# LIVESTOCK AND PASTURE LAND EFFECTS ON THE WATER QUALITY OF CHESAPEAKE BAY WATERSHED STREAMS

David L. Correll, Thomas E. Jordan, and Donald E. Weller

## INTRODUCTION

There have been surprisingly few studies in which the effects of livestock or managed grasslands on stream water quality could be unequivocally determined. Most of the research on stream water quality examined either relatively pristine streams with forested watersheds or larger streams with complex watersheds. These larger systems usually included both point and diffuse sources from multiple land uses. When these investigators attempted to relate land-based measurements of nutrient sources to stream water quality, the analyses were usually indirect. Nutrient loadings per land area and nutrient removals as livestock harvests were used to infer that most of the nutrients were unaccounted for and thus might appear in land discharges to streams (e.g., Wanielista et al., 1977). Measurements of nutrient accumulation in soil profiles under livestock areas or in infiltrating soil water were also used to infer eventual leaching to streams (e.g., Ryden et al., 1984).

In the 1970's and early 1980's, some studies measured land discharges, both overland storm flow and ground water, from managed grasslands, pasture lands, and concentrated livestock holding areas (Table 1). It is hard to generalize from these studies, since they were usually for periods of a year or two and were in different locations. Comparisons to other land uses in the same setting and weather conditions were usually lacking, and often the water quality parameters measured were different or not well specified. An interesting summary of nitrogen losses in land drainage for pastures as a function of cattle density in Connecticut found a fairly good fit to a linear relationship, where N loss increased 100 kg/ha/year for each increase of one cow/ha (Frink, 1970). Jones et al. (1976) measured discharges from 34 watersheds in Iowa for three years and regressed the concentrations or the discharge per area of total reactive phosphate and total ammonium against the number of standard cow units per ha. These regressions were statistically significant. Correlation coefficients varied from 0.41 to 0.66, and phosphate concentrations increased by 0.67 mg P/L with each animal unit

**Table 1. Early studies of pasture land nutrient discharges.**

| Location | Time (yrs) | Paired water-sheds | Regression on land use/stock | Measured Discharge[†] | Nutrient Parameters | Reference |
|---|---|---|---|---|---|---|
| Conn. | 3 | No | Yes | V,C OF,GW | TN | Frink 1970 |
| S. Dakota | 2 | Yes | No | V,C OF | TP,NO3,TKN OrgC | Harms et al., 1974 |
| Oklahoma | 1 | Yes | No | V,C OF | TP,DTP,DPi TKN,NH4,NO3 | Olness et al., 1975 |
| Iowa | 3 | No | Yes | C OF,GW | NO3,TNH4,TPi | Jones et al., 1976 |
| N. Carolina | 2 | No | Yes | C OF,GW | TP,NO3,NH4 TKN | Duda & Finan, 1983 |

[†] V=Volume, C=Concentration, OF=Overland Storm Flow, GW=Ground Water Flow, DPi=Dissolved Ortho-Phosphate, TPi= Total Ortho-Phosphate

per ha. Duda and Finan (1983) compared nutrient discharges from ten widely scattered watersheds in North Carolina with livestock populations and land use composition. Watersheds with concentrated livestock populations discharged 5 to 10 times more nutrients. However, the ten study watersheds had only 0 to 15% pasture lands.

We are aware of three on-going, long-term studies of pasture watersheds in which comparative data were also taken simultaneously for other land uses. One near Coshoctin, Ohio, used a series of sites to examine the effects of variations in cattle populations and the rate of mineral nutrient fertilization and to compare pastures with other land uses (e.g., Chichester et al., 1979; Owens et al., 1989, 1992). A second study in New Zealand compared pastures with native forest and pine plantations and studied the effects of riparian buffers and reforestation of pastures (e.g., Cooke, 1988; Cooke and Cooper, 1988; Cooper and Thomsen, 1988; Smith, 1992). The third site is the Rhode River watershed in the Coastal Plain of Maryland (Correll et al., 1977; Correll and Dixon, 1980; Correll, 1983; Correll et al., 1984; Jordan et al., 1986; Correll et al., 1992), with recent extension to the Piedmont and Appalachian physiographic provinces on the Chesapeake Bay watershed (Correll et al., in press). One other recently published study in England deserves special mention. Nitrate losses in overland flow and ground water from 14 hectare-sized experimental pastures were measured for up to 11 years and related to fertilization rates (Scholefield et al., 1994).

