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Water Quality of Two First Order Forested Watersheds in Coastal South Carolina

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Abstract. Understanding watershed hydrology and the concentrations of nutrients in stream waters are fundamental considerations for assessing water quality. Despite the fact that forests are generally recognized for providing clean water and used as a baseline for assessing the effects of other land uses, especially urbanization, there are ongoing concerns about the effects of forest management practices on receiving waters. Two first-order forested watersheds (WS 80 and WS 77) on poorly drained pine-hardwood stands at the USDA Forest Service Santee Experimental Forest in the South Carolina Coastal Plain have been monitored since mid-1960s to characterize their hydrology, water quality and vegetation dynamics. This study examined the nutrient concentrations and loading dynamics of these two watersheds using both outflow and concentration data collected since 2003. WS 80 remained as a reference throughout the study period, whereas WS 77 underwent a prescribed burning of the understory vegetation in May 2003 for Red-cockaded Woodpecker (Picoides barcalis) habitat management. Both watersheds were highly responsive of rainfall events with 8 to 46% of the annual rainfall lost to stream outflows depending upon years. Prescribed burning contributed to as much as 72% (147 mm) increase in outflows in 2005 for the treatment watershed (WS 77) compared to the pre-burning levels. However, by the first half of 2006 the effect reduced to only 13 mm increase. No difference was found in nutrient concentrations between the two watersheds, except for the NH_4-N, which seem to have increased. Both the nutrient concentrations and loading rates measured were small and were lower than the values published for pine forests in eastern North Carolina. Historic data and the data presented herein may serve as baseline information for assessing developmental impacts in the region and for assessing the Total Maximum Daily Loads (TMDLs).

Keywords. Outflows, Runoff Coefficient, Nutrient Concentration, Loading Rates, Prescribed Burning, Pine-hardwood stands, Understory Vegetation.

INTRODUCTION

In the last two decades, there has been a growing concern over the impact of both human activities (forest management, land use conversion, agriculture, and urbanization) and natural disturbances (droughts, fire, floods, and hurricanes) on the hydrologic, nutrient cycling, and export processes of forested wetlands (Amatya et al., 2005). Despite the fact that forests are generally recognized for providing clean water, there are ongoing concerns about the effects of forest management practices on receiving waters. As the extent of commercial forestry operations is predicted to increase in the South over the next 20 years (SOFRA 2002), this expectation increases the need to document the impact of silviculture on water quality in order to satisfy the public's desire to maintain high-quality water sources and industry's commitment to water quality precepts under the Sustainable Forestry Initiative. The SOFRA (2002) also emphasized that there is a need for research that will enable us to predict the long-term cumulative non-point source impacts of silvicultural management activities on water quality and overall watershed health. Research on watershed processes is needed to assure the public that providing benefits of clean and reliable sources of water is an integral part of managing forests and grasslands. (USDA Forest Service, 2006). Long-term experimental watershed studies conducted by Forest Service scientists have been key to understanding how healthy watersheds function (e.g., what processes enhance or impair the quantity and quality of water that comes from forests). Therefore, understanding both the watershed hydrology and the stream nutrient concentrations are fundamental considerations for assessing water quality. USEPA (2000) stated that water quality primarily includes stream nutrient concentrations and their loadings, as these constituents, particularly nitrogen and phosphorus, have been an issue of great concern for the aquatic health and inland waters.

Prescribed understory burning is one of the operational managements of the USDA Forest Service Francis-Marion National Forest (FMNF) in coastal South Carolina to maintain a healthy forest by reducing the potential risks of forest fire due to a large accumulation of biomass fuel on the forest floor and also for restoring endangered forest species (e.g. longleaf pine) and wildlife habitat, especially red-cockaded woodpecker. Zahner (1958) concluded that understory hardwoods complete significantly for soil moisture in upland pine forests of the Midsouth and may result in increased outflows when they are removed. However, the hydrologic and water quality effects of this management treatment are not well understood for the poorly drained low-gradient forested wetlands. Amatya et al. (2006) recently synthesized the hydrologic and water quality effects of prescribed burning using a long-term data set from two experimental watersheds at Santee Experimental Forest within the FMNF. Earlier studies on the same watersheds (Richter et al., 1980; 1983) indicated that hydrologic fluxes of N, P, S, and basic cations, from burned pine litter to ground and stream waters, are not likely to have appreciable impacts on water quality in the Atlantic and Gulf Coastal Plain. These results were, however, based on only a phase-wise burning during five successive years of a 160-ha treatment watershed. There is only a very limited study documenting the effects of a full-scale prescribed burning of the watershed on its stream outflow and water chemistry.

