EPA United States Environmental Protection Agency

EPA841-R-10-002
May 12, 2010

Guidance for Federal Land Management in the Chesapeake Bay Watershed

Chapter 5. Riparian Area Management

Nonpoint Source Pollution
Office of Wetlands, Oceans, and Watersheds
U.S. Environmental Protection Agency

Chapter 5.
Riparian Area Management

Contents

1 Introduction

1.1 What is a Riparian Area?

A riparian area is defined as

> A vegetated ecosystem along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of those two landforms. They will sometimes, but not in all cases, have all the characteristics necessary for them to be also classified as wetlands (USEPA 2005).

In other words, riparian areas are the areas between uplands and adjacent waterbodies that encompass the floodplain and some transitional upland area (Tjaden and Weber 1998). Both soils and vegetation in riparian areas are usually distinctly different from the surrounding uplands and typically support a diverse and unique population of animals as compared to uplands. They act as natural filters of nonpoint source pollutants, including sediment, nutrients, pathogens, and metals, to waterbodies such as rivers, streams, lakes, and coastal waters. The term *riparian buffer* is used to distinguish a specific area adjacent to the stream within a riparian area (see Figure 5-1) or, in some cases, it might include the entire area. Riparian buffers can also be referred to as riparian management zones, buffer strips, and streamside management zones.

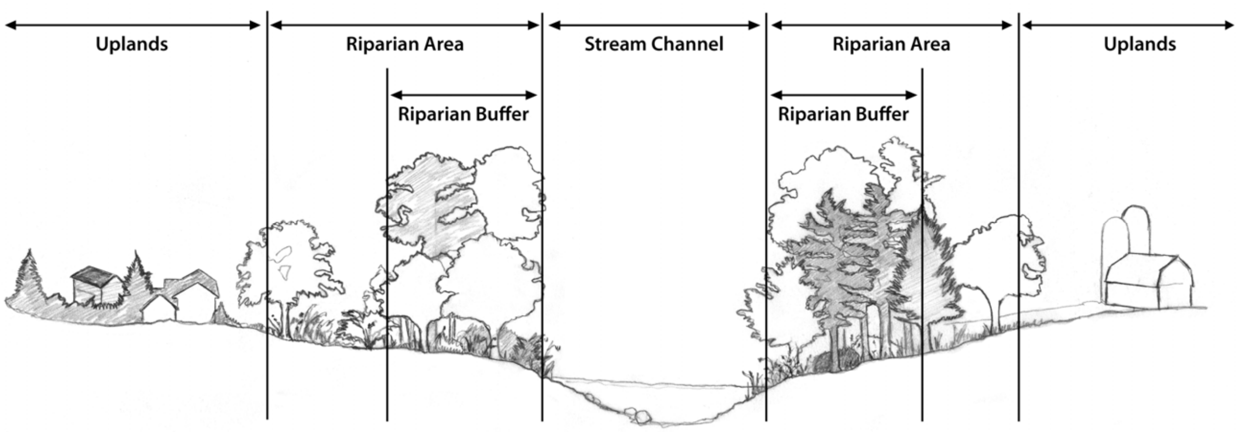


Figure 5-1. Relationship between uplands, riparian areas, riparian buffers, and the stream channel.

Riparian areas are inextricably linked to the stream itself. Disturbances that affect the riparian area affect the stream and vice versa. *Stream corridor* is a term used to describe the combined riparian/stream ecosystem (FISRWG 1998). Stream corridors in the Chesapeake Bay region evolved within temperate, forested watersheds (Williams 1989). Thus, system structure, functions, and biota in the corridor all developed within a range of natural conditions associated with forest ecosystems. For that reason, management plans aimed at restoring streams to a more natural state typically focus on restoring and protecting riparian forest buffers.

1.2 Why Riparian Buffers?

Riparian buffers (Figure 5-2) can significantly aid in reducing pollution contributions to the Chesapeake Bay, including nitrogen (N), phosphorus (P), and sediments. They also contribute to the protection of streams and streambanks and provide habitat for a multitude of species. Ideally, a network of buffers along a stream can act as a natural right-of-way, allowing the stream to move through the landscape *buffered* from direct influences of development in the watershed. Riparian forested buffers in particular have long been recognized as a vital part of the Chesapeake Bay ecosystem. For those reasons, the U.S. Environmental Protection Agency (EPA) considers the protection and restoration of riparian buffers to be a critical element of the Chesapeake Bay Program.

Figure 5-2. A riparian buffer.

> ***Riparian Buffer Goal for the Chesapeake Bay**:* Forest buffers should exist on at least 70 percent of all shorelines and streambanks in the watershed.

The Chesapeake Executive Council adopted the 70 percent riparian buffer goal for the Bay in 2003 (Chesapeake Executive Council 2003). EPA reiterates that goal in this guidance. An interim goal to achieve 63 percent by 2025 was adopted as part of the Chesapeake Bay Strategy under the Executive Order.

Approximately 58 percent of the Bay's riparian areas are forested. To reach both the interim goal of 63 percent and long-term goal of 70 percent coverage in the entire watershed, the Chesapeake Bay Program and its partners will need to restore at least 30,000 miles of riparian buffers and conserve all riparian areas that are forested. The following two implementation measures for riparian buffers will enable the forested riparian buffer goals to be met.

Implementation Measures:

R-1. Promote the restoration of the preexisting functions in damaged and destroyed riparian systems, especially in areas where the systems will serve a significant nonpoint source pollution-abatement function as well as the suite of valuable ecosystems services riparian buffers provide.

R-2. Protect from adverse effects riparian areas that are serving a significant nonpoint source pollution-abatement function and maintain this function while protecting the other existing functions of these riparian areas.

The measures are in line with past EPA guidance (USEPA 2005) as well those described in the National Research Council report *Riparian Areas: Functions and Strategies for Management* in 2002 (NRC 2002). Specifically, that restoration of riparian functions along America's waterbodies should be a national goal, and protection should be the goal for riparian areas in the best ecological condition.

1.3 Who is This Chapter For?

This chapter of the guidance document is written for federal land managers who manage riparian areas. EPA anticipates that it will be useful for others involved in watershed planning, including conservation districts, local municipalities landowners, and land use managers, total maximum daily load developers, conservation trusts, and natural resource contracts specialists.

1.4 What Does This Chapter Cover?

This chapter has three main sections:

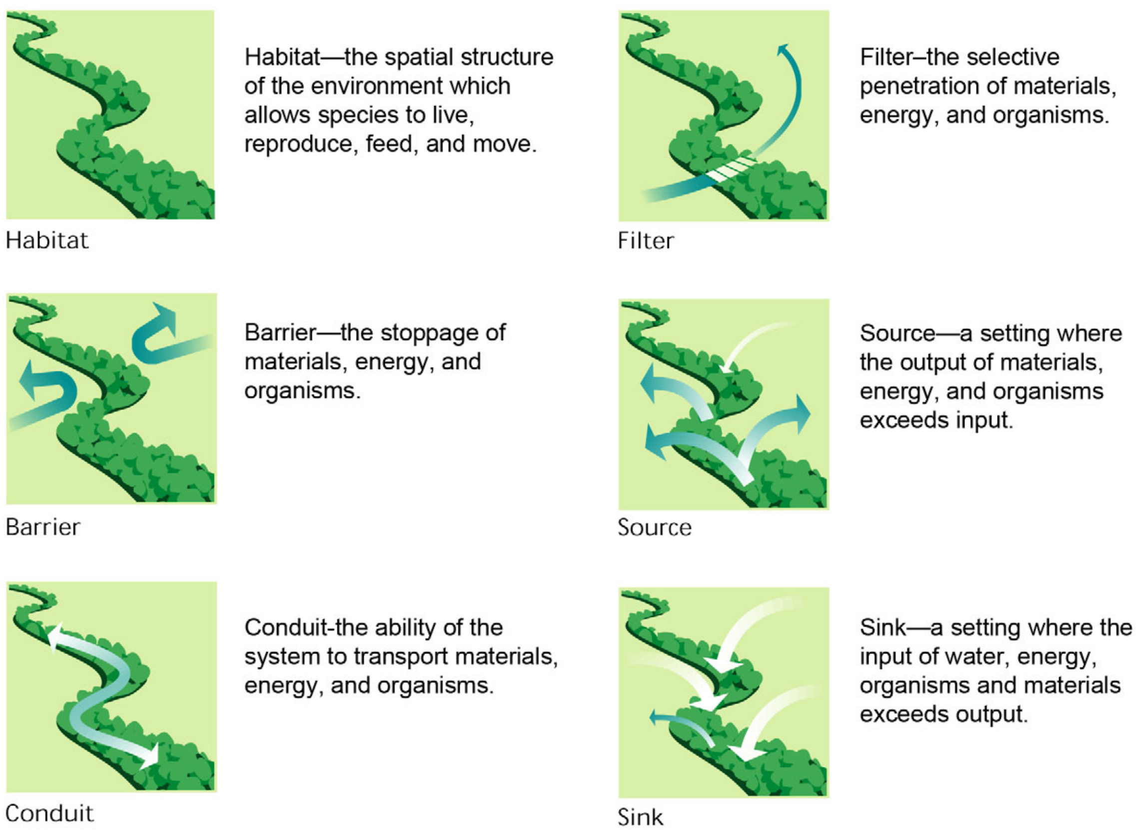
- Section 2 describes the benefits of buffers, including pollutant-removal efficiency and factors that affect it.
- Section 3 outlines recommendations for the restoration of forested buffers in the Chesapeake Bay and includes site selection, planting, and short-term maintenance of newly restored sites.
- Section 4 discusses strategies for the long-term maintenance and the protection of existing forested riparian areas. Such areas must first be identified and assessed before they can be properly maintained and protected.

2 Benefits of Natural Riparian Areas

Many benefits are associated with forested riparian areas. Some of those benefits can be replicated with technology such as reservoirs (flood control) and treatment plants (pollutant removal). However, none of those single-function replacement technologies provide the multiple, simultaneous functions of a healthy forested riparian area.

This section describes a few of the most important of the many benefits. In general, benefits can be categorized into one or more of six broad ecological functions (FISRWG 1998) (Figure 5-3):

- *Barrier and Filter*—The ability to stop or limit penetration of water, materials, energy, and organisms into, through, or along the stream corridor
- *Habitat*—The spatial structure of the riparian area and stream, which allows organisms to live, feed, and reproduce



Source: FISRWG 1998

Figure 5-3. Critical ecosystem functions.

- *Conduit*—The ability of the corridor to serve as a flow pathway for water, materials, energy, and organisms
- *Source* and *Sink*—The net movement of water, materials, energy, and organisms in or out of the buffer

2.1 Water Quality Benefits

2.1.1 Filtering Sediment Pollution

Erosion, transport, and deposition of various-sized soil particles from the watershed into the stream channel are natural processes that shape the landscape over time. Those processes are disturbed by human activities such as urban development and agriculture. The exposure of soil during construction, because of overgrazing or between growing seasons, combined with the increased surface runoff associated with increased impervious surfaces and soil compaction increase sediment loading to streams. That causes a variety of negative in-stream effects, including the following:

- Destroying beneficial channel structures such as pool and riffles
- Damaging gills of fish and aquatic insects
- Filling in pore spaces on the stream bed and suffocating benthic biota
- Interfering with fish spawning habitat, and egg and larval survival
- Reducing light penetration and interfering with algae and aquatic plant photosynthesis

Riparian areas help regulate the amount and size of sediment that reaches the stream from upland sources. Assuming that sediment-laden runoff moving through the riparian area is not allowed to concentrate, channelize, and convey directly to the stream, sediment will be deposited as riparian vegetation slows runoff and water infiltrates the soil.

2.1.2 Filtering Nutrient Pollution

N and P are two nutrients essential for the growth of algae and other aquatic plants. When present in excessive amounts, however, they can trigger algal blooms, nuisance levels of plant growth, and overall degradation of a stream. Altering land use for human activity has greatly increased the amount of nutrients in aquatic systems. Those excess nutrients come from lawn and agricultural fertilizers, animal wastes, sewage treatment plants, and septic systems. The potential pathways to a stream of the two nutrients differ, however, because of different chemical properties. Correspondingly, the filtering mechanisms for P and N within riparian areas also differ.

P has a strong tendency to sorb to soil particles and organic matter. Therefore, it is usually moved across the landscape attached to sediment that is carried in surface runoff. Consequently, the conditions and mechanisms that serve to filter out sediments in riparian areas serve to filter out P. As sediment settles from runoff and water infiltrates the soil, the attached P can either remain in the soil or be taken up by riparian vegetation.

