EFFECTS OF PRESCRIBED FIRE ON WATER QUALITY AT THE SANTEE EXPERIMENTAL WATERSHEDS IN SOUTH CAROLINA

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I INTRODUCTION

Natural fires have periodically affected many of the world's forests. Fires have a wide range of effects on forests, depending chiefly on quantity and quality of fuels, climate, weather, forest soil properties, topography, and frequency and intensity of fires. Wildfires, for example, can radically diminish soil fertility and the ability of watersheds to produce high-quality drainage waters. A number of studies indicate that wildfires can elevate stream water alkalinity and concentrations of base cations and presumably pH (12), whereas fires of low intensity (e.g., prescribed fires) have relatively minor effects on forest nutrients or site productivity and are useful in the multi-resource management of forests (14). However, studies that quantify effects of prescribed fires on stream and ground water chemistry are lacking.

The science and practice of controlled burning was largely developed in the pine forests of the southeastern Atlantic and Gulf coastal plains, where natural fire cycles are relatively short. Research in these areas has demonstrated that periodic fires can reduce the risk of wildfires, control certain tree pathogens, manipulate density and composition of understory vegetation, and promote habitat for wild and domestic animals. Cost-benefit analyses of prescribed fires as a management practice suggest a remarkable degree of economy. Prescribed burning is now applied annually to about 1 million hectares of forest in the southeastern United States, and as management of the southern pine forest intensifies, prescribed fire will almost certainly grow in popularity. The U.S. Forest Service, especially the Southeastern Forest Experiment Station, has played an active and long-term role in promoting much of this important fire research (8).

Important environmental concerns about prescribed fires center on off-site effects such as their influence on air and water quality and their long-term effects on the nutrient status of soils. This paper summarized effects of prescribed fires on the chemical quality of ground and stream waters, as reported in individual studies on the Santee Experimental Forest watersheds (1,3,7,9,10,11,15,).

The objective of these studies was to evaluate comprehensively chemical effects of a series of fires on forest floors, mineral soils, ground water, and stream water of a lower coastal plain flatwoods watershed. The general approach was to subject a pine-forested watershed to winter and summer fires in accordance with burning practices used for managing many pine stands in the coastal plain (5-year fire cycle). Effects of fire treatments thus simulated responses of an operational forest. This approach at the Santee Experimental Forest differs from a number of watershed studies in which treatments have been applied to entire watersheds. Studies at the Santee watersheds include the operational scaling factor inherent in forest management practices.

II METHODS

The pine-flatwoods watersheds on the Santee Experimental Forest are located within the Francis Marion National Forest, about 50 km north-northeast of Charleston, South Carolina and 25 km west of the Atlantic Ocean (Figure 1). The burned and unburned watersheds (WS 77 and 80) are about 160 and 200 ha in area, respectively, with topographic relief less than 5.5 m. Watershed divides are U.S. Forest Service roads with drainage channels to intercept surficial runoff from surrounding watersheds. Soils are mainly extremely acid Aquults (9), characterized by low base saturation throughout the profile, high organic matter in surface soils, and subsoils with heavy clays. Soil fertility is low because of the presence of heavy clays that tend to limit soil aeration, seasonally fluctuating water tables that may restrict rooting volumes, and low availability of soil phosphorus and nitrogen. Forest stands now present are mainly natural stands of loblolly pine (*Pinus taeda* L.), which have replaced stands of long-leaf pine (*P. palustric* Mill.) as a result of effective fire exclusion in the last 50 years (3,6).

The treatment watershed was subdivided into 20 management compartments (each about 7 ha) with 20-m-wide buffer strips bordering stream channels (Figure 2). During the winters of 1976-77, 1977-78, and 1978-79, 12 compartments were burned, four each year. A series of three summer fires were administered to the four compartments that had been burned the winter of 1976-77.

Forest floor samples were collected from 110 semi-permanent plots on the burned watershed on three occasions: before the fires, immediately after the fires, and after about 15 cm of rain had fallen on the burned areas. Mineral soils were collected both before the fires and after 15 cm of rain had fallen on the burned areas. Five samples of forest floor and mineral soil (taken from 0 to 5, 5 to 10, and 10 to 20 cm depths) were composited at each of the 110 plots. The sampling area covered about 80 ha of the 160-ha treatment watershed. The samples were prepared and analyzed by standard procedures (9).

