Initial Effects of Prescribed Fire on Quality of Soil Solution and Streamwater in the Southern Appalachian Mountains

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ABSTRACT: *Prescribed burning is being used in the Conasauga River Watershed in southeastern Tennessee and northern Georgia by National Forest managers to restore degraded pine/oak communities. The purpose of these burns is to restore shortleaf pine (*Pinus echinata *Miller)/mixed-oak forests with more diverse understories, which include native bluestem grasses (*Andropogon gyrans *Ashe and* Schizachyrium scoparium *(Michx.) Nash). Although burning might be an effective tool for restoring these stands to a shortleaf pine/mixed-oak/bluestem grass community type, it is not known whether these restoration burns will have a negative impact on water quality. Six subwatersheds (similar in vegetation, soil type, stream size and location, and disturbance history) were located within the Conasauga River Watershed. Four of the sites were burned in Mar. 2001, and two sites were designated as controls. To evaluate initial effects of prescribed burning on water quality, we measured soil solution and streamwater nutrient concentrations and streamwater sediment concentration (TSS; total suspended solids) weekly over a 10-month period. Consistent with goals of the land managers, all the prescribed fires resulted in low- to moderate-intensity and low-severity fires. Soil solution and streamwater* NO_3^-*-N and* NH_4^+*-N did not increase after burning on any of the sites. We found no differences in TSS between burn and control streams in any of the sample periods. In addition, we found no detectable differences between control and burned sites for concentrations of* PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, *or pH in soil solution or streamwater. Thus, these prescribed restoration fires did not have a significant effect on soil solution and stream chemistry or stream sediment (TSS) concentrations. Our results suggest that low-intensity, low-severity fires, such as those in this study, could be used as a tool to restore vegetation structure and composition in these mixed pine-hardwood ecosystems without negatively impacting water quality. South. J. Appl. For. 29(1):5–15.*

Key Words: Nitrate-nitrogen, sediment, disturbance, restoration, shortleaf pine ecosystems.

Natural and human forest disturbances can affect quantity and quality of streamwater and ecological integrity of aquatic ecosystems. Increasing societal concerns over quality of freshwater (Santhi et al. 2001, Baron et al. 2002, Zipper et al. 2002, Ice and Binkley 2003) has prompted forest managers to carefully evaluate effects of silvicultural treatments, including prescribed fire, on water quality. Many factors influence effects of fire on forest ecosystems including the quality and quantity of fuels, soil properties, topography, climate, and weather. In the southern Appalachians, stream nitrate-nitrogen (NO_3^--N) has been shown to be a sensitive indicator of ecosystem response to disturbance (Swank et al. 1981, Swank and Vose 1997, Swank et al. 2001). Response of stream nitrogen (N) due to disturbance, such as fire, can vary greatly depending on disturbance regime (type, severity, intensity, timing, and duration) and forest community type (vegetation composition

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Table 1. Stream descriptions of the six subwatersheds in the Conasuaga River Watershed in southeastern Tennessee and northern Georgia.

Site	Subwatershed size (ha)	Stream elevation range (m)	Flow direction	Stream order	Stream length (m)	Channel slope (%)[a]
HWB	4.5	375–360	SW	1st	1100	1.4
CSB	4.9	380–360	W	1st	450	4.4
MRB	8.1	280–270	S	1st	420	2.4
MRC	10.9	320–300	S	1st	380	5.3
SMB	4.9	280–260	SW	2nd	660	3.0
SMC	4.5	340–325	SW	2nd	330	4.5

NOTE: HWB, Halfway Branch Burn; CSB, Cohutta Springs Burn; MRB, Muskrat Branch Burn; MRC, Muskrat Branch Control; SMB, Sawmill Branch Burn; SMC, Sawmill Branch Burn. Elevation range and stream length were derived from topographic maps (2001 National Geographic Holdings: www.topo.com) and were determined for the section of the stream that bordered the subwatershed treatment area.

[a] Channel slope percents were estimated by: (elevation change ÷ stream length) × 100.

and structure, disturbance history, soils, topography). For example, Neary and Currier (1982) examined wildfires in the Blue Ridge Mountains of South Carolina and concluded that watersheds that had 30% of the area burned showed a threefold increase in stream NO_3^--N compared to a control watershed. Recent studies suggest that prescribed fires have little effect on long-term nutrient reserves or site productivity and serve purposes useful to forest management (Vose 2000). However, these studies are still quite limited and extrapolations across the range of site, vegetation, and fire conditions are not possible.

Prescribed burning is being used in the Conasauga River Watershed in southeastern Tennessee and northern Georgia by National Forest managers to restore degraded pine/oak communities to shortleaf pine (*Pinus echinata* Miller)/mixed-oak forests with more diverse understories, which include native bluestem grasses (*Andropogon gyrans* Ashe and *Schizachyrium scoparium* (Michx.) Nash). Heavy logging at the turn of the 20th century has increased densities of Virginia pine (*Pinus virginiana* Miller) in many oak/shortleaf pine stands, which are now succeeding to white pine (*Pinus strobus* L.). Anecdotal information from prescribed burning treatments currently being applied in the Conasauga River Watershed suggests that burning might be an effective tool for restoring these stands to a shortleaf pine/mixed-oak/bluestem grass community type. However, it is not known whether these restoration burns will have a negative impact on water quality. Any forest management activity, such as timber harvesting, mechanical site preparation, prescribed burning, or fire line clearing, adjacent to or intruding into a riparian area has the potential to negatively impact water quality (Phillips et al. 2000). Factors that affect water quality responses to fire include: 1) frequency, intensity, and spatial extent of burning; 2) climate, notably rainfall patterns; 3) watershed characteristics (e.g., slope, soil, ground-cover, proportion of vegetation burned and its regrowth); and 4) time interval between burning and subsequent runoff. To evaluate initial effects of prescribed burning on water quality, we initiated a study to measure soil solution and streamwater nutrient concentrations and streamwater sediment concentration (TSS; total suspended solids) over a 10-month period immediately following the prescribed burns.

Methods

Site Descriptions

The Conasauga River Watershed in southeastern Tennessee and northern Georgia encompasses 1,870 km^2 of the extreme southwestern edge of the Blue Ridge Physiographic province of the southern Appalachian Mountains. Six subwatersheds (similar in vegetation, soil type, stream size and location (Table 1), and disturbance history) were located within the Conasauga River Watershed (Figure 1). Four of the sites were burned in Mar. 2001, and two sites were designated as controls. Three sites were located in the Chattahoochee National Forest, Murray County, Georgia (34°49′ N, 84°41′ W) and the other three sites were located in the Cherokee National Forest, Polk County, Tennessee (35°00′ N, 84°39′ W). We named each site after the nearest stream and type of treatment: Georgia sites—Muskrat Branch Control (MRC), Muskrat Branch Burn (MRB), and Cohutta Springs Burn (CSB); Tennessee sites—Sawmill Branch Control (SMC), Sawmill Branch Burn (SMB), and Halfway Branch Burn (HWB). All subwatershed sites were 5–10 ha in size and <21 km from each other. All sampled streams were first or second order streams with a "B" Rosgen channel type (Rosgen 1996) and were similar in size and proximity to treated subwatersheds (Table 1). Site elevations ranged from 260 to 415 m and aspects were between 120° and 200°. Mean annual air temperature was 14° C, and mean annual precipitation was 1,350 mm measured at a nearby weather station (Cleveland, TN, National Climatic Database: www.ncdc.noaa.gov).

