WATER QUANTITY AND QUALITY FROM A SMALL GEORGIA PASTURE DURING 1998-2009: IMPACT OF DROUGHT

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Abstract. The water quality impact of pasture grazing in the Piedmont, which generally occurs under low-input management, is not well studied. Cattle, hydrologic and water quality data were collected from 1999 to 2009 from a rotationally grazed 7.8-ha pasture near Watkinsville Georgia. Grazing occurred during 69 time periods, with 20 to 225 head of cattle grazing 1 to 71 days each period. Mean cattle days (head of cattle x days spent) was 182.4 ha^{-1} grazing-period^{-1}. Drought occurred with 7 of the 11 years having below average annual rainfall. Runoff events were limited to 20 during 86 months of below average rainfall (deficit period) compared with 54 during 46 months of the non-deficit period. Instrument problems limited sample collection to 43-47 out of possible 67 events from 2000-2009. Across all data, mean event flow weighted concentration (FWC) in mg L^{-1} was < 1.0 for nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N), 3.7 for total nitrogen (TN), 9.1 for total organic carbon (TOC), 2.0 for ortho-P (PO_4-P), 2.4 for total P (TP), 0.23 for iron (Fe), and 0.06 for aluminum (Al). Nutrient loads in kg ha^{-1} event^{-1} averaged 0.04 for NO_3-N, 0.03 for NH_4-N, 0.19 for TN, 0.54 for TOC, 0.11 for PO_4-P, and TP, 0.02 for Fe, and 0.01 for Al. Peak nutrient concentrations and loads occurred during calving season and/or when monthly rainfall was above average. Total load was 3 to 6 times greater from non-deficit than deficit periods. Concentrations of N were well below drinking water standards. Nevertheless observed N and P losses could pose risk of eutrophication because it can be stimulated at low concentrations. Such long-term data are needed to help states set or refine water quality standards.

INTRODUCTION

Approximately 11% of the Piedmont (1.8 million ha) is used as pastures and hay fields, mostly under low-input management (NRCS, 1998). Grazed grassland under intensive management may potentially release large amounts of N into the environment (Scholefield *et al*., 1991). Excess nitrogen (N) from intensive farming operations has been implicated as promoting eutrophication in major river systems and hypoxia in coastal waters (Carpenter *et al*., 1998; Dagg and Breed, 2003; Boesch, 2004; Donner, 2007). Due to the mobility of nitrate, leaching to groundwater is considered the main contributor to N transport to streams. However, surface losses of N are also important because eutrophication can be stimulated at N concentration much lower than the nitrate drinking water standard (Sawyer, 1947; Sharpley *et al*., 1983; Willis *et al*., 1997). Barlow *et al*. (2007) cite several studies that show significant N export via surface runoff but stress that these studies were short-lived and that information on N loss via runoff is limited. Conley *et al*. (2009) argued that reduction in both N and P inputs is needed to reduce eutrophication and improve surface water quality. Total organic carbon content has been used as an indicator of pollution and to predict the likelihood of eutrophication (Folger, 1972; EPA, 2002). According to Goolsby (2000) and Showstack (2000), most of the nutrients causing eutrophication and hypoxia originate much further up watersheds in headwaters and other small streams. First and second order streams, largely draining rural and agricultural areas, comprise nearly three-quarters of the total stream length in the United States (Leopold *et al*., 1964).

Environmental impacts from grazing animals in low-input rotational systems are not well studied and documented, particularly in the southern USA. Because most excess N flows from small streams and catchments, grazing activities in the proximity of such zones may contribute to nonpoint source pollution of river systems. Long-term data that capture impacts of contrasting weather patterns, that include typical long and short term droughts, are needed to develop effective nutrient management strategies in grazing systems. Few studies have investigated the important subject of N and C loss in surface runoff over a sufficiently long-term period in the Southern Piedmont to cover such contrasting weather patterns. The objective of this paper is to relate 11 yr of hydrologic and 10 yr of N, P, TOC, Fe and Al runoff water quality data from a zero-order Piedmont catchment to low-input rotational grazing by black Angus (*Bos taurus*) cattle during a period with severe drought interrupted by some very wet months.

