Design Recommendations for Riparian Corridors and Vegetated Buffer Strips

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Complexity	Value as a Planning Tool	Cost
Low Moderate High	Low Moderate High	Low Moderate High

INTRODUCTION

Riparian zones occur as transitional areas between aquatic and upland terrestrial habitats. Although not always well-defined (Fischer et al. 2000), they generally can be described as long, linear strips of vegetation adjacent to streams, rivers, lakes, reservoirs, and other inland aquatic systems that affect or are affected by the presence of water. Riparian zones typically comprise a small percentage of the landscape, often less than 1 percent, yet they frequently harbor a disproportionately high number of wildlife species and perform a disparate number of ecological functions when compared to most upland habitats. Riparian zones have been widely recognized as functionally unique and dynamic ecosystems only within the past 25 years. Even more recently, these areas have become a major focus in the restoration and management of landscapes (Knopf et al. 1988, Naiman, Décamps, and Pollock 1993).

Unfortunately, many riparian zones in North America do not function properly (e.g., they are degraded to the point that they do not protect water quality or provide the resources needed to make them suitable as wildlife habitat or as movement corridors). This degradation also negatively affects many of the other important functions and values these landscape features provide.

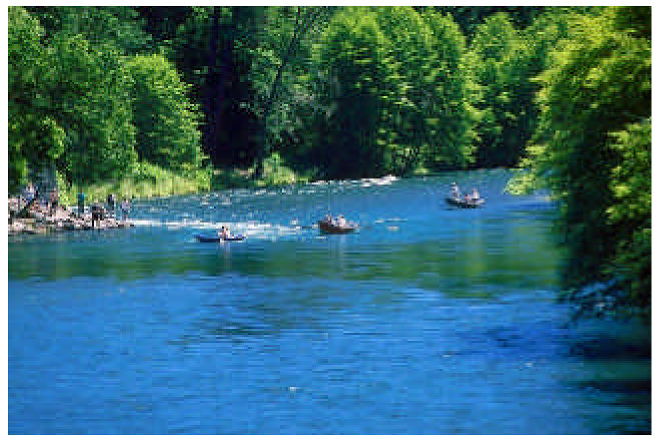

Figure 1. Characteristics of vegetated riparian buffer strips influence water quality, wildlife, and recreational opportunities (photo courtesy of the U.S. Army Corps of Engineers).

WHAT IS THE DIFFERENCE BETWEEN BUFFER STRIPS AND CORRIDORS?

There is considerable confusion in the literature regarding both wetlands and riparian zones (Fischer et al. 2000). At the heart of this confusion is the proper distinction between vegetated buffer strips and corridors. Riparian zones are most commonly referred to as vegetated buffer strips (e.g., riparian buffer

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strips) or as wildlife movement corridors (e.g., riparian corridors). These titles relate to the principal intended or recognized purpose of the riparian zones. Understanding the similarities and differences between these two terms, and having a clear idea of one's objectives, can have major implications for how one might attempt to manage a riparian ecosystem. These terms are defined below:

Riparian Buffer Strip. A linear band of permanent vegetation adjacent to an aquatic ecosystem intended to maintain or improve water quality by trapping and removing various nonpoint source pollutants (NPSP) (e.g., contaminants from herbicides and pesticides; nutrients from fertilizers; and sediment from upland soils) from both overland and shallow subsurface flow. Buffer strips occur in a variety of forms, including herbaceous or grassy buffers, grassed waterways, or forested riparian buffer strips. A buffer strip may provide habitat for a variety of plants and animals if sufficient land area is retained to meet the life-history needs of those species. Buffer strips may also function as movement corridors if they provide suitable connections between larger blocks of habitat (see below).

Riparian Corridor. A strip of vegetation that connects two or more larger patches of vegetation (i.e., habitat) and through which an organism will likely move over time. These landscape features are often referred to as "conservation corridors," "wildlife corridors," and "dispersal corridors." Some scientists have suggested that corridors are a critical tool for reconnecting fragmented habitat "islands."

WHY ARE BUFFER STRIPS AND CORRIDORS IMPORTANT?

