J. Range Manage.
52:615-620 November 1999

Nitrogen dynamics in stream and soil waters

JOHN D. STEDNICK AND A. G. FERNALD

Authors are professor Watershed Science Program, Department of Earth Resources, Colorado State University, Fort Collins, Colo. 80523-1482 and research fellow US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Ore. 97333, respectively.

Abstract

The mountainous riparian corridor performs important hydrologic functions including nutrient transfers between the terrestrial (upslope) and aquatic (stream) ecosystems. Nitrate-nitrogen and ammonium-nitrogen concentrations were determined on water samples collected in 1993 and 1994 from a montane riparian zone in Northern Colorado. Soil water samples were collected from the riparian corridor and upslope systems, under both losing (summer reservoir releases) and gaining (spring snowmelt runoff) streamflow conditions. Statistical analyses using least square means contrasts were made to identify spatial and temporal differences between: 1) the upslope system and the riparian corridor, 2) the upslope system and the stream, and 3) the riparian corridor and the stream. The Sheep Creek riparian corridor may serve as a sink for nitrate-nitrogen in both gaining and losing streamflow conditions, and as a source for ammonium nitrogen in gaining streamflow conditions. The length of the source or sink period is relatively short and is not meant to suggest differences in site productivity. Streamflow generation mechanisms help determine if the riparian corridor is a nutrient sink or source.

Key Words: riparian area, water quality, ammonium, nitrate, streamflow, lysimetry

Resumen

El corredor ribereño montañoso ejerce importantes funciones hidrológicas incluyendo la transferencia de nutrientes entre los ecosistemas terrestres (pendiente arriba) y los ecosistemas acuáticos (arroyos). Se determinaron las concentraciones de nitratos (NO3-_N) y amonio (NH4—N) en muestras de agua colectadas en la zona ribereña montañosa del norte de Colorado durante 1993 y 1994. Las muestras de agua se tomaron del corredor ribereño y en sistemas de pendiente arriba bajo condiciones de perdida (liberación de las represas en verano) o ganancia (escurrimientos de nieve derretida en primavera). Se realizaron análisis estadísticos utilizando contrastes de medias de mínimos cuadrados para identificar diferencias en espacio y tiempo entre: 1) el sistema de pendiente arriba y el corredor ribereño, 2) el sistema de pendiente arriba y arroyos y 3) el corredor ribereño y arroyos. El corredor ribereño "Sheep Creek" puede servir como almacén para los nitratos en ambas condiciones, de perdida o ganancia y como fuente de amonio en condiciones de ganancia. La longitud del período de fuente o almacén es relativamente corta y no es la intención sugerir diferencias en productividad del sitio. Los mecanismos de generación de la corriente ayudan a determinar si el corredor ribereño es fuente o almacén de nutrientes.

Riparian corridors have received considerable attention for their potential to reduce or eliminate water quality changes from upslope land use activities. Riparian vegetation buffer strips can reduce the amount of sediment (Pearce et al. 1998), nutrients (Green and Kauffman 1989, Gold and Groffman 1995), or pesticides (Morris 1991, Jordan et al. 1993) that may reach surface waters from upslope activities. Watersheds are a hydrologic and ecologic system of interconnected components overlaid by numerous land-use activities (Duttweiler and Nicholson 1983), most concentrated along the riparian corridor.

The riparian corridor is the aquatic-terrestrial interface. The soils of the riparian corridor include areas that may be submerged part of the year, and the interface occurs as a result of the headward and lateral expansion and contraction of stream area on the time scale of storms and seasons (Swanson et al. 1982). The riparian corridor is an immediate source of all streamflow output from a watershed. Since the riparian corridor has a greater perimeter to area ratio than upslope ecosystems, the streamside zone readily interacts with adjacent ecosystems (Lowrance et al. 1985). The maximum contact occurs in smaller or first order streams common in mountainous areas. The ability of the riparian corridor to act as a source or a sink for nutrients is influenced by the immediate interaction between the riparian corridor and the stream, and the movement of groundwater between the riparian corridor and the stream. The riparian corridor that borders upslope ecosystems is an important site for nitrogen processing (Whigham et al. 1988).

