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A Literature Review of Recommended Buffer Widths to Maintain Various Functions of Stream Riparian Areas

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ABSTRACT

This paper examines available scientific literature on the function of riparian areas along streams. Specifically, we reviewed literature containing recommendations for buffer widths to maintain those functions, and various methodologies for setting buffer widths.

Some commonly recognized functions of stream riparian zones include:

1) stabilizing streambanks and preventing erosion;
2) filtering suspended solids, nutrients, and harmful or toxic substances;
3) moderating the microclimate of a riparian system; and
4) supporting and protecting fish and wildlife species and providing migration corridors.

In small and intermediate-sized streams in the Pacific Northwest, riparian vegetation directly influences the physical conditions of the stream environment. The roots of riparian vegetation stabilize streambanks, retard erosion, and create overhanging cover for fish. The above-ground portions of plants dissipate the energy of stormflows, obstruct the movement of sediment and detritus, and provide large organic debris to streams.

The effects of land uses on riparian areas can be multiple and varied. The effect depends on the type of land use, degree of disturbance to streamside vegetation, size of stream, physical setting, and succession after disturbance. While land use may vary, the resulting environmental alterations generally affect riparian systems in similar ways.

Buffer widths for stream and wetland habitats may be established using two general methods. These are a fixed width to protect specific functions, or a variable width that considers specific site conditions. Fixed- or variable-width buffers each have advantages and drawbacks. An agency's available resources and constraints will figure strongly in the final choice of how buffers will be set.

Widths for vegetated buffers recommended by various investigators varies widely depending on the specific resource or function to be maintained. Buffer widths recommended by 38 separate investigators to maintain seven major riparian functions ranged from 3 to 200 meters (m). From our review, it appears buffers less than 10 m provide little if any maintenance of various riparian functions. Buffers of 15 to 30 m provide minimal maintenance for most functions; buffers greater than 30 m appear adequate for most functions. Despite whether a fixed buffer or variable width buffer is to be established, we recommend a *minimum* buffer distance of 15 to 30 m. This distance will vary depending on the riparian function to be maintained.

INTRODUCTION

During the past several years, there has been a growing interest in the effects of various land use practices on the natural resources in riparian zones in the Pacific Northwest. Specifically, there is a concern that various land uses such as livestock grazing, road construction, farming, urbanization, and timber harvest are reducing the amount and quality of riparian areas.

A common regulatory method for maintaining riparian systems is to establish vegetated "buffer" areas. Designating buffer areas between incompatible land uses or to lessen the impact of one activity or entity on another is a common regulatory mechanism. In general, there is little controversy about using buffers to maintain the various values and functions of our natural resources. There is, however, considerable controversy in determining the size of buffers to maintain these functions.

Many regulations have been enacted that specify "appropriate" buffer widths for many circumstances. Unfortunately, as Castelle et al. (1991a) report, most of these regulations are based primarily upon subjective criteria (e.g., maximum buffer sizes that the public, or interested groups, will tolerate). Often, the scientific literature supporting these regulations contains conflicting information because of the variability between site conditions and locations.

This paper briefly examines available scientific literature on the function of riparian areas along streams. We reviewed literature containing recommendations for buffer widths to maintain those functions, and various methodologies for setting buffer widths. While not exhaustive, this review included literature from many sources. Our primary sources were computer searches, annotated bibliographies, articles from scientific journals, proceedings of symposia specifically focused on riparian issues, and many texts. The annotated bibliography from Castelle et al. (1991b) was particularly helpful.

While vegetated buffers of wetlands and to some extent lakes are very similar to those of streams, this paper will focus on the riparian systems of streams. The function of vegetated buffers for wetlands are discussed thoroughly by Castelle et al. (1991a).

RIPARIAN TERMINOLOGY

Part of the conflict in the management of riparian systems arises from the imprecision of the terms used to describe this area. The terms describing riparian systems have been used loosely both in the scientific literature and administratively. The strip of land between stream channels and surrounding upland areas is often referred to by different names such as a riparian zone or buffer strip. Petersen et al. (1992) explain that if the strip is wider, it may be termed a riparian wetland, stream valley, and floodplain. When referring to an entire catchment and long lengths of channel the term "corridor" is sometimes used (Decamps et al. 1987; Chauvet 1988 as cited in Petersen et al. 1992).

Raedeke (1988) states:

> One must carefully distinguish between administratively defined terms such as "riparian zones" or "riparian areas" and ecologically defined "riparian communities." The term "riparian zone" is often defined in an administrative sense as the area within some arbitrary distance measured from the water's edge, such as 100 or 200 feet. It may include upland forest communities as well as the distinct riparian community.

Citing several authors, he further says that "riparian communities are unique in the sense that they are functionally wetland communities." Raedeke describes riparian systems as having long, linear shapes with high edge-to-area ratios and microclimates distinct from those of adjacent upland areas. Water is present at or near the soil surface during all or part of the year, resulting in variable soil moisture conditions and distinct plant communities. Periodic flooding causes habitat disturbances that result in a greater natural plant diversity than is present in the surrounding upland areas.

The different names for this streamside area have been used to describe differences in width, flooding conditions, soil conditions, and geomorphology. Conceptually, as Petersen et al. (1992) state, these terms all refer to the same piece of land--the interface between the channel and the terrestrial landscape. It is this area of land to which the varied terms used in this review refer.

FUNCTIONS/VALUES OF RIPARIAN SYSTEMS

To understand the effects of various management options, it is important to understand the influence of riparian systems on streams. The various functions of riparian systems have been reviewed by many authors (Karr and Schlosser 1977; Meehan et al. 1977; Budd et al. 1987; Raedeke 1988; Bilby 1988; Murphy and Meehan 1991; Gregory et al. 1991; Beschta 1991; Castelle et al. 1991a).

Bilby (1988), in discussing the major interactions between aquatic and terrestrial ecosystems, says that upland and aquatic systems are intricately interconnected physically, chemically, and biologically. Thus, they affect one another, and impacts to either can impact the other. The aquatic system directly influences the terrestrial system in forming the riparian zone, an area where soils are often saturated and periodically inundated. Because of the proximity of surface water, which produces water and soil conditions peculiar to this area, vegetation in riparian areas is often very different from that of upland areas. This is especially true in larger, low-gradient streams, where cutoff oxbows, backwaters, and extensive high water tables create unique biological communities found nowhere else.

In turn, upland areas influence riparian areas by dictating the shape of stream channels, controlling type, rate, and amount of material passing through the system, and providing a primary source of energy and nutrient inputs to the stream channel (see discussion below). Changes in these factors often lead to changes in the species composition and age structure of plant and fish and wildlife populations.

Some commonly recognized functions of stream riparian zones include (adapted from Castelle et al. 1991a):

1) stabilizing streambanks and preventing erosion;
2) filtering suspended solids, nutrients, and harmful or toxic substances;
3) moderating the microclimate of the riparian system; and
4) supporting and protecting fish and wildlife species and providing migration corridors.

Other important functions are not commonly recognized. These include moderating impacts of stormwater runoff, protecting and buffering stream habitats from adverse impacts, and maintaining and enhancing habitat diversity and integrity.

In small and intermediate-sized streams in the Pacific Northwest, riparian vegetation directly influences the physical conditions of the stream environment. The roots of riparian vegetation stabilize streambanks, retard erosion, and create overhanging cover for fish. The above-ground portions of plants dissipate the energy of stormflows, obstruct the movement of sediment and detritus, and provide large organic debris to streams (Meehan et al. 1977; Bottom et al. 1985; Hunter 1991; Sedell and Beschta 1991). Sedell and Beschta provide many insights on the interaction and influence of streamside vegetation on stream hydraulics.

