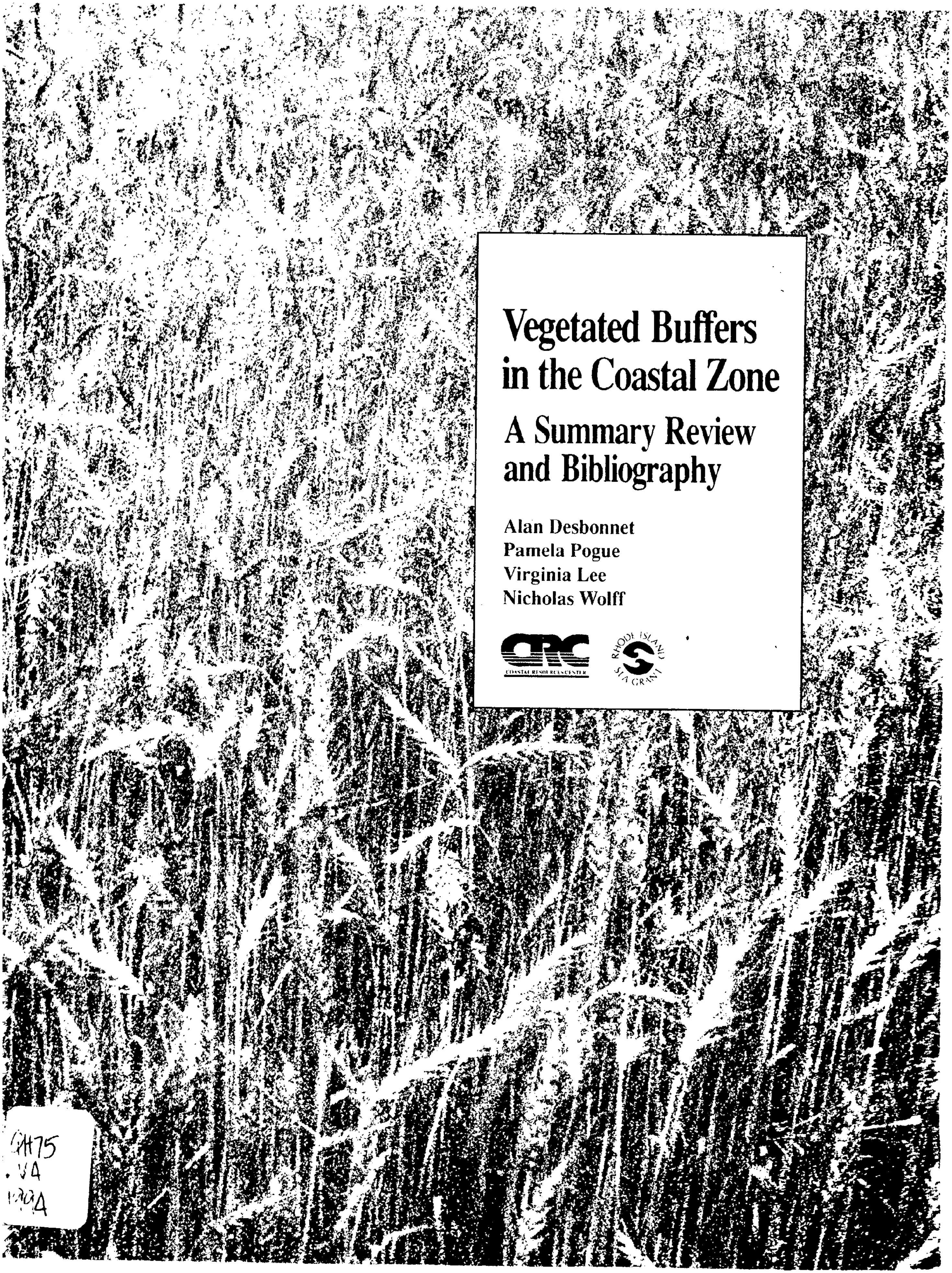

Vegetated Buffers in the Coastal Zone

A Summary Review and Bibliography

Alan Desbonnet
Pamela Pogue
Virginia Lee
Nicholas Wolff

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COASTAL RESOURCES CENTER
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COASTAL RESOURCES CENTER

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Acknowledgments

I. Introduction

Recent events, such as algae blooms; fish kills; closure to harvest of finfish and shellfish stocks; increased coastal development, tourism, and recreation; loss of tidal wetlands and wildlife habitat; and scenic degradation of coastal viewsheds, all have increased our awareness of the need to preserve, protect, and restore our nation's coastal resources. The problems observed along the coastal zone are not the result of any single event, but rather are a result of multiple changes that, when added together over time, have frayed and split the threads that link together ecosystem functions. In response, management schemes and regulations are developed that we hope will slow the rate of ecosystem change, smooth the frayed threads, and splice back together the severed links. One such management effort can be the application of vegetated buffers for use in the coastal zone. Vegetated buffers have been applied in the fields of forestry and agriculture to moderate nonpoint source degradation of water courses, in wildlife management to improve and provide habitat, and in landscape architecture to improve visual appeal. While great emphasis is being placed on the use of vegetated buffers to abate nonpoint source degradation of waterways, none of the above uses are exclusive of the others. It makes both good sense and good economics to pursue a multiple-use application of the vegetated buffer concept in coastal ecosystems.

It is the intent of this document to formulate concepts and ideas pertaining to the development of vegetated regions along the coastal zone that provide multiple benefits once implemented. It is not the intent of this review to provide the specific details, or provide critical comparison, of runoff sources and buffer effects when located on specific types of soils, for instance. There are many reviews of this type available in the published literature. This review differs from other published reviews of vegetated buffer uses in that it attempts to synthesize a broad spectrum of buffer benefits, effectiveness, and the variables that determine effectiveness.

■ Definition of vegetated buffer

Of the variety of definitions found in the literature (Table 1), all include the concept of a vegetated buffer acting as a transitional zone between differing land uses, and/or as a barrier to, and filter of, surface water runoff. As a result of their association with reducing the impact of development and landscape alteration on water resources, vegetated buffers are now being routinely employed as a tool for managing the environment. Vegetated buffers are often implemented, for instance, to mitigate the effects of nonpoint source pollution by removing pollutants from runoff through plant and microbial uptake, microbial degradation and conversion, physical trapping, and chemical adsorption. Phillips (1989a) describes vegetated buffers as "one of the most effective tools for coping with nonpoint source pollution." The U.S. Environmental Protection Agency (EPA, 1993) states: "...constructing vegetative treatment systems, will be considered in all coastal watershed pollution control activities." Statements such as these give significance to the use of vegetated buffers, and further contribute to their adoption and use for the control of nonpoint source pollution in current resource management schemes.

Resource managers are beginning to view vegetated buffers as one method of working toward compliance with recently drafted National Oceanic and Atmospheric Administration (NOAA) and EPA nonpoint source pollution control measures. The practice of implementing vegetated buffers, however, has generally focused upon their use as a "best management practice" (BMP). Overall, there is a lack of understanding with regard to developing vegetated buffers to provide benefits beyond what a typical BMP can provide. For instance, EPA (1993) states: "The term [*vegetated buffer*] is currently used in many contexts, and there is no agreement on any single concept of what constitutes a buffer, what activities are acceptable in a buffer zone, or what is an appropriate buffer width." This statement emphasizes the lack of general understanding and the common confusion concerning the use and effectiveness of vegetated buffers as a resource management tool.

Further confusion arises from the distinction, noted in Table 1, between a vegetated filter strip and a naturally vegetated area. Filter strips are typically considered a BMP engineered for a specific purpose, such as sediment removal. Forested buffers, on the other hand, are typically natural areas left along stream and river banks to mitigate the effects of logging on in-stream trout and salmon habitat. These practices are commonly considered separate entities — one edge of field (filter strips) and the 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.

greater incentive for voluntary adoption and participation in such programs.

Before vegetated buffers can become an effective multiple-use management tool, however, their variable uses and effectiveness must be better understood by resource managers, who can then develop programs to maximize the benefits and minimize the shortfalls for their use along the coastal zone. The implementation of vegetated buffer areas in the coastal zone can directly assist in pollution control, habitat diversification, and visual beautification. The application of multiple-use vegetated buffers, however, will best be implemented at a watershed scale to protect the rivers and streams, and in effect, the entire ecosystem, from which the coastal zone ultimately derives its health. Anything less than a system-wide approach will result, as it has in the past, in only partially solved problems. The implementation of vegetated buffer programs, however, regardless of the environment in which they are applied or the care and effort taken in their design and development, can neither take the place of, nor fully mitigate, the effects of poor land management techniques. Vegetated buffers should be considered a tool that can assist in the restoration of coastal and watershed ecosystems once sound land management practices have been developed and put into general practice, and not as an inexpensive technological savior to mitigate poor land and other natural resource management practices.

II. Vegetated Buffer Use and Effectiveness: A Review

■ Nonpoint Source Pollution Control

Nonpoint source pollution of our nation's waterways is of major concern for natural resources policy and management. The U.S. EPA recently estimated that 50 to 70 percent of the nation's threatened or impaired surface waters were being adversely affected by agricultural nonpoint source inputs, and that five to 15 percent of threatened or impaired surface waters were being adversely affected by urban runoff (Griffin, 1991). Concern is also growing for the degradation of groundwater due to nonpoint source impacts, which has implications with regard to subsurface recharge to streams, rivers, lakes, and estuaries, as well as to drinking water supplies. A national survey of wells conducted by the U.S. Geological Survey found that nearly 6.5 percent contained nitrate concentrations in excess of the EPA-established safe drinking water standard of 10 mg/l nitrate-nitrogen (Madison and Brunett, 1985).

Recent estimates of the impact of nonpoint source pollution have pushed forward a new era of regulation to abate water quality degradation. NOAA and EPA have both drafted new guidelines for regulations to limit nonpoint source pollutant impact on surface waters. Under the purview of Section 6217 of the Coastal Zone Management Act and Section 319 of the Clean Water Act, the mandated regulation of nonpoint source pollutants will begin in earnest.

The control of nonpoint sources of pollution, however, will not occur as easily as for point sources, which can usually be clearly identified, quantified, acted upon, and monitored for compliance to discharge standards. Nonpoint sources, by their very nature, are most often diffuse, cryptic, not easily monitored, and in many ways not fully understood. A further problem is that, even when a nonpoint source is clearly identified, it is often not the sole cause of any observed degradation of water quality or habitat. Instead, it is usually a result of the cumulative impact of many nonpoint sources within the area.

Although numerous problems are inherent in controlling nonpoint sources of pollution, abatement methods are being developed and implemented along watercourses throughout the world. Many of these are engineered control measures designed to mitigate the off-site impacts of development — catch basins, settling ponds, and grassy swales, for instance. The implementation of vegetated buffers as BMPs has generally been practiced by resource managers with the intent of removing sediments and attached pollutants from runoff water. This practice is well-supported and documented in the literature, where numerous studies can be found that describe the design and effectiveness of vegetated buffers as a BMP. Other measures employ increased planning to abate the impacts of future development. Rezoning, cluster development, setbacks from watercourses, and defining naturally vegetated areas as buffers are some examples of planned mitigation measures. Naturally vegetated buffers have typically been applied as habitat preservation measures, except within the field of forestry, where they have been extensively applied for sediment control.

In order to assess the potential value of implementing vegetated buffers as a nonpoint source pollutant control measure, the many variables that affect how buffers remove pollutants from runoff must be understood. A better understanding of how vegetated buffers work, and what factors limit their use and effectiveness as pollutant removal mechanisms, will assist in evaluation and implementation of practical and functional vegetated buffers.

■ Critical Variables Affecting Pollutant Removal

Vegetated buffers are typically employed with the primary objective of removing sediment and its attached pollutants from surface water runoff. Pollutant removal is primarily achieved by slowing the surface water flow that transports sediments, allowing time for the settling of sediments and the pollutants adhered to them. The effectiveness of a vegetated buffer in removing pollutants, however, will vary according to a number of conditions, such as:

- Soil type in the buffer
- Depth of the water table in the buffer
- Type, density, and age of vegetation in the buffer
- Pollutant concentrations contained in the runoff water entering the buffer
- Land use and size of areas draining into the buffer

- Hydrologic regime of the area within and adjacent to the buffer
- Width of the buffer
- Residence time of water in the buffer
- The path of runoff water into and through the buffer

Due to the inherent variability in the conditions that determine the effectiveness of vegetated buffers for the removal of pollutants, no single "best buffer" has been identified for widespread application. However, with better definition of those variables that determine buffer effectiveness, a better understanding can be gained as to what conditions, in general, promote pollutant removal effectiveness.

Surface Water Flow

In order for a vegetated buffer to effectively remove pollutants and sediments, the surface water flow through the vegetated buffer must be slow, shallow, and uniform (Broderson, 1973; Dillaha et al., 1986a). Surface water runoff should progress as shallow "sheet flow," and not become channelized as it moves across the buffer area. Slow flow allows for pollutants — which are often adsorbed to sediments — to settle out and become incorporated into surface soils (Lee et al., 1989). Settling will be most pronounced in runoff that contains large-sized sediment particles, and less pronounced in those containing fine silts and particulates, which often require long retention times and very slow flows in the vegetated buffer to effectively settle. Slow flow also promotes utilization of nutrients by plants, assists flood control by allowing water to percolate into the soil, and reduces erosion within the buffer area. Rough surfaces, which better reduce flow velocity and promote sheet flow, result in greater pollutant and sediment removal than smooth surfaces (Flanagan et al., 1986; Williams and Nicks, 1988).

Field tests, however, indicate that naturally occurring vegetated buffers are generally incapable of inducing sheet flow from storm water runoff due to the natural tendency of water to move in discrete channels. Dillaha et al. (1986a) report a range of 40 to 95 percent reduced efficiency of sediment, nitrogen, and phosphorus removal in vegetated buffers when runoff flow through the buffer area deviated from shallow sheet flow. Channelization of flow through the buffer was cited as a major problem and limitation to buffer effectiveness during the review of riparian buffers implemented on agricultural lands in the state of Virginia. Nearly all the vegetated buffers inspected needed some form of maintenance or engineering to reduce channelization of flow, and to increase effectiveness in the removal of sediment and pollutants from surface runoff. The natural tendency of water to move in discrete channels may be one of the greatest impediments to successful buffer implementation for nonpoint source pollution control, particularly when implementing nonengineered vegetated buffers.

When depth of the surface water flow is such that vegetation in the buffer is submerged, effectiveness is reduced. As submergence increases, filtering efficiency of the buffer declines to zero (Karr and Schlosser, 1978; Barfield et al., 1979). When storm events occur, such as sudden thunderstorms, precipitation can often be extremely heavy, submerging the buffer and allowing an initial heavy flow of pollutants into receiving waters. All vegetated buffers may experience temporary ineffectiveness during thunderstorms or similar events that bring heavy precipitation.

Groundwater Flow

As surface soils become saturated, water may move vertically rather than horizontally through the soil layer and enter into the groundwater recharge system. The net movement of groundwater depends on soil type, subsurface impermeable layers, geology, hydrologic regime, and slope. Groundwater carries soluble pollutants that have passed through soils in percolated water. As it eventually recharges to lakes, rivers, streams, and coastal waters, it can become a source of pollution to surface waters. Groundwater may also move into subsurface aquifers and degrade potable water supplies. In areas such as the coastal northeastern United States, groundwater recharge can be a significant source of nitrogen enrichment to coastal waters (Valiela et al., 1992; Weiskel and Howes, 1992). Leachate from septic tanks, leaking underground storage tanks, landfills, and accidental spills can all enter the groundwater system, eventually entering coastal waters.

Vegetated buffers, however, may only be able to remove a limited number of pollutants from groundwater — nutrients and some metals, for instance. Oils, most metals, and pesticides will generally not be effectively removed by vegetated buffers once they have entered the groundwater recharge system.

Furthermore, vegetated buffers located over deep water tables are not usually effective in the removal of pollutants from subsurface flow. Deep groundwater flows can move over considerable distances and over relatively long time frames (Hynes, 1983), and at depths where plant root systems are unlikely to reach them. Areas that are recharged from deep groundwater flows often receive pollutant inputs from distant sources that may have originated decades ago. A time lag may therefore develop between both cause and effect, as well as between the implementation of abatement measures and any observable effects.

Nutrient uptake and utilization by plants can be a major pathway of nutrient removal from groundwater supplies in a vegetated buffer. In areas that contain a shallow aquaclude (a subsurface impermeable soil layer), subsurface flow may be more horizontal than vertical, increasing the likelihood of groundwater being reached by the roots of overlying vegetation. In a forested area located over a shallow aquaclude (less than four meters deep), Peterjohn and Correll (1984) reported an 80 percent removal of nitrate from surface water flow, and Correll and Weller (1989) reported an 84 to 87 percent removal of nitrate from groundwater. In these instances the subsurface aquaclude kept the groundwater available to the root systems of plants in the buffer for uptake, as well as keeping it available to denitrifying microbial communities.

