

EFFECTIVENESS OF RIPARIAN BUFFERS IN REDUCING NITRATE-NITROGEN CONCENTRATIONS IN GROUND WATER

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ABSTRACT: A two-part study was begun in 1997 to evaluate the effectiveness of riparian buffers in reducing ground water nitrate concentrations in Coastal Plain aquifers of North Carolina. The first part of the study statistically compared 14 sites with and 14 sites without riparian buffers to determine possible differences in nitrate concentrations in discharging ground water. Nitrate concentrations were significantly lower ($p < 0.10$) in young ground water discharging from shallow aquifers at sites with buffers. Decreases in nitrate-nitrogen concentrations were estimated to be about 35% by dilution and 65% by denitrification at sites with riparian buffers. No differences ($p > 0.10$) in nitrate-nitrogen concentrations were detected between old ground water discharging from buffer and non-buffer areas. The second part of the study compared nitrate in ground water along flow paths from recharge to discharge areas at four selected field sites in different hydrogeologic settings to evaluate the importance of various processes affecting nitrate in ground water. A 50-60% decrease in nitrate concentration due to denitrification occurred in the streambed at one intensively studied site. Dilution by ground water from underlying confined aquifers or from recharge through the buffer was also a factor at two of the sites in reducing nitrate concentrations discharging ground water.

KEY TERMS: nonpoint source pollution, denitrification, nitrate, water quality, riparian buffers, ground water, wetlands

INTRODUCTION

The North Carolina Coastal Plain is a major agricultural area supporting crops, such as corn and soybeans, and large-scale livestock operations. Fertilizer and animal-waste application to fields result in increased concentrations of plant nutrients, such as nitrate, in surface runoff and ground water. Because typically more than half of streamflow in the Coastal Plain of the Albemarle-Pamlico Basin (Figure 1A) comes from ground water (McMahon and Lloyd, 1995), nitrate-contaminated ground water can contribute to the nitrogen load in streams. Riparian buffers have been suggested as a management tool for reducing nutrients moving from agricultural fields to streams (Gilliam et al., 1997). Riparian buffers are defined in this paper as forested strips, ranging from a few to several hundred meters wide, along a streambank. Buffers are present along many streams in eastern North Carolina, particularly along streams where the soil is too poorly drained to cultivate (Jacobs and Gilliam, 1985).

In 1997, a two-part study to evaluate the impact of riparian buffers on ground water flowing to streams in the Coastal Plain was initiated by the Ground Water Section of the North Carolina Department of Environment and Natural Resources (NCDENR) in cooperation with the U.S. Geological Survey (USGS) and North Carolina State University. The Contentnea Creek Basin, identified as a major contributor of nutrients to the Albemarle-Pamlico Sounds (Spruill et al., 1995), was selected as the focus of this study. During the first part of the study, the effects of riparian buffers on the chemistry of discharging ground water and streams were statistically analyzed by using 28 sites to determine whether riparian buffers are effective in removing nitrate from ground water. The second part of the study focused on describing and understanding the effects of riparian buffers on the nitrate and chemistry of ground water at four hydrogeologically varied sites in the Coastal Plain of North Carolina, primarily in the Neuse and Tar River Basins (Figure 1B). Sampling took place at these four sites over a 16-month period.

DESCRIPTION OF STUDY SITES

The study area for the statistically based study is located in the Contentnea Creek Basin (drainage area= 2538 km²) in the Coastal Plain (Figure 1A). Contentnea Creek is a tributary of the Neuse River in the Albemarle-Pamlico Drainage Basin in North Carolina. Contentnea Creek has been identified as a major source of both nitrogen and phosphorus loads in the Neuse River Basin (Spruill et al., 1995). More than 50% of land in the basin is used for agriculture, and most of the remaining area is forested (36%) or wetlands (9%) (McMahon and Lloyd, 1995). Soil types in the basin range from well-

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drained to moderately drained soils in uplands to moderately to poorly drained in stream valleys (McMahon and Lloyd, 1995). Streams in the Coastal Plain typically have a gradient of about 1m/km.