We now report a long-term summary of the nutrient discharges from a Rhode River pasture watershed, compare those with discharges from nearby forested and cropland/riparian forest watersheds, and report preliminary data from 47 sub-watersheds of the Gunpowder River in the Maryland Piedmont, the Conestoga River in the Great Valley of Pennsylvania, and Buffalo/White Deer Creeks in the Ridge & Valley of Pennsylvania. These 47 sub-watersheds have been placed in three groups dominated by pasture and livestock, cropland, or forest, respectively.

## METHODS

Volume-integrated discharges of organic C, total N and P and various fractions of N and P were measured for 16 complete years for a completely forested watershed (#110) and a cropland/riparian forest watershed (#109) and for 14 complete years for a pasture-dominated watershed (#111), ending in 1993. These three Rhode River sub-watersheds are underlain with a clay aquiclude that perches local ground water and forces it to percolate to the stream channel. The stream draining each watershed was monitored with a V-notch weir with its foundations bedded into this clay aquiclude. Thus, both overland flow and ground water discharges were measured. The weirs were equipped with both volume-integrating composite samplers and fraction collectors, which were activated to take separate discrete samples at known times and stage heights during storm events. Descriptions of these watersheds, the weirs, water discharge monitoring techniques, and analytical chemistry methods have already been published (Correll, 1977, 1981, 1983; Correll et al., 1977).

Livestock population data for the pasture watershed were obtained from the farm owner. Hereford beef cattle were rotated with another pasture so that a herd averaging 0.86 cows/ha was on the watershed area 50% of the time. From late March until early October, an equal number of calves were also present. Thus, mean livestock density was 0.43 cows and 0.22 calves/ha/year. Little or no fertilizer other than livestock waste was applied. At the end of the spring of 1989, the livestock were removed, and the field was planted in pine seedlings but remained unfertilized.

For the 47 other Chesapeake Bay sub-watersheds, only data on nitrate; dissolved organic C, N, and P; and dissolved ammonium and inorganic phosphate will be given. These streams were sampled eight times from July 1992 through June 1993, and samples were immediately filtered through Millipore HA, nominal 0.4-um pore size, filters that had been prewashed with distilled water. Samples were immediately placed on ice until analysis within two weeks. Only preliminary, approximate land use composition and livestock populations are known for these watersheds (Correll et al., in press).

## RESULTS

### RHODE RIVER WATERSHED

On average less total organic C and total N and P were discharged per ha/year from the pasture than from either the forest- or cropland-dominated watershed (Table 2). However, nitrate and total phosphate-P discharges of the pasture were intermediate between those of the forest- and the cropland-dominated systems (Table 2). The same land use relationship was true, on average, for total organic C each season but not always for total N and P (Table 2). Total N and P discharges were higher for pasture than for forest in the winter. Nitrate discharges from pasture were higher than from forest in all

Table 2. Long-term mean nutrient fluxes and flux ratios from Rhode River watersheds.