The management and restoration of riparian corridors and vegetated buffer strips is becoming an increasingly important option for improving water quality and conserving wildlife populations. There is solid evidence that providing riparian buffers of sufficient width protects and improves water quality by intercepting NPSP in surface and shallow subsurface water flow (e.g., Lowrance et al. 1984, 1986; Peterjohn and Correll 1984; Pinay and Decamps 1988). In the absence of proper buffer strips, there is a greater requirement for water treatment plants and other expensive restoration techniques (Virginia Department of Forestry 1998).

Buffer strips also clearly provide habitat for a large variety of plant and animal species, shade aquatic habitats, and provide organic matter (e.g., leaves) and large woody debris that is critical for aquatic organisms. Their role as movement corridors for wildlife species is not quite as clear, but they have become a popular tool in efforts to mitigate fragmentation and conserve biodiversity. They have been proposed, and in some cases documented, to be habitat components that promote faunal movement, enhance gene flow, and provide habitats for animals either outright or during disturbance in adjacent habitats (e.g., clearcut in upland). However, some scientists suggest that corridors are being used too frequently and at the expense of purchasing and conserving larger blocks of unfragmented habitat.

Vegetated riparian zones in urban areas, often called "greenbelts" or "greenways," are protected open spaces (usually along stream valleys and rivers) that are managed for conservation, recreation, and nonmotorized transportation. They provide numerous social benefits and are a focus of many community enhancement programs. Greenways can provide a community trail system for outdoor recreation activities, such as hiking, jogging, bicycling, rollerblading, horseback riding, cross-country skiing, or walking. Greenways can also stimulate the economy by providing an array of economic and quality-of-life benefits. Numerous studies demonstrate that linear parks not only can improve the quality of life in communities, they can increase nearby property values that in turn increase local tax revenues (McMahon 1994).

STATE OF THE SCIENCE

Many land managers throughout the country are in need of improved design criteria when planning for riparian corridor restoration and management, and they need information on how various land uses influence riparian vegetation, fauna, and water quality. Although the value of riparian buffer strips is increasingly being recognized, information available to make sound management decisions for enhancing some of the functions that riparian zones can provide is presently limited (Fischer et al. 1999). Criteria for determining proper dimensions of buffer strips for some functions is not well-established and recommended designs are highly variable. Economic, legal, and political considerations often take precedence over ecological factors, and most existing criteria address only reduction or elimination of NPSP (Lowrance et al. 1984, 1986; Peterjohn and Correll 1984; Pinay and Decamps 1988). However, water quality enhancements are only one of many functions performed by riparian buffers (Budd et al. 1987; O'Laughlin and Belt 1995). Because of the lack of information relating riparian zone characteristics to other specific functions, management prescriptions (e.g., width recommendations) are frequently based upon either water quality considerations or anecdotal information. There is little regard for the full range of effects these decisions may be having on habitat, flood conveyance and storage, recreation, aesthetics, and other riparian functions.

Although riparian buffer strips are being planted along thousands of streambank miles throughout the country, the benefits of variable buffer strip designs (e.g., width, length, type of vegetation, placement within the watershed) are effectively unrecognized. There have been few systematic attempts to establish criteria that mesh water quality width requirements with conservation and wildlife values; specifically, the ability of these buffer strips to function as habitat or as corridors for wildlife dispersal between habitats in highly fragmented landscapes. Even less information is available relating riparian vegetation characteristics to hydraulic, sediment transport, and bank stability conditions of streams.

The exact specifications for connectivity[1] provided by wildlife corridors are not well-known. Most connectivity-related research has been done in predominately agricultural and forested landscapes, not riparian systems. Furthermore, it is difficult to extrapolate from individual species connectivity requirements to general rules. However, it is known with certainty that connectivity is important for the survival of some plant and animal populations.

[1] In this case, connectivity refers to a measure of the extent to which riparian zones provide for biological and ecological pathways that sustain plant and animal species throughout a region.

WHAT ARE THE GENERAL DESIGN CONSIDERATIONS?

Unfortunately, there is no "one-size-fits-all" description of an ideal riparian buffer strip. First and foremost, the primary objectives of a buffer strip should be determined. Various objectives might include protection of water quality, streambank stabilization, downstream flood attenuation, or provision of wildlife habitat or movement corridors. In general, the ability of buffer strips to meet specific objectives is a function of their position within the watershed, the composition and density of vegetation species present, buffer width and length, and slope. Some benefits can be obtained for buffers as narrow as a few feet while others require thousands of feet.

