Restoring Wetland and Streamside/Riparian Buffers: An Introduction

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This review was originally prepared as a broad overview of the topic to stimulate dialogue within the Fish and Wildlife Service on what types of buffer zones it should be pursuing for its own Partners projects (Northeast Region) or in consultations with other agencies involving restoration of riparian buffers (e.g., NRCS's CREP). Information on wetland and streamside buffers for wildlife was collected for a presentation at the National Land Trust Rally '98 in Madison, Wisconsin. This introduction is not intended to be an exhaustive or complete treatment of the topic - it is simply a brief commentary on some pertinent issues with a list of useful references attached for additional information (including some buffer web sites). A report entitled "Vegetated Buffers in the Coastal Zone: A Summary Review and Bibliography" by A. Desbonnet, P. Pogue, V. Lee, and N. Wolff (1994) published by the Rhode Island Sea Grant Program was a major data source for this overview. Note that some of the references cited in the text are not listed in the list of selected references at the end of this overview; they are found in Desbonnet et al. (1994).

This introductory paper was originally prepared in 1999. In 2003, I added a few more references and some narrative regarding wildlife needs. A 1999 literature review by Seth Wenger of the Institute of Ecology at the University of Georgia is an excellent source of information and is highly recommended. Another useful reference is a report on wildlife use of wetland buffer zones in Massachusetts (Boyd 2001).

There is increasing interest in improving the quality of the nation's waters by reducing nonpoint source pollution (see former Vice President Gore's Clean Water Action Plan). One of the primary situations accelerating nonpoint source pollution effects is the destruction of streamside or riparian vegetation. Such activities provide a direct pathway for pollutants carried by surface water runoff to enter the stream without buffering. Restoration of streamside vegetation is one way to minimize this type of pollution. Buffers around wetlands are also recommended to preserve the functions these areas serve. Perhaps the most important question is - how wide should the buffer be? The following is a brief summary of current literature on this topic.

What is a Buffer?

A buffer is a strip of vegetation of varying dimension necessary to protect an adjacent area from disturbances that may reduce or impair its functions and its values to an ecosystem, society, or other entity.

For wetlands, a buffer is represented by the landward distance from the upper wetland boundary that is important to help maintain its functions including biological integrity. It is therefore measured from the outer edge of the wetland. For streams, a buffer is measured from the water's edge of each side of the stream (e.g., 100m from the left bank and 100m from the right bank).

The use of buffers was reportedly first conceived in the 1940s and 1950s to protect waterfowl habitat. Many waterfowl build their nests adjacent to wetlands in the drier uplands. Later, buffers were employed to protect the water quality of streams from the adverse effects of logging (timber harvest practices) and agricultural operations (cropland and pasture).

Vegetated buffers may be woody or herbaceous (grassy). Vegetation should extend from the streambank landward for some distance based on the desired improvement in a particular function. These strips lie between the watercourse and some type of development impact (e.g., lawn, cropland, pasture, clearcut, or impervious surfaces).

Use of Vegetated Buffers for Water Quality Improvement

EPA estimates that 50-70% of the nation's threatened or impaired surface waters are adversely impacted by agricultural nonpoint source runoff and that 5-15% is attributed to urban runoff (Griffin 1991).

Grassy buffer strips have been used in agricultural areas to reduce nonpoint source inputs. In forest management areas, natural vegetated buffer strips have been used to reduce sedimentation impacts.

The following factors have been noted to have some effect on removal of pollutants: 1) soil type, 2) depth to the water table in the buffer zone, 3) type, density, and age of vegetation, 4) pollutant concentrations in the runoff, 5) land use and size of area draining into the buffer, 6) hydrologic regime within and adjacent to the buffer, 7) width of the buffer, 8) residence time of water in the buffer, and 9) the path of runoff water into and through the buffer.

Clearly, channelized flow through the buffer is a problem. Also inundation of the buffer significantly reduces its filtering capacity (i.e., to zero during heavy thunderstorms). Once oils, most metals and pesticides enter the ground water, the buffer will not effectively remove these substances. Nutrients, however, can be taken up. One study (Ambus and Lowrance 1991) found that 68% of the denitrification occurred in the top 2cm of soil. Nitrate removal is greater in areas with shallow water tables (wetlands) than in areas with deep water tables (uplands) during both dormant and growing seasons. Slope also affects pollution abatement as steep slopes do not have sufficient retention time for runoff for nutrient uptake or denitrification to occur. A slope of less than 15% allows for adequate retention time and pollutant removal. Poorly drained soils are twice as effective at nitrogen removal than well drained soils (Groffman and Tiedje 1989a). Where long residence time occurs, high denitrification usually results. Sandy soils are most effective at removing sediments and bound pollutants, and less effective for soluble forms (Cooper 1990). Vegetated buffers are not recommended as effective pollutant removers in clay-rich soils (Scheuler and Bley 1987). As the particle size of the sediment decreases, the width of the buffer needed to remove it increases. In a grassy buffer (i.e., Bermuda grass), coarser materials were removed within 3.3m, most silt in 15m, and most clays in 90m (Wilson 1967). Vegetated buffers can become saturated over time, thereby reducing their effectiveness.

Grassy Buffers

Grasses should be left uncut (or at least not below four inches) - the worst case would be a grassy buffer mowed like a golf green. If mowed, clippings should be removed from the site. "Although grasses are effective as vegetated buffer species, they lack the versatility required of multiple-use buffers - for preserving wildlife habitat or promoting visual diversity, for instance - and generally are not suitable for use as the only cover within a multiple-use vegetated buffer area" (Desbonnet et al. 1994).

Woody Buffers

Hardwood species are better nitrogen removers than conifers (Spur and Barnes 1980). Species with shallow root systems may be ineffective at removing nitrogen from groundwater, so trees may be more effective than shrubs (Ehrenfeld 1987). Denitrification also occurs during the dormant season in areas with high seasonal water tables (wetlands) due to high organic matter content and microbial populations. There is however a significant decline, perhaps 64-81%, in nitrate removal from growing season to dormant season.

Buffer Widths for Water Quality Protection

Some Minimum Vegetated Buffer Widths:

1. No slope on slightly erodible soils = 10m (Clark 1977).

2. 30% slope on severely eroded soils = 50m (Clark 1977).

3. Forested buffer for sediment removal for slopes less than 50% = 15m; extremely sloped area = 66m (max.) (Broderson 1973).