One feature that separates the riparian corridor from terrestrial ecosystems is the potential anaerobic condition of their flooded soils, which alters the relative importance of various microbial transformations of inorganic and organic nitrogen compounds (Morris 1991). Anaerobic soils lack sufficient oxygen to continue the process of nitrification, and flooded soils have high losses of nitrate-nitrogen through denitrification (Brady 1984). Ammonium-nitrogen production would be expected in anaerobic conditions.

Two important factors, soil texture and water movement from upslope areas to the stream or from the stream to riparian groundwater, help regulate the movement of ammonium- and

Manuscript accepted 18 Jan. 1999.

nitrate-nitrogen through the riparian corridor. Soil porosity controls the maximum amount of water that can be held by the soil. Material with coarser grain sizes (sands) have larger pores allowing water to drain more easily and quickly toward the groundwater table. Finer sands and silts have smaller pores with stronger capillary forces to retain the water.

Snowmelt and the subsequent flow generation mechanisms results in water flowing toward the stream resulting in a gaining stream. During reservoir releases the channel is a losing stream, where the water table is higher in the stream than the adjacent land. The nutrient relationship between upslope ecosystems and the riparian corridor is partially controlled by hydrologic fluxes, which are defined as the movement of water, nutrients, and sediment between these 2 ecosystems. Hydrologic fluxes are a composite of many different biogeochemical processes, which act collectively to alter and usually improve the quality of surface waters (Hemond and Benoit 1988). Do changes in streamflow generation mechanisms affect water quality?

We evaluated the riparian corridor as a potential sink or source of nitrate-nitrogen and ammonium-nitrogen under gaining and losing streamflow conditions. Specific study objectives were: 1) to measure concentrations of nitrate-nitrogen and ammonium-nitrogen in streamwater, and soil waters in the riparian and upslope ecosystem; 2) to relate these concentrations to streamflow generation mechanisms; and, 3) to determine sink-source relations for these nitrogen species in the riparian corridor.

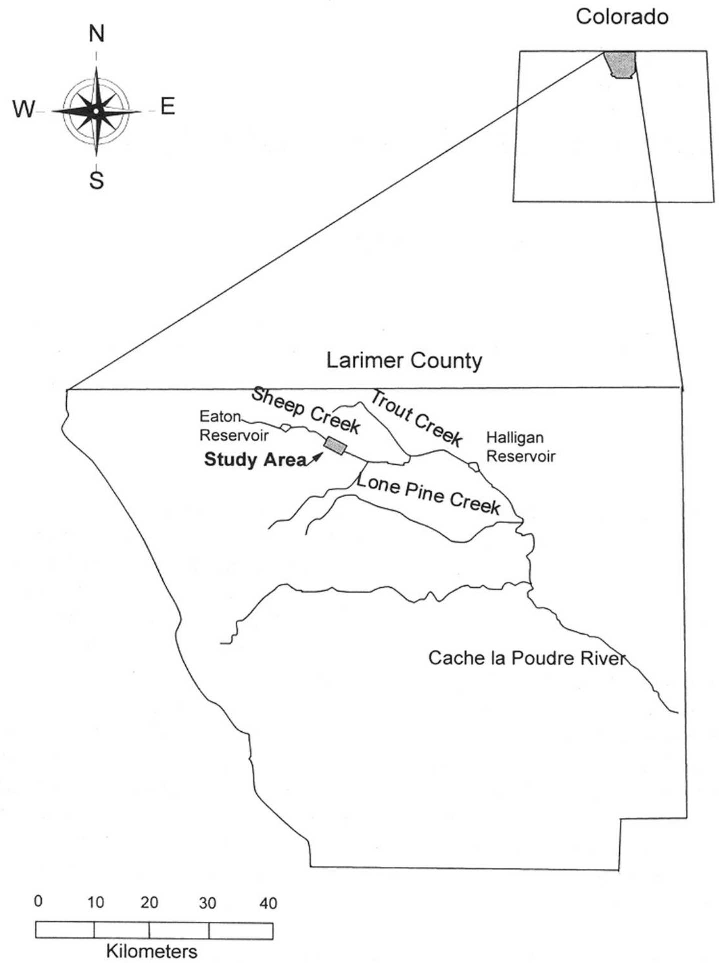

Fig. 1. Location map of Sheep Creek in relation to Larimer County and State of Colorado.

