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Long-Term Nitrogen Load from the Little River Experimental Watershed on the Coastal Plain of Southwest Georgia

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Abstract. *The USDA-Agricultural Research Service, Southeast Watershed Research Laboratory initiated flow measurement of the Little River in a 334 km² area near Tifton, Georgia in the late 1960's. Monitoring of stream nitrogen concentrations began in 1974 for seven of the eight nested subwatersheds in the area, known as the Little River Experimental Watershed. This paper summarizes the first 30 years of the stream nitrogen record, from 1974-2003. The calculated nitrogen loading data provides insight into the effects of changing land use and agricultural practices, stream-side riparian zones, and climate cycles on nitrogen cycling over the long term in the Southeast Coastal Plain.*

Keywords. Nitrogen, watershed, stream chemistry.

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Introduction

A large body of research shows that nitrogen originating from agricultural activities is associated with nitrate in groundwater, degraded stream and lake water quality, and environmental problems in estuaries and coastal waterways (Ritter and Bergstrom, 2001). The sources of the nitrogen include fertilizers, animal wastes, mineralized soil organic matter, and municipal waste solids (Ritter and Bergstrom, 2001). Nitrogen losses to surface and ground waters occur via the processes of leaching out the bottom of the root zone, lateral flow to riparian areas or streams, artificial subsurface drainage, and surface runoff. These processes are affected by climate, soil properties, topography, management practices, and crop rotation. Reducing the negative effects of nitrogen on ground, surface, and coastal waterways has been a major focus of agricultural research in the past decades (Mostaghimi et al., 2001).

The National Resource Conservation Service (NRCS) and Agricultural Research Service (ARS) are working together on a project named CEAP – Conservation Effects Analysis Project – for the purpose of quantifying the effects of conservation measures on water quality at the watershed scale (Mausbach and Dedrick, 2004). Of particular value in assessing watershed-scale effects are long-term stream chemistry records. Such records provide the basis for long-term trend analysis and a standard against which to calibrate and validate simulation models. A 30-year stream chemistry record exists for the Little River Experimental Watershed (LREW) in southwestern Georgia, near Tifton, one of the original 12 benchmark ARS watersheds identified in the CEAP initiative (Mausbach and Dedrick, 2004). Nutrient concentrations and loads of portions of the chemistry record have been analyzed and published previously; however, investigation of trends over the entire three-decade length of record has not been done.

The following is a review of research findings that involve the stream nitrogen record at the LREW. Sheridan et al. (1983) developed a nitrogen budget for the 1665-ha subwatershed K (LR-K) utilizing the stream water chemistry data collected from 1975 to 1978. They reported that average annual streamflow loss of nitrate-N for this period was $0.3 \text{ kgN ha}^{-1} \text{ y}^{-1}$. Lowrance et al. (1983) published nutrient budgets, including nitrate-N, ammonium-N and organic-N (ON), for the riparian zone of 1567-ha LR-N with 1979 data and concluded that 1/3 of the nitrate-N entering the riparian zone from upland water discharge and bulk precipitation, $3.9 \text{ kgN ha}^{-1} \text{ y}^{-1}$, was discharged through stream flow. In another study based on the LR-N 1979 data, Lowrance et al. (1984) estimated that total N annual streamflow load was about 29% of the precipitation input, or $3.5 \text{ kgN ha}^{-1} \text{ y}^{-1}$. Annual streamflow loads of nitrate-N, ammonium-N, organic-N, and total N for LREW watersheds J, K, N, and O for the years 1979 – 1981 were published by Lowrance et al. (1985), who found that streamflow loads of N were higher for LR-N and LR-O than for LR-J and LR-K. The per cent of watershed area was approximately 50% forest / 50% crops for LR-N and LR-O and 57% forest / 43% crops for LR-J and LR-K. The researchers concluded that although the differences in land use apparently did not affect hydrologic response, the larger areas in crop and pasture in LR-N and LR-O did affect the N load from the watersheds. The most comprehensive report of streamflow nutrient concentrations and loads for the LREW was published by Lowrance and Leonard (1988). The study involved five subwatersheds: M, K, J, I, and F, and spanned four years, from spring 1982 to spring 1986. Analysis of storm event data indicated that streamflow nitrate-N concentration was enriched during stormflow relative to baseflow. The researchers learned that mean concentrations and loads obtained by sampling at 3-h and 12-h intervals were not significantly different from one another. The results showed that streamflow nutrient loads were not correlated to percent of land in spring-planted row crops; however, there was correlation between nutrient loads and area in winter wheat, a crop that was typically fertilized in late fall or early winter just prior to the period of highest rainfall, lowest ET, and highest leaching potential in this region. In addition to