| Watershed Discharge Fluxes (kg/ha) | | | | Discharge Ratios (% or atomic ratio) | | | |
|---|---|---|---|---|---|---|---|
| | Cropland | Pasture | Forest | | Cropland | Pasture | Forest |
| **A. Winter** | | | | | | | |
| Total Organic-C | 7.68 | 3.38 | 3.66 | % N | 6.38 | 7.19 | 4.81 |
| | | | | % P | 1.27 | 1.64 | 0.596 |
| Total Organic-N | 0.490 | 0.243 | 0.176 | OrgC/N/P | 200/11/1 | 160/10/1 | 430/18/1 |
| Nitrate-N | 1.28 | 0.324 | 0.0281 | InorgN/OrgN | 2.84 | 1.55 | 0.321 |
| Total Ammonium-N | 0.112 | 0.0531 | 0.0284 | InorgP/OrgP | 1.51 | 1.16 | 1.05 |
| Total Nitrogen | 1.88 | 0.620 | 0.233 | InorgN/InorgP | 20.9 | 13.0 | 5.46 |
| Total Organic-P | 0.0976 | 0.0554 | 0.0218 | TN/TP | 17.1 | 30.9 | 4.32 |
| Total Phosphate-P | 0.147 | 0.0640 | 0.0229 | | | | |
| Total Phosphorus | 0.244 | 0.1194 | 0.0447 | | | | |
| **B. Spring** | | | | | | | |
| Total Organic-C | 15.6 | 4.40 | 12.5 | % N | 8.00 | 8.18 | 5.46 |
| | | | | % P | 2.26 | 2.27 | 0.902 |
| Total Organic-N | 1.25 | 0.360 | 0.681 | OrgC/N/P | 110/7.8/1 | 110/8.0/1 | 290/13/1 |
| Nitrate-N | 1.98 | 0.310 | 0.0948 | InorgN/OrgN | 1.73 | 1.05 | 0.267 |
| Total Ammonium-N | 0.205 | 0.0675 | 0.0870 | InorgP/OrgP | 1.91 | 0.797 | 0.793 |
| Total Nitrogen | 3.44 | 0.738 | 0.863 | InorgN/InorgP | 7.16 | 10.4 | 4.53 |
| Total Organic-P | 0.353 | 0.100 | 0.113 | TN/TP | 7.39 | 9.03 | 9.51 |
| Total Phosphate-P | 0.674 | 0.0803 | 0.0889 | | | | |
| Total Phosphorus | 1.03 | 0.181 | 0.201 | | | | |
| **C. Summer** | | | | | | | |
| Total Organic-C | 10.8 | 1.72 | 5.47 | % N | 11.2 | 7.31 | 6.65 |
| | | | | % P | 6.71 | 1.55 | 1.39 |
| Total Organic-N | 1.20 | 0.126 | 0.364 | OrgC/N/P | 38/3.7/1 | 170/10/1 | 190/10/1 |
| Nitrate-N | 0.569 | 0.0259 | 0.0133 | InorgN/OrgN | 0.606 | 0.430 | 0.118 |
| Total Ammonium-N | 0.163 | 0.0282 | 0.0298 | InorgP/OrgP | 0.825 | 1.40 | 0.783 |
| Total Nitrogen | 1.94 | 0.180 | 0.407 | InorgN/InorgP | 2.99 | 3.19 | 1.84 |
| Total Organic-P | 0.723 | 0.0267 | 0.0759 | TN/TP | 3.58 | 6.21 | 7.39 |
| Total Phosphate-P | 0.542 | 0.0375 | 0.0520 | | | | |
| Total Phosphorus | 1.20 | 0.0642 | 0.122 | | | | |
| **D. Fall** | | | | | | | |
| Total Organic-C | 1.46 | 0.933 | 3.53 | % N | 10.1 | 6.46 | 6.12 |
| | | | | % P | 2.70 | 1.14 | 0.919 |
| Total Organic-N | 0.147 | 0.0603 | 0.216 | OrgC/N/P | 96/8.2/1 | 230/12/1 | 280/15/1 |
| Nitrate-N | 0.127 | 0.0111 | 0.00469 | InorgN/OrgN | 1.06 | 0.398 | 0.0671 |
| Total Ammonium-N | 0.0288 | 0.0129 | 0.00980 | InorgP/OrgP | 1.46 | 2.75 | 0.590 |
| Total Nitrogen | 0.304 | 0.0843 | 0.230 | InorgN/InorgP | 6.00 | 1.82 | 1.68 |
| Total Organic-P | 0.0395 | 0.0106 | 0.0324 | TN/TP | 7.32 | 4.68 | 10.5 |
| Total Phosphate-P | 0.0576 | 0.0292 | 0.0191 | | | | |
| Total Phosphorus | 0.0920 | 0.0399 | 0.0487 | | | | |
| **E. Complete Year** | | | | | | | |
| Total Organic-C | 36.3 | 10.1 | 25.7 | % N | 8.71 | 7.55 | 5.72 |
| | | | | % P | 3.31 | 1.85 | 0.949 |
| Total Organic-N | 3.16 | 0.763 | 1.47 | OrgC/N/P | 78/5.8/1 | 140/9.0/1 | 270/13/1 |
| Nitrate-N | 3.90 | 0.649 | 0.138 | InorgN/OrgN | 1.80 | 1.05 | 0.201 |
| Total Ammonium-N | 0.524 | 0.154 | 0.157 | InorgP/OrgP | 1.21 | 1.08 | 0.750 |
| Total Nitrogen | 7.58 | 1.57 | 1.77 | InorgN/InorgP | 6.75 | 8.80 | 3.56 |
| Total Organic-P | 1.20 | 0.187 | 0.244 | TN/TP | 6.31 | 8.94 | 9.18 |
| Total Phosphate-P | 1.45 | 0.202 | 0.183 | | | | |
| Total Phosphorus | 2.66 | 0.389 | 0.427 | | | | |