4. See attached tables for results of some studies.

5. For removing sediments, a 25m vegetated buffer would likely remove 80% of sediment inputs (Desbonnet and others 1994). Removal of 60% of total suspended solids can be expected to be accomplished by a 6m-wide vegetated buffer, while to remove 80% would require a 60m strip.

6. For removing nitrogen, a 9m-wide buffer may remove 60%, while a 60m buffer is required to remove 80%.

7. For removal of total phosphorus, a 12m buffer strip would achieve 60% efficiency, whereas an 85m buffer would remove 80%.

8. The Forest Service has a recommended minimum of 28m and divides this buffer into 3 zones: a) 5m from water - no alteration; b) to 17m - limited use (e.g., selective harvest), and c) a 6m zone abutting the developed or disturbed area - vegetated area including lawn or hayfield, but not cultivated land or impervious surfaces (Welsch 1991).

Recommended Buffer Width for Water Quality Protection

Based on Desbonnet and others (1994) - "forty-five meter buffers appear adequate to protect water quality in general, at least within freshwater systems and areas where sediment and adsorbed pollutants are the major concerns."

Use of Buffers for Fish and Wildlife Habitat Protection

Wetland and riparian buffers are also needed to protect the quality of fish and wildlife habitat, to maintain travel corridors for wildlife, to provide refuge during high water, and to shield wetlands and streams against the adverse impacts of development and other land uses. The size of the buffer depends on numerous factors: 1) the ecological requirements of individual species, 2) the existing habitat quality of the area to be buffered, 2) the intensity of the land use, and 4) the characteristics of the land (vegetation, slope, soils, erodibility, groundwater levels, etc.). Another factor that may be the determining factor in establishing the limits of any buffer is politics, that is, the willingness of politicians to impose restrictions on the use of private property along wetlands and streams for the benefit of water quality and fish and wildlife species.

Buffers for Maintaining Fish Habitat

When forested buffers strips greater than 30m were left, there was no detectable adverse effect from logging on sedimentation on salmonid development or on other aquatic organisms in the Pacific Northwest. Such vegetation also is important for the aquatic ecosystem by providing leaf litter and insect drop that support aquatic food webs and by stabilizing streambanks, thereby reducing erosion and sedimentation. The 30m forested buffer strips kept water temperature within 1 degree C. A forested buffer of 24m is generally sufficient to shade most streams, but 30m is recommended (Castelle et al. 1994). Buffers from 5-10m provide little protection for aquatic resources under most conditions (Castelle et al. 1994).

Buffers for Maintaining Wildlife Habitat

Some wetland-dependent species nest in adjacent uplands (e.g., mallards, herons, and turtles). Many amphibians (e.g., wood frogs and salamanders) breed in wetlands but spend their adult lives in adjacent uplands. Burrowing small mammals occupying wetlands also need uplands.

The State of Washington found that 85% of terrestrial vertebrates use wetlands and their buffers (359 of 414 species in western Washington and 320 of 378 species in eastern Washington). Consequently, the State recommends the following buffer widths for wildlife protection (Castelle et al. 1994):

1. 50-150 feet to protect wetlands from human disturbance (e.g., vegetation trampling and trash disposal).

2. 200-300 feet to retain wetland-dependent species.

3. 100-200 feet for protection of other species.

If the objective is to improve wildlife habitat along streams for neotropical migrants or for wildlife movement corridors, the literature suggests buffers from 30-200m (see following discussion).

Wenger (1999) in summarizing literature on buffers, stated that while narrow buffers provide habitat benefits to many species, protection of diverse terrestrial riparian wildlife communities requires some buffers of at least 100m. He cautioned, however, that such buffers may not be practical on all streams in most areas, yet minimum buffers should be based on water quality and aquatic habitat functions. See Boyd (2001) for information on wildlife travel distances and habitat predictors for wetland wildlife within the 100-foot buffer zone in Massachusetts.

Buffers for Mammals

When considering buffers for various species, consideration of home range is important. Some home ranges for wetland mammals are: 5-100m from water for mink, 200-400m for muskrat, 100m for beaver (feeding zone; in dry regions = 30m), 30m for river otter (needs dryland for denning), and 250m for marsh rabbit. Moose in Ontario require a distance of 120m from aquatic feeding areas, mineral licks, and calving grounds. Squirrels in Mississippi needed more than 50m of forested buffers along streams. In studying small mammals along riparian corridors in southwest Oregon, Cross (1985) found that the diversity and species composition of small mammal populations in a 67m wide riparian buffer bordered by a clearcut forest was comparable to undisturbed forests.

Buffers for Birds

Birds also vary in their needs for buffers. Those requiring more than 500m-wide forested buffers include barred owl, red-shouldered hawk, ruby-throated hummingbird, American redstart, prothonotary warbler, and Swainson's warbler. The Mississippi kite needs a buffer greater than 1000m, while the swallow-tail kite needs one greater than 10,000m.

In central Pennsylvania, a riparian buffer greater than 125m was needed to match conditions in an undisturbed reference area (Croonquist and Brooks 1993). In disturbed areas, a 2m woody buffer did have an important effect on improving habitat for birds. Impoverished bird communities were observed when there was only 10m of vegetation on each bank. Sensitive species required 25m on each bank.

In a study of bottomland hardwoods in the Southeast, hardwood stream corridors of less than 50m and more than 1000m produced the highest bird counts (Kilgo et al. 1998). The researchers recommended widths of more than 500m to maintain characteristic bottomland hardwood avifauna. Unfortunately, much of the remaining bottomland hardwood stands are in narrow drainages. By 2030, the researchers expected a 15% decline in bottomland forests with about 64% due to timber harvest.

A Maryland and Delaware study (Delmarva Peninsula) examined 117 riparian corridors ranging from 25-800m wide (Keller et al. 1993). The wider the corridor, the higher the number of neotropical migrants and the lower the number of short-distance migrants. The latter birds dominated corridors less than 100m wide. The number of residents was not related to width. The researchers recommended a width greater than 100m to protect interior bird species.

Table 1 summarizes minimum width recommendations from various studies across the United States.

Table 1. Recommended minimum riparian buffer widths for birds. (Source: U.S. Army Corps of Engineers 2000).