The sites were mixed pine-oak forests with an overstory dominated by Virginia pine, shortleaf pine, scarlet oak (*Quercus coccinea* Muenchh.), white oak (*Quercus alba* L.), red maple (*Acer rubrum* L.), sourwood (*Oxydendrum arboreum* (L.) DC.), and blackgum (*Nyssa sylvatica* Marshall). Understory composition consisted primarily of mountain laurel (*Kalmia latifolia* L.) and white pine (*Pinus strobus* L.). A southern pine beetle (*Dendroctonus frontalis* Zimm.) outbreak occurred throughout the region during our study. The infestation caused extensive mortality of pine in four of the study sites: MRC, MRB, SMC, and SMB. The soils on all sites were classified as Junaluska and Junaluska-Citico or Junaluska-Brasstown complexes. The Junaluska series is a fine-loamy, mixed, mesic Typic Hapludult. The

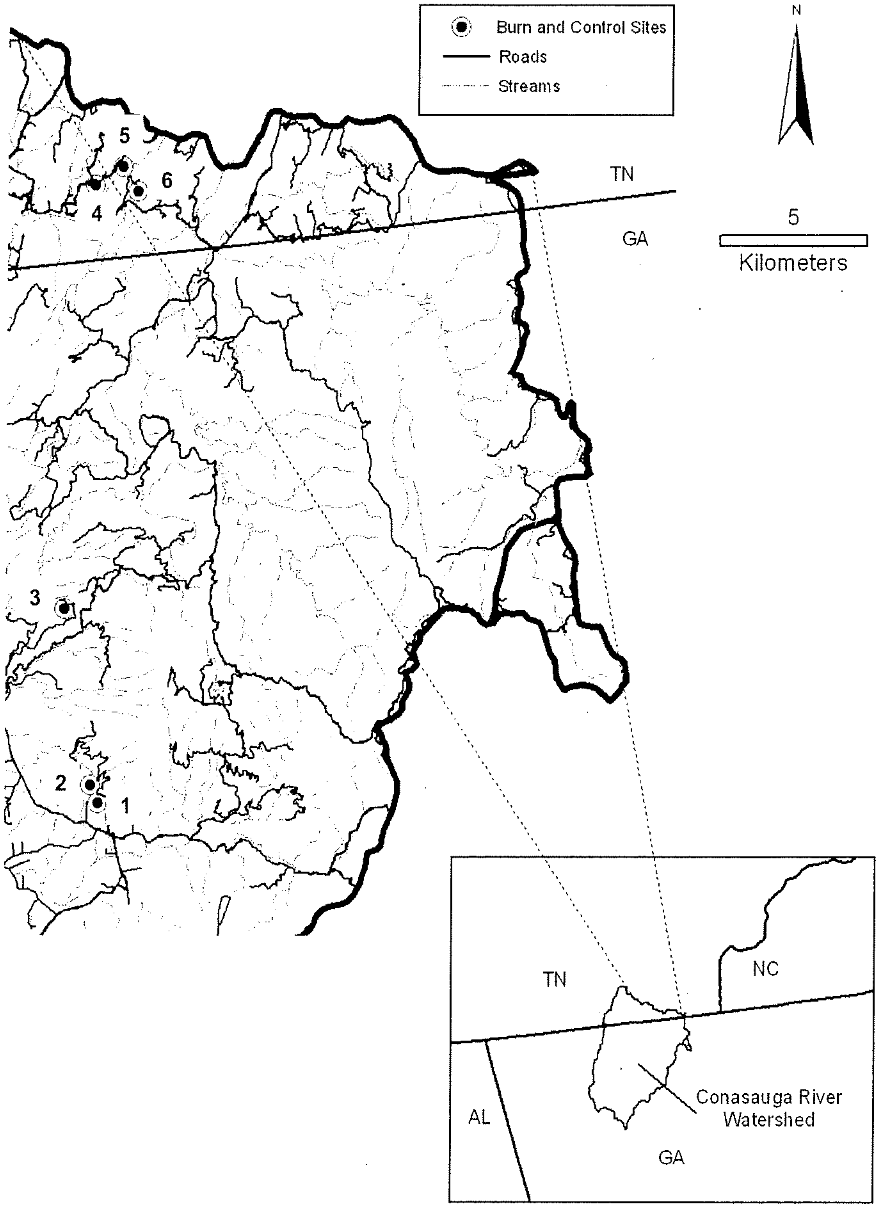

Figure 1. Map locations of the six subwatershed sites in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Site numbers are: 1, Muskrat Branch Burn; 2, Muskrat Branch Control; 3, Cohutta Springs Burn; 4, Sawmill Branch Burn; 5, Sawmill Branch Control; and 6, Halfway Branch Burn (adapted from Riedel and Vose 2002).

Citico series is a fine-loamy, mixed, mesic Typic Dystrochrept and the Brasstown is a fine-loamy, mixed, mesic Typic Hapludult (Newton and Moffitt 2001).

Treatments

Fire crews from the Ocoee and Cohutta Ranger Districts (Chattahochee National Forest, GA and Cherokee National Forest, TN) prescribe burned four of the six sites on Mar. 28, 2001. Two sites were left as controls. Air temperature averaged 14° C (SE = 1.4) and ranged from 8 to 18° C for the duration of the fire prescription (1000 to 1700 hours Eastern Standard Time). Relative humidity ranged between 42 and 25%, decreasing as the afternoon progressed. Wind speed was between 1 and 8 km h^{-1} across all sites for the day. The sites were burned in strips using drip torches. The burning technique was to backfire along the upper ridge and then ignite strip headfires at about 10- to 20-m intervals until the entire watershed had burned from the ridge to the riparian zone. Tennessee and Georgia have best management practices (BMP) programs that recognize the importance of retaining some form of streamside management zone (SMZ) (Tennessee Division of Forestry 1993, Georgia Forestry Commission 1995). However, for this study, fires were allowed to burn to the stream edge (i.e., no riparian buffer or SMZ was implemented).

Within each site, five 10- × 20-m permanent plots were established for a companion study (Hubbard et al. 2004) from the ridge to the riparian zone. To characterize the temperature of the burn, we placed four ceramic tiles (10- × 20-cm) in random locations within each of the permanent plots (n = 20 per site). We applied heat-sensitive chalk and paint (Omega Engineering, Inc., Stamford, CT) to the ceramic tiles. Two days prior to burning, tiles were suspended with metal conduit at 30-cm aboveground. Chalk temperature sensitivity ranged from 52 to 427 °C in approximately 14 °C increments. Heat sensitivities of the paint were 500, 550, 732, 804, and 899 °C. We also monitored heat penetration into the forest floor using a similar technique as above. In each 10- × 20-m plot, two long, narrow tiles painted with heat-sensitive paint were inserted 15 cm into the soil with the top edge being flush with the top of the litter layer. Threshold temperature sensitivity of the paints was 45–59 °C, a range that brackets the thermal lethal point for most plants (Hare 1961).