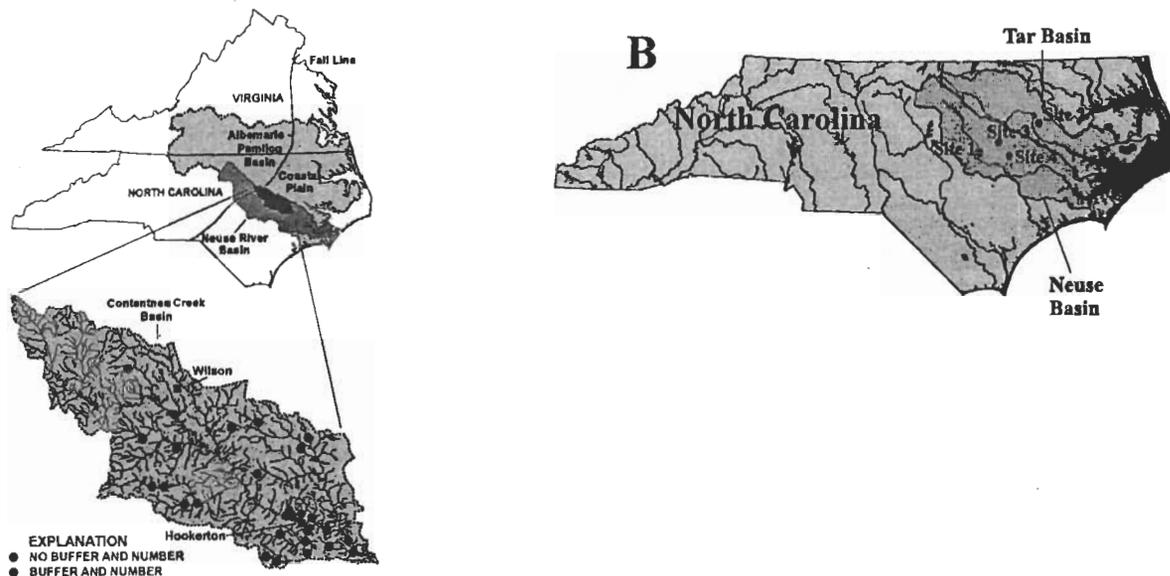


Figure 1. Locations of the (A) Contentnea Creek Basin and (B) Flowpath Study Sites.

Four flowpath study sites are located in the Neuse Basin (Figure 1B). Corn and soybeans are the primary crops grown at all four sites. Site 1 has about a 100-m wooded buffer with poorly drained soils in the lowlands and well-drained soils on the uplands. A coarse-grained shallow sand aquifer lies beneath the site on granitic bedrock. Site 2 has well-drained soil, a 200-m wooded riparian buffer, and is underlain by a medium to coarse-grained shallow sand aquifer. Corn and soybeans are planted next to the stream on the opposite bank, which has no riparian buffer. Site 3 has no buffer on the cultivated side, although the opposite bank and areas upstream from the site were extensively wooded. The site has well-drained soils in the uplands and poorly drained, but cultivated soils in the floodplain of the stream. A fine- to medium-grained shallow sand aquifer lies beneath the site with a confined aquifer beneath. Site 4 has a 100-m buffer, moderate to well-drained soils on the uplands, and poorly drained soils next to the stream. A fine to medium-grained shallow sand aquifer lies beneath the site with a confined aquifer underlying it.