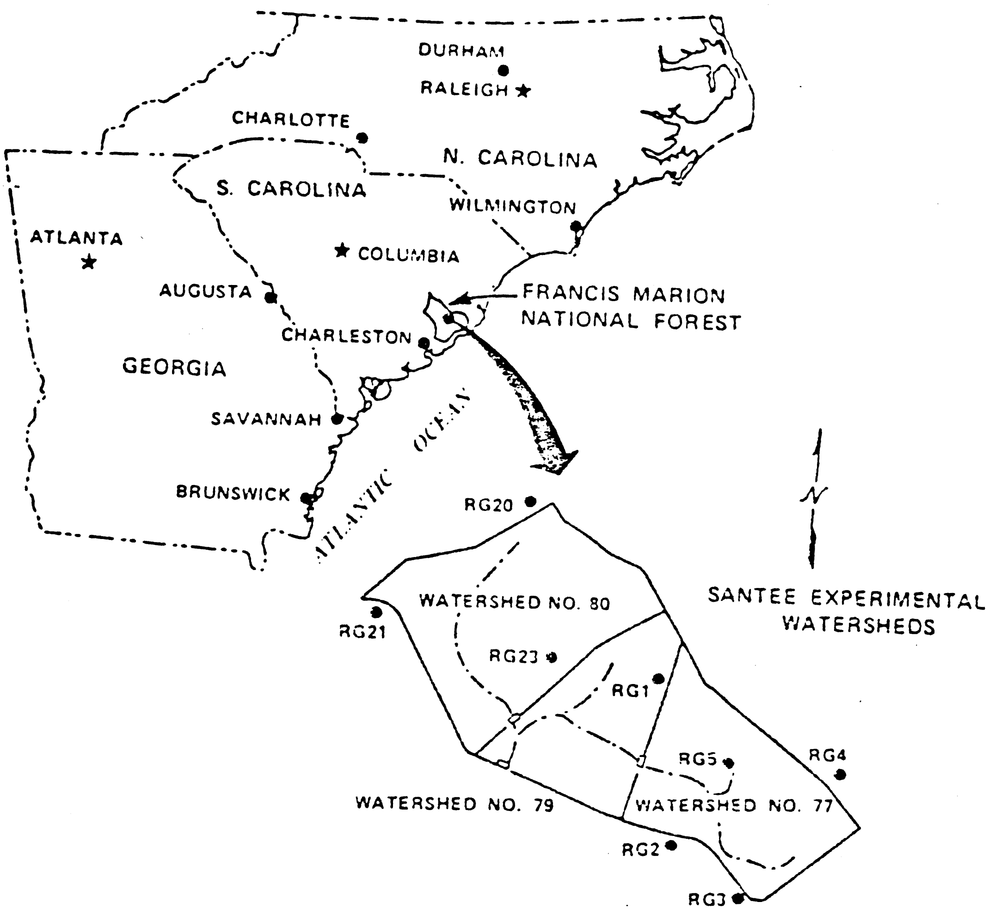

FIGURE 1

THE SANTEE EXPERIMENTAL FOREST WATERSHEDS LOCATED IN SOUTH CAROLINA'S LOWER COASTAL PLAIN IN THE FRANCIS MARION NATIONAL FOREST