Karr and Schlosser (1977), Bingham et al. (1980), and Petersen et al. (1992) reviewed the possible uses of near-stream vegetation to reduce the transport of sediment and nutrients and to decrease fluctuations in water temperatures. These investigators found that proper management of near-stream vegetation and channel morphology can lead to significant improvements in both the water and biological quality of many streams.

Riparian zones directly influence the life history of many species of Pacific Northwest fish and wildlife. Many examples are available that show this as it relates particularly to salmonids (salmon and trout). Murphy and Meehan (1991) list the influences of riparian systems on salmonids as:

- Besides contributing leaves [a major food source for many stream insects], many terrestrial insects that live on riparian vegetation fall into streams to supplement the diet of salmonids.

- Riparian vegetation contributes logs and branches that shape channel morphology, retain organic matter, and provide essential cover for salmonids.

- The roots of riparian vegetation stabilize stream banks and maintain undercut banks that offer prime salmonid habitat.

- In small streams, riparian vegetation forms a protective canopy that helps maintain cool stream temperature in summer.

Erman et al. (1977), Roby et al. (1977), Meehan et al. (1977) and Murphy and Meehan (1991) discuss the importance of overhead canopy shade and input of organic matter from the riparian zone to the aquatic and terrestrial invertebrate communities. Meehan et al. state that the food base for the biological communities of forest streams consists of leaves, needles, cones, twigs, wood, and bark. The insect communities that live on this plant material form a significant food component for trout and juvenile salmon.

Hynes (1970), Meehan et al. (1977), and Reiser and Bjornn (1979) say that the most widespread and important foodstuff of running-water fishes is invertebrates. Stream fish eat a wide range of invertebrates. During summer periods, 40 to 50 percent or more of the diet of stream dwelling trout and juvenile salmon can consist of terrestrial insects (Hynes 1970). These insects usually enter streams by falling or being blown off riparian vegetation (Reiser and Bjornn 1979). When terrestrial insects become scarce during winter periods, trout feed almost exclusively on aquatic insects.

Phinney et al. (1989) state that of the approximately 480 species of terrestrial and shoreline wildlife in Washington, 291 (60%) are regularly found in wooded riparian habitats. They further report that:

- 68 species of mammals, birds, and amphibians, and reptiles are considered to *require* riparian ecosystems to satisfy a vital habitat need during all or part of the year.

- At least 22 species of birds are specifically oriented to the aquatic component of the riparian ecosystem.

- In relation to their size, riparian areas are disproportionately important to salmon and over 70 other freshwater and estuarine fishes.

Knight (1988), citing several authors, states that riparian habitats generally have a higher diversity of bird species than other habitats. The reasons for this include the proximity of habitat requirements (i.e., food, cover, and water), the increased number of niches because of wider diversity of plant species and structure, and the high edge-to-area ratio that result from the linear shape of most riparian zones. Knopf and Samson (1988) list 17 species of Pacific Northwest birds that are dependent upon riparian systems. Knight (1988) says that of the raptor species (birds of prey such as hawks or owls) in western Washington and Oregon, 16 of 25 hunt for food primarily in riparian areas.

As mentioned above, many other species of Pacific Northwest wildlife, including some large mammals, are either dependent on or find optimum habitat in riparian systems. Bruce et al. (1985; cited by Cross 1988) lists 13 species of rodents that use the streamside riparian zone as "primary habitat." Cross (1988) lists 14 species of small mammals for which riparian areas are optimal habitat. Raedeke et al. (1988) identifies six species of larger mammals in Washington that are considered dependent on riparian areas. Raedeke (1988), citing the Washington Department of Ecology's Riparian Habitat Technical Committee (1985), states that another 103 species of wildlife are more numerous in riparian ecosystems or use them more heavily than upland habitats.

IMPACTS TO RIPARIAN AREAS

The effects of land uses on riparian areas can be multiple and varied, depending on the type of land use, degree of disturbance to streamside vegetation, size of stream, physical setting, and succession after disturbance. While land use may vary, the resulting environmental alterations generally affect riparian systems in similar ways. Increases in sediment to streams from the loss of riparian vegetation, for example, will be the same whether the loss of vegetation resulted from road construction, logging or livestock grazing.

Meehan (1991) states that "wherever livestock grazing occurs in western North America, it poses a potential threat to the integrity of salmonid habitat." Potential effects include decline of streambank vegetation and stability, increases in turbidity, nutrients and bacteria, and general loss of stability and structure. Grazing also decreases the shrub layer along streams, which with trampled soil, increases the addition of fine sediment to the stream as the filtering capabilities of vegetation and soil are reduced (Meehan et al. 1977).

The quality of agricultural runoff can significantly affect stream water quality. Burley Lagoon and Minter Bay in Kitsap County, for example, have been closed to commercial harvest of shellfish since the early 1980's because of excessive fecal coliform contamination (Struck 1990). In 1985, the Washington State Department of Ecology (WDOE) found that the primary source of pollution was on-site septic systems and small non-commercial farms in the upland watersheds. While no direct relationships between land-use and loading rates were observed, the highest relative load increases were associated with higher livestock densities. Vegetated buffers appear to contribute significantly to water quality improvements. Stream segments with extensive buffers between residential and agricultural developments generally experienced net decreases in fecal coliform loads.

Reduction of water quality in rivers in rural areas is often associated with runoff from farms (Bingham et al. 1980, Grismer 1981, Nelson et al. 1991). Unrestricted animal access accelerates bank erosion and sediment loading and contributes to increases in fecal coliforms. Effects of livestock are not limited to large-scale farming operations; they also come from small-scale commercial and hobby farms. Nelson et al. (1991), investigating the water quality of the Church Creek Basin of the lower Stillaguamish River in Snohomish County, Washington, found that turbidity and fecal coliform counts were highest in and downstream of agricultural areas where animals had access to the stream.

Thornburgh et al. (1991), in an intensive water quality study of the Snohomish River system, Washington, concluded that significant fecal coliform contributions occurred from commercial agriculture and from non-commercial farms and residential areas. Low dissolved oxygen and high fecal coliform levels were measured at most of the tributary sites. Levels of concern for nitrate and ortho-phosphate were also identified at many tributary sites. The study concluded that the highest fecal coliform levels were associated with the most intensive commercial farming operations.

The effects of altering streamside vegetation, particularly overhead canopy, have been the subject of considerable research and many reviews (Brett 1956, Brown 1969, Patton 1973, Beschta et al. 1988). Significant alteration to or removal of overhead canopy allows increased direct sunlight to reach the stream. Direct sunlight, especially in summer, can increase stream temperature and in turn affect fish and aquatic insect species composition and growth. High summer water temperatures can kill salmon and trout directly, increase the virulence of many fish diseases, provide a habitat that favors less desirable fish, inhibit spawning activity or block spawning runs into streams, affect the quantity of food available, and alter the feeding activity and body metabolism of fish (Lantz 1971).

Hicks et al. (1991) report that the importance of streamside management as a tool to protect fishery values has been demonstrated in several studies that have compared fish habitat and salmonid populations in streams that were and were not given riparian protection during timber harvests. The evidence shows that streamside management zones minimize damage to habitat and effectively maintain the integrity of fish populations. This evidence is generally consistent over a wide span of time and space.

