20 Failure of agricultural riparian buffers to protect surface waters from groundwater nitrate contamination

D. L. CORRELL, T. E. JORDAN & D. E. WELLER

Smithsonian Environmental Research Center, P.O. Box 28, Edgewater, Maryland 21037, USA

ABSTRACT For two years we studied the flux of nitrogen moving in shallow groundwater from double row-cropped uplands through a flood plain and into a second order stream in Maryland. Two floodplain sites were compared: one forested and the other vegetated by grass. At both sites, the soil layer through which the groundwater moved was very sandy. The nitrate concentrations leaving the crop fields were 20–30 mg N l^{-1} and averaged 25 mg N l^{-1}. Nitrate concentrations declined about 32% on average from the field edge to 48 m into the forest and this decrease was about 44% on average in the grassed buffer. These decreases were greater in the winter than in the summer. Nitrate to chloride ratios declined about 43% across the riparian forest transect. Declines in nitrate concentration were not accompanied by offsetting increases in dissolved organic N or ammonium. Soil E_h averaged 191 mV and 263 mV at 33 m and 48 m into the forest, respectively. While nitrate removal rates were the highest of three study sites we have investigated in the Maryland Coastal Plain, nitrate concentrations entering the stream channel were still high (12–18 mg N l^{-1}). The flux of nitrate in groundwater from the farm fields at this site clearly exceeded the nitrate removal capacity of these riparian buffers.

INTRODUCTION

Coastal receiving waters are often overenriched with nutrients, especially in cases where the drainage basins are intensively farmed or support large populations of humans (Beaulac & Reckow, 1982; Turner & Rabalais, 1991). This is clearly the case for the Chesapeake Bay on the eastern seaboard of the United States, where diffuse drainage basin discharges contribute approximately two-thirds of the nitrogen, one-quarter of the phosphorus, and all of the silicate inputs to the Bay (Correll, 1987). In this estuary, overenrichment with both nitrogen and phosphorus (Gallegos *et al.*, 1992; Jordan *et al.*, 1991a,b; Malone *et al.*, 1988) contribute to excessive plankton blooms and extensive reaches of hypoxic waters (Officer *et al.*, 1984). Much of the nitrogen inputs to Chesapeake Bay are nitrate from croplands, which infiltrates through the soils to groundwater, then percolates to surface water streams before entering the Bay.

Our past and continuing work has demonstrated the importance of landscape structure, particularly the configuration of riparian buffers, in controlling nutrient discharges from agricultural watersheds of the coastal plain (Correll & Weller, 1989; Correll, 1991; Correll *et al.*, 1992; Jordan *et al.*, 1993; Peterjohn & Correll, 1984, 1986). In these studies over 80% of the nitrate entering the riparian forest in shallow groundwater drainages from croplands was removed at all times of year. Other studies have reported similar findings in the coastal plain (e.g. Lowrance *et al.*, 1984; Gilliam & Skaggs, 1988) and in some other systems (Haycock & Pinay, 1993; Labroue & Pinay, 1986; Pinay & Labroue, 1986; Pinay & Décamps, 1988; Schnabel, 1986).

The present study extends our research on coastal plain riparian buffers to a new site which receives groundwater with nitrate concentrations two to three times higher than the previous two sites (Peterjohn & Correll, 1984; Jordan *et al.*, 1993). This site also has subsoils with high hydraulic conductivity due to high gravel and sand content. Thus, conditions at this site were favorable to observe saturation of this riparian buffer's nitrate removing potential.

