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Riparian Wetlands and Water Quality

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ABSTRACT

Because of wet soils adjacent to the streams, riparian buffers are frequently present between farming and urban activities on the uplands and small streams. These riparian areas have been shown to be very valuable for the removal of nonpoint-source pollution from drainage water. Several researchers have measured >90% reductions in sediment and nitrate concentrations in water flowing through the riparian areas. The riparian buffers are less effective for P removal but may retain 50% of the surface-water P entering them. I consider riparian buffers to be the most important factor influencing nonpoint-source pollutants entering surface water in many areas of the USA and the most important wetlands for surface water quality protection.

A PROMINENT FEATURE of most landscapes in the eastern and southern USA is forested areas. These forested areas are commonly present as narrow bands on either side of small streams or in relatively large blocks of land, which may either be adjacent to large streams or on interstream divides. Regardless of size or shape, the large majority of the forested areas are present in areas that were either too wet or too steep to conveniently clear for agricultural crops or urban development.

These wet areas are the result of either (i) restricted surface and subsurface drainage or (ii) water received from higher elevations. The soils next to ephemeral and intermittent stream channels generally are wet because both surface and subsurface water flows toward them. The largest continuous wet areas in the Atlantic Coastal Plain, where much of the research on effect of riparian areas on water quality has been conducted, occur on the interstream divides. These divides are wet because surface and subsurface drainage is slow in a region where rainfall exceeds evapotranspiration. There is a large difference between the water quality functions of the areas near the stream channels and the interstream divides, even though they may be equally wet. There are also differences between the narrow strips of trees along small streams separating agricultural land or areas developed for other purposes, and the flood plain swamps adjacent to larger streams.

A North Carolina Coastal Plain watershed considered typical is shown in Fig. 1 taken from a USDA-SCS County Soil Survey. This figure shows cultivation on the well-drained upland soils (*No*—Norfolk, Typic Paleudult) and Hydric soils on the interstream divides, the flood plain swamp and in part of the riparian areas. In the Atlantic Coastal Plain, interstream divides are frequently large, relatively flat areas where the drainage water may move toward either of two streams. Because of the low gradients and poor drainage outlets, these areas are usually Hydric soils. For this paper, the riparian areas adjacent to larger streams are called floodplain swamps and the narrow areas adjacent to small streams are referred to as *riparian buffers*. The narrow riparian buffers shown in Fig. 1 are nearly identical to those studied by Jacobs and Gilliam (1985a). Most of the soils in the narrow wooded areas beside the small intermittent streams are not mapped as Hydric soils. These areas are too small to map separately and most are dominated by somewhat poorly (non-Hydric) soils.