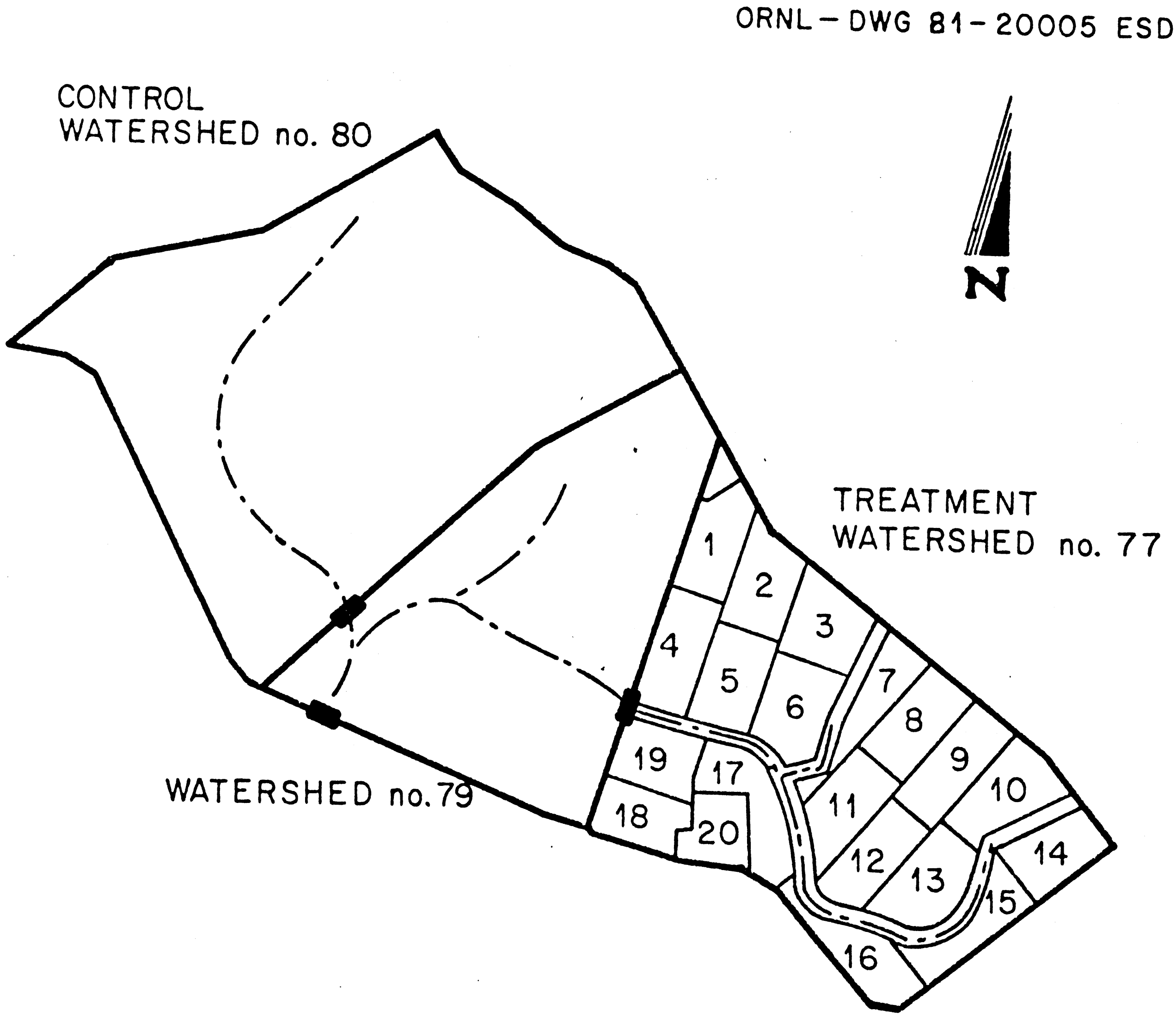

FIGURE 2

THREE LOWER COASTAL PLAIN WATERSHEDS USED TO EVALUATE THE EFFECTS OF INTENSIVE FORESTRY PRACTICES ON WATER CHEMICAL QUALITY. THE TREATMENT WATERSHED WAS DIVIDED INTO 20 MANAGEMENT COMPARTMENTS, FOUR OF WHICH WERE BURNED EACH WINTER, PLUS 15- TO 20-m-WIDE BUFFER STRIPS ALONG DRAINAGE CHANNELS

Soil solutions and shallow ground waters were sampled at 10 to 15 cm and 30 to 35 cm depths from a total of 32 wells, which were constructed from polyvinyl chloride pipe installed in burned and unburned areas of the treatment watershed. Samples were taken weekly for 5 weeks prior to the winter fires of 1978-79, and weekly and biweekly for 20 weeks following fire. Periodic sampling of wells continued for about 1 year following fire. Comparisons were made of the ground water chemistry between pre- and postburn periods and between burned and unburned areas.

Both watersheds were grab-sampled weekly near the weirs from the winter of 1976-77 to the summer of 1979. Thus, stream samples were collected for 1 year during the pretreatment calibration period and for 2.5 years during the application of a series of six prescribed burns. Water samples were analyzed for pH, conductivity, and alkalinity usually on the day of collection, then preserved with phenyl mercuric acetate (PMA) and stored at 4°C prior to chemical analysis. Samples were further analyzed by established procedures (9), using a Technicon Auto Analyzer for colorimetric determinations (NH_4, NO_3, Cl, SO_4, and H_2PO_4) and an atomic absorption spectrophotometer for analyses of metal cations (Ca, Mg, K, and Na). Stream water was also analyzed for total nitrogen.