METHODS AND MATERIALS

The study was conducted from 1999 to 2009 at a zero-order 7.8-ha catchment (W1) at the USDA-ARS near Watkinsville, GA (33°54' N and 83°24' W). The catchment features topography, soils and land use history typical of many sloping fields throughout the Southern Piedmont. Soils are Cecil (69%) and Pacolet (31%) series (fine, kaolinitic, thermic Typic Kanhapludults) with brownish-gray sandy loam to clay loam surface horizons overlaying red clayey argillic horizons. Soil samples taken from the 0- to 15-cm depth from 14 locations in W1 in Dec. 2009 had pH-water range of 5.6 to 6.5 with mean of 6.1. The average nitrogen and carbon contents were 0.24 and 2.55% on a dry-mass basis, respectively. Average daily air temperature ranges from 6 to 8^{o}C in winter and from 23 to 27^{o}C in summer. Mean annual rainfall is 1240 mm. Mean monthly rainfall varies from 78 to 90 mm for fall, 105 to 116 mm for winter, 95 to 136 mm for spring, and 95 to 121 mm for summer. Despite the high average annual rainfall, short and long-term periods of drought are common. The most recent long-term droughts occurred from 1998 to 2002 and 2006 to 2008, with 2007 being the driest in 73 yr.

The catchment has been grazed by cows and cow-calf pairs either alone or with one or two breeding bulls since 1960. Calving season extends from January through early April. Summer forage consists of warm season grasses (bermudagrass (*Cynodon dactylon*) and other species) while rye (*Secale cerale* L.) or wheat (*Triticum aestivum*) overseeded in fall make up winter grazing. Forage is grazed when it reaches approximately 3500 kg ha^{-1} and animals are rotated off to other paddocks at the Center after grazing to less than approximately 2000 kg ha^{-1}. The catchment is fertilized biannually (early spring and late summer) with 55-125 N kg ha^{-1} and P fertilization was limited to two approximately 52 kg ha^{-1} yr^{-1} applications from 2000 to 2003 only. Soil pH is maintained between 6.0 and 6.5 by liming on as needed basis.

An automated system, consisting of a tipping bucket rain gauge, flow depth sensing transducer and data logger, was used to measure rainfall and runoff depth and rate at a1.14m (3.75ft) high 2:1 concrete broad-crested V-notch weir. A portable sampler was used to collect runoff samples for nutrient analyses in 24 glass bottles, each of 300 mL capacity. Until February 2006, the sampler was configured to collect samples every 8 minutes through 6.5 of a runoff event. After that the configuration was changed to collect samples every 10 minutes through 12 hours of a runoff event. Samples were removed from the sampler within 36 hours of each runoff event and brought to the laboratory for processing. Sampling started in 2000 after testing in 1999.

In the laboratory, samples were composited into approximately hourly subsamples. A portion from each subsample was then filtered through 0.45-µm cellulose-nitrate membrane and refrigerated at 4^{o}C for analysis at a later date for NO3-N, NH4-N and PO4-P with standard laboratory methods. An unfiltered portion from each subsample was kept frozen for analysis at a later date for TN, TP, TOC, Fe and Al with standard laboratory methods. Total event nutrient load was calculated as the sum of the product of subsample runoff volume and subsample concentration. Event flow weighted concentration (FWC) was calculated from the total event load divided by total event runoff volume. Rain, runoff and nutrient FWCs and loads were grouped into deficit and non-deficit period categories based on monthly rainfall being less than the long-term average, or equal to or above the long-term average, respectively. Differences between categorical variables were tested using Wilcoxon Rank Sum Test after first running the Shapiro-Wilk Normality Test. Differences were considered significant at $P \leq 0.1$.