METHODS

For the statistically based study, potential ground and surface water sampling sites were selected by overlaying a digital map of Contentnea Creek and its principal tributary streams on digital map layers showing roads and land use. Land-use information was obtained from 30-m multiple-resolution land characteristics (MRLC) data obtained between 1990 and 1993. Land use divisions used in this analysis were pasture, crop, and forest. Only streams with bridge crossings were included as potential sites for this study. A 30-m-wide zone was delineated along both sides of each stream by using GIS software to determine the presence or absence of a buffer next to the streams. Where forested land was found on both sides of the stream, sites were classified as buffer sites. Remaining sites with no forested areas on both sides of the stream were classified as non-buffer sites. Fourteen sites having 30-m-wide or wider lowland hardwood forest buffer and 14 sites having no hardwood buffer between the cultivated area and the stream were randomly selected (Figure 1A).

Ground- and surface water samples were collected at all 28 sites during baseflow conditions when streamflow is sustained entirely from ground water. Ground water was sampled by using a minipiezometer placed near the center of the stream with the screened interval ranging between 0.3 and 0.6 m beneath the streambed. Samples collected near the center of the stream were assumed to be representative of old ground water (an assumption based on a modeling analysis of a generic aquifer in the Atlantic Coastal Plain by Modica et al., 1997) discharging to the stream, as indicated by a higher water level in the piezometer relative to the stream. A water sample from the centroid of flow in the stream also was collected in using a peristaltic pump. The stream samples were considered to represent primarily young, shallow ground water that discharged rapidly along short flowpaths to the stream. All samples for this study were collected during low-flow conditions in September and October 1997 by pumping the samples through a 0.45- μ m disposable capsule filter. Field measurements were

made for specific conductance, temperature, pH, and dissolved oxygen. Samples were analyzed for dissolved ammonium-nitrogen, nitrate-nitrogen, Kjeldahl-nitrogen (KN), and phosphorus, silica, iron, manganese, chloride, alkalinity and organic carbon (DOC). Statistical differences between buffer and non-buffer chemistry were evaluated by using a non-parametric Mann-Whitney Test (Conover, 1980). Differences were considered significant if $p < \alpha = 0.10$.

The four flowpath study sites (Figure 1B) located in farmed areas were chosen on the basis of the presence or absence of a buffer and the prevailing soil type (well drained or poorly drained). If the farm had significant areas being used to grow crops in poorly drained soils, it was categorized as poorly drained; if the site grew crops only in well-drained soils, it was categorized as well drained. Most sites had a mix of soil-drainage classes. Wells were installed at sites 1, 3, and 4 in November and December 1997 and at Site 2 in July 1998. Wells were installed in transects starting from the high point in the field, to the stream. Each site has one transect, containing two to three well clusters. Each cluster contains one to three wells, ranging in depth from the top of the water table to below the first confining layer, if possible. Water-quality samples were collected at each site at 1- to 2-month intervals between December 1997 and March 1999. Water samples were collected from the stream and from beneath the stream using a minipiezometer at each sampling. Water samples were collected in June of 1998 from a seepage meter placed on the streambed to evaluate possible changes in ground water quality that could occur within the streambed. Samples were collected from monitoring wells and prepared according to techniques presented in Koterba et al. (1995). Measurements were made in the field for pH, specific conductance, dissolved oxygen, and water temperature according to techniques described in Koterba et al. (1995). Samples were collected for dissolved calcium, sodium, silica, iron, manganese, nitrate-nitrogen, ammonium-nitrogen, KN, phosphorus, and chloride at each sampling event. The NCDENR Water-Quality Laboratory in Raleigh, North Carolina, analyzed all routine samples. The USGS National Water Quality Laboratory in Denver, Colorado analyzed selected samples for complete ionic composition. Chlorofluorocarbon samples, for age dating ground water (Busenberg and Plummer, 1992), and gas samples, to verify denitrification, were collected from selected wells and analyzed by the U.S. Geological Survey Laboratory in Reston, Virginia.