Sample Collection

We collected soil solution samples weekly beginning in Feb. 2001 (2 months before the burn treatments) and continued through Jan. 2002 (10 months following the burn treatments). To reduce the total number of laboratory analyses, we composited weekly soil solution water samples on a monthly basis. Soil solution chemistry was obtained by installing porous cup lysimeters at 30- and 90-cm depths. Sample depths were chosen from Natural Resources Conservation Service (NRCS) soil survey information, which indicated that these depths represented the A/B and C horizons for these soil types (Newton and Moffitt 2001). Lysimeters were installed in Nov. 2000 and allowed to equilibrate for 3 months before water samples were collected for analyses. During this time, lysimeters were pumped weekly to flush through the system. At each of the six sites, two 30-cm and two 90-cm depth lysimeters were placed approximately 20 m from the stream bank and near the two lower corners of the first permanent vegetation plot used in a companion study (Hubbard et al. 2004). For Nov. 2001, there was no water in the lysimeters on the control sites, and less than half of the lysimeters on the burned sites had water samples. Lack of soil water in lysimeters was attributed to low precipitation from Sept. to Nov. 2001 (Figure 2a).

We collected streamwater samples weekly beginning in Jan. 2001 (3 months before the burn treatments) and continued through Jan. 2002 (10 months after the burn treatments) from first-order streams that drained each of the

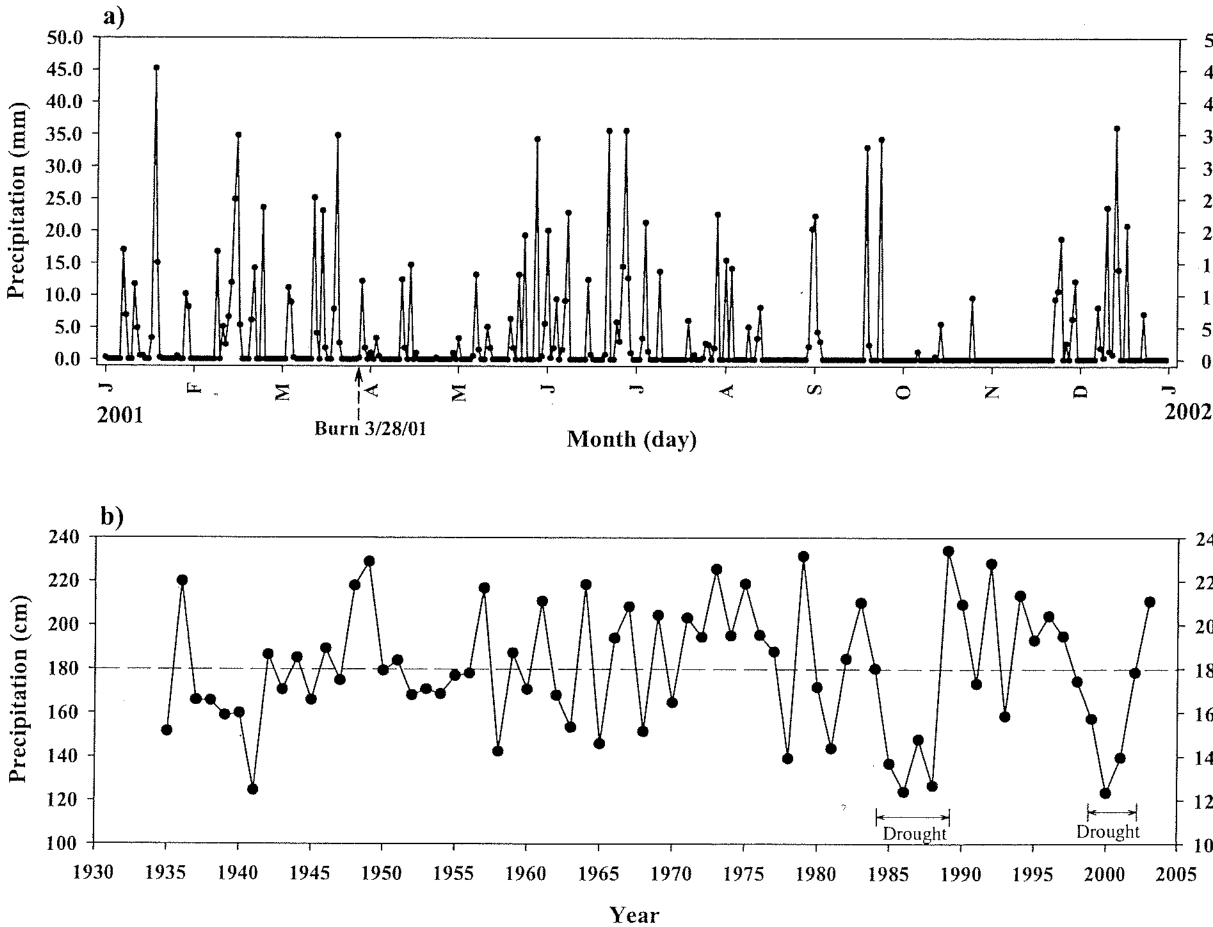

Figure 2. (a) Daily precipitation 3 months before and 9 months after the burn treatments (Jan. 1, 2001 to Dec. 31, 2002) taken from a nearby weather station (<75 km from the furthest burn site) (Cleveland, TN, National Climatic Database: www.ncdc.noaa.gov). (b) Regional total annual precipitation taken from Coweeta Standard Raingage, Climate Station 1 (latitude 35°03′ N, longitude 83°25′ W, 670 m elevation). Dashed line represents the mean annual precipitation over the 70-year record.

Table 2. Fire characteristics of the four burned sites in the Conasauga River Watershed, prescribed burn on Mar. 28, 2001.

Site	Fire behavior		Average soil depth (cm) of heat penetration		Temperature (°C) at 30 cm height	
	Flame length (cm)	Rate of spread (cm/s)	45° C	59° C	Average	Range
HWB	30–45	3.3–5.5	1.2 (0.40)	0.60 (0.22)	39.2 (7.7)	0–100
CSB	90–152	16–30	2.69 (1.11)	1.44 (0.61)	105.4 (11.3)	52–184
MRB	90–122	12–30	1.11 (0.23)	0.94 (0.53)	128.0 (16.8)	0–267
SMB	30–62	5.5–6.7	3.11 (0.34)	1.89 (0.35)	111.9 (14.4)	59–344

NOTE: HWB, Halfway Branch Burn; CSB, Cohutta Springs Burn; MRB, Muskrat Branch Burn; SMB, Sawmill Branch Burn. Standard deviations are in parentheses.

