The Role and Function of Forest Buffers For Nonpoint Source Management in the Chesapeake Bay Basin

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Introduction

When colonists first arrived in the Chesapeake Bay, they found vast forests covering over 95% of the watershed. These forests provided a biological and physical system that yielded high quality waters and a productive Bay. Unfortunately, much of the historic forest, including those along streamsides, has been lost or altered by human activities. Streamside soils were highly fertile and many were cleared for agriculture. Uncontrolled access to streams and rivers by livestock also destroyed riparian forests. More recently, urban and suburban development is contributing to the permanent loss of forests. Although today's forests have been reduced to less than 60% of their original extent, they are just as important in maintaining the purity of water and quality of life in the Chesapeake Bay watershed as they were in the 1600s.

A forest buffer is an area of trees, shrubs, and other vegetation designed to intercept surface runoff, wastewater, subsurface flow and deeper ground water flows from upland sources for the purpose of removing or buffering the effects of nutrients, sediment, organic matter, pesticides, or other pollutants prior to entry into surface waters and ground water recharge areas. Forest buffers can also be designed to enhance terrestrial and aquatic habitat (Welsch, 1991).

Riparian refers to the transition zone between the aquatic and terrestrial environments.

The Role of Forest Buffers

The problems of the Chesapeake Bay are largely the result of land uses and their resultant nonpoint source (NPS) pollutants. Conversion of forests to other land uses throughout the watershed, particularly adjacent to streams and rivers, has adversely affected the vitality of the Bay. There is an increasing recognition of the role that forests, combined with other management practices, can play in reducing pollution. Research results from a variety of sources have documented the effectiveness of riparian forest in reducing NPS loading from runoff and ground water. Most of this research has been conducted in agricultural watersheds or in connection with silvicultural activities. Forest buffers have wide applications in systems of best management practices (BMPs) in agriculture, land use planning, and stormwater management. Most attention is now focused on the use of riparian forest buffer strips as a water quality management practice. Forest buffers are also recognized for their high value in wildlife and fish habitat and in maintaining ecosystem integrity. This article discusses elements of the relationship between forests and water quality in the context of the forest buffer.

Components of a Forest Buffer

A forest buffer has three basic components whose characteristics determine its effectiveness in terms of NPS pollution control: 1) hydrology and soil; 2) the extent of surface litter/organic layer; and 3) the species, diversity, and age of forest vegetation.

Hydrology and Soil

Forest soils are generally regarded as highly effective in nutrient removal; however, efficiency is variable. The ability of a forest soil to remove nutrients in surface and ground water is partially dependent upon its depth and landscape position, relationship to geologic structure, permeability, presence of subsurface clay and gravel layers, extent and duration of shallow water table, and function as a ground water discharge zone (Pionke and Lowrance, 1991).

Organic Litter Layer

The organic litter layer in a forest buffer provides a physical barrier to sediments, maintains surface porosity and high infiltration rates, increases populations of soil mycorrhizae, and provides a rich source of carbon essential for denitrification. The organic soil provides a reservoir for storage of nutrients to be later converted to woody biomass. A mature forest can absorb and store as much as 14 times more water than an equivalent area of grass (NCASI, 1992).

Vegetation

Trees have several advantages over other vegetation in improving water quality. Trees aggressively convert nutrients into biomass. They are not easily smothered by sediment deposition or inundation during periods of high water level. Their deep-spreading root systems resist erosion, stimulate biological and chemical soil processes, and draw water and nutrients from deep within the soil profile. Trees produce high amounts of carbon needed as an energy source for bacteria involved in the denitrification process. The effectiveness of a forest for NPS pollution control varies with the age, structural attributes, and species diversity of its trees, shrubs, and understory vegetation.