In this paper we evaluate outflow and nutrient concentration data collected for a 42-month period following two types of disturbance regimes common to the coastal plain. We use two first-order forested watersheds (reference and treatment) to evaluate the effects of a prescribed burning of understory vegetation on 84% of the treatment watershed on both stream outflows and nutrient data. We also examined these data in the context of historic data 10 years prior to and immediately after Category IV Hurricane Hugo that impacted much of the experimental study site in September 1989 (Hook et al., 1991).

STUDY SITE

The long-term hydrologic study site with three experimental watersheds is located 60 km northwest of Charleston at 33.15° N Latitude and 79.8° W Longitude within the Santee Experimental Forest, a part of the USDA Forest Service's Francis Marion National Forest near Huger in South Carolina coastal plain (Fig. 1).

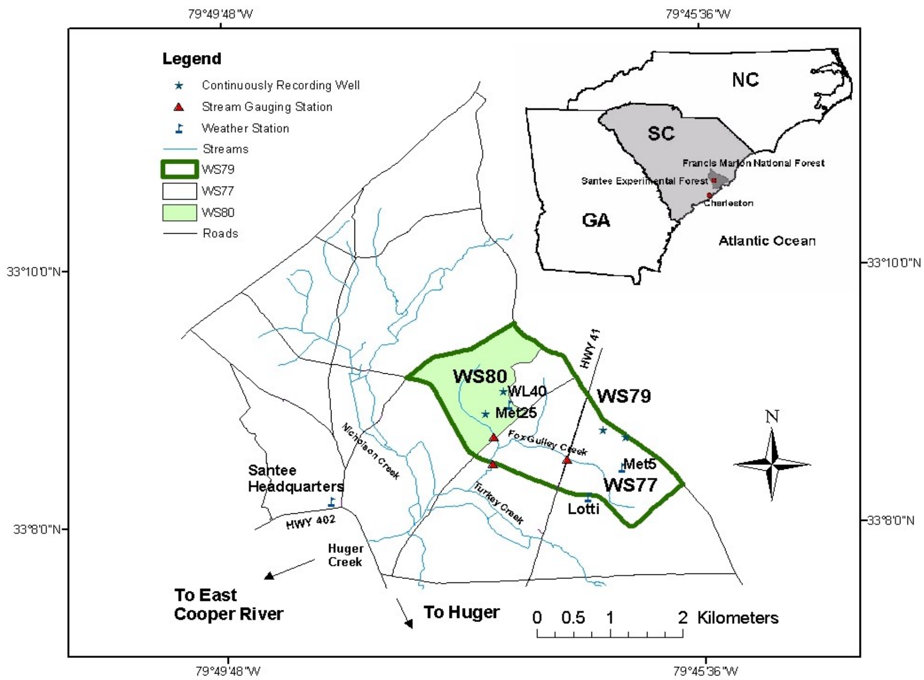

Figure 1. Location map of two experimental watersheds (WS 77 and WS80) within Santee Experimental Forest (SEF) near Huger, SC. Locations of monitoring stations are also shown (After Harder et al., 2006).

Two headwater watersheds (WS 77 and WS 80) drain the first order streams to Turkey Creek, a tributary of Huger Creek draining into East Branch of the Cooper River, a major tributary of Cooper River, which forms the Charleston Harbor System. Monitoring began in the mid-1960s, continued until May 1982, and again resumed in November 1989 after the Santee Experimental Forest experienced the full force of Hurricane Hugo on September 21, 1989. Over 80% of the trees and forest canopy was destroyed and nine long-term studies were prematurely terminated by this storm's passage (Hook et al., 1991). Common soils in the area are aquic alfisols and ultisols (SCS, 1980). These soils characteristics have a high surface water detention capacity and slow surface water drainage. The climate is mild and wet, with an average temperature of 18.3^{o}C, and an average annual precipitation of 1370 mm (Harder et al 2006). The annual water budgets and hydroperiods of these two watersheds for 1976-1980 and 1990-91 have been described by Sun et al. (2000), and for 1996-01 by Amatya et al. (2003). Amatya et al. (2006) recently presented a synthesis of historic hydrology and water quality data for this site.