Methods and Materials

Study Site Description

The study area was the riparian corridor and adjacent upslope ecosystems of upper Sheep Creek, Colo. (Fig. 1). Sheep Creek is in the Roosevelt National Forest, located in Larimer County, approximately 80 km northwest of Fort Collins, Colo. Sheep Creek flows southeasterly to merge with the North Fork of the Cache la Poudre River. The Sheep Creek study sites are 2,560 m above sea level. The watershed area above the study cross sections is 76.1 square kilometers.

Climatic data from nearby Redfeather Lakes (EarthInfo 1992) were used to characterize the area. Precipitation occurs year round, with snow accumulation during colder periods. Snowmelt usually begins in April. Summer precipitation is usually as thunderstorms.

The Sheep Creek watershed is dominated by Precambrian felsic and hornblendic gneisses (Braddock and Cole 1978). These metamorphic rocks may have been derived from volcanic rocks. The riparian corridor and upslope ecosystems contain alluvium deposited during the Quaternary period consisting of unconsolidated silt, sand and gravel and includes colluvium along the valley walls (Braddock et al. 1989).

Soils

Watershed soils include the Naz sandy-loam, the Redfeather sandy-loam, Schofield-Redfeather Rock outcrop, and the Haploborolls-Rock outcrop complex (U.S. Soil Conservation Service 1980). The Naz sandy-loam (Pachic cryoboroll) is the predominant soil in the riparian corridor and upslope ecosystems adjacent to the stream. It is a deep (76 to 154 cm depth to bedrock), gently sloping (3 to 25% slope), well-drained soil found on terraces and valley sides with moderately rapid permeability and medium available water holding capacity.

Vegetation

The vegetation of the Sheep Creek riparian zone consists of willows (*Salix* spp.), shrubby cinquefoil (P*otentilla fruticosa* L.), several carex (*Carex* spp.), rushes (*Juncus* spp.), Kentucky bluegrass (*Poa pratensis* L.), fowl bluegrass (*Poa palustris* L.), tufted hairgrass (*Deschampsia caespitosa* (L. Beauv.), and other minor species (Schulz and Leininger 1990). Upslope vegetation is widely spaced lodgepole pine (*Pinus contorta* Dougl.).

Hydrology

The annual hydrograph has 2 distinct peaks. The peakflow occurring in

April–May is the result of snowmelt. Releases from a reservoir approximately 5 km upstream from the study area causes a peak in July–August. The exact date of the water release depends on the precipitation during the preceding spring and summer as well as the time when this and other downstream dams reach full capacity. The Eaton Reservoir has a storage capacity of 4.6 million cubic meters. The rate of water release is 1.5 cubic meters per second (cms) for approximately 35 days[1]. Frequent summer thunderstorms are usually spatially isolated and do not result in streamflow responses.

Procedures

Field Procedures

A staff gauge located at the head of a riffle with near vertical streambanks measured stage. Streamflow discharge measurements were taken weekly using a Price current meter for the highflows and a Pygmy meter for low flows (U.S. Geological Survey 1978) to develop a stage-discharge relationship. Stream discharge estimates were made from stage observations.

Three different transects were established at approximately 500 m intervals along Sheep Creek. These cross sections included the stream and riparian and upslope environments. All had similar land use (grazing) and stream morphological characteristics.