Physical and Biological Functions

Sediment Filtering

The forest floor is composed of decaying leaves, twigs, and branches forming highly permeable layers of organic material. Pore spaces in these layers catch, absorb, and store water. With buffers of adequate size, 50 to 100% of sediment and its adsorbed nutrients have been shown to settle out in the streamside forest as runoff speed is reduced by the many obstructions encountered. Suspended sediment is further removed as runoff and sediments are readily incorporated into the forest floor. With a well-developed litter layer, infiltration capacities of upland forest soils generally exceed rainfall and can absorb overland flows from adjacent lands. Grass stands may actually be smothered by sediment deposition (Cooper et al., 1987).

Nitrogen and Phosphorus Removal

Forest ecosystems and forest buffers function similarly to wetlands by serving as filters, sinks, and transformers of suspended and dissolved nutrients (Richardson, 1989). The forest ecosystem retains or removes nutrients by rapid incorporation and long-term storage in biomass, improvement of soil nutrient holding capacity adding organic matter to the soil, reduction in leaching of dissolved nutrients in subsurface flow from uplands by evapotranspiration, bacterial denitrification in soils and ground water, and protection of soil during runoff events.

Studies of forest buffer performance on the coastal plain of Maryland showed reductions of up to 88% of nitrate (NO_3) and 76% of phosphorus (P) after agricultural runoff passed through a forest buffer (Peterjohn and Correll, 1984). On the coastal plains of Georgia, Lowrance et al. (1984) credited riparian forests with removing 80 to 90% of NO_3, 50% of P, and 99% of sediments generated from adjacent agricultural fields. Cooper et al. (1987) studied the role of riparian forests in sediment and nutrient reduction on the middle coastal plain of North Carolina and found reductions of as much as 93% of NO_3 and 50% of P over a 20-year period. Each of these studies was conducted using a water balance approach incorporating surface and ground water components. Studies conducted in Indiana (Karr and Gorman, 1975), on the Cache River in Arkansas by the Corps of Engineers (Kleiss et al., 1989), and in France (Pinay and Decamps, 1988) support these findings. In general, a third or more of nitrogen was accumulated in woody biomass while denitrification and other processes accounted for the remainder of the reduction. Phosphorus was primarily removed with particulate matter.

Stream Channel Stability

Streams and rivers are highly dynamic systems prone to change even without human interference. In-channel stream stability and streambank erosion at a given point are heavily influenced by land use and condition in the upstream watershed (Heede, 1980). Vegetation, especially woody vegetation, is essential for stabilizing streambanks (Karr and Schlosser, 1978). Although forest buffers alone can rarely be expected to control existing stream erosion problems, forests and large woody debris have an indirect effect on streambank stability by providing deep root systems which hold the soil in place more effectively than grasses and by providing a degree of roughness capable of slowing runoff velocities and spreading flows during large storm events. While slowing velocities may increase headwater flood height, downstream flood crest and flood damage is dramatically reduced (Karr and Gorman, 1975). These processes are also critical for building floodplain soils.

Shade and Temperature

The shade provided by a riparian forest buffer moderates stream temperatures and levels of dissolved oxygen. Removal of shade can increase daily peak temperatures by 10 to15oF and annual ambient temperatures by as much as 5 to 8oF. Shade is critical for fisheries and submerged aquatic vegetation, but also has water quality implications. Temperature increases the rate at which nutrients attached to suspended solids are converted to readily available (soluble) forms. As stream temperature increases above 60oF, significant increases in P release from sediments occur (Karr and Schlosser, 1978). Thus, loss of forest shade may exaggerate nonpoint pollutant effects by reducing the assimilation of organic wastes and inducing algae blooms and low oxygen levels.

Habitat

A great variety of habitats are found in structurally diverse riparian woodlands. Forested corridors connect isolated blocks of habitat and provide shelter for insects beneficial to agricultural pest control. Fallen and submerged logs and the root systems of woody vegetation provide cover for fish and invertebrates, while forest detritus is the basis of the stream's food web. Energy cycles in the aquatic system are often critically dependent on interaction with streamside woody vegetation. In many agricultural and urbanized areas, even narrow forest buffers can be essential to the survival of many important species. Urban forest buffers also provide a unique link between people and their environment.

