use:
(i) Stream segments having a defined channel of 10 feet or greater in width between the ordinary high-water marks; and a summer low flow greater than 0.3 cubic feet per second; and a gradient of less than 12 percent.
(ii) Ponds or impoundments having a surface area greater than 0.5 acre at seasonal low water; or
(d) Are highly significant for protection of downstream water quality. Tributaries which contribute greater than 20 percent of the flow to a Type 1 or 2 Water are presumed to be significant for 1,500 feet from their confluence with the Type 1 or 2 Water or until their drainage area is less than 50 percent of their drainage area at the point of confluence, whichever is less.

(4) **"Type 4 Water"** classification shall be applied to segments of natural waters which are not classified as Type 1, 2 or 3, and for the purpose of protecting water quality downstream are classified as Type 4 Water upstream until the channel width becomes less than 2 feet in width between the ordinary high-water marks. Their significance lies in their influence on water quality downstream in Type 1, 2, and 3 Waters. These may be perennial or intermittent.

(5) **"Type 5 Water"** classification shall be applied to all natural waters not classified as Type 1, 2, 3 or 4; including streams with or without well-defined channels, areas of perennial or intermittent seepage, ponds, natural sinks and drainageways having short periods of spring or storm runoff.

Riparian Zones

Riparian and floodplain areas are the critical interface between terrestrial (land) and aquatic (water) ecosystems. In most streams and wetlands in the Pacific Northwest, the riparian community of plants and animals directly influences the physical, chemical, and biological conditions in the aquatic ecosystem. Riparian vegetation plays a major role in providing shade, cover, and stream bank stability. In addition, root matter and woody debris from riparian trees acts to slow water velocities, retain sediments, provide organic matter to the streams, create physical structure that helps to form pools and complex habitat. In turn, salmon carcasses contribute to the health of the surrounding forests through nutrient inputs as the carcasses decompose. Thus, it is apparent that the riparian system connects the terrestrial and aquatic ecosystems.

The use of "riparian buffers" to protect aquatic ecosystems is common practice. The buffers are composed of land that has been set aside from the adjacent land use, and managed to protect a natural area from the effects of surrounding human activities (i.e., development, agricultural practices, forestry). Riparian buffers can be forested areas, landscaped areas, or grassy strips. Buffers are often designed to perform or protect specific functions. The width and composition of the riparian buffer determines how the various functions will be protected.

There are six key aquatic habitat functions that are protected by riparian vegetation and riparian buffers:

1) Moderate temperatures
2) Provide large woody debris (LWD)
3) Provide organic matter
4) Stabilize stream banks
5) Control sediment inputs
6) Regulate nutrient and pollutant inputs

BAS does not provide a specific buffer width that will protect all salmon habitat in all types of streams and river ecosystems. Instead, each study that has contributed to BAS has been done in a particular location, with particular conditions. Findings from each study are only partially transferable to other locations. Commonly, some of the conclusions are related back to fundamental ecological principles, and findings are generalized to conditions for other locations and habitats.

Collectively the findings from the BAS leads to a range of riparian buffers published that provide some level of documented habitat protection. Unfortunately, counties are required to present regulatory certainty and fairness. Typically, that has meant providing a simple buffer standard that can be used for all properties along similar riparian areas. Therefore, use of BAS to come up with a standard buffer value is an extrapolation. The standard buffers must be relatively conservative, providing protection in most all cases.

However, BAS clearly states that protection of ecological functions and preservation of PFC depends on site-specific conditions. In some cases, this will require a larger protection area. In other cases, a smaller protection area will be sufficient to preserve PFC. Deviations from the standard buffer must be based on sound science. To modify the standard buffer, there must be sufficient information about the site, and sufficient information about the watershed-scale processes. Therefore, any deviations from the standard buffer must be accompanied by a plan that addresses how necessary habitat protections will be met, and how the watershed-scale PFC will be maintained. Additionally, a watershed-scale management plan is needed to provide context for site-specific decisions for alterations from standard buffers.

The following table includes the findings from the scientific literature on riparian zones and protection of aquatic habitat functions. Included in Table 1 are the conclusions from each study for buffer widths grouped by functions that were studied. Most of these studies were also summarized in Johnson and Ryba (1992), Femat (1993), Spence et al. (1996), WDFW (1997) and May (1999). Each study in Table 1 was an experimental study or a monitoring study. The literature reviews are addressed under the following section.