At each transect, four, 50 mm diameter ceramic tension cup lysimeters were inserted approximately 30 cm (near the bottom of the soil B horizon) into the ground to collect soil water samples. A depth of 30 cm was chosen since the movement of nitrate-nitrogen occurs primarily in the upper layers of the soils (Lowrance 1992). The lysimeter transects were perpendicular to the stream. The first lysimeter was placed in the riparian corridor and other lysimeters placed 2–5 m apart to collect waters from the upland ecosystem. After each lysimeter was placed into the ground, the hole was backfilled with native soils collected from the lysimeter excavation to prevent water piping. Lysimeters were evacuated by a hand pump. As soil waters were collected, the lysimeter vacuum decreased over time. Time to collect sufficient soil water sample volumes for chemical analysis increased as the soils dried. Sampling intervals ranged from 6 days up to 4 weeks. Lysimeter water samples were pumped out of the lysimeter into plastic sampling bottles. Grab samples were taken from the stream near the lysimeter transect. Samples were iced until delivery to the lab the same day (Stednick 1991). Samples were filtered and frozen until sample analysis.

Water surface elevations were measured in observation wells and related to stream elevation. Water surface elevation profiles were used to define streamflow generation mechanisms of flows from the streambank (gaining) or into the streambank (losing).

Laboratory Analysis

Water quality samples were analyzed for ammonium-nitrogen and nitrate-nitrogen at the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, Colo. Higher ammonium values (>0.1 mg liter-1) were measured using the Lachat QuikChem 4200 Automated Ion Analyzer, however most samples were determined on the Waters 510 HPLC Pump and Waters 431 Conductivity Detector. The Waters ion chromatograph uses ion exchange to separate cations from anions and the Lachat uses a colorometric reaction with 0.01 and 0.001 mg liter^{-1} ammonium detection limits respectively. The nitrate detection limit was 0.01 mg liter^{-1}[1,2]. Due to budgetary constraints only ammonium- and nitrate-nitrogen were analyzed, coupled with the fact that nitrogen flux should be dominated by these species.

Approximately 10% of all samples were analyzed for quality assurance/quality control and included duplicates, blanks, and spikes. Duplicate samples were randomly collected.

Statistical Analysis

Least squares means were calculated for each sampling location (stream, riparian lysimeters, and upslope lysimeters) for both ammonium- and nitrate-nitrogen. The least squares mean is the expected value of the mean if the design were balanced (SAS/STAT 1989). It is calculated by fitting a general linear model to the data and adding up combinations of parameter estimates for each class of each parameter in the linear model. This allowed comparison of nitrogen concentrations at a distance from the stream to be effectively averaged over the 3 transects. Contrasts were calculated to test the null hypothesis that stream concentrations of ammonium- and nitrate-nitrogen equal lysimeter concentrations. Data distributions were not tested for normality due to the relatively small sample size. The least squares mean test is not dependent on data distribution.

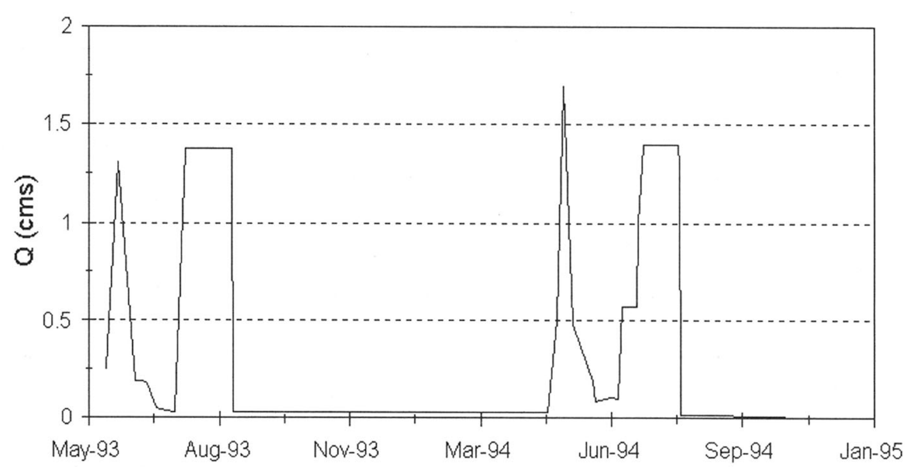

Fig. 2. Annual hydrograph for Sheep Creek for 1993 and 1994.

