Riparian Buffers

COMMON SENSE PROTECTION OF NORTH CAROLINA'S WATER

Produced by
ENVIRONMENTAL DEFENSE
in collaboration with
Cape Fear River Watch • Carteret County Crossroads • Catawba Riverkeeper Foundation
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Neuse River Foundation • North Carolina Coastal Federation • North Carolina Conservation Network
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Cover photos: Left, NC Wildlife Resources Commission. Right, Michael Parker.

This report was made possible with the generous support of the Beattie Foundation, the Mary Flagler Cary Trust, Education Foundation of America, the Hillsdale Fund, and the Z. Smith Reynolds Foundation. We also gratefully acknowledge the assistance of Dr. Douglas Wakeman, Dr. John Whitehead, Dr. Michelle Duval, Grady McCallie, Scott Jackson and Elaine Chiosso for their insightful review. Thanks also to Marilynn Robinson, Allison Cobb, and Bonnie Greenfield for their help through design and publication.

Our mission
Environmental Defense is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

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We all live downstream

In the early 1990s, Jim Protzman and his wife Jane purchased a lakefront home where they could raise their family. On lazy summer days, their little girl Lily and her friends played and swam in the inviting water of Eastwood Lake. Jim and Jane loved to paddle their canoe along the shoreline at sunset, watching the ducks and kingfishers. Several folks in the neighborhood fished and hosted cookouts with their catch. Little did the Protzmans and their neighbors suspect that they faced a rude awakening.

Fed by Cedar Fork and Booker creeks, Eastwood Lake was built in the 30s. A tight knit community of about 250 families flourished around this recreational center during the 1960s and 70s. About five years ago, though, the lake began to die. The water became thick and muddy; algae rotted along the shore; and you could hardly paddle a canoe without getting mired in muck. It seemed sudden, as if in the middle of the night malicious vandals had backed a truck up to the shoreline and dumped in a 10-ton mountain of dirt. In truth, the changes were gradual, and the culprits were working their mischief upstream, slowly killing the lake from a distance.

Careless development sent topsoil into the streams that fed the lake. The Estates apartment complex and a big strip mall played a large part, but individual homeowners clearing trees and fertilizing lawns were also responsible. Widening Airport Road did not help; the town scraped away a hillside for a community park; and even a local church decided its congregation should not have to tolerate all those trees between them and the creek. The ducks still come back to Eastwood Lake in the fall, but where they once thrived and nested, they now seem bewildered by the patchy puddles and mounds of silt.

The Protzman's situation is not unique: We all live downstream. Our property and our rights are diminished when upstream neighbors overload streams and creeks.

"The lake got so bad," Jim said, "that we had to raise $1.2 million to clean their mess off of our property. That's just not right. Common sense and fairness tell you that if some neighbor trashes your property, he should have to clean it up. But these people let their dirt wash down on us and left us to pay the bill." Like the other landowners along the lake, Jim and Jane paid $15,000 to help cover the cost of the cleanup. "And we were the lucky ones," Jim added. "Some of our neighbors simply couldn't afford to help. One couple decided to move away. One retired lady a few houses down from us had to take out a home equity loan to contribute her share. I don't know how she's going to pay it off."

From the start, the Protzmans were realistic about their investment. "Those of us who invested near the lake knew our property values were at risk," said Jim. "Like anybody else, we wanted to protect our property, but we found no help from the law. There ought to be laws to prohibit people from unloading their refuse into a neighbor's front yard." Unfortunately for the Protzmans, and the rest of us, legal remedies are few and far between.

The Protzman's situation is not unique: We all live downstream. Our property and our rights are diminished when upstream neighbors overload streams and creeks. Sometimes it is a lake full of silt; sometimes it is an estuary full of dead fish and algae; sometimes it is erosion eating away pasture or cropland; and sometimes it is more frequent and severe flooding. When upstream landowners do not practice responsible streamside stewardship, those who live downstream suffer the consequences.

Summary of key points

North Carolina's streams, rivers, estuaries and lakes are its most threatened natural communities. The pollution comes not only from factories and sewage treatment plants, but also from virtually every land-disturbing activity in the state, including agriculture, development and even individual homeowners fertilizing lawns. As farms and forests are put to more intensive use, the land loses its ability to absorb and filter runoff. This diffuse runoff, called nonpoint source pollution, is the number one cause of water quality problems in the state. Because nonpoint pollution is the result of innumerable small disturbances, it cannot be controlled by traditional strategies. North Carolina's growing population and urbanizing landscape will only worsen the problem.

Buffers of trees, shrubs and grass along waterways are the ideal way to slow runoff and filter out contaminants. Streamside buffers are essential to protect water quality, and they contribute numerous other ecological benefits. Buffers provide habitat for a variety of plants, animals and natural communities both in the water and on the land, and they reduce downstream flooding, stream bank collapse and erosion.

Conserving streamside buffers is socially valuable, economically viable and ecologically necessary. It costs more and takes longer to restore water quality than to protect it in the first place. Modest rules to protect narrow buffers can be fair to landowners, while preserving clean water for the entire state. Buffer rules are already contributing to better stewardship of shoreline lands in three North Carolina watersheds, and would be effective in all 17 of the state's watersheds.

A modest rule for streamside buffers would require:

- **A 50-foot setback for impervious development adjacent to all perennial and intermittent streams, estuaries and lakes;**
- **Maintenance of existing forested buffers;**
- **Limitation on logging adjacent to surface waters;**
- **Maintenance or re-establishment of functional buffers when agricultural or forestland is converted to more intensive uses;**
- **Exemption for all current activities at existing scale;**
- **Complementary strategies to address other components of the nonpoint source pollution problem.**

Introduction

As more and more farm and forest land in North Carolina is paved over for roads, homes, businesses and parking lots, the land loses its capacity to store and filter rainfall. Creeks are transformed into channels cut by rainwater as it races off paved and built upon surfaces. The increased flow of storm water scours out ever-widening channels, eroding stream banks and flooding adjacent land. This runoff is a form of diffuse, or "nonpoint," pollution. It carries a variety of contaminants that can render the water unfit for fish and humans.

For North Carolina to grow and prosper, the state must preserve the natural systems on which citizens depend. There are few things more fundamental to public welfare than clean water. Yet water quality continues to be damaged by human activities. The cause of this degradation is often not the obvious discharge from a pipe or culvert, but is instead, more widespread, diffuse runoff called nonpoint source pollution. Nonpoint pollution is the major threat to North Carolina's clean water (see appendix). It degrades water quality not with a single stroke but through the cumulative effects of countless minor insults from all sorts of land-disturbing activities. Controlling this pollution requires broad, watershed-wide strategies.

Nonpoint pollution is the major threat to North Carolina's clean water. It degrades water quality not with a single stroke but through the cumulative effects of countless minor insults from all sorts of land-disturbing activities.

The first objective should be to limit pollution at the source, either by reducing use of fertilizers and pesticides or by engineering land to control runoff. Obligating landowners to use engineered solutions to stop all runoff might be onerous and cost prohibitive. Managing the runoff from varied human activities requires a combination of lowering pollution at the source and lessening the amount of pollution that reaches important waterways.

Fortunately, there is a simple, cost-effective means to reduce runoff: streamside or riparian buffers. Natural vegetation on lands immediately adjacent to waterways can protect water quality and prevent stream bank erosion. These narrow bands of trees and grass slow runoff, filtering out pollution and reducing downstream flooding from intense storms.