RESULTS AND DISCUSSION

Statistical Study

Young Ground Water

Because surface water samples for this study were collected during baseflow conditions and no point sources were known to exist upstream from the sampling sites, water in the channel is derived from ground water of both shallow and deep origin. Surface water samples were considered to be representative of primarily young ground water, even though the water is known to be a composite mix of both old and young ground water. Specific conductance, dissolved chloride, nitrate-nitrogen, and calcium were significantly higher and pH lower in the non-buffer areas (Table 1). The higher concentrations of these constituents are a result of proximity of the source (agrochemicals applied to crops) to the stream and a lack of a substantial source of organic carbon from a buffer to stimulate microbial reactions. pH and concentrations of dissolved iron, manganese, phosphorus, and DOC were significantly higher in the buffer areas. These constituents are indicative of reducing conditions and appear to be a result of greater amounts of soluble organic material, as indicated by significantly higher DOC concentrations in the buffer areas. Lower nitrate and chloride concentrations in the buffer areas suggest that both dilution and denitrification occur within the buffer; the decrease in median chloride from 17.5 mg/L in the non-buffer area to 11.5 mg/L in the buffer areas indicates about a 35% dilution effect by the buffers. If dilution were the only factor, the buffer areas should have about a 1mg/L median nitrate-nitrogen concentration, a reduction of about 35% from the median nitrate-nitrogen concentration of 1.5 mg/L in non-buffer areas. However, the median nitrate-nitrogen concentration in young ground water from the buffer areas was about 0.06 mg/L, indicating an additional 65% reduction due to denitrification that was taking place in the buffer areas.

TABLE 1. Statistical Differences Between Selected Dissolved Constituents in Ground Water from Buffer and Non-buffer Sites.*

Ground Water Age	pH	DO	SC	DOC	ALK	CL	SI	NH4-N	KN	NO3-N	P	CA	FE	MN	NA
Young	B++		N+	B+++		N+				N+	B+	N+++	B++	B+	
Old	B++		B++	B+++	B++		B+++	B+++	B+++		B+++		B+++	B+++	

*DO=dissolved oxygen, SC=specific conductance, DOC=dissolved organic carbon, ALK=alkalinity, CL=chloride, SI= silica, NH4-N=ammonia-nitrogen, KN=Kjeldahl nitrogen, NO3-N=nitrate-nitrogen, P=phosphorus, CA = calcium, FE=iron, MN=Manganese, and NA=sodium in buffer (B) and non-buffer (N) sites in young and old ground water. The B or N category symbol is shown where the constituent was significantly higher ($p < 0.01$ (+++), $p < 0.05$ (++) , and $p < 0.10$ (+).

Old Ground Water

Statistically significant differences in values of pH, specific conductance, DOC, alkalinity, silica, ammonium, Kjeldahl nitrogen (KN), phosphorus, iron, and manganese in discharging ground water were found between buffer and non-buffer areas, with the highest concentrations occurring in areas having buffers (Table 1). The presence of buffers affected concentrations of many chemical constituents in discharging ground water, although there was no statistically significant effect on median nitrate-nitrogen concentrations (Table 1). Old ground water typically does not have high nitrate-nitrogen concentrations in the Contentnea Creek Basin. Denitrification can take place within the aquifer upgradient from riparian buffer zones along streams: organic carbon in aquifer sediments can drive denitrification (Speiran, 1996) and low dissolved oxygen (<2 mg/L) in ground water anywhere in the flow system will thermodynamically favor denitrification by bacteria (Puckett et al., 1999). The potential for denitrification is present in the buffer areas, as indicated by several chemical constituents that are indicative of reducing conditions. Decaying organic material in the streambed and floodplain deposits probably causes reducing conditions.