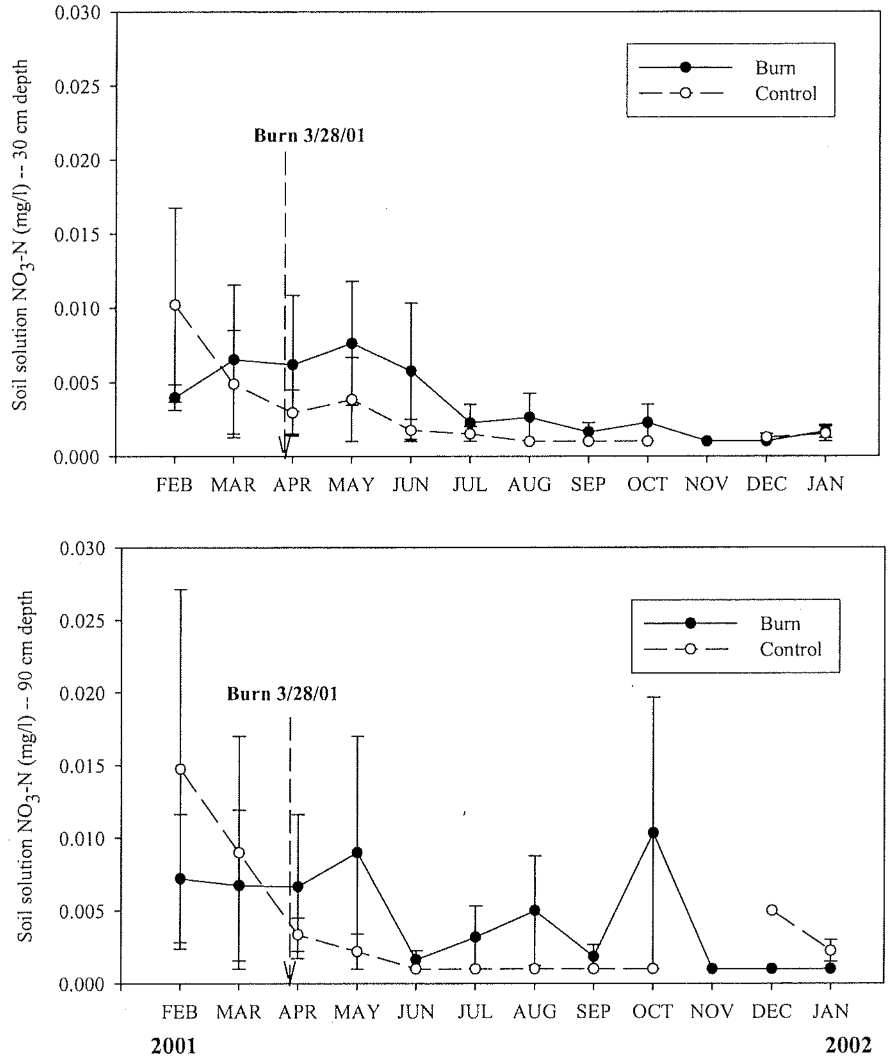

Figure 3. Soil solution nitrate-nitrogen (NO_3^--N) concentrations at: (a) 30 cm and (b) 90 cm soil depths for burn and control treatment sites from Feb. 2001 to Jan. 2002 in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Values are monthly means with standard error bars.

small subwatersheds. A 250-ml grab sample was taken from stream sample sites for cation and anion analyses. A second 1,000-ml sample was collected for total suspended solids (TSS). Samples were collected at the same location on the stream reach each sample period. Concentration of calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), orthophosphate (PO_4^{3-}), nitrate (NO_3^--N), ammonium (NH_4^+-N), and pH of soil solution and streamwater samples were analyzed at the Coweeta Hydrologic Lab with procedures described by Deal et al. (1996). Solutions were analyzed for NO_3^--N, PO_4^{3-}, SO_4^{2-}, and NH_4^+-N using a Perstorp Enviroflow 3500 ion chromatograph (Alpkem Corporation, Wilsonville, OR). A Perkin-Elmer 300 atomic adsorption spectrophotometer (Perkin Elmer Corporation,

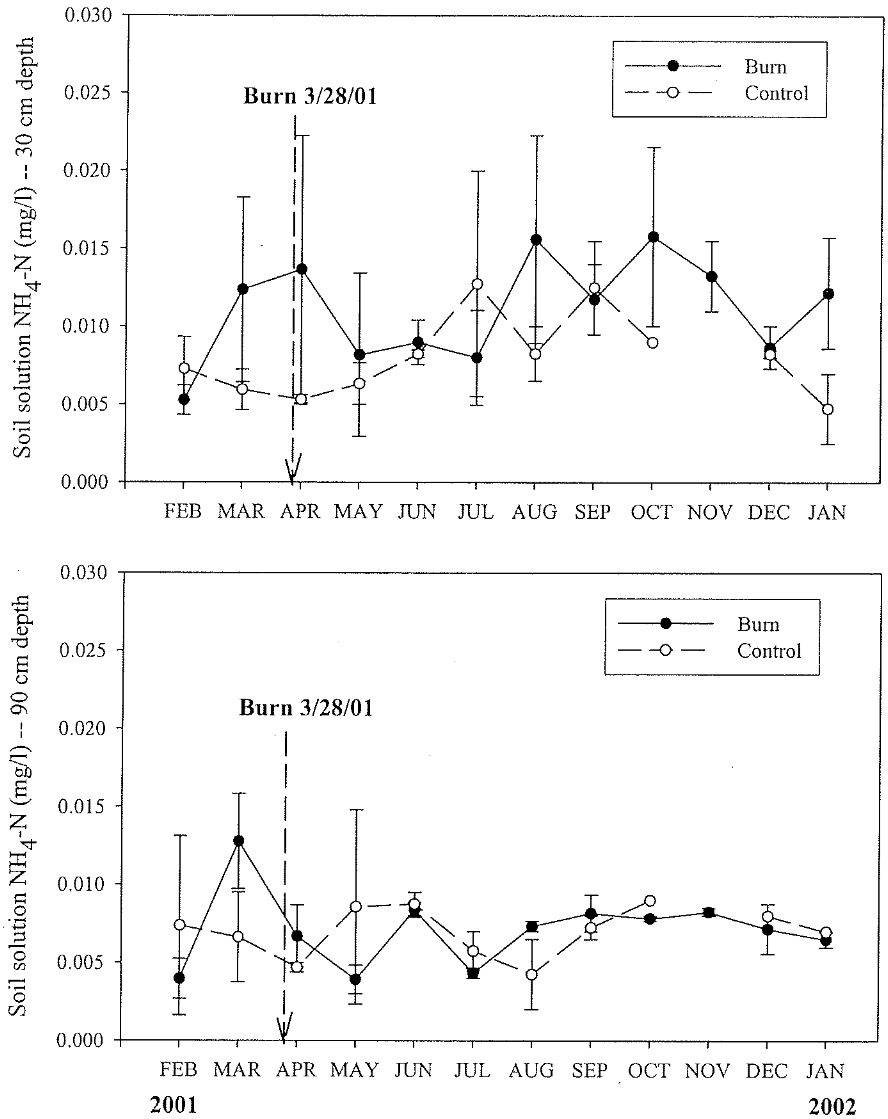

Figure 4. Soil solution ammonium-nitrogen (NH_4^+-N) concentrations at: (a) 30 cm and (b) 90 cm soil depths for burn and control treatment sites from Feb. 2001 to Jan. 2002 in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Values are monthly means with standard error bars.

Norwalk, CN) was used to determine Ca^{2+}, K^+, and Mg^{2+} concentrations in solution. The TSS concentrations were calculated by using a gravimetric method (USGS 1978). Within 24 hours of collection, stream water samples were filtered through Whatman GF/C glass 1.5-μm microfiber filter paper using a Millipore filtering apparatus attached to a vacuum pump. Filters were then dried at 125° C for 1.5 h and weighed. Weekly samples were stored at 4° C for 1–3 weeks.

Statistical Analyses

We statistically examined soil solution at two depths and streamwater nutrient and TSS concentrations with repeated measures ANOVA (PROC GLM, SAS 1999) for the entire 13-month period of this study; beginning with pretreatment (Jan. 2001) through the end of the sampling period (Jan. 2002). Mean concentration responses to treatment were identified with the repeated measures model. For soil solution nutrient concentrations, we used the composited monthly values in the repeated measures models. For stream nutrient and TSS concentrations, we used weekly values in the repeated measures models. We used analysis of variance (ANOVA) (PROC GLM, SAS 1999) to determine significant differences between control and burn soil solution and stream chemistry using the average concentrations across the 10-month sample period after the burn.