Placement with Watersheds. The spatial placement of buffer strips within a watershed can have profound effects on water quality. Riparian buffers in headwater streams (i.e., those adjacent to first-, second-, and third-order systems) have much greater influences on overall water quality within a watershed than those buffers occurring in downstream reaches. Downstream buffers have proportionally less impact on polluted water already in the stream (Alliance for the Chesapeake Bay 1996). Even the best buffer strips along larger rivers and streams cannot significantly improve water that has been degraded by improper buffer practices higher in the watershed. Many Corps projects occur along the higher order streams and rivers and have little or no control over water quality resulting from land-use practices higher in the watershed. However, buffer strips along these larger systems tend to be longer and wider than low-order systems, thus potentially providing significant wildlife habitat and movement corridors.

GIS can aid in determining where the most benefit can be accrued from placing buffers on a landscape. Knowledge of soils and valley-floor types provides important information regarding types of channels and riparian processes likely to be present in a given area (Hemstrom 1989). Because interactions between aquatic, riparian, and terrestrial ecosystems are a function of valley-floor morphology, digitized GIS data on valley-floor morphology aids in delineation of specific areas where erosion potential is high (e.g., where streams flow through alluvial deposits) or low (e.g., through bedrock). Thus, critical areas for buffer strips can be identified before significant impacts occur.

How Wide and How Long? Most of the focus on buffer design is the needed width, but the vegetation assemblage, layout, and length are also key design parameters. Buffer width, as defined herein, is measured beginning at the top of the bank or level of bankfull discharge. Width recommendations for buffer strips are either fixed or variable in nature. Fixed-width buffer strip recommendations tend to be based on a single parameter or function. They are easier to enforce and administer by regulatory agencies but often fail to provide for many ecological functions (Castelle, Johnson, and Conolly 1994). Variable width buffer strips are generally based on a variety of functions and usually account for site-specific conditions by having widths adjusted along the length of the strip depending on adjacent land use, stream and site conditions (e.g., vegetation, topography, hydrology), and fish and wildlife considerations (Castelle, Johnson, and Conolly 1994). Protection of water quality is often the most common consideration during buffer strip design recommendations. Although many buffer strip width recommendations tend to be arbitrary or based on anecdotal information, the scientific literature is replete with recommendations for maintaining or improving water quality in a variety of different settings (e.g., various soil types and different slopes) (Table 1).

Wildlife habitat and movement corridors in riparian zones are also an important consideration when determining widths. Appropriate designs for species conservation depend on several factors, including type of stream and taxon of concern (Spackman and Hughes 1995). Recommended widths for ecological concerns in buffer strips typically are much wider than those recommended for water quality concerns (Fischer et al. 1999; Fischer 2000) (Tables 2 and 3). Table 4 organizes buffer/corridor widths recommended in the literature in terms of functions, and Table 5 provides suggestions for general corridor restoration and management.

Management for long, continuous buffer strips adjacent to aquatic systems should be a higher priority in most cases than fragmented strips of greater width (Weller, Jordan, and Correll 1998). Continuous buffers are more effective at moderating stream temperatures, reducing gaps in protection from NPSP, and providing movement corridors for wildlife. Unfragmented buffer strips are also important as habitat. For example, Gaines (1974) found that yellow-billed cuckoos in California most often occur where the riparian vegetation exceeds 300 m in length and 100 m in width.

National and Regional Approaches. Recognizing the importance of riparian buffers and corridors, many Federal, state and local agencies have established riparian restoration and preservation programs. As part of the 1996 Farm Bill, the National Resources Conservation Service (NRCS) started the National Conservation Buffers Initiative to encourage landowners in agricultural and other urban and rural settings to install buffer strips primarily to improve the quality of our Nation's waters. The goal of the initiative is to restore 2 million miles (up to 7 million acres) of conservation buffers by the year 2002. The NRCS has set minimum and maximum widths that landowners can enroll in these programs ranging from a minimum of 30 ft (9m) for some herbaceous filter strips up to a maximum of 150 ft. (45 m) for forested riparian buffer strips. A variety of programs are available to landowners under the Farm Bill, including the continuous Conservation Reserve Program (CRP) sign-up, Environmental Quality Incentives Program (EQIP), Wildlife Habitat Incentives Program (WHIP), Wetlands Reserve Program (WRP), Stewardship Incentives Program (SIP),