Flowpath Studies

Site 1. Nitrate-nitrogen occurred in high concentrations of 10-12 mg/L under the field. Little difference existed in nitrate concentrations in water collected from shallow and deeper wells (Figure 2). This likely was due to the fairly uniform and transmissive deposits (indicated by young ground water ages (mid-1990's in JC-1, a deep well) and early 1990's in a downgradient deep well, JC-4 (not shown), low DOC concentrations (< 0.5 mg/L), and the lack of a confining layer to impede the vertical transport of water and nutrients. Not only were concentrations uniformly elevated vertically, but nitrate-nitrogen concentrations changed little in the downgradient wells in the buffer. However, water from wells placed near the stream (JC-7) and in the stream (the bedwell) contained little or no nitrate. The organic floodplain deposits near the stream composed of silt or organic debris were not very transmissive as indicated by the constant difficulty in collecting water from the minipiezometer in the streambed and the age of the water (1970) in these deposits. This stream typically does not flow during the summer months. Because the only bedwell samples collected were during the wet season when the stream was flowing, and no bedwell samples could be collected when the stream was dry, the bedwell samples could possibly represent only recent water stored in sandy pockets in the stream and floodplain sediments.

The functionality of the buffer in reducing nitrate concentrations in discharging ground water may be entirely due to site hydrology. In general, little ground water passes through the buffer area to the stream, either because ground water is removed via the atmosphere through evapotranspiration or because it discharges as underflow to another location. However, high DOC and low nitrate concentrations in samples from JC-7 (Figure 2) do indicate denitrification. More than 2.5 mg/L of excess nitrogen (measured gas concentration greater than expected for the observed temperature and pressure) was measured in water from a sample collected from JC-7 in February 1999, indicating that denitrification was taking place. In this setting, it seems that vegetative water use and nutrient uptake may be more important than denitrification in limiting nitrate movement to the stream.

Site 2. Nitrate-nitrogen occurred at concentrations of 5-15 mg/L beneath the farm field. In wells PM-2 and PM-1, the median nitrate concentration was 10.0 and 5.4 mg/L, at depths of 4 and 5.5 m, respectively (Figure 2). This indicates that nitrate is either diluted by low nitrate water or that some denitrification occurs at depth within the aquifer. A sample collected from PM-1 in February 1999 had 5.07 mg/L of excess nitrogen gas measured. The sample had less than 0.2 mg/L of dissolved oxygen and only 4 mg/L of nitrate-nitrogen, indicating that denitrification does occur. In the streambed, nitrate-nitrogen concentrations were much higher in ground water discharging from the right bank (the side *without* a buffer. Denitrification occurred within the last meter of the flowpath before discharging to the stream channel. Nitrate-nitrogen concentrations were still very high (4-11 mg/L) about 0.7 m below the streambed. However, the seepage meter samples represent this ground water after it has discharged vertically to the stream channel: concentrations of nitrate-nitrogen, after passing through the streambed, were about 50% lower and DOC higher on each side of the stream (Figure 2). The organic material of the streambed appears to exert a major effect on discharging ground water chemistry, as indicated by significantly higher DOC in the seepage meter samples. The probable origin of this organic material is vegetation and organic debris (either currently or historically) derived from vegetation growing within the watershed.

The riparian buffer and streambed combined seem to be effective in reducing nitrate-nitrogen concentrations in ground water. Comparison of median concentrations of nitrate-nitrogen in water from upgradient wells (about 8 mg/L in PM1 and PM2) and downgradient wells (about 4-5 mg/L in PM3 and PM4) on the buffer side indicates about a 3- to 4-mg/L loss of nitrate-nitrogen, or about a 35-40% reduction due to denitrification and/or dilution within the aquifer. From the left bank to the discharge point into the stream channel, concentrations drop to 2 mg/L in the seepage meter samples, resulting in an additional 60% decrease in nitrate-nitrogen concentrations through the streambed, resulting in an overall decrease of about 95%. This decrease is comparable to reductions estimated from the statistical study results reported in the previous section, implying that the streambed in forested buffer areas may reduce most of the nitrate from ground water before discharging to a stream. Despite the denitrification processes occurring at this site, ground water contributes nitrate-nitrogen to the stream by