Results and Discussion

Fire behavior, flame temperature, and heat penetration were variable within and among the four burned watersheds (Table 2). Consistent with the goals of the land managers, all the prescribed fires resulted in low- to moderate-intensity and low-severity. Fire severity (Simard 1991) was considered low based on criteria from Waldrop and Brose (1999): the litter layer (Oi layer) was reduced but the duff layer

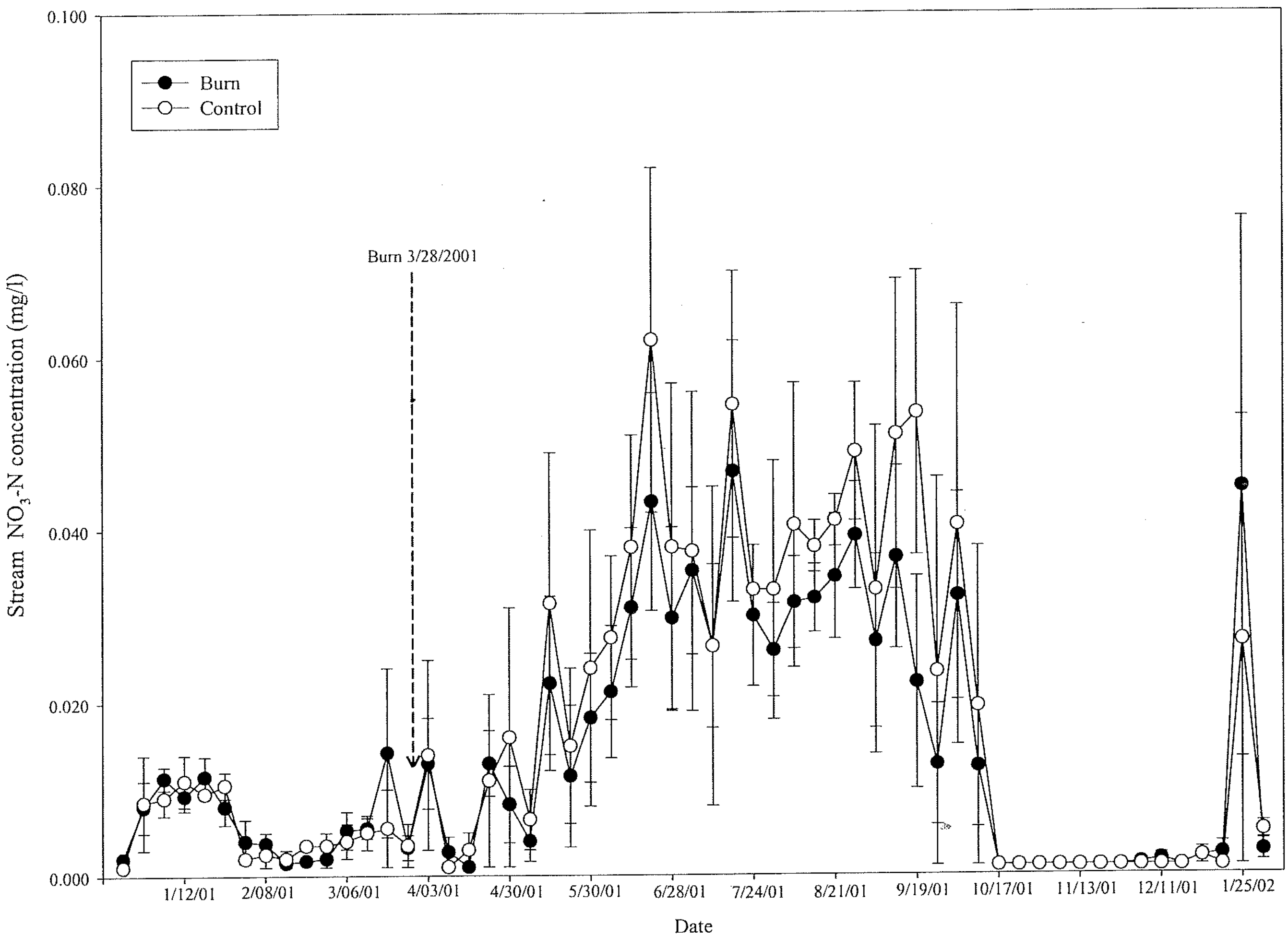

Figure 5. Stream nitrate-nitrogen (NO_3^--N) concentrations collected from burn and control treatment sites from Jan. 2001 through Jan. 2002 in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Values are weekly means with standard error bars.

(Oe+Oa layer) remained essentially intact (Hubbard et al. 2004), little soil was exposed, and heat penetration was near the soil surface (Table 2). The CSB and MRB sites had higher flame lengths and rates of spread than the other two sites. However, fire severity, based on soil depth of heat penetration, was higher on CSB and SMB than on HWB and MRB. The MRB site had the highest fire intensity (temperature at 30 cm) compared to the other sites. Overall, the prescribed fire at MRB was the most intense of the four sites with the highest temperature and fast rate of spread; whereas, SMB had the most severe fire probably because the rate of spread was relatively slow allowing a longer fire residence time compared to the other three sites. Because fire intensities were relatively low on our burn sites, total live biomass consumption was small (Hubbard et al. 2004), and no change in litterfall was detected (Hubbard et al. 2004). In addition, coarse wood (>7.5 cm diameter) was only reduced by 12%, forest floor litter (Oi layer) consumption was 70%, and humus and fermentation (Oe+Oa layer) consumption was minimal (Hubbard et al. 2004).

Soil solution NO_3^--N (Figure 3, a and b), NH_4^+-N (Figure 4, a and b), and stream NO_3^--N and NH_4^+-N (Figures 5 and 6) concentrations did not show any statistically significant increases after burning on any of the sites. Hubbard et al. (2004) found no significant response in soil N availability on any of these burned sites. Without a measurable response in soil N, it is not surprising that we did not detect a response in soil solution or streamwater N concentrations. In addition, we found no detectable difference between control and burned sites for 10-month posttreatment mean concentrations of PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, or pH in soil solution (Tables 3 and 4) or streamwater (Table 5).