the streamflow nutrient research mentioned above, results of previous studies in the LREW conducted on representative upland areas were reported by Hubbard and Sheridan (1983) on surface and subsurface losses of nitrate-N and by Lowrance (1992) identifying the division of surface and subsurface N losses by nitrate, ammonium, and organic N (ON).

The focus of the current research is the investigation of the stream nitrogen trends in the LREW over the past 30 years using regression analysis. Additionally, the effect of changes in cropping systems over time on stream chemistry will be studied by estimating planted areas by crop and relating the cropped acreage to the stream data. The objectives of this study are: (i) to determine if there are long-term trends in concentration or load for nitrogen species in the Little River at station K, and (ii) to determine if there are correlations between cropping system and stream nitrogen concentrations or loads.

Methods

Description of Watershed

The 33,400-ha LREW is located north and west of Tifton, Georgia in the Atlantic Coastal Plain physiographic region at the headwaters of the Suwanee River Basin (fig. 1). Landuse in the watershed has recently been classified as 50% forest, 41% mixed agricultural, 7% urban, and 2 % water (Bosch et al., 2006). Land slope in the watershed is relatively flat. Upland soils are typically loamy sands and sandy loams underlain by a dense, low-permeability argillic layer at a depth of 0.75 to 2.0 m (Hubbard et al., 1985). The dendritic, low-gradient stream network throughout the region stores water during the winter and early spring season in flat, low-lying bottomlands that are densely vegetated with a mixed plant community of hardwoods, evergreens, and herbaceous species. The climate is sub-humid tropical; average annual rainfall over the period 1974-2004 was 1213 mm. Past research has shown that 27% of rainfall becomes streamflow (Bosch et al., 2006) and that although 37% of the rainfall occurs during the first four calendar months of the year, 73% of the streamflow takes place during the same period (Sheridan, 1997). During the growing season, rainfall is primarily from convective thunderstorms and occasional tropical storms arriving from the Gulf of Mexico or Atlantic Ocean.

Streamflow Chemistry Data

Streamflow is measured at eight locations within the LREW, creating a nested subwatershed design. The flow measurement structures, installed between 1967 and 1971, consist of a horizontal broad-crested concrete weir with a center V-notch. The water level upstream of the control structures is measured with a pressure transducer and data logger at 5-minute intervals. Flow is calculated using rating curves developed for each structure. Additional details of the flow measurement and instrumentation system, the associated data management system, and the quality of the data can be found in Sheridan et al. (1995).

Monitoring of stream chemistry on seven of the subwatersheds began in 1974 with weekly grab samples taken from flow over the weir and tested for chloride, nitrate-nitrogen, and ortho-phosphate concentration. Ammonium-nitrogen, total Kjeldahl nitrogen (TKN), and total phosphorus were added to the list of analytes in 1979. The most intense monitoring has been performed on LR-K, where automatic sampling with a PS-69 pumping sampler was initiated in August 1974. For the August 1974 to August 1978 period, three samples per day were drawn from the stilling area immediately upstream of the control weir (Sheridan et al., 1983). Between storm events, only one daily sample was retained for laboratory analysis. From 1979 to 1992, automated, timed samples were taken at 12-h intervals. Two years of weekly grab sampling preceded the onset in 1995 of the current automated, flow-weighted composite sampling regime

using an ISCO 2910 sampler. Since 2003, the weekly composite sample has been maintained in a small refrigerator within a secure, ventilated structure.