[1]Wilkes, Edward. 1991. Personal communication. Divide canal and Reservoir Company, Eaton, Colo.

[2]O'Deen, Louise. 1996. Personal communication. USDA Forest Service. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Results and Discussion

Streamflow

The snowpack restricted site access until after snowmelt, thus no water quality samples were collected prior to snowmelt and increased streamflow. The sharp peakflows in May 1993 and April 1994 represent snowmelt (Fig. 2). Streamflows peak quickly as the snowpack melts. These conditions create a gaining streamflow condition. The free water surface (measured in observation wells) slopes from the hillslope to the channel.

The hydrographs during reservoir release had flat tops (Fig. 2). The Eaton Reservoir releases water (when senior water right holders call for the water downstream) at 1.5 cubic meters per second until the storage pool is emptied. Streamflows under these conditions create a losing stream where the free water surface decreases from the stream to the hillslope (Panayotou 1992, Stednick unpublished data). Water elevation changes were consistent between years and reflected the source of the peak hydrographs. The different streamflow generation mechanisms allow for clear discrimination of water quality data between losing and gaining streamflow conditions.

Ammonium-nitrogen

Ammonium-nitrogen concentrations were not correlated to time or streamflow for either year (Fig. 3), thus water quality data were pooled by location (stream, riparian, or upslope) for evaluation. In general, losing streamflow conditions had lower ammonium-nitrogen concentrations than gaining conditions (Table 1). Differences between the mean and median values suggest that these water quality data may be skewed. Most sample analyses were near detection limits with a few samples with relatively high concentrations (>1.0 mg N liter^{-1}).

Significant least squares means contrasts for ammonium-nitrogen occurred between the streamwater, riparian corridor and upslope lysimeters for the gaining streamflow period (Table 1). Ammonium-nitrogen concentrations were higher in the riparian soil water than in the stream or upslope soil water in gaining conditions. Therefore, the riparian corridor may be considered a source for ammonium-nitrogen during gaining streamflow conditions. Ammonium-nitrogen was higher in the riparian and upslope soil waters than the