Excess sediment is the principal pollutant of streamwater associated with forest management (Phillips et al. 2000) and is considered the primary threat to the integrity of aquatic resources (Henley et al. 2000). We found no statistically significant differences in TSS concentrations between burn and control streams in any of the sample periods (Figure 7). Excess sediment delivery to streams typically occurs after a measurable storm event. In this study, although a small rain event did occur the first day after the burn treatments (Mar. 29, 2001), this event brought less than 15 mm of rainfall (Figure 2a). Long-term (1935 to present) precipitation records from Coweeta Hydrologic Laboratory, western

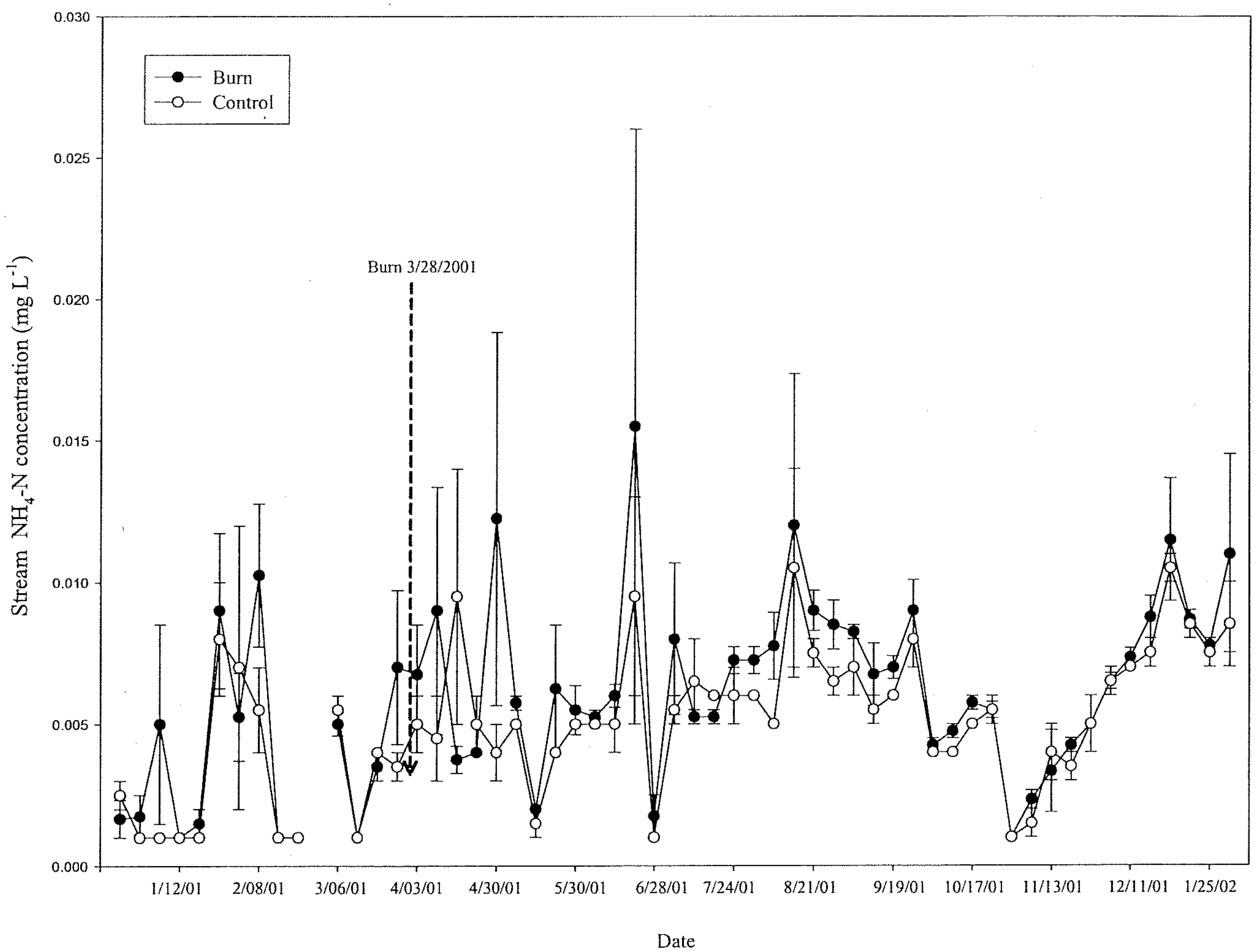

Figure 6. Stream ammonium-nitrogen (NH_4^+-N) concentrations collected from burn and control treatment sites from Jan. 2001 through Jan. 2002 in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Values are weekly means with standard error bars.

Table 3. Ten-month mean soil solution chemistry at 30-cm soil depth on the six sites and averaged for the burn and control treatments at the Conasauga River Watershed in southeastern Tennessee and northern Georgia.

Site	pH	NO_3^--N	NH_4^+-N	PO_4^{3-}	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+
				Nutrient concentrations (mg L^{-1})				
HWB	4.93 (0.08)	0.0012 (0.0002)	0.0064 (0.0028)	0.0041 (0.0024)	5.464 (0.831)	0.878 (0.112)	0.353 (0.048)	1.208 (0.356)
CSB	4.97 (0.20)	0.0070 (0.0092)	0.0076 (0.0053)	0.0035 (0.0018)	6.041 (1.173)	0.430 (0.060)	0.315 (0.076)	2.128 (0.176)
MRB	5.54 (0.05)	0.0011 (0.0002)	0.0080 (0.0022)	0.0392 (0.0064)	6.910 (0.635)	1.830 (0.173)	1.020 (0.132)	1.708 (0.098)
SMB	6.12 (0.28)	0.0056 (0.0060)	0.0208 (0.0096)	0.0044 (0.0026)	9.006 (1.892)	3.053 (0.705)	2.530 (0.892)	3.283 (1.456)
MRC	5.61 (0.14)	0.0018 (0.0012)	0.0086 (0.0053)	0.1207 (0.0668)	6.340 (1.377)	1.672 (0.098)	0.739 (0.047)	2.878 (1.023)
SMC	5.60 (0.14)	0.0018 (0.0019)	0.0081 (0.0030)	0.0049 (0.0046)	5.347 (0.887)	1.386 (0.191)	0.481 (0.054)	2.729 (2.148)
Burn	5.39 (0.28)	0.0037 (0.0015)	0.0107 (0.0034)	0.0128 (0.0088)	6.855 (0.776)	1.548 (0.580)	1.054 (0.518)	2.082 (0.442)
Control	5.61 (0.01)	0.0018 (0.0000)	0.0084 (0.0003)	0.0628 (0.0579)	5.844 (0.496)	1.529 (0.143)	0.610 (0.129)	2.803 (0.074)

NOTE: HWB, Halfway Branch Burn; CSB, Cohutta Springs Burn; MRB, Muskrat Branch Burn; SWB, Sawmill Branch Burn; MRC, Muskrat Branch Control; SMC, Sawmill Branch Control. NO_3^--N, nitrate-nitrogen; NH_4^+-N, ammonium-nitrogen; PO_4^{3-}, phosphate; SO_4^{2-}, sulfate; Ca^{2+}, calcium; Mg^{2+}, magnesium; K^+, potassium. For the individual sites, values are averages of the sample period after the burn and standard deviations are in parentheses. For burn and control treatment average values, standard errors are in parentheses.

North Carolina, showed a drought period for 1999–2001 where annual rainfall was 40–60 cm below the mean annual rainfall for the Southern Appalachian Region (Figure 2b). The low rainfall recorded in 2001, the year of this study, could have minimized potential effects of prescribed burning. If the prescribed burn had been implemented in years with average or above average rainfall, storm events would have had greater intensity and frequency and possibly greater influence on sediment delivery to the streams.

Several other authors have reported little to no soil erosion after light- to moderate-intensity fires in the southeastern United States (Neary and Currier 1982, Van Lear and Waldrop 1986, Van Lear and Danielovich 1988, Shahlee et al. 1991). For example, Douglas and VanLear (1983) found

Table 4. Ten-month mean soil solution chemistry at 90 cm soil depth on the six sites and averaged for the burn and control treatments at the Conasauga River Watershed in southeastern Tennessee and northern Georgia.