WS 77

This first-order watershed (155 ha) area was established in 1963. The water balance was first reported by Young (1968). Later this watershed served as a treatment watershed when the watershed (WS 80) was established. WS77 has received several silvicultural treatments over the past 40 years (Richter et al., 1982; Richter, 1982). This is a low-gradient watershed with elevations ranging from 9.98 m towards the northwest to about 5.8 m at the outlet (Miwa et al., 2003). Soils on the watershed are mostly poorly to moderately drained sandy loam to clayey soils with seasonally high water tables (SCS, 1980). Following Hurricane Hugo, this watershed was salvage harvested. Vegetation regenerated since then is comprised of loblolly pine, longleaf pine, and bottomland hardwoods in stream riparian zone. Mastication or mechanical mowing of understory vegetation occurred on portions of this watershed during February to November 2001. On May 10, 2003 prescribed fire affected about 84% of the watershed (Twomey, 2003).

WS 80

Gauging on this reference watershed (206 ha) watershed was established in 1968. In November 2001, a small part of the watershed in the northeastern corner was allowed to drain separately through a culvert reducing its area to only 160 ha. This is also a low-gradient watershed with elevation range from 4 to 6 m with 0 to 3% slopes. The watershed is also characterized by somewhat poorly to poorly drained soils. Before Hurricane Hugo, the vegetation was mostly old (> 80 yr) loblolly pine (*Pinus taeda L.)*. After the hurricane, the watershed remained undisturbed with no timber (including the fallen trees) removed. The forest vegetation since then has regenerated with loblolly pine and hardwoods predominating. Detailed descriptions of this site and field measurements are given elsewhere (Amatya et al. 2005; Amatya and Radecki-Pawlik, 2006; Harder et al. 2006).

METHODOLOGY

Rainfall

Rainfall has been measured using an automatic tipping bucket rain gauge (ONSET) with a HOBO data logger backed up by a manual gauge located at Met5 and Met 25 met-stations on watersheds WS 77 and WS 80, respectively (Figure 1). Breakpoint event rainfall data downloaded every two weeks were processed using MS Excel spreadsheet to obtain daily, monthly and annual values. Rainfall measurement methods and data prior to 2003 have been described recently by Amatya et al. (2006).

Stream Flow

Stream flow rates at the outlets of both the watersheds (WS 77 and WS 80) are determined using stage heights measured at 10-minute intervals by ISCO 4210 Flow meters upstream of the outlet weirs and the lookup table derived from stage discharge relationships. Details of the gauging stations and measurement methods have been described elsewhere (Amatya et al., 2006).

Stream Water Quality

Water samples at the watershed outlets have been collected using an ISCO 3700 sampler since January 2003 on WS 77 and since December 2003 on WS 80. Water samples are collected on a flow proportional basis. The sampling volume was calculated based on a median event volume for 15 events for WS 77 and 21 events for WS 80 using event flow data from 1997-98 period and four samples per bottle for 24 bottles to fill in one event. Bottles in the sampler are downloaded on a weekly basis or more frequently depending upon the storm size. Bottles preserved are frozen until the sample analysis at the Soil Chemistry laboratory in Charleston. Samples are analyzed for ammonia (NH_4-N), nitrate-nitrite (NO_3+ NO_2), total nitrogen (TN), total phosphorus (TP), chloride (Cl), dissolved organic carbon (DOC), calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na). In this paper we present the results for NH_4-N, NO_3+ NO_2, TN, and TP only. Ammonia in water was analyzed by QuikChem© Method, Flow Injection Analysis Colorimetry (Diamond, 1995; Knepel and Bogren, 2000). Nitrate-nitrite was determined by the QuikChem© Method 10-107-04-1, Flow Injection Analysis (Wendtwrp, 1995; Lynch, 2003). TP in water was determined by QuikChem© Method 10-115-01-3-E , FIA Colorimetry (In-Line Persulfate Digestion Method (Liao, 1996). TN in water was determined by QuikChem© Method 10-107-04-3-B, In-Line Digestion Followed By Flow Injection Analysis (Liao, 1997; Bogren, 2003). Concentration levels with below detection limits (BDL) (<0.2 mg L^{-1} for NO_3-N until July 2005 after which it dropped to <0.02 mg L^{-1} using a new method; <0.1 mg L^{-1} for NH_4-N until July 2005 and <0.02 mg L^{-1} after that; <0.3 mg L^{-1} for total-N until July 2005 and 0.1 mg L^{-1} after that; 0.1 mg L^{-1} for Total-P until July 2005 and 0.01 mg L^{-1} (or 10 μg L^{-1}) after that. For the analysis purpose, BDL itself was used for all measured BDLs. Other laboratory quality control was performed as per the procedures established at the Forest Service Soil Chemistry laboratory in Charleston, SC.