The Practical Uses of Forest Buffers

Opportunities exist for preserving, enhancing, and restoring riparian forest ecosystems. Improved land use planning can preserve forest buffers and greenbelts during development and land clearing. Narrow or intermittent forest buffers along streams can be expanded and connected through planting and better management, such as reduced mowing. Riparian forest can also be restored, although this is not an easy task. Compatibility with historic farm and pasture management, potential loss of cropland, small farm sizes, long-term protection of buffers, and social acceptance all present challenges. Stormwater engineering, high land values, and encroachment or physical damage may present problems in urban areas.

Agricultural Lands

Cropping practices, fertilization, pesticide application, field drainage, and livestock grazing and confinement all have the potential to seriously degrade water quality. Forest buffers can be used as a linear break in the pattern of row crops and pastures to manage sediment, wind, and runoff problems. Riparian forests form a buffer between agricultural uses and streams and can control NPS pollution while producing numerous additional benefits. When properly protected from livestock, forests protect streambanks. Forest buffers can be used in conjunction with other nutrient and erosion control practices. For example, a BMP system for a farm may combine conservation tillage, fencing, grass waterways, forest buffers, and nutrient management.

Urban and Suburban Development

Forests should be retained as greenbelts along streams and drainageways. Forests and forested wetlands can also be used as part of treatment systems for urban runoff, where design requirements can be met. Urban forest buffers filter runoff, air pollutants, and noise. Forests cool the air and provide corridors for movement of wildlife; these buffers may provide the only available habitat for many animals in urban areas. Integrating forest retention and restoration in development planning is essential.

Silvicultural Activities

Much like forest buffers on agricultural lands, streamside management zones are commonly used during timber harvesting to prevent sediment from logging roads, skid trails, and site-preparation activities from reaching streams and rivers.

Specifications for Establishment of Forest Buffers

The U.S. Department of Agriculture Forest Service and Natural Resource Conservation Service (NRCS) jointly established guidelines and specifications for establishment of forest buffers (Welsch, 1991). Location, width, fencing options, management objectives, and species selection should be taken into consideration in buffer design. State and federal incentive programs such as the Conservation Reserve Program, the Wetland Reserve Program, and the Stewardship Incentive Program can help rural landowners install buffers. Specifications for urban areas may be found in local zoning and land use plans.

Management of Forest Buffers

Proper management can improve the effectiveness of forest buffers for NPS pollution control (Lowrance et al., 1985). Mature forests have less potential to remove nutrients than vigorous mixed-age forests, but may be essential for near-stream habitat. Hardwood species are especially important for perpetuating organic litter layers.

Current silvicultural systems for even-aged or uneven-aged management are designed primarily to provide a sustained yield of wood products. Systems that focus on a variety of landowner desires while protecting riparian values are most appropriate. Pionke and Lowrance (1991) recommend that uneven-aged silvicultural systems be employed in forest buffers to maximize water quality benefits. However, trees should be harvested periodically to sustain this growth and diversity and remove nutrients sequestered in tree stems and branches.

Research Needs

Forested riparian buffer strips have been shown to be effective in reducing nutrient and sediment levels in runoff. Riparian ecosystems can exert major control on NO3 concentrations in riparian zone ground water, especially when subjected to shallow water tables (Pionke and Lowrance, 1991). However, it is generally accepted that NO3 removal efficiency varies in different geographic provinces. Research should continue to document forest buffer effectiveness in mountain, hill and valley, piedmont, and coastal plains areas, and compare performance of various forest types with other practices, such as grass filters. In each case, additional quantification of expected performance is needed.