On the other hand, N does not sorb strongly to sediment. While N in particulate form can be physically filtered by vegetation, similar to sediments, nitrate in dissolved form can infiltrate the soil, move with groundwater, and potentially enter the channel with shallow subsurface flow or baseflow.

Bacteria residing in riparian soils play an important role in filtering N through a process called *denitrification*. That process reduces nitrate to primarily dinitrogen gas (N_2) with possible production of trace amounts of nitrous oxide, a potent greenhouse gas, both of which are released into the atmosphere. The basic requirements for denitrification are anaerobic conditions or restricted oxygen availability (saturated soil conditions), a good supply of nitrate and electron donors such as organic material, and warm conditions (above 50 degrees Fahrenheit [°F]). Other microorganisms and biota in the soil take up N, as do plants if the root zone is saturated part of the time.

2.1.3 Estimated Pollutant Removal

The Mid-Atlantic Water Program at the University of Maryland led a project in 2006–2007 to review and refine definition and effectiveness estimates for best management practices (BMPs) in the Chesapeake Bay watershed, including grassed and forested riparian buffers in agricultural areas. The objective was to develop estimates that reflect the average operational condition representative of the entire watershed to better reflect monitored data in modeling scenarios and watershed plans. Table 5-1 summarizes the nutrient and sediment reduction efficiencies for forest and grass buffers in agricultural areas on the basis of the literature review performed for this study. As indicated by the results, forest buffers are better at reducing N loads to the Chesapeake Bay; however, forest and grass buffers are the same in their ability to reduce P and sediment loads.

Table 5-1. Average nutrient and sediment reduction efficiency comparison of riparian forest and grass buffers

	TN reduction (%)		TP reduction (%)		TSS reduction (%)	
Location	**Forest**	**Grass**	**Forest**	**Grass**	**Forest**	**Grass**
Inner Coastal Plain	65%	46%	42%	42%	56%	56%
Outer Coastal Plain Well Drained	31%	21%	45%	45%	60%	60%
Outer Coastal Plain Poorly Drained	56%	39%	39%	39%	52%	52%
Tidal Influenced	19%	13%	45%	45%	60%	60%
Piedmont Schist/Gneiss	46%	32%	36%	36%	48%	48%
Piedmont Sandstone	56%	39%	42%	42%	56%	56%
Valley and Ridge—marble/limestone	34%	24%	30%	30%	40%	40%
Valley and Ridge—sandstone/shale	46%	32%	39%	39%	52%	52%
Appalachian Plateau	54%	38%	42%	42%	56%	56%

Source: Simpson and Weammert 2009
Note: TN = total nitrogen; TP = total phosphorus; TSS = total suspended solids

It is important to remember that all buffers do not have the same efficiency for pollutant reduction (Speiran et al. 1998). Pollutant-removal estimates in Table 5-1 are based on average conditions in agricultural areas and were developed for use in EPA's Chesapeake Bay Water Quality Model. Research on pollutant removal in urban and suburban areas is limited. In addition, site-specific conditions can greatly affect pollutant-removal processes. Hot spots, regions of disproportionately high reaction rates compared to the surrounding area, or hot moments, short periods when disproportionately high reaction rates occur compared to typical conditions, can occur and alter annual contaminant budgets at the watershed scale (Vidon et al. 2010).

Hydrology plays a significant role in buffer effectiveness. The filtering functions of a buffer are greatly reduced when runoff enters the riparian area as concentrated flow or channelizes while flowing through the buffer. Denitrification in riparian zones is affected by the depth of the water table and the presence of subsurface carbon and dissolved oxygen in groundwater. Pollutant removal is reduced where ideal conditions do not occur. For example, in urban areas, surface runoff is usually diverted into a stormwater management system that conveys water directly into streams. Similar short circuiting occurs in agricultural areas that are tile drained. In those situations, runoff completely bypasses riparian buffers and does not receive any of their pollutant-removal benefits.

Because of those and other factors, pollutant source control, discussed in the other chapters of this document, is extremely important in addition to the use of riparian forest buffers for water quality.

The U.S. Department of Agriculture (USDA) Agricultural Research Service Southwest Watershed Research Laboratory developed the Riparian Ecosystem Management Model (REMM), for researchers and natural resource agencies to help quantify the water quality benefits of riparian buffers under varying site conditions. REMM requires weather data, pollutant input information, riparian soils, vegetation, and litter information and is calibrated only for the Coastal Plain in Georgia, but it would be useful in areas with similar conditions where the required input parameters are available.

2.2 Floodplains and Streambanks

During intense storms, water levels in the stream can rise above bankfull elevation and spill into the hydrologic floodplain. Flooding is important because it reconnects the floodplain to the stream and provides habitat conditions critical for the reproductive cycle of some species of fish, insects, amphibians, and reptiles. Increased impervious surfaces or compacted soils associated with urban development in a watershed increases flow energy in streams, which can cause greater rates of streambank erosion. That erosion can become so significant that even with the increased runoff entering the stream, the stream becomes incised and completely disconnected from its floodplain.

The presence of a healthy riparian area can mitigate the effects of such altered hydrology. One study found that vegetation restoration of bare ground and livestock trampled riparian zones reduced catchment export of sediment from more than 100 kilograms per hectare per year to less than 10 within one year, mainly by reducing bank erosion and stabilizing the stream channel (McKergow et al. 2003).

Woody riparian vegetation in the floodplain serves to dissipate flow energy during floods. Root systems of riparian vegetation immediately adjacent to the stream help bind sediments, which can reduce bank erosion. Riparian forests contribute large woody debris to streams, such as branches, logs, and root wads. The roughness they create in the channel can slow stream velocity, which promotes channel bed and bank stability and sediment deposition (Harmon et al. 1986). Dams created by the debris can also increase sediment deposition in channels and increase flooding frequency that promotes sediment deposition on floodplains (Dosskey et al. 2010). Deposition of sediment also removes sediment-bound chemicals (such as P) and soil organic matter from the water column, which in turn contributes to biogeochemical processes in floodplains and the stream channel.

2.3 Maintaining Aquatic Habitat

Stream biota, including bacteria, algae, macrophytes, zooplankton, macroinvertebrates, fish, amphibians, reptiles, and mammals, all require a hospitable aquatic environment to live, reproduce, interact, and thrive. The riparian area plays a crucial role in maintaining a range of suitable habitats and conditions within the channel for a diverse and self-sustaining cycle of aquatic life. Good quality terrestrial habitat is essential for maintaining water quality and natural flows in the stream channel.

As discussed in Section 1 of this chapter, a riparian area usually includes the streambank, floodplain, and some portion of the transitional upland area. Natural features within such areas add structural variety and might include wetlands, natural levees, oxbow lakes, and other landforms. Diversity of riparian features usually results in corresponding diversity in soils, vegetation, and biota—important attributes of a healthy terrestrial habitat.

A few important benefits of forested riparian areas for habitat are described below.

- *Contributing wood debris to the channel*—Large, woody debris that falls into the channel creates additional habitat diversity for fish and other aquatic biota, especially in smaller streams. They often create a damming effect that traps sediment and create scour holes and function as fish habitat.
- *Provides allochthonous input of organic matter*—Energy sources that drive metabolic activity in a stream come from either autochthonous sources (within the stream channel via algae and aquatic plant photosynthesis) or allochthonous sources (outside the stream channel). In smaller, shaded headwater streams, there is little aquatic primary production because of lower light levels. Here, allochthonous input of woody material, leaves, and other organic matter is critical for the base of the food chain. Bacteria and fungi break the material down, and their microbial biomass becomes food for shredding invertebrates. Organic particles are subsequently transported to provide energy for downstream organisms.
- *Maintaining stream temperature*—Water temperature determines the range and viability of aquatic species. Some species, such as trout, require cold water temperatures. Other species, such as smallmouth bass, tolerate warmer temperatures. Riparian vegetation that covers the channel reduces solar radiation and keeps water temperatures cooler. Baseflow (from groundwater inflow) helps keep water temperatures stable year round.

2.4 Aesthetic Value

Besides water quality and habitat benefits, riparian areas can add value to property providing seasonal changes, such as shade in summer, flowers and birds in spring, and color in fall (Baird and Wetmore 2003). A study in 2006 in Missouri found that residents are willing to pay to live in an area with community-owned and accessible buffers and are willing to pay even more to live adjacent to such areas (Qiu et al. 2006). That pattern is consistent with other studies (Patterson and Boyle 2005; Netusil 2006).

2.5 Forested versus Grassed Buffers: Increased Focus on the Buffer/Stream Interface

Sweeney and Blaine (2007) point out that buffers have been historically viewed almost exclusively in terms of their barrier and filter functions; specifically, their ability to filter out upland sediment, nutrients, and other pollutants before they reach the channel. Such a focus on the upland/buffer interface resulted in a general acceptance of grass buffers as a reasonable alternative to forested buffers, because some studies show similar pollutant-removal efficiencies. For cultural, sociological, budgetary, and other reasons, grass buffers were even sometimes promoted as the preferred choice for riparian vegetation.

Research in the past decade, however, has revealed that grass buffers are about 68 percent as effective as forest buffers in reducing total nitrogen (TN) (Todd 2002). But perhaps more significant, the positive effects that riparian forest buffers have on stream systems have been more fully explored and documented. Sweeney (1992, 1993) reinforced the idea that stream processes, functions, and biota were developed in concert with riparian forests rather than riparian grasslands, and the absence of trees creates considerable stress on the natural aquatic ecosystem. For example, a study of forested and deforested small streams in the Piedmont region demonstrated that deforestation caused significant channel narrowing which, in turn, reduced stream habitat and processing of organic matter and nutrients (Sweeney et al. 2004). The study also determined that a forested stream ecosystem had 2 to 10 times more uptake of N than a grass ecosystem. For those reasons, this chapter focuses on forested riparian buffers.

That is not to say that upland/buffer interface is not an important consideration for buffer design, because that is where most sediment deposition and much biogeochemical removal occurs. However, the buffer/stream interface must not be overlooked.

3 Restoring and Reestablishing Riparian Forest Buffers

Implementation Measure R-1:

Promote the restoration of the preexisting functions in damaged and destroyed riparian systems, especially in areas where the systems will serve a significant nonpoint source pollution-abatement function as well as the suite of valuable ecosystems services riparian buffers provide.

3.1 Introduction

Approximately 58 percent of the streams in the Chesapeake Bay have riparian forest buffers, short of the 2025 goal of 63 percent, and the long-term goal of 70 percent. That means that restoring or reestablishing riparian forests is required to meet the Bay goal. Maryland, Virginia, Pennsylvania, and the District of Columbia have proposed in their tributary strategies to restore some 50,000 miles of riparian forest buffers to help reach water quality goals for major rivers that drain into the Bay (Greiner and Vogt 2009).

Successful restoration and reestablishment of buffers in the Chesapeake Bay area require that landowners, managers, public agencies, and other responsible parties assess ecological functions provided by existing riparian soils and vegetation and then make the best adjustments and improvements possible given cost, funding, and other practical constraints. In many cases, restoration will include planting seedlings and eventually reestablishing fully functioning riparian forest.

3.1.1 Organization of This Section

This section is organized to cover the basic steps for undertaking a successful riparian forest buffer restoration project.

- Selecting and prioritizing areas for restoration (Section 3.2)
- Analyzing existing conditions and identifying potential problems at the site level (Section 3.3)
- Importance of connectivity and determining the appropriate buffer width (Section 3.4)
- Selecting, planting, and protecting tree seedlings (Section 3.5)

Much of the information presented in Sections 3.2 and 3.4 are based on the Maryland Department of Natural Resources Forest Service (DNR FS) manual, *Riparian Forest Buffer Design and Maintenance* (2005). For details about the methods and procedures described, see that manual.

Section 3.6 wraps up the chapter by discussing costs of riparian buffer restoration.

3.2 Selecting and Prioritizing Areas for Restoration

As discussed in Section 2.1, to get certain pollutant-removal benefits, riparian buffers must intercept pollutants. While seemingly obvious, it is usually easier said than done. While it is easy to identify areas where runoff would bypass riparian buffers, such as areas with stormwater outlet pipes and gullies, other factors are less obvious. A few studies have found that groundwater seeps due to macropores from roots can also reduce buffer effectiveness and have a significant effect on stream chemistry (O'Driscoll and DeWalle 2010; Angier and McCarty 2008). Identifying those conditions is expensive and time consuming, and it is not possible on every riparian restoration site. Fortunately, land managers can use information such as stream order and geographic information system (GIS)-based data analysis tools to locate areas where maximum pollutant-removal benefits are most likely.