Data Analysis

In this paper we analyzed the rainfall and stream outflow data for the two watersheds from January 2003 to June 2006. Stream nutrient concentrations data (NH_4-N, NO_3+ NO_2-N, (here onwards NO_3-N), TN, and TP) for both of the watersheds were available only through March 2006 as there were negligible outflows on both watersheds with no samples collected until August 2006. Nutrient data for the reference watershed (WS 80) were not available until December 2003. Stream nutrient loading rates were calculated as a product of instantaneous 10-minute flow rate and corresponding measured concentration from discrete bottles. Monthly and annual loading rates were obtained by integrating all 10-minute increments. Both rainfall and outflows on both the watersheds were analyzed for monthly and annual periods. Annual runoff coefficient (ROC) as a percentage of rainfall was also calculated. Descriptive statistics (mean, maximum, standard deviation) for all nutrient parameters for both the watersheds were computed for each year. These data for the 2003-06 period were compared with the historic data (1976-81; 1990-94) to examine whether the stream nutrient concentrations have changed significantly in their magnitude and temporal distribution, especially after hurricane Hugo in 1989. A paired watershed approach is being used with these data to quantify the effects of this treatment on both the stream outflows and nutrient concentrations. Pre-burning calibration coefficients for both the outflows and concentrations were obtained from Amatya et al. (2006).

RESULTS

Rainfall

Monthly and annual rainfall recorded at the Santee Experimental Forest Headquarter from January 2003 to November 2006 are compared with the 50-year (1951-2000) long-term data in Table 1. Clearly, years 2003 and 2005 were wetter than average and 2004 and 2006 (11-month) were below the average. As expected, summer months (June-August) generally yielded high rainfall amounts as affected by the tropical depressions. March, May, June, July, and October were wetter and January and December were drier than the average monthly in both 2003 and 2005. Year 2004 had below average monthly rainfall in all months but February, June, and August making this year with the third lowest rainfall in last 42 years (1965-2004) (Amatya et al., 2006). Rainfall amounts from December 2005 through May 2006 were consistently below average. Spatial variability of rainfall among this station and the gauges on WS 77 and WS 80 located within 5 km distance was obvious based on the rainfall data shown in Table 1 and Table 2.

Table 1. Monthly and annual rainfall measured at Santee Experimental Forest Headquarter, SC.

Period	Monthly rainfall, mm												Annual Rainfall, Mm
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1951-2000	108	90	108	77	98	153	180	172	143	89	71	89	1378
2003	19	67	200	134	115	265	436	86	160	96	17	47	1671
2004	38	133	18	76	68	173	89	304	78	38	27	60	1101
2005	44	100	126	35	193	280	227	239	20	213	80	74	1631
2006	78	75	16	73	78	187	101	231	142	89	121	N/A	1191

Annual rainfall as shown in Table 2 was similar for both the watersheds for all years, except in 2003, when WS 77 recorded about 100 mm more (1770 mm) than WS 80 (1671 mm). Annual rainfall on WS 80 in 2003 (1671 mm) and 2005 (1514 mm) was higher than the long-term average of 1378 mm at the SEF site (Table 1). This was also true for WS 77. However, the total rainfall on the two watersheds in 2004 to 2006 had a small variability with only a difference within 4% from each other.