A major pathway for nitrate removal in groundwater is denitrification. The process of denitrification, which converts nitrate to nitrogen gas, which is then released to the atmosphere, is reliant upon the existence of a microbial community of denitrifying bacteria. The microbial community is partly reliant upon anaerobic conditions — a circumstance in which no free oxygen is present. The oxygen present in nitrate (NO_3) is utilized for metabolism by the microbial community, and nitrogen gas is released to the atmosphere as a metabolic by-product. A further limitation to this process is the availability of a source of carbon (organic material) to support the microbial community (Obenhuber and Lowrance, 1991). Soils that are poorly drained and rich in organic materials will typically provide conditions that promote denitrification.

Areas with a shallow water table, such as wetlands and areas with poorly drained soils, most readily provide the conditions conducive to the removal of nitrate contained in both surface and groundwater supplies. A series of related studies by Gold et al. (1991), Simmons et al. (1992), and Groffman et al. (1992), reported that nitrate removal was greater in areas with shallow water tables than in those with deep water tables during both dormant and growing seasons. Ambus and Lowrance (1991) found that 68 percent of the denitrification they observed occurred in the top two centimeters of soil. A shallow water table keeps groundwater close to the surface and in the area where carbon sources (i.e., organic leaf litter) are most likely to promote the growth of denitrifying microbes. Correll and Weller (1989), based on biomass removal estimates for nitrate-nitrogen, suggest that denitrification may be the most important nitrate removal mechanism from groundwater in forested areas.

There is, however, some concern that use of vegetated buffers to treat surface water runoff may actually increase groundwater nitrate and other soluble pollutant concentrations by promoting percolation into soils. Gold et al. (1989) and Weiskel and Howes (1992) have both reported that nitrate can readily travel through soils and into groundwater supplies with little or no removal in transit. This may be true for many soluble forms of pollutants, particularly in areas with highly permeable or very well-drained soils (Schwer and Clausen, 1989). Under some soil conditions — well-drained, sandy soils, for instance — the vegetated buffer could slow surface flow, promoting rapid percolation of surface water to groundwater, and actually degrade potable water supplies or coastal waters. It is presently unclear, however, to what extent this event occurs, and further study is needed to determine if and when vegetated buffers promote groundwater contamination.

Slope

Areas of steep slope do not allow for long retention time of runoff water, and since pollutant removal is at least partially time-dependent (i.e., to allow plant uptake and denitrification to occur), steep slopes reduce vegetated buffer effectiveness. Furthermore, steeply sloped areas negate the velocity-reducing effects of surface roughness, and thereby promote erosion. Even though a steeply sloped area may be thickly vegetated, it may be ineffective at removing sediments and pollutants because it promotes erosion and channelization of flow through the buffer area. The shallower the slope, the longer the residence time, the slower the flow, and the greater the ability of sediment and pollutants to settle and be removed from the runoff.

A slope of less than 15 percent reportedly allows for adequate retention time and pollutant removal, while steeper slopes may not be suitable for vegetated buffers due to the slopes' erosion potential and lack of adequate retention time (Schueler and Bley, 1987; Niewswand et al., 1990; Palmstrom, 1991). Clark (1977) gives some examples of minimum buffer widths for water quality protection according to slope and soil erodibility: he recommends a minimum width of 10 meters for areas with no slope on slightly erodible soils, extending to 50 meters for 30-percent slopes on severely erodible soils. Trimble and Sartz (1957) suggest adding an extra 0.6 meters of vegetated buffer width for each one-percent increase in slope within the vegetated buffer for minimum effectiveness, and a 1.2-meter increase per one percent slope increase to attain greatest water quality protection. Broderson (1973), in a study of the effectiveness of forested buffers to remove sediment from runoff before the runoff enters a stream, suggests that fifteen-meter buffers are sufficient at slopes less than 50 percent, and a maximum 66-meter buffer is sufficient for extremely sloped areas. Comerford et al. (1992) note, from a review of the literature, that slopes greater than 30 percent generally allow inadequate retention time in a vegetated buffer for any significant denitrification to occur.

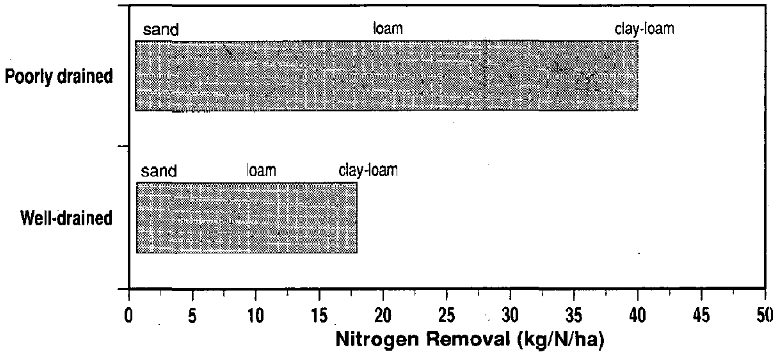
Slope of the area preceding the vegetated buffer also can affect pollutant and sediment removal. Steep slopes leading into a flat buffer area often tend to cause the bulk of the transported sediment to be deposited on the leading edge of the buffer area, forming a berm (Magette et al., 1986; Robat and Sabol, 1988). Once a berm is formed at the leading edge of the vegetated buffer, water will be channeled around the buffer, rendering it useless. Eventually the berm will be breached, causing channelization of flow into the vegetated buffer, increasing erosion and reducing buffer effectiveness for pollutant and sediment removal.

Soil Characteristics

Soils with high permeability generally provide greater filtration of sediment and attached pollutants (Chescheir et al., 1988; Lee et al., 1989). Once the pollutants enter the soil layer, they can become incorporated through physical, chemical, and biological interactions. However, highly permeable soils, such as sandy soils, may allow for the rapid movement of water into the groundwater recharge system. The movement may be so rapid that no removal of pollutants is allowed by plants, and only minimal removal by physical and chemical adsorption, particularly for dissolved forms of pollutants.

Figure 1 shows that well-drained soils are only half as effective for the removal of nitrogen as poorly drained soils. Sandy soils provided the least nitrogen removal, regardless of drainage capacity. Ehrenfeld (1987) found that nitrogen from septic system leachate moved greater distances vertically than horizontally through the permeable sandy soils of the New Jersey Pinelands, where the nitrate-laden septic leachate quickly percolated below the root zone of buffer vegetation. In some soils, vegetated buffers that are not located directly in the septic system leach field plume will be ineffective in removing nitrate. The contaminants contained in

Figure 1. Nitrogen removal in various poorly drained and well-drained soil types. Nitrogen removal is more than doubled in poorly drained soils compared to well-drained soils. Sandy soils provided poor nitrogen removal regardless of soil wetness. Data from Groffman and Tiedje, 1989a.



septic system leachate can readily enter nearby waterways under these conditions.

Poorly drained soils generally retain water long enough, and often under conditions favorable enough, that pollutant removal is accomplished. Figure 1 presents a range of nitrogen-removal data reported by Groffman and Tiedje (1989a) for a variety of soil types and conditions. Poorly drained soils were found to be more than twice as effective as well-drained soils for the removal of nitrogen. Poorly drained soils that contain a higher organic content are more apt to promote the growth and maintenance of denitrifying microbial communities and hence greater nitrogen removal (Nichols, 1983; Peterjohn and Correll, 1986; Groffman et al., 1991a). In cases where long residence time occurs in saturated, organic soils, nitrogen removal may be high (Cooper, 1990). These conditions are typically found in salt marshes, wetlands, and wet forests, all of which have been repeatedly reported to express high denitrification potential. Saturated, organically rich soils, therefore, can be useful in the removal of both soluble and sediment-bound pollutants, while sandy soils may be most effective in removing sediments and bound pollutants, and soluble forms only marginally.

Soils rich in clay content are often relatively impermeable, and removal of pollutants from surface waters by soil percolation can be low. Scheuler and Bley (1987) do not recommend vegetated buffers as effective pollutant removal mechanisms in clay-rich soils. Mixed clay soils, however, as shown in Figure 1, often are effective in the removal of pollutants. Clay soils often have high affinities for binding positively charged pollutants, particularly metals, by acting as a cation (negatively charged) exchange site. Provided the clay soils are not compacted, and runoff over the area is slow, pollutant removal via chemical binding may be significant (Zirschky et al., 1989). Chemical removal, however, is finite: once metals are adsorbed to soils, they can be freed for transport by further chemical or physical disturbance of the soil layer, and may be moved during the next runoff event. A ranking of stability of soil-bound metals given in Baker and Chesnin (1975) shows that copper has the greatest tendency to remain stable once adsorbed. Zirschky et al. (1989), experimenting with copper, nickel, zinc, cadmium, chromium, iron, lead, and manganese, found that only copper and zinc were consistently removed. Other metals may therefore not be effectively removed from surface runoff by vegetated buffers, even in buffers with conditions conducive to metals removal, and other methods may need to be explored if removal of metals is of major concern.

Pollutant Characteristics

Many studies indicate that most pollutants and nutrients transported by surface runoff are attached to sediments. This tends to be true for metals (Zirschky et al., 1989), pesticides (Lake and Morrison, 1977), phosphorus (Karr and Schlosser, 1977; Chescheir et al., 1988; Lee et al., 1989), and some forms of nitrogen (Karr and Schlosser, 1977; Chescheir et al., 1988). Nitrate, however, has less affinity to sediments, and is most often found in a dissolved phase (Chescheir et al., 1988). Runoff that characteristically contains pollutants bound to sediment need only move through a buffer able to remove the sediment load. When runoff characteristically carries pollutants in dissolved or soluble forms, the buffer area will need to promote long retention times in order for those pollutants to be effectively adsorbed to soils or utilized by plant and microbial communities.

The effectiveness of pollutant removal will be related to the concentration of pollutants entering the vegetated buffer from outside sources. Much of the reviewed literature reports testing buffer efficiency in response to sources that have very high concentrations of incoming pollutants, particularly sediments and nutrients. For instance, Edwards et al. (1983) measured concentrations of total suspended solids, nitrogen, and phosphorus entering grassed buffers from a cattle feedlot to be: 10,200 mg/l TSS; 705 mg/l N; 152 mg/l P. In most cases, very favorable removal efficiencies were reported, despite a high input rate. In the Edwards et al. (1983) study, removal rates of 87 percent TSS, 83 percent N, and 84 percent P were recorded after the feedlot runoff had moved through a settling basin and sixty meters of grassed buffer. This may suggest that vegetated buffers treating more "average" concentrations of pollutant inputs *might* produce even greater removal efficiencies than those reported in the published literature (see Schueler (1987), for example, for average concentrations of various pollutants contained in urban runoff water).

In contrast, Nichols (1983) reported that removal efficiency for nitrogen and phosphorus decreased as loading of those nutrients into a wetland treatment area increased. Reuter et al. (1992) report similar results. The U.S. Army Corps of Engineers (1991) suggests that, despite reported high removal efficiencies for pollutants in vegetated buffers, high pollutant loading rates into the buffer may result in degradation of adjacent sensitive water bodies. For example, Castelle et al. (1992) reported that 55 percent of the assessed buffers implemented to protect wetlands that bordered residences using lawn maintenance systems showed impacts from fertilizer applications. The symptoms ranged from increased wetland plant growth to wetland plant death from nitrogen toxicity. Under high pollutant loading conditions, the percentage of pollutants *not* removed may be sufficient to cause degradation of water quality and other resources. This is further exemplified by the study of Edwards et al. (1983), in which, despite high removal rates (87 percent TSS, 83 percent N, 84 percent P), the pollutant load leaving the sixty-meter grass buffer was high (988 kg TSS, 63 kg N, 15 kg P), as were concentrations (3,840 mg/l TSS; 260 mg/l N; 51 mg/l P). Although high pollutant removal rates in vegetated buffers will certainly reduce loadings to receiving water, they may not necessarily equate to protection of water quality.

Over time, a vegetated buffer may become "saturated" with sediments and pollutants, reducing overall removal efficiency. Eventually the buffer could become a source of pollutants to adjacent water bodies. It is well known that physical disturbance can cause pollutants trapped in a vegetated buffer to become available for transport out of the buffer area. However, not enough research has been conducted on vegetated buffers to adequately assess either the conditions that lead to saturation with pollutants or the circumstances under which an undisturbed vegetated buffer becomes a pollutant source.

Karr and Schlosser (1977) note that pollutants contained in surface runoff are generally bound to smaller-sized sediment particles, such as silts and clays, and that the effectiveness of any vegetated buffer will partially depend on how well it removes silts and clays from runoff water. Clay sediment in runoff generally exists at very small sizes, and Karr and Schlosser (1978) report that, as particle size decreases, the buffer width required to remove a greater percentage of those particle sizes increases dramatically. Wong and McCuen (1982) similarly found that disproportional increases in buffer width — from 33 to 66 meters — were required to increase sediment removal efficiency of a grassed buffer from 90 to 95 percent. The largest sediment particles are generally deposited within the first few meters of the vegetated buffer, leaving the fine silts and clays in suspension. For example, Neibling and Alberts (1979) reported that only 37 percent of clay-sized sediment and particulates were removed within a 0.6 meter width of grass vegetated buffer, while 91 percent of the total sediment load was removed within the same effective buffer width. Wilson (1967) found that most coarse-grained sediment was removed in 3.3 meters, most silt in 15 meters, and most clays by 90 meters in a buffer vegetated with Bermuda grass.

Relatively narrow buffers, provided they promote shallow sheet flow through the buffer area, will effectively remove coarse-grained sediments and their associated pollutants. Wider buffers, however, will be required to remove smaller-sized particles of sediment and the pollutants adsorbed to them. Pollutants in dissolved forms may require even greater buffer width to be effectively removed by chemical interactions, plant uptake, or microbial transformation.

Vegetation Type

The vegetative ground cover within a buffer serves multiple purposes with regard to overall buffer effectiveness by removing pollutants, providing habitat, and creating aesthetic appeal. The type, density, and age of the vegetative ground cover play a large role in determining the effectiveness of pollutant removal, the habitat value to wildlife, and the overall aesthetic appeal of the vegetated buffer. The vegetative ground cover contained in a buffer can be manipulated, often in a cost-effective manner, to better achieve the goals for which the vegetated buffer was implemented. For instance, the vegetative cover in the buffer could be manipulated to enhance the removal of various pollutants of concern, thereby providing some flexibility to resource managers for achieving their specific goals.

Table 2 provides a range of removal rates reported in the literature for nitrogen, phosphorus, and sediment in both grassed and forested buffers and over a variety of site-specific conditions. Nitrogen was the most widely reported pollutant with regard to removal in vegetated buffers. The removal rates provided in Table 2 may be useful to resource managers for estimating potential nitrogen removal in implemented buffers, based upon vegetation and other general characteristics. In the event that pollutant loadings were able to be estimated, actual removal rates for a proposed vegetated buffer could be estimated, based upon Table 2 and site-specific data, and the buffer area modified in order to achieve the desired pollutant removal goal.

The removal rate values for nitrogen presented in Table 2 are graphically presented in Figure 2 to visually show the range of nitrogen removal rates in grassed and forested buffers. The range of nitrogen removal rates represented in Figure 2 shows that, overall, grassed buffers have greater nitrogen removal potential than forested buffers. Forested areas, particularly wet forests, are frequently noted in the published literature to be more effective nitrogen removers than grassed areas. In Figure 2, however, grassed buffers are shown to have the potential to remove nitrogen at a rate approximately three times greater than that of forested areas. The potential for forested areas to remove nitrogen may be underestimated in the presented data, since some of the grassed buffers were treated with direct nitrogen applications (fertilizers), thus providing a greater representation of their overall nitrogen removal potential. Studies conducted with forested buffers generally did not include fertilizer treatments; therefore, their range of potential nitrogen removal may be underestimated. However, unfertilized control plots of Kentucky bluegrass utilized by Morton et al. (1988) had removal rates of only 2.0 kg/N/ha/yr, which is considerably lower than the lowest removal rates reported for forested areas (see Table 2 and Figure 2). Furthermore, fewer studies for grassed buffers reported removal in kg/ha/yr than for forested buffers, and the average removal rate for grassed buffers may more closely approximate those for forested, given greater representation (see Figure 2).

Grasses and woody-stemmed species are described separately below because of the unique characteristics of each type, as well as the differences each group exhibits in the removal of sediment and pollutants from runoff. Furthermore, the literature on the two types of ground cover is very different. Most of the work completed for grass buffers comes from studies of vegetated filter strips where the primary pollutant of concern is sediment (and its adsorbed pollutant load). The results of grassed buffer studies are generally reported as percent removal and typically have treated source areas with a high pollutant load. Studies of wooded buffers generally have focused on naturally forested areas, with the removal of nitrogen the primary focus. Nitrogen removal typically is through biological rather than physical/chemical pathways, such as denitrification and plant uptake and storage. Forested buffer studies less often reported source areas that contained high pollutant loads, and generally treated logged or urban areas rather than livestock and agricultural areas. The result is very much two separate bodies of knowledge, which have taken two separate paths of study. This makes for some difficulty in directly comparing grassed and forested buffer studies, as the methods and reporting of results are generally different. Enough of each, however, has been reported in similar units that some preliminary comparisons can be made and relationships proposed.