Table 1. Literature summary for functions provided by riparian zones. Those studies denoted with an asterisk may not qualify as peer-reviewed science under WAC 365-195-900 through 925.

Function	Buffer Studied	Notes	Reference
Temperature Moderation			
	30 m	provided 50-100% shading	Beschta et al. 1987
	11 m - 24 m	provided 60-80% shading	Brazier and Brown 1973
	15 m		Broderson 1973*
	12 m		Corbett and Lynch 1985
	15 m - 30 m	provided 60-80% shading	Hewlett and Fortson 1982
	30 m - 43 m	provided 50-100% shading	Jones et al. 1988
	30 m	provided 50-100% shading (equivalent to mature forest)	Lynch et al. 1985
	18 m		Moring 1975
	23 m - 38 m	provided 80% shading	Steinblums et al. 1984
LWD			
	31 m		Bottom et al. 1983
	50 m	Based on site potential tree height (SPTH)	Collier et al. 1995*
	45 m		Harmon et al. 1986
	30 m - 46 m		McDade et al. 1990
	30 m	99% origin of in-stream LWD	Murphy and Koski 1989
	50 m[1]		Robison and Beschta 1990
	50 m		Van Sickle and Gregory 1990
Organic Litter			
	30 m	Based on SPTH	FEMAT 1993
Bank Stabilization			
	30 m	Based on SPTH, may be larger in braided channels	FEMAT 1993

Sediment Control			
	60 m - 91 m	50% sediment removal	Belt et al. 1992
	61 m	90% sediment removal	Broderson 1973*
	38 m	Minimum to protect streambanks from erosion	Cederholm 1994
	5 m - 9 m	53-98% sediment removal	Dillaha et al. 1988
	30 m	80% sediment removal	Erman et al. 1977*
	30 m		Davies and Nelson 1994
	88 m	50% sediment removal	Gilliam and Skaggs 1988*
	30-38 m	75% sediment removal	Karr and Schlosser 1977
	30 m - 80 m		Lowrance et al. 1986
	30 m	75-80% sediment removal in managed forests	Lynch et al. 1985
	5 m - 9 m	66-82% sediment removal	Magette et al. 1989
	30 m	90% sediment removal in logging areas	Moring 1982
	19 m - 40 m	90-94% sediment removal	Peterjohn and Correll 1984
	30 m		Raleigh et al. 1986
	61 m		Terrell and Perfetti 1989
	91 m - 262 m	80% sediment removal depending on slope	Vanderholm and Dickey 1978
	30 m - 61 m	90-95% sediment removal	Wong and McCuen 1982
	21 m - 27 m	66-93% sediment removal	Young et al. 1980
Nutrient Control			
	16 m	Min. for nitrogen removal	Jacobs and Gilliam 1985
	7 m	Nitrogen uptake	Hubbard & Lowrance 1992
	50 m - 60 m	94% nitrogen reduction	Lowrance 1992
	16 m	96% nitrogen reduction	Osborne and Kovacic 1993
	10 m	95% nitrogen reduction	Xu et al. 1992
	5 m - 9 m	54-84% nitrogen and phosphorus reduction	Dillaha et al. 1988
	19 m	80-90% nitrogen and phosphorus reduction	Shisler et al. 1987
	5 m - 9 m	41-53% phosphorus reduction	Magette et al. 1989
	20 m - 28 m	67-81% phosphorus reduction	Mander et al. 1997
	50 m	73-84% phosphorus reduction	Peterjohn and Correll 1984
	10 m	Minimum for phosphorus removal	Petersen et al. 1992
	8 m - 16 m	66-95% phosphorus reduction	Vought et al. 1994

	30 m	Fecal coliform removal	Grismer 1981*
	30 m - 43 m	Fecal coliform removal	Jones et al. 1988
	30 m	Fecal coliform removal	Lynch et al. 1985
	20 m	Nutrient removal	Schultz et al. 1995
	36 m	Nutrient removal	Young et al. 1980
	30 m - 183 m	Range for vegetation	Terrell and Perfetti 1989

[1] Note: The study findings were not based on a field study. Instead, the authors modeled the likelihood of trees falling into a stream and contributing to LWD.