3.2.1 Stream Order

As a mainstem stream moves through its watershed, it drains an increasing amount of land area. The mainstem stream is continuously fed by a network of feeder streams. Strahler (1957) proposed a classification system to identify the position of all streams in a watershed network. Small streams with no tributaries are first-order streams (Figure 5-4). When two first-order streams flow together, they become a second-order stream. The confluence of two second-order streams creates a third-order stream, and so on.

Lower order streams dominate the landscape in terms of numbers and stream mileage. It is estimated that 75 percent of streams in the United States are first- and second-order streams and 90 percent are first-, second-, or third-order streams (FISRWG 1998; Leopold et al. 1964). Therefore, meeting the short- and long-term goals for forested riparian buffer coverage in the Chesapeake Bay watershed requires managers to focus primarily on restoring buffers of lower order streams.

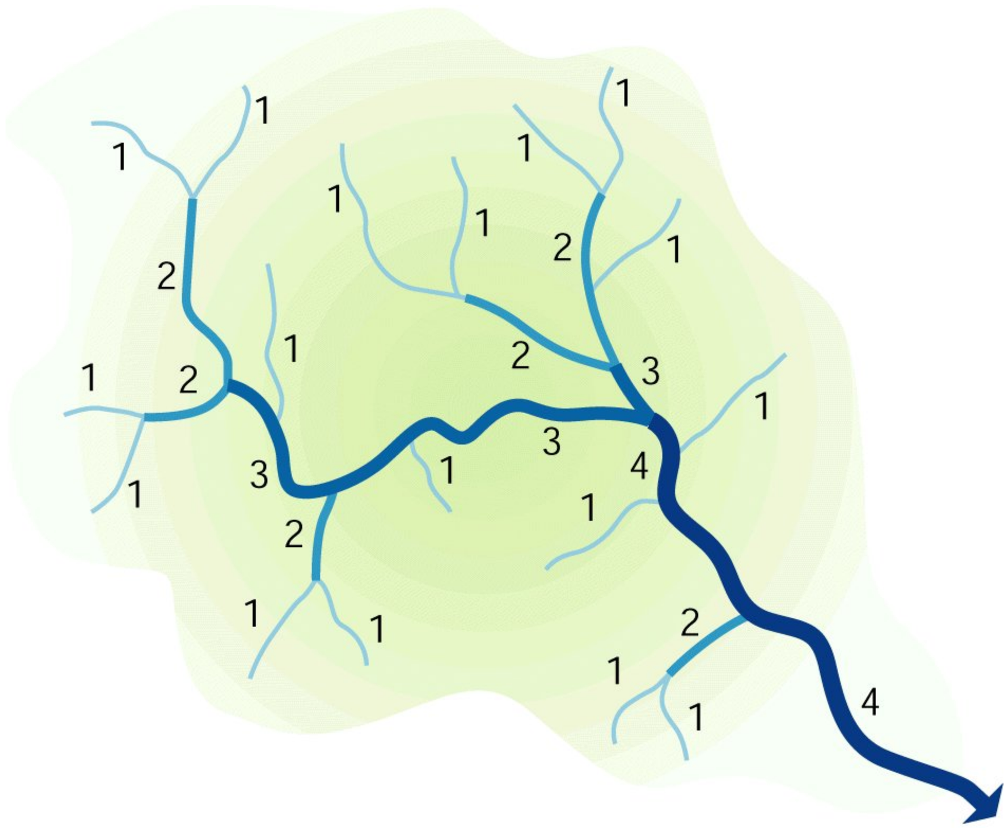


Figure 5-4. Strahler's stream classification.

The relatively small scale of headwater streams also increases the magnitude of influence the riparian area has on them (Sweeney and Blaine 2007). A forest canopy, for example, can easily extend across small streams and keep stream temperature cool. Large, woody debris adds proportionally more structure to the channel, and allochthonous materials are distributed throughout the channel and support life in virtually all microhabitats.

Because a small stream's watershed is also smaller in size, a forest buffer of even modest proportions can effectively regulate the lateral flow of water and filter a commensurate volume of sediments, P, and other pollutants (Dosskey et al. 2005; Polyakov et al. 2005). Groundwater flow is usually shallower and therefore more likely to pass within the root zone of trees as it travels downslope. That increases the opportunity for N uptake before groundwater flow reaches the channel (Craig et al. 2008). In addition, as stream order increases, direct surface runoff to the channel tends to increase, meaning that in smaller watersheds, a greater proportion of upland runoff will actually be intercepted by the riparian zone (McGlynn and Seibert 2003; Tomer et al. 2003; Wondzell and Swanson 1996).

3.2.2 GIS Tools for Buffer Placement

Stream order is only one factor in determining where buffers might have the most influence on water quality. Upland nutrient loading, depth to water table, and slope are some of the many factors that land managers should take into account to prioritize areas for restoration in terms of maximum pollutant-removal benefit. Several GIS tools are being developed to synthesize the information and identify critical areas where buffers are most needed in terms of water quality benefit. One example is the Chesapeake Bay Riparian Forest Buffer Targeting Scheme.

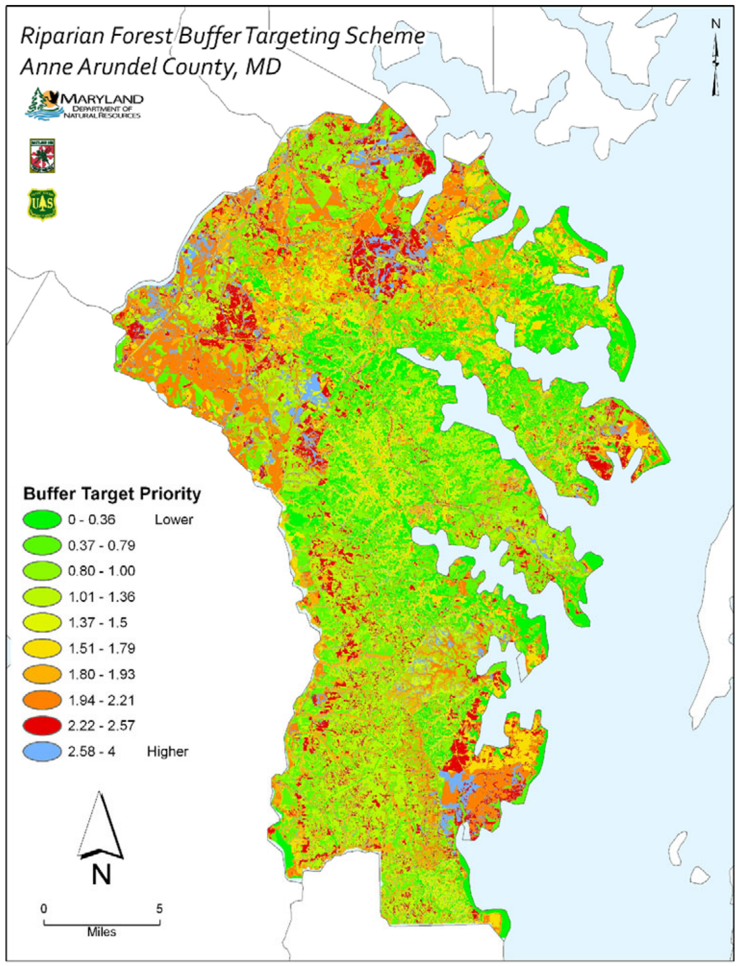


Figure 5-5. Riparian Buffer Prioritization Map of Anne Arundel County, Maryland.

In 2008 the Chesapeake Bay Forestry Workgroup developed a scientifically based scheme to identify areas in the watershed where performance of riparian forest buffers might be expected to be high. The scheme is in the form of a targeting matrix that captures the variables that influence the efficiency of nutrient removal in a buffer, namely, hydrology (specifically depth to water table), slope, land use, and source nutrient loading.

Each of the attributes is weighted according to importance and then scored, with a higher score given to conditions that would result in more pollutant removal (such as a shorter depth to water table). The scores are analyzed in GIS to create a map like the one in Figure 5-5. For more information on the matrix, including an explanation of why the attributes listed here are the most likely to result in the successful placement of riparian forest buffers in areas of the Chesapeake Bay watershed, see http://archive.chesapeakebay.net/pubs/calendar/FWG_11-18-08_Handout_3_9152.pdf and http://archive.chesapeakebay.net/pubs/calendar/FWG_11-18-08_Presentation_1_9152.pdf.

3.3 Analyzing Existing Conditions and Identifying Potential Problems

Every riparian forest buffer has a unique set of conditions that managers must understand before developing a restoration plan. How those conditions link to pollutant removal and ecological function is important to success. Three key areas that need to be addressed are (1) hydrology, (2) soils, and (3) existing vegetation. In addition, special characteristics and potential problems associated with converting a previous land use to a forest buffer should be considered.

3.3.1 Hydrology

As discussed throughout this chapter, riparian areas are driven by hydrology (NRC 2002). Identifying pathways of water flow through the site provides clues on how well beneficial functions in the riparian area will operate once reforested. Ideal site hydrological conditions include the following:

- Local groundwater originating from adjacent upland takes a relatively shallow path through the soil and comes into contact with the root zone of buffer vegetation. That contact increases the likelihood that N will be taken up by vegetation, immobilized by microorganisms, or undergo denitrification by bacteria.
- Runoff water originating from the uplands does not concentrate, channelize, and convey directly to the stream and bypass riparian vegetation and groundwater recharge areas. Gently sloping vegetative landscapes are preferred because they promote sheetflow and naturally reduce runoff velocity. These attributes increase the residence time of surface runoff and increase the likelihood of infiltration. Lower slopes also tend to reduce the velocity of groundwater flow and increase its contact time with buffer vegetation roots and other processes that remove or immobilize N.

Hydrologic analysis at the site should include an evaluation on how well the above conditions are met.

3.3.2 Soils

Success in regulating the lateral flow of water, filtering sediment and nutrient pollution, and maintaining important processes and functions in the stream itself ultimately depends on riparian soils and the organisms that reside in them. Features within the riparian area such as natural levees and wetlands have their own unique soil characteristics. Soil complexity is beneficial because different soil attributes affect the occurrence and efficiency of ecological functions as well as supporting a diverse vegetative community (FISRWG 1998). Some important soil characteristics to assess include the following:

- *Soil composition and texture*—Soils are composed of various inorganic mineral particles that can be categorized by size (sand, loam, or clay) and organic matter (in various stages of decomposition). Soils that promote infiltration and transmission of water need to have a high porosity, such as coarse-textured sandy/loamy soils held together with organic matter, as opposed to fine-textured clayey soils.
- *Soil moisture*—The ability of the upper layer of soil to hold water by surface tension in fine pores is very important to the growth and survival of vegetation. Loamy/clayey soils have the best water-holding properties. Sandy soils are the most porous and do not have much capacity to hold water.
- *Soil compaction*—Human activity, especially in urban areas, can compact natural soils and reduce infiltration and water-holding capacity as well as killing root systems. About 50 percent pore space is ideal (MDNR FS 2005).
- *Wetland soils*—Wetlands in riparian areas typically occur where the water table is at or near the surface. Soils are hydric, meaning they are saturated during all or portions of the growing season and develop anaerobic conditions. Only plants adapted to these conditions can survive in wetlands. Saturated areas are also important areas for denitrification, a bacterial process that removes nitrate from groundwater before it reaches the stream channel, and should be identified and protected.

The Pennsylvania Stream ReLEAF Forest Buffer Toolkit, section 2 of the Maryland DNR *Riparian Forest Buffer Design and Maintenance* guide, and section 4 of the *Chesapeake Bay Riparian Handbook: a Guide for Establishing and Maintaining Riparian Forest Buffers* (Palone and Todd 1997) contain guidance on soil evaluation.

3.3.3 Riparian Vegetation

Soil properties, topography, shading, seed stock, water availability, and other factors determine the density and distribution of vegetative species within a riparian area. Plants play an important role in filtering, storing, and processing pollutants and lessening their effect on stream quality. Riparian vegetation also performs several ecological functions. Restoring vegetative structure, especially reestablishing trees, is often the most visible aspect of a riparian restoration project.