Location	Minimum Width	Reference
California	>100m	Gaines 1974
Canada, British Columbia	70m	Kinley and Newhouse 1997
Canada	>60m	Darveau et al. 1995
Canada, Newfoundland	>50m	Whitaker and Montevecchi 1999
Delaware & Maryland	>100m	Keller et al. 1993
Georgia	>100m	Hodges and Drementz 1996
Kentucky	>100m	Triquet et al. 1990
Maine	>150m	Vander Haegen and DeGraff 1996
New Hampshire	>100m	Mitchell 1996
Oregon	>40m	Hagar 1999
South Carolina	>500m	Kilgo et al. 1998
Vermont	>150m	Spackman and Hughes 1995
Virginia	>50m	Tassone 1981

Lambert and Hannon (2000) studied the effect of timber harvest on ovenbirds in riparian buffer strips. They found that 20m strips did not support ovenbirds and that 100m and 100m buffers retained ovenbirds during the year following harvest. Long-term harvest effects require further study.

Buffers for Herptiles

In the Southeast, streamside hardwood buffers greater than 30m supported more herptiles than those less than 25m. Researchers studying turtle nesting in South Carolina found that all nesting occurred within 275m of the wetland, while 90% of the nesting took place within 73m (Burke and Gibbons 1995).

Also in the Southeast, Dickson (1989) reported that medium (30-40m) and wide (>50m) streamside zones supported many more amphibians and reptiles than narrow (<25m) zones (Dickerson 2001). Later, Rudolph and Dickson (1990) found similar conditions within streamside zones of pine plantations. The wider zones had more overstory and midstory vegetation with sparse shrub and herbaceous cover.

In the Pacific Northwest, reptiles and amphibians dependent on riparian habitats may need buffers of 75-100m (Gomez and Anthony 1996). Many of these species also required neighboring old growth forests and upland habitats.

For southern Illinois, Burbrink and others (1998) reported that reptile and amphibian diversities in a 100m naturally vegetated riparian zone were as high as those in a similar 1km-wide zone.

An Ontario study found that a 120m buffer strip was no sufficient to protect either herps or mammals (Finlay and Houlahan 1996). They believed that removing 20% of the forest within 1000m of a wetland may have the same effect on species as destroying 50% of the wetland. These conclusions may be site-specific, but they suggest that overall, land use practices around wetlands may be as important to wildlife habitat quality as the size of the wetland itself.

Recommendation for a Multiple-Use Buffer Strip

The minimum width suggested by Desbonnet and others (1994) is 15m. They believe that this should be "implementable" in only moderately developed areas. This should provide about 60% pollutant removal and will offer minimal wildlife habitat value. For undeveloped areas, they suggest wider buffers (e.g. 50m or more). Such widths should also be considered for all publically owned lands. For areas of critical wildlife importance, they suggest 100m.

Flexible vs. Fixed Buffers

Flexible buffers are ones that vary in width due to site conditions and considerations for the resource to be protected. Although good in theory, such buffers require much data. As such, flexible buffers are likely to be unrealistic for widespread application. Fixed wetland buffers are easier to implement and enforce. They also offer greater predictability and are easier for people to understand.

Priorities for Buffer Restoration and Protection

For restoration, priorities should include: 1) areas with no vegetation, and 2) areas with vegetated buffers less than 50m wide.

For protection, priorities should consider: 1) areas around sensitive wetlands and high quality coldwater streams, and 2) areas with large buffers intact.

Buffer Web Sites

http://www.unl.edu:80/nac/pubs/afnotes/afnrip3.htm
(National Agroforestry Center: A Riparian Buffer Design for Cropland)

http://www.nhq.nrcs.usda.gov/CCS/BufrsPub.html
(USDA Natural Resources Conservation Service)

http://www.willow.ncfes.umn.edu/buffer/cover.htm
(USDA Forest Service's Riparian Forest Buffers)

http://www.chesapeakebay.net/facts/forests/ripfor.htm
(Chesapeake Bay Program: Riparian Forest Buffers)

http://www.dnr.state.wi.us/org/water/wm/dsfm/shore/documents/BufferBiblio.pdf
(Wisconsin DNR list of buffer references)

http://outreach.ecology.uga.edu/tools/buffers/lit_review.pdf
(University of Georgia, Institute of Ecology's review of riparian buffer width literature)

http://www.umass.edu/umext/nrec/pdf_files/Final_Project.pdf
(University of Massachusetts report on wildlife use of wetland buffer zones)

Also try a search engine like google.com for additional sites

Selected References

(Note: Any text references not listed came from and can be found in Desbonnet et al. 1994)

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*Good overviews of multiple functions of buffers.

Attachments (Selected Tables from Desbonnet et al. 1994) other edge of stream (forested buffers) — despite their similarities in purpose. Together they make up a range of functional uses greater than either considered alone.

This review incorporates information taken from both vegetated filter strip and forested buffer studies, since the use of both is important in developing a general understanding of the effectiveness of vegetated buffers, particularly from a multiple-use perspective. When the term "vegetated buffer" is used in this document, particularly with regard to management implications for the coastal zone, it specifically refers to naturally vegetated areas that have been, or are being, set aside along the coastline, whether grassy or wooded. When reference is made to designing vegetated buffers where they presently do not exist, the intent is to develop a vegetated area that mimics native vegetation appropriate to the same locale. Our choice of the term "vegetated buffer" keeps with its original use to designate naturally vegetated areas, but we develop further the concept of multiple use and multiple benefits for this versatile management tool, as adapted from information on both natural and engineered vegetated buffers.

■ Multiple benefits

Vegetated buffers often produce many benefits that are neither well-documented nor originally intended. They can be used for providing wildlife habitat; for promoting visual diversity; for bird watching, hiking, and picnicking; for preserving the integrity of historical and cultural sites; for flood zone management by setting development back from the immediate banks of waterways; and for protecting structures from storm damage. Establishment of vegetated buffers throughout the coastal zone also can help provide for the long-term economic viability of the resource by maintaining an aspect of the natural wilderness of the coast that draws people to the shoreline.

Vegetated buffer programs, however, are rarely developed to fully consider the multiple benefits and uses that they offer to resource managers and to the general public. The "single use/single benefit" approach used more often tends to alienate some sector of the public that does not view that single use/single benefit as a priority. Public awareness that the vegetated buffers support multiple benefits — pollution control, wildlife habitat diversification, and scenic improvement, for instance — may lead to more effective implementation, as well as giving

Table 1. A selection of definitions for vegetated buffers.