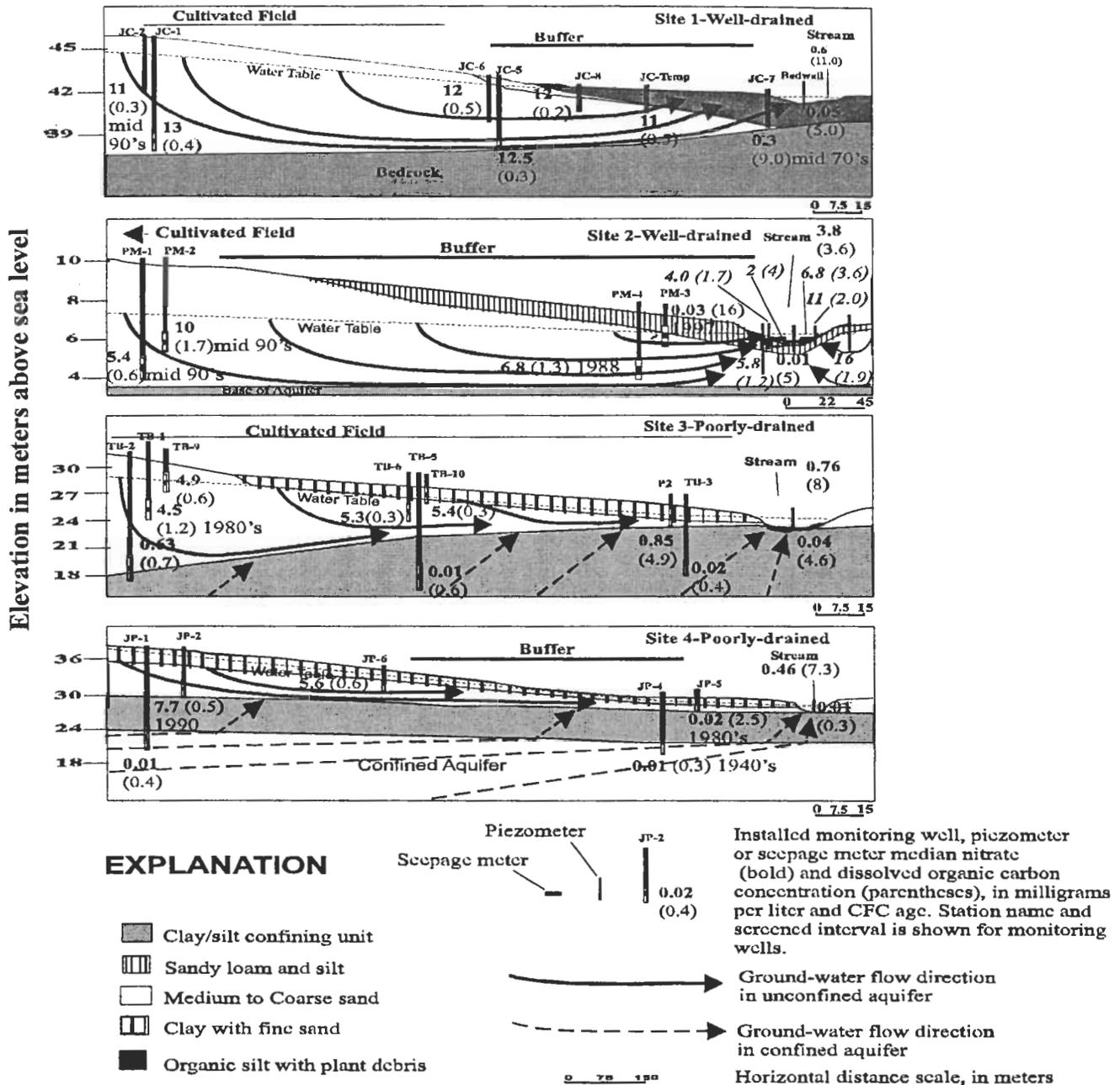


Figure 2. Cross Sections of Sites Showing Changes in Nitrate-Nitrogen along the Flow Path from Recharge to Discharge Area. Samples collected during June or July 1998 at Site 2 are shown in italics. Ground water ages are shown where available.

as much as 7 mg/L on the right bank (non-buffer) side. The median nitrate-nitrogen concentrations in the surface water sample was about 4 mg/L, suggesting a major influence of non-buffer high-nitrate ground water discharge to the stream.