SUMMARY OF TECHNICAL LITERATURE

Widths for vegetated buffers recommended by various investigators varies widely depending on the specific resource or function to be maintained. The buffer widths recommended by 38 separate investigators to maintain seven major riparian functions ranged from 3 to 200 meters (m) (Table 1). Some variation is due to the lack of a consistent focus for research efforts. While extensive data is available, for example, on the ability of vegetated buffers to reduce the quantity of fecal coliform bacteria in surface runoff, individual researchers typically emphasized different aspects of the issue. Various investigators studied infiltration of bacteria into soil, bacterial die-off rates during manure storage, the design of grass swale filter strips, and the dilution of wastes before spreading on pastures. Data on other buffer functions showed a similar range of investigational issues.

The recommended buffer widths for each major function will be summarized and discussed individually. A thorough summary with additional information prepared by Castelle et al. (1991a) is in Appendix A and will not be repeated here. It is important to note that the initial emphasis of this report was on reviewing information relating to local conditions (i.e., western Washington). It soon became apparent that except for grazing, the results of the various studies from across the nation and from Europe consistently ranged from 15 to 50 m. Our review thus expanded to include research conducted in humid, temperate climates (i.e., western Washington and Oregon, eastern coastal areas, and portions of the Mid-west).

Investigations of the effects of grazing on riparian systems are primarily from the Great Basin of the western United States. The climate of this area, which is mostly semi-arid or arid, is very different from the humid climate of western Washington. Because of this and other differences with this region, we did not include this information in our review. Platts (1991) throughly summarizes information on effects of grazing on stream systems in the Great Basin.

The efficacy of vegetated buffers in maintaining water quality, including sediment removal, fecal coliform reduction, nutrient reduction, and stormwater runoff management generally increases with increasing buffer width. Most investigators recommend buffer widths of 30 to 122 m (Table 1; Appendix A).

Table 1. Various functions of vegetated buffers and recommended widths to maintain those functions.

Function	Recommended Buffer Width	Reference
Miscellaneous Functions		
--system stability	• minimum 20-30 m	• Corbett and Lynch 1985
--fenced areas	• minimum 5 m from top of bank	• Helfrich et al. 1985
	• area inundated by high flows	• Bottom et al. 1985
--recruitment of woody debris	• 31 m	• Bottom et al. 1983[1]
--noise reduction	• 6-15 m	• Harris 1986
	• 32 m	• Groffman et al. 1990
--maintenance of benthic communities	• 30 m	• Erman et al. 1977
	• 30 m	• Roby et al. 1977
	• 30 m	• Newbold et al. 1980
Reduce Fecal Coliforms	• 30 m	• Grismer 1981
	• 23-92 m	• SCS 1982
Nutrient Reduction	• 36 m	• Young et al. 1980
	• 30 m	• Lynch et al. 1985
	• 30-43 m	• Jones et al. 1988
	• 16 m	• Jacobs and Gilliam 1985
	• minimum 10 m	• Petersen et al. 1992
	• minimum 15 m	• Castelle et al. 1991a
	• 4 m	• Doyle et al. 1997[2]
Sediment Removal	• 30 m	• Erman et al. 1977
	• 3 m (sand), 15 m (silt), and 122 m (clay)	• Wilson 1967
	• 30 m	• Moring 1982
	• 30 m	• Lynch et al. 1985
	• 75% removal in 30-38 m	• Karr and Schlosser 1977
	• 50% deposition w/in 88 m	• Gilliam 1988[3]
	• 8-46 m depending on slope	• SCS 1982
Control Water Temperatures by Shading	• 30 m	• Lynch et al. 1985
	• 30-43 m	• Jones et al. 1988
	• 12 m	• Corbett and Lynch 1985
	• 15-30 m	• Hewlett and Fortson 1982
	• 60-80% shade in 11-24 m	• Brazier and Brown 1973
	• 60-80% shade in 23-38 m	• Steinblums et al. 1984

Table 1. cont'd

Function	Recommended Buffer Width	Reference
Wildlife Habitat	30 m--cutthroat	Hickman and Raleigh 1982
	30 m--brook trout	Raleigh 1982
	30 m--chinook salmon	Raleigh et al. 1986
	30 m--rainbow trout	Raleigh et al. 1984
	61 m	Zeigler 1988
	23 m	Mudd 1975
	75-200 m (birds), 100 m (large mammals), 67-93 m (small mammals)	Jones et al. 1988
	30-100 m (beaver)	Allen 1983
	15 m	Milligan 1985
	18 m	Anonymous 1988
	30-50 m	Dickson 1989
	15 m	Castelle et al. 1991a
	32 m	Groffman et al. 1990
	27 m	WDOE 1981[1]
	10 m	Petersen et al. 1992

[1]cited in Budd et al. 1987
[2]cited in Bingham et al. 1980
[3]cited in Mauermann 1989

The widest range in recommended widths was for buffers to filter suspended sediments. This is largely due to one reference (Wilson 1967) that reports separate buffer widths for filtering sediment particles of different sizes. These include sand (3 m), silt (15 m), and clay (122 m). Four of the remaining authors suggest buffers of 30-38 meters; one recommends 88 meters.

Brazier and Brown (1973), Hewlett and Fortson (1982), Steinblums et al. (1984), and, in particular, Beschta et al. (1987) comment on the effects riparian vegetation on stream temperatures. Beschta et al. report the relative degree of shading provided by a buffer strip depends on a range of factors (e.g., species composition, age of stand, density of vegetation). Buffer strips with widths of 30 m or more generally provide the same level of shading as that of an old-growth stand.

Recommended buffer widths to maintain wildlife habitat range from 30 m to protect salmonid habitat, 67-93 m for small mammals, 75-200 m for some birds during the breeding season, and 100 m for large mammals. This broad range is the result of the wide variation in the requirements of different wildlife species. For terrestrial species, for example, the recommended buffer is for direct maintenance of essential habitat. For fish, the buffer is to protect elements of riparian system that contribute directly to required habitat.

Benthic communities (aquatic insects) were investigated by Erman et al. (1977), Roby et al. (1977), and Newbold et al. (1980). They concluded that logged streams with buffer strips of at least 30 m supported benthic communities indistinguishable from unlogged streams. Benthic communities in streams with no buffers, or with buffers less than 30 m, were significantly different from unlogged streams. These three authors agree that 30 m was the width necessary to protect benthic communities.

Harris (1986) studied the ability of vegetated buffers to abate noise along busy streets. A 6 m mature vegetated barrier is recommended to match conventional noise barriers. Groffman et al. (1990) suggest a heavily forested buffer of 32 m to reduce the noise of commercial areas to background levels.

Helfrich et al. (1985) recommend that fences to minimize streambank damage by unrestricted movement of livestock be built well back from the streambank. They recommend a minimum distance of five meters from the top of the streambank (not the water's edge) to protect streambank plants and prevent flood damage to fencing. Bottom et al. (1985) state that in fencing stream corridors, the fence line must be far enough from the channel that ice and debris transported by high flows do not damage the fence.

EXAMPLES OF NATIONAL AND LOCAL BUFFER REQUIREMENTS

As mentioned above, many regulations have been enacted that specify "appropriate" buffer widths for many combinations of circumstances. Required buffer distances vary from 6 to 300 m (Table 2). Some requirements reported in Table 2 have changed since the date reported. In Montana, for example, buffer widths of 6-10 m have been increased. The 1991 Montana Streamside Management Act mandates a minimum 15 m streamside management zone to protect water quality during logging operations (Logan and Clinch 1991). This is a minimum distance in that, if wetlands are next to a stream, the management zone "must reach out beyond 15 m to protect wetlands." Additional distances can be required if steep slopes or erosive soils are present at a particular site.