This report makes the case that conservation and careful stewardship of riparian lands is socially valuable, economically viable and ecologically necessary. We make concrete recommendations for statewide protection of riparian buffers that accommodates reasonable use and enjoyment of private property while achieving socially important ecological objectives. While the specific objectives achieved by buffers differ among watersheds, every creek, stream, lake and estuary in the state—and for that matter every citizen who swims, fishes or draws drinking water from our surface waters—will benefit from modest protection against nonpoint source pollution. As experiences in the Tar-Pamlico and Neuse River basins have shown, *riparian buffers are not the sole answer; but they are an essential part of any effective strategy to control nonpoint pollution, and a strategy that is doable, affordable, and can be implemented today.*

The common sense of streamside stewardship

It has become increasingly obvious during the last 50 years that human activity can irreparably harm the environment. North Carolina is beginning to manage its complex natural systems to ensure they continue to provide the goods and services on which people depend. However, the state's growing population continues to dramatically alter the landscape and undermine natural systems. North Carolina is reeling from three decades of unprecedented growth, with no sign of moderation. Between 1970 and 2000, the state's population grew by nearly 60%, from approximately 5 million to more than 8 million. That figure is projected to reach 10.9 million by 2020. This growth and the urbanization of landscapes will only worsen nonpoint source pollution. North Carolinians should preserve remaining clean waterways and restore creeks and wetlands that have already been degraded.

Everyone lives in a watershed. Human activity on any piece of land can affect the nearest streams and creeks. However, the lands that are most critical to water quality are those in immediate proximity to the water, known as "riparian" lands. Because all animals need access to water, these lands are especially important habitat for wildlife. It is, therefore, appropriate and necessary that special precautions be taken in the stewardship of riparian lands. Managed properly, riparian lands provide critical ecological benefits, protecting water quality and wildlife habitat, and preventing stream bank erosion and downstream flooding. If trees and shrubs on riparian lands are cut down, or if the land is paved over, dug up or otherwise degraded, those benefits are sacrificed. Naturally vegetated riparian land acts as a buffer, easing the incorporation of human activity into the natural system.

Between 1970 and 2000, North Carolina's population grew by nearly 60%, from approximately 5 million to more than 8 million. That figure is projected to reach 10.9 million by 2020.

The more distant lands are from surface waters, the less critical they are to protecting water quality. Hence, while protecting land right next to the water is extremely cost effective, the benefits become less significant as one moves farther landward. The optimal width of a buffer that separates land-disturbing activities from the water requires balancing competing private and public interests.

In order to be effective, buffers have to be protected relatively consistently throughout a watershed. The vast majority of streamside land in North Carolina is private property; it is simply not possible for the state to purchase enough land to protect the many thousands of miles of waterways. Therefore, the state must develop a baseline regulatory program that respects the interests of private property while serving the needs of the larger society for good water quality.

Protecting water quality with careful management of streamside lands is a common sense measure used for years by landowners. Georgia, Oregon, Massachusetts and Wisconsin have adopted comprehensive statewide buffer regulations. Several counties and municipalities in North Carolina and across the United States have established local buffer protection ordinances. The North Carolina Progress Board, a diverse group of business and community leaders planning the state's future, has recommended protecting riparian buffers in all of North Carolina's 17 watersheds. The North Carolina Wildlife Resources Commission's fundamental guidance on mitigation of cumulative impacts recommends that local governments protect riparian buffers of 50 and 100 feet on all intermittent and perennial streams, respectively, and even wider buffers in environmentally sensitive watersheds.

Existing rules for riparian buffers in North Carolina

In the late 1980s and early 1990s the state appropriately focused attention on the severe water quality problems caused by excessive nutrient pollution in coastal estuaries. The state had done a great deal to reduce pollution from industry and wastewater treatment plants, but that success was being overwhelmed by pollution from nonpoint sources. To reduce this pollution, the state developed limited buffer rules for the Neuse and the Tar-Pamlico River basins. Those carefully crafted coastal buffer protection rules are a model for this statewide proposal. They do not restrict existing uses of property, but do require that existing forested buffers be maintained. Active farm, pasture, forest and developed uses of land are "grandfathered," and free to continue without restriction. The rules stipulate that only when agricultural or forested land is converted to more intensive uses, a vegetated riparian buffer must be re-established.

While the rules limit further degradation, they do little to reduce existing pollution. For example, the buffer rules do not limit ongoing agricultural operations in the riparian zone. Therefore, because farms contribute to nutrient pollution, the state developed a complementary incentive program to direct more than $200 million in federal assistance to pay farmers in designated nutrient sensitive watersheds to convert riparian crop or pasture land into functional buffers. These voluntary measures, for which the landowners are paid, enhance the effectiveness of the baseline rules moderating development. If the rules and these complementary programs are effectively applied, streams, rivers and estuaries of these two watersheds will no longer be choked by excessive nonpoint nutrient pollution.

When similar buffer rules were proposed to deal with erosion and sedimentation in the Catawba River basin, the buffer issue was made more murky than the water itself. Misinformation and acrimony frightened some landowners into thinking the rules would, in effect, steal their land. They feared buffers would be open to public access and used for public purposes. None of this is true. The truth is none of the buffer rules applied in the state or proposed here allow public access on private property. The rules merely protect public resources and private property downstream.

Some landowners were also concerned that buffer rules would require them to change the way they use their land; this concern was particularly frustrating for conservation-minded landowners who had cared for and protected their property. However, existing and proposed buffer rules in North Carolina do not restrict current land uses. Active agriculture, businesses, roadways and industry can all continue under the proposed rules. The modest rules being considered are specifically designed only to (1) maintain existing buffers, and (2) minimize new paved or built-on surfaces near the water. The proposed rules do not deprive the land of its economic value, but rather preserve the economic value of downstream lands and the health of our commonly held waters.

In the Catawaba watershed, the landscape and the pollutant of concern differ markedly from the Neuse and Tar-Pamlico. The dynamics, hydrology and topography of the piedmont and mountain areas of the Catawba are simply not the same as the wide, flat rivers to the east. Where the coastal estuarine systems were plagued by nutrient pollution, the Catawba's main problem—and that of virtually every other river basin in the state—is excessive erosion and sedimentation. Despite these variations, the modest buffer rule offered here would be effective in all the state's watersheds. The nature of the nonpoint source pollution problem and the promise for its resolution justify the application of a single, minimum riparian rule in all 17 of the state's watersheds. Topographical differences, pollution problem differences and other regional concerns are addressed in the details of the proposal and discussed in several places throughout this report. The minimum buffer proposed as a statewide rule in this report offers a baseline for environmental protection. Limits on the percent of impervious surface in the watershed, better management of sediment and erosion control on disturbed lands, control of stormwater runoff from developed areas, and, in many cases, wider buffers, will be necessary to fully achieve water quality and wildlife habitat protection objectives. The Wildlife Resources Commission has recommended an excellent set of guidelines for adoption by local municipalities to achieve stronger protection of North Carolina's surface waters (see "Highlights from the NC Wildlife Resources Commission's Guidance Memorandum to Address Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Resources and Water Quality," below).

Highlights from the NC Wildlife Resources Commission's Guidance Memorandum to Address Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Resources and Water Quality (2002)

http://216.27.49.98/pg07_WildlifeSpeciesCon/pg7c3_impacts.pdf

GENERAL MITIGATION MEASURES FOR ALL WATERSHEDS

1) 100-foot forested buffer on perennial streams and 50-foot forested buffer on intermittent streams and wetlands.
2) 30% of development area as greenspace.
3) Prohibit development within the 100-year floodplain.
4) Limit impervious surfaces to less than 10% of the watershed. Maintain predevelopment hydrographic condition.
5) Use bridges instead of fill and culvert, where practicable. If needed, design culverts to allow passage of aquatic organisms.
8) Implement strong erosion and sediment control plans.