During the 1974-1978 period, nitrate-N plus nitrite-N sample concentration was determined by the technique of Armstrong et al. (1967) and FWPCA (1969) (Sheridan et al., 1983). Nitrate-N plus nitrite-N and ammonium-N sample concentration were analyzed by standard spectrophotometric techniques (APHA, 1976) from 1979 and later. TKN was determined by digesting unfiltered samples on a Buchi digester (Brinkman Instruments, Westbury, NY) and analyzing the digestate by Technicon Method no. 376-75 W/B (Technicon Instruments, Tarrytown, NY). Total N was calculated as nitrate-N plus TKN. Streamflow nutrient loads were calculated as the product of streamflow volume and associated nutrient concentration.

Land Use and Cropping Systems

Harvested crop area data were obtained from the USDA National Agricultural Statistics Service (USDA, 2006) for Turner County, Georgia, in which LR-K is located. The harvested areas were plotted by crop for the period 1974 – 2005 (fig. 3), the period for which stream chemistry data are available. Two sets of years were chosen for further analysis. During each of the sets of years the percentages of the given crops under cultivation was relatively stable. The purpose of the analysis was to determine if differences could be detected in the stream record between periods of years with differences in the dominant cropping system. The sets of years chosen for analysis were: 1985 – 1990 when peanut was the dominant crop and corn, soybean, cotton, and winter wheat were approximately equal in area; and 1998 – 2003 when 89% of harvested area was in cotton and peanut.

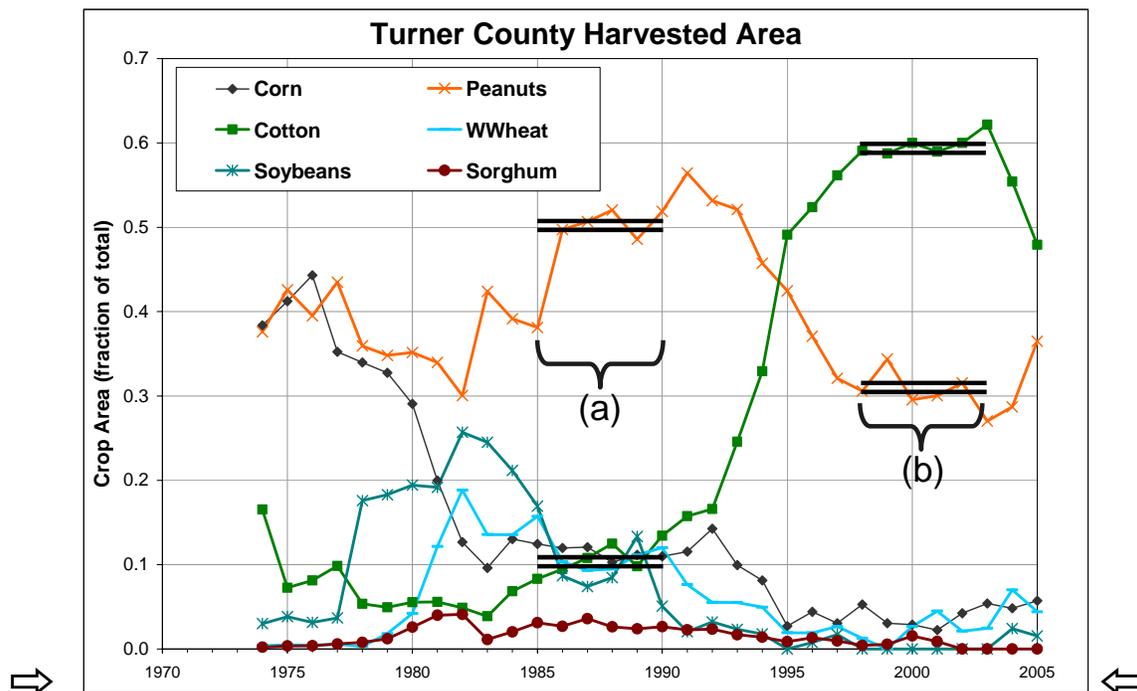


Figure 3. Periods of differing cropping systems in Turner County, (a)1985-1990 and (b)1998-2003 .