Grasses

Grasses tend to be very effective in reducing overland flow, as well as being effective nutrient and sediment removers. Removal rates reported in Table 2 and used in Figure 2 show that grassed buffers treated with fertilizer applications can remove up to 290 kg N/ha/yr. Despite high reported removal rates and efficiencies, it is often unclear how this relates to water quality protection. Morton et al.(1988) found nitrate leachate concentrations leaving fertilized plots of Kentucky bluegrass to be well below the EPA drinking water standard of 10 mg/l nitrate-nitrogen. Nitrate concentrations ranged from 0.51 to 4.02 mg/l, with the higher values found leaving heavily fertilized, overwatered experimental plots. The results of this study suggest that home lawn fertilization practices may not always pose a direct threat to drinking water supplies. Although these reported concentrations do not appear threatening to potable water supplies, concentrations at the upper portion of the range could, when combined with other sources of nitrogen, contribute to eutrophication of coastal waters. This may be particularly true in the temperate coastal zone, where soils are typically composed of glacial till and sand, which often allow rapid movement of groundwater to coastal waters with only minimal removal of nitrogen.

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]

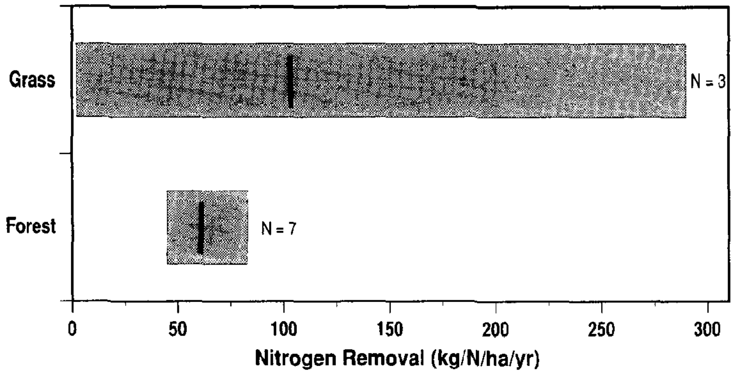
Reference	Removal Rate	Details
NITROGEN		
Ehrenfeld, 1987	75 - 80 kg N/ha/yr	Hardwood wetland getting septic tank leachate
Ehrenfeld, 1987	45 - 56 kg N/ha/yr	Pine upland getting septic tank leachate
Ehrenfeld, 1987	68 - 69 kg N/ha/yr	Oak upland getting septic tank leachate
Peterjohn & Correll, 1984	77 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—0.53μg 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]



Grasses are desirable as part of the vegetative matrix that constitutes the vegetated buffer. They are generally able to respond rapidly to increased concentrations of nutrients, grow rapidly and densely, and typically grow well in nearly all climates. Thickly planted, clipped grasses provide a dense, obstructive barrier to horizontally flowing water. This increases the roughness of the terrain, which reduces flow velocity, promotes sheet flow, and increases sediment and adsorbed pollutant removal efficiency. This also increases residence time in the buffer, which promotes uptake of nutrients by plants. Low-cropped grasses, however, may not be adequate in areas that experience frequent flooding, as they are rendered temporarily useless when submerged. Grasses that are to be used as part of the vegetated matrix of the buffer should therefore be left in an uncut condition, or at least not cut below a height of three or four inches. A worst-case grassed buffer would be one that is highly manicured and clipped low, resembling a golf course putting green. These become flooded very easily, thus being rendered useless as a pollutant filter. Medium height, thickly growing grasses represent the ideal for a grassed buffer area.

The use of grasses in vegetated buffers has many maintenance benefits. Mowing is relatively easy, and the clippings can be readily collected for a more permanent removal of nitrogen and other pollutants from the buffer area. Considering that grasses — particularly thickly growing covers — are also effective at reducing runoff velocity, they may be used with the additional effect of promoting slow, shallow sheet flow of runoff into a naturally wooded buffer area. 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. Grasses therefore are suitable as part of the vegetated matrix that makes up the buffer area, or as ground cover in the area immediately preceding the naturally vegetated buffer.

Woody-stemmed Species

Woody-stemmed species generally have deeper and more well-developed root systems than grasses, and when the root system is greater than two feet deep, the vegetated buffer may be effective for the removal of pollutants from groundwater (Ehrenfeld, 1987; Groffman et al., 1991b). In general, hardwood species are better nitrogen removal mechanisms than are conifer species (Spur and Barnes, 1980), but the overall removal of pollutants will vary according to characteristics of the forested buffer site — such as vegetative composition, depth to the water table, and hydrology.

For wooded buffers, poorly drained forest plots have been found to provide greater denitrification than well-drained forest plots by creating better living and growth conditions for denitrifying microbes, as well as by keeping water within the organically enriched surface soil layer and close to root systems of resident vegetation (Correll, 1991; Groffman et al., 1992). Figure 2 shows removal rates as high as 85 kg N/ha/yr have been reported for nitrogen removal in forested areas. The range of nitrogen removal rates for forested buffers is small, suggesting that removal and storage in these sites are, on average, fairly consistent. With regard to plant uptake, Ehrenfeld (1987) found that brush species did not show an increased nitrogen content in the presence of septic system leachate, while hardwood and conifer species did. This suggests that species with shallow root systems may often be ineffective at removing nitrogen from groundwater supplies, except in poorly drained areas where groundwater remains near surface soils. Areas with a deep water table will need to rely on deep-rooted species to realize any nitrate removal prior to recharge from groundwater supplies to nearby waterways.

There is considerable variation in the documented nitrate-reducing capacity of forested buffers, depending on site and climate. Whole-watershed studies conducted by Peterjohn and Correll (1984) and Lowrance et al. (1984a,b) report high levels of nitrate removal from surface water within forested buffers of mid-Atlantic latitudes, while work conducted by Warwick and Hill (1988) noted very little nitrate removal in northern latitudes (Canada). Warwick and Hill (1988), however, did note that reduced nitrate removal at their study site may have been at least partially due to minimal retention time of runoff during their experiments, and that increased retention time of runoff water in a forested buffer should increase nitrate removal efficiency.

Groffman et al. (1992) and Simmons et al. (1992), in companion studies, noted that nitrate-nitrogen reduction in a vegetated buffer is dominated by plant uptake during the growing season, but that soil microbial denitrification is the dominant nitrate removal mechanism during the dormant season. Denitrification during the dormant season was a result of a higher seasonal water table that allowed nitrate-laden waters to remain near surface soils, which are richer in organic content and allow for microbial denitrification. Groffman et al. (1991b) reported that nitrate removal decreased by 64 percent between the growing and dormant seasons in their study of vegetated buffers in Rhode Island, while Correll et al. (1992), during a study of vegetated buffers in Maryland, reported 97 percent nitrate removal rates from groundwater in the fall (growing season), declining to 81 percent removal in winter months (dormant season).

These findings suggest that, at least in temperate latitudes, seasonal variability in vegetated buffers can be expected. Actively growing vegetation will be effective at nutrient removal during summer months, when coastal waters are typically most susceptible to nutrient inputs. During the dormant season of vegetation, at least in areas where groundwater can rise near the soil surface, denitrification will continue to remove nitrate, but possibly at a reduced rate. Cold weather months, however, may result in vegetated buffers becoming ineffective as the ground freezes and becomes generally impermeable.

Although not as simple as mowing the grass, selective harvesting of woody-stemmed species is possible, thereby permanently removing nutrients from the vegetated buffer system (Lance,1972; Leak and Martin, 1975; Todd et al., 1983; Lowrance et al., 1984c; Ehrenfeld, 1987). Should a vegetated buffer not be periodically harvested, eventually the nitrogen stored in plant tissues will reenter the system through decomposition. Woody-stemmed species are good long-term nitrogen sinks, but removal of the entire plant also removes the nitrogen uptake and storage mechanism. As trees are removed from the buffer area, they will need to be replaced for continued nutrient removal at a more or less steady rate.

Ehrenfeld (1987) noted that most primary production by trees is converted to leaf materials, and Peterjohn and Correll (1984) found that 81 percent of the nitrogen uptake in a riparian buffer was returned to the forest floor as leaf litter at the end of the growing season. Removal of leaf litter from vegetated buffers may therefore be considered an effective permanent nitrogen removal mechanism in buffer management schemes. The removal of leaf litter, however, results in the loss of organic/detrital material to soils in the vegetated buffer, changing one of the conditions — high organic content — that promotes the growth of denitrifying microbial communities. The positive or negative effects of leaf litter removal may be site-specific (e.g., presence of a high water table).

Buffer Width

Buffer width variability is one of the most versatile tools available to the resource manger. Other variables that affect the efficience of vegetated buffers in the removal of pollutants are often unchangeable, or at least may not be altered in a very cost-effective manner. Buffer width, however, is often easy to manipulate in order to better achieve the desired affect (e.g., water quality protection).

Table 3 lists vegetated buffer widths reported in the literature to be adequate for generalized purposes.

The range of buffer widths runs from two meters to nearly 200 meters, with a variety of vegetation types reported. These data are presented graphically in Figure 3, showing the overall range of values reported to be adequate to protect water quality in several categories of water bodies. The values contained in the table and figure suggest that even relatively narrow buffers (less than 10 meters wide) have some reported value as a resource mangement tool for the protection of water quality. Based upon mean values reported by category, however, 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 concern.

Table 4 presents a range of pollutant removal effectiveness values, according to buffer width, reported in the literature. Although values for the removal of other pollutants may have been given in the publications cited, those presented in Table 4 — sediment, total suspended solids (TSS), nitrogen, nitrate, and phosphorus — were reported most frequently, and were felt to provide the best range of values for review purposes. Also provided in the table, when given in the original manuscript, is information on runoff (pollutant) source, vegetation type(s), and slope of the buffer.

What is immediately obvious is the variability in pollutant removal over both the range of buffer widths and within similar buffer widths summerized

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	

in Table 4. This variability in vegetated buffer pollutant removal effectiveness is a direct result of the site-specific conditions previously discussed. Most of the reported pollutant removal values come from studies that have utilized buffers vegetated with grasses to treat runoff from sources rich in pollutants — manure, sewage spray, and feedlots for instance. The range of values for removal effectiveness presented in Table 4 may therefore be biased toward the treatment of extreme pollution sources, compared to what may be considered typical for runoff water. Furthermore, studies of grassed buffers have provided most of the data summarized in Table 4, with the result that forested buffers are potentially underrepresented with regard to pollutant removal efficiency.

The data presented in Table 4 are graphically shown in Figure 4 through Figure 8 for sediments, total suspended solids, nitrogen, nitrate, and phosphorus. An associated "best fit" curve — a logarithmic function using percent removal as the dependent variable — is also provided to show the modeled relationship between buffer width and pollutant removal efficiency. The relationship between buffer width and polutant removal agrees with those previously developed by Karr and Schlosser (1978), Wong and McCuen (1982), and others, in which removal efficiency increases rapidly up to a certain buffer width, after which large increases in buffer width are needed to improve removal efficiency by even a small amount. It is important to note that the data used to construct the graphs in Figures 4 through 8 do not come from a single, controlled study, but from a wide variety of studies reported in the literature. The studies were conducted at a variety of sites and treated different pollutant sources with differing input concentrations (see Table 4). The relationships between percent removal and vegetated buffer width given here, therefore, integrate buffer effectiveness over a range provided in the literature, and are to be interpreted as generalized, or average, pollutant removal effectiveness.

Removal of sediment and suspended solids

Sediments are readily removed from surface water runoff moving through vegetated buffers. This is evident from Table 4 and is further exemplified in Figure 4, which shows that removal efficiencies are typically high, even for relatively narrow vegetated buffers. From the modeled relationship, a vegetated buffer of even two meters in width could be expected to remove about sixty percent of the sediment load entering the vegetated buffer. A twenty-five-meter-wide vegetated buffer could be expected to remove about eighty percent of sediment inputs. Only slight increases in removal efficiency with increasing buffer width are noted for buffers greater than 25 meters wide. Overall, vegetated buffer width must increase by a factor of 3.5 in order to achieve a 10 percent increase in the removal of sediment in the vegetated buffer. Although the majority of data that was used to develop the curve shown in Figure 4 comes from grassed buffers, the few reported values that come from forested buffers are high, particularly at larger buffer widths.

The pattern noted for the removal of total suspended solids (TSS; Figure 5, following page) in vegetated buffers is similar to the relationship seen for the removal of sediment. In vegetated buffers six meters in width, the expected removal efficiency for TSS is about sixty percent. Eighty percent removal

Figure 3

Figure 3. A range of vegetated buffer widths reported in the literature to be adequate for the protection of water quality in various water body types. The range represents buffer widths noted in the literature, as reported in Table 3. The General category contains buffer widths that were reported to protect water quality, but were not specific to a type of water body. The heavy line contained in the bar represents the mean of the data that make up the range. [1 meter = 3.28 feet]

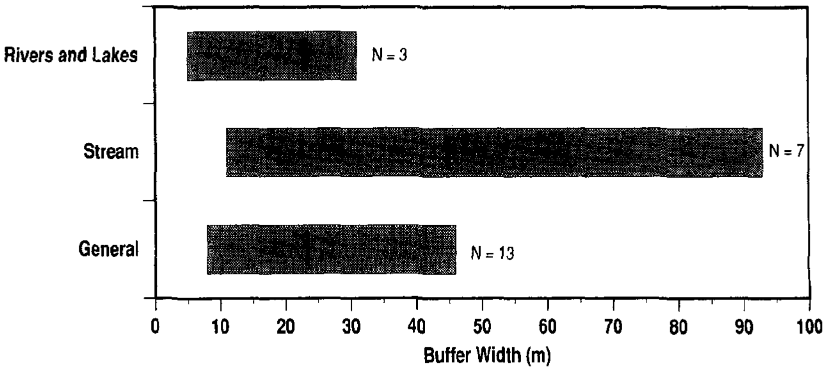


Table 4. A summary of pollutant removal effectiveness values according to width of the vegetated buffer. Removal efficiency values are given as percent removal for each of the various pollutants treated in the vegetated buffer — sediment, TSS, total nitrogen, total phosphorus, and nitrate-nitrogen. [1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

		PollutantRemoval (%)				
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		

occurs at about sixty meters of buffer width, beyond which improved removal efficiency is slight with increased buffer width. For TSS removal, an approximate increase in buffer width by a factor of 3.0 provides a 10 percent increase in removal efficiency. The greater vegetated buffer widths required for TSS removal, compared to sediment removal, may be due to smaller-sized particles and a greater amount of particulate matter, which in general requires greater buffer width to be adequately removed from surface water runoff. As with sediment removal, the few included forested buffer values are high for the removal of TSS from runoff.

Removal of total and nitrate-nitrogen

The removal efficiency of vegetated buffers for nitrogen varies considerably, particularly within the range of narrow buffer widths. This is very evident from both Table 4 and Figure 6. Removal efficiency of nitrogen in a nine-meter-wide vegetated buffer is expected, from the modeled relationship, to be about sixty percent. Removal efficiency increases with increasing buffer width to about 80 percent removal at sixty meters of buffer width, after which point the rate of removal of nitrogen per unit increase in buffer width slows. An approximate increase in vegetated buffer width by a factor of 2.6 is required to achieve a 10 percent increase in nitrogen removal efficiency.

The nitrogen removal efficiency data used in Table 4 and Figure 6 are mainly from studies performed in grassed buffers, and therefore may not adequately portray removal efficiencies of forested buffers. However, the scatter in the forested buffer data included in Figure 6 appears as wide and as variable as that noted for grassed buffers.

Nitrate removal is variable, but generally low, according to the data given in Table 4 and shown in Figure 7, for all buffer widths. The modeled nitrate removal-to-buffer width relationship shown in Figure 7 suggests that approximately 50 percent of the nitrate present will be removed in buffers of one hundred meters in width. The modeled relationship for nitrate removal suggests that increased removal will only occur given enormous increases in vegetated buffer width. It is unclear if the low removal efficiency of nitrate in vegetated buffers provided by this model is due to the data being generally from grassed buffers, which are often less than ideal denitrification sites, or if the relationship between buffer width and nitrate removal is simply inappropriate. Considering that nitrate removal predominantly occurs through biological rather than physical or chemical means, site-specific variables, such as denitrification potential, may need to be considered in order to better estimate nitrate removal in vegetated buffers.

Removal of total phosphorus

The data given in Table 4 and modeled in Figure 8 suggest that the removal efficiency of phosphorus in vegetated buffers is quite variable, and relatively low at very narrow buffer widths. Buffer efficiency increases rapidly to twelve meters of buffer width, where approximately sixty percent phosphorus removal is achieved. Buffer efficiency improves with added buffer width, until approximately eighty percent removal is achieved in an eighty-five-meter-wide vegetated buffer. Greater phosphorus removal, as with other pollutants, is achieved only with large additions of buffer width after this point. Overall, an approximate increase in buffer width by a factor of 2.5 is required to achieve a 10 percent increase in phosphorus removal.

Although phosphorus is reported to be typically bound to sediments, it is generally bound to smaller-sized sediment particles (Karr and Schlosser, 1977). Since smaller-sized particles and particulates are typically not as effectively filtered out by vegetated buffers as coarse-grained sediments, this may result in the differences noted between sediment and phosphorus removal efficiencies, as seen when comparing the removal patterns in Figure 4 and Figure 8. The forested buffer data given in Figure 8 appear to be as variable and scattered as those for grassed buffers.