SITE DESCRIPTION

The study site (39° 2′ N, 75° 57′ W) was a flood plain along a second-order stream draining approximately 4.5 km^2 of land. This stream is a tributary near the lower end of German Branch, a fifth-order stream draining 52 km^2 of land. German Branch in turn is a tributary of the Choptank River, which is the largest river on the eastern shore of Chesapeake Bay and drains directly into the Bay. Approximately 90% of the uplands at the study site were used for row crop production. The fields were double-cropped and spray irrigated during dry periods. Two areas within the flood plain were studied. One was vegetated with a stand of mixed species of deciduous hardwood trees. The other was vegetated with mown grass. The surface sediments in this region of the coastal plain are part of the Pensauken formation, which forms the Columbia aquifer. Throughout the region, this aquifer is perched on the less permeable sediments of the Chesapeake Group (Bachman & Wilson, 1984), which are highly clayey with hydraulic conductivity of less than 1 x 10^{-4} cm hour^{-1} (Jordan *et al.*, 1993).

METHODS

We installed transects of groundwater wells at both the forested and grassed areas (Fig. 1). The wells were installed with bucket augers and were lined with polyvinyl chloride pipes, which were perforated from just below the soil surface to the bottom of the well. The wells extended from 1 to 4 m below the soil surface with the bottoms of the wells at approximately the same elevation as the stream bed. Wells were arranged at various distances from the crop fields with sets of three replicates spaced 10 m apart laterally (Fig. 1). We sampled the wells about once a month from May 30, 1991, till May 25, 1993, by first pumping the wells dry, then sampling the water that immediately refilled the wells. We filtered the samples through 0.45 μm pore-size membrane filters. We measured dissolved Kjeldhal N, nitrate, ammonium, phosphate, total P, organic C, chloride, pH, and conductivity (Correll & Weller, 1989; Jordan *et al.*, 1993). Triplicate analyses were routinely performed on about 10% of the samples to provide a check on analytical precision. At the forested area we also measured E_h below the water table with platinum electrodes (Faulkner *et al.*, 1991) placed near wells 32 and 42 (Fig. 1).

RESULTS AND DISCUSSION

Both the forested and grassed riparian buffer areas (Fig. 1) seemed to remove nitrate from groundwater. Nitrate concentrations declined significantly with distance from the crop fields (Figs. 2 & 3). At the edge of the fields, NO_3^- concentrations averaged 25 mg N l^{-1} at both buffer areas. In the forested buffer, the NO_3^- concentration declined to 17 mg N l^{-1} at 48 m from the field. In the grassed buffer, the NO_3^- concentration declined to 14 mg N l^{-1} over a distance of 37 m. Concentrations of dissolved organic N and dissolved ammonium (Figs. 2 & 3) did not increase significantly, so the NO_3^- was not converted to dissolved reduced forms of nitrogen. In the forested buffer, dissolved ammonium