Appreciation for the values and functions of the wetlands in the New Jersey Pineland National Reserve, coupled with an awareness of potential impacts imposed by development activities, provided the incentive for requiring some of the largest buffer protection areas encountered during this review. Under the New Jersey Pinelands Comprehensive Management Plan, development is not permitted within 100 m of any wetland, unless the applicant can prove that the proposed development will not have a significant adverse impact on the wetland (Roman and Good 1985).

Table 2. Examples of buffer widths required by various jurisdictions across the United States and Canada.

Jurisdiction	Required Buffer Width	References
California	31 m to maintain water quality 31 m or greater	Zedler 1984[1] Mauermann 1989
Connecticut	30 m	Murphy and Phillips 1989
Idaho	no established minimum, but water quality must be maintained	Broderson 1973[1]
Maine	46-93 m to filter agricultural runoff	Clark 1977[1]
Maryland	93 m for maximum nitrate removal from septic tanks	O'Meara et al. 1976[1]
Massachusetts	31 m permit zone	Shisler et al. 1985
Montana	6-9 m to stop silt flows minimum 15 m	Broderson 1973[1] SMA 1991[2]
New Jersey	15-93 m, some case-by-case considerations	Roman and Good 1986
New Hampshire	23 m	Mauermann 1989
North Carolina	23 m for areas of environmental concern	La Prade 1985[1]
Oregon	no established minimum buffer, shade and soil integrity should be maintained	Broderson 1973[1]
Rhode Island	31 m for rivers <3 m wide, 62 m for rivers >3 m	Bryan 1981[1]
Vermont	case-by-case basis to maintain streambank stability and shading	Shisler et al. 1985
Washington	61 m for shorelines of significance 12 m, or 3x bank-to-bank stream width to prevent increases in water temperature	RCW 90.58 Broderson 1973
Wisconsin	93 m around navigable rivers, 304 m around navigable lakes	Schultz 1981[1]
Ontario, Canada	27-55 m	Ontario MNR 1988

[1]cited in Shisler et al. 1985
[2]cited in Logan and Clinch 1991

The buffer widths or zones required by local regulations generally range from 7 to 30 m (Table 3). An exception to this is riparian systems within 61 m of shorelines along lakes, streams, and tidal waters defined as shorelines of the state or shorelines of statewide significance. Thurow et al. (1975) (cited in Mauermann 1989) noted that existing regulatory standards have generally been established according to three factors: scientific evidence; precedent; and political consensus.

Table 3. Examples of buffer widths required by local jurisdictions.

Jurisdiction	Buffer Policy	Reference
Island County	31 m - category A 8 m - category B	Mauermann 1989
King County	31 m - class 1 streams and wetlands 15 m - class 2 streams and wetlands 8 m - class 3 wetlands	Mauermann 1989
Pierce County	31 m	Mauermann 1989
City of Bellevue	15 m - type A 8 m - type B	Mauermann 1989
City of Federal Way	31 m - class 1 streams 15 m - class 2 streams	Federal Way Comprehensive Plan 1990
City of Olympia	8-31 m depending on size of wetland	Mauermann 1989
Western Washington	7.6-30 m	WAC 222-30-020 1988

METHODS FOR DETERMINING BUFFER WIDTHS

The confusion in riparian terminology has been accompanied by the difficulty in developing a standard method to delineate riparian systems. Gebhardt et al. (1989) provide the following perspective:

> In a riparian system, environmental conditions are not stable. The likelihood of soil and water environmental conditions at many riparian sites remaining stable, over several decades or even years, is remote. For example, fine sediment may be deposited over gravel (aggradation) creating a new soil or substrate with different profiles, permeabilities, and other soil moisture characteristics. Other sites may be eroded or in some manner have their soil structure or water supplies altered. Therefore, a riparian site may change with time from one defined riparian type to another through aggradation or degradation of the site or through major change of the water supply to the site.

Buffer widths for stream and wetland habitats may be established using two general methods. These are a fixed width to protect specific functions, or a variable width that considers specific site conditions. Examples of fixed-width buffers have been cited throughout this document (see summary of technical literature). Investigators proposing methods for determining variable buffer widths using a variety of site factors include Darling et al. 1982; Steinblums et al. 1984; Barton et al. 1985; Roman and Good 1985; Budd et al. 1987; and Groffman et al. 1990. Several investigators recommend minimum buffer widths based on slope conditions (Table 4 below).

Although a vegetated buffer may maintain several different riparian functions, the factors used in sizing buffers are similar whatever the function to be maintained. These factors include the existing quality, size, and sensitivity to disturbance of the area to be buffered, the composition, age, and condition of buffer vegetation, adjacent land use, slope, aspect, and soil characteristics (e.g., moisture, erosion, and compaction), species (animal or plant, aquatic or terrestrial, threatened or endangered) present in buffer area and protected area, and regional geology (Castelle et al. 1991a, Roman and Good 1986, Shisler et al. 1985, Steinblums et al. 1984, Darling et al. 1982).

Some design factors are specific to habitat type (e.g., streams) or to adjacent land use (e.g., logging, pasture, agricultural, residential). Examples include:

- Streams: the recruitment of large organic debris (LOD) for stream structure and microhabitat features, susceptibility of trees in buffer areas to windthrow, size, shape, and stability of the stream channel, and critical fish and wildlife habitat (e.g., spawning or nesting sites).

- Forest harvest operations: prevailing wind direction and speed, distance across adjacent clearcuts, slope, soil moisture, and other factors that can affect susceptibility of large vegetation to windthrow.

- Pasture and residential adjacent land: anticipated pollutants in stormwater runoff (fecal coliforms, pesticides, petroleum products, heavy metals), slope, quality and conditions of the buffer vegetation, density of livestock, type and condition of soil, and volume of runoff.

The appropriateness of a buffer width will depend on the linear distance or spatial area necessary to maintain desired functions. A large buffer in an area of high-intensity land use, for example, is more essential than in low-intensity land use areas. Similarly, all other factors being equal, a sensitive area such as a small tributary will benefit more from a large buffer than does a larger river.

Several investigators recommend minimum buffer widths for areas with slopes less than 1%, along with additional distance for slopes ranging up to 70% (Table 4). The distance recommended is based on adjacent landuse, purpose of the buffer, and slope. The Soil Conservation Service (1982), for example, recommends buffers of 3 to 8 m next to pastures with 0-30% slopes, 8 to 46 m near logging operations in areas of 0-70% slopes, and 23 to 92 m for livestock feedlots and liquid waste treatment on 2-6% slopes.

Table 4. Recommended buffer widths as a function of slope.

Minimum 8 m plus 0.6 m for each 1% percent of slope above stream up to 50 m for slopes of 70%	Haussman and Pruett 1978[1]
Minimum 15 m plus 6 m for each 5 percent of slope up to 34 m for slopes ≥15% (additional 1.2 m for each 1% increase in slope)	Clark 1977[1] Trimble and Sartz 1957[2]
Minimum 3 m for slopes <1% and proportionately greater up to at least 8 m for 30% slopes (0.17 m for every 1% slope increase) in healthy pasture; minimum 8 m for slopes <1% and proportionately greater to at least 20 m for slopes of 30% and 46 m for slopes of 70% in forestry operations (0.54 m for every 1% increase in slope)	SCS 1982

[1]cited in Shisler et al. 1985
[2]cited in Mauermann 1989

RECOMMENDED BUFFER WIDTHS BASED ON REVIEW OF AVAILABLE LITERATURE

Although the literature review for this project was not exhaustive, similar recommendations were found time and again for many functions (Table 1; Figure 1). Within the range given for each function certain values predominate. While the shade from buffers of 11 to 43 m wide maintains stream temperatures to varying degrees, the general indication from most of the literature reviewed was that the greatest benefit occurred with 30 meters. Nutrient reduction occurs in buffers of 10 to 40 meters, with four of six investigators recommending buffer widths of 15 to 30 m. While sediment removal occurs with buffers of 3 to 122 m, three of the five references suggest 30 meters for this function. Buffer widths of 15 to 46 m were reported to reduce the volume of stormwater runoff.