Performance standards

From the values given in Table 4, and the modeled relationships seen in Figure 4 through Figure 8, an estimated removal standards matrix was constructed (Table 5). Other than for nitrate, the matrix suggests that, on average, 50 percent overall pollutant removal can be expected to occur in vegetated buffers five meters wide. Seventy percent removal efficiency can generally be expected to occur in vegetated buffers of about thirty-five meters in width, while eighty percent removal efficiency might be expected in buffers of about eighty-five meters in width. Vegetated buffer widths between

Figure 4.

Figure 4. Relationship of percent removal to buffer width for the treatment of sediments contained in surface water runoff. An approximate increase in vegetated buffer width by a factor of 3.5 is required to achieve a 10 percent improvement in removal of sediment. The most efficient vegetated buffers, based upon width-to-removal ratios, will be about 25 meters in width, after which large additions of buffer width are required to achieve only small increases in sediment removal efficiency. The modeled line is: % removal = [(7.613 * ln(width in meters)) + 55.8]. Data are taken from Table 4. [1 meter = 3.28 feet]

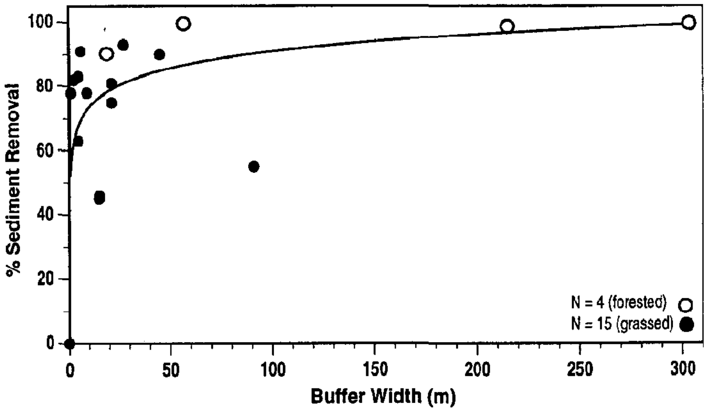
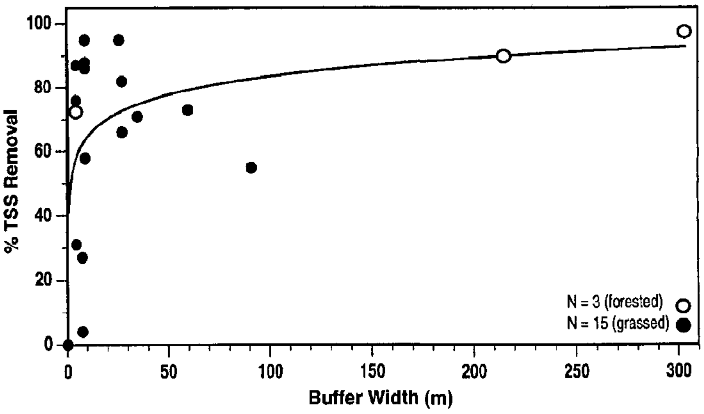


Figure 5.

Figure 5. Relationship of percent removal to buffer width for the treatment of TSS contained in surface water runoff. An approximate increase in vegetated buffer width by a factor of 3.0 is required to achieve a 10 percent improvement in removal of TSS. The most efficient vegetated buffers, based upon width-to-removal ratios, will be about 60 meters in width, after which large additions of buffer width are required to achieve only small increases in TSS removal efficiency. The modeled line is: % removal = [(8.34 * ln(width in meters)) + 45.1]. Data are taken from Table 4. [1 meter = 3.28 feet]



250 and 550 meters will be needed to achieve 90 – 99 percent overall pollutant removal effectiveness.

The matrix given in Table 5 may be useful in estimating the potential overall removal of a vegetated buffer for a given buffer width, or for estimating the removal of a given buffer width for a specific pollutant of concern. These values should be held in light of the site-specific conditions in and around the actual buffer area, and buffer width adjusted according to best professional judgment for best estimating a buffer width to achieve the desired removal efficiency.

■ Wildlife Habitat Protection

For the purposes of this review, the term "wildlife" refers to both animal and plant species. The use of the term wildlife, with regard to its animal component, is generally meant to encompass all except large mammals. This is particularly true at narrow buffer widths, but large mammals may become part of the vegetated buffer complex as the width of the buffer increases, providing more suitable conditions and space for large mammals.

The vegetated buffer concept has reached its greatest application for wildlife habitat protection in the development of "greenway," "stream corridor," and "habitat corridor" management programs. These practices generally set aside vegetated strips along rivers and streams to promote good water quality, maintain wildlife habitat, and provide wildlife travel corridors. Current paradigms suggest that increased environmental diversity and complexity promote increased biodiversity (see Wilson, 1988). Therefore, the establishment of vegetated buffers can be viewed as one step in maintaining local ecosystems and promoting regional biodiversity. The following highlights some of the potential benefits to wildlife of vegetated buffers, as noted by Groffman et al. (1991b):

- Increased species diversity: mixed habitat types promote greater diversity
- Increased foraging sites: mixed vegetation provides greater food availability
- Wildlife dispersal corridor: wider buffers provide a better travel corridor
- Escape from flooding
- Hibernation sites
- Breeding and nesting sites: wider buffers reduce nest parasitism
- Decreased disturbance from neighboring areas
- Decreased predation: wider buffers further reduce predation

It is difficult to be specific about the value to wildlife of vegetated buffers as habitat, since the vegetative makeup of the buffer area will often determine what species will use it, as well as how they use it. The habitat value of vegetated buffers for different animal and plant species will also be determined by width of the buffer, proximity to other required habitat types, proximity and density of predators and competitors, and proximity of each organism to others of its species. Furthermore, noise disturbance from developed or developing areas affects habitat quality and use. The greater the disturbance, the greater the buffer required to reduce the impact upon the use of adjacent environments by wildlife. In some instances, buffers may need to be established *around* habitat areas in order for them to be successfully utilized by wildlife. This will be most critical in areas that are highly developed and create a lot of disturbance — noise, for instance. The value of narrow buffers as habitat will therefore be directly related to the amount of disturbance they receive from adjacent areas.

Table 6 provides a summary of buffer widths reported in the literature considered to provide habitat for various broad wildlife categories: this summary is presented graphically in Figure 9. Several authors (for example, Tassone, 1981; Cross, 1985; Triquet et al., 1990; Groffman et al., 1991b) note that vegetated buffers that are contiguous to areas of natural vegetation are likely to support, or be used by, a greater number of species. Even small vegetated buffers can be enhanced in value by being close to undisturbed areas that more fully satisfy species-specific resource requirements.

From the reported values in Table 6, which range from 15 to 200 meters, it is difficult to determine a "best size" buffer width for general wildlife habitat. It has been noted that 15-meter buffer widths provide habitat under certain conditions, and it may be that widths much less than that will not provide adequate space — bird nesting sites for instance — for resident species. Buffers less than 15 meters wide, however, may provide adequate habitat for the temporary activities, such as resting or feeding, of both resident and transitory species.

Figure 6.

Figure 6. Relationship of percent removal to buffer width for the treatment of nitrogen contained in surface water runoff. An approximate increase in vegetated buffer width by a factor of 2.6 is required to achieve a 10 percent improvement in removal of nitrogen. The most efficient vegetated buffers, based upon width-to-removal ratios, will be about 60 meters in width, after which large additions of buffer width are required to achieve only small increases in nitrogen removal efficiency. The modeled line is: % removal = [(10.5 * ln(width in meters)) + 37.4]. Data are taken from Table 4.
[1 meter = 3.28 feet]

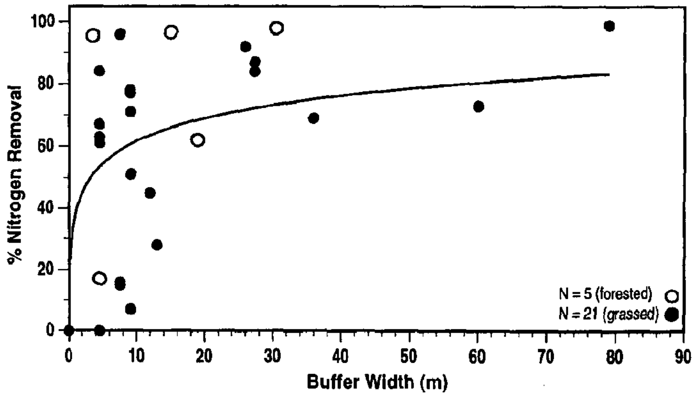


Figure 7.

Figure 7. Relationship of percent removal to buffer width for the treatment of nitrate contained in surface water runoff. Unlike the other modeled pollutant removal-to-buffer width relationships, that for nitrate is suggested to be inappropriate. Nitrate is typically removed by biological processes rather than through physical and chemical means, and the variables that control denitrification may better determine the removal of nitrate in vegetated buffers than does buffer width. Data are taken from Table 4.
[1 meter = 3.28 feet]

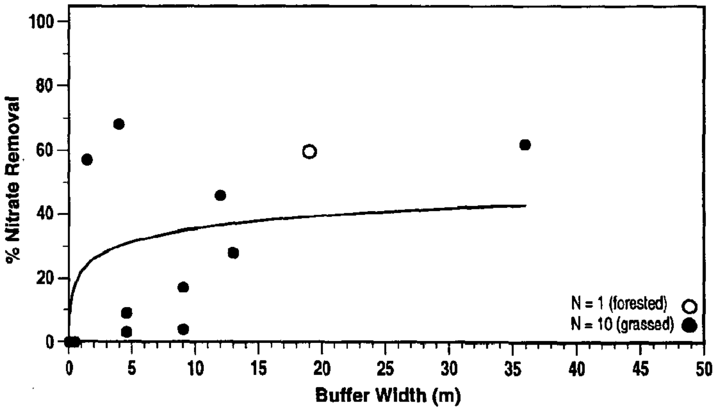


Figure 8.

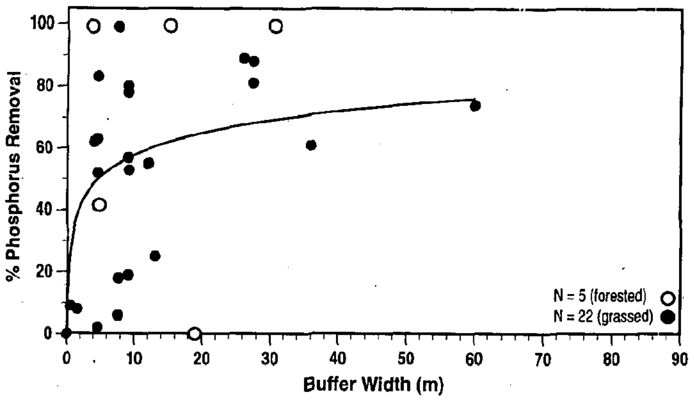


Figure 8. Relationship of percent removal to buffer width for the treatment of phosphorus contained in surface water runoff. An approximate increase in vegetated buffer width by a factor of 2.5 is required to achieve a 10 percent improvement in removal of phosphorus. The most efficient vegetated buffers, based upon width-to-removal ratios, will be be about 75 meters in width, after which large additions of buffer width are required to achieve only small increases in phosphorus removal efficiency. The modeled line is: % removal = [(10.3 * ln(width in meters)) + 34.1]. Data are taken from Table 4. [1 meter = 3.28 feet]

Table 5. Estimated removal standards matrix for specific pollutants as taken from the modeled relationships shown in Figure 4 through Figure 8 for vegetated buffers. In general, greater than 50 percent removal standards can be met with vegetated buffers about 5 meters wide. The 80 percent removal category generally marks the optimal width-to-removal ratio boundary, above which the increase in removal efficiency for a given increase in buffer width is small. [1 meter = 3.28 feet]

	Buffer Width (m)				
% Removal	**Sediment**	**TSS**	**Nitrogen**	**Nitrate**	**Phosphorus**
50	0.5	2	3.5	>100	5
60	2	6	9	—	12
70	7	20	23	—	35
80	25	60	60	—	85
90	90	200	150	—	250
99	300	700	350	—	550

Many studies have determined buffer widths for wildlife habitat by determining species-specific needs — such as those for rare, threatened, or endangered species — and then applying them to buffer width requirements. Few studies, however, have determined overall needs for multiple-species use of buffers, and fewer still have studied use patterns of wildlife for existing or newly established vegetated buffers that are part of a multiple-use resource management program. It is therefore difficult to determine how buffers of various widths and vegetative makeup, once implemented, will be used by wildlife.

However, if current paradigms are correct, then with regard to value of vegetated buffers to wildlife, bigger is better, and some is better than none. Large buffers may be required in areas where species preservation is a major focus of vegetated buffer development, while smaller buffers may be adequate in other areas, particularly where more contiguous stretches of habitat are nearby. Larger buffers will provide a greater diversity of resources over the long term for wildlife in general, while small patches will provide "island" habitats in the larger mosaic. The greater the diversity of available resources, the greater the potential for the long-term survival of the targeted or intended wildlife species, as well as for incidental users.

Some caution, however, is noted in a summary by Groffman et al. (1991b) of vegetated buffers as wildlife habitat. The authors note that sharp contrasts between habitat types, such as engineered buffers, may promote the growth of weed species. The weed species could invade nearby natural areas, replacing resident vegetation with opportunistic and transient species. This was reported by Dillaha et al. (1986a) to be a common problem in vegetated buffers assessed in the state of Virginia. Weed species have been known to invade nearby habitats, thereby reducing the habitat value of the buffer. This is a most important consideration if the vegetated buffer is established for the protection of rare, threatened, or endangered species, and may also be a consideration in the development of small buffers that represent island patches.

This suggests that care should be taken in designing and designating vegetated buffers next to sensitive areas, or where rare or endangered species live. In these cases, the vegetated buffers could be developed to graduate into the sensitive habitat, rather than providing a sharp contrast between habitat types. In some cases where no buffer exists, a sharp contrast may be unavoidable, and transient wildlife may be the major users of the vegetated buffer area. Wider buffers will provide less contrast, since they will produce a larger gradient between habitats, and will become habitat themselves. Some routine assessment and maintenance practices may be required to maintain habitat value and keep invading species from overtaking implemented buffers.

■ Erosion and Flood Control

Vegetated buffers employed as erosion controls are generally applied as best management practices to mitigate the off-site impacts of development and construction activities. However, by their very nature, vegetated buffers can assist in reducing erosion even when not specifically designed for that purpose. Since vegetated buffers slow the velocity of runoff flow, as well as dissipate flow and reduce channelized flow, they will reduce the probability of erosional problems downstream of buffer areas.

It was previously noted, however, that vegetated buffers can become clogged with sediment removed from surface water runoff. Vegetated buffers that are employed specifically for erosion control — for instance, to control sediment movement from construction sites — may need to be rehabilitated after construction work if they are intended to continue functioning as a multiple-use buffer.

Vegetated buffers also have value for flood control, and have been employed for this purpose. They control flooding by reducing flow velocity, allowing absorption and storage of water in soils, and by moving water from surface to subsurface watercourses. Vegetated buffers also mitigate property destruction by maintaining some undeveloped land along waterways and keeping developed or developing areas back from floodwaters, storm surges, and extreme high tides.

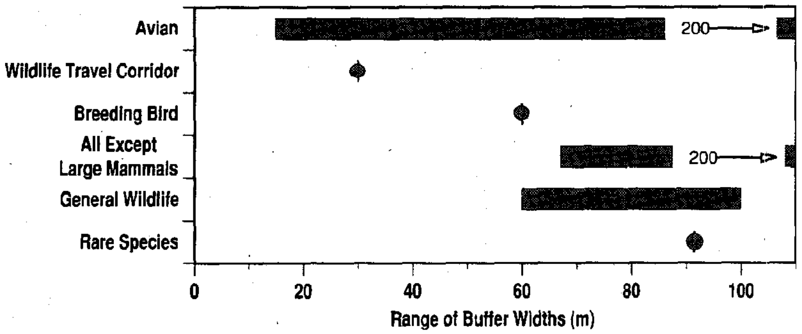
The capacity of the buffer area to provide flood control will depend on rainfall and runoff intensity, soil characteristics, hydrologic regime, and slope of both the buffer and the source of runoff water. Even under ideal conditions, the ability of a vegetated buffer to control flooding will be related to the water source area. A buffer that is small relative to the water source area will have only limited ability to control flooding. When buffers are applied with a primary intent of flood control, water-holding

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]



capacity of the buffer area will need to be determined, and proper width applied to the buffer in order to store the water received during a given storm event.

■ Historical and Cultural Preservation

While vegetated buffers are best known for their use in preserving and protecting water quality and wildlife habitat, application of coastal buffer zones may also have value in preserving and protecting historical and cultural sites. In Rhode Island, for instance, many of the important archaeological sites pertaining to Native Americans — such as summer encampments and trading sites — are within 200 feet of the coast. The same may be true for other coastal states. If so, establishing coastal vegetated buffers can preserve potentially important sites for future archaeological study.

■ Scenic and Aesthetic Enhancement

Aesthetic and scenic qualities of vegetated buffers often provide an "extra" value or benefit to the major purpose for which the vegetated buffer was designed. As noted in Mann (1975), Simeoni (1979), and Forman and Godron (1986), landscapes with high visual diversity are generally more appealing than nondiversified landscapes. Designed planting of trees and shrubs within the buffer area can enhance visual diversity and thus aesthetic appeal. As the vegetated buffer attracts wildlife, such as songbirds, visual and biological diversity are both enhanced. In areas previously cleared of vegetation, reestablishing native species can assist in rebuilding the sense of "wilderness" often associated with coastal expanses. It is this sense of isolation and wilderness that makes coastal regions attractive to those who visit.