Reference	Definition
Palfrey and Bradley, 1982	Zones of undeveloped vegetated land extending from the banks or high water mark of a water course or water body to some point landward. Their purpose is to protect the water resources, including wetlands, they adjoin from the negative impacts of adjacent land use.
Dillaha et al., 1986a	Bands of planted or indigenous vegetation used to remove sediment and nutrients from surface runoff.
Soil Conservation Service, 1989	Strips of grass or other vegetation that trap pollutants from land areas before they reach adjacent water bodies.
Chesapeake Bay Local Assistance Act, 1990	An area of natural or established vegetation managed to protect other components of a Resource Protection Area and state waters from significant degradation due to land disturbances.
Brown et al., 1990	Transitional areas between two different land uses where one mitigates the impact from the other.
Palmstrom, 1991	Intended to provide a neutral area to lessen the impact of man's activities (i.e., fertilizer use, on-site septic systems, urban runoff) on sensitive resources.
Comerford et al., 1992	A barrier or treatment area protecting adjoining areas from the off-site effects of some disturbance.
Dodd et al., 1993	.....strips of land in transitional areas between aquatic and upland ecosystems. From a water quality management perspective, riparian buffers can be defined as areas designed to intercept surface and subsurface flow from upland sources for the purpose of improving water quality.
EPA, 1993	Strips of vegetation separating a water body from a land use that could act as a nonpoint source.

Table 2. Removal rates for various pollutants in vegetated buffers. The values reported for removal in grassed buffers may be high relative to forested buffers because most received direct fertilizer treatments, whereas forested buffers did not. Removal rates for forested buffers may therefore be underestimated with regard to their actual removal potential. [1 kilogram = 2.2 pounds; 1 hectare = 2.47 acres]

Reference	Removal Rate	Details
NITROGEN		
Ehrenfeld, 1987	75 - 80 kg N/ha/yr	Hardwood wetland getting septic tank leachate
Ehrenfeld, 1987	45 - 56 kg N/ha/yr	Pine upland getting septic tank leachate
Ehrenfeld, 1987	68 - 69 kg N/ha/yr	Oak upland getting septic tank leachate
Peterjohn & Correll, 1984	77 kg N/ha/yr	Mid-Atlantic coastal plain forest trees
Palazzo, 1981	290 kg N/ha/yr	Orchard grass; sewage waste treated
Fail et al., 1986	50 kg N/ha/yr	Plant uptake and storage in a coastal plain riparian forest
Cole & Rapp, 1981	75.4 kg N/ha/yr	Mean of 14 temperate deciduous forests
Lowrance et al., 1984c	51.8 kg N/ha/yr	Aboveground plant storage in riparian forests
Lowrance et al., 1984c	31.5 kg N/ha/yr	Denitrification in riparian forests
Morton et al., 1988	2.0 kg N/ha/yr	Kentucky bluegrass control plot
Morton et al., 1988	32 kg N/ha/yr	Kentucky bluegrass; overwatered and fertilized
Brown & Thomas, 1987	194 kg N/ha	Bermuda grass on sandy soils with repeated harvesting
Peterjohn & Correll, 1984	11 kg/ha particulate organic N	Riparian forest treating agricultural watershed
Peterjohn & Correll, 1984	0.83 kg/ha ammonium N	Riparian forest treating agricultural watershed
Peterjohn & Correll, 1984	2.7 kg/ha nitrate N	Riparian forest treating agricultural watershed
Peterjohn & Correll, 1984	45 kg/ha nitrate N in groundwater	Riparian forest treating agricultural watershed
Groffman & Tiedje, 1989a	10 kg N/ha/yr	Well-drained loam
Groffman & Tiedje, 1989a	11 kg N/ha/yr	Somewhat poorly drained loam
Groffman & Tiedje, 1989a	24 kg N/ha/yr	Poorly drained loam
Groffman & Tiedje, 1989a	18 kg N/ha/yr	Well-drained clay—loam
Groffman & Tiedje, 1989a	17 kg N/ha/yr	Somewhat poorly drained clay—loam
Groffman & Tiedje, 1989a	40 kg N/ha/yr	Poorly drained clay—loam
Groffman & Tiedje, 1989a	0.6 kg N/ha/yr	Well-drained sand
Groffman & Tiedje, 1989a	0.8 kg N/ha/yr	Somewhat poorly drained sand
Groffman & Tiedje, 1989a	0.5 kg N/ha/yr	Poorly drained sand
Groffman et al., 1991a	311 g N/ha/day	Well-drained aerobic forest soil with nitrate added
Groffman et al., 1991a	365 g N/ha/day	Poorly drained aerobic forest soil with nitrate added
Groffman et al., 1991a	7,889 g N/ha/day	Tall fescue on aerobic soil with nitrate added
Groffman et al., 1991a	4,537 g N/ha/day	Reed canary grass on aerobic soil with nitrate added
Groffman et al., 1991a	1.1 g N/ha/day	Well-drained anaerobic forest soil, no nitrate added
Groffman et al., 1991a	1,306 g N/ha/day	Well-drained anaerobic forest soil; nitrate added
Groffman et al., 1991a	13.1 g N/ha/day	Poorly drained anaerobic forest soil, no nitrate added
Groffman et al., 1991a	1,402 g N/ha/day	Poorly drained anaerobic forest soil, nitrate added
Groffman et al., 1991a	1.0 g N/ha/day	Tall fescue on anaerobic soil, no nitrate added
Groffman et al., 1991a	17,208 g N/ha/day	Tall fescue on anaerobic soil, nitrate added
Groffman et al., 1991a	1.0 g N/ha/day	Reed canary grass on anaerobic soil, no nitrate added
Groffman et al., 1991a	15,208 g N/ha/day	Reed canary grass on anaerobic soil, nitrate added
Warwick & Hill, 1988	0.05—0.53 μg N/m^2/day	Sandy sediments
Warwick & Hill, 1988	0.08—1.20 μg N/m^2/day	Organic sediments
Warwick & Hill, 1988	1.05—3.19 μg N/m^2/day	Watercress bed detritus and sediments
Hook & Kardos, 1977	388 kg N/ha/yr	Reed canary grass; sewage waste treated
Rhodes et al., 1985	0.341—7.265 g N/hr/acre	Mean of 111 high-altitude wet meadow samples
Lemunyon, 1991	99.3 / 37.5 kg N/ha	Smooth Bromegrass in 15m^2 well-drained plot; urea treated
Lemunyon, 1991	56.1 / 20.6 kg N/ha	Garrison grass in 15m^2 well-drained plot; urea treated
Lemunyon, 1991	73.9 / 48.9 kg N/ha	Kentucky bluegrass in 15m^2 well-drained plot; urea treated
Lemunyon, 1991	87.6 / 38.4 kg N/ha	Orchard grass in 15m^2 well-drained plot; urea treated
Lemunyon, 1991	44.0 / 25.7 kg N/ha	Perrenial ryegrass in 15m^2 well-drained plot; urea treated