Fixed- or variable-width buffers each have advantages and disadvantages. An agency's available resources and constraints will figure strongly in the final choice of how buffers will be set. Fixed-width buffers are more easily enforced, do not require regulatory personnel with specialized knowledge of ecological principles, and require smaller expenditures of both time and money to administer. This option, however, may result in arbitrary buffer distances that sometimes may not be appropriate. Depending on site conditions, a fixed width may not include essential components of the buffer, nor adequately buffer the riparian or stream system. Naiman et al. (1992) state that simple prescriptive management, such as riparian zones of fixed width, is less effective than management techniques adapted to local topography and natural disturbance regimes. In other cases, again depending on site conditions and the riparian function to be maintained, a smaller buffer may adequately protect the stream and riparian community.

Variable-width buffers allow greater flexibility for varying site conditions and land management practices for landowners. Variable-width buffers can be tailored to existing site conditions and desired functions, eliminating the need to protect features non-existent in an area. The quality of buffer and site conditions (e.g., quality and age of vegetation, severity of impact, livestock density, or sensitivity of the system to disturbance) should be considered in determining a buffer width. This option requires that professional judgement be employed in the decision-making process, and thus, may not be feasible for small or newly formed departments lacking experienced personnel. Because of the variability of sites requiring buffers, individual site visits and detailed information are prerequisites for a buffer-width decision. While this is a more costly and time-consuming process, it may protect the environment more completely without causing undue losses to landowners.

From Figure 1, it appears that buffers less than 10 m provide little if any maintenance of the functions listed. Buffers of 15 to 30 m provide minimal maintenance for most functions; buffers greater than 30 m (30-50 m) appear to provide adequate protection for most the functions listed. Based on our review of the scientific literature, whether a fixed buffer or variable width buffer is to be established, we recommend a *minimum* buffer distance of 15 to 30 m. It should be noted that this is a minimum distance and that this distance will vary depending on the riparian function to be maintained. If a specific function is being targeted for protection or maintenance, the buffer width is determined by the requirement for that function alone (Figure 2). If several functions or critical stream or buffer elements are to be protected, the most sensitive function or the one with the largest buffer requirement will decide the buffer width for the stream.

It should be emphasized that buffers will have little or no effect on sediment or nutrient removal if water flows across the buffers as channelized flow. Buffers can only be effective in this capacity if they resist channelization and maintain overland flow as sheetflow.

Figure 1. Range of buffer widths recommended by various investigators to maintain selected functions of riparian areas. See text for discussion and references. (x) indicates number of studies on which average and range are based.

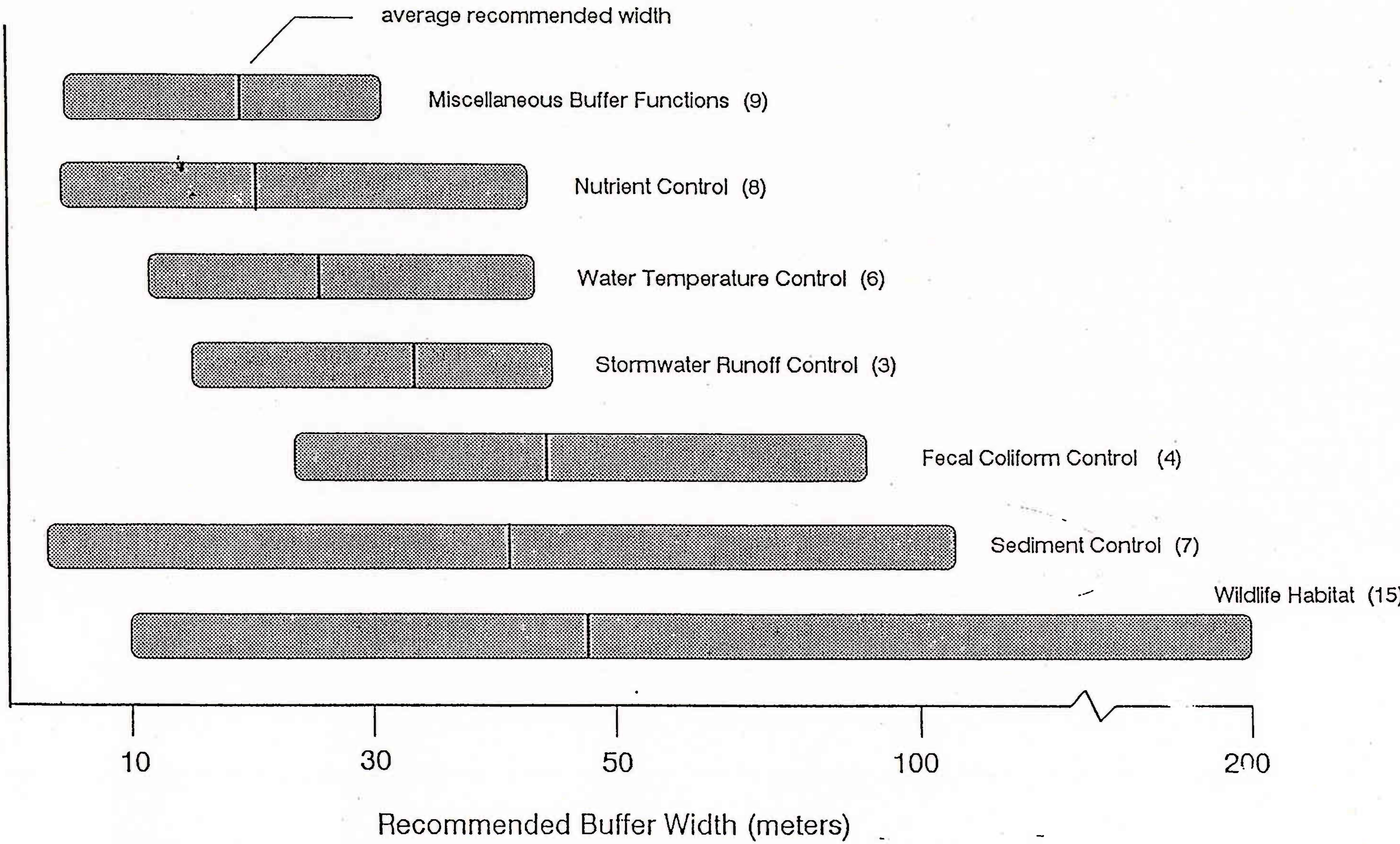
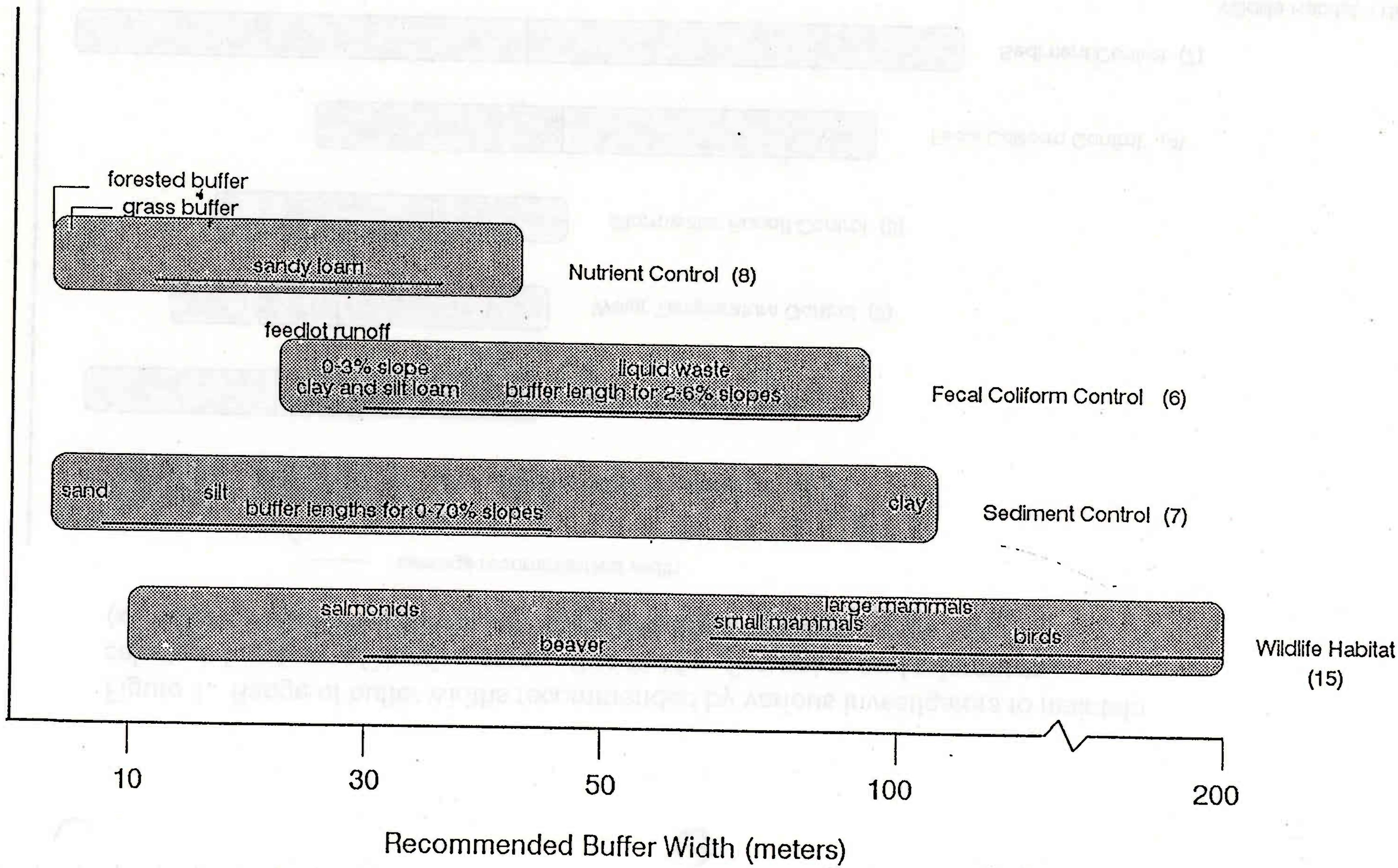