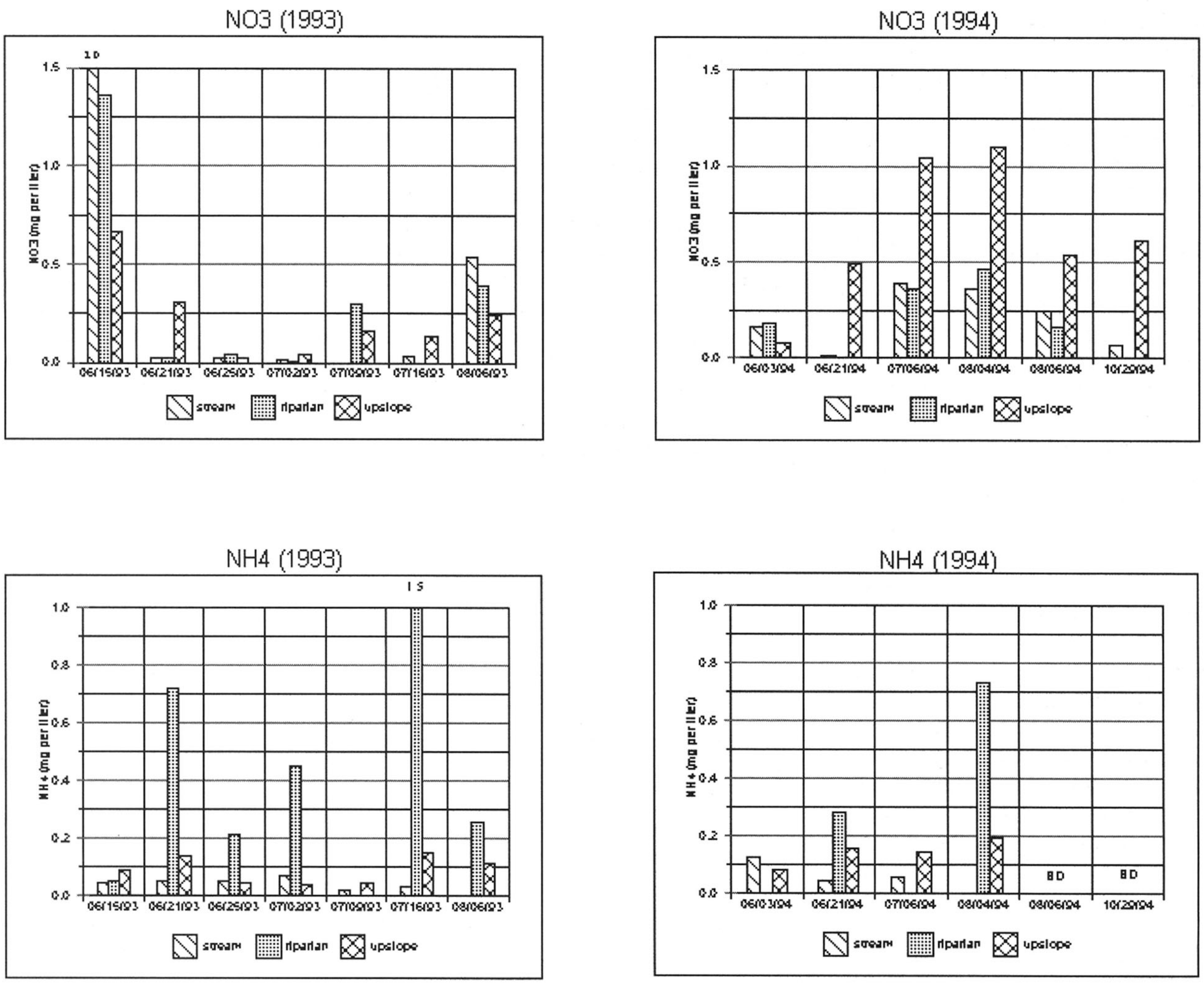

Fig. 3. Stream and lysimeter ammonium- and nitrate-nitrogen concentrations. Sheep Creek 1993 and 1994. BD represents concentrations below analytical detection limits.

Table 1. Summary statistics for ammonium- and nitrate-nitrogen (mgN liter-1) in stream, riparian, and upslope soil waters under gaining and losing streamflow conditions. Significant differences (p<0.05) designated by different letters.

	Stream		Riparian		Upslope	
	gaining	losing	gaining	losing	gaining	losing
Ammonium-nitrogen						
sample size(n)	16	6	9	6	28	16
mean (mg liter^{-1})	0.06a	0.04a	0.52b	0.15c	0.10c	0.18abc
median(mg liter^{-1})	0.04	0.02	0.45	0.05	0.06	0.03
range (mg liter^{-1})	0.01–0.13	0.01–0.06	0.03–1.5	0.01–1.0	0.01–0.34	0.01–1.0
SD						
Nitrate-nitrogen						
sample size (n)	14	16	9	8	20	20
mean (mg liter^{-1})	0.30a	0.26a	0.24a	0.31a	0.61a	0.62a
median (mg liter^{-1})	0.03	0.26	0.02	0.36	0.01	0.33
range (mg liter^{-1})	0.01–1.96	0.01–0.52	0.01–1.36	0.01–0.46	0.01–1.61	0.02–1.98
SD	0.66	0.19	0.44	0.15	0.87	0.61

stream in losing streamflow conditions. Thus the riparian can be considered a sink for ammonium-nitrogen in losing streamflow conditions. The discussion of nutrient sinks or sources should not imply nor suggest site productivity differences.