RESULTS

Cattle. Cattle grazed W1 a total of 69 time periods from 1999 to 2009, and an average of 91 head of cattle grazed an average of 19.2 days during each period. Grazing period was least in 2009 (17% of the year) and greatest in 2003 (54% of the year) with an overall mean of 33%. Mean monthly cattle days varied from 570 to 940 except for Dec (74), January (371) and February (1384). Details for cattle head, grazing days and cattle days per grazing period are summarized in Table 1. Calving did not take place in W1 in 2001 and 2009.

Table 1. Grazing statistics per grazing period †

Variable	Cattle Group	Mean	STD ERR	Min	Max
Cattle Head	Bulls	0.4	0.1	0.0	2.0
	Calves	35.0	4.3	0.0	112.0
	Cows	56.3	3.1	11.0	120.0
	All	91.0	6.7	21.0	224.0
Grazing Days	Bulls	4.5	1.1	0.0	46.0
	Calves	11.3	1.8	0.0	71.00
	Cows	19.2	1.8	1.0	71.0
	All	19.2	1.8	1.0	71.8
Cattle Days	Bulls	5.3	1.2	0.0	46.0
	Calves	463.1	60.0	0.0	2352
	Cows	936.0	90.7	31.0	3192.0
	All	1404.3	127.4	63.0	4704.0

† Statistics based on 69 grazing periods of 1 to 71 days.

Mean monthly cattle days were approximately similar between deficit and non-deficit periods (753 and 693, respectively) but the totals were different (64,748 and

31,192, respectively) because of the differences in duration.

Rain-runoff. Drought that began in May 1998 covered 65% of the period through the end of 2009. Annual rainfall was between 166 and 454 mm below the long-term average in seven of the 11 yr of study (Fig. 1). The number of months that had rainfall below the long-term monthly average varied from 4 in 2005 to 11 in 2007. The driest year in 73 yr of record was 2007. On the other hand, a series of unseasonal rains in September and October 2009 made 2009 the 3rd wettest in 73 yr. The majority of daily rainfall during the study did not reach the approximate threshold value to trigger runoff (> 20 mm). This category of rainfall occurred in only 5% of the study period. There was no daily rainfall during 69% of the study period.

Overall 74 runoff events were recorded. The 1-d rainfall that led to runoff had a mean and median value of 45 and 38 mm, respectively, with a range of 8 to 129 mm. Close to 90% of runoff events were caused by 1-d rainfall of 20 mm or more. The 1-d rainfall explained 46.4% of the variability in runoff. Event runoff as percent of event rainfall (percent runoff) varied from < 1 to 65% and had mean and median values of 9 and 4%, respectively. The impact of the drought on runoff is apparent from the annual, monthly and seasonal rainfall and runoff data. Number of runoff events varied from 1 in 2007 and 2008 to 10 in 2001, 2003, and 2009, and 13 in 2003. There were 20 runoff events recorded during the 86 deficit months compared to 54 for the 46 non-deficit months. During the deficit months, < 1% of the 5262 mm of rainfall was recorded as runoff compared with 5% of the 6666 mm of rainfall during the non-deficit months. Over the whole period only 3% of the 11927 mm rainfall was recorded as runoff. The nonparametric Wilcoxon Rank Sum Test showed that differences between deficit and non-deficit periods were significant for monthly rainfall, runoff and percent runoff across all years. Over the whole period, there were more runoff events during winter (29) than the other seasons (15 each).

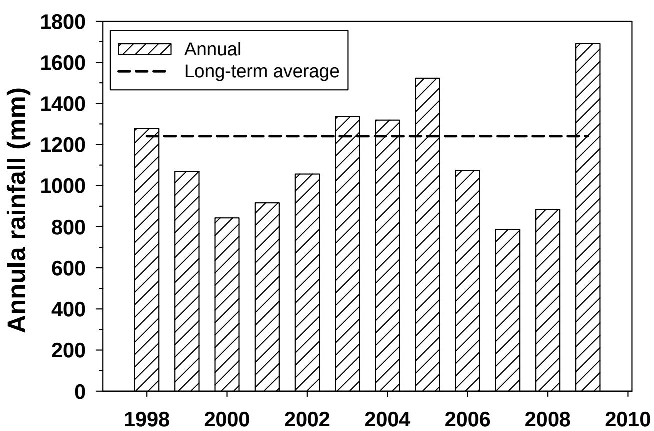

Figure 1. Annual rainfall from 1998 to 2009 compared to the long-term annual average.