seasons, but total phosphate-P discharges were less than for forest in the spring and summer (Table 2). On average for the year, total N discharged by the pasture was 49% organic N, 41% nitrate N, and only 10% ammonium N, while total phosphorus discharged was 48% organic P and 52% inorganic phosphate P (Table 2).

Organic matter discharged from the pasture watershed had a higher percentage of N and P than organic matter discharged from the cropland or forest in the winter and spring, while the N and P content was intermediate between cropland and forest in the summer and fall (Table 2). The atomic ratio of inorganic N to organic N for pasture was intermediate between cropland and forest for all seasons, while the atomic ratio of inorganic P to organic P for pasture was higher than for the other land uses in the summer and fall but intermediate in the winter and spring (Table 2). The atomic ratio of inorganic N to P for pasture was intermediate between cropland and forest in the winter and fall but higher in the spring, summer, and overall for the year (Table 2).

Concentrations of total organic C in both overland storm and base flows were lower for pasture than for either forest or cropland (Table 3). Pasture base flow discharges had substantially higher dissolved organic C concentrations than storm flow, while storm flow had much higher particulate organic C concentrations. However, both dissolved and particulate organic C concentrations during base flow and storm flow were lower than corresponding concentrations from either forest or cropland (Table 3). Nitrate and dissolved ammonium concentrations for pasture base flow and storm discharges were intermediate between forest and cropland, but particulate ammonium concentrations in both base flow and storms were higher than for the other land uses. Dissolved organic N concentrations were lowest in pasture, but particulate organic N concentrations from pasture were highest in storm flow and intermediate for base flow (Table 3).

Dissolved phosphate concentrations during storms were higher from pasture than from forest or cropland, but base flow concentrations were 50% higher in forest than in pasture discharges (Table 3). Particulate phosphate concentrations were intermediate for pasture both in base flow and storm flow. Dissolved organic P concentrations from pasture were highest during base flow and lowest during storm events (Table 3). Particulate organic P concentrations from pasture were intermediate for both base flow and storm events.

Time series plots of volume-weighted mean seasonal nutrient concentrations of N (Figure 1) and P fractions (Figure 2) show both the seasonality and the high interannual variability in nutrient discharges for the pasture land watershed. Changes in N and P concentrations were often unrelated. For example, high N concentrations in 1977-78 were coincident with rather low P concentrations; however, P concentrations were high in 1988, but N concentrations were rather low.