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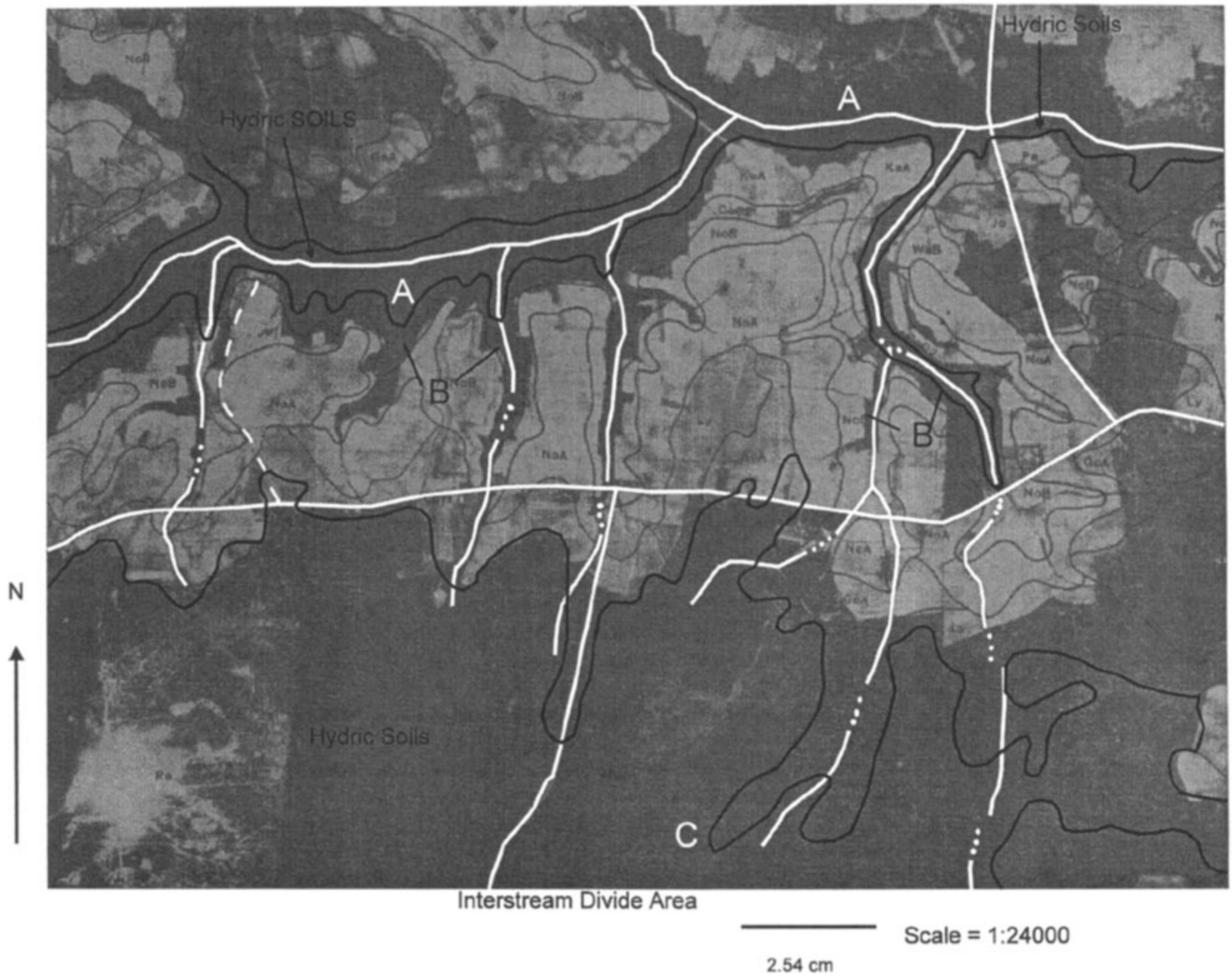

Fig. 1. Typical North Carolina Coastal plain watershed. Hydric soils in the flood plain swamp are marked with *A*. The areas marked *B* are typical riparian buffers, and *C* is placed on the interstream divide.

REMOVAL OF SEDIMENTS AND NUTRIENTS IN RIPARIAN AREAS

In the early 1980s, three research groups in the USA and one each in Canada, New Zealand, and Estonia independently began investigating the effect of vegetated riparian areas in reducing nonpoint-source pollution present in surface and subsurface drainage water originating in upslope areas. Although using somewhat different research approaches in these varied areas, the results and preliminary conclusions of each were amazingly similar. Later research by these and other groups have substantiated the original conclusions that riparian areas in native vegetation are very important for water quality preservation. In the following sections, nonpoint pollutant removal by riparian areas will be discussed in order of importance relative to effectiveness in protection of surface water quality.

Table 1. Accumulation of sediment during a 25-yr period in various depositional sites in an Atlantic Coastal Plain watershed (data from Cooper et al., 1987).

Landscape category	Sediment depth	Sediment mass	%
	cm	Mg	
Forest edge	15–50	2830	19
1st and 2nd-order stream	5–15	2840	19
Higher-order streams	5–15	5900	41
Flood plain swamp	0–5	3300	21
Total		14870	100

Sediment Removal

It has long been known that planted vegetative filters can be tremendously effective for removing sediment from surface runoff water. Thus, it is no surprise that the naturally vegetated riparian areas are also valuable for sediment removal. Since sediment is generally recognized as the nonpoint-source pollutant causing the greatest problems (Clark et al., 1985), riparian filters would be valuable if all they removed was sediment.