Summary of Table 1

Shading: The studies reviewed found riparian vegetation providing fully-forested levels of shading for aquatic systems at distances ranging between 11 m and 46 m (35 and 150 feet). The ranges represent between 60% and 100% of shading that is similar to levels of light below the canopy of old-growth riparian trees.

LWD: The studies reviewed found riparian trees contributing to LWD up to 180 feet from the stream bank. In channels that migrate, trees anywhere in the channel migration zone can contribute LWD to the system. Buffers ranging between 30 m to 55 m (100 to 180 feet) have been predicted to provide approximately 80%-90% of the LWD into the river or stream system.

Organic Litter: Most fine organic litter originates within 30 m (98 feet) from the channel (FEMAT 1993).

Bank Stabilization: The stabilizing influence of riparian root structure is provided by trees within 0.5 potential tree heights (30 m, or 98 feet) from the stream channel (FEMAT 1993).

Sediment Control: Studies have found vegetated riparian buffers ranging between 3 m and 122 m (10 feet and 400 feet) fully maintain this function. Most of the studies found buffers between 30 m and 90 m (100 feet to 300 feet) to be protective of sediment inputs. The wide range of effectiveness is due to slope, composition of vegetation (i.e., forest or grasses), and time of year. Sediment control is related to the slope of the land, and whether channelized flow occurs.

Nutrients and Other Dissolved Materials: Studies have found vegetated riparian buffers between 4 m and 60 m (33 feet and 200 feet) fully maintain this function. Overall, most of the studies recommended buffers of about 30 m (100 feet) to reduce nutrient and other pollutant inputs. The wide range of effectiveness is due to slope, composition of vegetation (i.e., forest or grasses), and time of year.

Table 2 contains the summary of findings from this literature review. For comparison, a summary table that was in a previous literature review conducted by WFDW (1997) is included below. WDFW combined the findings of scientific studies with synthesis documents (other literature reviews with management recommendations), so there are discrepancies between Table 2 and Table 3 for some of the findings. The WDFW summary (Table 3) contains documents in the review that were not available for this literature review. The WDFW (1997) literature review also contains recommendations for protection of habitats not considered outside the scope of this report.

Table 2. Summary of minimum buffers to protect listed aquatic habitat functions. In all cases, site specific conditions may require larger buffers to provide protection of the function.

Function	Range of Effective Buffers (feet)	Minimum Buffer Width	Notes
Shade	72-150 feet	100 feet	Provide shade equivalent to mature forest conditions, and maintain background water temperatures
LWD[1]	33-328 feet	150 feet	Provide 80-90% of background inputs of LWD
Organic Matter	98 feet	100 feet	Provide background inputs of organic matter to the stream
Streambank stability	98 feet	100 feet	Provide stability to streams
Control sediments	10-400 feet	100 feet	Majority of sediment removal
Nutrients and pollutants	33-200 feet	100 feet	Majority of nutrient removal

[1] Note: In streams with channels that migrate, LWD can be contributed throughout the entire channel migration zone.

Management Recommendations

Riparian buffers should be established for specific land uses and should be designed to maintain the full array of ecological processes needed to create and maintain favorable conditions through time. There are two issues for determining appropriate buffers based on BAS. According to Spence (1996), "… riparian management can be divided into two components: delineation of appropriate riparian buffer widths and determination of allowable activities within the riparian buffer zone."

Buffers should vary in absolute widths based on specific reach-level characteristics (Spence 1996). For example, large mainstem rivers should have buffers that protect all of the habitat-forming processes. A smaller tributary stream that does not sustain salmonids should have protections that focus on water quality and the impacts to higher order streams. Another example of site conditions requiring different buffers would be when contrasting a river deep in a steep ravine vs. a river with an extensive floodplain with side channels and meanders. These specific buffers must be determined through an assessment of the site conditions, needed habitat functions and proposed use.

The second component to determining appropriate buffers is to assess the allowable activities and the requirement that those activities will not impact PFC. This component needs to be addressed on a case-by-case basis, because individual activities need to be assessed along with potential mitigation measures and the overall scope of the development proposal.