SPECIFIC MITIGATION MEASURES FOR WATERS CONTAINING FEDERALLY LISTED SPECIES

1) Stormwater permits for new developments exceeding 6% imperviousness.
2) 200-foot forested buffer on perennial streams and 100-foot forested buffer on intermittent streams, or the full extent of the 100-year floodplain, for all new developments.
3) Establish emergency management procedures which will contain runoff from fire fighting or hazardous spills that may endanger nearby streams

Ecological and public benefits provided by riparian buffers

Careful stewardship of riparian land cost-effectively achieves numerous ecological benefits: protecting water quality and aquatic habitats, providing terrestrial habitat, mitigation of floods and droughts, detoxifying and decomposing wastes, cycling and moving of nutrients, generating and preserving soils, and maintaining biodiversity. Protected riparian lands also provide for valuable aesthetic, educational and recreational opportunities.

Water quality

Sediment is the number one pollutant of North Carolina's rivers, streams and lakes. Detrimental effects result both from suspended sediment in the water column and sediment deposited in streambeds. Suspended sediments reduce light transmittal and can lead to decreased dissolved oxygen. Both suspended and deposited sediment degrades habitat for fish and the invertebrates upon which the fish feed. It can even kill fish and other aquatic organisms. Excessive sedimentation reduces the capacity of reservoirs and must be filtered from municipal water supplies to protect human health and industrial processes, often at considerable cost.

Sediment is the number one pollutant of North Carolina's rivers, streams and lakes. Both suspended and deposited sediment degrades habitat for fish and the invertebrates upon which the fish feed. It can even kill fish and other aquatic organisms.

Nitrogen and phosphorous nutrient pollution from hog waste, fertilizer and other sources is of greatest concern in coastal watersheds and lakes. Excessive nutrient loads imbalance natural aquatic systems and can lead to algae blooms, conditions with little or no oxygen dissolved in the water, and fish kills. In addition to sediment and nutrient pollution, runoff can contain heavy metals and pesticides. These toxic pollutants can concentrate in bottom sediments and undermine aquatic systems.

Riparian land, naturally vegetated with grass, trees and shrubs, filters pollutants that would otherwise wash into the river. The effectiveness of buffers in reducing nonpoint source pollutants varies according to the contaminant and the width, topography and vegetation of the buffer itself. Nonetheless, the effectiveness of even modest riparian buffers is unquestionable; research indicates that appropriately vegetated buffers of 50 -100 feet will sequester and treat most nonpoint contaminants.

Stream bank stabilization

Research provides strong evidence that stream banks with insufficient riparian vegetation are significantly more likely to collapse and erode. Not only does such collapse smother the stream with sediment, but it also alters the dynamic of the stream course, making the stream wider, shallower and straighter. Stream bank erosion and collapse is often the primary source of sediment pollution in a watershed and hastens the decline of the riparian land and the stream itself. More paved surfaces upstream worsen the effect by causing peak water flows to increase after storms.

While it is possible to restore natural, deep-rooted vegetation to previously eroded stream banks, it is difficult and expensive. Returning functionality to a restored riparian buffer also takes time. Trees take time to grow and soils compacted during deforestation take years to restore their naturally high infiltration rates. Artificial stabilization (like bulkheading or riprap) is even less desirable because it, too, is costly, can increase downstream erosion, and does not afford the habitat benefits of naturally vegetated riparian areas. Despite the costs, restoration is often the only way to halt stream bank erosion once it has begun; but the obvious, best solution is to maintain natural, functional riparian areas in the first place. This is truly a case where an ounce of prevention is worth a pound of cure.

Water storage and flood control

An important characteristic of every stream system and watershed is its natural flood regime, the cyclic rise and fall of water levels, which shapes the dynamics and ecology of the stream and adjacent riparian areas. Riparian areas with deep-rooted vegetation protect the structure of the stream and reduce the energy and extent of downstream flooding by slowing and absorbing storm water as it runs to the stream channels. However, human activities that alter the watershed, by removing vegetation, decreasing soil storage capacity or adding impervious surfaces, exacerbate the frequency, duration and extent of flooding. Intact vegetated riparian buffers lessen the effects of upland development and diminish the downstream effects of flooding. Conversely, unvegetated riparian areas can become conduits for stormwater and worsen the effects of flooding. To truly minimize the adverse consequences of flood waters, the entire floodplain and all adjacent wetlands should be maintained in natural vegetation.

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Aquatic and terrestrial habitat

Careful stewardship of streamside lands preserves habitat for numerous species. Water quality is itself a critical component of habitat, especially for aquatic species. Because aquatic ecosystems are the most threatened of North Carolina's natural communities, riparian stewardship is crucial to maintaining our state's biodiversity. One quarter of our native species of fish, mussels and crayfish are threatened with extinction. Many of these imperiled species, such as freshwater mollusks and commercially important trout and shellfish, are extremely susceptible to nonpoint source pollution. In addition to filtering out pollution, well-managed riparian land can maintain healthy in-stream temperatures and provide organic matter critical to aquatic ecosystems.

Retaining native vegetation in riparian areas is critical to stream dynamics and vitality. Riparian forests drop large, woody debris into streams and rivers, providing habitat for fish, mussels and larger invertebrates. Organic matter, like leaf litter and terrestrial invertebrates, adds food and energy to streams. This organic matter forms the base of the food web. Naturally vegetated riparian areas also are essential to many aquatic invertebrates that live a portion of their life and reproduce on land. Even small changes in water temperature or light can disrupt a stream's natural balance. Riparian forests provide shade, keeping the temperature cool enough for fish like trout and limiting excessive light, which can stimulate unhealthy levels of algae growth. Research indicates that forested riparian buffers of at least 30 feet, and perhaps as great as 100 feet, are necessary to ensure adequate sources of woody debris and organic matter for a healthy aquatic system, and to maintain stream temperatures.

Riparian areas are important terrestrial habitats in themselves. Research has documented that the micro-habitat variations of riparian zones support a significant level of biodiversity, including birds, mammals, reptiles and amphibians. Most habitat research on riparian areas has focused on animals, but some studies have documented the important role of riparian corridors for plant diversity and dispersal. Native plant communities support healthy populations of native animals and help maintain stream hydrology. Very wide buffers of 300 feet or more are needed to protect diverse terrestrial communities; but even buffers of 50 feet, which contribute substantially to water quality and aquatic habitat goals, can offer good habitat to terrestrial species. Narrow riparian buffers also can act as wildlife corridors, connecting larger tracts of upland forests.

Landscape and global scale benefits

Riparian areas are key components of the natural systems that stabilize the climate, detoxify wastes, generate fertile soils, maintain biodiversity and provide respite from human-dominated environments. Riparian corridors not overly dominated by human activity are naturally dynamic. Protecting riparian areas allows ecological systems to be more resilient to natural and human-induced changes.

Economic implications of streamside stewardship

The legal and economic implications of buffer rules are intertwined. Over the years the courts have clarified the rights and responsibilities of property ownership; owning private property does not include the right to pollute adjacent properties or streams. It is not incumbent on the downstream landowner or the citizenry to pay the landowners not to pollute; rather the responsibility resides with the landowner to assure that his or her behaviors do not degrade adjacent waterways. The principle that the person causing pollution should pay the costs associated with pollution prevention (i.e. polluter pays) is one of the most durable, and important doctrines in U.S. common law. Modern environmental state law, as reflected in the Clean Air Act, Clean Water Act, etc., is built upon this premise that the person generating pollution is responsible for control and remediation of that pollution.