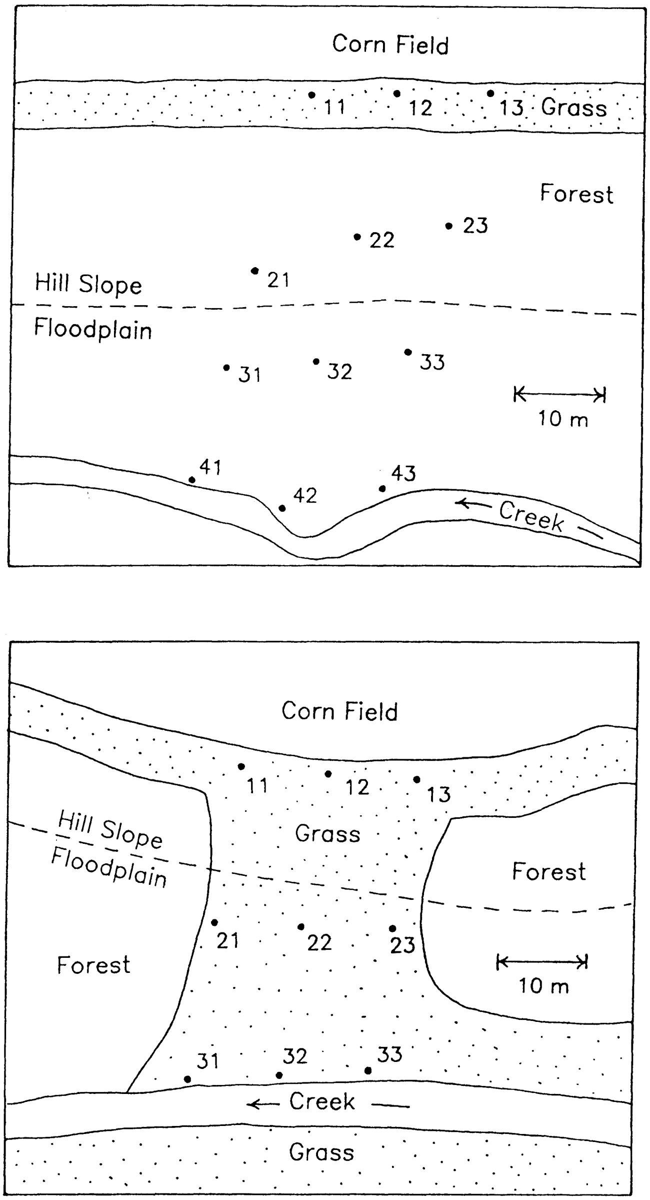

Fig. 1 Layout of groundwater wells (numbered points) in two riparian buffers (39° 2′ N, 75° 57′ W) on the flood plain of a second-order stream, tributary to the German Branch of the Choptank River in Maryland, United States. In the forested buffer platinum electrodes were located near wells 32 and 42 for monitoring soil E_h.

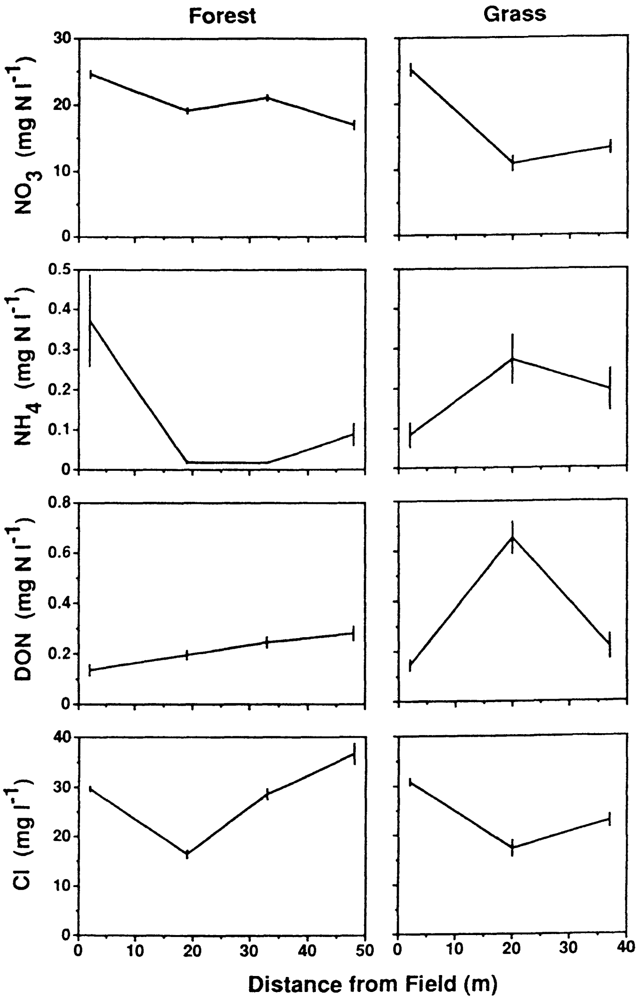

Fig. 2 Concentrations in groundwater versus distance from upland crop fields along transects through riparian buffers. Values are means of monthly samples over a two year period from May 30, 1991, to May 25, 1993. Brackets are standard errors of means.