Statistics

The presence of a linear trend in the concentration and load data for each analyte over the period 1974 – 2003 was tested by simple linear regression. The null hypothesis was that the slope of the regression line was not significantly different from zero (Haan, 2002). The means of the concentrations and loads for the two six-year periods 1985 – 2000 and 1998 – 2003 were tested for differences assuming normal distributions. The level of significance, α , for all tests was 5%.

Annual precipitation and streamflow for LR-K over the period of record, along with the trend lines, are shown in figure 4. Precipitation trended down over the 30 years at an average of 5.4 mm y^{-1} , while streamflow trended down at approximately half the rate, 2.5 mm y^{-1} . The ratio of streamflow to precipitation averaged 0.30 for LR-K for the three decades under study.

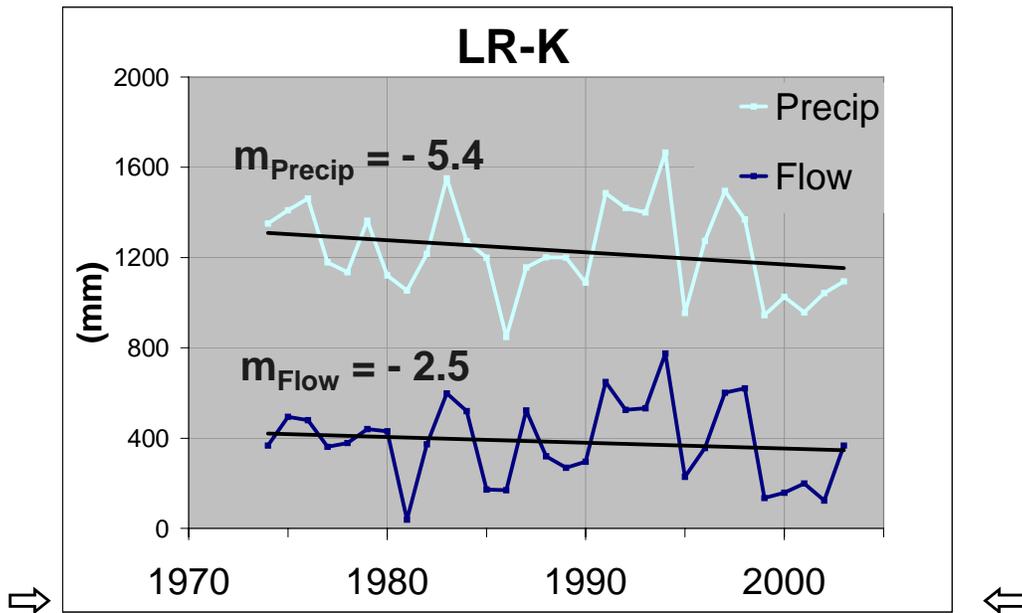


Figure 4. Annual precipitation and streamflow for LR- K, 1974-2003.

Results

The graphs of annual nutrient load over the three decades of study for nitrate-N, ammonium-N, TKN, and Total N are shown in figure 5. The plot includes the linear regression trend line for the load data. Annual streamflow for LR-K is included on the graphs to provide the context of flow conditions.