Table 1. Recommended Widths of Buffer Zones and Corridors for Water Quality Considerations

Authors	State	Width	Buffer Type	Benefit
Woodard and Rock (1995)	Maine	≥15m	Hardwood buffer	The effectiveness of natural buffer strips is highly variable, but in most cases, a 15m natural, undisturbed buffer was effective in reducing phosphorus concentrations adjacent to single family homes
Young et al. (1980)		≥25m	Vegetated buffer	25m buffer reduced the suspended sediment in feedlot runoff was reduced by 92%
Horner and Mar (1982)		≥61m	Grass filter strip Vegetated buffer strip	Removed 80% of suspended sediment in stormwater
Lynch, Corbett, and Mussalem (1985)		≥30m		30-m buffer between logging activity and wetlands and streams removed an average of 75 to 80% of suspended sediment in stormwater; reduced nutrients to acceptable levels; and maintained water tempertures within 1°C of their former mean temperature.
Ghaffarzadeh, Robinson, and Cruse (1992)		≥9m	Grass filter strip	Removed 85% of sediment on 7 and 12% slopes
Madison et al. (1992)		≥5m	Grass filter strip	Trapped approximately 90% of nitrates and phosphates
Dillaha et al. (1989)		≥9m	Vegetated filter strip	Removed an average of 84% of suspended solids, 79% of phosphorus, and 73% of nitrogen
Lowrance et al. (1992)		≥7m		Nitrate concentrations almost completely reduced due to microbial denitrification and plant uptake
Nichols et al. (1998)	Arkansas	≥18m	Grass filter strips	Reduced estradiol (estrogen hormone responsible for development of the female reproductive tract) concentrations in runoff into surface water by 98%.
Doyle et al. (1977)		≥4m	Grass filter strips and forested buffers	Reduced nitrogen, phosphorus, potassium, and fecal bacteria from runoff.
Shisler, Jordan, and Wargo (1987)	Maryland	≥19m	Forested riparian buffer	Removed as much as 80% of excess phosphorus and 89% of excess nitrogen

Table 2. Recommended Widths of Corridors and Vegetated Buffer Strips for Vegetation, Reptiles and Amphibians, Mammals, Fish, and Invertebrates

Authors	State	Width	Benefit
Spackman and Hughes (1995)	Vermont	≥30m	Needed to capture >90% of vascular plant species
Brosofske et al. (1997)	Washington	≥45m	...buffers at least 45m wide on each side of the stream are needed to maintain an unaltered microclimatic gradient near streams (but could extend up to 300m in other situations)
			Reptiles and Amphibians
Burbrink, Phillips, and Heske (1998)	Illinois	100-1000m	Wide (>1000m) areas of riparian habitat did not support greater numbers of species of reptiles and amphibians than narrow (<100 m) areas
Rudolph and Dickson (1990)	Texas	≥30m	"We recommend retaining streamside zones of mature trees at least 30 m wide and preferable wider when forest stands are harvested. Zones this wide will benefit amphibians, reptiles, and other vertebrates."
Semlitsch (1998)	Eastern U.S.	≥165m	To maintain viable populations and communities of ambystomatid salamanders, attention must be directed to the terrestrial areas peripheral to all wetlands; maintaining the connection between wetlands and terrestrial habitats will be necessary to preserve the remaining biodiversity of our remaining wetlands.
Buhlmann (1998)	South Carolina	≥135m	Aquatic turtles (e.g., chicken turtle [*Deirochelys reticularia*]) may spend a greater proportion of a year in terrestrial habitat (e.g., buffer strips adjacent to wetlands) than in the wetland where they would have been predicted to occur
			Mammals
Dickson (1989)	Texas	≥50m	The minimum width of streamside management zones that will maintain gray squirrel (*Sciurus carolinensis*) populations is about 50m.
			Invertebrates
Erman, Newbold, and Roby (1977)	California	≥30m	Maintained background levels of benthic invertebrates in streams adjacent to logging activity
			Fish
Moring (1982)		≥30m	Increased sedimentation from logged, unbuffered stream banks clogged gravel streambeds and interfered with salmonid egg development. Buffer strips at least 30m wide allowed eggs to develop normally