Cooper et al. (1987) estimated the effect of riparian wetlands on the deposition of sediment leaving agricultural land in surface runoff in a 1900-ha watershed (Table 1). They found that much of the sediment leaving agricultural fields was deposited in the riparian area very close to the fields' edge. In this watershed and in many others observed by the author, a dense vegetative growth was

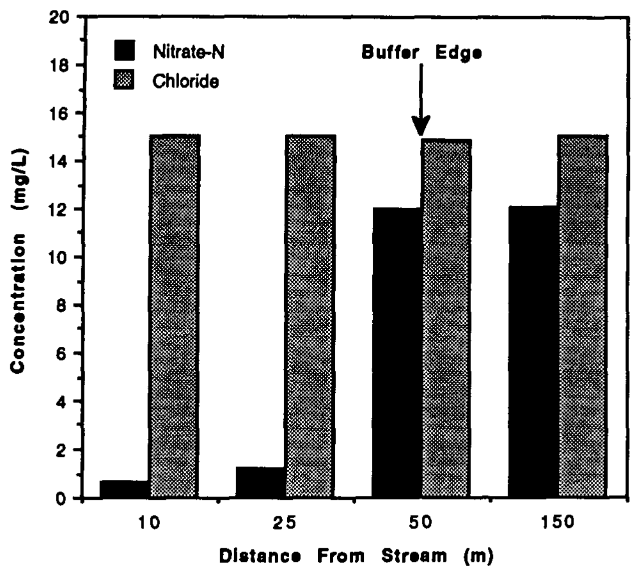

Fig. 2. Nitrate-nitrogen and chloride concentrations in shallow groundwater flowing from a cultivated Coastal Plain field through a wooded riparian filter to a small stream. (data from Jacobs and Gilliam, 1985a).

usually present at the field–forest interface. This growth slows the flow of the surface drainage water so that much of the coarser sediment is deposited near the field. A very common landscape feature was sandy fans in the edge of the forest where the surface runoff water entered the area. Frequently the depth became sufficiently great so that it formed a barrier to water and the flow was forced to enter the forest at another area and a new fan began to form. As the water moved further through the watershed into the higher-order streams and into the flood plain swamp, the texture of the sediments deposited became finer and finer. In the flood plain swamp, for example, the sediment layer is much thinner and consists largely of clay-sized materials.

The watershed studied by Cooper et al. (1987) was also used by Humenik et al. (1983) for a 208 nonpoint-source best management practice study. They measured the loss of sediment and nutrients from the watershed over a 3-yr period. If we assume that the average sediment loss they measured extended over the previous 25 yr when the ^{137}Cs-labeled sediment was deposited, we can estimate the efficiency of the wooded wetland uplands in the removal of sediment. This procedure indicated that 85 to 90% of the sediment leaving the agricultural fields was trapped in the wooded riparian areas.

Lowrance et al. (1988) also used ^{137}Cs to determine effectiveness of riparian filters in removing sediment from surface waters. They determined that more sediment was deposited in the riparian forest than was lost from the adjacent agricultural field. This difference was attributed to deposition from upstream portions of the watershed. From this and earlier work (Lowrance et al., 1986), this group has concluded that riparian ecosystems are efficient and important sediment traps.

Chescheir et al. (1991) measured sediment deposition in a forested wetland receiving pumped agricultural drainage and found that approximately 90% of the sediment was removed in the treatment area. We have unpublished data from the Piedmont of North Carolina, which shows removal of approximately 90% of the sediment as water flows through a grass riparian strip. Similar data have also been collected in Kentucky (Coyne et al. 1994). Thus, sediment removals of 90% by riparian areas are not unusual. However, it must be noted that Dillaha et al. (1987) found that not all vegetative filters are effective in removal of sediment because of formation of channels through the filters.

Nitrate Removal from Subsurface Water

In the past decade, removal of NO_3^- in riparian areas has been investigated more than any other potential pollutant. Nearly all riparian researchers who have looked at NO_3^- have observed that a large percentage of the NO_3^- in subsurface flows moving toward the streams was removed from the water as it passed through the riparian areas.

Jacobs and Gilliam (1985a) observed in the Coastal Plain of North Carolina that the NO_3^--N in the shallow groundwater moving from agricultural fields toward the small streams shown in Fig. 1 was reduced from approximately 15 mg/L to 1 to 2 mg/L (Fig. 2). This reduction occurred in the first 10 to 15 m of the riparian area. The percentage reductions observed by Peterjohn and Correll (1984) in Maryland and Lowrance et al. (1984) were similar. Cooper (1990) and Schipper et al. (1991) in New Zealand, Hill and Sanmugadas (1985) in Canada, and Haycock (1991) in England have also found that riparian buffers are very effective in reducing NO_3^- in shallow subsurface water before the water enters the adjacent stream. Haycock and Pinay (1993) in Great Britain noted removal of 99% of the NO_3^- by a poplar (*Populus italica*) vegetated riparian zone and 84% removal by a grassed permanent pasture. The only report of total failure of a riparian buffer to reduce NO_3^- was by James et al. (1990) in Maryland. These authors reported that leguminous trees in their riparian areas actually increased the NO_3^- in groundwater.