Site 3. Most of the decrease in nitrate-nitrogen occurring at this site appeared to take place within the streambed sediments or by dilution from water moving into the stream from the confined aquifer (Figure 2). Ground water sampled from the bed wells usually had elevated concentrations of DOC (>3 mg/L), ammonium, low nitrate-nitrogen (<0.5 mg/L), and elevated iron, phosphorus, silica, and pH, compared to water from the upgradient wells. These constituents indicate reducing conditions and were associated, based on the statistical study, with buffer sites. Even though this site has no buffer, nitrate-nitrogen concentrations in surface water were reduced because of the particular hydrogeologic characteristics of the site, where the confined aquifer contributes low-nitrate water and denitrification occurs within the streambed at the end of the flowpath. In addition, wooded areas on the opposite bank and upstream provide a source of organic debris to the streambed. This site may exemplify watershed-scale effects of stream buffers. Nitrate-nitrogen concentration reduction of 70-90% between shallow

ground water and the stream appears to be due to denitrification in the streambed and hyporheic zone and dilution by deep ground water from a confined aquifer. This site demonstrates the importance of understanding the hydrogeology in order to accurately evaluate the independent effects of geology, riparian buffers, or streambed processes on stream chemistry.

Site 4. Approximately 25% of the nitrate was removed from the recharge area (7.7 mg/L in JP-2, Figure 2) as it moved downgradient through the aquifer to just upgradient from the riparian buffer (5.6 mg/L in JP-6, Figure 2). Although some denitrification occurred (as indicated by some excess nitrogen gas measured in both JP-2 [1.03 mg/L] and JP-5 [1.09 mg/L]), the relatively low excess nitrogen gas concentrations suggest that a process other than denitrification within the buffer may be more important in accounting for the decrease in nitrate. Shallow ground water downgradient from the riparian buffer is almost totally devoid of nitrate-nitrogen (0.02 mg/L in JP-5, Figure 2). The upward gradient observed in the downgradient deep well (JP-4, Figure 2) suggests that dilution by water from the confined aquifer or dilution by recharge through the buffer also may account for the low nitrate-nitrogen stream concentrations (0.46 mg/L) observed. Further analysis will be required to better define probable causal factors accounting for nitrate reduction at this site.

CONCLUSIONS

Statistically, riparian buffers are effective in reducing nitrate in ground water discharging to streams. Specific conductance, chloride, nitrate-nitrogen, and calcium were significantly higher in young discharging ground water at sites without riparian buffers. In this Coastal Plain watershed, nitrate-nitrogen reduction in ground water was estimated to be generally about 35% by dilution and 65% by denitrification at sites with riparian buffers. Riparian buffers seemed to be less effective in reducing nitrate in ground water moving beneath the riparian buffers in old deep ground water, but this is probably because the old ground water is already low in nitrate. However, reducing conditions in the streambed at most of the sites, as indicated by elevated concentrations of DOC, iron, phosphorus, bicarbonate, silica and other constituents, could reduce any nitrate potentially present in discharging ground water. Riparian buffers affect ground water quality by providing (1) dissolved carbon for denitrification of shallow ground water moving beneath a buffer to a stream, and (2) carbon to the streambed in the form of leaf litter and organic debris, which affects the chemical quality of deep ground water discharging through the bed. Dilution by ground water from underlying confined aquifers or from recharge through the buffer also is important, and was a factor in decreasing nitrate-nitrogen concentrations at two of the sites studied.

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