Table 3. Recommended Minimum Widths of Riparian Buffer Strips and Corridors for Birds

Authors	Location	Minimum Width	Benefit
Darveau et al. (1995)	Canada	≥60m	There was evidence that 50-m-wide forested buffer strips were required for forest-dwelling birds. Bird populations may decline in strips before regeneration of adjacent clearcuts provide suitable habitat for forest birds
Hodges and Krementz (1996)	Georgia	≥100m	Riparian strips >100 m were sufficient to maintain functional assemblages of the six most common species of breeding Neotropical migratory birds
Mitchell (1996)	New Hampshire	≥100 m	Need >100m-wide buffers to provide sufficient breeding habitat for area sensitive forest birds and nesting sites for red-shouldered hawks
Tassone (1981)	Virginia	≥50 m	Many Neotropical migrants will not inhabit strips narrower than 50 m
Triquet, McPeek, and McComb (1990)	Kentucky	≥100 m	Neotropical migrants were more abundant in riparian corridors wider than 100 m; riparian areas <100 m wide were inhabited mainly by resident or short-distance migrants
Spackman and Hughes (1995)	Vermont	≥150 m	Riparian buffer widths of at least 150 m were necessary to include 90% of bird species along mid-order streams
Kilgo et al. (1998)	South Carolina	≥500 m	Although narrow bottomland hardwood strips can support an abundant and diverse avifauna, buffer zones at least 500m wide are necessary to maintain the complete avian community
Keller, Robbins, and Hatfield (1993)	Maryland; Delaware	≥100 m	Riparian forests should be at least 100 m wide to provide some nesting habitat for area-sensitive species
Gaines (1974)	California	≥100 m	Provide riparian breeding habitat for California yellow-billed cuckoo populations
Vander Haegen and deGraaf (1996)	Maine	≥150 m	Managers should leave wide (>150 m) buffer strips along riparian zones to reduce edge-related nest predation, especially in landscapes where buffer strips are important components of the existing mature forest
Whitaker and Montevecchi (1999)	Canada	≥50 m	50-m-wide riparian buffers only supported densities <50% of those observed in interior forest habitats
Hagar (1999)	Oregon	>40m	Although riparian buffers along headwater streams are not expected to support all bird species found in unlogged riparian areas, they are likely to provide the most benefit for forest-associated birds species if they are >40 m wide

Table 4. General Riparian Buffer Strip Width Guidelines

Function	Description	Recommended Width[1]
Water Quality Protection	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 10 m, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability, or where NPSP loads are particularly high.	5 to 30 m
Riparian Habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife.	30 to 500 m +
Stream Stabilization	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wider buffer. Excessive bank erosion may require additional bioengineering techniques (see Allen and Leach 1997).	10 to 20 m
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects, they intercept overland flow and increase travel time, resulting in reduced flood peaks.	20 to 150 m
Detrital Input	Leaves, twigs and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	3 to 10 m

[1]Synopsis of values reported in the literature, a few wildlife species require much wider riparian corridors.

Table 5. General Recommendations for Corridor Restoration and Management[1]

• Think at a watershed scale when planning for or managing corridors. Many species that primarily use upland habitats may, at some stage of their life cycle, need to use corridors for habitat, movements, or dispersal.
• Corridors that maintain or restore natural connectivity are better than those that link areas historically unconnected.
• Continuous corridors are better than fragmented corridors.
• Wider corridors are better than narrow corridors.
• Riparian corridors are more valuable than other types of corridors because of habitat heterogeneity, and availability of food and water.
• Several corridor connections are better than a single connection.
• Structurally diverse corridors are better than structurally simple corridors.
• Native vegetation in corridors are better than non-native vegetation.
• Practice ecological management of corridors; burn, flood, open canopy, etc. if it mimics naturally occurring historical disturbance processes.
• Manage the matrix with wildlife in mind; apply principles relative to the native plant and animal communities in the area.