Figure 2. Examples of variabilty in buffer widths recommended by various authors. See text for discussion and references. (x) indicates number of studies reviewed for each function.



If the ultimate procedure for conserving rivers and streams is the proper planning and control of complete catchments, then the management of riparian zones forms an important first step (Petersen et al. 1987; cited in Boon 1992). Petersen et al. (1992) state that the first step in any stream restoration program must be to protect and set aside land along the length of the stream. They further say that "if the natural functions of a small stream are to be restored and maintained, then it is a waste of time to make changes in the channel without protecting the channel banks and the riparian area."

Above all, in considering the many facets of this issue, the goal of resource management should be to maintain the integrity of our natural systems. Whatever method is chosen, it should be apparent in the decision process which riparian and stream functions are going to be maintained and which are going to be allowed to degrade. As stated by Reeves et al. (1991):

> "All habitat modification procedures . . . have had variable success. These methods cannot be relied upon to mitigate poor management practices. The importance of preventing habitat degradation now, instead of being forced to rebuild habitats in the future because of today's management practices, cannot be overemphasized. Protection of habitat is by far the most effective stream rehabilitation and enhancement technique."

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APPENDIX A. FINDINGS AND RECOMMENDATIONS FROM SCIENTIFIC LITERATURE REGARDING VEGETATED BUFFER WIDTHS.

The following information is from Castelle et al. (1991a). While the focus of their report was on buffers for wetland areas, much of the information is pertinent to stream systems.

The scientific basis for buffer requirements is rooted in the myriad functions buffers serve. While several investigations have examined buffer requirements and effectiveness holistically, many other researchers have isolated one or two specific buffer functions or applications in their studies. The following wetland buffer functions are discussed:

1) erosion control and stabilization;
2) sediment removal;
3) nutrient removal;
4) stormwater impact moderation;
5) system microclimate moderation;
6) habitat diversity enhancement;
7) human impact deterrence; and
8) wetland wildlife and habitat protection.

There are several approaches used to assess the adverse wetland impacts from adjacent landuses and to determine what buffer width will be effective in mitigating that impact. Scientists are approaching this problem from various perspectives. Researchers have examined various biological, chemical, and physical components to assess wetland impacts. These studies include monitoring water quality and quantity; examining plant and animal species distribution; monitoring habitat quality and composition; and measuring levels of human use. Each of these approaches gives a portion of the information necessary to make informed decisions about buffer widths.

1) <u>Erosion Control and Stabilization</u>: Vegetated wetland buffers function to control erosion by: blocking the flow of sediment and debris; stabilizing the streambank or wetland edge; and promoting infiltration by decreasing the rate of flow (Shisler et al. 1987). The physical barrier of the vegetation serves to slow the velocity of the surface flow of water. The roughness of the vegetation mechanically traps sediment and debris. The proper functioning of a buffer zone depends in great part on its ability to resist channelization (Broderson 1973). If the majority of stormwater moving through the buffer does so as sheet flow, the rate of flow is significantly slower, and the residence time of the water in the buffer is increased allowing more time for settling of water-borne sediments and infiltration. In addition, the root systems of the buffer vegetation aid in the maintenance of soil structure and bank stability (Broderson 1973).

2) <u>Sediment Removal</u>: Wong and McCuen (1982) analyzed the ability of vegetated buffers to trap sediment. They found that average particle size, slope, roughness of vegetated cover, and runoff characteristics must be taken into account in determining buffer widths effective to trap a given percentage of sediment in stormwater flow. Vegetative cover causes the velocity of surface flow to decrease, increasing the amount of sediment settling out of the water column. Using these parameters, they derived an equation to determine effective buffer widths. While small buffers were found to remove small amounts of sediments, these investigators found that the direct relationship between buffer width and percent sediment removal was non-linear and that disproportionately large buffer width increases were required for incrementally greater sediment removal. For example, effective buffer widths approximately doubled (from 100 ft to 200 ft at 2% slope) when the design criteria increased from 90% to 95% sediment removal. The authors did not address the removal of the soluble components in stormwater. Young et al. (1979) looked at sediment trapping from livestock feedlots and found that an 80-foot vegetated buffer reduced the suspended

sediment in the runoff by 92%. Horner and Mar (1982) found that a 200 foot grassy swale removed 80% of the suspended solids and total recoverable lead.