Outflows

Annual outflows from the treatment watershed (WS 77) were higher than the reference (WS 80) in years 2004 and 2005 (Table 2). However, annual outflow for WS 80 (784 mm) in 2003 with a runoff coefficient (ROC) of nearly 46% was higher than that for WS 77 (638 mm) with a ROC of only 36% despite of the 99 mm higher rainfall on WS 77 than on WS 80. The outflow of 252 mm from January to early May 2003 (before the burning treatment) for WS 80 was higher than the treatment (WS 77) (188 mm). The post-burning outflow from May to December in 2003 was still higher by 82 mm on the reference (532 mm) than the treatment (450 mm). Unfortunately, the post-burning outflow from WS 80 includes some extrapolated data for events affected by beaver activities (Harder et al., 2006) making the comparison complicated. A prolonged period with lower than average rainfall from October 2003 to May of 2004, except in February, resulted in annual outflow of only 89 mm from WS 77 and 73 mm on the reference (WS 80) in 2004. Consequently, the difference in outflows and ROC was also small. Monthly outflows from WS77 continued to be larger than the reference starting in later part of 2004 to the end of 2005, except for the month of July, perhaps due to 25 mm more rain recorded on WS 80 than on WS 77 (Amatya et al., 2006). The differences in monthly outflows were as large as 25 mm for wet summer events in 2005. As a result, the ROC for the treatment in 2005 was nearly 30% higher than that for the reference. By June 2006, the outflows from the treatment watershed continued to be lower than the reference resulting in 11% ROC compared to 13% for the reference.

Table 2. Annual rainfall, stream outflow, and ROC from January 2003 to June 2006 and annual average nutrient concentrations (standard deviation) and loading rates for January 2003 to March 2006 for WS 77 and WS 80. No concentration data was available for WS 80 in 2003.

Parameters	Watershed 77 (WS 77)				Watershed 80 (WS 80)			
	2003	2004	2005	2006	2003[1]	2004	2005	2006
Rainfall, mm	1770	976	1497	458	1671	962	1514	440
Outflow, mm	638	89	351	54	784	73	276	55
R/O, %	36	9	23	11	46	8	18	13
NO_3-N, mg L^{-1}	0.22 (±0.098)	0.2 (0)	0.089 (± 0.09)	0.037 (± 0.043)	N/A	0.2 (±0.013)	0.10 (±0.089)	0.093 (± 0.27)
NH_4-N, mg L^{-1}	0.16 (± 0.11)	0.17 (± 0.35)	0.069 (± 0.043)	0.05 (± 0.095)	N/A	0.12 (± 0.04)	0.065 (± 0.04)	0.044 (± 0.069)
DIN, mg L^{-1}	0.38	0.37	0.158	0.087	N/A	0.32	0.165	0.137
Total N, mg L^{-1}	0.64 (± 0.27)	0.64 (± 0.2)	0.64 (± 0.24)	0.24 (± 0.14)	N/A	0.69 (± 0.25)	0.86 (± 0.28)	0.35 (± 0.34)
DON, mg L^{-1}	0.26	0.27	0.482	0.153	N/A	0.37	0.695	0.213
Total P, Mg L^{-1}	0.1 (0)	0.1 (0)	0.063 (± 0.044)	0.011 (± 0.021)	N/A	0.1 (0)	0.065 (± 0.042)	0.011 (± 0.003)
NO_3-N, kg ha^{-1}	0.58	0.11	0.43	0.018	N/A	0.15	0.29	0.054
NH_4-N, kg ha^{-1}	0.36	0.077	0.25	0.027	N/A	0.092	0.18	0.024
Total N, kg ha^{-1}	1.46	0.37	2.33	0.12	N/A	0.45	2.23	0.19
Total P, Kg kg^{-1}	0.25	0.053	0.24	0.005	N/A	0.072	0.18	0.006