III RESULTS

Fires consumed an average of about 5.0 ± 0.8 metric tons/ha (mean ± standard error, n = 110) of forest floor, usually less than one-third of the total mass of forest floor, 21.7 ± 0.6 metric tons/ha. Weight loss varied greatly between fires, averaging from about 2.5 to 7.5 metric tons/ha (10).

Release of nutrients from the burned forest floor was evaluated from nutrient concentrations and contents of litter samples that were collected immediately after burning and again after postburn rainfall of about 15 cm. Amounts of total N, P, S, Ca, Mg, and K in burned forest floor were little altered by this rainfall. Concentrations of water-soluble Ca, Mg, and K, and NH_4Cl-extractable K were, however, reduced significantly by postburn rainfall of about 15 cm (Table 1). The quantities involved were small (i.e., decreases in concentrations caused by initial rainfalls were equivalent to about 0.5, 0.5, and 1.0 kg/ha of water-soluble Ca, Mg, and K, respectively). Total K and Mg appeared to be reduced by about 2.4 and 1.8 kg/ha, respectively.

Analyses of mineral soils before fires and after rain had fallen on the burned areas indicated minor effects of fires on chemical properties of even the most surficial soil depth sampled, 0-5 cm, despite wide variations in fires intensities and in postburn leaching conditions. Changes in total C, N, and P in mineral soil were nonsignificant, as were those for dilute acid-extractable NH_4, NO_3, H_2PO_4, Ca, Mg, K, and Na. Results were consistent with those found for litter-leaching experiments described above. It has recently been demonstrated that air-drying these Aquults prior to extraction had much greater effects on dilute acid-extractable nutrients than those attributable to fires, drying generally elevating extractable N, P, and base cations. Results of these air-drying experiments will be reported by Gilliam and Richter (4).

TABLE 1 CONCENTRATIONS OF TOTAL, NH_4Cl-EXTRACTABLE, AND WATER-SOLUBLE NUTRIENTS IN BURNED FOREST FLOORS IMMEDIATELY AFTER FIRE AND AFTER 15 cm OF RAINFALL ON THE BURNED AREAS

Sample	P	Ca	Mg	K
		Total (ug/g)		
Before rain	480 + 20	5600 + 300	890 + 30	630 + 20
After rain	460 + 20	5400 + 200	780 + 30*	480 + 20*
		NH_4Cl-Exchangable (ug/g)		
Before rain	--	2330 + 110	680 + 60	320 + 10
After rain	--	2640 + 140	650 + 30	220 + 10*
		Water Soluble (ug/g)		
Before rain	--	164 + 10	110 + 8	205 + 6
After rain	--	129 + 9*	76 + 5*	142 + 6*

* Mean concentration after rain significantly different from mean concentration before rain (paired student-test).

Results from ground-water analyses indicated no fire effects on specific conductance, pH, or concentrations of NH_4, NO_3, H_2PO_4, SO_4, Cl, Ca, Mg, K, or Na in ground waters collected from surface soils and subsoils during the 20-week postburn sampling. Concentrations of NO_3-N, NH_4-N, and H_2PO_4-P were very low in these waters, averaging about 0.01, 0.20, and 0.02 mg/L, respectively, in surface soils, and 0.006, 0.03, and 0.01 mg/L, respectively, in subsoil horizons. Periodic samples taken over 1 year following burns indicated no effects of fire on pH or specific conductance (Figure 3).

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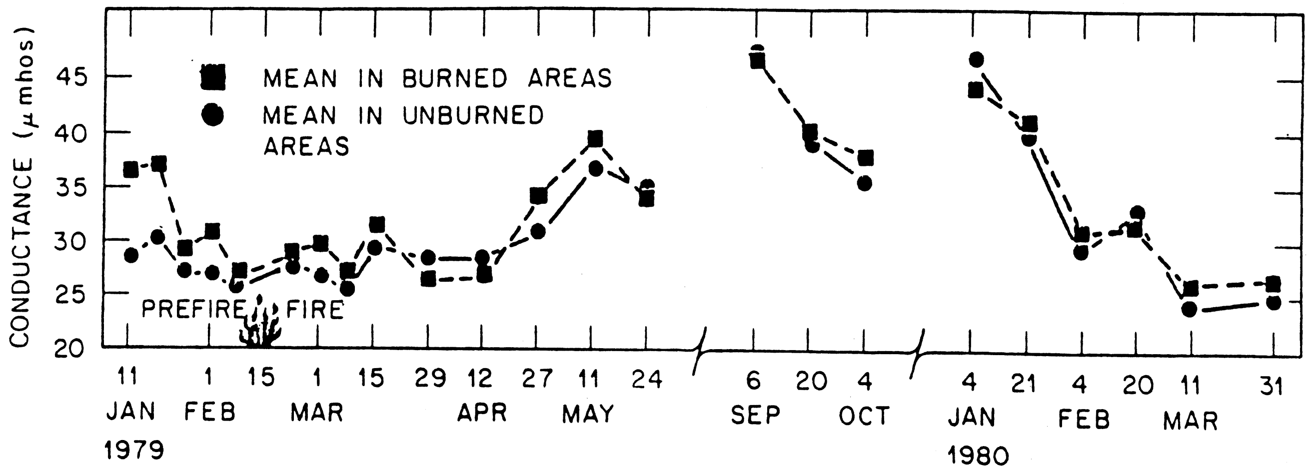