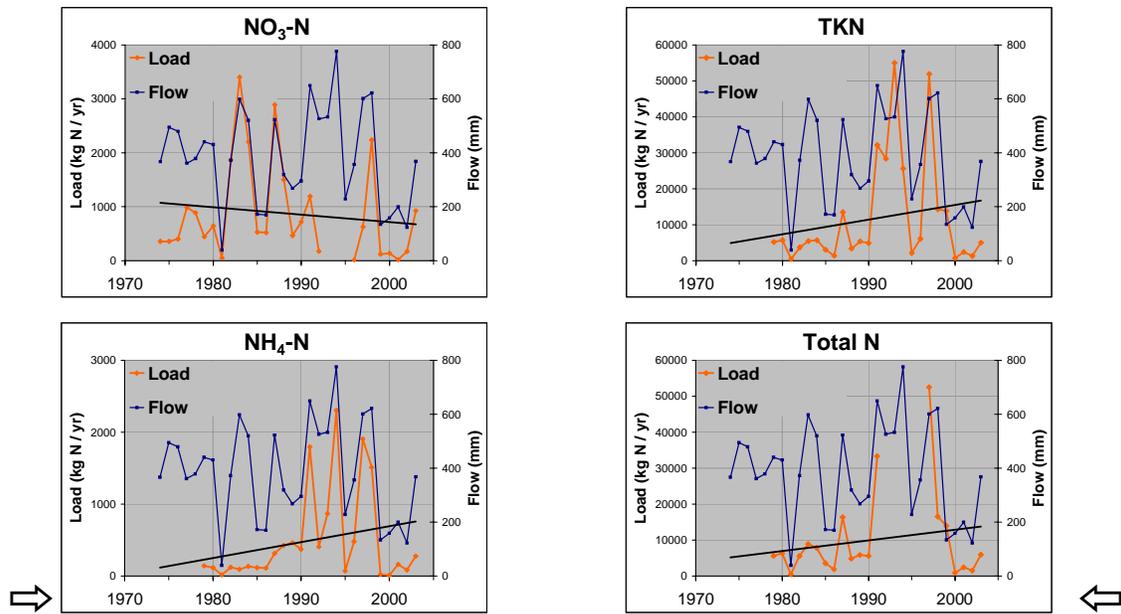


Figure 5. Load trends for N species and total N for LR-K, 1974-2003.

The results of the regression test were that the null hypothesis (the regression line slope was zero) could not be rejected for any of the species. Although visual inspection of the slopes at the scales shown in fig. 5 indicates apparent trends, especially in the ammonium-N and TKN graphs, the variability in the data and statistically short period of record contribute to the lack of statistical evidence to reject the null hypothesis. The magnitude of the losses of each N species reveals something about the nature of low gradient Coastal Plain streams with dense riparian vegetation. Organic N stream loads, represented by TKN, are roughly an order of magnitude greater than mineral nitrate-N loads. The source of the organic N load is in great measure the biomass of the riparian vegetation, decomposing litter and detritus. Nitrate-N load averaged 946 kg N yr^{-1} , or $0.57 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ for LR-K. On a per hectare basis, nitrate-N load from this Coastal Plain watershed is a small fraction of that observed in agricultural watersheds in the Midwest. For example, Jaynes et al. (1999) measured annual stream loads of 4 to $66 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (average of $29 \text{ kg N ha}^{-1} \text{ yr}^{-1}$) in the 5130-ha Walnut Creed watershed in central Iowa over the years 1992 – 1995. Past research in the LREW has shown that a relatively large amount of N, $56 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, are either retained in the watershed or lost through gaseous emissions from the uplands (Lowrance et al., 1985). Thus, the Coastal Plain stream system exhibits low loss of nitrate-N and a proportionately higher, yet still modest loss of organic N.

The graphs of the annual average concentrations of nitrate-N, ammonium-N, TKN, and Total N versus year are shown in figure 6. Although again there appears to be a positive slope and an increasing trend, in this case for TKN and total N, the null hypothesis that the slope of the trend line is zero cannot statistically be rejected.

Regression analysis of the graph of annual average concentration versus annual stream flow (fig. 7) indicated that there was positive correlation between concentration and flow for ammonium-N and TKN, but that there was no trend for nitrate-N and total N. Although annual concentrations and flows have not previously been analyzed for the LREW, Lowrance and Leonard (1988) reported results for the test of dilution or enrichment during storm events. They found that nitrate-N concentrations increased significantly and ammonium-N and total N concentrations showed no effect with increasing flow during storm events.