Jacobs and Gilliam (1985a) estimated that the riparian areas in the Beaverdam watershed shown in Fig. 1 was decreasing the NO_3^- from an average annual loss of 31 kg/ha of NO_3^--N at the agricultural fields edge to approximately 5 kg/ha at the watershed edge. The vast majority of this reduction occurred in the narrow riparian areas between the agricultural fields and the small streams indicated by the arrows in Fig. 1. The large areas of wooded wetland contributed little to the reduction in NO_3^--N, because the water had been essentially treated before reaching this area. The wetland soils present in this wooded flood plain have a very large capacity for denitrification, but it was hardly utilized because little NO_3^- ever reaches it. I believe that the location of the wetland in the hydrologic gradient has much more influence on water quality than the degree of wetness. Those wetlands immediately adjacent to streams that receive surface or subsurface flows from the adjacent higher areas are extremely important for the removal of NO_3^- from agricultural drainage waters.

Table 2. The total P deposited with the sediment in an Atlantic Coastal Plain watershed during a 25-yr period (data from Cooper and Gilliam, 1987).

Depositional area	P deposited	%
	kg	
Forest edge	515	6
1st and 2nd-order stream	1030	12
Higher-order streams	3100	37
Flood plain swamp	3667	44
Total	8312	100

Most researchers agree that the primary mechanisms of NO_3^- removal in riparian zones are denitrification and plant uptake. There is not agreement on the relative importance of these two processes in the Atlantic Coastal Plain. Jacobs and Gilliam (1985a) noted the big change in NO_3^-/Cl^- ratio as the water flowed from the agricultural field through the riparian zone (Fig. 2) and measured low reduction-oxidation potentials where the NO_3^- was removed. They concluded that denitrification was largely responsible for NO_3^- removal. Lowrance and his group in Georgia measured N uptake in riparian zones and concluded that uptake was the most important removal mechanism. One problem with assuming that denitrification is primarily responsible for the NO_3^- losses measured is that losses have been noted in soils with very low available C (Groffman et al., 1991; Lowrance, 1992). A problem with assuming that plant uptake is primarily responsible is that the loss frequently occurs within a few meters of the riparian zone and both movement into riparian zones and losses are larger during the winter months when many plants are dormant.

Researchers working in organic riparian wetlands in several locations have clearly identified denitrification as the most important mechanism causing loss of NO_3^- (Warwich and Hill, 1988; Cooper, 1990; Schipper et al., 1993; Ambus and Christensen, 1993). In these areas, NO_3^- usually limits the denitrification rate as opposed to available C.

Even though our understanding of the processes causing the losses of NO_3^- is incomplete, particularly with regard to kinetics, all who have worked in this research area agree that riparian zones can be tremendously effective in NO_3^- removal.

Phosphorus Removal

Cooper and Gilliam (1987) measured the P deposited with the sediment (Table 1) in a wooded wetland during a 25-yr period (Table 2). They found that the finer particles deposited in the area of the higher-order streams and in the flood plain swamps contained a higher concentration of P than did the coarse materials at the edge of the forest. Even though the flood plain swamp accumulated sediment at a low rate, the sediments deposited there contained a relatively high concentration of P. Thus, the large flood plain swamp was much more important for the deposition of P than for N or sediment. However, the total deposition of P in the riparian wetland over a 25-yr period was estimated to be 50% of that entering from the agricultural areas. Lowrance et al. (1984) estimated that the retention of total P entering the riparian areas of their watershed in Georgia was 30%.

Chescheir et al. (1991) concluded in their study that the removal of P from pumped agricultural drainage water required the codeposition of sediment. This agrees with the data of Cooper and Gilliam (1987), who found that the equilibrium P concentration of riparian sediments was actually higher than the dissolved P concentration in the surface runoff water entering the riparian areas in their watershed. Thus, the sediments would not be expected to remove P in solution from the runoff water. Peterjohn and Correll (1984) found that the dissolved P concentrations in surface water entering and leaving their riparian areas were unchanged. It is the author's conclusion that riparian buffers do a reasonably good job of removing P attached to sediment, but are relatively ineffective in removing dissolved P.