Table 2. Removal rates for various pollutants in vegetated buffers. Continued

Lemunyon, 1991	80.9 / 34.1 kg N/ha	Reed canary grass in $15m^2$ well-drained plot; urea treated
Lemunyon, 1991	65.2 / 33.5 kg N/ha	Sweet vernal grass in $15m^2$ well-drained plot; urea treated
Lemunyon, 1991	78.2 / 37.9 kg N/ha	Tall fescue in $15m^2$ well-drained plot; urea treated
Lemunyon, 1991	40.5 / 11.7 kg N/ha	Big bluestem in $15m^2$ well-drained plot; urea treated
Lemunyon, 1991	29.1 / 18.5 kg N/ha	Switchgrass in $15m^2$ well-drained plot; urea treated
Hill & Sanmugadas, 1985	37—412 mg N/m^2/day	24-hour stream sediment incubation
Hill & Sanmugadas, 1985	33—223 mg N/m^2/day	48-hour stream sediment incubation
Schellinger & Clausen, 1992	0.72 kg/m^2/yr TKN	22.9 X 7.6m mixed species grass buffer; 2% slope
Schellinger & Clausen, 1992	0.32 kg/m^2/yr Ammonia-N	22.9 X 7.6m mixed species grass buffer; 2% slope
PHOSPHORUS		
Peterjohn & Correll, 1984	3.0 kg/ha total particulate P	Riparian forest treating agricultural watershed
Lowrance et al., 1984c	3.8 kg P/ha/yr	Aboveground plant storage in riparian forests
Schellinger & Clausen, 1992	0.15 kg/m^2/yr TP	22.9 X 7.6m mixed species grass buffer; 2% slope
Schellinger & Clausen, 1992	0.12 kg/m^2/yr Dissolved P	22.9 X 7.6m mixed species grass buffer; 2% slope
Schellinger & Clausen, 1992	0.09 kg/m^2/yr Ortho P	22.9 X 7.6m mixed species grass buffer; 2% slope
Cole & Rapp, 1981	5.6 kg P/ha/yr	Mean of 14 temperate deciduous forests
SEDIMENT & OTHER		
Peterjohn & Correll, 1984	4.1 kg/ha/yr of particulates	Riparian forest treating agricultural watershed
Schellinger & Clausen, 1992	1.13 kg/m^2/yr TSS	22.9 X 7.6m mixed species grass buffer; 2% slope

Figure 2

Figure 2. Ranges of nitrogen removal for grass and forested buffers. The heavy line contained in the bar represents the mean of the data that constitute the range. Data taken from Table 2. [1 kilogram = 2.2 pounds; 1 hectare = 2.47 acres]

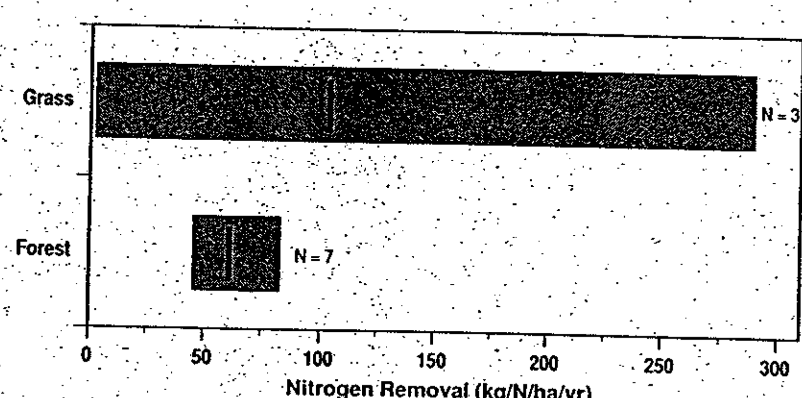


Table 3. Recommended vegetated buffer widths for pollutant removal, giving the desired effect of the implemented buffer. The reported values are generally intended as minimum buffer width values to achieve the desired purpose. [1 meter = 3.28 feet]

Author(s)	Width (m)	Objective	Specifics
in: Comerford et al. 1992	2	Maintain stream channel stability	Ozark Mts
Ahola, 1990	2 - 10	Stream habitat protection	
Ahola, 1990	5 - 20	River/lake protection	
Scheuler and Bley, 1987	7	Low level pollutant removal	Grassed buffer
in: Comerford et al., 1992	7 - 12	General purpose use	Low slope; rural land
Palmstrom, 1991	7.6	General purpose use	
Doyle et al., 1975	7.6	Protect water quality from animal wastes	Forested buffer
in: Comerford et al., 1992	8	Protect general water quality	
in: Comerford et al., 1992	9	Protect water quality from ground-based herbicide applications	
Martin et al., 1985	10	Protect water quality from clear-cut	Forested buffer
Clark, 1977	10	General purpose use	0% slope over slightly erodible soils
Swift, 1986	10 - 19	Protect general water quality	Road runoff sediment
Trimble & Sartz, 1957	10.6 - 12.2	Protect water quality from logging	<10% slope
Florida Div. Forestry, 1990	11	Protect general water quality	Primarily streamside
in: Comerford et al., 1992	11	Protect small stream water quality	Forested buffer
in: Comerford et al., 1992	12 - 24	Protect general water quality	Forested buffer
in: Comerford et al., 1992	12 - 83	Moderate erosion protection	Forested
in : Comerford et al., 1992	15	Protect water quality from pesticides	
Phillips, 1989b	15 - 60	Protect general water quality	Well-drained soils
in: Comerford et al., 1992	15 - 103	Severe erosion protection	Forested buffer
Corbett & Lynch, 1985	20 - 30	Protect water quality from logging	Forested buffer
Clark, 1977	23	Protect water quality from logging	Forested buffer
Moring, 1982	30	Protect salmon egg and juvenile development	Forested buffer
Erman et al., 1977	30	Protect stream water quality from logging	Forested buffer
USACE, 1991	30	90% removal of TSS	Grassed buffer
in: Comerford et al., 1992	30	Protect water quality from aerial herbicide applications	
in: Comerford et al., 1992	31	Protect large stream/river water quality	Forested buffer
Phillips, 1989b	40-80	Protect general water quality	Poorly drained soils
Clark, 1977	45	Protect general water quality	30% slope over severely erodible soils
Clark, 1977	46	Protect general water quality	
in: Comerford et al., 1992	91	Protect private residences from aerial herbicide applications	
Phillips, 1989b	93	Protect stream water quality	Under all conditions
Roman & Good, 1983	100	Wetland protection	NJ Pinelands habitat
Brown et al., 1990	178	Protect wetland water quality	