The aesthetic value of vegetated buffers is, however, mostly based on subjective factors, and therefore not fully transferable in implementation practices. Although no criteria for aesthetic values of vegetated buffers exist, aesthetics will continue to be included as an intrinsic value of vegetated buffers that are implemented for natural resource management.

■ General Guidelines for Multiple-use Vegetated Buffers

Although the conditions determining the actual effectiveness of a multiple-use vegetated buffer will be of a local and/or site-specific nature, some general guidelines can be developed for the use of vegetated buffers. Table 7 provides a generalized overview of the pollutant removal effectiveness — taken from the modeled relationships and as presented in Table 5 — and wildlife habitat value, taken from Table 6 — for a range of buffer widths for multiple-use vegetated buffers. The effectiveness of vegetated buffers for pollutant removal, as well as for wildlife use, is presented as increasing steps of buffer width.

Using the generalized set of buffer widths presented in Table 7 for developing and implementing a vegetated buffer policy requires that local conditions and intended uses be taken into consideration. The buffer widths listed in Table 7 are meant to be useful in a general sense for planning purposes. For example, the table values may be overly large if removal of sediment is the intended effect, and if the area of buffer implementation is very conducive to sediment removal. Similarly, the table values may be too small if the removal of metals is the intended effect and the proposed buffer area overlies impermeable soils on steep slopes.

From the values presented in Table 7, a multiple-use vegetated buffer of five meters could be considered a reasonable minimum-buffer-width standard. A five-meter-wide vegetated buffer will provide approximately 50 percent sediment and nutrient removal (except for nitrate). While a vegetated buffer of this width may not provide good overall wildlife habitat, it may be sufficient to provide resting and feeding areas for both resident and migratory species. A five-meter-wide multiple-use vegetated buffer can be practically implemented, except in areas of very dense development, and these exceptions could be reviewed as a variance to general buffer policy. A five-meter-wide vegetated buffer could be established as a minimum goal for the restoration of already developed areas. Establishing a minimum buffer width will also maintain or improve the scenic and aesthetic quality of the area, and will act as nondestructive, natural fencing between public waters and private uplands.

It should be kept in mind, however, that a five-meter-wide vegetated buffer removing approximately 50 percent of pollutants and sediment contained in surface waters may not meet minimum performance standards in all instances. If an approximate performance criterion of 80 percent removal is desirable, then a 75-meter-wide vegetated buffer may be the acceptable minimum. This buffer width will also provide minimum general habitat value. If protection of habitat for significant species is to be the main purpose of the vegetated buffer, then 200 meters may be the minimum acceptable buffer width. This width will also provide approximately 90 percent removal of sediment and pollutants. As minimum buffer width increases, however, conflict may arise in areas where small-sized land parcels or extensive development already exists.

For general-purpose buffers that will provide some value as wildlife habitat, a minimum width of 15 meters is suggested. A vegetated buffer of this width should be implementable in most areas that are only moderately developed. Vegetated buffers of 15 meters should provide some water quality protection for most waterways (e.g., approximately 60 percent pollutant removal); will offer minimal wildlife habitat value and greater visual and aesthetic appeal; and can provide a natural physical barrier between public and private properties.

For areas that are undeveloped, or are characterized by large lot sizes, buffers of 50 meters or more could be applied to ensure that some areas are providing general wildlife habitat. Buffers of this width could be applied to all publicly owned lands, such as state parks, recreation areas, and conservation areas. For areas that are considered critical, or provide habitat for rare, threatened, or endangered species, the buffer width could be extended to 100 meters or more to ensure sufficient habitat diversity and isolation from disturbance, and to promote the long-term survival of these species and their ecosystem. The minimum acceptable width will be determined by the function or functions of the vegetated buffer. Resource managers may need to define present and future uses for the regions under their purview, and then develop minimum multiple-use vegetated buffer widths for the goals and uses desired.

■ Implementation Approaches to Multiple-use Vegetated Buffer

One approach to multiple-use buffer implementation is applying a fixed vegetated buffer width along all waterways. For instance, a vegetated buffer of 25 meters in width could be required bordering all waterways. This approach, according to Table 7, would provide approximately 70 percent overall removal of sediment and pollutants, and provide minimal general wildlife habitat. Along many areas, however, a 25-meter vegetated buffer may make some developable lots unusable due to site constraints, and may not give sensitive resources adequate protection. Shifting the fixed width to higher or lower values alleviates problems on one end while creating them at the other. This approach has many limitations, but has been used by resource managers in vegetated buffer programs.

A variation of the fixed-width vegetated buffer approach is that recommended by the U.S. Forest Service in a recently published booklet describing riparian buffers (see Welsch, 1991). In this case, a vegetated buffer has a minimum width of 28 meters, and consists of three zones. The zone closest to the water is of a fixed width (five meters) and allows for no alteration of the buffer. The second, or middle, zone has a minimum width (17 meters) but can be expanded based upon local or site–specific conditions or to achieve a given effect (e.g., rare species protection). Limited use, such as selective harvest of timber, may be allowed in this zone of the buffer area. The third, or most inland zone, abuts a developed or disturbed area and possesses a minimum width (6 meters) that can also be expanded based on local conditions. This inland zone might consist of lawn in a residential setting or hay field in an agricultural setting. This approach alleviates some problems by allowing greater buffer widths to be applied as needed, but still may be restricted in its applicability in areas where small lot sizes are common.

A further modification of the fixed-width approach to vegetated buffer implementation is setting a realistic minimum vegetated buffer width based upon lot size or land use. A minimum width could be established for small lots or high-density residential areas so the buffer will provide some benefit for pollutant removal and/or habitat while not inordinately restricting use of property. The minimum vegetated buffer width could then be expanded as lot size and/or land use changes to provide greater benefits of pollution removal and habitat provision, while not overly restricting use of private or public lands. One example of this approach is that developed by the state of Rhode Island, which is provided in full detail in Appendix A.

An alternative to a fixed-width vegetated buffer is a vegetated buffer tailored to each site, using a model to generate a buffer width based upon a variety of data, but dependent upon site-specific conditions. This approach is often data-intensive,

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 uncertainty, restrictions, and flexibility inherent in each of the different approaches.

The "Ideal" Buffer

Although it is not possible to develop a "one best" vegetated buffer for all purposes, it is possible to describe the components of an "ideal" vegetated buffer for multiple use. If the vegetated buffer is intended to reduce pollutant inputs to waters from nonpoint sources, provide wildlife habitat, and establish a visual and physical barrier, it is possible to develop a general description of an ideal vegetated buffer. This description may prove useful in creating vegetated buffers that will perform within expectations and provide the results for which they were established.

Contour

The ideal multiple-use vegetated buffer for the removal of pollutants, regardless of width, would be relatively flat in contour in order to promote shallow sheet flow through the buffer. This would increase residence time, allow greater absorption of water into the soil layer, and reduce the probability of channelized flow. The vegetated buffer would not have any gullied or channelized areas within it. Similarly, the landscape surrounding and leading into the buffer would not promote channelized flow into the buffer area, and would have adequate vegetation or engineered design to reduce sedimentation at the leading edge of the buffer zone. Engineered designs might include the installation of level spreaders, or mechanical grading of the soils to produce a less steep slope, and/or alteration of the "preferred" direction of surface flow to promote shallow sheet flow into the buffer.

Vegetation

Ideally, the vegetation within the multiple-use vegetated buffer would consist of a mix of species. The leading edge of the buffer might consist of a thickly growing grass maintained at a height of about four inches. Beyond the grassy area would grow a mix of trees, brush, and possibly native grasses. The species of trees would have well-developed root systems capable of exploiting nitrogen stores traveling in groundwater, particularly in areas that are serviced by septic systems. Brush or woody-stemmed understory species would also provide a well-developed root system and canopy. Wherever possible, wetlands — both coastal and inland — would be incorporated into the buffer area. These areas most often provide the conditions that are conducive to denitrification, as well as often providing valuable habitat. Furthermore, upland buffers would be designated around wetland areas to provide habitat for the many animals that use wetlands as feeding and foraging areas but rely upon the uplands for breeding sites and refuge from predators.

Vegetation species growing in the buffer would be native, or species that are known to grow in similar habitat and climate. Ornamental species may be appropriate, provided they will not exclude or outcompete native species. Many state agencies or nongovernmental organizations — land trusts, universities, and botanical societies — have put together pamphlets that list and describe plant species native to a region. These publications would be consulted when planning a vegetated buffer to best ensure an indigenous cover within the buffer area. This is important for ensuring the longevity of the vegetation in the buffer, for providing adequate cover and forage for resident species, and for preventing problems associated with invasions of nonnative species.

To provide greatest value to wildlife, the ideal buffer would contain a mix of vegetation that fruits on a progressional schedule in order to provide a variety of feed types over the greatest length of time. Vegetation in the buffer would be as randomly distributed as possible — woody vegetation interspersed with areas of grass — to provide increased diversity within the buffer habitat landscape. Vegetation of various heights and canopy thickness would provide the greatest diversity to avian wildlife, and would promote use by the greatest diversity of birds, as well as other fauna. Some bird species — herons and osprey, for example — require large trees as nesting sites, and providing some large trees in the vegetated buffer would promote the nesting activities of these and other species.

For aesthetic appeal, a mix of vegetation would provide visual diversity. Although some tall trees within the buffer area would be kept to provide canopy habitat, short trees and brush would be dispersed throughout the buffer to allow water views from areas landward of the leading edge of the buffer. Based upon vegetation type and pollutant uptake rates, the buffer area would be determined to remove a given portion of those pollutants of concern, and then aesthetically fit into the landscape based upon development patterns and paths of surface water flow.

The ideal multiple-use vegetated buffer would be designated in existing natural areas. Designating vegetated buffers composed of existing vegetation assures the habitat value of the buffer to the support of native species. Designation of preexisting vegetated areas as buffers is also more economical since the costs of design and engineering are avoided.

Although the ideal vegetated buffer may not be realized under most circumstances, the concept of the ideal buffer is useful as a reference or goal during design and implementation phases. It can help ensure that the buffers that are eventually implemented will contain the most desirable traits possible, given natural limitations and site restrictions, and thereby be the most practical. The closer to the ideal a given buffers becomes, the more closely it will serve its intended purpose and provide the anticipated results.

III. Use of Vegetated Buffers in the Coastal Zone

■ Application and Approach

Vegetated buffers hold the promise of being an effective multiple-use management tool for sustaining the diverse uses of the coastal zone. The range of multiple-use vegetated buffer widths, five to 200 meters (or more; see Table 7), provides resource managers with a set of tools that can be applied according to developmental conditions along the coast. It also allows flexibility with regard to purpose and use of the multiple-use vegetated buffer area. Adopting some form of vegetated buffer program that applies minimum buffer widths according to existing or potential development and density, as well as applying wider buffer zones around areas of critical concern, can result in the development of a contiguous, or nearly contiguous, band of vegetated land bordering the coast. Such a program will assist in reducing the nonpoint source contribution of pollutants flowing into coastal waters, provide a diversity of wildlife habitats, provide for the protection and enhancement of scenic and aesthetic appeal of the coastal zone, promote flood and erosion control, and provide a visual and physical transition zone between public and private coastal properties. Development of such a program is realistic, equitable, and feasible.

A coastal zone buffer policy can be readily established using a variety of available resources. U.S. Geological Survey topographic maps, town zoning maps, aerial photographic survey results, or Geographical Information Systems (GIS) databases can readily be used to interpret conditions along the coast, and then to establish vegetated buffer widths for a given region. Habitat for rare, threatened, or endangered species; areas particularly prone to erosion and/or flooding; areas bordering poorly flushed estuaries or significant shellfish beds; and areas of particular historic or scenic significance may be identified as critical resource areas by coastal managers, and larger buffer widths implemented to provide for a greater degree of protection and/or preservation.

Although the removal rates presented in Table 2 cannot be used directly to provide a required width for implementing a vegetated buffer, they can be used to estimate annual removal rates for a given area of vegetated buffer. If estimates of pollutant input to the vegetated buffer can be arrived at — through nonpoint source loading models, for instance — an estimate of removal efficiency can be obtained for a given buffer area. Given the rapidity of the growth and sophistication of nonpoint source loading models and computerized geographic information systems, it is not unrealistic to imagine calculating pollutant loadings to the coastal zone, locating sensitive habitat areas or especially scenic or otherwise "special" areas, determining the vegetated buffer area required to provide expected benefits, and then designing the location, extent, and configuration of the vegetated buffer.

Some coastal areas, such as historical seaports and coastal villages, gain much of their charm and ambiance by their location directly on the water. In such instances, a vegetated buffer may be inappropriate, and other ways to mitigate nonpoint source pollution impacts and create wildlife habitat, if possible, may need to be considered. Resource managers will have to evaluate the various uses of their coastal zone, decide on a vegetated buffer approach, and then define where and how to implement the vegetated buffer program.

■ Public Perception

It is important to acknowledge that humans are a species that utilizes the coastal zone for a variety of purposes. This must be not only considered, but incorporated into vegetated buffer policy. Design and implementation of a coastal vegetated buffer zone program that disregards human use of the coastal zone is bound to meet both resentment and resistance, which could potentially be great enough to force the abandonment of the use of this important management tool for preserving and protecting coastal resources.

Establishing a program that utilizes vegetated buffers for multiple use — pollution control, wildlife habitat, scenic improvement — would help in making the program more appealing to a wider audience. Furthermore, a multiple-use approach to a coastal vegetated buffer program would make the results of its implementation more "real" in the eyes of many. Increased scenic improvement, or greater wildlife sightings, are both very tangible, very visible, and very real public "benefits" of a multiple-use buffer program. Certainly they are more tangible than increased pollutant removal, which is often in-visible to, and misunderstood by, the general public.

The ideal buffer program, however, would be one that is acceptable to the landowner who is being requested to "donate" the fringe of coastal acreage for the benefit of the public. Certainly the private landowner will garner some benefit from the program — increased wildlife sightings and the presence of a natural barrier between his personal lands and those of the public, for instance — but resentment due to land use limitations is often felt by private landowners. Given some leeway for manipulation and use of the buffer area, most landowners will feel less threatened by the program's infringing upon their rights of ownership and use.

■ Management and Maintenance

Regulatory agencies should develop a vegetated buffer use, maintenance, and management booklet that outlines to abutting landowners what is permissible within the buffer, information sources for the proper maintenance and management of the buffer area, and a calendar and schedule of recommended or required maintenance procedures. An assessment of implemented buffers by Castelle et al. (1992) reported that 95 percent of the assessed buffers showed signs of alteration after their implementation. In all cases where the buffer was part of a residential lot, the buffer was eventually replaced with lawn by the homeowner. The authors suggest that a lack of clear use and management objectives for the buffer, as well as a lack of buffer monitoring, resulted in the high alteration rate. A strong public education program implemented with the adoption of the buffer policy into the regulatory framework will go a long way toward helping landowners understand why the buffers were established and how landowners can use and maintain these areas. This is supported by the findings of Castelle et al. (1992), who note that buffers on the property of landowners who understood the purpose of the buffers were less affected by homeowner manipulation and impact than those buffers on property of landowners who had little or no understanding of buffer purpose.

The management of coastal zone multiple-use vegetated buffers will need to balance landowners' rights to use of their property with maintenance of the purpose for which the buffer was originally implemented. Winding trails and footpaths would be allowed within the vegetated buffer to provide access to the water's edge, and the trails would be checked and maintained on a regular basis for erosion or promotion of channelized flow through the buffer area. An occasional picnic table, gazebo, or similar use structure might be suitable within some vegetated buffers, provided it promotes neither a loss of effectiveness nor overuse of the buffer as a travel zone to and from the structure. Areas that have buffers established to protect critical habitat or significant wildlife may not be suitable for any manipulation for recreational use. Such manipulation will have to be assessed on a case-by-case basis in order to ensure that the original intent for which the buffer was established is not jeopardized. Appendix B provides an example of a multiple-use vegetated buffer management and maintenance program. This example is taken from the Rhode Island Coastal Resources Management Program (CRMP), and was developed to complement the vegetated buffer policies for the state of Rhode Island CRMP (Appendix A).

All woody-stemmed species of vegetation would be pruned and trimmed on a schedule to promote vigorous growth and utilization of nutrients. As trees and brush mature, or as individual plants succumb to natural causes, selective harvesting would maintain a vigorously growing and diverse plant community. Leaf litter and other organic debris, providing that it does not present a hazard or limit other intended uses of the buffer area, would not be removed from the buffer area. The breakdown of leaf litter provides a natural source of carbon to the soil layer, which is one requirement for the process of denitrification. Considering that coastal waters are generally nitrogen-sensitive, and nitrate is a readily usable form of nitrogen in marine waters, the promotion of denitrification in coastal zone vegetated buffers should be considered a priority. Grass clippings may or may not be removed from the buffer area, and worn or thin spots may be overseeded. Although neither fertilization nor watering of the buffer area would be needed as a regular maintenance activity, either or both might be appropriate in establishing new buffer areas or restoring existing ones.