Removal of Pesticides and Fecal Bacteria

Much interest has been expressed by various state and regulatory agencies in knowing the effectiveness of riparian areas in removal of pesticides from agricultural runoff and fecal bacteria in runoff from land where animal wastes have been applied. Very little information is available at this time on removal of either of these contaminants. Researchers in Tifton, GA, and Auburn, AL, are measuring the removal of selected pesticides in riparian areas, and workers in Kentucky are investigating the removal of fecal bacteria. Preliminary data on fecal bacterial removal indicate that the percentage retained in the filters is highly variable (Coyne et al., 1994).

WET SOILS ON THE INTERSTREAM DIVIDES AND LARGER FLOODPLAINS

There are large areas of wet soils present on the interstream divides of the Atlantic Coastal Plain that are wet because of poor development of outlets for surface drainage. In North Carolina, these areas are more extensive than the wet areas adjacent to streams (Daniels et al., 1984). It is my opinion that the wet areas on the interstream divides have little effect on water quality. They cannot remove pollutants from runoff water, because they receive no runoff water. When drainage is improved on these flat, poorly drained soils and they are used for agricultural production, the loss of sediment and nutrients is less than that from any other soil used for agricultural production in North Carolina (Skaggs et al., 1980; Gilliam, 1991). It is my belief that development of land on the interstream divides would have less of a detrimental effect on water quality than development of any other soils in the region.

Brinson, (1991, 1993) published two excellent papers on wetlands on interstream divides (interfluves) and along environmental gradients. He forcefully argued that these areas should not only be evaluated for their water quality benefits but by their complete biogeochemical functioning. My argument in the preceding paragraph pertains only to their water quality function.

The soils of the flood plain swamps in the Atlantic

Coastal Plain have a tremendous capacity for denitrification and assimilation of other nutrients (Brinson et al., 1984). However, in the watersheds that I have examined (Jacobs and Gilliam, 1985b), this capacity is underutilized because most of the water purification occurs in the narrow riparian strips upstream.

DISCUSSION

All researchers who have worked on the water quality benefits of riparian buffers are frequently asked the questions: "How wide do they need to be to achieve a certain purification?" "What effect does type of vegetation in the buffer have on the effectiveness for water purification?" These questions cannot be answered with any certainty with the information currently available. One factor that is currently poorly understood is the hydrology of both surface and subsurface flows in the riparian areas. Until a better understanding of the hydrology is obtained, it will be impossible to accurately predict the removal of pollutants from the water flowing through the riparian areas whether it is surface or subsurface flow. However, even with the limitations in knowledge, some good attempts have been made to make recommendations for design of riparian buffers for water quality (e.g., Welch, 1991).

It is my opinion that the most important factor influencing the amount of sediment and nutrients getting into streams from nonpoint sources in the Eastern and Southern USA is the frequent presence of vegetated riparian areas between man's activities and small streams. Everyone who has worked with these areas agree that they have immense water quality benefits. Thus, there should be a strong effort to preserve a wet, vegetated buffer next to ephemeral and intermittent channels or streams. These are the areas that initially receive the surface runoff water and where shallow groundwater seeps into surface water. I believe these areas are the most important areas for preserving water quality whether or not they are classified as wetlands.

REFERENCES

Ambus, P., and S. Christensen. 1993. Denitrification variability and control in a riparian fen irrigated with agricultural drainage water. Soil Biol. Biochem. 25:915–923.

Brinson, M.M. 1991. Landscape properties of pocosins and associated wetlands. Wetlands 11:441–465.

Brinson, M.M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13:65–74.

Brinson, M.M., H.D. Bradshaw, and E.S. Kane. 1984. Nutrient assimilative capacity of an alluvial flood plain swamp. J. App. Ecol. 21:1041–1057.

Chescheir, G.M., J.W. Gilliam, R.W. Skaggs, and R.G. Broadhead. 1991. Nutrient and sediment removal in forested wetlands receiving pumped agricultural drainage water. Wetlands 11:87–103.

Clark, E.H., J.A. Haverkamp, and W. Chapman. 1985. Eroding soils: The off-farm impacts. The Conservation Foundation, Washington, DC.

Cooper, A.B. 1990. Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. Hydrobiologia 202:13–26.

Cooper, J.R., and J.W. Gilliam. 1987. Phosphorus redistribution from cultivated fields into riparian areas. Soil Sci. Soc. Am. J. 51:1600–1604.

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian areas as filters for agricultural sediment. Soil Sci. Soc. Am. J. 51:416–420.