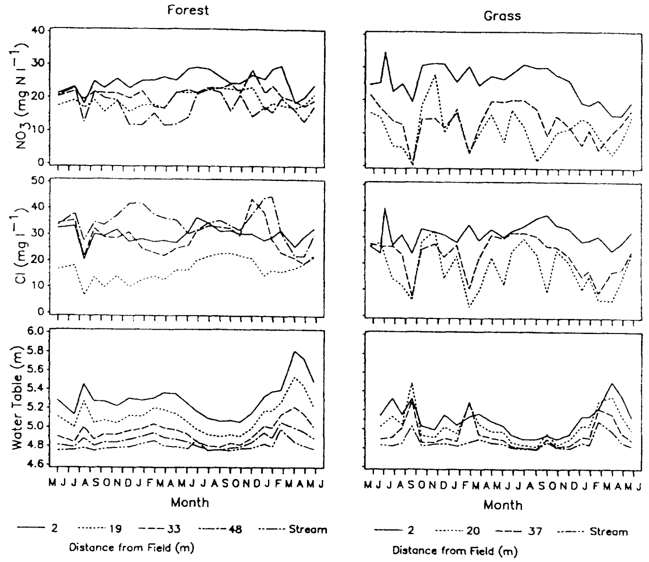

Fig. 3 Nitrate and chloride concentrations and water table elevations versus date at different distances from the crop field along transects through riparian buffers. Sampling was from May 30, 1991, to May 25, 1993. Stream water elevations are also shown with water table elevations. Elevations are relative to an arbitrary reference point.

decreased 0.3 mg N l^{-1} while dissolved organic N increased by 0.12 mg N l^{-1}. In the grassed buffer, dissolved ammonium increased by 0.1 mg N l^{-1} while dissolved organic N increased by less than 0.1 mg N l^{-1}.

Lateral flow toward the stream channel is indicated by the slope of the water table (Fig. 3). However, despite the regional presence of a clayey Chesapeake Group layer, it is possible that some groundwater from more distant source areas could have entered the riparian areas from sandy layers between the sampling depth and the clayey layer. Concentrations of Cl^- can indicate dilution by another water source or concentration by evapotranspiration. At the forested site, Cl^- decreased from about 30 mg l^{-1} at the edge of the field to 16 mg l^{-1} 19 m from the field, then increased to 36 mg l^{-1} 48 m from the field (Fig. 2). The low Cl^- at 19 m suggests possible mixing with another water source. Transient dilution of both Cl^- and NO_3^- by rain and infiltration of overland flows is suggested when low concentrations coincide with peaks in water table elevation following rain (Fig. 3). The increase in Cl^- between 19 and 48 m from the field in the forested area may be due to evapotranspiration. If so, NO_3^- concentrations should also increase, unless NO_3^- was being removed in the buffer.

Nitrate removal seemed to be less effective in the early summer than in the winter, judging from the steeper concentration gradients in winter (Fig. 3). Nitrate may be removed by denitrification, which can occur when E_h is below 300 mV (Correll & Weller, 1989). Between November and March soil E_h in the forest buffer averaged 191 mV (standard deviation=25) near well 32 and 263 mV (sd=21) near well 42.

In the grassed riparian area, Cl^- concentration decreased 42% from 30 mg l^{-1} near the field to 18 mg l^{-1} 20 m away. Over the same distance, NO_3^- dropped 56% from 25 to 11 mg N l^{-1}. Some of the NO_3^- decline may result from dilution rather than removal of NO_3^- in the riparian zone. Chloride and NO_3^- concentrations responded to transient increases in water table elevation as at the forested site (Fig. 3). However, the tranient increases in water table elevation also resulted in reversals of water table slope with the water table at 20 m and 37 m from the field higher than at the edge of the field. This suggests a faster rate of recharge of groundwater at 20–37 m from the field than at the edge of the field. Such recharge would be a possible source of dilution effects on Cl^- and NO_3^-.