Nitrate-nitrogen

There were no differences between nitrate-nitrogen concentrations in the streamwater and any of the soil waters (Table 1). Nitrate-nitrogen concentrations were not correlated to time or streamflow. Nitrate-nitrogen concentration data were variable, with infrequent but high (> 1.0 mg liter^{-1}) concentrations. The median may better represent the central tendency of these samples. Although the means are not statistically different, the median concentration values suggest that the riparian corridor is a sink for nitrate-nitrogen for upslope soil waters in both gaining and losing streamflow conditions and a sink for nitrate-nitrogen for streamwater in gaining streamflow conditions. These data are consistent with our current understanding of nutrient cycling in the riparian corridor.

If nitrogen concentrations were higher in the stream than the riparian corridor, the riparian corridor was considered a sink and vice versa. The riparian corridor has been reported as both a source and a sink for nutrients, depending on the characteristics of the individual riparian corridor (Devito et al. 1989, Triska et al. 1994). Nutrient loading rates are dictated by wetland topography, hydrology, and vegetation type (Hemond and Benoit 1988). To classify the riparian corridor as either a sink or a source of nutrients, a nutrient budget must be calculated. Reliable nutrient budgets are difficult to compute as a result of nutrient dynamics (variation), and uncertainties in hydrologic data and in nutrient measurements (Devito et al. 1989). However, the bulk of the nitrogen flux will be as ammonium- and nitrate-nitrogen; and the water elevation profiles will define soil water movement direction not rates.

The variability of the ammonium- and nitrate-nitrogen concentrations over time and space do not allow for categorical conclusions at Sheep Creek, however these study results suggest patterns and processes similar to other studies. Significant spatial and temporal variations in nitrogen concentrations are common (Gold and Groffman 1995). The degree of nitrate-nitrogen production varies in the soil and there is no relationship between stream nitrate-nitrogen and soil nitrate-nitrogen levels (Gosz 1978). Nitrate production occurs easily under oxidizing conditions, and nitrate moves easily in subsurface waters (Lowrance et al. 1985) and in moderately-well and well-drained soils (Jacobs and Gilliam 1985) common in the Sheep Creek Watershed.

Conclusions

Annual streamflows in Sheep Creek present a unique opportunity to study the influence of streamflow generating mechanisms on water quality. Two annual peaks are generated; one from snowmelt and the other by a storage reservoir release. The peakflows create a gaining (snowmelt) streamflow condition and a losing (reservoir release) streamflow condition. Water quality samples were collected for 2 years from stream water and soil waters by grab samples and tension cup lysimetry respectively.

Ammonium- and nitrate-nitrogen concentrations were generally low, although anomalously high (>1 mg liter^{-1}) concentrations were measured in a few lysimeter samples. There were no correlations between ammonium-nitrogen and nitrate-nitrogen concentrations and streamflow or time. Variability in both ammonium-nitrogen and nitrate-nitrogen concentrations was large.

Nonetheless, streamflow generation mechanisms appear to influence water quality. The Sheep Creek riparian corridor serves as a sink for nitrate-nitrogen in both gaining and losing streamflow conditions. Median nitrate-nitrogen concentrations were lower in the riparian water samples than samples from stream or upslope lysimeters. The riparian corridor appears to serve as a source of ammonium-nitrogen in gaining streamflow conditions. The length of the source or sink period is relatively short and is not meant to suggest differences in site productivity.

Literature Cited

Braddock, William A. and J.C. Cole, 1978. Preliminary Geologic Map of the Greeley 1 Degree by 2 Degree Quadrangle, Colorado and Wyoming. USDI Geol. Surv. pp. 78–532.

Braddock, W.A., J.C. Cole, and D.H. Eggler, 1989. Geologic Map of the Diamond Peak Quadrangle, Larimer County, Colorado, and Albany County, Wyoming. USDI Geol. Surv., Miscellaneous Investigation Series, 1614. l pp.

Brady, Nyle C., 1984. The nature and properties of soils. New York, N.Y.Macmillan Publ Co. 618 pp.

Devito, K.J., P.J. Dillon, and B.D. Lazerete, 1989. Phosphorus and nitrogen retention in five Precambrian shield wetlands. Biogeochem. 8:185–204.