Coyne, M.S., R.L. Blevins, and R. Rhodes. 1994. Sediment and fecal bacteria containment by vegetative filter strips. J. Soil Water Conserv. (in review).

Daniels, R.B., H.J. Kleiss, S.W. Buol, H.J. Byrd, and J.A. Phillips. 1984. Soil systems in North Carolina. North Carolina Agric. Res. Service Bull. 467.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, V.O. Shanholtz, and W.L. Magette. 1987. Evaluating nutrient and sediment losses from agricultural lands: Vegetative filter strips. CBP/TRS 4/87. Chesapeake Bay Liaison Office, USEPA, Annapolis, MD.

Gilliam, J.W. 1991. Wet soils in the North Carolina lower coastal plain. Wetlands 11:391–398.

Groffman, P.M., E. Axelrod, J.L. Lemunyon, and W.M. Sullivan. 1991. Denitrification in grass and forest vegetated filter strips. J. Environ. Qual. 20:671–674.

Haycock, N.E. 1991. Riparian land as buffer zones in agricultural catchments. Ph.D. diss. Univ. of Oxford, UK.

Haycock, N.E., and G. Pinay. 1993. Nitrate retention in grass and poplar vegetated buffer strips during the winter. J. Environ. Qual. 22:273–278.

Hill, A.R., and K. Sanmugadas. 1985. Denitrification rates in relation to stream sediment characteristics. Water Res. 19:1579–1586.

Humenik, F.J., B.A. Young, and F.A. Koehler. 1983. Investigation of strategies for reducing agricultural nonpoint sources in the Chowan River Basin. Rep. 211. Water Resources Res. Inst. of the Univ. of North Carolina, Raleigh, NC.

Jacobs, T.J., and J.W. Gilliam. 1985a. Riparian losses of nitrate from agricultural drainage waters. J. Environ. Qual. 14:472–478.

Jacobs, T.J., and J.W. Gilliam. 1985b. Headwater stream losses of nitrogen from two coastal plain watersheds. J. Environ. Qual. 14: 467–472.

James, B.R., B.B. Bagley, and P.H. Gallagher. 1990. Riparian zone vegetation effects on nitrate concentrations in shallow groundwater. p. 605–612. *In* J.A. Mihursky and A. Chaney (ed.) New perspectives in the Chesapeake system: A research and management partnership. Proc. of a Conf. Baltimore, MD. 4–6 Dec. 1990. Publ. 137. Chesapeake Research Consortium, Solomons, MD.

Lowrance, R., S. McIntyre, and C. Lance. 1988. Erosion and deposition in a field/forest system estimated using cesium-137 activity. J. Soil Water Conserv. 43:195–199.

Lowrance, R.R. 1992. Groundwater nitrate denitrification in a coastal plain riparian forest. J. Environ. Qual. 21:401–405.

Lowrance, R.R., J.K. Sharpe, and J.M. Sheridan. 1986. Long-term sediment deposition in the riparian zone of a Coastal Plain Watershed. J. Soil Water Conserv. 41:266–271.

Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1984. Nutrient cycling in an agricultural watershed: Streamflow and artificial drainage. J. Environ. Qual. 13:27–32.

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

Schipper, L.A., A.B. Cooper, and W.J. Dyck. 1991. Mitigating nonpoint source nitrate pollution by riparian zone denitrification. p. 401–413. *In* I. Borgardi and R.K. Kulzelka (ed.) Nitrate contamination: Exposure, consequence and control. NATO ASI Ser. G. Springer-Verlag, New York.

Schipper, L.A., A.B. Cooper, C.G. Harfoot, and W.J. Dyck. 1993. Regulators of denitrification in an organic riparian soil. Soil Biol. Biochem. 25:925–933.

Skaggs, R.W., J.W. Gilliam, T.J. Sheets, and J.S. Barnes. 1980. Effect of agricultural land development on drainage waters in the North Carolina Tidewater Region. Rep. 159. Water Resources Res. Inst. of the Univ. of North Carolina, Raleigh, NC.

Warwick, J., and A.R. Hill. 1988. Nitrate depletion in the riparian zone of a small woodland stream. Hydrobiologia 157:231–240.

Welch, D.J. 1991. Riparian forest buffers—function and design for protection and enhancement of water resources. USDA-Forest Service Publ. Na-PR-07-91. USDA-Forest Service, Radnor, PA.