Site	pH	NO_3^--N	NH_4^+-N	PO_4^{3-}	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+
				Nutrient concentrations (mg L^{-1})				
HWB	5.42 (0.214)	0.0012 (0.0004)	0.0063 (0.0020)	0.0039 (0.0029)	2.848 (0.651)	0.262 (0.022)	0.374 (0.030)	0.690 (0.104)
CSB	5.24 (0.069)	0.0013 (0.0004)	0.0062 (0.0011)	0.0014 (0.0002)	2.274 (0.414)	0.146 (0.017)	0.547 (0.058)	0.311 (0.029)
MRB	5.86 (0.195)	0.0010 (0.0001)	0.0067 (0.0021)	0.0051 (0.0024)	4.055 (0.129)	1.148 (0.079)	1.008 (0.070)	0.504 (0.053)
SMB	5.55 (0.166)	0.0098 (0.0099)	0.0079 (0.0025)	0.0048 (0.0038)	6.159 (0.824)	1.141 (0.295)	0.815 (0.166)	1.790 (0.310)
MRC	5.92 (0.212)	0.0014 (0.0008)	0.0053 (0.0028)	0.0272 (0.0466)	4.429 (0.802)	2.142 (0.331)	0.430 (0.032)	0.159 (0.080)
SMC	5.49 (0.103)	0.0022 (0.0017)	0.0079 (0.0031)	0.0059 (0.0031)	6.017 (0.465)	0.812 (0.095)	0.891 (0.125)	0.677 (0.111)
Burn	5.52 (0.13)	0.0033 (0.0021)	0.0068 (0.0004)	0.0038 (0.0008)	3.834 (0.859)	0.674 (0.273)	0.686 (0.140)	0.824 (0.331)
Control	5.71 (0.21)	0.0018 (0.0003)	0.0066 (0.0013)	0.0166 (0.0106)	5.223 (0.794)	1.477 (0.665)	0.661 (0.230)	0.417 (0.259)

NOTE: HWB, Halfway Branch Burn; CSB, Cohutta Springs Burn; MRB, Muskrat Branch Burn; SWB, Sawmill Branch Burn; MRC, Muskrat Branch Control; SMC, Sawmill Branch Control. NO_3^--N, nitrate-nitrogen; NH_4^+-N, ammonium-nitrogen; PO_4^{3-}, phosphate; SO_4^{2-}, sulfate; Ca^{2+}, calcium; Mg^{2+}, magnesium; K^+, potassium. For the individual sites, values are averages of the sample period after the burn and standard deviations are in parentheses. For burn and control treatment average values, standard errors are in parentheses.

Table 5. Ten-month mean stream total suspended solids (TSS) and chemistry for the six sites and averaged for the burn and control treatments at the Conasauga River Watershed in southeastern Tennessee and northern Georgia.

Site	pH	TSS	NO_3^--N	NH_4^+-N	PO_4^{3-}	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+
					Concentrations (mg L^{-1})				
HWB	6.83 (0.14)	1.380 (0.545)	0.008 (0.010)	0.007 (0.007)	0.005 (0.004)	3.241 (0.027)	1.939 (0.437)	1.294 (0.195)	0.316 (0.054)
CSB	6.51 (0.15)	3.721 (1.885)	0.028 (0.027)	0.006 (0.002)	0.009 (0.006)	8.098 (1.236)	1.886 (0.209)	0.947 (0.071)	0.650 (0.136)
MRB	6.71 (0.12)	2.843 (2.163)	0.026 (0.023)	0.008 (0.006)	0.021 (0.014)	6.733 (1.041)	2.409 (0.312)	1.394 (0.131)	0.423 (0.043)
SMB	7.12 (0.16)	1.109 (0.636)	0.012 (0.013)	0.006 (0.002)	0.009 (0.016)	9.418 (2.696)	4.613 (1.350)	1.829 (0.392)	0.542 (0.130)
MRC	6.94 (0.13)	2.538 (2.005)	0.029 (0.025)	0.005 (0.002)	0.018 (0.010)	5.552 (0.721)	2.639 (0.406)	1.384 (0.158)	0.415 (0.047)
SMC	7.09 (0.14)	1.151 (0.591)	0.014 (0.017)	0.006 (0.003)	0.006 (0.005)	5.141 (1.619)	3.210 (1.093)	1.502 (0.358)	0.471 (0.124)
Burn	6.80 (0.12)	2.263 (0.617)	0.018 (0.005)	0.007 (0.001)	0.011 (0.004)	6.873 (1.328)	2.712 (0.645)	1.366 (0.182)	0.483 (0.072)
Control	7.02 (0.07)	1.845 (0.694)	0.022 (0.008)	0.006 (0.001)	0.012 (0.006)	5.347 (0.205)	2.924 (0.286)	1.443 (0.059)	0.443 (0.028)

NOTE: HWB, Halfway Branch Burn; CSB, Cohutta Springs Burn; MRB, Muskrat Branch Burn; SWB, Sawmill Branch Burn; MRC, Muskrat Branch Control; SMC, Sawmill Branch Control. TSS, total suspended solids; NO_3^--N, nitrate-nitrogen; NH_4^+-N, ammonium-nitrogen; PO_4^{3-}, phosphate; SO_4^{2-}, sulfate; Ca^{2+}, calcium; Mg^{2+}, magnesium; K^+, potassium. For the individual sites, values are averages of the sample period after the burn and standard deviations are in parentheses. For burn and control treatment average values, standard errors are in parentheses.

no significant differences in runoff or soil export between burned and unburned watersheds in the Piedmont of South Carolina. Swift et al. (1993) reported that only minor and very localized movements of burned plant fragments and soil were observed after a fell-and-burn treatment in xeric pine-hardwood stands in the southern Appalachian Mountains of North Carolina. In their study, the residual forest floor was resistant to erosion over the range of burn intensities in their fire treatments, and sediment was prevented from leaving the site by unburned brush and undisturbed forest floor at the lower margins of the treatment areas (Swift et al. 1993).

Similar to other studies on effects of prescribed fire on streamwater quality (Richter et al. 1982, Douglas and Van Lear 1983, Vose et al. 1999, Clinton et al. 2003), we found no detectable changes in streamwater chemistry after burning. Several possible factors may explain why these prescribed fires produced this result. First, the low-intensity—low-severity prescribed fire consumed less than 20% of the forest floor mass (Oi+Oe+Oa layers), which was composed of pine and oak litter having low nutrient content (Hubbard et al. 2004). Second, suspension of ash particles and solutions of water-soluble elements may have been filtered by unburned litter and soil layers before washing into the stream. Third, timing of the burn was in the spring when vegetation uptake and microbial immobilization are typically high. For example, Clinton et al. (2003) compared stream NO_3^--N responses from watersheds burned in the fall and those burned in the spring. The two sites that showed a stream NO_3^--N response were burned in the fall, whereas the sites that were burned in the spring showed no response.