The water table slopes usually indicated flow towards the stream, but the slopes were not as steep in the grassed area as in the forested area (Fig. 3). This suggests a higher rate of groundwater flow through the forest buffer than through the grassed buffer. Thus, the mass of NO_3^- removed could be higher in the forest than in the grass despite the greater change in NO_3^- concentration within the grassed buffer.

Our results clearly indicate that conditions at this groundwater/surfacewater ecotone combined to exceed its buffering capacity. The contibuting conditons included high nitrate concentrations (mean of 25 mg N l^{-1}), and high velocity of groundwater movement due to a coarse-grained substrate and fairly high water table slopes. Groundwater entering the stream channel had an average nitrate concentration of 14 or 17 mg N l^{-1} in the two areas. While this is much higher than we found in two other Coastal Plain riparian sites in Maryland (less than 1 mg N l^{-1}; Correll & Weller, 1989; Jordan *et al.*, 1993), the decrease in nitrate concentration within the riparian buffer at this site was greater than at the other two sites.

ACKNOWLEDGEMENTS

This research was supported by a grant from the National Science Foundation (BSR-89-05219) and a grant from the Governor's Research Council of Maryland.

REFERENCES

Bachman, L. J. & Wilson, J. M. (1984). *The Columbia Aquifer of the eastern shore of Maryland.* Report 40, Maryland Geological Survey, Baltimore, Maryland, United States.

Beaulac, M. N. & Reckhow, K. H. (1982). An examination of land use-nutrient export relationships. *Water Resources Bulletin,* **18**, 1013–22.

Correll, D. L. (1987). Nutrients in Chesapeake Bay. In *Contaminant Problems and Management of Living Chesapeake Bay Resources*, ed. S.K. Majumdar, L.W. Hall Jr. & H.M. Austin, pp. 298–320. Philadelphia: Pennsylvania Academy of Science.

Correll, D. L. (1991). Human impact on the functioning of landscape boundaries. In *The Role of Landscape Boundaries in the Management and Restoration of Changing Environments,* ed. M.M. Holland, P.J. Risser & R.J. Naiman, pp. 90–109. New York: Chapman & Hall.

Correll, D. L., T. E. Jordan, & Weller, D. E. (1992). Nutrient flux in a landscape: Effects of coastal land use and terrestrial community mosaic on nutrient transport to coastal waters. *Estuaries,* **15**, 431–42.

Correll, D. L. & Weller, D. E. (1989). Factors limiting processes in freshwater wetlands: an agricultural primary stream riparian forest. In *Freshwater Wetlands and Wildlife,* ed. R.R. Sharitz & J.W. Gibbons, pp. 9–23. Aiken: Savannah River Ecology Laboratory.

Faulkner, S. P., Patrick Jr., W. H., Gambrell, R. P., Parker, W. B. & Bood, B. J. (1991). *Characterization of Soil Processes in Bottomland Hardwood Wetland-Nonwetland Transition Zones in the Lower Mississippi River Valley,* Contract Report WRP-91-1, Vicksburg: United States Army Corps of Engineers, Waterways Experiment Station.

Gallegos, C. L., Jordan, T. E., & Correll, D. L. (1992). Event-scale response of phytoplankton to watershed inputs in a subestuary: Timing, magnitude and location of blooms. *Limnology and Oceanography*, **37**, 813–28.

Gilliam, J. W. & Skaggs, R. W. (1988). Nutrient and sediment removal in wetland buffers. In *Proceeding of National Wetland Symposium: Wetland Hydrology*, ed. J.A. Kusler & G. Brooks, pp. 174–7. Berne: Assoc. State Wetland Mgrs. Assoc. State Wetland Mgrs.

Haycock, N. E. & Pinay, G. (1993). Nitrate retention in grass and poplar vegetated riparian buffer strips during the winter. *Journal of Environmental Quality,* **22**, 273–8.