Table 2. Statistics for nutrient event flow weighted concentration in mg L^{-1}†

Nutrient & Period	Mean	Med	SE	Min	Max
NO_3-N					
DEF	1.11	0.65	0.29	0.23	3.41
NDF	0.85	0.56	0.20	0.04	6.23
ALL	0.96	0.64	0.17	0.04	6.23
NH_4-N					
DEF	0.53	0.36	0.12	0.02	1.46
NDF	1.13	0.26	0.39	0.03	12.23
ALL	0.97	0.30	0.29	0.02	12.23
TN					
DEF	3.84	2.86	0.69	1.37	8.16
NDF	3.65	2.38	0.66	0.71	15.63
ALL	3.70	2.51	0.51	0.71	15.63
TOC					
DEF	8.94	8.72	0.81	5.14	14.73
NDF	9.18	8.48	0.64	2.74	18.56
ALL	9.12	8.25	0.51	2.74	18.56
PO_4-P					
DEF	2.11	2.14	0.29	0.83	4.20
NDF	2.01	1.64	0.22	0.51	7.07
ALL	2.03	1.72	0.18	0.51	7.07
TP					
DEF	2.77	2.55	0.45	0.82	5.31
NDF	2.27	1.79	0.30	0.36	7.59
ALL	2.41	1.97	0.25	0.36	7.59
Fe					
DEF	0.23	0.20	0.03	0.12	0.50
NDF	0.23	0.20	0.02	0.03	0.55
ALL	0.23	0.20	0.02	0.03	0.55
Al					
DEF	0.03	0.00	0.02	0.00	0.17
NDF	0.07	0.00	0.02	0.00	0.55
ALL	0.06	0.00	0.02	0.00	0.55

† Periods are: DEF– deficit; NDF- non-deficit; ALL- both deficit and non-deficit periods. Statistics are: Med- median, SE- standard error of the mean, Min- minimum, and Max- maximum.

Nutrients. Across all analyzed events (n = 43 to 47), event flow weighted concentration (FWC) had a mean of approximately 1.0 for inorganic N and 3.7 for TN (Table 1). Mean FWC was 30 to 70% greater than the median FWC for inorganic and total N. In ≥ 90% of the events, FWCs for inorganic-N and TN were < 8 mg L^{-1}. Approximately 80% of events had FWC < 4 mg L^{-1}for

TN, which is below the current Georgia EPD maximum water quality criteria for TN for the photic zone in several

Table 3. Statistics for event nutrient load in kg ha^{-1}†

Nutrient & Period	Mean	Med	SE	Min	Max
NO_3-N					
DEF	0.011	0.004	0.005	0.000	0.070
NDF	0.048	0.014	0.011	0.000	0.220
ALL	0.038	0.008	0.008	0.000	0.220
NH_4-N					
DEF	0.011	0.002	0.007	0.000	0.091
NDF	0.039	0.018	0.011	0.000	0.294
ALL	0.031	0.008	0.009	0.000	0.294
TN					
DEF	0.088	0.024	0.062	0.000	0.760
NDF	0.220	0.052	0.055	0.000	1.261
ALL	0.184	0.039	0.045	0.000	1.261
TOC					
DEF	0.263	0.056	0.199	0.003	2.249
NDF	0.641	0.335	0.148	0.001	3.640
ALL	0.542	0.160	0.123	0.001	3.640
PO_4-P					
DEF	0.035	0.011	0.020	0.000	0.252
NDF	0.147	0.080	0.029	0.001	0.635
ALL	0.114	0.034	0.023	0.000	0.635
TP					
DEF	0.040	0.012	0.022	0.000	0.295
NDF	0.144	0.065	0.030	0.000	0.546
ALL	0.114	0.030	0.023	0.000	0.546
Fe					
DEF	0.007	0.001	0.005	0.000	0.062
NDF	0.019	0.008	0.005	0.000	0.110
ALL	0.016	0.003	0.004	0.000	0.110
Al					
DEF	0.001	0.000	0.001	0.000	0.010
NDF	0.008	0.000	0.004	0.000	0.095
ALL	0.006	0.000	0.003	0.000	0.095