Table 3. Mean proportions of nutrients in dissolved and particulate phases during storm events (Storm) and baseflow (Base) conditions. Concentrations are given in mg C, N, or P per liter.

| | Cropland | | Pasture | | Forest | |
|---|---|---|---|---|---|---|
| Nutrient Fraction | Base | Storm | Base | Storm | Base | Storm |
| Diss. Organic-C | 10.2 | 9.8 | 9.94 | 5.80 | 23.6 | 27.3 |
| Part. Organic-C | 18.4 | 77.3 | 11.7 | 20.6 | 13.1 | 33.9 |
| Total Organic-C | 28.6 | 87.1 | 21.6 | 26.4 | 36.7 | 61.2 |
| | | | | | | |
| Nitrate | 1.21 | 1.61 | 0.201 | 0.402 | 0.0549 | 0.140 |
| Diss. Ammonium | 0.173 | 0.146 | 0.143 | 0.097 | 0.0856 | 0.0734 |
| Part. Ammonium | 0.0206 | 0.0291 | 0.0289 | 0.0520 | 0.0095 | 0.0501 |
| Diss. Organic-N | 0.165 | 0.461 | 0.0583 | 0.258 | 0.261 | 0.495 |
| Part. Organic-N | 0.538 | 2.51 | 0.350 | 2.90 | 0.266 | 0.892 |
| Diss. Total-N | 1.55 | 2.22 | 0.402 | 0.757 | 0.402 | 0.708 |
| Part. Total-N | 0.559 | 2.54 | 0.379 | 2.95 | 0.276 | 0.942 |
| Total-N | 2.11 | 4.76 | 0.781 | 3.71 | 0.678 | 1.65 |
| | | | | | | |
| Diss. Phosphate-P | 0.0210 | 0.0279 | 0.0212 | 0.0346 | 0.0331 | 0.0227 |
| Part. Phosphate-P | 0.230 | 0.821 | 0.161 | 0.150 | 0.0785 | 0.0628 |
| Diss. Organic-P | 0.0107 | 0.0204 | 0.0145 | 0.0146 | 0.0120 | 0.0416 |
| Part. Organic-P | 0.202 | 1.45 | 0.0793 | 0.606 | 0.0371 | 0.224 |
| Diss. Phosphorus | 0.0317 | 0.0483 | 0.0357 | 0.0492 | 0.0451 | 0.0643 |
| Part. Phosphorus | 0.432 | 2.27 | 0.240 | 0.756 | 0.116 | 0.287 |
| Total Phosphorus | 0.464 | 2.32 | 0.276 | 0.805 | 0.161 | 0.351 |
| | | | | | | |
| % Diss. Organic-C | 35.7 | 11.3 | 46.0 | 22.0 | 64.3 | 44.6 |
| % Diss. Ammonium | 89.4 | 83.4 | 83.2 | 65.1 | 90.0 | 59.4 |
| % Diss. Organic-N | 23.5 | 15.5 | 14.3 | 16.8 | 49.5 | 35.7 |
| % Diss. Phosphate | 8.4 | 3.3 | 11.6 | 18.7 | 29.7 | 26.5 |
| % Diss. Organic-P | 5.0 | 1.4 | 15.5 | 2.4 | 24.4 | 15.7 |

## PIEDMONT AND APPALACHIAN WATERSHEDS

Dissolved nutrient concentrations in base flow from pasture-, cropland-, and forest-dominated watersheds in the Piedmont and Appalachian (PAP) physiographic provinces of the Chesapeake Bay watershed (Table 4) can be compared with analogous data from Rhode River (RR) watersheds (Table 3). Dissolved organic C concentrations in pasture-dominated PAP drainages were 59% higher than for the RR pasture watershed, while dissolved organic C was about the same for cropland watersheds in both places and was much lower for forested PAP drainages. The dissolved organic matter from the pasture-dominated PAP streams also contained over three times as much N but only 68% as much P as the organic matter from the pasture RR watershed. Differences in composition of dissolved organic matter had different patterns for the other land uses. Thus forested PAP watersheds discharged organic matter containing only 39% more N, but almost four times as much P, while cropland PAP watersheds released organic matter with 44% more N, but only 5% more P than RR watersheds (Tables 3, 4).