The effectiveness of using buffers to improve water quality adjacent to logging operations was examined by Broderson (1973), Darling et al. (1982), Lynch et al. (1985), and Corbett and Lynch (1985).

Broderson studied three watersheds in western Washington (Green River, North Fork Snoqualmie River, and South Fork Tolt River). Broderson noted that buffers will have little or no effect on sediment removal if sediment-laden water flows across the buffers as channelized flow; buffers can only be effective if they resist channelization and maintain overland flow as sheetflow. Broderson found that 50-foot buffers were sufficient for controlling most sedimentation on less than 50% slopes, while steeper slopes required wider buffers. A maximum buffer width of 200 feet was found to be effective even on extremely steep slopes. Furthermore, Broderson recommended that buffer widths be measured not from the top of the streambank, but rather from "visual signs of high water."

Corbett and Lynch (1985), citing research done for an earlier paper by Corbett et al. (1978), concluded that a 40-foot buffer may be adequate to protect streams from excessive temperature elevation following logging, but that a zone of 66 to 100 feet may be necessary to buffer the entire ecosystem, especially when steep slopes are encountered and increased runoff with heavy sediment loads are generated.

Darling et al. (1982) assessed an Oregon State University (OSU) formula for protecting streams and wetlands from tree blowdowns and subsequent large debris and sediment incursions into streams and wetlands. This formula includes factors such as slope, and horizontal and elevational distances from the midpoint of the buffer to the top of the nearest major ridge in the direction of the prevailing winds. Additionally, soil stability and antecedent soil moisture are considered. These investigators were primarily interested in buffer stability over time, and concluded that the OSU formula could be successfully applied in Olympic National Forest, Washington. Further, they found that the best-functioning buffers were the most stable, and that buffer stability was in turn enhanced by high percent vegetative cover and dense stands of trees, rather than by sparse vegetation or individual trees protruding above an understory. They did not, however, directly address buffer widths.

Lynch et al. (1985) assess the success of 30-meter (98-foot) buffer strips between logging activity and wetlands and streams in Pennsylvania. They found that these buffers removed an annual average of approximately 75 to 80% of the suspended sediment in stormwater. Greater sedimentation resulted from forested areas which had been commercially clear-cut and then denuded with an herbicide. Surface flow in these areas tended to be channelized rather than sheetflow, although Lynch et al. (1985) made no recommendations for larger buffers in such areas.

3) Nutrient Removal: A number of studies have assessed the impact of soluble nutrient transport on water quality and the use of buffers to control this source of pollution influx into wetland and stream surface water. Vanderholm and Dickey (1978) monitored feedlots exposed to natural levels of rainfall and found buffer widths ranging from 300 feet (at 0.5% slope) to 860 feet (at 4.0% slope) to be effective in removing 80% of the nutrients, solids, and oxygen-demanding substances from surface runoff through sediment removal and nutrient uptake. Doyle et al. (1977) also assessed the effect of forest and grass buffer strips at improving the quality of runoff from manure application. Doyle et al. found that both forested and grass buffers were effective at reducing nitrogen, phosphorus, potassium, and fecal bacteria, in 3.8 and 4.0 m (12.5 and 13.1 feet) respectively. In addition, grass buffer strips were effective in reducing nitrate and sodium levels. Lynch et al. (1985) evaluated the utility of vegetated buffers in reducing soluble nutrient levels in runoff from logging operations. They round that a 30m (98 foot) buffer reduced nutrient levels in the water to "far below drinking water standards."

A slightly different approach was used by Bingham et al. (1980), who studied pollutant runoff from caged poultry manure. Rather than recommending specific buffer widths, the authors reported that a 1:1 buffer area to waste area ratio was successful in reducing nutrient runoff to background levels for animal waste applications. Overcash et al. (1981) analyzed grass buffer strips as vegetative filters for non-point source pollution from animal waste with a one dimensional model, and also concluded that a 1:1 ratio of buffer area length to waste area length was sufficient to reduce animal waste concentrations by 90% to 100%. Wooded riparian buffers in the Maryland coastal region were found to remove as much as 80% of excess phosphorus and 89% of excess nitrogen, most of it in the first 19 m (62.3 feet) (Shisler et al. 1987).

Lowrance and Orden (1981) evaluated the ability of riparian forest vegetation to remove sediment and nutrient discharges from surrounding agroecosystems. They found that nutrient uptake and removal by the soil and vegetation in the upland forested buffer was high, and prevented outputs from adjacent disturbances from reaching the stream channels. However, they did not recommend any specific buffer widths.

4) Moderation of Stormwater Runoff: Wetland buffers affect both quantity and quality of stormwater runoff. A vegetated buffer zone that resists channelization is effective in decreasing the rate of water flow, and in turn, increasing the rate of infiltration (Broderson 1973). Bertulli (1981) concluded from his study of a southern Ontario, Canada, watershed that adjacent forest vegetation and litter lowered stream flow from 388 to 207 inches in a 100-year event.

Buffers also function to improve water quality. The uptake of dissolved heavy metals and large amounts of nutrients by plants has been well-documented (Murdoch and Capobianco 1979, Shisler et al. 1987, Gallagher and Kibby 1980). For example, Murdoch and Capobianco (1979) found that *Glyceria grandis*, a common wetland grass in western Washington, took up 80% of the available phosphorus, and also took up significant quantities of lead, zinc, and chromium. Gallagher and Kibby (1980) found that other wetland species such as *Carex lyngbyei* (Lyngbi's sedge), *Salicornia virginiana* (pickleweed), *Juncus balticus* (Baltic rush), and *Potentilla pacifica* (Pacific silverweed) accumulated copper, chromium, iron, manganese, strontium, lead, and zinc.

5) Moderation of Water Temperature: Forested buffers adjacent to wetlands function to provided cover, thereby helping to maintain lower water temperatures in summer and lessen temperature decreases in winter. The ability of forested buffer strips to maintain lower water temperatures in the summer months has been investigated by several researchers. Broderson (1973) found that 50-foot buffers provided 85% of the maximum shade for small streams (defined as streams with mean annual discharges of less than 5 cubic feet per second). Broderson found that buffer widths along slopes could decrease with increasing tree height. For instance, a stand 200 feet tall on level ground provides shade approximately 90 feet from the trunk during mid-July when temperature problems often occur. If this stand of trees were on a 60% slope, the effective shade width would increase to 150 feet. Shadow length also increases in the summer months with increasing latitude.

Lynch et al. (1985) found that a 30-meter (98-foot) buffer from logging operations maintained water temperatures within 1° C of their former average temperature. Barton et al. (1985) found a strong correlation between maximum water temperatures and buffer length and width for trout streams in southern Ontario, Canada. They derived a regression equation in which buffer dimensions accounted for 90% of the observed temperature variation.

In their study, Brazier and Brown (1973) sought to define the characteristics of buffer strips that were important in shading small streams adjacent to logging. They found that 73 feet (24 meters) was often ample buffer to shade these streams, maintaining pre-logging temperature ranges. They advocated establishing a buffer range that would apply to different situations of slope, exposure, and canopy cover on a case by case basis.

6) Maintenance of Habitat Diversity: Often birds and animals that are considered to be wetland species have specific needs which can only be met in the adjacent upland buffer (Naiman 1988). Species such as wood ducks, great blue herons, pileated woodpeckers, and ospreys require large trees for nesting. Amphibians such as the Pacific tree frog spend only a short portion of their life span actually in a wetland, although they cannot complete their life cycle without one. Many birds such as black-capped chickadees, swallows, and Lincoln's sparrows, which feed in wetlands, breed and raise their young in the buffer. This is often true of small mammals such as mink, river otters, and dusky shrews (Ziegler 1990). These animals must burrow above the high water mark to avoid inundation of their burrow, and this means that they spend significant portions of their lives in the buffer.