† Periods are: DEF– deficit; NDF- non-deficit; ALL- both deficit and non-deficit periods. Statistics are: Med- median, SE- standard error of the mean, Min- minimum, and Max- maximum.

lakes (4.0 mg L^{-1}; GEPD, 2005). All FWCs for nitrate were well below the national drinking water standard of 10 mg L^{-1}. Atmospheric N deposition had likely occurred with mean monthly concentration of 0.6 to 1.0 mg L^{-1} for NO_3-N and 0.1 to 0.3 for mg L^{-1} for NH_4-N based on data from the National Atmospheric Deposition Program from 4 Georgia and 3 North Carolina counties (NADP, 2010).

For TOC, mean and median FWCs were close at approximately 8 to 9 mg L^{-1}. At approximately 2 to 3 mg L^{-1}, mean or median FWCs for phosphorus were several orders of magnitude above the standard for europhication risks. As P application on the pasture was limited and poultry litter was not used as fertilizer, the source for most P was cattle manure. For iron, mean and median FWCs were close at approximately 0.2 mg L^{-1}, while for aluminum, mean FWC was 0.6 mg L^{-1} and median was zero. The range of FWCs was greater for the non-deficit than for the deficit periods (Table 1). However, nutrient mean FWCs were not different between events for deficit and non-deficit periods according to the nonparametric Wilcoxon Rank Sum Test ($p > 0.1$). The top 10 percentile FWCs for all nutrients generally occurred during the calving period (January to early April) and/or when monthly rainfall was above average in 2001, 2003, 2005, or 2006.

Across all analyzed events (n = 43 to 47), mean event load for inorganic-N species averaged 0.3 to 0.4 kg ha^{-1} while that for TN averaged 0.18 kg ha^{-1} (Table 2). Mean event load was approximately 2 to 5 times greater than the median for N species. Approximately 85% of the events had inorganic-N event load of ≤ 0.07 kg ha^{-1}. Approximately 95% of the events had TN event load of ≤ 0.76kg ha^{-1}. For all events, mean event load for TOC was approximately 3.4 times greater than the median (Table 2). Mean event load for non-deficit periods was significantly greater than that for deficit period by: 4.4 for NH_4-N, 3.5 for NO_3-N, 2.5 for TN, and 2.4 for TOC (Nonparametric Wilcoxon Rank Sum Test, $0.01 < p \leq 0.06$). Phosphorus loss occurred essentially as PO_4-P (Table 2). Mean P load was approximately 2 to 3 times greater than the median load. Phosphorus load was approximately 4 times greater from the non-deficit than the deficit periods. Mean event load for iron was 0.016 kg ha^{-1} with that from non-deficit period approximately 2.7 times that from deficit period. For aluminum mean load during non-deficit periods was 8 times greater than that for deficit periods. The median for Al load was zero. The top 10 percentile event load values generally occurred during the calving period (January to early April) and/or where monthly rainfall was above average in 2001, 2005, or 2006. Assuming means would hold for all 74 runoff events, total nutrient discharge over the 11 yr from the whole of W1 would have been approximately 0.26, 0.21, 1.27 3.65, 0.76, 0.77, 0.11, 0.04 kg ha^{-1} yr^{-1} for NO_3-N, NH_4-N, TN, TOC, PO_4-P, TP, Fe and Al, respectively. However, because the data are skewed, these values are 3 to 5 time greater than estimates that would be based on median values except for Al (zero median).