The vitality of North Carolina's natural systems is one of the reasons that so many people want to live or visit here. Tourism is the state's number one industry and revenue producer. With 43 million visitors last year, North Carolina ranks sixth among the nation's most visited states. Tourist revenues for 2001 were estimated at $11.9 billion dollars. The tourist industry employs approximately 196,000 people, with an annual payroll of $4 billion. Clean rivers and other benefits provided by riparian buffers on our state's waterways are important fuel for this economic engine.

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While it is true that in some cases restricting the use of land sometimes reduces flexibility for landowners to extract profit from it, in many cases preserving riparian buffers can actually increase the value of the land and adjacent properties. For landowners, riparian buffers provide aesthetic and wildlife habitat values, stabilize stream banks, and protect the property value from being diminished by upstream pollution. Buffers provide significant economic benefits to downstream neighbors and the public through reduced flood damage, lower costs for water treatment and enhanced recreational values.

Converting active farmland into a buffer may involve both fixed costs (e.g. mortgage, interest) and opportunity costs (e.g. rent or crop values). The state's current rules and our recommendations would only protect existing buffers, and do not require that farming, or any other on-going activity be halted. However, federal and state-funded agricultural programs like the Conservation Reserve Program (CRP) can be an ideal complement to the proposed buffer rules. Such incentive-based programs encourage landowners to do more than the rules would require, and finance the conversion of active farmland into functional riparian buffers. Research on citizen "willingness to pay" indicates that the public will support such subsidies to farm and forest landowners to gain environmental benefits. Thus, farmers and private landowners can reap similar financial return from conservation as from development of their property.

The proposal presented in this report also recommends a fair tax policy for all riparian lands maintained as functional buffers. A tax rate appropriate to the diminished property value should be developed. These tax advantages should automatically apply to the regulated buffers, and they could be extended up to 300 feet for voluntary protections of wider buffers.

Buffer protections do not deprive the land of its economic value, but rather preserve the economic value of downstream land, water quality and wildlife habitat.

Active agriculture and previously developed land are exempted, or grandfathered, from the rules. The activity is grandfathered, not the landowner. A landowner can pass the land to heirs or sell the property with no decrease in the current level of activity. Only when land is to be converted to residential or commercial development is re-establishment of the functional riparian landscape required. Thus, buffer protections do not deprive the land of its economic value, but rather preserve the economic value of downstream land, water quality and wildlife habitat.

The modest riparian buffer protection rules proposed in this report should be applied statewide on all intermittent and perennial streams, lakes and estuaries. To apply the rules in only some watersheds would create a perverse incentive for excessive development in unprotected areas. If the rules are applied statewide, then all landowners will recoup balanced economic return if they decide to convert their property to residential or commercial development. Downstream landowners will not suffer the diminished property values that would result if their streams were choked with runoff from development upstream.

Riparian buffer protection is fair, responsible and legal

The modest buffer rules herein proposed do not encourage public access to private land, nor do they eliminate all economic use of the property; therefore, they do not constitute a taking. Like ordinary setbacks from roads or property lines that local governments require of new development, the proposed rules protect the safety, rights and well-being of everyone in the community. Because the rules restrict a landowner from conducting activities that have adverse off-site impacts, they protect the property of those living downstream.

Not only is there overwhelming evidence of the importance and economic viability of riparian buffers, there is also a firm legal basis to restrict inappropriate use of riparian land. Some may argue that such rules are an infringement on property rights, but for a host of reasons their position is untenable. The rights of the public to a clean and healthy environment and to unpolluted waters are explicitly acknowledged by the North Carolina Constitution and a lengthy list of state environmental laws and regulations. North Carolina is committed to protecting surface waters and the environment, and the state has the clear right to restrict the use of private property to attain this objective.

Not only is there overwhelming evidence of the importance and economic viability of riparian buffers, there is also a firm legal basis to restrict inappropriate use of riparian land.

Even so, in the pursuit of protecting public interests, the state should respect the interests of private property owners. The modest buffer protection rules currently applied in parts of North Carolina and proposed here for extension statewide, do not even suggest allowing public access and only partially restrict uses on a portion of property. Crop production, pasture and existing development are not affected. Actively managed forestlands are subject to only modest restrictions. In fact, the proposed buffer rules only affect existing economic uses when land is to be converted from agricultural or forest use to impervious development. Under the proposed rules, landowners would continue to enjoy considerable latitude in the use of their property, and in many cases, property values may increase.

The state has not only the right but also the obligation to protect the public welfare, and there are few things more fundamental to public welfare than clean water.

A modest proposal for riparian buffer protection

- A 50-foot setback for impervious development adjacent to all perennial and intermittent streams, lakes and estuaries
- Maintenance of existing forested buffers
- Limitation on timber harvest adjacent to surface waters
- Maintenance or re-establishment of functional buffers when agricultural or forestland is converted to more intensive uses
- Complementary strategies to address other components of the nonpoint pollution problem
- Supported by credible science

A 50-foot wide forested riparian buffer, measured horizontally from the top of the stream bank, will provide considerable protection for water quality, wildlife habitat and downstream property. Such buffers are essential to maintaining ecological communities. Even these relatively narrow strips of land are sufficient to (1) filter most sediment from overland flow provided it is not concentrated in channels; (2) slow down and allow storm water runoff to percolate into the ground, reducing downstream flooding and erosion; (3) provide shade to maintain in-stream temperatures; (4) ensure stream bank stability; (5) supply organic matter for aquatic food chains; and (6) provide important aquatic and terrestrial habitat.

The recommended forested buffer system includes two components: Zone A, the 30 feet immediately adjacent to the water and Zone B, the next 20 feet landward. Zone A should be naturally forested, although selective harvest and maintaining view corridors could be allowed even in this zone. The main purpose in Zone A is to assure that the soil is undisturbed and the forest floor and vegetation remain intact. The only restrictions in Zone B would be to prohibit impervious surfaces and prevent channelized flow.

The proposed riparian buffer protection rules call for minimum buffer widths that are essential to protect the most critical streamside lands. In environmentally sensitive watersheds wider buffers should be protected either by regulation or through complementary incentive programs. The narrow buffer widths proposed in this report will not trap all nonpoint contaminants, or prevent all flooding, or will they fulfill all the habitat needs to protect the state's diverse wildlife. The rules will, however, guard against increases in most nonpoint source pollution, reduce flooding and contribute to the most universal of habitat needs.

Regional differences between the mountains, piedmont, coastal plain and tidewater have implications for buffer rules. In mountain watersheds, the topography often forces land-disturbing activities closer to streams. In fact, building roads and structures on steeper grades can cause worse erosion than building on more level land closer to streams. Many of these regional differences can be addressed by denoting a matrix of allowed activities and conditions under which those activities may occur. Measuring the buffer horizontally should partially account for variations in slope. In all circumstances, incursions into the buffer must be avoided if there is a practical alternative, minimized when unavoidable and, in some cases, mitigated (ideally, on-site).

Buffers of different widths or vegetation vary in the degree to which they filter different pollutants. Deep-rooted forest vegetation intercepts subsurface flow that may be high in nitrogen and stabilizes stream banks, whereas grassed buffers filter sediments and phosphorus in surface runoff. Nonetheless, a modest buffer system, such as proposed here, will trap and filter most constituents of nonpoint source pollution. Regardless of whether the target pollutant is sediment or nutrients, buffers of the proposed width and vegetation should be an essential element of watershed management.

This proposal does not target only impaired waters; it is equally important to protect streams that are not yet degraded. The purpose of the rules is to hold the line against further degradation, not to resolve existing problems. The proposal also does not apply only to high quality waters; nonpoint source pollution can render any stream unsuitable for swimming, fishing or other important uses. The proposed buffers will be of value in every one of the state's 17 watersheds.