FIGURE 3

SPECIFIC CONDUCTANCE OF GROUND WATER COLLECTED AT A MINERAL SOIL DEPTH OF 10 TO 15 cm BEFORE AND AFTER PRESCRIBED BURNS OF 1978-79

Weekly stream sampling, in combination with paired-watershed regression models of dissolved chemical contents in weekly streamflows before (1976) and after fires (1977-79), indicated little alteration of chemical constituents in stream water that could be attributable to fires. Volume-weighted concentrations of NO_3-N, NH_4-N, and H_2PO_4-P in stream water averaged about 0.02, 0.03, and 0.03 mg/L. respectively, in water draining both burned and unburned watersheds, with no differences detectable between pre- and postburn periods. A plot of specific conductance of streamflows from the burned and unburned watersheds helps confirm the general conclusion of the absence of detectable fire effects (Figure 4). Greater concentrations of Ca and greater alkalinity in stream water from the unburned watershed compared with those of the burned watershed were attributable to the influence of calcareous substrata that occur along the lower stream channel of the unburned watershed, sediments that have been found to contain shell fragments and soft marl. In any case, the effects of fires on Ca and alkalinity in stream water were certainly less than the natural variation found in stream water of the lower coastal plain. Supplementary stream sampling above and below burned areas of the treatment watershed also confirmed the minor influence of fires on stream water chemistry (7). Further stream sampling and analysis from 1979-83, during which time three additional burns were administered to the treatment watershed, produced no changes in stream chemistry that could be attributed to fires (3).

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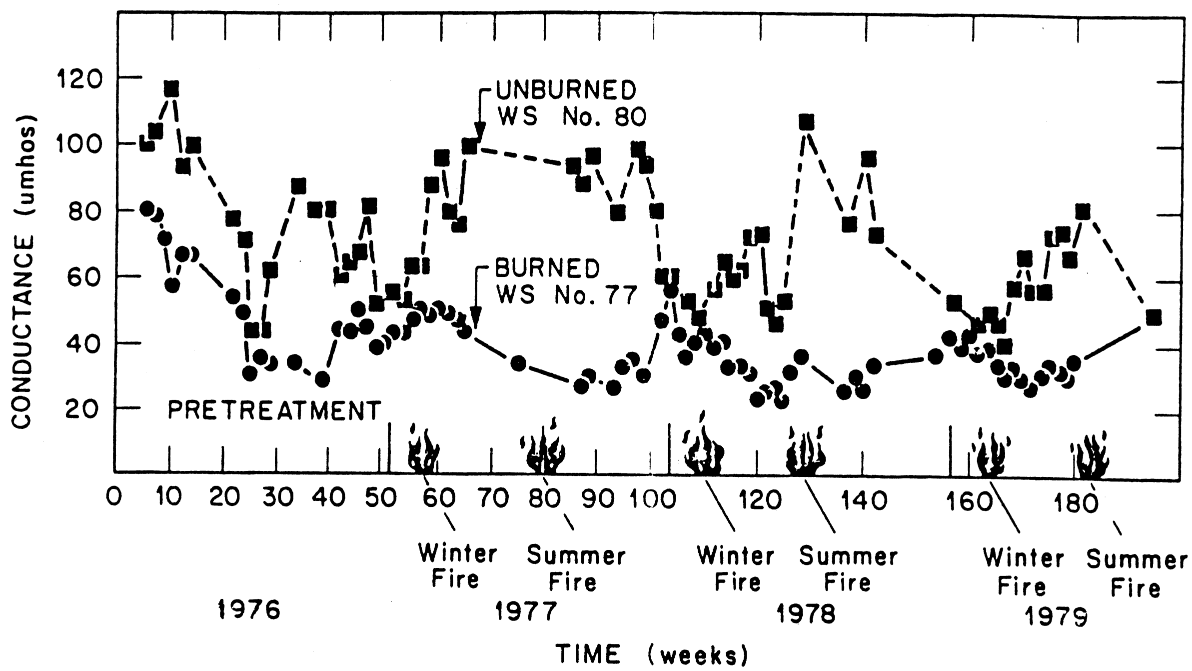