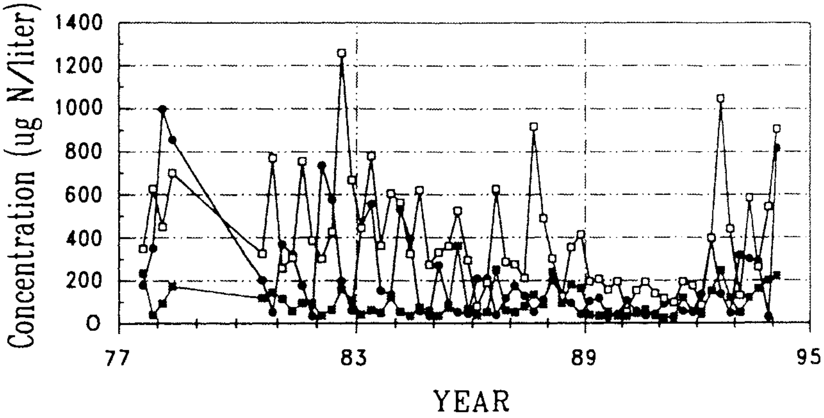

Figure 1. Seasonal volume-weighted concentrations of nitrate (solid points), total ammonium (shaded squares), and total organic N (open squares) in combined overland storm and perched ground water discharges from a Rhode River pasture land watershed (# 111). Beef cattle at an average density of 0.43 cows and 0.22 calves grazed the pasture until livestock were removed in spring of 1989. No mineral fertilizers were applied. No data were taken from the spring of 1978 until the summer of 1980.

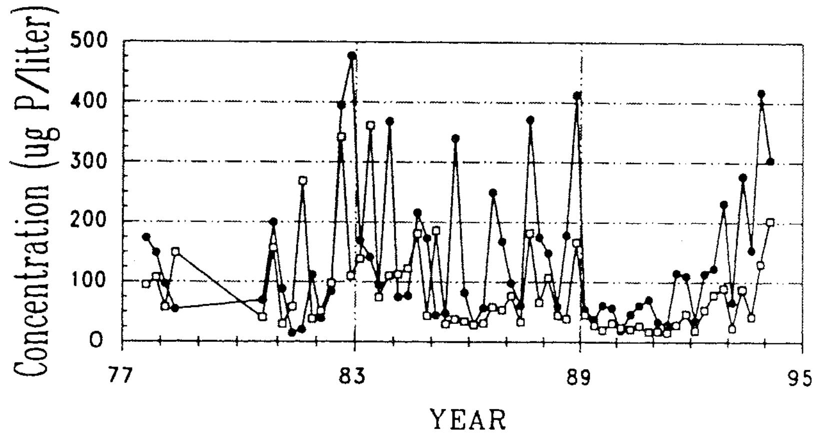

Figure 2. Seasonal volume-weighted concentration of total phosphate P (solid points) and total organic P (open squares) in combined overland storm flow and perched ground water discharges from a Rhode River pasture land watershed (# 111). Land management as in Figure 1.

Table 4. Dissolved nutrient concentrations in streams draining Piedmont and Appalachian Regions of the Chesapeake Bay watershed. Values are annual means ± 1 standard deviation.

| Nutrient Parameter | Cropland-Dominated (17 streams) | Pasture-Dominated (13 streams) | Forest-Dominated (17 streams) |
|---|---|---|---|
| Organic C (mg C/L) | 9.78±1.07 | 15.8±2.70 | 8.13±1.76 |
| Organic C | | | |
| (% N) | 2.33±0.52 | 1.86±0.51 | 1.54±1.51 |
| (% P) | 0.11±0.01 | 0.10±0.03 | 0.20±0.20 |
| Nitrate (mg N/L) | 5.58±2.57 | 7.99±4.17 | 0.54±0.51 |
| Ammonium (ug N/L) | 79.4±71.4 | 117±100 | 21.3±16.9 |
| Organic N (ug N/L) | 229±59.4 | 290±85.0 | 125±26.4 |
| Phosphate (ug P/L) | 25.3±21.7 | 55.1±43.2 | 6.32±9.27 |
| Organic P (ug P/L) | 10.6±1.64 | 15.4±4.77 | 16.1±16.6 |
| Atomic Ratio (DIN/DIP) | 942 | 653 | 314 |
| Atomic Ratio (OrgC/OrgN/OrgP) | 4800/83/1 | 6300/120/1 | 4000/55/1 |