This recommended forested buffer system is supported by available research as an appropriate minimum width to achieve reasonable water quality protection (see appendix). It is in line with the recommendations of the NC Environmental Management Commission's Mountain Stream Buffer Technical Advisory Committee (see appendix). Lastly, the proposed statewide buffer protection rules would be very similar to existing buffer protection rules in the Neuse and Tar-Pamlico Basins. A uniform buffer protection rule across the state will facilitate compliance.

The first purpose of the proposed rules is to maintain existing forested buffers

Existing forested buffers of 50 feet should be protected on all perennial and intermittent streams and the shorelines of lakes and estuaries.

Ephemeral watercourses (streams that flow only for short periods following precipitation) can be major sources of sedimentation during storms. However, applying buffer rules to all ephemerals in the state could pose unreasonable and difficult-to-enforce restrictions on landowners. Therefore, this proposal for a statewide rule does not extend to ephemeral streams. However, we do recommend that certified sediment and erosion control plans during development activity, and stormwater runoff controls after development, ensure that ephemeral channels are not overwhelmed.

For ongoing forestry operations, some limited harvest in accordance with best management practices for water quality (and associated guidelines for streamside management zones) would be allowed in the buffer. A minimum of 10 feet immediately adjacent to the water should remain undisturbed except for the removal of dead or dying trees and trees that threaten property. Forest vegetation should be maintained in the remaining landward 20 feet of Zone A, but selective harvest would be permissible. The selective harvest in Zone A should minimize land disturbance. Burning and pesticide and fertilizer use would be restricted. Agricultural land that currently has forested riparian buffers would be subject to these same rules for selective harvest and could be subsequently reforested or used for other agricultural pursuits. These rules do not restrict timber harvest from Zone B.

The second purpose of the proposed rules is to minimize new paved or built-on surfaces near the water

The proposal requires re-establishing or maintaining buffers only when agricultural or forested land is to be converted to more intensive, land-disturbing uses. In those cases, the buffer rule acts as a setback, and new development of impervious surfaces should be excluded from the 50-foot buffer. Many activities, including maintenance of existing structures and installing wells, fences, decks or view corridors, would be exempt from the rules. Other new development in the buffer could be permitted if there were no practical alternative and it were mitigated by on-site water quality enhancement efforts. Of course, special cases would require flexibility, and variances could be granted where appropriate.

Beyond buffers: complementary strategies for protecting water quality

Buffers should be complemented by enhanced efforts to stop pollutants at their source through the use of other storm water and sediment and erosion controls.

The buffer protection rules proposed here are a critically important stop-gap measure to reduce the worsening problems of non-point source pollution. They do not completely address existing or future water quality problems, but they provide the all-important base for a statewide rule. Environmental Defense joins the Wildlife Resources Commission in urging local governments to develop more comprehensive rules and wider buffers, especially in environmentally sensitive areas, to establish limits on the total impervious surface allowed in a given watershed, and to require effective stormwater and sediment pollution controls (see "Highlights from the NC Wildlife Resources Commission's Guidance Memorandum to Address Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Resources and Water Quality," page 6). One of the most severe sources of sediment pollution is runoff from residential and commercial development. The modest riparian buffer rules already applied in North Carolina and here proposed are designed to address this problem by helping control the increase in sediment pollution from an urbanizing landscape. Though farming and other activities also contribute, the proposed rules do not address existing agricultural operations. Therefore, the buffer rules need to be complemented by efforts specifically targeted at existing sources of urban and agricultural runoff.

The effectiveness of riparian buffers has been documented by exhaustive research (see appendix). But narrow buffers on developing properties are not a stand-alone strategy. Buffers should be complemented by enhanced efforts to stop pollutants at their source through the use of other storm water and sediment and erosion controls. Incentive programs should complement and extend regulatory efforts. For example, incentives could finance agreements with farmers or others to voluntarily limit their activities immediately adjacent to the water, or to protect or restore larger buffers.

Conclusion

The most pervasive water quality problems in the state's rivers basins are caused by nonpoint source runoff from virtually every human activity in the watershed. The only cost-effective and proven way to keep such pollution out of our streams is to moderate human activity and limit paved and built-on surfaces in riparian areas.

The current buffer rules for three watersheds in North Carolina are the products of exhaustive public processes that have incorporated the interests of private landowners, businesses and other stakeholders. Conservation-minded North Carolinians support these rules as a reasonable and equitable means to protect public resources and private property downstream. Similar modest protections, such as those proposed in this report, should be extended to every water basin in the state. The state's health and economic vitality depend on it.

APPENDIX

Riparian buffers in North Carolina: variables affecting function and performance

Although riparian areas occupy a small portion of a watershed, they are hot spots of diversity and biological productivity when compared to the upland landscape (NRC 2002; Naiman et al. 1993). Riparian buffers along streams provide a wide array of environmental services ranging across hydrologic, geomorphic and biological processes (Table 1). The NC Environmental Management Commission's Mountain Stream Buffer Technical Advisory Committee stated that buffers in the mountainous portions of North Carolina are essential tools for maintaining current high water quality and should be directed at protecting water temperature, controlling sediment pollution and supplying organic debris to support aquatic life (Mountain Stream Buffer Technical Advisory Committee 2000). Most forested riparian buffers, regardless of their targeted application, provide all the above environmental services as well as storm water storage, reduction of flooding, and maintenance of both aquatic and terrestrial biodiversity (NRC 2002).

The importance of riparian buffers to ecosystem function is emphasized by the National Research Council (NRC) report (2002), which recommends that

- Restoration of riparian functions along America's waterbodies should be a national goal.
- The importance of protecting riparian areas for water quality and fish and wildlife benefits calls for state-level land-use regulations that treat all riparian landowners equally.
- Protection should be the goal for riparian areas in top ecological condition, while restoration is needed for degraded riparian areas.

The recommendations of the NRC Riparian Buffer Committee for protecting riparian areas are generally shared by Wenger (1999) and the University of South Carolina's Center for Environmental Policy (2000) in their excellent reviews of the scientific literature on riparian buffers. Gilliam (1994) notes that riparian areas along ephemeral and intermittent streams are the most important for preserving water quality. The NRC (2002) report estimates that, on average, ephemeral and first- and second-order streams combined comprise approximately 90% of total stream length in a watershed and, if proportional to hydraulic inflow, of total pollution loading. Both the NC Department of Environment and Natural Resources (NC DENR 2000) and the NC Progress Board[1] have recognized the crucial role of riparian buffer protection in water quality management. In its most recent publication, *NC 20/20 Report* (2001), the Board set the interim goal of protection of riparian buffers in all of North Carolina's 17 river basins by 2010 as necessary to achieving the ultimate goal of a sustainable environment.

[1] The NC Progress Board is an independent state board, appointed by the Governor, the General Assembly and the Board itself, to represent a cross section of the state.

Buffer characteristics

The width and vegetative makeup of buffers have been the subject of much research. The optimal buffer for many situations is a combination of grass and forest vegetation that interacts with both surface and subsurface flow (Wenger 1999). To take advantage of the benefits of both grassed and forested buffers, Welsch (1991) designed the three-zone riparian-forest buffer system for permanent or intermittent streams. The combination of a forested and a grassed buffer maximizes filtration capacity over a long period of time. The three zones are designed to perform three different functions. Zone 1 is undisturbed forest, the goal of which is to provide stream bank stabilization, temperature moderation, and organic material deposition. Zone 2 is managed forest, where periodic harvesting can occur, and (along with Zone 1) provides for the removal of nitrogen from the groundwater.