FIGURE 4

SPECIFIC CONDUCTANCE OF STREAMFLOWS DRAINING BURNED AND UNBURNED WATERSHEDS AT THE SANTEE EXPERIMENTAL FOREST WATERSHEDS IN SOUTH CAROLINA (10)

IV DISCUSSION AND CONCLUSIONS

The prescribed fires at the Santee Experimental Forest produced no detectable changes in the chemical composition of ground and stream waters for a variety of reasons. Prescribed fires on a 5-year fire cycle consumed, at most, about one-third of total forest floor weight. These findings are comparable to those of others (5). Steep moisture gradients between forest floor surface and mineral soil were probably responsible for confining combustion of organic matter to the surficial layers of litter, leaving unburned the basal layers of forest floors, which have relatively high surface area and exchange capacity. Thus, relatively small amounts of ash elements were leached as a result of the fires. Moreover, exchangeable acidity, which dominates the cation exchange surfaces of these acid soils, probably promoted adsorption of metal cations and neutralization of bases produced by fires. Suspensions of ash particulates were filtered by unburned litter and soil layers before emerging as streamflow, and filtration was also provided by unburned buffer strips adjacent to stream channels. Finally, application of fire treatments on a 5-year cycle introudced a substantial dilution factor (i.e., scaling factor), since stream water collected at the weir included runoff from both burned and unburned portions of the treatment watershed. It is not likely, however, that this dilution factor had an important influence of the results of this study, an interpretation consistent with the similar chemistry of stream water collected upstream and downstream of burned management compartments (7). An overriding factor in these studies appears to be that relatively small amounts of ash nutrients were released from burned forest floors by these fires.

These results indicate that hydrologic fluxes of nutrients from periodically burned pine stands are not likely to have appreciable effects on the chemical quality of waters that drain southern watersheds, especially watershed having fine-textured soils like those of the Santee. On sandy soils, fires may produce detectable effects on water chemistry, although the findings of this study suggest that such effects will not be of large magnitude. In any event, prescribed fire, like many forestry practices, is a management tool applied on multi-year cycles, a procedure that produces an important dilution or scaling factor with respect to the water draining an entire forest. In sum, considering the utility of periodic fires in the multi-resource management of southern pine forests, it appears doubtful that alternative practices could accomplish these objectives with such small environmental costs.

As a postscript, it seems important to emphasize the long-term value of information supplied by watershed management studies such as those conducted at the Santee. First, the scope of forestry has broadened substantially in recent years, so that the purview of silviculture now encompasses the whole forest (2). For example, even the classic and farsighted forestry textbook by Toumey and Korstian, The Foundations of Silviculture Upon an Ecological Basis, which was published in 1937, states rather bluntly that the aim of silviculture is the production of wood (13). In this era of multi-resource management, it is necessary to understand how forest management affects the variety of forest resources and how to limit adverse effects to acceptable levels. Effects of forest land management on the water resource are especially important in this regard. Moreover, increases in human populations are placing additional demands on southeastern forest lands, a trend that has far-reaching implications for forestry and one that may intensify well into the future. Thus, the southeastern population boom in combination with the broadening scope of forest management will increase the value of information supplied by watershed management studies such as those at the Santee Experimental Forest.

V SUMMARY

Prescribed fire is an important practice in the multi-resource management of forests, and controlled burning is now applied annually to about 1 million hectares (2.4 million acres) of forest in the southeastern United States. Prescribed fires

had few detectable effects on forest soils, nutrient cycling, and hydrologic systems of a pine-flatwoods watershed at the Santee Experimental Forest in the Francis Marion National Forest in South Carolina, a site of long-term watershed research by the U.S. Forest Service and Duke University. Experiments were designed so that treatment effects would simulate responses of an operational southern pine forest, and it was concluded that nutrient fluxes from burned pine litter to ground and stream waters are not likely to have appreciable effects on the quality of waters that drain southern pine watersheds, especially those with fine-textured soils.

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