Table 4. A summary of pollutant removal effectiveness values according to width of the vegetated buffer. Removal efficiency values are given as percent removal for each of the various pollutants treated in the vegetated buffer — sediment, TSS, total nitrogen, total phosphorus, and nitrate-nitrogen. [1 meter = 3.28 feet]

		Pollutant Removal (%)				
Author(s)	**Width (m)**	**Sediment**	**TSS**	**N**	**P**	**NO_3**
Doyle et al., 1977	0.5				9%	0%
Neibling & Alberts, 1979	0.6	91%				
Neibling & Alberts, 1979	0.6	37%				
Neibling & Alberts, 1979	1.2	78%				
Doyle et al., 1977	1.5				8%	57%
Neibling & Alberts, 1979	2.4	82%				
Doyle et al., 1975	3.8			95%	99%	
Doyle et al., 1977	4.0				62%	68%
Young et al., 1980	4.06			84%	83%	9%
Dillaha et al., 1988	4.6		31%	0%	2%	
Dillaha et al., 1988	4.6		87%	61%	63%	
Dillaha et al., 1988	4.6		76%	67%	52%	3%
Magette et al., 1987	4.6		72%	17%	41%	
Dillaha et al., 1986b	4.6	63%		63%	63%	
Neibling & Alberts, 1979	4.9	83%				
Neibling & Alberts, 1979	6.1	90%				
Doyle et al., 1975	7.6			96%	99%	
Schellinger & Clausen, 1992	7.6		4%	15%	6%	
Schellinger & Clausen, 1992	7.6		27%	16%	18%	
Dillaha et al., 1988	9.1		58%	7%	19%	
Dillaha et al., 1988	9.1		95%	77%	80%	4%
Dillaha et al., 1988	9.1		88%	71%	57%	17%
Dillaha et al., 1986b	9.1	78%		78%	78%	
Magette et al., 1987	9.2		86%	51%	53%	
Thompson et al., 1978	12			45%	55%	46%
Bingham et al., 1978	13			28%	25%	28%
Mannering & Johnson, 1974	15	45%				
Doyle et al., 1977	15.2			97%	99%	
Lake & Morrison, 1977	15.2	46%				
Peterjohn & Correll, 1984	19	90%		62%	0%	60%
Young et al., 1980	21.3	81%				
Young et al., 1980	21.3	75%				
Schwer & Clausen, 1989	26		95%	92%	89%	
Young et al., 1980	27.4	93%				
Young et al., 1980	27.4		66%	87%	88%	
Young et al., 1980	27.4		82%	84%	81%	
Edwards et al., 1983	30		23%	31%	29%	
Doyle et al., 1975	30.5			98%	99%	
Patterson et al., 1977	35		71%			
Thompson et al., 1978	36			69%	61%	62%
Wong & McCuen, 1982	45	90%				
Woodard, 1988	57	99%				
Edwards et al., 1983	60		87%	83%	84%	
Baker & Young, 1984	79			99%		
Karr & Schlosser, 1978	91	55%	50%			
Karr & Schlosser, 1978	215	97.5%	90%			
Karr & Schlosser, 1978	304	99%	97%			
Lowrance et al., 1984				85%	30-42%	83%
Jacobs & Gillam, 1985						99%
Rhodes et al., 1985						99%
Reuter et al., 1992			85%		97%	85-90%
Schipper et al., 1989						98%

Table 4. A summary of pollutant removal effectiveness values according to width of the vegetated buffer. Continued

Runoff source	Vegetation	Slope	Other
Dairy manure	Grass-fescue	10%	90 mT/ha
Bare soil	Grass	7%	For coarse-grained sediments
Bare soil	Grass	7%	For clay-sized particles
Bare soil	Grass	7%	For clay-sized particles
Dairy manure	Grass		90 mT/ha
Bare soil	Grass	7%	For clay-sized particles
Dairy manure	Forest/scrub	35-40%	Gravely, silt-loam soils
Dairy manure	Grass		
Dairy feedlot		4%	
Dairy manure	Orchard grass	5%	Concentrated flow
Dairy manure	Orchard grass	11%	Av. 10,000 kg/ha manure application
Dairy manure	Orchard grass	16%	Av. 10,000 kg/ha manure application
Dairy manure	Forest/scrub	35-40%	Gravely, silt-loam soils
Fertilized cropland	Orchard grass		
Bare soil	Grass	7%	For clay-sized particles
Bare soil	Grass	7%	For clay-sized particles
Dairy yard runoff	Fescue & rye mix	2%	Poorly drained, surface sample.
Dairy yard runoff	Fescue & rye mix	2%	Poorly drained, subsurface sample
Dairy manure	Orchard grass	5%	Concentrated flow
Dairy manure	Orchard grass	11%	Av. 10,000 kg/ha manure application
Dairy manure	Orchard grass	16%	Av. 10,000 kg/ha manure application
Dairy manure	Orchard grass		
Poultry manure	Fescue	6-8%	
	Bluegrass sod		
Dairy manure	Forest/scrub	35-40%	90 mT/ha; Gravely, silt-loam soils
	Bluegrass sod		
Agricultural runoff	Forested		
Feedlot runoff	Corn	4%	
	Oats	4%	
Milk house waste	Fescue & rye mix	2%	
	Corn	4%	25-year, 24-hour storm simulation
	Orchard grass	4%	25-year, 24-hour storm simulation
	Sorghum/grass	4%	25-year, 24-hour storm simulation
Feedlot runoff	Fescue	2%	Settling basin, then through 60 m of grass buffer
Dairy manure	Forest/scrub	35-40%	Gravely, silt-loam soils
Liquid dairy waste	Fescue	3.4%	
	Natural, mixed		
Feedlot effluent	Fescue	2%	Moved through 2 consecutive 30m VFS
Fertilizers	Grass		
	Bermuda grass		
	Forested		
	Forest/wetland		79.6 ha undisturbed watershed
Fertilized field runoff	Man-made gravel		
Sewage spray	Forested pine		