<u>Nutrient Concentrations</u>

Annual average total nitrogen (TN) concentrations remained the same (0.64 mg L^{-1}) for the treatment watershed WS 77 in all years, except in 2006 (Table 2) with data for only January to March and when the lower BDL was used. Similarly, NO_3-N levels diminished from 0.22 mg L^{-1} in 2003 to 0.037 mg L^{-1} by 2006 and NH_4-N levels from about 0.16-0.17 in 2003/2004 to 0.05 by 2006 perhaps for the same reason as TN. Dissolved inorganic nitrogen (DIN) as a sum of NO_3-N+ NH_4-N varied from as much as 0.38 mg L^{-1} in 2003 to 0.087 by 2006 on WS 77. Accordingly, the dissolved organic nitrogen (DON) as a difference of TN and DIN remained the same around 0.26 mg L^{-1} in 2003-04 but increased to 0.48 mg L^{-1} in 2005 and again went back to 0.15 mg L^{-1} for a 3-month period in 2006 (Table 2). The DON level was below 45% of the TN in first two years after burning which increased to more than 63 % by 2006. Although the annual average NO_3-N levels in WS 80 varied from 0.093 (with lower BDL) to 0.2 mg L^{-1} (with higher BDL) they were within one standard deviation (Table 2), indicating no difference among years. The same observation was true for NH_4-N, which had concentration levels as high as 0.12 mg L^{-1} in 2004 to 0.044 mg L^{-1} for the 3-month period in 2006. In contrast with the treatment watershed (WS 77) the DON levels in all three years (2004-06) were higher than 50% of TN. The total phosphorus (TP) concentrations did not change from year-to-year on both the watersheds, except for 2006 with data only through March and lower BDLs.

Data in Figure 2 compares the measured annual average concentrations with standard deviations for all nutrients between the two watersheds for 2004 to 2006. TN concentrations were higher for the reference watershed (WS 80) than for the treatment (WS 77). The difference, however, was within one standard deviation indicating no significant difference in any of the nutrients between the two watersheds. Although the annual average TN was 0.86 mg L^{-1} or less, a maximum of 2.77 mg L^{-1} was observed on WS 77 in April of 2003. This was due to increase in both the NO_3-N and NH_4-N concentrations for very wet events.

Similarly, all other nutrients including TP were similar on both watersheds for all three years, except for NO_3-N in 2006 with only three months of data. No seasonal pattern was found for any nutrients.

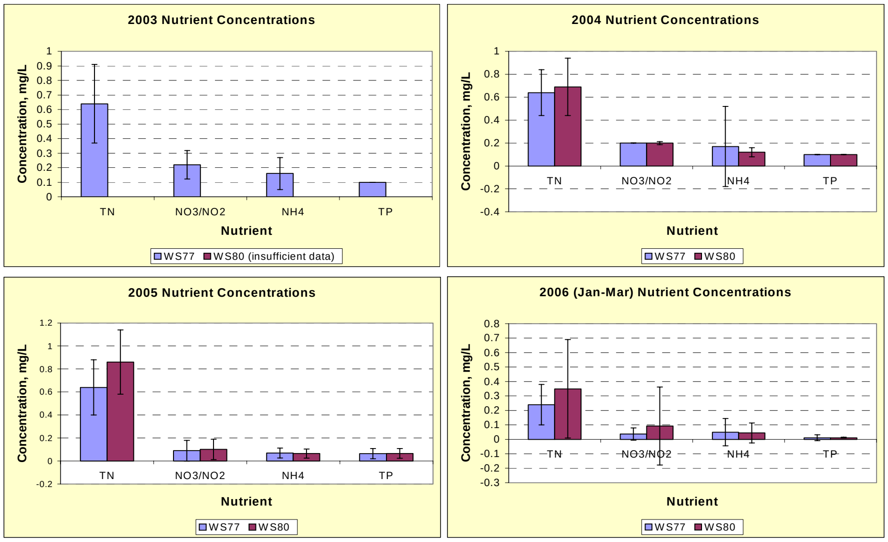

Figure 2. Comparison of annual average nutrient concentrations between WS 77 and WS 80. Data for WS 80 in 2003 was not available.