SUMMARY AND CONCLUSIONS

States (and tribes) have the authority to set water quality standards, subject to EPA approval, and are required to review standards every three years. The EPA has published ecoregion nutrient criteria (EPA, 2000) intended to provide guidance to the states in establishing their water quality standards. Georgia currently has approximately 850 approved total maximum daily load (TMDL) plans in place to restore impaired water bodies into compliance with water quality standards for designated use (Risse and Tanner, 2009a). Most focus on fecal coliform bacteria, guidelines for fish consumption, metals sediments and dissolved oxygen. Georgia continues to make progress on expanding currently limited nutrient standards for diverse water bodies (Risse and Tanner, 2009b). Both the establishment and refinement of water quality standards need to be based on reliable information. Long-term data that encompass variable conditions that might have impact on water quality, such as those in this research, are needed in this effort, and are encouraged by EPA.

Event flow weighted concentrations for nitrate throughout this study were well below the national standard for drinking water of 10 mg L^{-1}. The current Georgia Environmental Protection Division water quality standards do not address TN in rivers and streams; however, the water quality criterion for TN in the photic zone for several lakes has a maximum limit of 4 mg L^{-1} (GEPD, 2005). Event flow weighted concentration for TN was below this limit in 80% of the events assessed during this study. As pointed out by Sawyer (1947), Sharpley *et al*. (1983), and Willis *et al*. (1997), eutrophication risks occur at much lower concentrations; therefore, N and P losses observed in this research, and at the low-input pasture management level, are of concern. The reference conditions (water quality criteria target) for TN and TP for rivers and streams in the Piedmont (Level III Ecoregion 45 within Aggregates Ecoregion IX) are 0.615 and 0.03 mg L^{-1}, respectively, (EPA, 2000). Reference conditions represent conditions that are minimally impacted by human activities and are taken as the lower 25th percentile of the population of one median value per monitored stream in a region. In this study the median and mean FWC for TN were 4 to 6 times, and for TP several orders of magnitude, the reported reference levels for rivers and streams in the Piedmont. The relatively large P mean or median concentrations were primarily a result of cattle manure and not of fertilizer input, as P fertilization was limited. Nor was poultry litter applied as fertilizer, which can occur in some farms that have mixed management resulting in additional concerns with water quality.

Concerns with such relatively high nutrient exports from W1 can be considered in the context of possible nutrient transformations in headwater streams, such as the one receiving runoff for W1, reducing downstream transport of nutrients. Peterson *et al*. (2001) found that headwater streams can reduce by more than half downstream export of dissolved inorganic N input from watersheds. Fisher *et al*. (2000) reported the effectiveness a pond located downstream of W1 in reducing numbers for fecal indicator bacteria to levels comparable to pristine sites; the authors of this paper have observed (unpublished data) the same pond sequestering N to below detection limits at the outlet, especially in summer. In addition, non-management related sources of nutrients, such as atmospheric N deposition, contribute to nutrient export from watersheds. The EPA encourages refinement of water quality criteria (up or down) based on long-term data relevant to designated uses. The findings of this study will form part of a suite of databases the state of Georgia can consider in establishing and/or refining water quality standards across the state.

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DISCLAIMER

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REFERENCES

Barlow, K., D. Nash, M. Hannah, F. Robertson. 2007. The effect of fertilizer and grazing in nitrogen export in surface runoff from rain-fed and irrigated pastures in south-eastern Australia. Nutr Cycl Agroecosyst 77:69-82.

Boesch, D.F. 2004, The Gulf of Mexico's dead zone. Science 306:977- 978.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998.

Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. App. 8:559 - 568.
Conley, D. J., H. W. Paerl, R. W. Howarth, D. F. Boesch, S. P. Seitzinger, K. E. Havens, C. Lancelt, and G. E. Likens. 2009. Controlling eutrophication: Nitrogen and Phosphorus. Science 323:1014-1015.
Dagg, M.J., and G.A. Breed. 2003. Biological effects of Mississippi River nitrogen on the northern Gulf of Mexico- a review and synthesis: J. Marine Syst. 43:133 – 152.
Donner, S.D. 2007. Surf or turf: A shift from feed to food cultivation could reduce nutrient flux to the Gulf of Mexico. Global Environmental Change-Human and Policy Dimensions 17:105-113.
EPA (U.S. Environmental Protection Agency). 2000. Ambient Water quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Ecoregion IX. EPA/822/B-00/019, 108pp.
EPA (U.S. Environmental Protection Agency). 2002. Mid-Atlantic Integrated Assessment (MAIA) Estuaries 1997-98: Summary Report, EPA/620/R-02/003,115 pp.
Fisher, D.S., J.L. Steiner, D.M. Endale, J.A. Stuedmann, H.H. Schomberg, A.J. Franzluebbers, and S.R. Wilkinson. 2000. The relationship of land use practices to surface water quality in the Upper Oconee Watershed of Georgia. Forest Ecology and Management 128:39-48.
Folger, D.W. 1972. Characteristics of estuarine sediments of the United States: U.S. Geological Survey Prof. Paper 742, 94 pp.
GEPD (Georgia Environmental Protection Division). 2005. Rules and regulations for water quality control. Chapter 391-3-6. Revised – November 2005. Georgia Environmental Protection Division, Georgia Department of Natural Resources. Atlanta Ga.
Goolsby, D.A. 2000. Mississippi basin nitrogen flux believed to cause Gulf Hyopxia. EOS 81 29:321-327.
Leopold L.B., M.G. Wolman and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Company.
NADP (National Atmospheric Deposition Program). 2010. Monitoring our changing Chemical Climate. Available at http://nadp.sws.uiuc.edu/ (Verified 20 Dec. 2010).
NRCS (USDA National Resource Conservation Center). 1998. MLRA 136-Southern Piedmont. NRCS MO15, USDA-NRCS, Washington, DC. Available at http://www.mo15.nrcs.usda.gov/technical/MLRAs/mlra_136.html (Verified 20 Dec. 2010).
Peterson, B.J., W. M. Wollheim, P. J. Mulholland, J. R. Webster, J. L. Meyer, J. L. Tank, E. Martí, W. B. Bowden, H. M. Valett, A. E. Hershey, W. H. McDowell, W. K. Dodds, S. K. Hamilton, S. Gregory and D. D. Morrall. 2001. Control of Nitrogen Export from Watersheds by Headwater Streams. Science 292 (5514): 86-90
Risse, L. M., and H.S. Tanner. 2009a. Total maximum daily loads in Georgia. Bulletin 1242-2. The University of Georgia Cooperative Extension, College of Agricultural and Environmental Sciences & Family and Consumer Sciences. Athens GA.
Risse, L. M., and H.S. Tanner. 2009b. Georgia's water quality standards. Bulletin 1242-3. The University of Georgia Cooperative Extension, College of Agricultural and Environmental Sciences & Family and Consumer Sciences. Athens GA.
Sawyer, C. N. 1947. Fertilization of lakes by agricultural and urban drainage. J New England Water Works Assoc. 61:109-127.
Scholefield D., D.R. Lockyer, D.C. Whitehad, and K.C. Tyson. 1991. A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. Plant and Soil 132:165-177.
Sharpley, A.N., J.K. Syers, and R.W. Tillman. 1983. Transport of ammonium- and nitrate-nitrogen in surface runoff from pasture as influenced by urea application. Water, Air, and Soil Pollution 20:425-430.
Showstack, R. 2000.Nutrient over-enrichment implicated in multiple problems in U.S. waterways. EOS 81 (43) 497-499.
Willis, G.H., L.M. Southwick, J.L. Fouss, C.E. Carter, and J.S. Rogers. 1997. Nitrate losses in runoff and subsurface drain effluent from controlled-water-table plots. Bull. Environ. Contam. Toxicol. 58:566-573.