In a fell-and-burn treatment in pine-oak communities, Knoepp and Swank (1993) found no response of soil solution NH_4^+-N and only a small response of soil solution NO_3^--N that also led to a small response observed in the stream. Concentrations of streamwater NO_3^--N increased after treatment, from <0.01 mg L^{-1} up to a maximum of 0.075 mg L^{-1}, and remained elevated for 8 months. In contrast, Douglas and Van Lear (1983) described no change in stream NO_3^--N in control and burned watersheds in the Piedmont of South Carolina. In their study, even though the entire watershed was burned, they found no significant increase in stream NO_3^--N in the burned watersheds compared to control watersheds. In addition, Vose et al. (1999) found no increases in stream NO_3^--N following a stand-replacement fire in pine-oak communities in the southern Appalachians. Vose et al. (1999) suggested that even though fire intensity was high in some areas across the watershed, the unburned riparian zone may have buffered fire effects. Walker et al. (2002) demonstrated the effectiveness of riparian zones in reducing NO_3^--N delivery to streams through microbial uptake. In our study, fire did burn up to the stream bank. However, the lowest burn intensities across each site occurred near the stream (Hubbard et al. 2004) because the fires were ignited at the ridge and the last

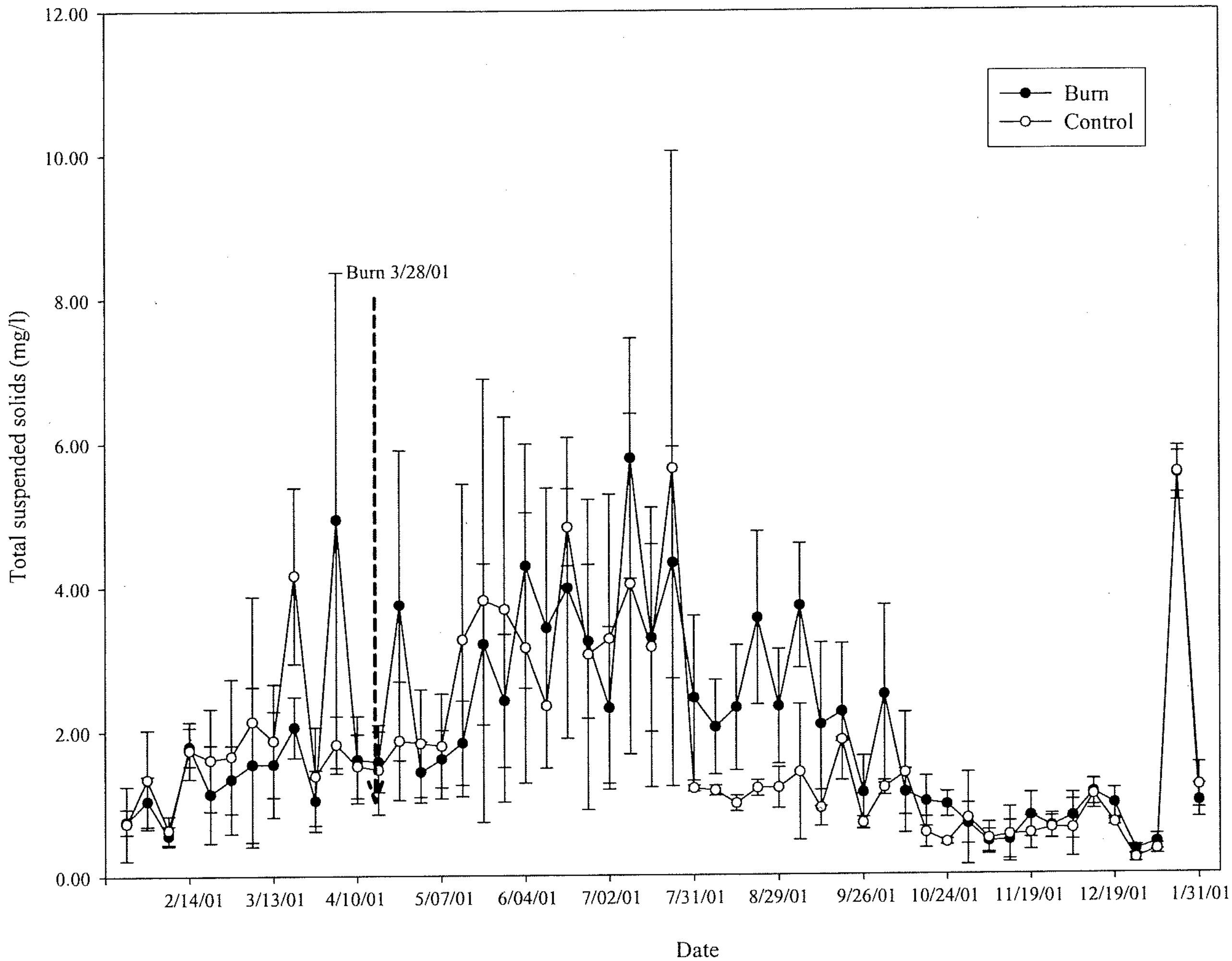

Figure 7. Stream total suspended solid (TSS) concentrations collected from burn and control treatment sites from Jan. 2001 through Jan. 2002 in the Conasauga River Watershed in southeastern Tennessee and northern Georgia. Values are weekly means with standard error bars.

ignition strip was placed at ≥50 m from the stream edge. By the time the fire reached near the stream edge, fire movement was slow (i.e., rate of spread ≤5.0 cm s^{-1}) and flame lengths were <30 cm.

Nitrate-nitrogen concentrations varied seasonally in all the measured streams in the Conasauga River Watershed, with highest concentrations occurring from May through Sept. (Figure 5). Because the reported stream nutrient concentrations were not flow-weighted, we cannot determine whether the higher concentration during the growing season months was due to low-flow periods (plant water uptake combined with low rainfall) or to higher biological activity (e.g., decomposition of organic material, nitrogen mineralization) in the growing season. However, this seasonal pattern in stream NO_3^--N concentration was similar to reported trends in other southern Appalachian streams (Swank and Vose 1997, Clinton et al. 2003).

In a recent national evaluation of forested streams, National Council for Air and Stream Improvement (NCASI 2001) found that NO_3^--N concentrations for small forested watersheds averaged 0.31 mg N L^{-1} (median 0.15 mg N L^{-1}), and some streams averaged 10 times that level. In the six streams monitored during our study, nitrate-N concentrations were an order of magnitude lower than the average reported from NCASI (2001). Although stream NO_3^--N and NH_4^+-N concentrations in our study were very low and frequently near or below detection limits (e.g., in Figure 5 from 10/17/01 values ≤0.002 mg L^{-1}), they were similar to low-elevation reference streams measured at Coweeta Hydrologic Laboratory in western North Carolina (Swank and Vose 1994, Swank and Vose 1997).

Conclusions

We investigated initial effects of prescribed burning on soil solution chemistry and streamwater quality in degraded pine/oak communities in the Conasauga River Watershed of northwest Georgia and southeast Tennessee. The purpose of the prescribed burn was to restore these degraded pine/oak communities to shortleaf pine-dominated forests with a diverse herbaceous understory. All of the prescribed fires resulted in low- to moderate-intensity and low-severity fires across the four sites. These prescribed restoration fires did not have a significant effect on soil solution and stream chemistry or stream sediment (TSS) concentrations. We attribute low stream N response in this study to three factors. First, there was no mechanism for long-distance transport of N to the streams because the forest floor remained intact (Hubbard et al. 2004). Second, any NO_3^--N mobilized by burning (Knoepp and Swank 1993) and transported downslope by subsurface flow is likely to be used by vegetation in the lightly burned riparian and lower slope positions. Third, there was a lack of large storm events and surface runoff during the course of this study. Soil and streams showed no response and fire effects were limited to minor decreases of the forest floor (Hubbard et al. 2004). Our results suggest that forest managers could use low-intensity, low-severity prescribed fire to restore vegetation structure and composition in these mixed pine-hardwood ecosystems without negatively impacting water quality.

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