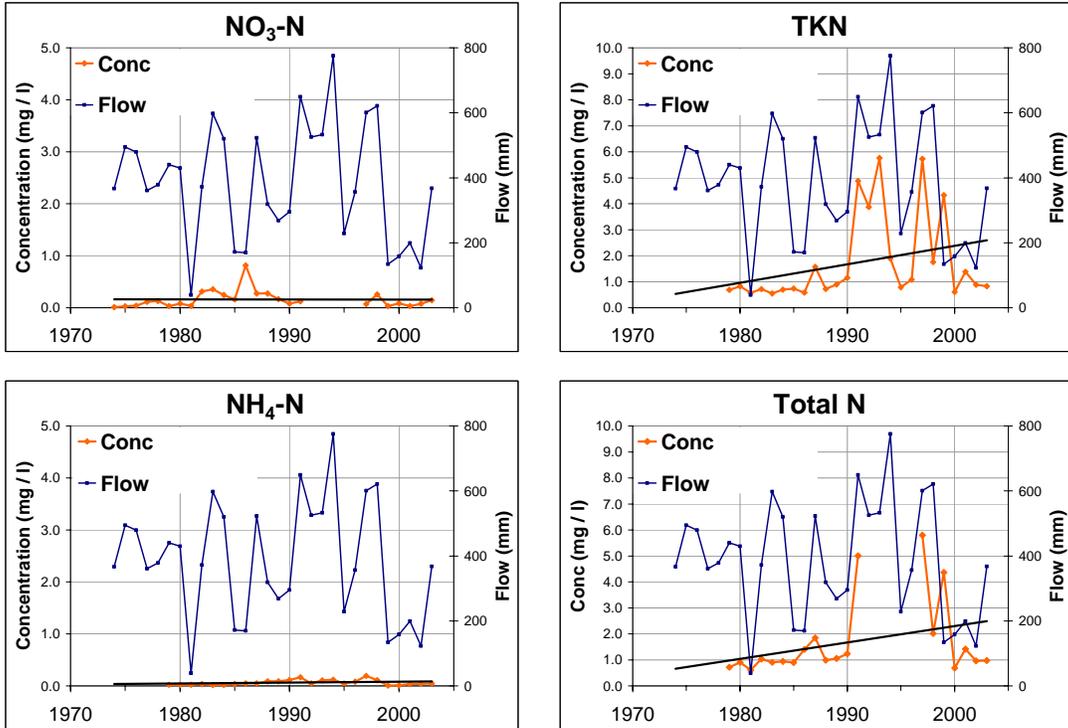


Figure 6. Concentration trends for N species and total N for LR-K, 1974-2003.