TABLE 1

Function of riparian areas and their relationship to environmental services

Examples of functions	Indicators that functions exist	On-site/off-site effects of functions	Goods and services valued by society
Hydrology and sediment dynamics			
Stores surface water over the short term	Floodplain connected to stream channel	Attenuates downstream flood peaks	Reduces damage from floodwaters
Maintains a high water table	Presence of flood-tolerant and drought-intolerant plant species	Maintains vegetation structure in arid climates	Contributes to regional biodiversity through habitat (e.g. forest canopy) provision
Accumulates and transports sediments	Riffle-pool sequences, point bars and other features	Contributes to fluvial geomorphology	Creates predictable yet dynamic channel and floodplain dynamics
Biogeochemistry and nutrient cycling			
Produces organic carbon	A balanced biotic community	Provides energy to maintain aquatic and terrestrial food webs	Supports populations of organisms
Contributes to overall biodiversity	High species richness of plants and animals	Provides reservoirs for genetic diversity	Contributes to biocomplexity
Cycles and accumulates chemical constituents	Good chemical and biotic indicators	Intercepts nutrients and toxicants from runoff	Removes pollutants from runoff
Habitat and food web maintenance			
Maintains streamside vegetation	Presence of shade-producing forest canopy	Provides shade to stream during warm season	Creates habitat for cold-water fish
Supports characteristic terrestrial vertebrate populations	Appropriate species having access to riparian area	Allows daily movements to annual migrations	Supplies objects for bird watching, wildlife enjoyment, and game hunting
Supports characteristic aquatic vertebrate populations	Migrations and population maintenance of fish	Allows migratory fish to complete life cycles	Provides fish for food and recreation

Note: Effects of functions sometimes are experienced off-site. Indicators are often used to evaluate whether or not a function exists, and are commonly used as shortcuts for evaluating the condition of riparian areas. The functions listed are examples only and are not comprehensive.

Source: (NRC 2002)

TABLE 2
Neuse River Basin riparian area rule: protection and maintenance of riparian areas with existing forest vegetation

	Zone 1A	Zone 1B	Zone 2
Location	←Stream bank		Upland→
Width	10 feet wide	20 feet wide	20 feet wide
Vegetation	Forest vegetation (trees, shrubs, saplings, vines, herbaceous plants)	Forest vegetation	Grassed
Management	Undisturbed: removal of diseased or dangerous vegetation allowed	Limited harvest: basal area at or above 75 square feet per acre	Mowing or harvest: provided sheet flow maintained

Zone 3 is grass or hay, with periodic harvesting allowed, and provides for the creation of sheet flow and the removal of sediment from surface runoff.

In North Carolina's Neuse and Tar-Pamlico River basins, this three-zone combined grassed and forested buffer design concept, presented as a two-zone design, is the basis for protecting existing forested riparian buffers as part of the Nutrient Sensitive Waters Management Strategy (Table 2).

Benefits of buffers

SEDIMENT REMOVAL

Sedimentation impairs water quality by increasing turbidity and covering the stream bottom. Suspended sediment can clog the gills of fish and shellfish, while excessive amounts of sediment reduce dissolved oxygen, adversely impacting aquatic organisms. Sediment covering the stream bottom can smother shellfish and other aquatic invertebrates and inhibit the development of fish eggs (Welsch 1991; Rudek et al. 1998).

Stream bank erosion can be another significant source of sediment pollution (Trimble 1997; Lowrance et al. 1985). Without deep-rooted vegetation to hold the bank together, the bank is undercut, and soil sloughs off into the stream

NITROGEN REMOVAL

The nitrogen-removal function of buffers is critical in North Carolina rivers draining to the coastal plain because of coastal waters' sensitivity to nitrogen pollution. Though less of a problem in the western Piedmont and mountains of North Carolina, where animal waste from pastures or trout farms can be sources of nitrogen (NC DEHNR 1997), there is still potential for this nutrient pollution to lead to excessive algal growth and decreased dissolved oxygen levels in the water (NC DENR 1998).

Since nitrate nitrogen is very water soluble, it moves with the water through the ground. Thus nitrogen pollution removal occurs mainly in the groundwater. The two main nitrogen removal processes are denitrification and plant uptake. The general consensus is that denitrification is the more important of the two processes (Gilliam 2000). Unlike plant uptake, denitrification levels can be quite high even in winter months when plants are dormant (Haycock and Pinay 1993). Denitrification rates are highest in the root zone of anaerobic soils where oxygen, leaked out of roots, creates an aerobic zone around the root. The roots also provide the carbon needed by the denitrifying bacteria (Gilliam et al. 1997). Groundwater does not have to flow through the root system as long as it flows through its zone of influence, where carbon and nitrate are present (Lowrance et al. 1997). However, if the water table is too low, groundwater flows under the root system of the riparian buffer, and neither plant uptake nor denitrification of any significance can occur.

PHOSPHORUS REMOVAL

While buffers are effective at removing particulate phosphorus from runoff, they are less effective at removing dissolved phosphorus. Though some dissolved phosphorus is taken up by plants, almost all phosphorus removed by buffers is in the particulate form attached to sediment, particularly fine clay particles, as opposed to coarser sand particles (Cooper and Gilliam 1987). Generally, grassed buffers remove phosphorus better than forested. Buffers need to be maintained through the periodic removal of excess sediment; otherwise they can become ineffective after a short time (Dillaha and Inamdar 1997; Uusi-Kämppä et al. 1997). Since buffers are less effective at removing dissolved phosphorus, other best management practices (BMPs) need to be used if dissolved phosphorus is a concern (Gilliam 2000).

PESTICIDE REMOVAL

Buffers are not as consistently effective in pesticide removal. Pesticide removal in buffers occurs in two ways: by being filtered out with the sediment or through uptake by plants (USDA 2000). Studies show significant pesticide removal from surface runoff where sediment-adsorbed forms predominate, but there is little evidence of removal from subsurface waters (Harris and Forster 1997). Pesticide removal in buffers has the potential to be effective, but more research needs to be done. Buffer-width recommendations in available literature are somewhat limited due to the variability of removal rates. The USDA states that buffers of about 15 m 50 ft.) can reduce pesticides by 50% if sheet flow is maintained.

REDUCED WATER YIELD

Buffers along streams can reduce water yield from upland parcels and decrease the chance of downstream flooding. Without buffers, more water from storm events reaches the stream. Vegetation growing along streams increases soil storage capacity, which allows more water to infiltrate (NCASI 1992).

Water yield has been shown to increase following a forest cutting, but a buffer can minimize the effect (Lynch and Corbett 1990). An increase in water yield can speed up erosion along the bank, adding more sediment to the stream and destabilizing the stream bank.

In urban and residential areas, riparian buffer loss is compounded by increased impervious surface. This results in decreased water infiltration and stream bank degradation. Overland flows and peak runoff rates increase, often exceeding the capacity of natural channels, leading to channel erosion and flooding (NRC 2002).

STREAM BANK STABILIZATION

A stable stream bank is important for protecting the natural stream channel. Without vegetation along a stream, stream banks slough off, often resulting in wider, shallower and straighter streams. For example, in southern California, Trimble (1997) found that channel erosion accounted for two-thirds of the sediment yield. Even with a minimal buffer along the bank, the natural stream channel can be maintained. In stabilizing a stream bank, width is less important than root density and depth, but buffers wide enough for other purposes, such as preserving water quality, are generally wide enough for bank stabilization (NCASI 2000; Wenger 1999).

PROTECTING HABITATS AND BIODIVERSITY

Forested riparian zones create habitats for organisms both in and out of the stream. For an adequate contribution of large woody debris, a buffer between 20 m (66 ft.) and 30 m (100 ft.) is recommended (NCASI 2000). Woody debris creates important habitat on which fish such as trout depend to reach adulthood (Murphy and Hall 1981).