The development of a forest buffer and its attendant litter layer is likely to affect efficiency. This comparison is important for comparing forest buffers to grass filters. Although grass filters in riparian zones contain less organic matter in their surface soils, information is lacking to determine the levels necessary for optimal denitrification. The role of organic carbon in this process needs further study.

Information is needed on: 1) the minimum buffer width necessary to achieve effective nutrient reduction, 2) optimal species mix, 3) nutrient uptake processes, 4) the time necessary to establish functioning forest buffers, and 5) management prescriptions to improve long-term nutrient removal effectiveness.

Recommendations

The following list identifies specific actions (many of which are currently being implemented) needed for an effective program of forest buffer use Bay-wide:

- Identify and evaluate existing state and local land use regulations to determine which effectively ensure retention or restoration of forest buffers during development.
- Develop highly visible pilot demonstration projects to evaluate proper uses of forest buffers on working farms.
- In high-density urban areas, when implementing BMP retrofits, include pilot demonstration projects illustrating the use of forests in stormwater management systems.
- Review existing manuals and technical specifications in each jurisdiction to ensure that guidelines are in place to effectively promote and implement forest buffers.
- Coordinate and enhance federal, state, and local forest inventory efforts to better assess pressure on existing forest resources, target critical areas for forest buffer restoration, and provide consistent information to modeling efforts needed to evaluate changes in forests.
- Determine the feasibility of establishing forest buffer goals in Bay tributaries to enhance and connect existing buffers to provide corridors for wildlife movement.
- Develop materials and strategies needed to conduct a Bay-wide program for education and training on implementation of forest buffers in different field situations.

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References

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian area as filters for agriculture sediment, *Soil Science Society of America Journal* 51(6):417-420.

Heede, B. 1980. *Stream Dynamic: An Overview for Land Managers*. Technical Report RM-72, USDA Forest Service, Rocky Mountain Range and Experiment Station, Fort Collins, CO.

Karr, J.R. and O.T. Gorman. 1975. Effects of land treatment on the aquatic environment, In: *Nonpoint Source Pollution Seminar*, EPA 905/9-75-007, U.S. Environmental Protection Agency, Washington, DC.

Karr, J.R. and I.J. Schlosser. 1978. Water resources and the land-water interface, *Science* 201:229-234.

Kleiss, B.A., E.E. Morris, J.F. Nix, and J.W. Barko. 1989. Modification of riverine water quality by adjacent bottomland hardwood wetlands. In: *Proceedings of the Symposium on Wetland Concerns and Successes. American Water Resources Association, Tampa, FL, September, 1989*.

Lowrance, R., R. Leonard and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution, *Journal of Soil and Water Conservation* Jan-Feb, pp. 87-91.

Lowrance, R., R.L. Todd, J. Fail, Jr., O. Henrickson, Jr., R. Leonard, and L.E. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34:374-377.

NCASI. 1992. *The Effectiveness of Buffer Strips for Ameliorating Offsite Transport of Sediment, Nutrients, and Pesticides from Silvicultural Operations*. Technical Bulletin No. 631. National Council of the Paper Industry for Air and Stream Environment, Inc., New York, NY.

Peterjohn, W.T. and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest, *Ecology* 65(5):1466-1475.

Pinay, G.and H. Decamps. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: A conceptual model, *Regulated Rivers: Research and Management* 2:507-516.

Pionke, H.B. and R.R. Lowrance, 1991. Fate of nitrate in subsurface drainage waters, In: *Managing Nitrogen for Groundwater Quality and Farm Profitability*, Soil Science Society of America, Madison, WI.

Richardson, C.J. 1989. Freshwater wetlands: Transformers, filters, or sinks? *FOREM* 11(2), Duke Univ. School of Env. Studies, Durham, NC.

Welsch, D. 1991. *Riparian Forest Buffers - Function and Design for Protection and Enhancement of Water Resources*, USDA Forest Service Technical Publication #NA-PR-07-91, Northeastern Area State and Private Forestry, Radnor, PA.