Jordan, T. E., Correll, D. L., Miklas, J. & Weller, D. E. (1991a). Long-term trends in estuarine nutrients and chlorophyll, and short-term effects of variation in watershed discharge. *Marine Ecology Progress Series,* **75**, 121–32.

Jordan, T. E., Correll, D. L., Miklas, J. & Weller, D. E. (1991b). Nutrients and chlorophyll at the interface of a watershed and an estuary. *Limnology and Oceanography,* **36**, 251–67.

Jordan, T. E., Correll, D. L. & Weller, D. E. (1993). Nutrient interception by a riparian forest receiving agricultural runoff. *Journal of Environmental Quality,* **22**, 467–73.

Labroue, L. & Pinay, G. (1986). Epuration naturelle des nitrates des eaux souterraines: possibilites d'application au reamenagement des lacs de gravieres. *Annals Limnologie,* **22**, 83–8.

Lowrance, R. R., Todd, R. L., Fail, J. Jr., Hendrickson, O. Jr., Leonard, R. & Asmussen, L. (1984). Riparian forests as nutrient filters in agricultural watersheds. *Bioscience*, **34**, 374–7.

Malone, T. C., Crocker, L. H., Pike, S. E. & Wendler, B. W. (1988). Influence of river flow on the dynamics of phytoplankton production in a partially stratified estuary. *Marine Ecology Progress Series,* **48**, 235–49.

Officer, C. B., Biggs, R. B., Taft, J. L., Cronin, L. E., Tyler, M. A. & Boynton, W. R. (1984). Chesapeake Bay anoxia: origin, development, significance. *Science,* **223**, 22–7.

Peterjohn, W. T. & Correll, D. L. (1984). Nutrient dynamics in an agricultural watershed: observations of the role of a riparian forest. *Ecology,* **65**, 1466–75.

Peterjohn, W. T. & Correll, D. L. (1986). The effect of riparian forest on the volume and chemical composition of baseflow in an agricultural watershed. In *Watershed Research Perspectives,* ed. D.L. Correll, pp. 244–62. Washington: Smithsonian Press.

Pinay, G. & Décamps, H. (1988). The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: A conceptual model. *Regulated Rivers: Research & Management,* **2**, 507–16.

Pinay, G. & Labroue, L. (1986). Une station d'epuration naturelle des nitrates transportes par les nappes alluviales: l'aulnaie glutineuse. *C. R. Académie Sciences de Paris*, **302**, (III), 629–32.

Schnabel, R. R. (1986). Nitrate concentrations in a small stream as affected by chemical and hydrologic interactions in the riparian zone. In *Watershed Research Perspectives,* ed. D.L. Correll, pp. 263–82. Washington: Smithsonian Press.

Turner, R. E. & Rabalais, N. N. (1991). Changes in Mississippi River water quality this century. *Bioscience,* **41**, 140–7.

INTERNATIONAL HYDROLOGY SERIES

Groundwater/Surface Water Ecotones: Biological and Hydrological Interactions and Management Options

Edited by
Janine Gibert *University of Lyon*
Jacques Mathieu *University of Lyon*
Fred Fournier *UNESCO, Division of Water Sciences*

UNESCO

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge CB2 1RP, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, United Kingdom
40 West 20th Street, New York, NY 10011-4211, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1997

Printed in the United Kingdom at the University Press, Cambridge

Typeset in 9½/13pt Times

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data

Groundwater/surface water ecotones : biological and hydrological
interactions and managment options / [edited by] Janine Gibert,
Jacques Mathieu, Fred Fournier.
p. cm. – (International hydrology series)
ISBN 0-521-57254-1 (hbk.)
1. Groundwater ecology. 2. Hydrogeology. 3. Groundwater.
I. Gibert, Janine. II. Mathieu, Jacques. III. Fournier, Frédéric.
IV. Series.
QH541.5.G76G77 1997
574.5′2632–dc20 96–18933 CIP

ISBN 0 521 57254 1 hardback