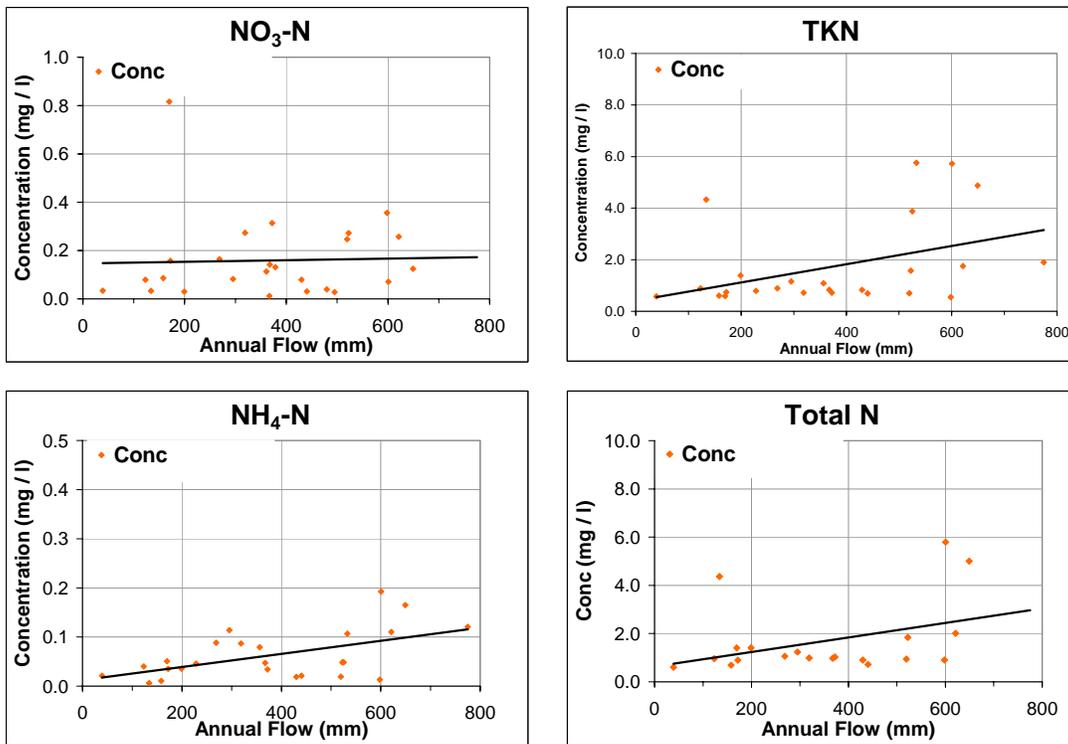


Figure 7. Concentration versus flow for N species and total N for LR-K, 1974-2003.

The average stream nitrate-N concentrations for the 1985-1990 and 1998-2003 periods were $0.29 (\pm 0.27)$ and $0.10 (\pm 0.08)$ mg l^{-1} , respectively. The graph of annual mean concentration by year for the entire study is shown in figure 8, along with the means and the ranges of \pm one standard deviation for concentrations during the two six-year intervals. Although the average value for the later period was 1/3 of the average value for the earlier period, there was no statistical difference between annual mean nitrate-N concentrations between the two periods representing two different cropping systems. The average stream nitrate-N loads for the 1985-1990 and 1998-2003 periods were $1103 (\pm 957)$ and $603 (\pm 867)$ kg N , respectively (fig. 9). With high variances in loads over the two six-year periods, there was not a statistical difference between the means. The 1998-2003 mean nitrate N load was 45% less than for the 1985-1990 period. Over the respective intervals, flow was reduced by 8%.

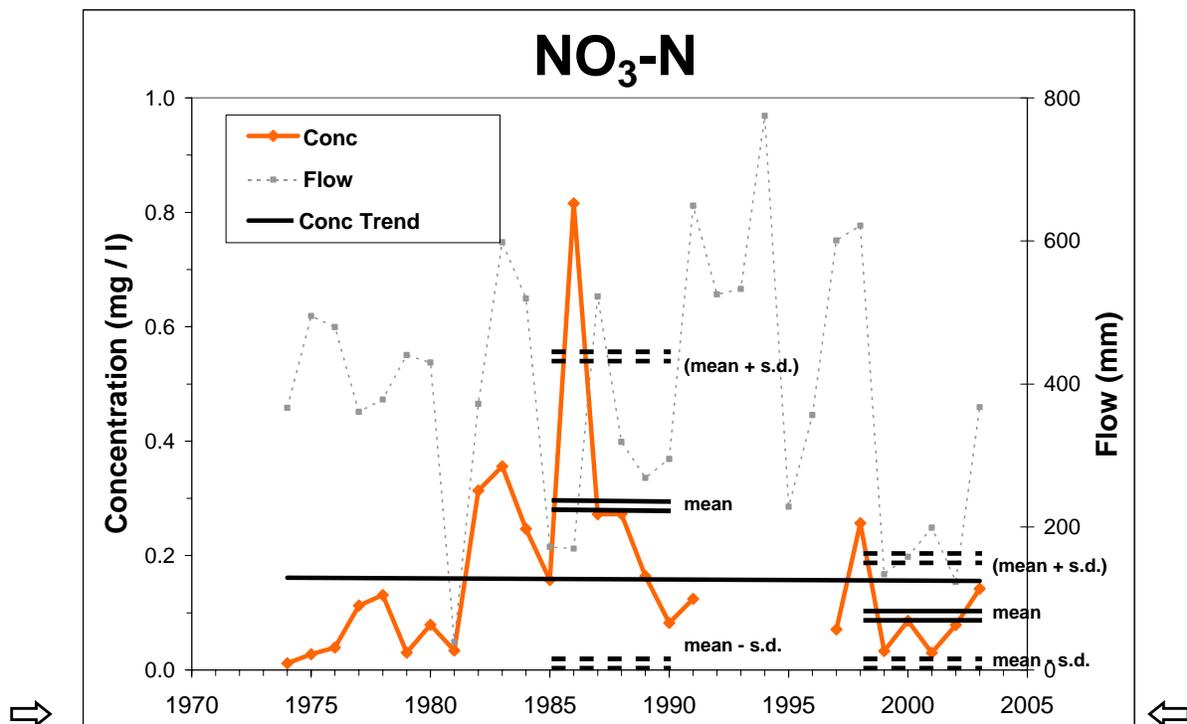


Figure 8. Average annual nitrate-N concentrations, \pm one standard deviation (s.d.) for two six-year periods: 1985-1990 and 1998-2003.