Nitrate concentrations for pasture-dominated PAP watersheds were very high, comprising most of the dissolved nitrogen, and were 40 times higher than RR pasture lands (Tables 3, 4), but dissolved ammonium concentrations were somewhat lower for the pasture-dominated PAP watersheds than for RR. Dissolved organic N concentrations were about five times higher in pasture-dominated PAP streams than in the RR pasture stream. Dissolved phosphate concentration in PAP pasture watersheds was more than double that of the RR pasture, but dissolved organic P was about the same concentration in both. The atomic ratio of dissolved inorganic N to dissolved inorganic P was 650 for pasture PAP systems but only 36 for the pasture RR system. The atomic ratios of organic C to N to P were also much higher for pasture PAP systems (6300/120/1) than for pasture RR system (1800/8.9/1).

## DISCUSSION

Our results seem to suggest several generalizations about water quality effects of livestock management in the mid-Atlantic region. First, the mere maintenance of managed grassland in this region where forest is the natural vegetative cover may result in some significant, but not very dramatic, differences in the nutrient composition of streams. For the Rhode River site, pasture lands, even when not grazed, have lower discharges per unit area of organic C, N, and P and higher discharges of nitrate and inorganic phosphate than undisturbed mature forest lands (Tables 2, 3). However, there was only one of each type of watershed available for comparison at the Rhode River site. Therefore, it is uncertain whether the differences arise from land use effects or other unknown factors. When grazing was discontinued on the Rhode River pasture in spring of 1989, there were no major changes in nutrient discharges (Figures 1, 2). The apparent decline in nutrient concentrations for the first few years after grazing was discontinued, and the subsequent increases in nutrient concentrations may or may not have been long-term effects of altered land management.

A second generalization seems to be that high nitrate discharges from intensively managed pasture lands may be the result of high rates of fertilization with mineral fertilizer and/or high inputs of nitrogen as winter feed supplements as reported by Owens et al. (1992) and Scholefield et al. (1994). Our nutrient concentration data for Piedmont and Appalachian watersheds (Table 4) dominated by livestock could be converted to rough estimates of flux by assuming that the combination of overland storm flow and ground water discharge was 35 cm/year, a value typical for this region (Correll, 1982). These pasture-dominated watersheds discharged approximately 28 kg nitrate N, 0.41 kg dissolved ammonium N, and 1.0 kg dissolved organic N/ha/year, respectively. This is a much higher rate for nitrate than the long-term average of 0.65 for the Rhode River pasture (Table 2) but lower than nitrate losses of 38.5 to 134 kg N/ha/year to ground water from pastures fertilized with 200 to 400 kg mineral N/ha/year (Scholefield et al., 1994). Ground water discharges from a New Zealand pasture (0.29 nitrate N, 0.05 ammonium N, and 0.81 organic N) were similar to those from the Rhode River pasture (Cooper and Thomsen, 1988). It would seem that the nitrogen discharges reported by Frink (1970), 60 to 230 kg N/ha/year, were unusually high.

It should be noted that in the Piedmont and Appalachian regions we sampled, it is common practice to allow livestock access to stream channels and sometimes even to fence them into stream channel/riparian areas during the day, while at the Rhode River site cattle were fenced out of the stream most of the time. Some of the Appalachian sites studied have among the highest livestock densities found in the United States (Correll et al., in press).

## SUMMARY

Managing land for livestock production has significant effects on stream water quality. Even if a mid-Atlantic coastal watershed is managed only to maintain it as a grassland, the water quality of the streams will be altered in comparison with a watershed allowed to remain in the natural forest vegetation for this region. When livestock are managed at high densities using mineral fertilizers and imported food, the quality of both overland storm flow and ground water moving from these lands to local streams will be seriously affected.

There is a need for more information on the effects of livestock production on stream water quality. Studies need to be designed to accurately and quantitatively relate stream water quality to both overland storm discharges and ground water infiltration from livestock production areas. Good hydrologic data, as well as a complete suite of water quality parameters, should be measured on representative samples. Such studies need to be long-term in order to observe the effects of variations in weather. Livestock and land management practices need to be better documented.

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*Edited by*
Kenneth Steele

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