■ An Example: Rhode Island's Coastal Buffer Program

An example of multiple-use vegetated buffer policies that have been developed for use in the coastal zone of Rhode Island is provided in Appendix A. It applies various-sized, fixed-width vegetated buffers, based on the summary given in Table 7, for residential lands; a fixed-width buffer on areas of concern or significance; and a case-by-case approach to other development, such as industrial, residential subdivisions, and commercial uses.

The Rhode Island example institutes vegetated buffers along the entire coastline of the state, while taking into consideration land parcel size and existing coastal development patterns. The program strives to strike a balance between land use by the homeowner and protection of coastal resources. The widths of the established buffers are determined according to lot size and Coastal Resources Management Council (CRMC) water type. The CRMC water type is a designation of the predominant use of coastal waters (i.e., I-Conservation Areas; II-Low Intensity Boating; III-High Intensity Use; IV-Multipurpose Waters; V-Commercial and Recreational Harbors; VI-Industrial Waterfronts and Commercial Navigation Channels). Special measures (e.g., wider buffers) are applied along areas that are considered critical or sensitive, such as wetlands or habitat that is used by rare, threatened, or endangered species.

The vegetated buffer policies and regulations are limited to residential areas (existing and infill) and allow for limited use of the buffer areas so that homeowners are not unduly denied use of their coastal property. These policies and regulations are used as guidelines for other types of development (commercial/industrial), but the final determination of buffer width for development other than single family residential is performed on a case-by-case basis by CRMC staff engineers and biologists to mitigate any potential impacts to the coastal zone.

The Rhode Island vegetated buffer program was developed to provide for multiple uses and multiple benefits. During development of the program, it was quickly realized that implementing vegetated buffers that would provide both high pollutant removal and high quality habitat was not practical in all coastal areas. Attempting to implement such buffers would either lead to the proposed program's not being adopted, or to requests for variances on nearly all permit applications.

Given this, a program was developed that balances the landowners' rights and the CRMC's mandate to "preserve, protect, and where possible, restore ecological systems." Narrow buffer widths are applied on small lots so as not to cause the lots to become unusable, and with the realization that pollutant removal will be limited and habitat value minor. As lot size increases, wider buffers are implemented, increasing their value for pollutant removal, wildlife habitat, and visual appeal.

In all cases, and for all lot sizes, wider buffers are implemented where they border waters whose primary use has been designated Type I — Conservation, or Type II — Low Intensity Boating. The reasoning is that these types of waters require a higher degree of protection and preservation in order to maintain their designated primary uses. Wider buffer widths are also applied when the area receiving the buffer abuts an area of critical concern, special significance, or scenic or historical importance.

The actual regulatory program, as adopted by the state of Rhode Island, is included in Appendix A exactly as it appears in the state's regulatory coastal program documentation. Appendix B includes a complementary vegetated buffer maintenance and management document created as part of the vegetated buffer program implemented by the Rhode Island CRMC.

■ State Coastal Buffer Programs: A Summary

This review of coastal states' programs, policies, and/or regulations that could be used to establish vegetated buffers along the coastal zone concerns itself only with those that are a part of the states' Coastal Zone Management Programs. Policies and regulations applied by other state agencies are mentioned when the state CZMP defaults to other programs to avoid replication, or when no CZMP has been established for a given state. Finally, despite the fact that the shores of the Great Lakes are considered under the federal coastal zone management program, this review restricts itself to a description of those states bordering saltwater coastlines.

Table 8 provides an overview and summary of the differences among states' policies, regulations, and requirements for the establishment of vegetated buffers along the coastal zone. A similar description of state buffer policies has been put together in Castelle et al. (1992), but pertains strictly to wetlands and buffers around wetlands. Readers with a particular interest in wetlands may want to review that document. The program descriptions given here are based on a review of published state programs and/or discussions with state agency personnel. Any errors, omissions, or misinterpretations are those of the authors.

Of the twenty-three state programs reviewed, four had buffer programs applying to the entire coastal zone as an element of their state coastal zone management programs. Two other states had buffer elements that pertained only to a certain portion of their coastal zone. Nearly all states had some form of mitigation procedure that could be applied during the permitting process to establish vegetated buffers in the coastal zone. Construction or septic system setbacks, which could be used to establish vegetated buffers, were reported by most states, although many reported those to be established by town rather than state regulations.

The various setbacks and buffer policies being used by state coastal zone management programs that could establish vegetated buffers range from 20 feet to 300 feet of buffer width (excluding the possibility of no buffer). This represents a range of buffer effectiveness (from Table 7) from fifty percent pollutant removal and poor habitat value to eighty percent pollutant removal and good general wildlife habitat value. No state program had policies or regulations that provided greater than 80 percent pollutant removal, and none provided buffer widths that were in the category (from Table 7) considered excellent as wildlife habitat, although either or both could potentially be achieved during case-by-case buffer development.

Alabama

The state of Alabama has a 40-foot construction setback requirement, but it is only applicable to land along the shoreline areas immediately on the Gulf Coast; it does not include back bays and coves. The application of the 40-foot setback is meant to protect beach dune systems and is measured from the dune crest. Vegetated buffers may be established through local zoning regulations of coastal districts but are not a requirement of the state coastal zone program.

Alaska

In the state of Alaska, separate requirements for coastal vegetated buffer areas may be established through local government mandates for each regional borough. Regulations exist that require leaving vegetation along coastal areas being logged, but the actual vegetated width preserved is determined on a case-by-case basis. On city- and state-owned lands, a 100-foot no-cut zone is required, while on private property there is a 66-foot no-cut zone. This relates to timber harvest areas only, and as noted above, is subject to modification on a case-by-case basis. No statewide coastal zone program buffer requirement currently exists.

California

The state of California buffer program focuses on wetland habitat protection. The program requires a minimum 100-foot buffer around coastal wetlands, with additional width required if adjacent lands are biologically significant, if sensitive wildlife inhabit the buffer, if the area is highly susceptible to erosion, or if proposed development poses significant potential impact. The 100-foot buffer, however, is used as guidance only, and may be negotiated on a case-by-case basis. Buffer regulations may exist at local levels of government, and may be more or less stringent than the 100-foot buffer guideline suggested by the state coastal program. Vegetated buffers may be applied to riparian areas when coastal program jurisdiction is extended into watersheds that drain into sensitive coastal areas.

Connecticut

The state of Connecticut coastal zone program has policies that promote preservation of vegetated coastal areas but has no statewide requirements. Implementation of vegetated buffers or construction setbacks along the coast may occur through zoning regulations and requirements at local levels of government. Construction setbacks that do exist in local zoning ordinances may vary by town throughout the coastal zone of the state. New vegetated buffer policies and regulations are being drafted by state regulatory agencies. While these new policies are generally focused on riparian systems, their application may be extended into the state's coastal zone.

Delaware

In the state of Delaware, establishment of vegetated buffers in the coastal zone is not a requirement of the coastal zone management program but may occur at the local level, according to local zoning regulations. State CZMP staff may require the establishment of a vegetated buffer during 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.

Georgia

The state of Georgia has no statewide requirements for the establishment of vegetated buffers, and at present is not a participant in the federal coastal zone management program. A Marshland Protection Act may create vegetated buffers in the coastal zone adjacent to protected marshes (or as the marsh itself), but the primary purpose of the Act is to protect marshlands, not create vegetated buffers. The Shoreline Protection Act gives state regulatory agency staff some discretionary power to establish vegetated coastal buffers through the permitting and review process.

Hawaii

The state of Hawaii has policies and regulations within the state coastal zone program to establish vegetated buffers along the coast. For all of the Hawaiian island group, a 40-foot shoreline setback is required, beginning at the shoreward edge of the coastal vegetation line and extending inland. The buffer is generally intended to remain in an undisturbed state, but certain uses are allowed, and variances may be sought for limited development within the buffer. In cases in which hardship can be proven, the mandatory 40-foot setback buffer can be reduced to 20 feet. Each of the islands in the Hawaiian island group may develop its own regulations with regard to the shoreline setback, but the width may not be less than the 40 feet mandated by state regulations.

Louisiana

The state of Louisiana has no statewide policies or regulations that establish vegetated buffers in the coastal zone. Vegetated buffer areas may be established on a case-by-case basis as part of the state permitting process. When established, buffers are used to protect significant habitat or resources by moving development activities away from the resource to a region of minimal impact.

Maine

The state of Maine, as part of its Shoreline Zoning Act, has implemented a coastal vegetated buffer establishment program. The coastal zone program mandates a 75-foot minimum vegetated area, measured from mean high water, along the entire Maine coast. The buffer must be kept in a vegetated state, with no more than 40 percent of existing trees in the buffer being harvested every 10 years. Pruning and other maintenance procedures are allowed, but complete removal of grasses or understory in the buffer is prohibited. A vegetated buffer 250 feet wide is required along areas bordering sensitive wetlands. The larger buffer width is implemented to provide added protection to wildlife, especially waterfowl, while the minimum buffer width of 75 feet is implemented for protection of water quality and visual appeal.

The buffer applies to new construction only, and preexisting lots are exempt from the 75-foot buffer requirement. Preexisting lots may not expand by greater than 30 percent, may not expand toward the water's edge, and if outside the 75-foot buffer zone, may not extend into the buffer area during expansion. Local zoning ordinances may require a greater buffer width than the minimum 75-foot buffer mandated by the state program.

Maryland

It is the policy of the Maryland coastal zone program to promote the establishment of vegetated buffers along the coast, and buffers may be required on a case-by-case basis, particularly around wetland areas. As part of the Chesapeake Bay Program, all land 1000 feet inland of the shoreline of the Chesapeake Bay and its tributaries is subject to a 100-foot buffer requirement. The buffer requirement may be waived if "good conservation practices" are employed at the shoreline site. Furthermore, the buffer requirement is only applicable to new development — existing development and previously platted lots are "grandfathered" to preexisting requirements. Other state programs share the cost of buffer strip implementation with farmers actively using land bordering the Chesapeake Bay and its tributaries.

The major emphasis of this policy has been in tidal tributaries of Chesapeake Bay. The emphasis in non-Chesapeake Bay portions of the Maryland coastal zone has been on stabilization of the coast by promoting planting and preservation of vegetated areas. Vegetation within the buffers along the coast has focused on grass species, while woody–stemmed species have received greater emphasis along tidal tributaries.

Plummer (1993) provides a more comprehensive review of Maryland buffer policies and regulations, as well as a review of implementation within the coastal zone program.

Massachusetts

The state of Massachusetts coastal zone program does not currently have policies or regulations that establish vegetated buffers along the coast. Establishment of vegetated buffer areas may occur at local levels of government through zoning ordinances and regulations, or may be established on a case-by-case basis through the coastal zone program permitting process. The state coastal zone program, however, is in the process of developing a buffer zone program, which is presently being drafted.

Mississippi

The state of Mississippi coastal zone program has no statewide policies or regulations that establish vegetated buffers in the coastal zone. During the permitting process, however, vegetated buffers that consist solely of tidal wetlands may be established to protect significant resources and habitats. The establishment of vegetated buffer areas applies only to tidal wetland environments, and does not apply to upland areas adjacent to the coast.

New Hampshire

The state of New Hampshire coastal zone program, through state wetlands regulations, requires the establishment of a 100-foot vegetated buffer around coastal wetlands, beginning at the mean high tide mark. Although the buffer area is a requirement, activities can still be conducted within the buffer, provided that proper permits have been issued.

New Jersey

The state of New Jersey has a coastal zone program element that may be used to establish vegetated buffers along the coast. The program element requires a buffer width of 0 to 300 feet, determined on a case-by-case basis, and is dependent on the potential impact to water resources from the proposed development activity. The buffer program applies to private property, and to all activities conducted in the coastal zone by any state agency. The buffer program, however, is only applicable to those areas of the shoreline designated as significant or sensitive areas. Furthermore, local plans and zoning ordinances supersede the state coastal buffer program, and do not have to be consistent with state coastal zone policy. Plummer (1993) provides a more detailed review of New Jersey buffer policy and regulations, as well as implementation examples.

New York

The general policy of the state of New York coastal zone program is to protect significant coastal resources and habitats, and therefore vegetated buffer areas may be established during the permitting process on a case-by-case basis. The state coastal zone program encourages the protection and/or planting of vegetation along the shoreline, but does not require it as part of the program mandate.

Through the regulatory program of the Department of Conservation, a construction setback regulation exists that may establish vegetated buffer areas. The regulations require a setback from wetland areas of 75 feet (30 feet in New York City). The setback regulation does not require that the buffer area be vegetated, but encourages the use of vegetation. Local government may develop and implement vegetated buffer policy and regulations according to local zoning ordinances.

North Carolina

In the state of North Carolina, the portion of the coastal zone that lies within 75 feet of the water's edge is subject to permit approval for development purposes. Vegetated buffers may be established through the permitting process on a case-by-case basis. When buffer areas are established, they need not be vegetated as a requirement, but vegetation is encouraged. A 30-foot buffer is required around waters that are classified as high quality and/or of high significance, but the buffer need not be vegetated. The 30-foot buffer requirement is most typically used to protect public water supply watershed areas. Local zoning ordinances may require the establishment of vegetated buffers along the coast. Phillips (1989d) reviews some local-level buffer requirements in North Carolina.

Oregon

The state of Oregon has several statewide policies that require local governing bodies to be consistent in their planning and zoning efforts. Statewide policies to preserve and protect significant coastal habitats, cultural and historic resources, and scenic qualities may result in the establishment of vegetated buffers along the coastal zone through local adoption and implementation. Areas marked for preservation and/or restoration in estuaries may also be viewed as vegetated buffers.

Rhode Island

The state of Rhode Island coastal zone program has a policy for the establishment of vegetated buffers, but it is implemented on a case-by-case basis under the purview of program staff. When applied, the buffer is measured from the inland edge of the coastal feature (as defined by the program), with buffer width based on potential impacts of development and the sensitivity and use of the adjacent land and water. The state coastal zone program also requires a minimum 50-foot construction setback, but local zoning ordinances or regional Special Area Management Plans may require the establishment of a buffer area, or require a greater setback distance.

The state of Rhode Island has developed a more complete vegetated buffer program, a final version of which is included in Appendix A. Adoption of the program occurred during early 1994. Appendix B contains a copy of the vegetated buffer management and maintenance document that accompanies the state's buffer program.

South Carolina

In the state of South Carolina, vegetated buffers may be established on a case-by-case basis along or within critical or sensitive areas, such as salt marshes. Typically, the program regulates activity within the critical or sensitive areas, rather than establishing buffers around them. The coastal zone program also has jurisdiction within a setback area inland of coastal dune systems. The setback width is determined by erosional rates, and although vegetated buffers could be established within the coastal setback, the focus of the program is to regulate activity in the setback area rather than to establish it as a buffer area. The overall intent of the setback is to protect property by removing structures from erosional zones along the coast.

Texas

The state of Texas is in the process of developing its coastal zone program, and therefore at present has no policies or regulations that establish vegetated buffers along the coast. The program that is in development recognizes the value of coastal buffer zones, and several policies within the draft program deal with the concept of vegetated (and nonvegetated) buffers.

Virginia

The state of Virginia has a buffer program applicable to the shoreline of the Chesapeake Bay under the Chesapeake Bay Preservation Act, but the program does not apply to other coastal areas in the state. The coastal zone program recommends the use of vegetation and vegetated buffer areas for shoreline stabilization and other uses, but it is accomplished on a voluntary basis by property owners.

Along the shores of the Chesapeake Bay, the Chesapeake Bay Preservation Act requires a 100-foot vegetated buffer along all shoreline that drains to or is adjacent to the Chesapeake Bay. The program does provide for limited use within the vegetated buffer, and variances may be sought to utilize lands within the buffer area. No variances will be provided that result in less than a 50-foot vegetated buffer remaining along the shoreline (except for agricultural uses).

Water-dependent uses — such as marinas and docks — are generally allowable within the 100-foot buffer area. Agricultural land uses that abut the shoreline may seek a smaller vegetated buffer width of 50 feet, and a 20-foot buffer may be allowed for agricultural purposes, provided that a management plan has been developed and is actively being implemented. Plummer (1993) provides a more complete review of the Virginia Chesapeake Bay Preservation Area Program, as well as implementation examples.

Washington

The state of Washington coastal zone program recommends the use of vegetated areas for shoreline stabilization and other purposes, but does not require their use. Each of the coastal counties in the state is required to develop its own master plans and zoning ordinances, which may, but are not required to, include regulations for the establishment of vegetated buffers at a local level.

IV. Selected Bibliography

This bibliography represents a search of the literature for works that relate to vegetated buffers. The selected bibliography presents a wide range of subjects, ranging from pollutant removal research to the aesthetic and scenic value of vegetated buffers. The selected works are definitely biased towards research on pollutant removal efficiency of vegetated buffers. The reason for this is twofold: (1) the bulk of the published literature is the results of research with this as their focus, and (2) in light of the recent emphasis on control of nonpoint source pollutants, this portion of the literature is extremely valuable in pursuing the use of vegetated buffers as a nonpoint source control mechanism. However, the selected references presented here represent a reasonable introduction to the diversity of uses of vegetated buffers as a multiple-use resource management tool.