Different attributes affect the occurrence and efficiency of ecological functions. Important characteristics that managers need to assess and then maintain or restore include the following:

- *Trees adjacent to the stream*—The importance of trees to stream ecology is discussed in Section 2 of this chapter. The annual cycle of growth and senescence of trees provides organic material to the stream, which serves as the base of the food chain in headwater streams. Streamside trees also add large, woody material to the channel, which provides important habitat functions for a variety of aquatic biota. Additionally, the root systems of streamside trees help bind bank sediments and reduce the potential for erosion.

- *Horizontal complexity*—A riparian area with diverse population of vegetation is generally a reflection of a diversity of soils, drainage conditions, flooding patterns, and other conditions across the area. A mix of herbaceous plants, shrubs, and trees provide varying levels of sediment, nutrient, and pollutant removal efficiencies (FISRWG 1998). Complex vegetation habitat also typically results in a wider variety of wildlife.
- *Edge habitat*—Two distinct habitats within a riparian forest area are edge habitat and interior habitat. The edge habitat is the area of transition between an upland ecosystem and the interior forest. Compared to interior habitat, edge habitat, by virtue of its position, receives higher and more fluctuating levels of solar and wind energy, precipitation, and water and materials flowing from the adjacent land use. Therefore, it functions as the first line of defense for regulating runoff and filtering pollutants. Flora and fauna that inhabit edge habitat are species that can tolerate more intense and fluctuating conditions.
- *Interior habitat*—Interior habitat is a more stable environment, sheltered from conditions endured by edge vegetation. In general, more sensitive and rare species of plants and animals are in interior habitat, away from the dynamic processes in the edge habitat. Therefore, if protecting sensitive or rare species is an objective of riparian forest buffer restoration, managers must ensure that there is adequate interior habitat in the buffer.
- *Vertical complexity*—Birds and other tree-dwelling wildlife depend on a variety of layers of vegetation to thrive and reproduce. A vertically complex area also reflects a diversity of age composition and indicates a successful pattern of succession and new growth.

3.3.4 Special Characteristics and Potential Problems Associated with a Previous Land Use

If all or a portion of the riparian area being restored was used for some other purpose (e.g., cropland, pastureland, lawns, parkland), there might be special characteristics or potential problems that should be assessed. As described in *Riparian Forest Buffer Design and Maintenance* (MDNR FS 2005), those could include the following:

- *Compacted soils*—Soil compaction is often a problem in developed areas. Compacted soil restricts the movement of water into the ground and inhibits root penetration. It is often a problem in urban and suburban soils because of vehicle or foot traffic, playing areas, or other use. Compacted soils in pastureland might be due to cow paths or other animal or equipment traffic. Usually soil compaction is not a problem in agricultural lands; however, there might be a compacted layer of soil below the plow zone. If compaction presents a problem for tree rooting, a moderate amount of discing or tilling can be employed to loosen the soil.

- *Fill material or other problem soils*—Fill material, especially in suburban and urban areas, might have been imported and placed on the site. Fill can contain any variety of material not amenable for growth of native trees and vegetation. Conditions could include low fertility, high sand content, high clay content, low organic matter content, excessive rocks, and low microfauna content. Soil testing that includes composition and pore analysis, pH, and organic and nutrient content can help determine soil limitations and what amendments might be needed for healthy growth. Depending on the results, amendments might include fertilizers, composted manure, peat moss, mulch, or decompaction agents.
- *Noxious or invasive weeds*—Weeds can and often will outcompete and kill young trees. Present and future generations of noxious or evasive weeds might reside at the site (Figure 5-6). Weed seeds are very hardy and can lay dormant in the soil for years waiting for favorable conditions to germinate. Controlling noxious and invasive weeds should occur before tree planting through a mowing or other removal method. In some cases, it is prudent to even delay planting for a year to get more complete control of weed populations. When converting cropland to riparian forest buffer, establishing a cover crop is a convenient weed control method.
- *Animal damage*—A variety of animals can damage tree seedlings by rubbing or trampling them or by feeding on leafs, stems, bark, or roots. Managers need to make plans to keep them away from planted areas.

Figure 5-6. *Ailanthus altissima*, or Tree of Heaven is a common invasive found in riparian forest buffers.

- *Human damage*—Riparian buffers are sometimes damaged by the actions of well-meaning residents. Mowing, clearing, and other landscaping *improvements* can limit ecological functions. Public education and creating an awareness of the buffer value and purpose will help limit this problem.

3.4 Buffer Width and Connectivity

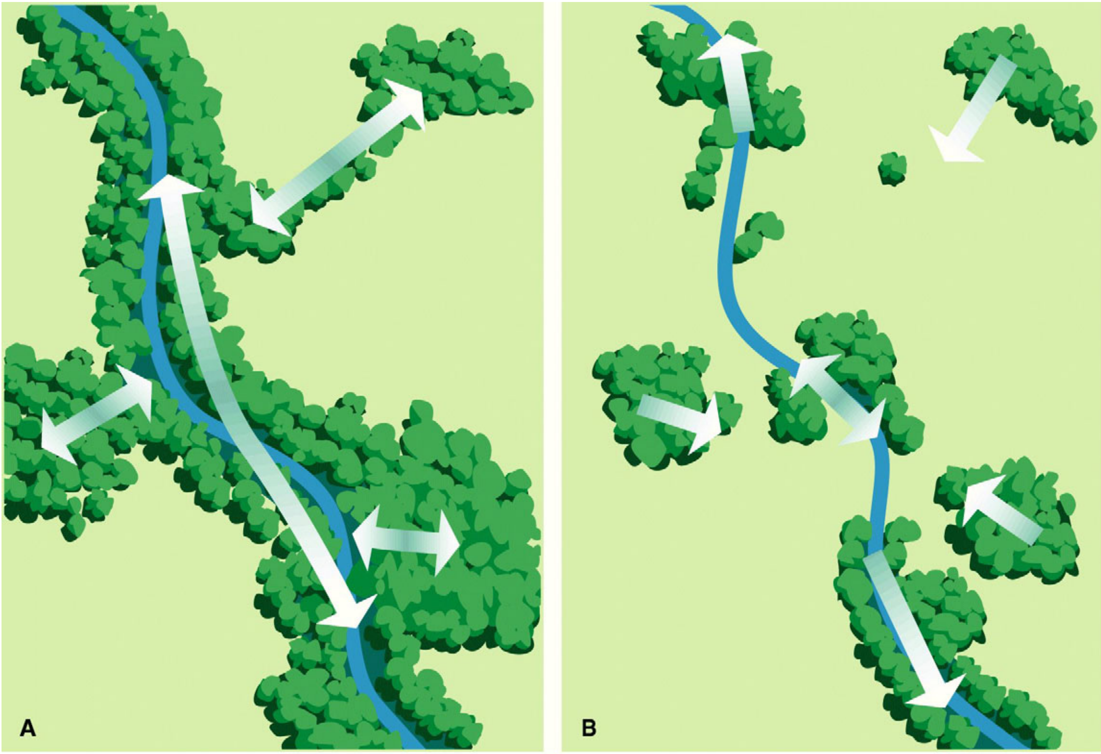
Two important dimensional characteristics of riparian buffers are

- *Width*—The lateral measure of buffer vegetation on either side of the stream.
- *Connectivity*—The measure of how continuous the buffer is both laterally and longitudinally. Gaps or breaks in the buffer serve to lessen connectivity (Figure 5-7).

In general, ecological functions are enhanced when buffers are wide and connected rather than narrow and full of gaps. For example, wider contiguous buffers create more space and a wider diversity of soils and vegetation to filter out sediment, nutrients, and other pollutants from upland sources before they reach the stream. Gaps in the buffer decrease buffer continuity and increase the chance of upland runoff concentrating and shooting through the gap to the stream. Gaps also discourage the movement of wildlife along the stream corridor. For those and other reasons, buffer-restoration objectives typically include making the buffer as wide and as connected as possible.

Width is a controversial aspect of buffer design and protection. There is much variation in buffer width recommendations in state and federal guidelines and peer-reviewed literature. Because factors that influence ideal buffer widths such as soil type and subsurface biochemistry, are site-specific, the location of a forest buffer can be more important than buffer width (Speiran 2010). Additionally, optimal widths are function dependent. In other words, the ideal buffer width at a location will also vary depending on whether the highest priority in terms of buffer function is water quality, stream temperature, or wildlife habitat. For example, DeWalle (2010) found that increasing buffer widths beyond 12 meters has a limited effect on stream shade and that the density and height of buffer vegetation near the stream are more important.

For further discussion on the scientific data related to width and pollutant removal, see Mayer et al. 2005 and Okay 2007. Todd (2002) points out that a clearly defined relationship does not exist between buffer efficiency and width that can be applied to the Chesapeake Bay region but concludes that the potential risk for failure of a buffer to remove excess nutrients before they reach the stream clearly increases with decreasing buffer width.

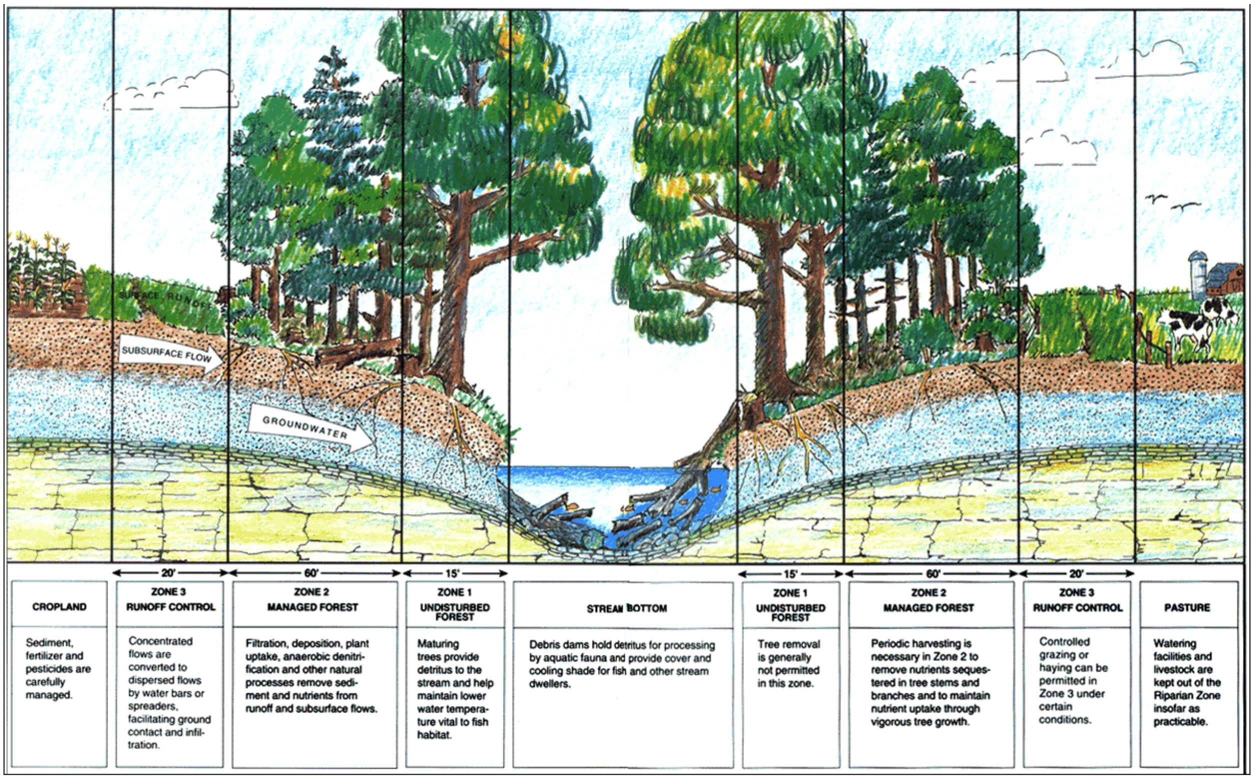


Source: FISRWG 1998

Figure 5-7. Connectivity within a landscape.

In 1991 the U.S. Forest Service released specifications for riparian forest buffer design for protecting and enhancing water resources (Welsch 1991). That document recommends that a riparian buffer should follow a *three-zone* design, illustrated in Figure 5-8.