Duttweiler, D.W. and H.P. Nicholson, 1983. Environmental problems and issues of agricultural nonpoint source pollution. ed. Frank W. Schaller and George W. Bailey. Agr. Manage. and Water Quality. Iowa State Univ. Press. pp. 3–16.

EarthInfo, Inc., 1992. National Climatic Data Center Summary of the Day West 1, Boulder, Colo.. Compact Disc.

Gold, A.J. and P.M. Groffman, 1995. Groundwater nitrate removal in riparian buffer zones. *In:* Clean Water-Clean Environment-21st Century. Team Agr. Working to Protect Water Res. Vol. 2, Nutrients. ASCE, St. Joseph, Mich. pp. 63–66.

Gosz, J.R., 1978. Nutrient inputs to stream water from forests along an elevational gradient in New Mexico. Water Res. 12:725–734.

Green, D.M. and J.B. Kauffman 1989. Nutrient cycling at the land-water interface: The importance of the riparian zone. *In:* Practical Approaches to Riparian Resource Management: An Educational Workshop. Amer. Fis. Soc. pp. 61–68.

Hemond, H.F. and J. Benoit, 1988. Cumulative impacts on water quality functions of wetlands. Environ. Manage. 12(5):639–653.

Jacobs, T.C. and J.W. Gilliam, 1985. Riparian losses of nitrate from agricultural drainage waters. J. Environ. Qual. 14(4):472–478.

Jordan, T.E., D.L. Correll, and D.E. Weller, 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. J. Environ. Qual. 22:467–473.

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

Lowrance, R.R., R. Leonard, and J. Sheridan, 1985. Managing riparian ecosystems to control nonpoint pollution. J. Soil and Water Cons. 40:87–91.

Morris, J.T., 1991. Effects of nitrogen loading on wetland ecosystems with particular reference to atmospheric deposition. Amer. Rev. Ecol. Syst. 22:257–279.

Panayotou, D.Y., 1992. Seasonal patterns of nitrate-nitrogen in the Sheep Creek riparian corridor. M.S. Thesis. Dept of Earth Res., Colorado State Univ., Fort Collins, Colo. 75 pp.

Pearce, R.A., G.W. Frasier, M.J. Trlica, W.C. Leininger, J.D. Stednick, and J.L. Smith. 1998. Sediment filtration in a montane riparian zone under simulated rainfall and overland flow conditions. J. Range Manage.51:309–314.

SAS/ STAT, 1989. User's Guide. Version 6. Fourth Edition, Vol. 2. Cary, N.C. SAS Institute. 891 pp.

Schulz, T.T. and W.D. Leininger, 1990. Differences in riparian vegetation structure between grazed areas and exclosures. J. Range Manage. 44:294–299.

Stednick, J.D., 1991. Wildland water quality sampling and analysis. Harcourt Brace Jovanovich. San Diego, Calif. Academic Press, Inc. 218 pp.

Swanson, F.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell, 1982. Land-water interactions: The riparian zone. Analysis of Coniferous Forest Ecosystems in the Western United States. ed. Robert L. Edwards. Hutchinson Ross Publishing Co., Strondsburg, Penn. pp. 267–289.

Triska, F.J, A.P. Jackman, J.H. Duff, and R.J. Avanzino, 1994. Ammonium sorption to channel and riparian sediments: a transient storage pool for dissolved inorganic nitrogen. Biogeochem. 26:67–83.

United States Geological Survey, 1978. Calibration and maintenance of vertical-axis type current meters. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 8, Chapter B2, pp. 1–16. Available from U.S. Government Printing Office, Washington, D.C.

U.S. Soil Conservation Service, 1980. Soil Survey of Larimer County Area, Colorado. USDA/SCS and Forest Service. 174 pp.

Whigham, D.F., C. Chitterling, and B. Palmer, 1988. Impacts of freshwater wetlands on water quality: a landscape perspective. Env. Manage. 12(5):663–671.