[1] Craig Johnson, Utah State University, Presentation made at National Conservation Buffers Workshop, San Antonio, TX, January 1998.

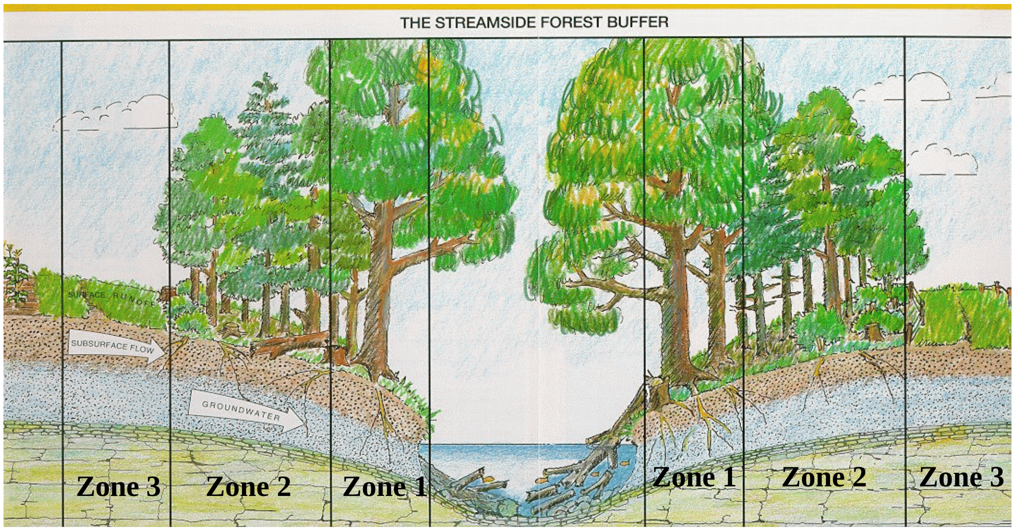

Figure 2. Depiction of a three-zone buffer approach developed for the Chesapeake Bay Watershed. This approach may be applicable to most forested riparian buffer strips in North America (from Welsch 1991).

and Emergency Watershed Protection Program (EWP). Information on these programs can be found on the Internet at
http://www.nhq.nrcs.usda.gov/OPA/Buffers.html

The Chesapeake Bay watershed has been the focus of a large restoration effort to improve water quality within the watershed. As part of this initiative, a three-zone riparian buffer was developed to assist with planning, design, and long-term management of forested riparian buffer strips (Welsch 1991). This approach provides a framework through which water quality, habitat, and other objectives can be accomplished. Figure 2 depicts the relative positions of the three zones. The width of each zone is determined by site conditions and objectives, as discussed below.

Zone 1. This zone begins at the stream edge and is the area that provides streambank stabilization and habitat for both aquatic and terrestrial organisms. Primary functions of this zone include provision of shade, and input to the stream or river of detritus and large woody debris from mature forest vegetation. Vegetation in this zone also helps reduce flood effects, stabilize streambanks, and remove some sediments and nutrients. Vegetation should be composed of native, non-invasive trees and shrubs of a density that permits understory growth; it should also tolerate frequent inundations. The width of this zone typically varies between 15 and 25 ft (5 and 8 m) or more.

Zone 2. This zone extends upslope from Zone 1 from a minimum of 10 ft (3 m) up to several hundred feet, depending on objectives, stream type, soil type, or topography. The objective in this zone is to provide a managed riparian forest with a vegetation composition and character similar to natural riparian forests in the region. Species of vegetation used in this zone should be reasonably flood- and drought-tolerant. The primary function of Zone 2 is to remove sediments, nutrients, and other pollutants from surface and groundwater. This zone, in combination with Zone 1, also provides most of the enhanced habitat benefits, and allows for recreation and aesthetic benefits.

The cost of installing and managing a buffer strip is a strong concern to some land managers, as it is often viewed as a loss of productive land. However, these opportunity costs can be offset by including practices such as periodically harvesting trees in this zone for sawtimber or pulp, growing nuts, berries, and fruits for commercial purposes, or leasing lands out for hunting (Washington County Soil and Water Conservation District 1999). Periodic selection harvests within this zone likely release the growth of smaller trees that will absorb nutrients from the soil at a higher rate than the more mature trees.