Several bibliographies, some annotated, are given in the following list of literature references. One of special note, however, is that compiled by Dr. David Correll at the Smithsonian Environmental Research Center (Correll, 1993). This bibliography is specific to the literature regarding forested buffers, and is indexed according to the parameters researched in each citation given. The bibliography also contains references culled from international sources, and provides a robust compendium of research in forested buffers.

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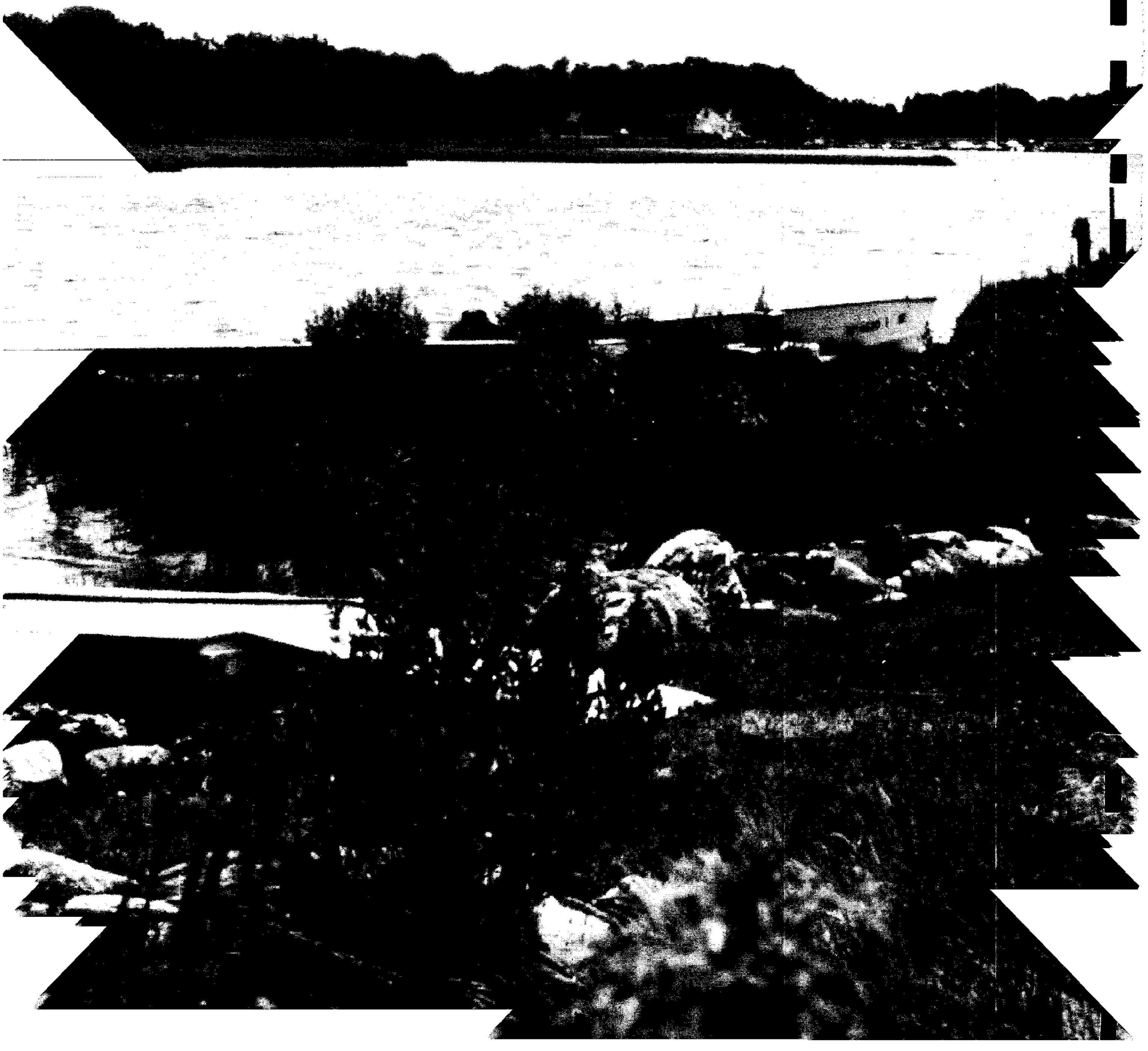


Appendix A — The Rhode Island Coastal Zone Buffer Program

Adopted April 1994, RI CRMP

Section 140 Setbacks

Amend Section 140. C to read as follows:

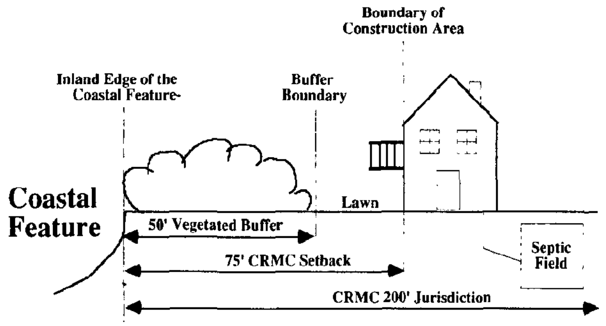
"C. Setbacks shall extend a minimum distance of either fifty (50) feet from the inland boundary of the coastal feature or twenty-five (25) feet inland of the edge of a Coastal Buffer Zone, whichever is further landward. In areas designated by the Council as Critical Erosion Areas-(Table 2), the minimum distance of the setback shall be not less than 30 times the calculated average annual erosion rate for less than four dwelling units and not less than 60 times the calculated average annual erosion rate for projects proposing more than 4 dwellings units.

"SECTION 150 COASTAL BUFFER ZONES

A. Definition

1. A Coastal Buffer Zone is a land area adjacent to a Shoreline (Coastal) Feature that is, or will be, vegetated with native shoreline species and which acts as a natural transition zone between the coast and adjacent upland development. A Coastal Buffer Zone differs from a construction setback (Section 140) in that the setback establishes a minimum distance between a shoreline feature and construction activities, while a buffer zone establishes a natural area adjacent to a shoreline feature that must be retained in, or restored to, a natural vegetative condition (Figure 2). The Coastal Buffer Zone is generally contained within the established construction setback.

Figure 2 An example of the application of a Coastal Buffer Zone.



B. Findings

1. The establishment of Coastal Buffer Zones is based upon the CRMC's legislative mandate to preserve, protect and, where possible, restore ecological systems.

2. Vegetated buffer zones have been applied as best management practices within the fields of forestry and agriculture since the 1950s to protect in-stream habitats from degradation by the input of sediment and nutrients (Desbonnet et al 1993). More recently, vegetated buffer zones have gained popularity as a best management practice for the control and abatement of nonpoint source pollutants (contaminated runoff) and are routinely applied in both engineered and natural settings (Desbonnet et al 1993; EPA 1993).

3. Coastal Buffer Zones provide multiple uses and multiple benefits to those areas where they are applied (Desbonnet et al 1993). The multiple uses and benefits of Coastal Buffer Zones include:

(a) *Protection of Water Quality*: Buffer zones along the perimeter of coastal water bodies can be effective in trapping sediments, pollutants (including oil, detergents, pesticides, herbicides, insecticides, wood preservatives and other domestic chemicals), and absorbing nutrients (particularly nitrogen) from surface water runoff and groundwater flow. The effectiveness of vegetated buffers as a best management practice for the control of nonpoint source runoff is dependent upon their ability to reduce the velocity of runoff flow to allow for the deposition of sediments, and the filtration and biological removal of nutrients within the vegetated area. In general, the effectiveness of any vegetated buffer is related to its width, slope, soil type, and resident species of vegetation. Effective buffers for nonpoint source pollution control, which remove at least 50%, and up to 99%, of sediments and nutrients entering them, range from 15 feet to 600 feet in width.

The removal of pollutants can be of particular importance in areas abutting poorly flushed estuaries that are threatened by an excess of nutrients or are contaminated by runoff water, such as the South Shore Salt Ponds and the Narrow River. Large, well flushed water bodies, such as Narragansett Bay, are also susceptible to nonpoint source pollutant inputs, and can be severely impacted by nonpoint source pollutants as has been documented in studies completed for the Narragansett Bay Project.

(b) *Protection of Coastal Habitat*: Coastal Buffer Zones provide habitat for native plants and animals. Vegetation within a buffer zone provides cover from predation and climate, and habitat for nesting and feeding by resident and migratory species. Some species which use coastal buffer zones are now relatively uncommon, while others are considered rare, threatened or endangered. These plants and animals are essential to the preservation of Rhode Island's valuable coastal ecosystem.

The effectiveness of vegetated buffers as wildlife habitat is dependent upon buffer width and vegetation type. In general, the wider the buffer the greater its value as wildlife habitat. Larger buffer widths are typically needed for species that are more sensitive to disturbances (e.g., noise). Furthermore, those buffers that possess vegetation native to the area provide more valuable habitat for sustaining resident species. A diversity of plant species and types (e.g., grasses, shrubs and trees) promotes biodiversity within the buffer area, and the region overall.

(c) *Protection of Scenic and Aesthetic Quality*: One of the primary goals of the Council is to preserve, protect, and where possible restore the scenic value of the coastal region in order to retain the visual diversity and unique visual character of the Rhode Island coast as seen by hundreds of thousands of residents and tourists each year from boats, bridges, and such vantage points as roadways, public parks, and public beaches (Section 330). Coastal Buffer Zones enhance and protect Rhode Island's scenic and visual aesthetic resources along the coast. Coastal buffers also preserve the natural character of the shoreline, while mitigating the visual impacts of coastal development. Visual diversity provides for both contrast and relief between the coastal and inland regions, leading to greater aesthetic value of the landscape.

(d) *Erosion Control*: Coastal Buffer Zones provide a natural transition zone between the open coast, shoreline features and upland development. Natural vegetation within a Coastal Buffer Zone helps to stabilize the soil, reduces the velocity of surface water runoff, reduces erosion of the soil by spreading runoff water over a wide area, and promotes absorption and infiltration through the detrital (leaf) layer and underlying soils. The extensive root zones often associated with buffer zone vegetation also help prevent excessive shoreline erosion during coastal storm events by stabilizing underlying soils.

(e) *Flood Control*: Coastal Buffer Zones aid in flood control by reducing the velocity of runoff and by encouraging infiltration of precipitation and runoff into the ground rather than allowing runoff to flow overland and flood low lying areas. In addition, Coastal Buffer Zones often occupy the flood plain itself and thus add to coastal flood protection.

(f) *Protection of Historic and Archaeological Resources*: Coastal Buffer Zones protect areas of cultural and historic importance such as archaeological sites by helping prevent intrusion while protecting the sites' natural surroundings.

C. Policies

1. The establishment of a Coastal Buffer Zone is based upon the CRMC's legislative mandate to preserve, protect and, where possible, restore ecological systems. The determination of the inland boundary of the Coastal Buffer Zone must balance this mandate with the property owner's rights to develop and use the property.

2. The Council shall require Coastal Buffer Zones in accordance with the requirements of this section for the following: a) new residential development; b) commercial and industrial development; c) activities subject to Section 300.8 and Section 300.13; and d) inland activities identified in Section 320. For existing residential structures, the Council shall require a Coastal Buffer Zone for category "A" and "B" activities when the RIDEM requires the modification or expansion of an existing septic system or when the footprint of the structure is expanded.

3. The vegetation within a buffer zone must be either retained in a natural, undisturbed condition, or properly managed in accordance with the standards contained in this section. In cases where native flora (vegetation) does not exist within a buffer zone, the Council may require restoration efforts which include, but are not limited to, replanting the Coastal Buffer Zone with native plant species.

4. Coastal Buffer Zones shall remain covered with native flora and in an undisturbed state in order to promote the Council's goal of preserving, protecting, and restoring ecological systems. However, the Council may permit minor alterations to Coastal Buffer Zones that facilitate the continued enjoyment of Rhode Island's coastal resources. All alterations to Coastal Buffer Zones or alterations to the natural vegetation (i.e., areas not presently maintained in a landscaped condition) within the Council's jurisdiction shall be conducted in accordance with the standards contained in this section as well as all other applicable policies and standards of the Council. In order to ensure compliance with these requirements, the Council may require applicants to submit a Buffer Zone Management Plan.

Table 2a.
Coastal Buffer Zone designations for residential development.

	Water Use Category	
Residential Lot Size (sq. ft.)	Type 3, 4, 5 & 6	Type 1 & 2
	Required Buffer (ft)	
<10,000	15	25
10,000 – 20,000	25	50
20,001 – 40,000	50	75
40,001 – 60,000	75	100
60,001 – 80,000	100	125
80,001 – 200,000	125	150
>200,000	150	200

5. In order to enhance conservation, protect water quality, and maintain the low intensity use characteristic of Type 1 and 2 waters, greater buffer widths shall be applied along the coastline abutting these water types.

6. In critical areas and when the property owner owns adjoining lots, these lots shall be considered as one lot for the purposes of applying the values contained in Table 2a and ensuring that the appropriate buffer zone is established.

D. Standards

1. All Coastal Buffer Zones shall be measured from the inland edge of the most inland Shoreline (Coastal) Feature.

2. *Coastal Buffer Zone Requirements for New Residential Development*: The minimum Coastal Buffer Zone requirements for new residential development bordering Rhode Island's shoreline are contained in Table 2a. The Coastal Buffer Zone requirements are based upon the size of the lot and the CRMC's designated Water Types (Type 1 - Type 6). Where the buffer zone requirements noted above cannot be

met, the applicant may request a variance in accordance with Section 120. A variance to 50% of the required buffer width may be granted administratively by the Executive Director if the applicant has satisfied the burdens of proof for the granting of a variance. Where it is determined that the applicant has not satisfied the burdens of proof, or the requested varriance is in excess of 50% of the required width, the application shall be reviewed by the full Council.

3. *Coastal Buffer Zone Requirements for Existing Residential Structures that Expand the Footprint of the Structure and for Structures Required by the RIDEM to Modify or Expand an Existing Septic System*: When an existing residential structure does not meet the Council's Coastal Buffer Zone requirements contained in Table 2a (e.g., the existing structure does not have a buffer zone or has a buffer zone with a width less than the value contained in Table 2a), the following Coastal Buffer Zone requirements shall apply to each modification of the residential structure until the property's Coastal Buffer Zone equals, but does not exceed, the value contained in Table 2a:

(a) Where alterations to a residential structure result in the expansion of the structure's footprint (square footage of the ground floor area encompassed by the structural foundation of an existing building), the Coastal Buffer Zone requirement shall be established with a width equal to the percentage increase in a structure's footprint as of April 15, 1994 multiplied by the value contained in Table 2a ([square foot increase of footprint/square footage as of April 15, 1994] X value contained in Table 2a = Coastal Zone Buffer Requirement);

(b) Where alterations to a residential structure result in an increase in flow to the Individual Sewage Disposal System (ISDS) and the RIDEM has required the modification or expansion of the existing ISDS, the Coastal Buffer Zone requirement shall be established with a width equal to 25% of the value contained in Table 2a (0.25 X value contained in Table 2a = Coastal Buffer Zone requirement).

These requirements only apply to category "A" and "B" assents. In addition, the Executive director shall have the authority to grant a variance to these requirements for category "A" assents in accordance with the burdens of proof contained in Section 120.

4. *Coastal Buffer Zone Requirements for all Commercial and Industrial development and activities subject to the requirements of Section 300.8, Section 300.13, or Section 320*: Coastal Buffer Zones shall be determined on a case-by-case basis by the Council. Table 2a may be used as appropriate guidance. However, depending on the activity proposed and its potential impacts on coastal resources, the Council may require a Coastal Buffer Zone with a width greater than that found in the Table 2a.

5. All property abutting critical habitat areas, as defined by the Rhode Island National Heritage Program or the Council, shall possess a minimum vegetated buffer zone of 200 feet between the identified habitat and any development area. The Executive director shall have the authority to grant a variance to these requirements in accordance with the burdens of proof contained in Section 120.

6. All property abutting Coastal Natural Areas (Section 210.4) shall have a minimum vegetated Coastal Buffer Zone of 25 feet from the inland edge of the coastal feature. The Executive director shall have the authority to grant a variance to these requirements in accordance with the burdens of proof contained in Section 120.

7. All property located within the boundaries of a Special Area Management (SAM) Plan approved by the Council shall meet additional buffer zone requirements contained within these SAM plans. When a SAM plan's buffer zone requirements apply, the buffer width values contained in this section will be compared to those required by the SAM plan, and the larger of the buffer widths applied.

8. The setback (Section 140) for all new residential, commercial, and industrial structures shall exceed the Coastal Buffer Zone requirement by a minimum of 25 feet for fire, safety, and maintenance purposes. Where the 25 foot separation distance between the inland edge of the buffer and construction setback cannot be obtained, the applicant may request a variance in accordance with Section 120. The Executive Director shall have the authority to grant variances to this requirement. However, a vegetated Coastal Buffer Zone shall not directly contact any dwelling's footprint.