Isolated and riparian wetlands and their buffers often afford most of the greenspace in urban environments. These wetlands and buffers allow animals and birds to travel through the urban landscape with some protection from humans and domestic animals. These wildlife corridors have become increasingly important to wildlife with the continuing fractionalization of the landscape.

Buffers also function as a transition zone between upland and wetland environments. The ecotone, or area where one ecotype touches another, is recognized as a boundary having a set of characteristics uniquely defined by space and time scales, and by the strength of the interaction between the adjacent ecological systems (Naiman et al. 1988). "Edge effect" is a well-known concept, first coined by Leopold in 1933, that proposes that species numbers of both plants and animals increases at edges, due to overlap from adjacent habitats and to creation of unique edge-habitat niches. Edges are the location of increased wildlife use including: feeding; roosting; breeding and rearing of young; and using the increased cover for safety and mobility (Ranney et al. 1981). Ranney also found that forest edge plants had higher primary productivity (seed and vegetative growth) than those in adjacent habitats. So we see that buffer zones are important habitats unto themselves, in addition to affording protection to wetland.

7) Discouraging Adverse Human Impact: Buffer zones function to protect wetland from direct human impact through limiting easy access to the wetland and by blocking the transmittal of human and mechanical noise to the wetland. Direct human impact to wetlands most often consists of refuse dumping, the trampling of vegetation, and noise. Shisler et al. (1987) analyzed 100 sites in coastal New Jersey to evaluate the relationship between buffer width and direct human disturbance (DHD) to wetlands. Shisler et al. found that the adjacent land use type accounted for much of the variation found in the level of human disturbance. In all cases, human disturbance was higher in wetlands adjacent to dense residential or commercial/industrial uses. They also found that there was an inverse relationship between buffer width and DHD. Shisler et al. found significant decreases of DHD in forested wetlands with increasing buffer width, and non-significant decreases in DHD in salt marshes and freshwater tidal wetland with larger buffer widths. They believed that the latter finding of non-significance was probably due to sample size. The authors found that construction debris, refuse, and trampling were the most common forms of disturbance.

The ability of vegetated buffers to abate noise has been further studied. Harris (1986) studied vegetated borders along busy streets, and concluded that the insertion loss per foot through an evergreen vegetated buffer was between 0.2 - 0.3 decibels(A), and a 20' wide mature evergreen vegetated buffer would provide an insertion loss of approximately 4-6 decibels(A). (A loss of 3-4.5 decibels(A) corresponds to approximately tripling the distance between the source of noise and the receptor.)

Vegetated buffers provide visual separation between wetland and developed environments, blocking glare and human movement from sensitive wildlife (Young 1989).

8) Wetland Species Distribution and Diversity: Often the "health" of a particular type of habitat is measured by the presence or abundance of a particular species of plant or animal or by the presence of particular community types. These "indicator species" and communities are often studied to determine the

amount or extent of protection that a habitat needs in order to maintain its viability in the landscape. Protection afforded to wetlands by buffers has been assessed using various species of birds and animals as indicators.

Milligan (1985) studied bird species distributions in 23 urban wetlands in King County, Washington. She found that bird species diversity, richness, relative abundance, and the breeding numbers were moderately positively correlated with wetland buffer size. Specifically, there were small increases in species diversity were associated with wetland buffer size increases from 50 to 100 to 200 feet. While Milligan concluded that wetland size and the amount of wetland edge was more important than buffer size, her work suggests a minimum 50 feet of buffer for bird habitat preservation. Finally, Milligan noted that larger buffers may be required for wetlands adjacent to high intensity land uses.

Heifetz et al. (1986) analyzed juvenile salmonids in assessing the success of stream buffers in logged areas. They found that buffers protected the pool habitat and consequently increased salmonid habitat area and population. Hickman and Raleigh (1982) also studied salmonids, specifically cutthroat trout, and recommended that 100-foot buffers be maintained, although they offered no quantification for their recommendation. Moring (1982) assessed the effect of sedimentation following logging with and without buffer strips of 30 m (98 feet). The author found that increased sedimentation from logged, unbuffered streambanks clogged gravel streambeds and interfered with salmonid egg development. With buffer strips of 30 meters or greater, the salmonid eggs and alevins developed normally.

Erman et al. (1977) also found that a 30 m (98 foot) buffer zone was successful in maintaining background levels of benthic invertebrates in streams adjacent to logging activity in a study of California streams.

A series of Habitat Suitability Index Models has been published by the United States Department of the Interior, Fish and Wildlife Service, describing key environmental variables and habitat features essential for particular species. Allen (1983, 1984) discusses mink and muskrat habitat needs. Muskrat depend primarily upon emergent vegetation for food and cover, but Allen found that optimal habitat provided a dense, herbaceous border along the wetland at least 10 meters (32.8 feet) wide containing a 50-80% canopy cover. Muskrat populations were found to suffer from livestock use adjacent to the wetland from trampling of burrows and decreased vegetative cover. Mink were found to tolerate human activity if enough food were present. Optimal conditions for mink include surface water that is present for at least 9 months of the year, and the presence of woody vegetation within 100 meters (274 feet). In small forested or scrub-shrub wetlands, the adjacent 100 meters (274 feet) of wetland was found to be of relative importance.

Habitat Suitability Index Models have also been prepared for various species of fish. McMahon (1983) found that vegetated buffers were important for survival of juvenile coho salmon, both for temperature moderation and increased food supply. Brook trout are also extremely susceptible to elevated temperatures, and Raleigh (1982) recommends a 30 m (98 foot) buffer width with 50-75% midday shade as optimal. Eighty percent of this buffer should be vegetated, for erosion control, for maintaining the undercut bank areas, and for providing essential cover for the trout along the bank. Raleigh et al. (1984) describe similar habitat requirements for rainbow trout, and recommend the same size and make-up for buffer areas.

Habitat Suitability Index Models have also been published for several bird species which depend upon wetlands for part or all of their life cycle. Sousa and Farmer (1983) found that wood ducks preferred a ratio of 50-75% cover to 25-50% open water for ideal breeding and brood rearing conditions. They nest in cavities in trees from 0-1150 feet from water; therefore, forested buffer was essential for breeding success. Isolated wetlands less than 10 acres in sized were considered marginal for wood duck habitat. Schroeder (1984) wrote that black brant, feeding in estuaries on eelgrass beds and sea grass exposed at high tide, are sensitive to human activities. Schroeder recommends buffer widths ranging from 600 feet (for highly disruptive activities such as helicopter flights or shellfish harvesting), to 300 feet (for low levels of human activity such as swimming, boating or low-density residential shoreline development).

Some researchers have assessed the value of buffers for several species concurrently and offer general buffer recommendations. Mudd (1975) studied the Touchet River, analyzing current conditions along the river, and the amount of riparian and wetland wildlife habitat that existed. Bird, mammal, and plant species were surveyed, although game species were studied in the greatest depth. Mudd found that a minimum of 75 feet of natural riparian, primarily mature, vegetated buffer promoted optimum wildlife populations.

In summary, eight broad wetland functions have been examined by the research and regulatory community in relation to buffer widths. The ability of different buffer widths to protect wetland function increases proportional to increasing width.