Overall, most studies have recommended buffers between 30 m and 55 m (100 feet to 180 feet), although the FEMAT (1993) study highlights in channels that migrate, buffers up to 100 m can supply LWD to the system. These buffers (100 - 180 feet) have been modeled to provide approximately 80%-90% of the LWD into the river or stream system.

Johnson and Ryba (1992) conducted a literature review for King County. The study's conclusions were that buffers of 100 feet would provide a minimum amount of habitat protection. Buffers between 100 and 150 feet were recommended as providing "adequate protection for most of the functions listed." Buffers less than 15 m (about 50 feet) were found to be inadequate for protection of aquatic habitat functions.

FEMAT (1993) and **Thomas et al. (1993)** conducted a literature review as a part of the forest plan that was required to address the listing of spotted owls as threatened under the ESA. One factor that the reviews addressed was whether the forest plan recommendations would protect habitat for other species, including salmonids. The conclusions were that watershed analysis would provide specific buffers for each watershed, but that as an interim measure, the US Forest Service should adopt a conservative buffer to protect aquatic habitat. The interim recommendations called for buffers of 300 feet on fish bearing streams and rivers, 150 feet on year-round non-fish bearing streams, and 100 feet on ephemeral (seasonally-flowing) streams. In all cases, if the 100 year floodplain extended beyond the recommended buffer, the reports recommended including the entire 100 year floodplain within the riparian buffer.

Spence et al. (1996) reviewed literature for aquatic habitat requirements for salmonids. The study determined that one SPTH, or about 200 feet, would be needed on all perennial and intermittent streams to protect aquatic habitat from impacts from logging. However, the study indicated that over the long term, a much larger buffer may be necessary to provide for functions, such as microclimate control, that would be necessary for ecosystem persistence. If the 100 year floodplain or channel migration zone extended beyond the recommended buffer, the reports recommended including the entire 100 year floodplain or channel migration zone within the riparian buffer.

Washington Department of Fish and Wildlife (1997) conducted a review of fish and wildlife habitat requirements as a part of the priority habitats and species program. Table 3, below, is taken from the WDFW document. The table includes a range and average widths to retain riparian function as reported in the literature. The literature review also included recommendations for riparian buffers of 250 feet for Type 1 and Type 2 streams, rivers, and Shorelines of the State, 200 feet on some Type 3 streams, 150 feet on other Type 3 streams and Type 4 streams. The review recommends a 225 foot riparian buffer on Type 3 and Type 4 streams with a high mass wasting potential.

Table 3. Summary of literature review completed by WDFW (from WDFW 1997)

Riparian habitat function	Range of reported widths in feet	Average of reported widths in feet
Temperature control	35-151	90
Large woody debris	100-200	147
Sediment filtration	26-300	138
Pollution filtration	13-600	78
Erosion control	100-125	112

May (1999) conducted a literature review for Kitsap County as a part of the ESA compliance strategy for Kitsap County. Buffers were reviewed for protection of riparian ecosystem and aquatic habitat functions. The study determined that buffers of 30 m (100 feet) were necessary to provide adequate sediment control, pollutant removal and water temperature control. Buffers of 80 m (250 feet) were recommended for LWD recruitment, and larger buffers were recommended for microclimate control.

Summary

The following recommendations are proposed for the Unified Development Code as minimum standard buffers. There will be cases where these buffers are insufficient and other cases where the buffers will be excessive for the site conditions. For example, a river channel that migrates may require protection of the entire migration zone. Another example would be in areas where the is an identified high potential for mass wasting (landslides). There may also be some types of development that could continue to provide protection of riparian functions with a smaller riparian buffer. However, the minimum recommended buffer width provides a general level of protection for each of the functions indicated.

Table 4. Buffer Recommendations for the Unified Development Code.

Water Type	Designation	Minimum Buffer
TYPE 1	Shorelines of statewide significance	150 feet
TYPE 2	Waters of high use & importance in water quality	150 feet
TYPE 3	Waters of medium use & importance in water quality	100 feet
TYPE 4	Waters with influence on downstream water quality	100 feet
TYPE 5	Waters not included in types 1 through 4	0-50 feet

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