While buffers will vary in accordance with factors discussed above, generally, the first zone next to the stream should be at least 15 feet wide and consist of mature tree cover, which protects streambanks, reduces thermal impacts, and contributes organic matter to the stream. Immediately adjacent to the first zone is the second zone, which typically should have a minimum width of 60 feet and consists of trees and shrubs. The primary purpose of the second zone is to capture and transform nutrients, sediments, and other pollutants from surface runoff and shallow groundwater. Zone three should be approximately 25 feet wide and contain natural grasses. That zone is an important area for the spreading, filtration, and infiltration of surface water.



Source: Welsch 1991

Figure 5-8. A typical 3-zone buffer design.

Following those guidelines, the minimum buffer width should be 100 feet for maximum pollutant-removal benefits, or wider where pollutant flows are greater or there is greater risk to downstream waterbodies. That is consistent with riparian buffer ordinances in Virginia, Pennsylvania, and Maryland (Baird and Wetmore 2003; MD CAC 2010; CWA PA 2009). Natural Resources Conservation Service (NRCS) Conservation Practice Standards for Riparian Forest Buffers in Maryland, Pennsylvania, and Virginia require a minimum 35-foot width of forested area for cost sharing. However, a wider buffer is recommended in high nutrient, sediment, and animal waste application areas, to include wetlands, steep slopes, and other critical elements, or when buffers are planted for carbon storage (NRCS 2006, 2008, 2009). Additionally, in areas where sediment is a major concern, a grassed filter strip (zone 3) at least 24 feet wide is required.

More information about the benefits of the 3 zone design is in the USDA booklet titled *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources* at http://www.na.fs.fed.us/spfo/pubs/n_resource/riparianforests/ (Welsch 1991).

3.5 Establishing Riparian Vegetation

Choosing the species of trees to populate a riparian forest buffer requires matching growing requirements with site conditions and planning objectives. In general, managers should strive to create species patterns that mimic reference conditions in the area. Managers should also consider the following when selecting plant species:

- Vegetation in the riparian forest buffer should be tolerant of different types of meteorologic and hydrologic conditions.
- Choose plants that have multiple values, such as erosion control, nesting habitat, food sources (nuts and fruit), and filtering capability.
- In areas of high erosion or where concentrated flow is an issue, trees, leaves, and woody debris might be ineffective for the amount of sediment retention desired (Daniels and Gilliam 1996; Knight et al. 2010). Consider adding a grass filter between the upland and the riparian forest. Tall, dense, stiff grass species are preferred in such areas (Dosskey 2001).

3.5.1 Natural Regeneration

Natural regeneration is the least expensive option for establishing a riparian forest buffer. Generally, natural regeneration will take longer to reach mature forest conditions, but it eliminates the need (and costs) for selecting and planting trees. Key attributes for success are the availability of native trees to function as a natural seed source and quality, non-compacted soils that promote good seed contact. To achieve that latter attribute, some site preparation work might be necessary.

Common tree species that generate windborne seeds that travel reasonably far distances include poplar, ash, pine, sycamore, birch, sweetgum, and maple. Seeding by heavier seed species (e.g., oaks and hickories) require trees that are fairly close by, preferably upslope.

Initial germination might yield thousands of seedlings per acre (Bradburn et al. 2010). Therefore, thinning the buffer at some point might be appropriate to create a healthier population of trees.

More information is in chapter 3 of the Maryland DNR FS *Riparian Forest Buffer Design and Maintenance Guide* (http://www.dnr.state.md.us/forests/download/rfb_design&maintenance.pdf).

3.5.2 Planting Trees

Planting results in more control of the location, density, and species on the site. It also speeds up the restoration process. However, it can be considerably more expensive than natural regeneration. Seeds, seedlings, or more mature trees can be planted on the site, depending the budget and objects of the planting.

- *Direct seeding*—Seed can be directly sown in the soil and aided by raking or discing, depending on the density of the seeds. Because of potential predation by squirrels, birds, and other animals, a fairly large number seeds is required. If germination is successful, dense stands can develop, which might need to be eventually thinned.
- *Seedling planting*—Seedlings can be planted by hand or using a planting machine. Unlike direct seeding, managers can tightly control tree location, pattern, and density. In addition to a good selection of seedling species available from nurseries, planting seedlings is usually the most cost-effective method of establishing trees in a riparian forest buffer. Care must be taken, however, to not damage or dry out seedlings during the plant process. Managers generally choose to plant seedlings in rows because such a configuration is easiest to design, install, and maintain. It also generates a full canopy closure more rapidly than other configurations.
- *Tree planting*—In some cases, managers might want to plant more mature trees at the site. Digging planting holes is more costly, but it avoids trampling high-traffic areas.
- *Species choice*—Choosing the species of trees to populate in the riparian forest buffer requires matching growing requirements with site conditions and planning objectives. In general, managers should strive to create species patterns that mimic reference conditions in the area.

Forest conditions, and corresponding ecological functions, develop more quickly with a high density of trees. If the rapid creation of a canopy for shading out weeds or providing cover and shade to a stream is the objective, high-density planting is recommended (e.g., 500 trees per acre). However, thinning back to 100 to 150 trees per acres will eventually be needed to create a healthy, self-sustaining riparian forest buffer (MDNR FS 2005).

The Stroud Water Research Center recommends planting at least 8 to 10 species when restoring a riparian area. In all cases, species must match the environmental characteristics of the site, and plans should be defined to protect seedlings from weeds and animals.

Additional information, including suggestions for the species to plant in the Chesapeake Bay area, is in the following resources:

- Pennsylvania Stream ReLeaf ToolKit (http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StreamReleaf/Forestbufftool/default.htm)
- Chapter 3 of the Maryland DNR FS *Riparian Forest Buffer Design and Maintenance Guide* (http://www.dnr.state.md.us/forests/download/rfb_design&maintenance.pdf).
- Chesapeake Bay Alliance (http://www.alliancechesbay.org/project.cfm?vid=158)
- University of Maryland (http://www.riparianbuffers.umd.edu/fact/FS725.html)
- Virginia Department of Forestry (http://www.dof.virginia.gov/mgt/rfb/rfb-common-plants.htm)

3.5.3 Protecting Seedlings

Young seedlings are susceptible to competition from weeds and animal damage. Protecting the investment is an important part of riparian forest buffer management.

Many species of grasses and weeds can out-compete tree seedlings for light, water, nutrients, and growing space. Fortunately, riparian forest buffer managers have several options to protect the planting investment until they get a foothold.

- *Hand clearing*—Pulling and cutting weeds species by hand is an option for small riparian areas. It is labor intensive, however. Some invasive species require the removal of entire root systems.
- *Mats, collars, and mulch*—Physical barriers for weed growth can be very effective in preventing weed competition around young trees. Some mats and tree collar products can be treated with a selective herbicide for added protection. Mulch can also provide a physical barrier to protect seedlings from weeds, but it too can be expensive and must be replenished.
- *Tree shelters*—Tree shelters are designed to protect young trees from weeds and wildlife. Sweeney et al. (2002) found that using shelters yields a survival rate four times higher than seedlings without shelters. In addition, sheltered trees have 19 times better vertical growth. Tubes that are ventilated, lighter in color, and designed to let in more light tend to work best (Figure 5-9).

Figure 5-9. Trees protected with tubes.

In addition to weeds, several animal species can harm seedlings above and below the ground. Manager can use several techniques to discourage or prevent their access to young trees.

- *Fencing*—Fencing can be used to limit access to the riparian forest buffer by livestock, deer, and other larger animals (Figure 5-10). It can be electric or woven wire. To be effective, deer fencing needs to be well-designed and around 8 feet tall. Gates might need to be built in for human access. Additional information on livestock exclusion fencing is in the Agriculture chapter.

- *Tree shelters*—Shelters are a physical barrier for browsing deer. They also keep voles from seedling roots provided that the tube is pushed into the soil a few inches.

Figure 5-10. Fencing limits access to the stream.

3.5.4 Reinforcement Planting

Reinforcement plantings might be necessary if some portion of original seedlings die. Before undertaking such an action, however, riparian managers should investigate why they did not survive or how they were damaged and then adjust planting methods and follow-up care accordingly. In some cases, a single factor might be the cause of tree mortality; in other instances, a combination of factors might be in play.

3.6 Cost

Costing is, of course, a key part of the planning process. The Maryland Cooperative Extension Service estimates that a typical forest buffer costs between $218–$729 per acre to plant and maintain (Tjaden and Weber 1998). However, costs vary widely and depend on the size and type of buffer. Managers must make choices at each step in the development process; from site-preparation alternatives, to planting methods, to seedling protection approaches, and follow-up maintenance. There is also a cost in taking the land out of crop production if the landowner or a renter is farming the land. The National Agroforestry Center developed an Excel-based tool called Buffer$ (http://www.unl.edu/nac/buffer$.htm) to help landowners analyze cost benefits of buffers compared to traditional crops.

The following resources are available for helping landowners determine the cost of establishing a riparian buffer on property:

- Klapproth and Johnson. 2009. *Understanding the Science Behind Riparian Forest Buffers: Resources for Virginia Landowners*.
- Maryland Cooperative Extension. Fact Sheet 774. *When a Landowner Adopts a Riparian Buffer—Benefits and Costs* (http://www.riparianbuffers.umd.edu/PDFs/FS774.pdf).
- North Carolina State University, Cooperative Extension Service. 2003. *Cost and Benefits of Best Management Practices to Control Nitrogen in the Upper and Middle Coastal Plain* (http://www.neuse.ncsu.edu/Ag%20621.pdf).
- USDA NRCS. 1997. 1997 Conservation Reserve Program practice cost and flat rate payment estimates for Virginia, March 1997.

4 Protection and Maintenance of Riparian Areas

Implementation Measure R-2:

Protect from adverse effects riparian areas that are serving a significant nonpoint source-abatement function and maintain that function while protecting the other existing functions of the riparian areas.

4.1 Background

The current rate of loss of riparian forests in the Chesapeake Bay is unknown. The long-term goal of having riparian forests on 70 percent of all streambanks and shorelines in the Chesapeake Bay requires not only the restoration of buffers, but also strong protections for existing buffers to maintain that goal. Existing riparian buffers and restored riparian buffers (Figure 5-11) that have been established for several years must be protected and maintained to keep them functioning as desired.

Figure 5-11. A healthy riparian buffer.

The previous section discusses restoring and reestablishing riparian forest buffers. This section provides information on recommended long-term maintenance activities and methods jurisdictions can use to protect existing riparian buffers.

An example of a riparian area evaluation on the watershed scale is that of Johnson County, Indiana (Letsinger 2004). In that study, the author assessed the current status of buffers (width and type) in the watershed. She digitally mapped existing buffers on an aerial photograph base and used multiple field surveys to ground truth the remote-sensing methods. Next she used a simplified numerical model to simulate hydraulic routing. She used the model to identify all riparian areas, impaired areas, and areas with the potential for flooding or increased erosion. That is useful in determining which areas should be the focus protection and maintenance efforts.

4.2 Long-Term Maintenance

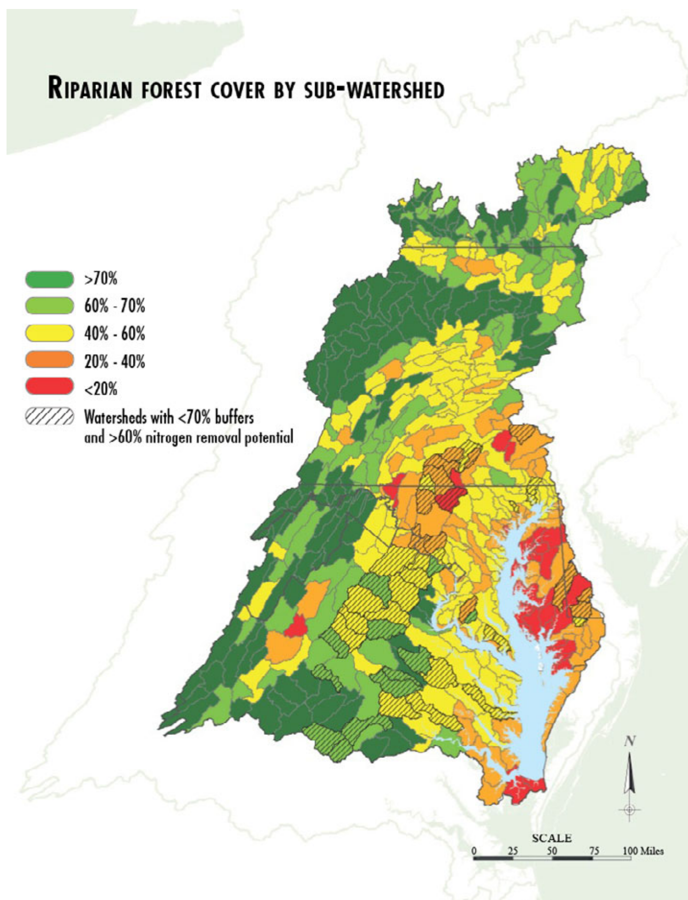
Existing riparian buffers, including those that have been restored, require long-term maintenance to maintain their desired functions, especially in terms of filtering P, N, and sediments from upland areas and preventing those pollutants from entering the Chesapeake Bay.