Zone 3. This zone typically contains grass or herbaceous filter strips and provides the greatest water quality benefits by slowing runoff, infiltrating water, and filtering sediment and its associated chemicals. The minimum recommended width of Zone 3 is 15 ft (4.5 m) when used in conjunction with Zones 1 and 2, or 35 ft (10.6 m) when used alone. The primary concern in this zone is initial protection of the stream from overland flow of NPSP such as herbicides and pesticides applied to lawns, agricultural fields, and timber stands. Properly designed grassy and herbaceous buffer strips may provide quality habitat for several upland wildlife species, including the northern bobwhite (*Colinus virginianus*), which has experienced significant population declines during the last 2 decades.

Buffer Composition. Generally speaking, vegetation used for buffer projects should consist of a mix of trees, shrubs, and herbaceous plants that are native to the region and well-adapted to the climactic, soil, and hydrologic conditions of the site. The relative effectiveness of different vegetation types at meeting specific objectives within a buffer strip is listed in Table 6. A botanist familiar with local flora should be enlisted to select those species most likely to meet project objectives, as well as ensure that plants are placed in the proper zone in the floodplain (e.g., those that thrive with frequent inundation at the edge of the stream versus those less tolerant of flooding further from the stream). The composition of the natural riparian community in adjacent locations can be a good guide and is often used as a starting point for the revegetation design.

Establishing diverse vegetation, either directly or through succession, is desirable for a variety of reasons. A relatively large number of species means an array of environmental tolerances is represented. As the project site experiences fluctuations in various environmental conditions over time, such as water level, temperature, and herbivory, some plants or species will not survive, but others may thrive. A diverse array of plant species is essential to a riparian system's ability to provide and to sustain a number of functions. Various plant species association and hydrological conditions provide required habitats for different life-history phases of animals, such as feeding, winter cover, and breeding (Heitmeyer et al. 1984, Frazer et al. 1990). Vegetation diversity in a buffer can be increased in numerous ways by:

a. Planting an array of different species in different amounts.

b. Planting a variety of growth forms such as herbaceous ground cover, shrubs, saplings and tree species, or emergents.

c. Planting species with a variety of life histories (e.g., annuals, short-lived or long-lived perennials).

d. Providing a range of site conditions (e.g., through elevational changes, creation of habitats with varying aspects/orientations) to support a diverse range of plant species.

Plans for acquiring plants must be made well in advance of the project implementation (sometimes 1 to 2 years). The availability of plants of the appropriate species, size, and quality is often a limiting factor in the final selection and plant acquisition process. Some native plant species are very difficult to propagate and many desirable species are not commonly available through commercial suppliers. As a general rule, it is advisable to specify as many species as possible and require the use of some minimum number of these species. Table 7 provides guidance for the minimum percentage of any one tree species in a revegetation plan.

Table 6. Relative Effectiveness of Different Vegetation Types for Providing Specific Benefits

Benefit	Vegetation Type Grass	Shrub	Tree
Stabilizes bank erosion	Medium	High	Medium
Traps sediment	High	Medium	Low
Filters nutrients, pesticides, microbes			
sediment-bound	High	Low	Low
soluble	Medium	Low	Medium
Provides aquatic habitat	Low	Medium	High
Provides wildlife habitat			
range/pasture/prairie wildlife	High	Medium	Low
forest wildlife	Low	Medium	High
Provides economic products	Medium	Low	Medium
Provides visual diversity	Medium	Medium	High
Prevents bank failures	Low	Medium	High
Provides flood conveyance	High	Low	Low

Modified from Dosskey, Schultz, and Isenhart (1997).