Table 6. Recommended buffer widths for wildlife habitat. The reported widths are generally intended as minimum values to provide the desired habitat requirement to meet the given objective. [1 meter = 3.28 feet]

Author(s)	Width (m)	Objective	Specifics
Triquet et al., 1990	15 - 23	General avian habitat	Riparian wooded area
Shisler et al., 1987	15 - 30	Protect wetland habitat from low-intensity disturbances	Densely growing mixed species buffer
Tassone, 1981	30	Wildlife travel corridor	
Shisler et al., 1987	30 - 45	Protect wetland habitat from high-intensity disturbances	Densely growing mixed species buffer
Howard and Allen, 1989	60	General wildlife habitat	
Tassone, 1981	60	Breeding sites for fragment-sensitive bird species	
Groffman et al., 1991b	60 - 100	General wildlife habitat	
Cross, 1985	67	Small mammal habitat	Wooded riparian area
Groffman et al., 1991b	91.5	Protect significant wildlife habitat	Natural vegetation
Brown et al., 1990	178	Wetland habitat protection	
Scheuler, 1987	200	Diverse songbird community	
U.S. ACE, 1991	<200	For all but large mammals	Riparian forest

Figure 9.

Figure 9. Ranges of buffer widths noted in the literature to provide effective habitat for several broad categories of wildlife. The ranges of categories represented by a circle arise from one study, and therefore may not be very representative of that particular category. Two reported values make up the range shown by each of the horizontal bars. Data are taken from Table 6. [1 meter = 3.28 feet]

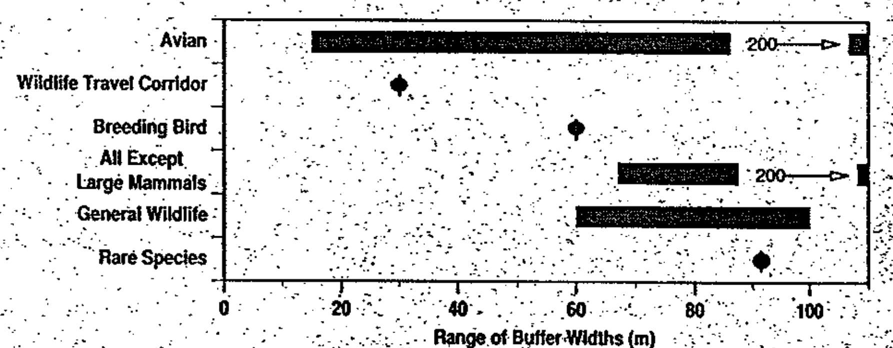


Table 7. A summary of pollutant removal effectiveness and wildlife habitat value of vegetated buffers according to buffer width. The stepwise increments are adapted from Table 5 and Table 6, and reflect changes in pollutant removal effectiveness and wildlife habitat value according to width of the vegetated buffer. [1 meter = 3.28 feet]

Buffer Width (m)	Pollutant Removal Effectiveness	Wildlife Habitat Value
5	Approximately 50% or greater sediment and pollutant removal	Poor habitat value; useful for temporary activities of wildlife
10	Approximately 60% or greater sediment and pollutant removal	Minimally protects stream habitat;poor habitat value; useful for temporary activities of wildlife
15	Greater than 60% sediment and pollutant removal	Minimal general wildlife and avian habitat value
20	Approximately 70% or greater sediment and pollutant removal	Minimal wildlife habitat value; some value as avian habitat
30	Approximately 70% or greater sediment and pollutant removal	May have use as a wildlife travel corridor as well as general avian habitat
50	Approximately 75% or greater sediment and pollutant removal	Minimal general wildlife habitat value
75	Approximately 80% sediment and pollutant removal	Fair-to-good general wildlife and avian habitat value
100	Approximately 80% sediment and pollutant removal	Good general wildlife habitat value; may protect significant wildlife habitat
200	Approximately 90% sediment and pollutant removal	Excellent general wildlife value; likely to support a diverse community
600	Approximately 99% sediment and pollutant removal	Excellent general wildlife value; supports a diverse community; protection of significant species

but does result in a given buffer width that will better approximate a specific performance standard. The modeled approach, however, will only be as good as the site-specific data from which the model is run. High quality data for use in a model will often be expensive (e.g., time put into collecting it), which may limit its overall practicality for general use in resource management programs. Furthermore, most modeled approaches only consider one vegetated buffer benefit — pollutant removal, for instance — and neglect other potential benefits. Many of the existing buffer delineation models were developed to mitigate construction impacts, and therefore may not be readily applicable in establishing multiple-use vegetated buffers in already developed or undeveloped areas. A further limitation to the site-specific modeled approach is that regulatory staff will be required to delineate vegetated buffers on a case-by-case basis, which could become time consuming. Furthermore, permit applicants will not be able to incorporate vegetated buffer widths during the initial design process. This will add cost to all development requiring a permit, and the cost will be borne by both the permit applicant and the permitting agency.

Despite its limitations, the modeling approach is often considered the most accurate and dependable method of delineating vegetated buffer widths, and is commonly used by regulatory agencies. A strictly modeled approach, because it is based solely upon "real" data, leaves less room for argument of required buffer widths (other than whether or not the input data or the actual model is appropriate) and is therefore generally viewed as more "justifiable." Since a strictly modeled approach is very "black-and-white," it is generally inflexible, and may limit full implementation of multiple-use vegetated buffers by resource managers. Using a modeled approach to determine buffer widths to achieve a given pollutant removal standard, and then reviewing the modeled buffer width using best professional judgment to achieve other benefits (e.g., provision of wildlife habitat) may provide more flexibility and a better multiple-use vegetated buffer program.