4.2.1 Watershed-Scale Evaluation

The first step in determining long-term maintenance of riparian buffers on a broad scale (at the state or county level) is to determine the extent of riparian buffers in the watershed.

Buffer boundaries can be mapped and, with proper legal authority, specific rules can be applied to protect and manage the buffer. Some maps already exist that show riparian buffer areas in the Chesapeake Bay. For example, Pennsylvania State University mapped the extent and change in riparian forest buffers for the entire Chesapeake Bay watershed (Day and Crew 2005) using the 1992 National Land Cover Dataset and the University of Maryland's MA-RESAC 2001 data set (Claggett et al. 2010). The extent of riparian buffers in any watershed can be determined using tools such as GIS, remote sensing, and hydrologic modeling. Satellite images and high-resolution aerial photography can help in the evaluation of each riparian area. For example, the Connecticut's Changing Landscape project, at the University of Connecticut's Center for Land Use Education and Research used basic GIS analysis tools and remotely sensed land use data to evaluate land cover change within riparian corridors between 1986 and 2006. (http://clear.uconn.edu/projects/riparian_buffer2/index.htm).

The Riparian Buffer Mapper (RBMapper) software developed by GDA Corp with support from the Chesapeake Bay Program,



Source: Chesapeake Bay Program 2005.

Figure 5-12. A forest cover map.

U.S. Geological Survey (USGS), and USDA FS is a tool that might be helpful for buffer delineation. The program outputs a land cover map of riparian buffers (Figure 5-12) and a text report with land cover statistics.

On-site methods might also be needed, such as performing various types of field surveys that look at geomorphology, hydrology, habitat, wildlife, soils, plant inventories, and so forth. A good approach would be to use a combination of remote and on-site methods to evaluate the streambanks in the watershed in terms of channel geometry, land use, soil types, and vegetation. The targeting matrix proposed by the Chesapeake Bay Program Forestry Workgroup and described in Section 3.3 might also be useful in helping to identify areas where riparian buffers are most likely to exist.

Some sources of maps, satellite imagery, and land cover data in the Chesapeake Bay watershed include the following:

- RBMapper (http://gdacorp.web5.hubspot.com/rb-mapper/)
- Chesapeake Bay Program (www.chesapeakebay.net/maps.aspx?menuitem=16825)
- USGS (http://www.usgs.gov/pubprod/)
- Mid-Atlantic Regional Earth Science Applications Center (MA-RESAC) (www.geog.umd.edu/resac/)

It is also important to evaluate the size (length, width) of each existing riparian buffer area to determine whether it is adequate to protect the Chesapeake Bay from nonpoint source pollution or serve other functions such as providing wildlife habitat, stabilizing streambanks, or protecting the fish population. Typically, longer and wider buffers are better at filtering and removing pollutants and provide better wildlife and aquatic habitat, as described earlier in this chapter.

4.2.2 Evaluation of Buffer Quality

Once the buffers are located in the watershed, it is important to determine whether they are achieving the desired functionality. Riparian buffers that are functioning well should be maintained and protected, while those buffers not functioning well might need more significant restoration (see Section 3 of this chapter). Specifically, land managers should evaluate the following:

- Hydrologic Condition
- Adjacent Land Use
- Wildlife Habitat

Hydrologic Condition

> As described in earlier sections, one of the most important functions of a riparian buffer is to protect water quality by filtering nonpoint source pollution coming from adjacent land. While that is an important function, riparian buffer managers should not alter riparian areas to improve their water quality function at the expense of other functions.

Managers must understand existing and future hydrogeomorphic conditions and consider them when developing management plans to ensure that riparian buffers maintain their functions. Hydrologic and geomorphic conditions help maintain many of the functional aspects of a riparian area, such as pollutant removal, habitat maintenance, and water storage and transport. It is important to understand the natural flow patterns (frequency, magnitude, duration) associated with each riparian buffer, especially where flow regimes have been modified (NRC 2002). Channel incision and widening from certain land use practices can curtail overbank flows. Information on historical conditions from overbank flood events is useful to know whether healthy riparian communities are possible and whether incision and widening is reversible (NRC 2002).

Climate change creates uncertainty in managing riparian areas in the Chesapeake Bay. In the upcoming years, plant species might experience a change in their growth rates and be exposed to higher average temperatures and changes in typical rainfall (Sprague et al. 2006). In light of this, hydrologic regimes are likely to change. Streams might experience more frequent effects of severe floods, droughts, and hurricanes. To prepare for that, managers should assess how the stream channel will function ecologically under extreme low-flow or high-flow conditions and inspect the condition of a riparian buffer after a significant metrological or hydrological event occurs to determine if any maintenance is needed.

Adjacent Land Use

Land use directly affects the characteristics of runoff through a riparian buffer. The pollutant-removal effectiveness of the buffer will depend on the conditions of the upland land cover where the runoff originates (i.e., urban, suburban, pervious, impervious, agricultural, tilled, no till) (NRC 2002). Therefore, addressing practices in the upland land uses that contribute to riparian degradation is an important component of a successful riparian restoration project.

Agriculture runoff (high in nutrients, bacteria, and TSS) will be different from urban runoff (high in nutrients, heavy metals, pesticides, hydrocarbons, temperature, oxygen-demanding substances, and trash and debris) (USEPA 1996). Forested land has unique factors that managers should consider in terms of maintaining and protecting existing riparian areas. For example, timber harvesting must be managed so it does not increase water and sediment yields and lead to stream channel destabilization and loss of aquatic habitat. The forest landowner should also not decrease woody, in-stream cover. Doing so could destabilize streambanks, reduce shading, increase water temperatures, reduce inputs of fine litter to the waterbody, and reduce the diversity of plants and animals in the area. From a landscape perspective, managing a greater proportion of the riparian area for uneven-aged, mixed stands of longer-lived species suitable to the site can help protect riparian functions and values. The Agriculture, Forestry, and Urban and Suburban chapters of this document provide detailed information on managing different land uses to prevent and reduce nonpoint source pollution from entering the Chesapeake Bay.

Habitat

Managers should evaluate habitat to determine whether it is adequate to support the desired plant and animal species. Examples of both terrestrial and aquatic habitat assessments include the following:

- Maryland DNR (http://www.dnr.md.gov/streams/pubs/ea03-4phi.pdf)
- Ohio Environmental Protection Agency (http://epa.ohio.gov/portals/35/wqs/headwaters/PHWHManual_2009.pdf)
- The Nature Conservancy Active River Area (http://www.nature.org/initiatives/freshwater/files/active_river_area.pdf)

Additional Information

The following sources have additional information on the proper assessment of riparian buffers:

- *Riparian Area Management—Process for Assessing Proper Functioning Condition* (USDI 1998)
- *Methods for Evaluating Riparian Habitats with Applications to Management* (Platts et al. 1987)
- *Riparian Assessment Using the NRCS Riparian Assessment Method* (NRCS 2004)
- *Development of Methodologies to Evaluate the Health of Riparian and Wetland Areas* (Hansen et al. 2000)

4.2.3 Managing Plants

In addition to the factors discussed in the previous section, the plant species in riparian buffers need to be maintained so that the areas retain their desired functions. Some studies have found that pollutant-removal functions can increase over time (Rheinhardt et al. 2009). Consider the planting, harvesting, pruning, and nurturing protocols required to protect the riparian species from degradation. Managers might need to deal with new plants, invasive species control, wildlife damage issues, and disease issues. A landowner can contact the local NRCS office or a nursery for assistance.

Plantings

To manage existing areas so that they are effective long into the future, managers should determine the variations in riparian communities in a watershed and whether they are appropriate on the basis of factors such as soil type, hydrology, and land use. The species that exist in the riparian buffer need to be examined to determine whether they are appropriate for the desired effects of the buffer (such as wildlife and aquatic habitat) and whether they are suitable for the site conditions. Native vegetation is typically better capable of withstanding local water, climate, soil, and pest conditions.

Riparian buffer managers should consider the following:

- Climate change could bring about changes in temperature and rainfall amounts that could affect vegetation's growth and survivability and could increase the types or amount of invasive species.
- Keep an eye on riparian areas for plant die-off. First, determine the cause of the issue (for example, is the die-off due to wildlife damage, or are the site conditions inappropriate for the plants that are struggling?). Next, act quickly to repair any damage or replant additional vegetation.
- Some riparian sites warrant botanical generalists, whereas other might warrant wetland specialists. It depends on the site conditions. Remove certain species that are not appropriate to the site conditions or plant new vegetation.

Weed Control

Riparian buffers should be managed over the long-term to ensure that native vegetation is being established/maintained along the waterways. As mentioned in Section 3, weeds and invasive species can overtake a riparian area, causing damage to other species by competing for resources. Techniques to remove weeds, such as mowing and hand clearing, are important to consider using for long-term maintenance of a riparian buffer. For details on those techniques, see Section 3.

Some good resources for identifying weeds and invasive species in the Chesapeake Bay are

- USDA NRCS (http://plants.usda.gov/java/noxiousDriver)
- Native plant societies

- Virginia (www.vnps.org/)
- Maryland (www.mdflora.org/)
- District of Columbia (www.botsoc.org/)
- Pennsylvania (www.pawildflower.org/)

Preventative management, however, is the best method of weed control. This includes things like not disposing of plant clippings in riparian areas, not planting invasive species nearby, and removing problem plants as soon as they are spotted.

Note: When considering weed removal, when mechanized clearing is employed in an aquatic area, a permit may be required from the U.S. Army Corps of Engineers pursuant to Clean Water Act section 404.

Pruning, Harvesting, and Nurturing

In an existing riparian forest buffer, riparian buffer managers should check the conditions of any plants in the buffer periodically, especially after significant storm events, and consider planting additional species if needed to maintain the buffer's integrity. Check the area for damaged, diseased, or dying trees and shrubs that might need to be pruned or removed and replaced (contact NRCS, a cooperative extension, or local nursery for assistance). Check for fallen or leaning trees and whether they present a hazard to upland land uses. Although fallen trees can provide valuable habitat, trees threatening to cause significant damage might need to be pruned or removed.

Check during drought conditions, and water plants if necessary. Some trees might need to be harvested to remove nutrients and chemicals stored in their stems (Schultz et al. 1997) and to allow stronger trees to grow. However, managers must take care not to overharvest because that could be disruptive to the existing plant and animal communities and could lead to increased streambank erosion (USEPA 2005).

Below are sources of additional information on pruning, harvesting, and nurturing protocols.

- USDA FSA (http://plants.usda.gov/java/noxiousDriver)
- Maryland DNR Forest Service (http://www.dnr.state.md.us/Forests/)
- Virginia Forest Service (http://www.vaforestservice.com/Forest_Management.aspx)
- Pennsylvania DNR (http://www.dcnr.state.pa.us/trees.html)
- Weeds Gone Wild (http://www.nps.gov/plants/alien/)

If the riparian forest buffer is part of an ongoing forestry operation, some limited harvest in accordance with BMPs for water quality (and associated guidelines for streamside management zones) may be allowed in the buffer, but workers should minimize land disturbance. Burning and pesticide and fertilizer use might also be restricted. For more information, see Chapter 4 of this document.

Agricultural land that has forested riparian buffers should be addressed using these same principles for selective harvest and could be subsequently reforested or used for other agricultural pursuits. For more information, see Chapter 2 of this document.

Fencing

Fencing, in some cases, can be an effective means of protecting riparian vegetation. Fences can be used to keep out or control livestock movement and grazing and to direct human activities into other areas. Fences serve to delineate land uses and prevent human activity from encroaching on the riparian zone. Many different fencing options exist, and it is important to identify the specific management requirements so that the location and design of fencing and gates, is appropriate and effective. Fencing needs to be inspected regularly for damage caused by weather, wildlife, or vandalism, and repaired if needed. Additional information on livestock exclusion fencing is in Chapter 2 of this document.