E. Buffer Management and Maintenance Requirements

1. All alterations within established Coastal Buffer Zones or alterations to natural vegetation (i.e., areas not presently maintained in a landscaped condition) within the Council's jurisdiction may be required to submit a Buffer Zone Management Plan for the Council's approval that is consistent with the requirements of this section and the Council's most recent edition of *Buffer Zone Management Guidance.* Buffer Zone Management Plans shall include a description of all proposed alterations and methods of avoiding problem areas such as the proper placement and maintenance of pathways. Applicants should consult the Council's most recent edition of *Buffer Zone Management Guidance* when preparing a buffer management plan.

2. In order to promote the Council's goal to preserve, protect and, where possible, restore ecological systems, Coastal Buffer Zones shall be vegetated with native flora and retained in a natural, undisturbed condition, or shall be properly managed in accordance with Council's most recent edition of *Buffer Zone Management Guidance.* Such management activities compatible with this goal include, but are not limited to:

(a) *Shoreline Access Paths*: Pathways which provide access to the shoreline are normally considered permissible provided they are less than or equal to 6 feet wide and follow a path that minimizes erosion and gullying within the buffer zone (e.g., a winding, but direct path). Pathways should avoid, or may be prohibited in, sensitive habitat areas, including, but not limited to, coastal wetlands. Pathways may be vegetated with grasses and mowed or may be surfaced with crushed stone or mulch.

(b) *View Corridors*: Selective tree removal and pruning and thinning of natural vegetation may be allowed within a defined corridor in order to promote a view of the shoreline. Only the minimal alteration of vegetation necessary to obtain a view shall be acceptable to the Council. Shoreline access paths shall be located within view corridors to the maximum extent practicable in order to minimize disturbance of Coastal Buffer Zones. View corridors shall be prohibited in sensitive or critical habitat areas.

(c) *Habitat Management*: Management of natural vegetation within a buffer zone to enhance wildlife habitat and control nuisance and non-native species of vegetation may be allowed. Homeowner control of pest species of vegetation such as European bittersweet and nuisance species such as poison ivy is normally considered acceptable. However, the indiscriminate use of herbicides or the clear-cutting of vegetation shall be prohibited. The use of fertilizers is generally prohibited within the Coastal Buffer Zone except when used to enhance the replanting of native vegetation (e.g., hydro-seeding) approved by the Council. However, the clearing or outright elimination of natural vegetation for such purposes as controlling ticks or pollen shall not be permitted.

(d) *Safety and Welfare*: Selective tree removal, pruning and thinning of natural vegetation within a Coastal Buffer Zone may be allowed by the Council on a case-by-case basis for proven safety and welfare concerns (e.g., removal of a damaged tree in close proximity to a dwelling). In order to promote child safety and manage pets in areas harboring ticks, fences along the inland edge of a Coastal Buffer Zone and along shoreline access pathways may be permitted.

(e) *Shoreline Recreation*: The CRMC recognizes that shoreline recreation is one of the predominant attractions for living on, or visiting the Rhode Island Coast. In order to allow for such uses, minor alterations of buffer zones may be permitted along the shoreline if they are determined to consistent with Council's requirements. These alterations may include maintaining a small clearing along the shore for picnic tables, benches, and recreational craft (dinghies, canoes, day sailboats, etc.). Additionally, the CRMC may allow small, non-habitable structures including storage sheds, boat houses and gazebos within Coastal Buffer Zones, where appropriate. However, these structures may be prohibited in sensitive or critical habitat areas. Due to the potential for these structures to impact values provided by Coastal Buffer Zones, the Council shall exercise significant discretion in this area."

Appendix B — Rhode Island Coastal Buffer Zone Management Guidance

Revised January 7, 1994

CRMC Coastal Buffer Zone Management Guidance

*A. **Guidelines for preparing an application for Coastal Buffer Zone Management:***

1. All proposals for buffer zone management must be designed with respect to the one or more of the "Management Options" identified in Section "B" of these guidelines and must utilize appropriate techniques for managing vegetation as defined in Section "C".

2. Photographs and site plans must be submitted for all applications in order to minimize the need for on-site inspections. Actual field inspections will only be performed when deemed necessary by CRMC staff. All applications should be complete, clear and concise. Applications which are unclear or imprecise will be returned.

3. Applications which propose acceptable alterations within Coastal Buffer Zones (as determined by CRMC staff) will be processed as a "Category "A" and will receive administrative approval. In cases where CRMC staff determines the application to be unacceptable, an effort will be made to negotiate a resolution with the applicant. If a favorable resolution cannot be reached, CRMC staff will make a recommendation to the Executive Director that the application be processed as a Category "B" review requiring final decision by the full Coastal Council.

4. All proposals for Coastal Buffer Zone management should involve minor alterations which do not depreciate the values and functions of Coastal Buffer Zones as defined by Section 150 of the RICRMP. At a minimum, **at least sixty (*60%*)** of a buffer zone shall remain completely unaltered. Typically, Coastal Buffer Zone Management Plans which affect **25% or less** of a buffer zone are more likely to be approved. Areas to remain unaltered should be clearly identified on the proposed plans. An exception to this requirement is allowed for **"Suburban Coastal Buffer Zones"** - see Section B.6 of this Guidance material.

5. Where appropriate, Coastal Buffer Zone management may be applied to Coastal Banks. However, the CRMC may impose greater restrictions on alterations affecting coastal banks.

6. Tree damage and removal - in cases where a small number of dead, diseased, or storm damaged trees need to be removed from a buffer zone, the applicant may request an expedited review. In such cases, a description of work and a photograph of the area may be sufficient for CRMC review.

*B. **Management options within coastal buffer zones:***

1. Shoreline Access Paths - Pathways which provide access to the shoreline are normally considered appropriate. Pathways may be 6' wide or less and follow a winding, but direct path that does not promote erosion within the buffer zone. Shoreline access paths must be designed to minimize disturbance and may be prohibited in sensitive habitat areas, including but not limited to, coastal wetlands. Pathways may be vegetated with grasses and mowed or may be surfaced with crushed stone or mulch. Fertilizers may only be allowed for the initial establishment of grassed pathways. Proper site plans must be submitted which show the location of the proposed path through the buffer zone. Applicants may also be required to delineate the path on site for CRMC staff inspection.

2. View Corridors - Selective tree removal and pruning and thinning of natural vegetation may be allowed within a defined corridor in order to promote a view of the shoreline. Only the minimal alteration of vegetation necessary to obtain a view shall be considered acceptable (clear cutting is not allowed). Shoreline access paths (if proposed) should be located within a view corridor to minimize disturbance within the buffer. Applicants proposing a view corridor must prepare a plan showing the view corridor's location within the Coastal Buffer Zone with respect to view points from a dwelling or other viewing area. View corridors are typically trapezoidal in shape, being narrow at the inland edge and expanding toward the shore. On residential lots of 2 acres or less, only **one view corridor** is typically considered acceptable. View Corridors may not affect more than **25 % of the length** of the Coastal Buffer Zone as measured along the shoreline feature. View Corridors may be prohibited in sensitive or critical habitat areas.

3. Habitat Management - The management of natural vegetation within a Coastal Buffer Zone to either enhance wildlife habitat or control nuisance and/or non-native species of vegetation may be allowed where it is demonstrated that the existing environmental conditions will be improved for native plantlife and wildlife. Additionally, homeowner control of nuisance species of vegetation such as European Bittersweet and poison ivy are considered acceptable **within managed portions** of Coastal Buffer Zones. However, the indiscriminate use of herbicides is prohibited and fertilizers may only be used to enhance the replanting of native vegetation. In addition, maintaining a buffer zone in a "landscaped condition", or establishing lawn are not considered appropriate habitat management activities and are prohibited. In Coastal Buffer Zones encompassing **one acre** or more, clearing may be allowed to establish field conditions which contain **native** grasses and herbaceous plants. In such cases, clearing for field establishment shall not affect more than **25%** of the Coastal Buffer Zone. All Buffer Zone Management plans involving habitat management within a Coastal Buffer Zone of one acre or more, or in sensitive or critical habitat areas (as determined by CRMC staff) shall submit a buffer zone management plan prepared by a qualified environmental professional or biologist.

4. Safety and Welfare - Selective tree removal and pruning and thinning of natural vegetation within a Coastal Buffer Zone may be allowed on a case-by-case basis for proven safety and welfare concerns (e.g., removal of a damaged or diseased tree in close proximity to a dwelling). In order to promote child safety and manage pets in areas harboring ticks, fences along the inland edge of a Coastal Buffer Zone and along shoreline access paths or shoreline recreation areas may be permitted (fences must be of an "open" type construction to permit the passage of wildlife, e.g. split rail or similar). Coastal Buffer Zone management plans shall include methods of avoiding problem areas such as the proper placement and maintenance of paths.

5. Shoreline Recreation - The CRMC recognizes that shoreline recreation is one of the predominant attractions for living on, or visiting the Rhode Island coast. In order to allow for such uses, minor alterations of Coastal Buffer Zones may be permitted along the shoreline if they are determined to be consistent with CRMC's goals and policies as noted in the Rhode Island Coastal Resources Management Program (RI CRMP). Appropriate alterations typically include maintaining a small clearing along the shore for picnic tables, benches, and recreational craft (dinghies, canoes, day sailboats, etc.). Additionally, where appropriate, the CRMC may allow small (**200 sq. ft. total floor space, or less**), non-habitable structures including storage sheds, boat houses, and gazebos within Coastal Buffer Zones. Due to the potential for these structures to impact natural values provided by Coastal Buffer Zones, the Council shall exercise significant discretion in this area.

6. Suburban Coastal Buffer Zones - Where the Coastal Buffer Zone requirement is **25' or less (as per RICRMP Section 150, Table 2a)**, the CRMC shall consider such buffer zones "Suburban Coastal Buffer Zones". Suburban Coastal Buffer Zones may be managed in their entirety (100%) by selective tree removal, selective pruning, selective thinning and restorative planting. However, the CRMC may require that several trees be maintained or planted to protect scenic quality.

C. Appropriate techniques for managing vegetation within a coastal buffer zone:

1. Selective Tree Removal - In cases where the applicant wishes to remove a few select trees, trees proposed to be cut must be specifically identified for CRMC staff review. In most cases, photographs of the buffer area may be sufficient provided the affected trees are clearly shown in relation to the surrounding buffer and shoreline. Trees may also be marked on-site to allow inspection by CRMC staff. In order to minimize disturbance and allow monitoring by CRMC staff, tree stumps of fallen trees shall not be removed. CRMC staff may make a follow-up inspection to verify that only marked trees were cut based upon stump counts. Should the applicant wish to remove a fallen tree from the buffer zone, this must be performed in a manner which does not disturb remaining vegetation. Selective tree removal is often a preferred technique for the establishment of a view corridor.

2. Selective Pruning - Pruning as defined for CRMC purposes involves cutting branches from trees, tree saplings and shrubs. For certain Coastal Buffer Zone Management options, pruning the tops of shrubs and forest undergrowth (topping) may be appropriate to discourage growth in height. On level ground, shrubs and forest undergrowth should be pruned to a height of **not less than 4'-5'**. In areas where the ground surface descends toward the shoreline, topping should only be performed to a height that allows a view of the water. Applicants proposing pruning must describe in detail the work proposed, provide photographs and a site plan, and/or mark those portions of the Coastal Buffer Zone where vegetation will be pruned on-site. The species of vegetation to be pruned should be identified since some species of vegetation cannot tolerate excessive pruning or topping. Selective pruning is often a preferred technique for the establishment of a view corridor.

3. Selective Thinning - Thinning as defined for CRMC purposes involves the selective removal of tree saplings, shrubs and vines occurring in brush areas and in the undergrowth of forested buffer zones. Applicants proposing thinning must describe in detail the work proposed, provide photographs and a site plan, and/or mark areas to be thinned on-site. The species of vegetation to be removed from a Coastal Buffer Zone management area must be differentiated from those species which are to be retained and encouraged. Selective thinning is often a preferred technique in areas where habitat management will be performed.

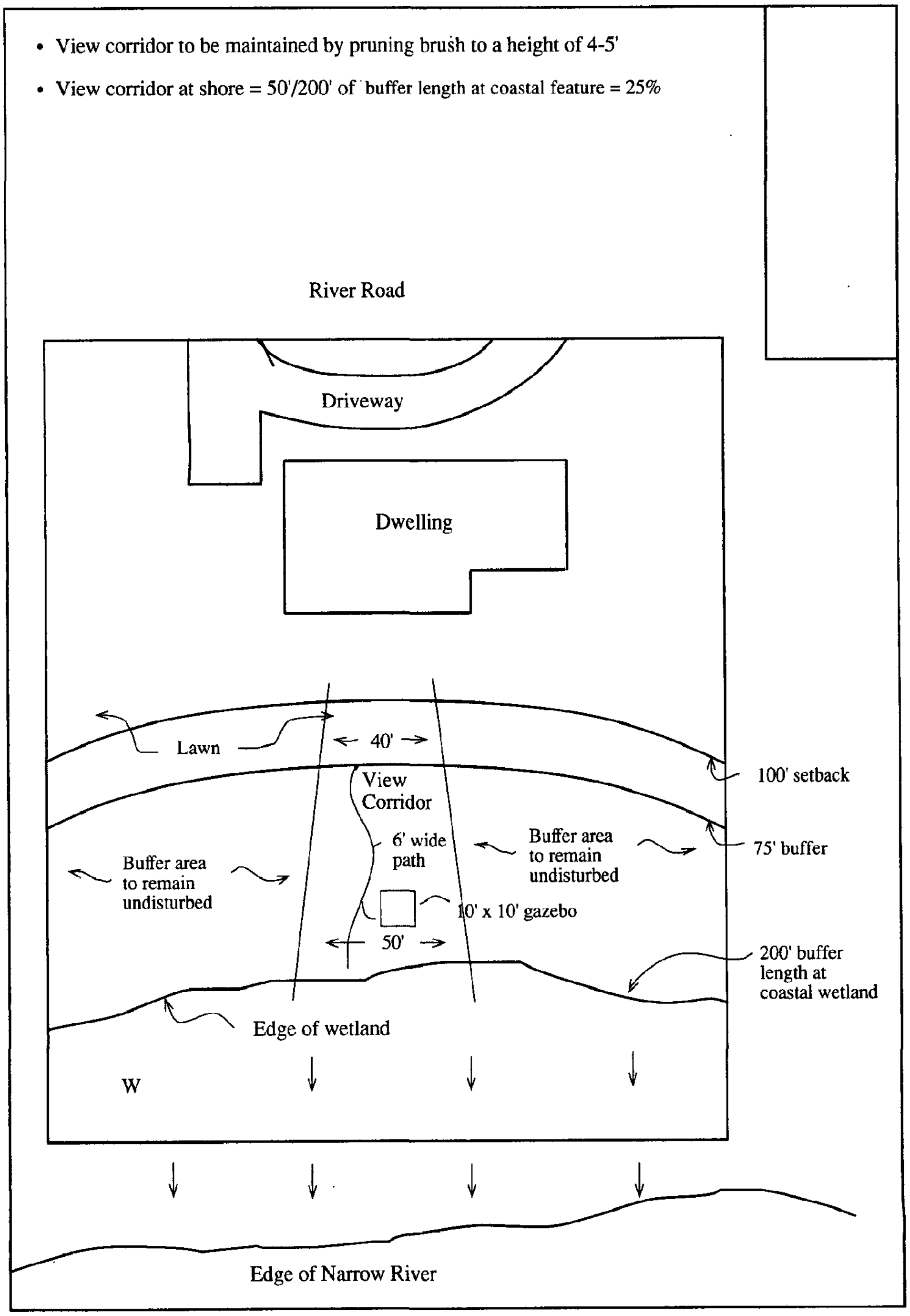
4. Restorative Planting - For purposes of Coastal Buffer Zone Management, restorative planting shall be strictly defined as the planting or replanting of **natural vegetation native to the Rhode Island shoreline**. However, naturalized species such as Rugosa Rose may be allowed, as determined by CRMC staff. The planting of non-native, landscape and exotic species, in most cases, shall not be considered appropriate in Coastal Buffer Zones.

5. Mowing - In most cases, mowing of vegetation within a Coastal Buffer Zone shall be prohibited unless associated with the establishment and maintenance of shoreline access path or approved shoreline recreation area. However, for certain habitat management options, annual or biannual mowing may be allowed to maintain field vegetation where such vegetation is considered valuable to wildlife and other natural values. In such cases, mowing shall be confined to **25%** of the Coastal Buffer Zone area, or less.

6. Clearing - Clearing or clear-cutting of vegetation within a Coastal Buffer Zone shall only be allowed for the establishment of shoreline access paths, shoreline recreation areas and in certain cases, habitat management options which are designed to maintain a field of native grasses and herbaceous plants. Clearing shall not affect more than **25%** of the Coastal Buffer Zone area. Clearing for habitat management shall not be allowed in Coastal Buffer Zones of less than one acre.

7. Filling and grading - Minor filling (10 cubic yards or less) and grading shall only be allowed in Coastal Buffer Zone areas for the establishment of shoreline access paths and shoreline recreation areas. Certain minor cutting and filling activities may also be allowed on a case-by-case basis to promote these uses. Filling and grading shall not be allowed for habitat management options.

Figure 10. Example of an adequate buffer zone management plan drawn by owner.



- View corridor to be maintained by pruning brush to a height of 4-5'
- View corridor at shore = 50'/200' of buffer length at coastal feature = 25%

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