Each approach to the application of vegetated buffers as a management tool has both good and bad points, and it will be up to the implementing authority to determine what trade-offs are the most reasonable and the most acceptable. Costs and benefits will have to be weighed and examined in light of the

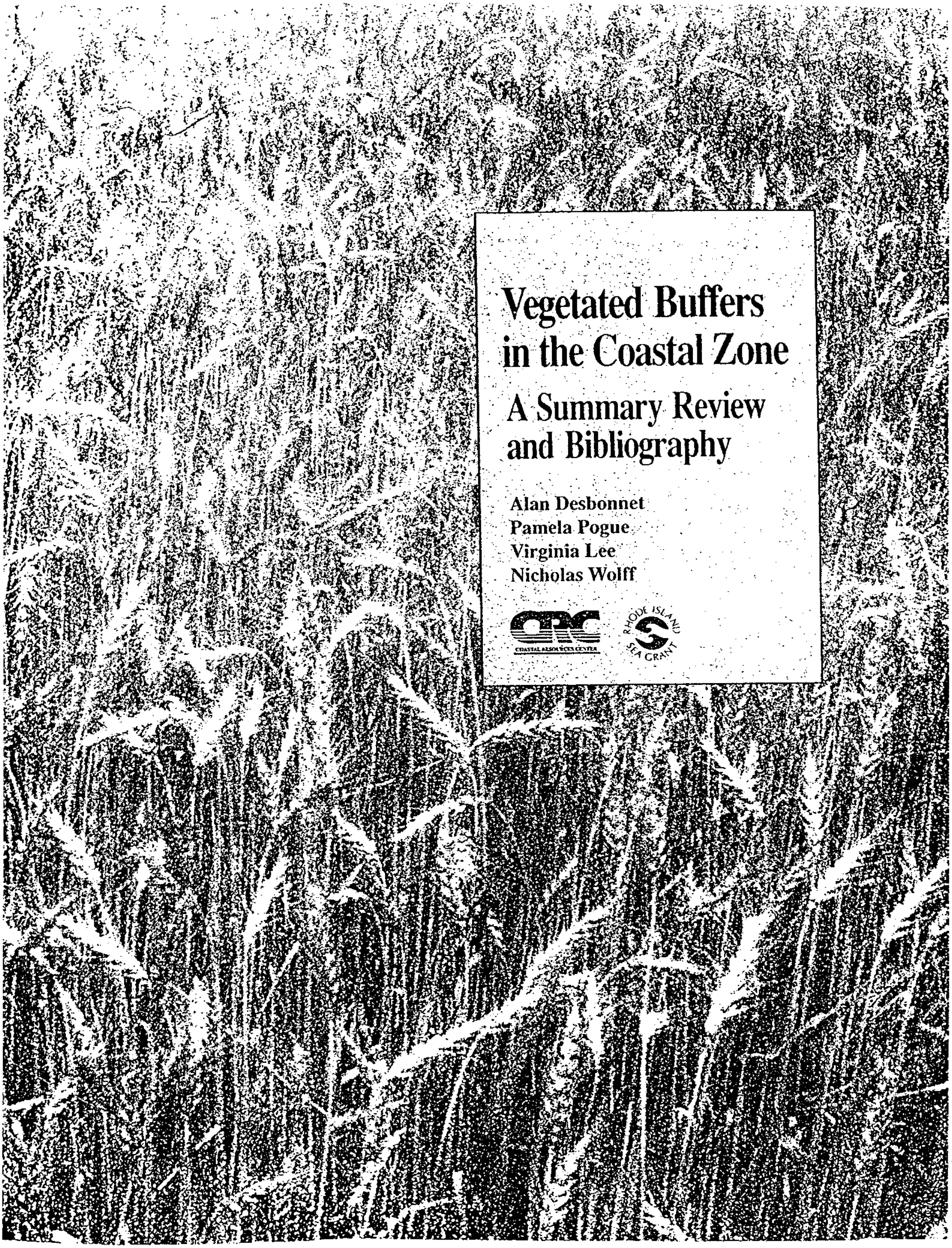
Table 8. A listing of buffer and setback widths that coastal states have established through their coastal zone management programs. M denotes the width is mandated, while R denotes that the width is recommended only. [1 foot = 0.305 meters]

State	Buffer Width	Status	Setback Width	Status	Comments
Alabama			40'; Applies to Gulf Coast only	M	Primarily for dune protection and preservation
Alaska			100' city/state lands; 66' private property	M	Applies only to timber harvest operations
California	100' around wetlands	R			Mainly for habitat preservation
Connecticut					Through local ordinances
Delaware			50' from mean high water mark	M	Also through local ordinances
Florida					Through local ordinances
Georgia					No CZMP at present
Hawaii			40' from shoreward vegetation line; 20' if hardship shown	M	Applies to all islands in the Hawaiian islands group
Louisiana					Through local ordinances
Maine	75' along entire coast; 250' along sensitive wetland areas	M			Also has a buffer management program
Maryland	100' along Chesapeake Bay shore	M			Case-by-case on non-Chesapeake Bay shores
Massachusetts					In process of development
Mississippi					Rarely; case-by-case
New Hampshire	100' along wetlands	M			The definition of wetlands includes the entire NH coast
New Jersey	0-300' on a case-by-case basis	R			Only along sensitive areas; local zoning supersedes state
New York			75' from wetlands (30' in New York City)	M	Vegetation not required in the setback
North Carolina	30' around significant waters	M			Vegetation not required in buffer
Oregon					Through local ordinances
Rhode Island	0-200' on a case-by-case basis	R	50' from the coastal feature	M	New buffer program being reviewed
South Carolina			Variable, according to erosional rates	R	Only applicable in coastal dunes; vegetation not required
Texas					CZMP being developed
Virginia	100' along Chesapeake Bay shore	M			Not required along other state coastal areas
Washington					Through local ordinances

permitting process on a case–by–case basis. Furthermore, a 50-foot construction setback from the edge of a water body or wetland is required, and may act as a vegetated buffer. The state coastal zone program also requires the use of vegetation for shoreline stabilization as a first choice during the permitting process. Rip-rap or other engineered shoreline stabilization structures may be allowed where vegetation proves inefficient or impractical. A major focus of the program is the creation of wetland areas as the shoreline stabilization structure of choice.

Florida

In the state of Florida, vegetated buffers may be established in the coastal zone as part of the permitting process on a case-by-case basis, or as mitigation requirements due to proposed development impacts. Furthermore, requirements for vegetated buffers may exist at local levels of government through implementation of construction setback regulations for development along the coast. State-mandated setbacks in the coastal zone relate only to requirements for the setback of septic systems from coastal wetlands.



Vegetated Buffers in the Coastal Zone

A Summary Review and Bibliography

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