Table 7. Species Diversity Guidelines for Trees

Number of Trees	Maximum % of Any One Species
10 to 19	50%
20 to 39	33%
40 or more	25%

Other factors that determine species percentages within a plant selection are:

a. Desired ultimate composition of the plant community.

b. Function within the plant community (i.e., overstory, understory, shrub, groundcover, herbaceous).

c. Dominance in the plant community.

d. Growth characteristics and compatibility with other species.

e. Aggressive, fast-growing species such as elderberry (*Sambucus* spp.) and poplar (*Populus* spp.) should be proportioned and managed to reduce conflict with slower growing species.

f. Slower-growing species, such as wintergreen (*Gaultheria* spp.) and spruce (*Picea* spp.) may require a higher percentage to be successful in the development of the plant association.

g. Some species may not be appropriate for the initial planting phase. These include many of the herbaceous understory plants, such as ferns, and others that demand a micro-environment that can only develop over time.

The planting distance between woody species (trees and shrubs) should account for anticipated maintenance practices. If maintenance is necessary, planting trees and shrubs in well-spaced rows makes maintenance activities, such as mowing or mulching, much easier. Care should be taken to offset the rows of trees and shrubs so as to form a diamond pattern. Tree rows should generally be spaced about 6 to 10 ft (2 to 3 m), and shrubs about 3 to 6 ft (1 to 2 m). Within the row, spacing should be 3 to 6 ft (1 to 2 m) for small shrubs, 5 to 8 ft for large shrubs, 6 to 10 ft (2 to 3 m) for evergreens, and 8 to 12 ft (3 to 4 m) for deciduous trees. If the riparian zone will not be maintained with equipment, there is no need to plant in rows and a more natural-appearing planting arrangement should be utilized.
Other considerations influencing plant spacing are:

a. The competitive strength of the plants at the end of the plant establishment period.

b. Weed control. Densely spaced vegetation hinders weeds from establishing.

c. Species that need support from surrounding plants in order to compete and develop into a functional plant association. Examples are snowberry (*Symphoricarpos*), wild rose (*Rosa* spp.), Salal (*Salal spp.*), leatherleaf (*Mahonia* spp.), and Spiraea (*Spiraea* spp). The initial plant spacing should be based on closure of the planting after approximately three years. The plants will form a thicket over time. This plant layer is important for weed control in its supportive role in the plant community.

d. Species that form groupings or groves should be spaced to support the development of individual plants that form the desired cluster.

e. Climax trees should be spaced to resemble the distribution in the natural plant community.

f. Pioneer species should be spaced to quickly perform their function in the plant succession scheme without causing undesirable competition with desirable plants. Consider a management program that includes periodic removal of plants that have outlived their function.

In grassy buffers, the use of a mixture of native cool- and warm-season grasses planted in a heterogeneous pattern is recommended. This will not only assist in protecting water quality but will also provide wildlife habitat benefits. The inclusion of warm-season grasses provides many wildlife benefits that cool-season grasses alone cannot provide, such as abundant nesting cover for upland game species. In addition, many non-game species such as field nesting songbirds can find protection in the thick canopy this grass provides. Warm-season grasses grow in a dense manner, and resist collapse from snow and ice (they also provide a degree of winter cover when little or no snow cover exists). Finally, warm-season grasses are good seed-producers, creating abundant food for wildlife.

The authors have begun to compile woody and herbaceous vegetation commonly found in riparian systems, including the floodplain zone where they typically are found, and the region of the country where they occur. This will be published as a future ERDC technical note.

APPLICABILITY AND LIMITATIONS

The ability of a riparian buffer strip to provide various functions (e.g., attenuate floods, protect water quality, provide habitat or wildlife movement corridors) depends on such factors as width, length, degree of fragmentation, and type, density, and structure of vegetation present. Objectives may also be constrained by land ownership, extent of potential for growth of riparian vegetation, soil type, slope, or past land-uses.

In all cases, buffers wider than 10 m should be promoted for optimizing a range of multiple objectives for water quality, stability, and habitat functions. However, widths of 100 m or more are usually needed to ensure values related to wildlife habitat and use as migration corridors. Increasing widths to encompass the geomorphic floodplain is likewise desirable to optimize flood- reduction benefits. If only a narrow forested buffer strip is possible, it should at least be wide enough to sustain a forest or shrub community that will adequately stabilize the streambank from erosion. These recommendations apply to either side of the channel in larger river systems and to total width for lower-order streams. Recommended widths in this report are intended to provide a starting point for land managers to make decisions regarding design of buffer strips in their own area. Proper widths for various objectives may vary significantly by region and depend on a variety of ecological and physical factors.

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