Erosion and Sediment Control

Riparian buffers should be inspected annually and after significant rainfall events for signs of erosion. Bare areas should be replanted, and additional soil might need to be added. In addition, over time or after a significant rainfall event, sediment that is trapped in the riparian area can build up and bury groundcover. Sediment can also build up at the edge of a buffer and block water flow. In those cases, the sediment should be removed, and some vegetation might need to be replanted. If it becomes an ongoing problem, the adjacent area might need better management practices installed.

4.3 Protection

Federal, state, nonprofit, and private programs, both regulatory and nonregulatory, exist to protect riparian functions. Creating ordinances and zoning to protect existing riparian areas is likely to be less expensive than establishing new areas or restoring degraded ones (Mayer et al. 2005). It has been recommended by a federal interagency report that states should, “Limit or eliminate development within riparian areas, using a similar approach such as Maryland’s Critical Areas legislation and Virginia’s Chesapeake Bay Preservation Act” and “create incentives to ensure that restored buffers remain intact” (Greiner and Vogt 2009).

4.3.1 Acquisition

The vast majority of land within the Chesapeake Bay watershed is held by private landowners. However, a government agency, nonprofit organization, or private citizen can purchase land where riparian areas exist as a means of protecting them from future degradation. Millions of acres of habitat in the 64,000-square-mile Chesapeake Bay watershed are already protected by federal, state, and local government programs and private organizations such as The Nature Conservancy, The Natural Lands Trust, and other land trusts (Greiner and Vogt 2009).

Fee Simple Acquisition

A local government or conservation group can do a fee simple acquisition, which gives it the full ownership of riparian land and provides the greatest amount of control over the use and maintenance of a property. This type of ownership is most desirable if the resources on the land are highly sensitive, and protection of the resources cannot be reasonably guaranteed using other approaches for conservation.

Conservation Easement

An alternative to buying riparian land is to purchase the property owner's right to use that riparian land for specific purposes by purchasing a conservation easement. A conservation easement is a written legal agreement between a landowner and a land trust or a local government that permanently restricts some landowner rights to the use of a property to protect its conservation value.

Some easement transactions offer tax benefits. A landowner who donates an easement or sells it for less than fair market value (for example, to a land trust) could be entitled to a federal income tax deduction. Such land must be used exclusively for conservation purposes. The easement is legally transferred but at no cost or at below-market value to the easement holder. That allows the landowner to qualify for a tax-deductible charitable donation.

4.3.2 Zoning and Protective Ordinances

Local governments often administer the regulations or incentives necessary to encourage private landowners to protect riparian areas. Land use ordinances are commonly used for that purpose. Land use ordinances define land use restrictions and plans. Zoning is one of the most common types of land use ordinances. Zoning that protects riparian buffers might be part of an existing natural resource protection ordinance, stormwater ordinance or floodplain ordinance in a state. Managers should review such regulations for their adequacy in protecting riparian areas. An overlay zoning ordinance pertaining to riparian buffer protection is appropriate in a municipality that already has a zoning ordinance in place. For a municipality that does not have zoning ordinances in place, a separate, freestanding ordinance might be necessary to protect riparian buffers.

A stream buffer ordinance can be used to establish minimal acceptable requirements for buffer design to protect streams and waterbodies in and around the Chesapeake Bay and to provide for the environmentally sound use of the jurisdiction's land resources. To see examples of ordinances that can be used to protect natural resources, see www.stormwatercenter.net. The stream buffer ordinance is an example of a model ordinance that can be used to guide future growth while safeguarding local natural resources. By examining the example provided, community decision makers should find the language to craft an ordinance that is appropriate for their conditions. A strong buffer ordinance is one step in preserving stream buffers.

> An example of a nonprofit agency that obtained a conservation easement in the Chesapeake Bay is the Conservation Fund (http://www.conservationfund.org/chesapeake_bay_initiative). The Conservation Fund launched an ambitious program that seeks to protect 100,000 acres of high-priority land and water within the watershed by 2010. Three miles of historic Chester River shoreline, 600 acres of unique Delmarva Bays, a 90-acre waterfowl sanctuary, and important habitat for bald eagle and endangered fox squirrel are now preserved forever under the 5,200-acre Chino Farms conservation easement—the largest in Maryland's history. The fund, collaborating with the landowner, Maryland DNR, Queen Anne County, and U.S. Fish and Wildlife Service, ensured the protection of more than 8 square miles of critical riparian habitat and wetlands. This easement keeps Chino Farms in agricultural production while conserving valuable natural resources in the Chesapeake Bay watershed.

Another example of a riparian buffer ordinance is the Riparian Buffer Conservation Zone Model Ordinance, which was prepared in 2005 by the Passaic River Coalition and New Jersey Department of Environmental Protection, Division of Watershed Management: http://www.marsh-friends.org/marsh/pdf/ordinance/StreamBufferOrdinance.pdf.

In some cases, through the municipal planning code, municipalities can take a regulatory or incentive-based approach to protect riparian areas in new developments. The degree of riparian area protection is likely to vary with the approach. Best results occur when a municipality identifies riparian areas to protect early in the planning stage of a new development. Communication during early planning stages, before commitments and decisions have been made, often promotes goodwill efforts from the developer. Amenities such as greenways or trails along stream corridors that result from municipal intervention can benefit the developer and protect the water resource because such green spaces can enhance the desirability of property in a new development.

In some jurisdictions, developers can be awarded increased building densities for developments that conserve natural areas, such as riparian corridors. Conversely, municipalities can employ density limits to encourage conservation of natural areas. For example, a jurisdiction could establish a minimum and maximum density and permit the higher density to a developer that plans for natural areas and open space techniques while lowering the allowable density for developments that do not incorporate preservation of natural areas.

Vermont River Management Program

Created in 1999, this program strives to manage toward, protect, and restore natural geomorphic conditions in streams. A big part of this program is river corridor protection. The two protection mechanisms are state and municipal land use restrictions on development in fluvial erosion hazard area and the purchase of river corridor conservation easements. The state used Stream Geomorphic and Reach Habitat Assessment protocols to delineate river corridors throughout the state and used this information to develop FEH areas. River corridor easements were created to augment the FEH land use ordinances. The purpose of the easement is to give the river the space to re-establish a natural slope, meander pattern, and floodplain connection (Kline and Cahoon 2010). More information on this program can be found at http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm

The Stormwater Center (http://www.stormwatercenter.net/) includes a template and sample ordinances, including one from Baltimore County, Maryland. Some of the major sections of a stream buffer ordinance are

- The intent of the ordinance
- Examples of what type of land buffers are applied to (i.e., forest, agriculture)
- Plan requirements (i.e., maps, surveyed streams and forest buffers, limits of a 100-year floodplain, mapped hydric soils, slopes measures, summary of species of vegetation)
- Design standards for forest buffer (i.e., width, slope)
- Management and maintenance of buffers (i.e., limitations on alteration of natural conditions, maintenance of roads, bridges, paths, utilities, stormwater management)
- Enforcement procedures (i.e., checking for violations, civil or criminal penalties)
- Waivers/Variance (i.e., ordinance applies to all development after effective date)
- Conflict with other regulations (i.e., more restrictive regulation will apply)

In some states, like Pennsylvania, a riparian buffer can be used as a stormwater credit, which is a technique that developers can use to reduce their stormwater management costs (Alliance for the Chesapeake Bay 2004). A stormwater credit for a stream buffer would be given when runoff from upland areas is treated by a grass or wooded buffer. Such techniques reduce runoff volumes, which helps to avoid the construction of costly stormwater management facilities.

4.3.3 Water Quality Standards

A state can use its water quality standards to protect existing riparian areas. For example, North Carolina has the Sediment Pollution Control Act, under which it declares that for forestry operations, a streamside management zone (SMZ) (i.e., buffer) must be established and maintained along the margins of intermittent and perennial streams and perennial waterbodies. The SMZ must be of sufficient width to confine within the SMZ visible sediment resulting from accelerated erosion (NCDENR 1999).

In Maryland's water quality standards, it is the policy that riparian forest buffers adjacent to certain waters must be retained when possible to maintain water temperature to protect salmonid fish. Maryland and Virginia have water quality standards that allow certain waters to be listed as exceptional state waters, which receive certain protections from antidegradation. (MDE 2009; VDEQ 2009).

4.3.4 Regulation and Enforcement

Individual local governments create and adopt development regulations to help retain riparian forest buffers in urbanizing areas. In Virginia, many local buffer ordinances (Section 4.3.2) were developed as part of implementing the Chesapeake Bay Act (VDCR 2010). An evaluation of the Maryland Critical Area Program found a much higher rate of loss of resource lands outside the designated critical areas after the program's enactment (Hillyer 2003). Maryland also has the Forest Conservation Act, which requires conservation of forests and mitigation of forest loss within a hierarchy that recommends that riparian forests be the highest priority for protection (MDNR FS 1991).

4.3.5 Education and Training

Activities that encroach on buffers are often not done purposefully but out of a lack of awareness. Education and outreach are important tools for promoting an understanding of the importance of riparian areas in maintaining water quality and protecting habitat and other valuable functions that they perform (USEPA 2005). Communities should work to make buffers more visible to the public and publicize the buffer's purpose and value to adjacent property owners. That can be accomplished in many ways, as recommended by EPA and the Center for Watershed Protection, including

> Baltimore County Public Schools have an annual Forest Buffer Restoration Project and Forest Buffer Maintenance Project where every high school in Baltimore is invited to participate. In the spring of 2008, almost 900 high school students from 18 Baltimore County Schools took part in the restoration effort and planted over 700 native trees and shrubs in conjunction with the Chesapeake Bay Trust, Baltimore County Forestry Board, and Baltimore County Department of Recreation and Parks and either take place on school land or at another designated location. During the Forest Buffer Maintenance Project students will map the planting areas to show where the trees and shrubs were planted, complete a survival/mortality count, and perform maintenance on the plantings such as pruning and staking. These activities are taught in the Forestry Unit of the High School Environmental Science Curriculum.

- Marking buffer boundaries with permanent signs that describe allowable uses (see Figure 5-13)
- Educating property owners about buffer benefits and uses via newsletters, pamphlets, meetings, and such and encourage a stewardship ethic
- Teaching courses in restoration techniques for landowners
- Ensuring that when property is sold, the new owners receive information about allowable uses and limits of the buffer
- Conducting annual *buffer walks* to assess buffer health and check for encroachment

Figure 5-13. Sign for a 1.2-acre riparian forest buffer restoration in Virginia.

5 References

Alliance for the Chesapeake Bay. 2004. *Riparian Forest Buffers*. Public Policy Program White paper, July 2004. Alliance for the Chesapeake Bay, Annapolis, MD.

Angier, J.T., and G.W. McCarty. 2008. Variations in base-flow nitrate flux in a first-order stream and riparian zone. *JAWRA*. 44(2):367–380.

Baird A., and D. Wetmore. 2003. *Riparian Buffers Modification and Mitigation Guidance Manual*. Virginia Department of Conservation and Recreation.

Bradburn, B.N., W.M. Aust, C.A. Dolloff, D. Cumbia, and J. Creighton. 2010. Evaluation of riparian forests established by the Conservation Reserve Enhancement Program (CREP) in VA. *Journal of Soil & Water Conservation* 65(2):105–112.

Chesapeake Bay Program. 2005. Maps—Bay Watershed. <http://www.chesapeakebay.net/maps.aspx?menuitem=16825>. Accessed February 2010.

Chesapeake Executive Council. 2003. Directive No. 03-01 Expanded Riparian Forest Buffer Goals. Chesapeake Bay Program, Annapolis, MD.

Claggett, P.R., J.A. Okay, and S.V. Stehman. 2010. Monitoring regional riparian forest cover change using stratified sampling and multiresolution imagery. *JAWRA* 46(2):334–343.

CWA PA (Clean Water Action Pennsylvania). 2009. *Buffers 100: Taking a Positive Trend Statewide*. Clean Water Action Pennsylvania, Philadelphia, PA.

Craig, L.S., M.A. Palmer, D.C. Richardson, S. Filoso, E.S. Bernhardt, B.P. Bledsoe, M.W. Doyle, P.M. Groffman, B.A. Hassett, S.S. Kaushal, P.M. Mayer, S.M. Smith, and P.R. Wilcock. 2008. Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment* 6(10):529–538.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. *Soil Science Society of America Journal* 60:246–251.

Day, R.L., and R.C. Crew. 2005. *Chesapeake Bay Riparian Forest and Wetland Buffer Inventory: Final Report*. Pennsylvania State University, Land Analysis Laboratory.