Nutrients Loadings

NO_3 –N loadings from WS 77 were found to be higher in the years 2003 (0.58 kg ha^{-1}) and 2005 (0.43 kg ha^{-1}), the years with large stream outflows (Table 2). This was true for the reference watershed (WS 80) also although the 2003 data was not available. The TN loading was as high as 2.33 kg ha^{-1} in 2005 followed by 1.46 kg ha^{-1} in 2003 on the treatment watershed (WS 77). Although NH_4 –N concentration for WS 77 in 2005 (0.07 mg L^{-1}) was less than half of that observed in 2004 (0.17 mg L^{-1}), the estimated loading of 0.25 kg ha^{-1} in 2005 was more than 3 times higher than in 2004 (0.08 kg ha^{-1}). This was mainly due to much increased outflows in 2005 compared to 2004 (Table 2). The loading of DIN did not exceed 0.94 kg ha^{-1}, which was observed in the wettest year 2003 on WS 77. All nutrient loadings from the reference watershed were slightly higher than the treatment in 2004 with only small outflows, which were in general higher for the reference. TN loading was slightly lower on WS 80 (2.23 kg ha^{-1}) than on WS 77 (2.33 kg ha^{-1}) in 2005 despite its almost 40% higher concentration because of its 22% lower outflow than that of WS 77 (Table 2). Although the TP levels were very similar between two watersheds in 2004-06, the loadings were slightly different again as a result of difference in outflows.

DISCUSSIONS

Amatya et al. (2006) compared the January 2003 to February 2006 stream outflows between these two watersheds in context with the historical data starting in 1964 for WS 77 and 1969 for WS 80. The limited data for the 1996-99 period after Hugo showed a reversal in stream outflow pattern 7 years (1996) after Hugo compared to the historic data (1969-81; 1990-92) with higher runoff coefficient (ROC) from the reference watershed (WS 80) than the treatment (WS 77). The fact that this trend was visible again from October 2002 until April 2003 before the burning in May shows no effects from masticating the understory vegetation conducted in 2001. However, the beaver effects during some of the large flow events on WS 80 (Harder et al., 2006) complicated the evaluation of post-burning effect on outflows in 2003.

In this study, compared to pre-burning data from 1997-98 (Amatya et al., 2006) we observed 6%, 66%, 72%, and 30% increases in outflows in 2003, 2004, 2005, and 2006 respectively, from the treatment watershed, 84% of which was burned in May 2003. The increase in outflows, equivalent to 59 mm, 36 mm, 147 mm, and 13 mm, indicate the reversal of outflows back to the pattern observed during the calibration period prior to Hugo (1989), when the treatment watershed yielded higher outflows than the reference (Amatya et al., 2006). This was attributed to reduction in evapotranspiration (ET) due to the understory vegetation removal by both the prescribed fire and earlier mastication in 2001. The increases were smaller in the very wet year 2003 and very dry year 2004 compared to 2005. These effects, however, were small by June 2006 with only a 13 mm increase, which is only 3% of the rainfall and may be well within be measurement errors. This may indicate the hydrologic recovery to pre-burning levels of early 2003 and 1996-99 with higher flows from WS 80. Further observation beyond June 2006 was limited by a new thinning treatment implemented on WS 77 in August 2006. The results observed here are different than those reported in earlier studies (Richter, 1980; Richter et al., 1982) which reported no significant effects of burning on stream flows when the watershed was burned up to only 60% over six years.

The evaluation for effects of burning on stream water chemistry in this study was affected by two factors: first, no measurements of nutrients were available in 2003 for the reference (WS 80), and secondly, the below detection limits (BDL) in laboratory measurement for all nutrients were lowered by almost an order of magnitude for samples starting in July 2005. As a result the comparison between watersheds was not possible for 2003 and comparison among years for each watershed was complicated. For the same reason the increased concentrations of both the NO_3-N and NH_4-N in 2003 and 2004 may possibly be due to reduction in vegetation uptake following the burning on the watershed in May 2003 as well as due to the use of one order of magnitude higher BDL in these years than in 2005-06. The NO_3-N concentrations observed here even with lower BDLs in 2005-06 are 4-5 times higher than those (average of 0.017 mg L^{-1}) reported by Binkley (2001) for these streams for the historic data (1976-81; 1990-94 post-Hugo data). However, the annual average NH_4-N levels in 2005-06 have remained similar to 0.045 mg L^{-1} observed for the historic period. Based on the post-Hugo (1990-94) characteristic differences, there was no difference in annual average nutrient concentrations between two watersheds, except for the NH_4-N levels which seem to have increased as much as 79% in 2004 after prescribed burning.