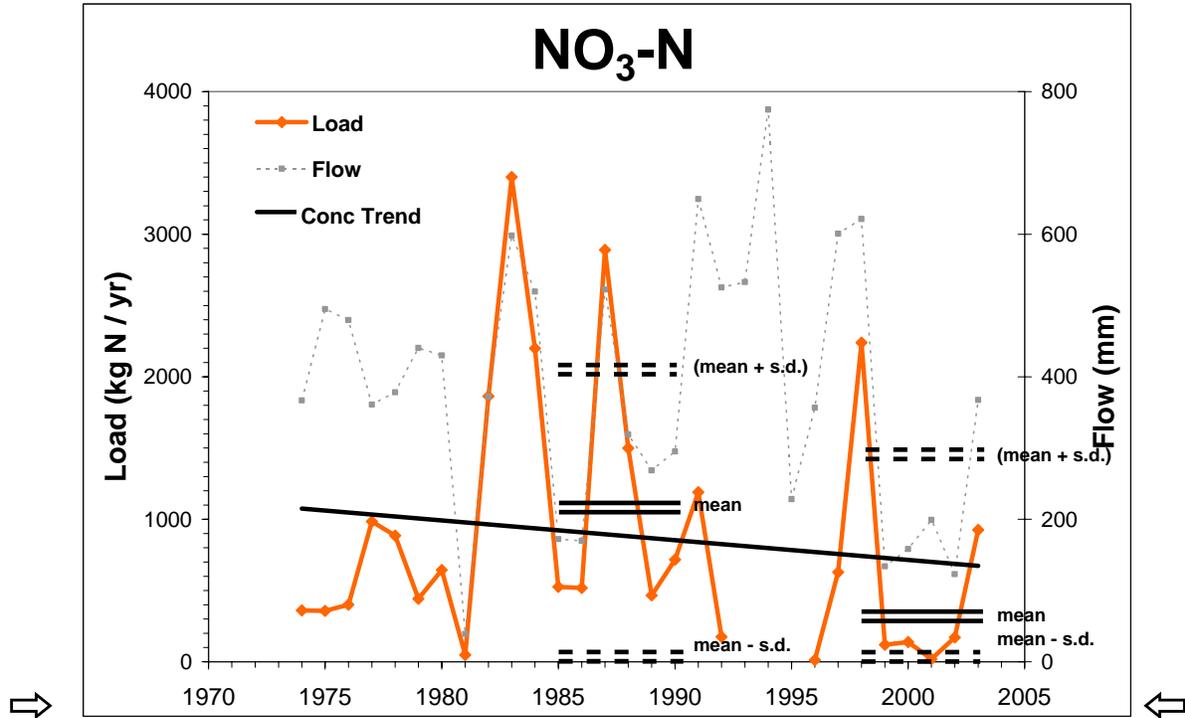


Figure 9. Average annual nitrate-N loads, \pm one standard deviation (s.d.) for two six-year periods: 1985-1990 and 1998-2003.

Conclusion

Statistical analysis of stream N concentrations and loads in the LREW over the 1974-2003 period indicate that there are no long-term trends in either concentrations or loads. The results of this study confirm previous research suggesting the key role of the riparian forest in reducing impact of agricultural practices on stream water quality in Coastal Plain systems. Additional analysis of the long-term LREW water record is planned. Phosphorus concentration and load trends will be analyzed. Examination of shorter-term trends within the 30 years is scheduled. The potential influence of changes to animal agriculture over the study period will be investigated.

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