Two biological indicators of high water quality that are also important links in stream food chains are macroinvertebrates and freshwater mussels. Newbold et al. (1980) found that to preserve macroinvertebrates after logging, buffers needed to be at least 30 m (100 ft.). Freshwater mussels cannot survive in sediment-polluted water because sediment covers the stream bottom where they live (Williams et al. 1992). The impact of sediment and other types of pollutants on aquatic organisms in North Carolina has been severe. More than 50% of the approximately 60 species of freshwater mussels and 25% of the approximately 200 species of native fishes in North Carolina are listed as endangered, threatened, or of special concern (NCWRC 2002).

The diversity of aquatic organisms often decreases at logged sites, although the overall biomass can increase, as the ranks of the few pollution-tolerant species can swell. Studies on species diversity and abundance have produced variable results. Davies and Nelson (1994) found that logging without at least a 30-m (100-ft.) buffer decreased macroinvertebrate abundance while Newbold et al. (1980) found decreased diversity but not abundance of macroinvertebrates in streams. Murphy and Hall (1981) found that initially macroinvertebrates were higher in abundance and diversity at clear-cut sites. However, the rate of production dropped off within 10–-20 years of regrowth. Murphy and Hall postulated that increased pollution subsequent to logging was masked by the high productivity, but the long-term health of the stream was in question as a result of sedimentation associated with clear cutting.

Buffers contribute terrestrial benefits as well. The stream bank, trees, grasses, and shrubs create homes for birds, mammals, reptiles, amphibians, and insects. While narrow buffers provide habitat for some species, to maintain biodiversity a large buffer of 100 m (328 ft.) or more is needed on both sides of the stream. This size is not feasible in many areas, but preserving larger stretches of land is necessary to maintain biodiversity (Wenger 1999). However, narrower buffers along streams can be important habitat corridors for connecting wildlife preserves (Tewksbury et al. 2002).

TEMPERATURE CONTROL

Streams without forested buffers receive more light and thus have higher water temperatures than buffered streams. Wenger (1999) states that to protect stream temperature, a buffer must be at least 10 m (32 ft.) wide while NCASI (2000) found that buffers approaching 30 m (100 ft.) are more effective at providing the shade needed to maintain water temperature.

Considerations for design and function of buffers

SLOPE

Slope affects how well a buffer can work to control pollution from surface runoff. Dillaha et al. (1989) tested buffers of 4.6 and 9.2 m (15 and 30 ft.) on slopes of 11 and 16% for surface water pollutant reduction. They found less sediment, phosphorus, and nitrogen reduction on the steeper plots. To get more reduction on these steeper slopes, buffer width must increase.

Some authors believe that certain slopes are too steep to be effective for filtering processes. However, there is no consensus on this critical angle. Buffers on slopes between 10 and 40% have been studied with varying recommendations (Nieswand et al. 1990; Budd et al. 1987; Herson-Jones et al. 1995). After reviewing many recommendations, Wenger (1999) suggested that the critical angle for effective buffers was 25%. The reality may be that buffer effectiveness varies enough from site to site that establishing a cut-off angle would impede implementing buffers for cost-effective water quality protection. Buffers can work on steeper slopes for filtering sediment and nutrients if they are properly maintained to allow for sheet flow (Dillaha and Inamdar 1997). They can efficiently remove nitrogen on steep slopes where the water table is high enough for groundwater to flow through root systems. Of course, the value of forested buffers in stabilizing stream banks is not affected by slope. Buffer effectiveness on sloped areas is discussed further in the “Width” section that follows.

MAINTENANCE

Buffers are excellent filters of sediment and nutrients but will not work unless maintained. Effectiveness decreases over time as sediment, phosphorus, and pesticides accumulate in buffers. As buffers retain more sediment, the likelihood increases that water will accumulate at the buffer’s edge, creating channels as it breaks through the sediment barrier (Parsons et al. 1994). With maintenance,

TABLE 3
Recommended buffer width and vegetation type by function

Function	Vegetation	Width
Sediment removal	Grass	9 m–30 m
Nitrogen removal	Forested	15 m–30 m
Phosphorus removal	Grass	9 m–30 m
Water quantity	Forested or grass	All of floodplain
Stream bank stabilization	Forested	Root density dependent
Habitat—in the stream	Forested	20 m–30 m
Habitat—on the bank	Forested	100 m
Temperature moderation	Forested	10 m minimum
Pesticide removal	Forested or grass	15 m minimum

Note: Does not include steeply sloped areas

TABLE 4

Formulas for calculating buffer widths based on slope (in meters)

Buffer purpose	Width formula (in meters)	Source
Preventing sedimentation, general	8–9 + 0.6 per 1% slope increase	Trimble and Sartz 1957
Preventing sedimentation, municipal watershed	16–17 + 1.2 per 1% slope increase	Ibid.
Sedimentation	Without a brush barrier: 13 + 0.42 per 1% slope increase With a brushbarrier: 10 + .12 per 1% slope increase	Swift 1986
	8 + .6 per 1% slope increase	Haussman and Pruett 1978 (see Castelle and Johnson 1994)
	15 + 6 per 5% slope increase	Clark 1977 (see Castelle and Johnson 1994)
Water quality	$2.5TS^{1/2}$ [T = time of travel of overland flow (seconds) S = slope]	Nieswand et al. 1990
	Three-Zone Buffer Ranges from 30 to 46 total with separate zones	Welsh 1991
Habitat preservation	Energy area (i.e. tree height) *e^(1+slope)	Erman et al. 1996
	In highly erodible areas: Energy area*e^[1+ slope + detachability[a] - (slope* detachability)]	Ibid.
Urban stream protection	15 + 1.2 per 1% slope (additional formulas use vegetation density and particle size)	Herson-Jones et al. 1995

[a] The detachability value accounts for how easily a soil erodes.

buffers can handle the sediment load during large rain events (Daniels and Gilliam 1996). Periodic removal of sediment from grassed buffers prevents nutrients trapped in the sediment from building up (Dillaha and Inamdar 1997). Maintaining dense vegetative cover, using a level spreader, or creating water bars parallel to the buffer will help insure sheet flow and improve buffer function (Dillaha and Inmadar 1997, Welsch 1991).

WIDTH

Width is one of the most important aspects of effectiveness. Larger buffers generally remove more pollutants than smaller ones. Magette et al. (1989) found that

TABLE 5

Filter strip width (in meters) for forest roads from USDA Forest Service (1973)

Slope (%)	0	10	20	30	40	50	60
Width needed for slight erosion hazard	9	17	25	34	43	53	64
Width needed for moderate erosion hazard	12	23	31	45	56	68	84
Width needed for severe erosion hazard	15	27	41	54	69	85	103

Source: Swift 1986

grass buffers of 4.6 and 9.2 m (15 and 30 ft.) removed 65.5% and 82.2%, respectively, of suspended solids from runoff. However, sediment and chemical removal rates are not linearly related to width. At first buffer effectiveness increases rapidly as width increases, but the rate of improved effectiveness decreases as width further increases, and the effectiveness curve flattens out.

There is no consensus on widths needed for effective buffers. In fact, buffer width depends on the desired buffer function. Wenger (1999) generally recommends a 30-m (100-ft.) buffer for sediment removal. He reports that a narrower buffer, with a minimum width of 9 m (30 ft.), is adequate on flatter or less erosive lands. A study by Ghaffarzadeh et al. (1992, see NCASI 2000), examined buffer effectiveness for sediment removal at varying widths ranging from zero to 18.3 m (60 ft.), on 7 and 12% slopes. They found no improvement beyond the 85% sediment removal rate at 9.1 m (30 ft.) with increased width for either slope. Table 3 summarizes buffer-width and vegetation-type recommendations for different buffer functions from references in this review.