The fact that the TN was slightly higher on WS 80 than on the WS 77 and the DIN was almost the same on both indicates the high DON in stream water draining the reference. DON levels were only 2-4 times higher than the DIN levels for both watersheds compared to the earlier data with greater than an order of magnitude difference (Binkley, 2001). Richter (1980) reported that the concentrations of NO_3-N, NH_4-N, and PO_4 on these watersheds were not related to stream outflows and their values were small compared with concentrations in rainfall, a consequence of biotic uptake, as well as retention of PO_4 by mineral soils. This was not verified in the study assuming it would not change. The concentrations observed on these watersheds were lower than those from other Southeastern forested watersheds dominated by conifers (Chescheir et al., 2003). Temporal trends observed in stream concentrations probably resulted from both fluctuations in outflows and seasonal factors, e.g. temperature and rainfall. Wolaver and Williams (1986) reported that mineral dissolution, forest floor litter decomposition in hardwood swamps, and atmospheric inputs (sea salts) all influence intermittent black water stream water geochemistry in coastal South Carolina.

The total inorganic nitrogen (TIN) loading observed in each of the years in this study was much less than half of 2.36 kg ha^{-1} reported by Richter et al. (1983) for the atmospheric deposition at the site. This indicates that much of the TIN is stored in the system. However, the fact that the annual TP loading of 0.13 kg ha^{-1} or less for both watersheds is similar or lower than the atmospheric deposition of 0.13 kg ha^{-1} for PO_4 indicates that PO_4 may not have been stored in the watersheds. The nutrient exports in 2006 were similar to the post-Hugo data (Wilson et al., 2006). However, the higher nutrient loadings observed in 2003-05 (Table 2) compared to the post-Hugo (e.g. 0.02-0.11 kg ha^{-1} for NO_3-N and 0.02-0.18 kg ha^{-1} for NH_3-N) are most likely due to the higher BDL limits. Nutrient loadings in these systems were more influenced by the stream outflows, as the concentrations did not vary much. However, these loadings are much less than the data reported for coastal forests in eastern North Carolina (Chescheir et al., 2003).

Long-term data on stream outflows and nutrient concentrations from these experimental forested watersheds in the coastal South Carolina can serve as a baseline information as recently used by Lu et al. (2005) in developing a water quality model for Dissolved Oxygen for the Charleston Harbor System. These long-term data will continue to be a great information source for evaluating impacts of continuing urbanization near coastal waters (Tufford et al. 2003; Wahl et al., 1997). Furthermore, data from this study may serve as a basis for the new study being conducted at the site to evaluate the watershed-scale effects of thinning (August 2006) followed by prescribed burning (summer 2007) as a means of reducing forest biomass.

SUMMARY AND CONCLUSIONS

A study was conducted to evaluate stream outflow and nutrient concentrations measured for a 42-month (2003-06) period from two paired first-order watersheds at USDA Forest Service Santee Experimental Forest in Coastal South Carolina. Prescribed burning of the understory vegetation on 84% of the area of the treatment watershed was implemented in May 2003. Burning in this scale implemented all at once increased the stream outflows by as much as 72% (147 mm) in the second year (2005) but reduced back to 30% (13 mm) by the first-half of the third year (2006) compared to the pre-burning period. Since no nutrient data was available for the reference watershed in 2003 and the laboratory methods were changed lowering the below detection limits during the middle of the study, evaluation of effects on nutrient concentrations and loadings were complicated and may have been biased. In general, there was no difference in annual average nutrient concentrations between two watersheds, except for the NH_4-N levels, which seem to have increased after prescribed burning. Nutrient loadings in these systems were mostly affected by the stream outflows and most of the nutrient loadings in stream water were lower than the atmospheric deposits suggesting their storage in the watersheds. Data from this and earlier studies at this site indicate much lower nutrient concentrations and loadings compared to the pine forests in eastern North Carolina, suggesting these systems are healthy with good water quality and have a potential to be used as reference systems for TMDL developments. Furthermore, additional data currently being collected for a thinning study at this site should provide even better understanding of the nutrient export dynamics on these low-gradient forested watersheds.

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