DeWalle, D.R. 2010. Modeling stream shade: Riparian buffer height and density as important as buffer width. *JAWRA*. 46(2):323–333.

Dosskey, M.G. 2001. Toward quantifying water pollution abatement in response to installing buffer on crop land. *Environmental Management* 28(5):577–698.

Dosskey, M.G., D.E. Eisenhauer, and M.J. Helmers. 2005. Establishing conservation buffers using precision information. *J Soil Water Conserv* 60(6):349–354.

Dosskey, M.G., P. Vidon, N.P. Gurwick, C.J. Allan, T.P. Duval, and R. Lowrance. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. *JAWRA* 46(2):261–277.

FISRWG (Federal Interagency Stream Restoration Working Group). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3. Federal Interagency Stream Restoration Working Group.

Greiner, J., and B. Vogt. 2009. *Habitat and Research Activities to Protect and Restore Chesapeake Bay Living Resources and Water Quality (202g) Report.* National Oceanic and Atmospheric Administration Chesapeake Bay Office, and U.S. Fish and Wildlife Service.

Hansen, P.L., W.H. Thompson, R.C. Ehrhart, D.K. Hinckley, B. Haglan, and K. Rice. 2000. Development of methodologies to evaluate the health of riparian and wetland areas. In *Proceedings of the Fifth International Symposium of Fish Physiology, Toxicology and Water Quality*, November 10–13, 1998, Hong Kong, China. V. Thurston, ed. EPA/6000/R-00/015. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Harmon, M.E., J.F. Franklin, F.W. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* 15:133–302.

Hillyer, S.C. 2003. *An Evaluation of the Maryland Critical Area Program Effects on Conservation of Resource Lands and Patterns of Development*. The Abell Foundation, Baltimore, MD.

Klapproth, J.C., and J.E. Johnson. 2009. *Understanding the Science Behind Riparian Forest Buffers: Benefits to Communities and Landowners*. Virginia Cooperative Extension, Blacksburg, VA.

Knight, K.W., R.C. Schultz, C.M. Mabry, and T.M. Isenhart. 2010. Ability of remnant riparian forests, with and without grass filters, to buffer concentrated surface runoff. *JAWRA* 46(2):311–322.

Leopold, L.B., M.G. Wolman, and J.P. Miller 1964. *Fluvial Processes in Geomorphology*. W.H. Freeman and Company, San Francisco, CA.

Mayer, P., S.K. Reynolds Jr., and T.J. Canfield. 2005. *Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Regulations*. EPA/600/R-05/118. U.S. Environmental Protection Agency, Washington, DC.

MD CAC (Maryland Critical Area Commission for the Chesapeake and Atlantic Coastal Bay). 2010. *Preserving Our Precious Natural Resources*. <http://www.dnr.state.md.us/criticalarea/preserving.html>. Accessed February 2010.

MDNR FS (Maryland Department of Natural Resources Forest Service). 1991. *The Maryland Forest Conservation Act.* Natural Resources Article, Section 5-1601 through 5-1613. Maryland Department of Natural Resources, Forest Service, Annapolis, MD.

MDNR FS (Maryland Department of Natural Resources Forest Service). 2005. *Riparian Forest Buffer Design and Maintenance.* Maryland Department of Natural Resources, Forest Service, Annapolis, MD.

MDE (Maryland Department of the Environment). 2009. *Maryland Water Quality Standards*. Code of Maryland Regulations (COMAR) 26.08.02. Maryland Department of the Environment, Baltimore, MD.

McGlynn, B.L., and J. Seibert. 2003. Distributed assessment of contributing area and riparian buffering along stream networks. *Water Resour Res.* 39(4):1082

McKergow, L.A., D.M. Weaver, I.P. Prosser, R.B. Grayson, and A.E.G. Reed. 2003. Before and after riparian management: Sediment and nutrient exports from a small agricultural catchment. *Western Australia. Journal of Hydrology* 270:253–272.

NRC (National Research Council). 2002. *Riparian Areas: Functions and Strategies for Management*. National Academy Press, Washington, DC.

NRCS (Natural Resources Conservation Service). 1997. *1997 Conservation Reserve Program practice cost and flat rate payment estimates for Virginia, March 1997*. U.S. Department of Agriculture, Natural Resources Conservation Service, Virginia State Office. Richmond, VA

NRCS (Natural Resources Conservation Service). 2004. *Riparian Assessment Using the NRCS Riparian Assessment Method*. U.S. Department of Agriculture, Natural Resources Conservation Service Bozeman, MT.

NRCS (Natural Resources Conservation Service). 2006. Maryland Conservation Practice Standard Riparian Forest Buffer, Code 391. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

NRCS (Natural Resources Conservation Service). 2008. Pennsylvania Conservation Practice Standard Riparian Forest Buffer, Code 391. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

NRCS (Natural Resources Conservation Service). 2009. Virginia Conservation Practice Standard Riparian Forest Buffer, Code 391. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

NCDENR (North Carolina Department of Environment and Natural Resources). 1999. *Sedimentation Pollution Control Act of 1973 (SPCA), as amended through 1999*. North Carolina General Statutes Chapter 113A Article 4. North Carolina Division of Land Resources, Raleigh, NC.

Netusil, N. 2006. Economic Valuation of riparian corridors and upland wildlife habitat in an urban watershed. *Journal of Contemporary Water Research & Education* 134:39–45.

O'Driscoll, M.A., and D.R. DeWalle. 2010. Seeps regulate stream nitrogen concentration in a forested Appalachian catchment. *J. Environ. Qual.* 39:420–431.

Okay, J.A. 2007. *Appropriate Riparian Forest Buffer Widths and Functions for Chesapeake Bay Program Tracking*. jokay@chesapeakebay.net. Forestry Work Group (FWG) Document 41307.

Palone, R.S., and A.H. Todd, eds. 1997. *Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers*. NA-TP-02-97. U.S. Department of Agriculture, Forest Service, Radnor, PA.

Patterson, R.W., and K.J. Boyle. 2005. *Costs & Benefits of Riparian Forest Management: A Literature Review*. Minnesota Forest Resources Council, St. Paul, MN.

Platts, W.S., C.L. Armour, G.D. Booth, M. Bryant, J.L. Bufford, P. Cuplin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.T. Monsen, R.L. Nelson, J.R. Sedell, and J.S. Tuhy. 1987. *Methods for evaluating riparian habitats with applications to management*. General Technical Report INT-221. U.S. Department of Agriculture Forest Service, Ogden, UT.

Polyakov, V., A. Fares, and M.H. Ryder. 2005. Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. *Environ Rev* 13:129–144

Qiu, Z., T. Prato, and G. Boehm. 2006. Economic valuation of riparian buffer and open space in a suburban watershed. *Journal of the American Water Resources Association (JAWRA)* 42(6):1583–1596.

Rheinhardt, R.D., M. McKenney-Easterling, M.M. Brinson, J. Masina-Rubbo, R.P. Brooks, D.F. Whigham, D. O'Brien, J.T. Hite, and B.K. Armstrong. 2009. Canopy composition and forest structure provide restoration targets for low-order riparian ecosystems. *Restoration Ecology* 17:51–59.

Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Center for Watershed Protection. Silver Spring, MD.

Schultz, R.C., P.H. Wray, J.P. Colletti, T.M. Isenhart, C.A. Rodrigues, and A. Kuehl. 1997. *Stewards of our Streams: Buffer Strip Design, Establishment, and Maintenance*. Iowa State University, Department of Forestry, Ames, IA.

Simpson, T.W., and S.E. Weammert. 2009. *Riparian Forest Buffer Practice (Agriculture) and Riparian Grass Buffer Practice: Definition and Nutrient and Sediment Reduction Efficiencies for use in Calibration of the Phase 5.0 of the Chesapeake Bay Program Watershed Model*. University of Maryland, Mid-Atlantic Water Program, College Park, MD.

Schumm, S.A. 1977. *The Fuvial System*. John Wiley and Sons, New York, NY.

Speiran, G.K., P.A. Hamilton, and M.D. Woodside. 1998, *Natural Processes for Managing Nitrate in Ground water Discharged to Chesapeake Bay and Other Surface Waters—More than Forested Buffers*. U.S. Geological Survey Fact Sheet 178-97. U.S. Geological Survey, Reston, VA.

Speiran, G.K. 2010. Effects of groundwater-flow paths on nitrate concentrations across two riparian forest corridors. *JAWRA* 46(2):246-260.

Sprague, E., D. Burke, S. Claggett, and A. Todd. 2006. *The State of Chesapeake Forests*. The Conservation Fund, Arlington, VA.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *American Geophysical Union Transactions* 38:913–920.

Sweeney, B.W. 1992. Streamside forests and the physical, chemical, and trophic characterisitics of piedmont streams in eastern North America. *Water Science and Technology* 26:2653–2673.

Sweeney, B.W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in Eastern North America. In *Proceedings of the Academy of Natural Sciences of Philadelphia* 144:291–340.

Sweeney, B.W. 2002. Streamside forests and the physical, chemical, and trophic characteristics of Piedmont Streams in Eastern North America. *Water Science and Technology* 26:2653–2673.

Sweeney, B.W., and J.G. Blaine. 2007. Resurrecting the in-stream side of riparian forests. *Journal of Contemporary Water Research and Education* 136:17–27.

Sweeney, B.W., S.J. Czapka, and L.C.A. Petrow. 2007. How planting method, weed abatement, and herbivory affect afforestation success. *South. J. Appl. For*. 31(2) 2007.

Sweeney, B.W., S.J. Czapka, and T. Yerkes. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. *Restor. Ecol*. 10(2):392–400.

Sweeney, B.W., T.L. Bott, J.K. Jackson, L.A. Kaplan, J.D. Newbold, L.J. Standley, W.C. Hesslon, and R.J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *PNAS* 101(39) 2004.

Tjaden, R.L., and G.M. Weber. 1998a. *Riparian Buffer Management: An Introduction to the Riparian Forest Buffer*. Fact Sheet 724. Maryland Cooperative Extension, University of Maryland, College Park, MD.

Todd, A. 2002. *Nutrient Load Removal Efficiencies for Riparian Buffers and Wetland Restoration*. U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry, Annapolis, MD, on behalf of the Forestry Work Group.

Tomer, M.D., D.E. James, and T.M. Isenhart. 2003. Optimizing the placement of riparian practices in watershed using terrain analysis. *J Soil Water Conserv* 58:198–206

USDI (U.S. Department of the Interior). 1998. *Riparian Area Management: Process for Assessing Proper Functioning Condition*. Technical Reference 1737-9. U.S. Department of the Interior, Bureau of Land Management Service Center, Denver, CO.

USEPA (U.S. Environmental Protection Agency). 1996. *Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices*. EPA-843-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005. *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution*. EPA 841-B-05-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2006. *Wadeable streams assessment: A collaborative survey of the nation's streams*. EPA 841-B-06-002. U.S. Environmental Protection Agency, Washington, DC.

Vidon, P., C. Allan, D. Burns, T. P. Duval, N. Gurwick, S. Inamdar, R.d Lowrance, J. Okay, D. Scott, and S. Sebestyen. 2010. Hot spots and hot moments in riparian zones: Potential for improved water quality management. *JAWRA* 46(2):278–298.

VDEQ (Virginia Department of Environmental Quality). 2009. *9 VAC 25-260 Virginia Water Quality Standards with Amendments Effective August 20, 2009*. Statutory Authority § 62.1-44.15 3a of the Code of Virginia. Virginia State Water Control Board.

VDCR (Virginia Department of Conservation and Recreation). 2010. *A Virginia Priority…A Local Option*. <http://dcr.virginia.gov/soil_and_water/ordinanc.shtml>. Accessed February 2010.

Vought, L.B., M.J. Dahl, C.L. Pedersen, and J.O. Lacoursiere. 1994. Nutrient retention in riparian ecotones. *Ambio* 23(6):343–348.

Welsch, D. 1991. *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources*. NA-PR-07-91. U.S. Department of Agriculture Forest Service, Radnor, PA.

Williams, M. 1989. *Americans and their Forest: A Historical Geography*. Cambridge University Press, Cambridge, U.K.

Wondzell, S.M., and F.J. Swanson. 1996. Seasonal and storm dynamics of the hyporheic zone of a 4th-order mountain stream. I: Hydrologic processes. *J North Am Benthol Soc* 15:3–19.