Over the last few decades, scientists have come up with many formulas to set buffer widths considering variables like slope. One of the most commonly encountered formulas is that from Trimble and Sartz (1957) (Table 4). In these formulas, as in most, increased slopes result in wider buffer requirements.

Swift (1986) studied logging roads in western North Carolina to test recommendations by Trimble and Sartz (1957). Swift found that Trimble and Sartz's formula resulted in wider filter strips than needed and adapted their formula accordingly (Table 4). Nieswand et al. (1990) developed a buffer-width formula that incorporated several factors in addition to slope (Table 4). The equation from Erman et al. (1996) includes an exponential relationship between width and slope to estimate width needed on steep slopes (Table 4). The Erman formula did not set a minimum width like that of Trimble and Sartz but instead related the base width to the energy area of the stream. The energy area was set to have a width equal to the height of the trees along the stream. They developed an additional formula that accounted for erodibility. Herson-Jones et al. (1995) also diverged from Trimble and Sartz. Their goal was to create an urban buffer formula based on the logging buffer. They added vegetation density and particle size variables to their buffer-width equation to account for human disturbance.

The Forest Service, in its *Guide for Managing the National Forests in the Appalachians,* developed guidelines for filter strips along forest roads (Table 5) based on the Trimble and Sartz equation (Swift 1986). The Forest Service standards required larger filter strips than Trimble and Sartz, and included soil erosion potential in its guidelines.

TABLE 6
Recommended buffer widths on various slopes

Purpose	Slope	Width used (in meters)	Source
Preventing sedimentation	0%	9, 12, 14 (low, moderate, severe erodibility respectively)	Balmer et al. 1982 (from Clinnick 1985)
	30%	32, 43, 52 (low, moderate, severe erodibility respectively)	Ibid.
	60%	55, 71, 88 (low, moderate severe erodibility respectively)	Ibid.
Preventing sedimentation	flat	15	van Groenwoud 1977 (from Clinnick 1985)
	steep	65	"
Water quality	35–40%	7–8	Doyle et al. 1975 (from NCASI 2000)
Preventing sedimentation	20–28%	6 (severe erodibility)	Haupt 1959 (from Clinnick 1985)
	60%	43 (severe erodibility)	Ibid.

There are numerous examples of buffers on steep slopes that succeed in protecting water quality (Table 6). Buffers with widths ranging from 55 to 88 m, depending on soil erodibility, have been found to reduce sediment in runoff on slopes as steep as 60%.

Land use

FORESTRY

Increases in stream flow because of reduced evapotranspiration and increased runoff are commonplace after forest harvesting (Clinnick 1985). With increased flow, especially without any vegetation along the stream, the bank erodes and the channel widens. Davies and Nelson (1994) found that where buffers were less than 30 m (100 ft.), logging had a significant impact on stream habitats and aquatic organisms. Buffers, especially those with dense vegetation, reduce water yield increases and provide bank stabilization (Lynch and Corbett 1990).

Turbidity and sedimentation of the stream channel become a problem after clear-cutting if an ineffective buffer is used (Auburtin and Patric 1974). Many studies have found that when buffers are part of forestry BMPs, impact on the stream is minimal (Clinnick 1985; Lynch and Corbett 1990; Lynch et al. 1985). Clinnick generally recommends a 30-m (100-ft.) buffer on all perennial streams with adjustments for slope. Clinnick further recommends a 20-m (66-ft.) buffer on all ephemeral streams. After reviewing various studies on buffers used in the logging industry, Clinnick generalized that in many instances, the water quality and habitat benefits of using stream buffers far outweighed costs incurred by lost timber production.

AGRICULTURE

Generally, agriculture is the largest source of sediment pollution to streams (EPA 2000; Rudek et al. 1998). Plowing close to streams or allowing animals access to streams can cause erosion and sedimentation. Buffers act as a barricade between livestock and streams. Streams without livestock tend to be narrower and deeper, a more natural profile (Platts and Rinne 1985). In a study conducted on a pasture where the slope ranged from 2 to 35%, sediment concentration in storm flow was 57% less after cattle were fenced out of the stream area (Owens et al. 1996). In general, pastured buffers along streams do not need to be very large to stabilize stream banks.

If done properly, maintaining stream quality is possible by allowing cattle access to only small sections of the stream (Karssies and Prosser 1999). Simply providing an alternative water source for cattle has been shown to greatly reduce the amount of time cattle spent close to the stream (Sheffield et al. 1997). The cattle chose the water trough over the stream 92% of the time, and stream bank erosion was reduced by 77%. Average concentrations of total suspended solids in the stream were reduced by 90%.

Economic considerations are a factor in selecting the best approach to stream protection. There are costs to building fencing and alternative water sources as well as lost opportunity costs for land taken out of production. High value, slow-growing trees can be planted and selectively harvested in these fenced-off areas. Allowing animals to graze a few times a year during periods of low rainfall can benefit the buffer. Grass buffers need to be maintained, and limited grazing can accomplish this task (Sheffield 2000).

CHRISTMAS TREE FARMING

From the mid-1970s to the mid-1990s, Christmas tree sales in North Carolina increased eight-fold (Leavenworth 1994). Since Christmas tree farming often occurs on steep slopes, the potential for erosion can be quite high. Very little research on buffer use on these farms is available, but there seems to be potential for buffers as a good secondary BMP for sediment control.

The greatest potential for sediment loss is following harvesting. Planting grass crops in between rows of trees reduces erosion during growth and after harvesting. On steep slopes, if both ground cover and buffers are used, there should be a reduction in the amount of sediment entering streams. The NC Cooperative Extension Service (1997) recommended 10 to 25-ft. (3 to 7.6-m) buffers along Christmas tree farms. However, even their maximum of 25 ft. (7.6 m) seems too small to be effective in areas with steep slopes and high erosion potential. This assertion is extrapolated from research done on logging operations, especially highly erosive areas like steep-sloped logging roads (Trimble and Sartz 1957; Clinnick 1985).

Christmas tree farms tend to be pesticide-intensive, and buffers could reduce the amount of pesticide entering nearby streams. Since neither pesticide removal nor buffers on Christmas tree farms have been extensively studied, it is difficult to say how effective buffers would be. However, as Christmas tree farms now occupy a significant amount of land in North Carolina's mountains, the need to implement effective buffers in combination with other BMPs is urgent if aquatic resources in these areas are to be protected.

URBAN

The building of houses, businesses, and roads has a significant impact on streams. Klein (1979) tested the water quality of streams in urban areas and found that the most biodiversity existed in wooded streams. When not buffered, the stream channel widens and becomes shallower, impacting how stormwater affects the watershed. A study by Robinson in 1976 (see Klein 1979), found that streams draining developed watersheds averaged twice the channel width of rural streams.

Generally, as watershed imperviousness increases, base-flow decreases and channel width increases over time (Klein 1979). These two changes in stream morphology also affect the aquatic organisms living in the stream. Buffers along rivers can protect streams draining watersheds with a higher percentage of imperviousness (Horner et al. 1999).

Wenger (1999) recommends that urban buffers extend throughout the floodplain. This may not always be feasible, but an effort should be made to limit impervious surface and other structural developments in the floodplain (NRC 2002). Using buffers in combination with storage ponds will reduce stormwater flow. Storage ponds collect excess rainwater so floods are less severe. Further, they reduce the sediment load going into streams during flood events (Gardiner and Perala-Gardiner 1997).

Herson-Jones et al. (1995) recommended urban buffer widths of 15 m (50 ft.) plus 1.2 m (4 ft.) per 1% slope increase on slopes less than 10% (Table 4). On steeper slopes, buffers should be used as a secondary BMP. As much as possible, imperviousness on steep slopes should be limited.

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