Wildfire Effects on a Ponderosa Pine Ecosystem: An Arizona Case Study

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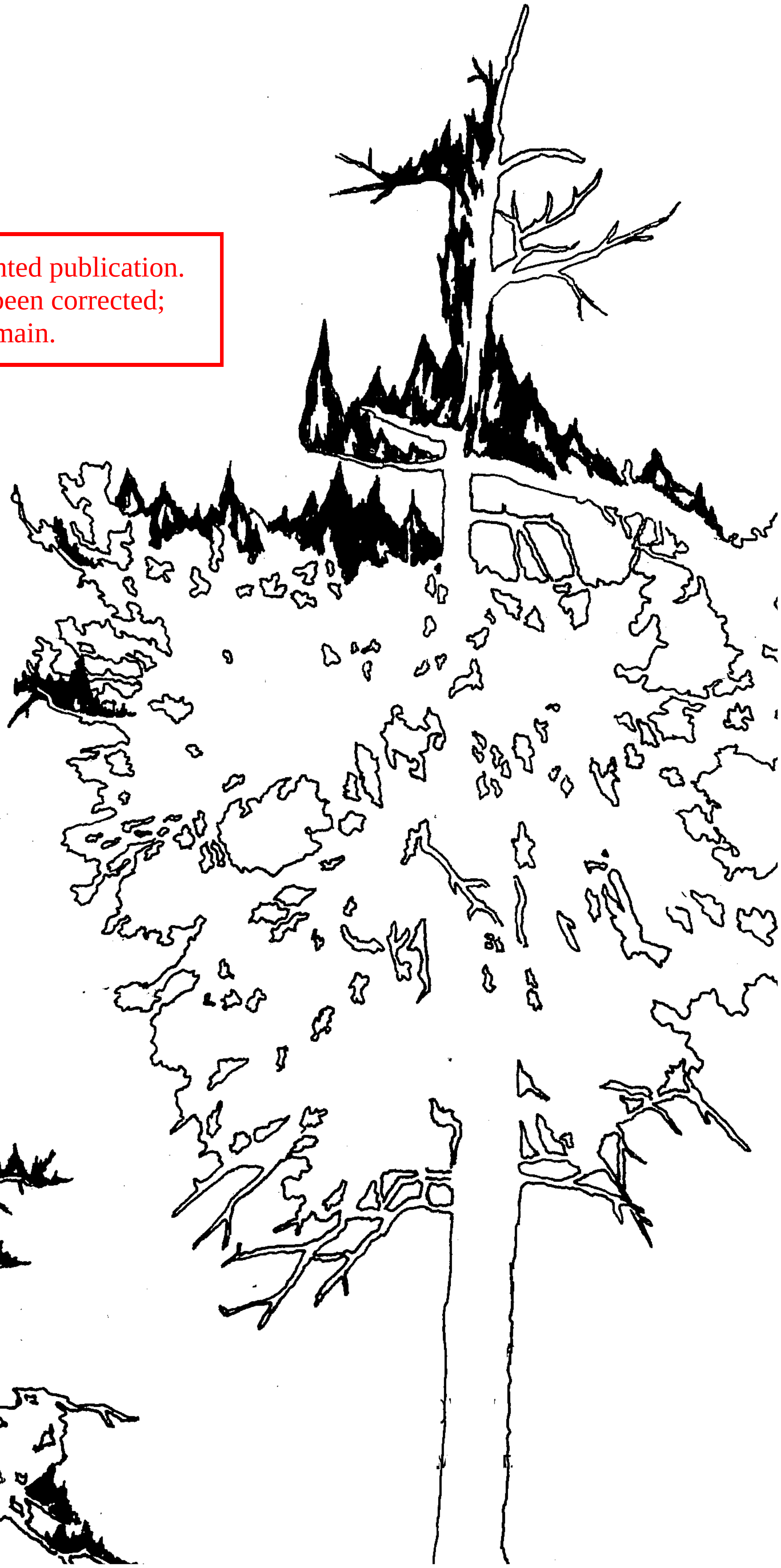

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Range Experiment Station
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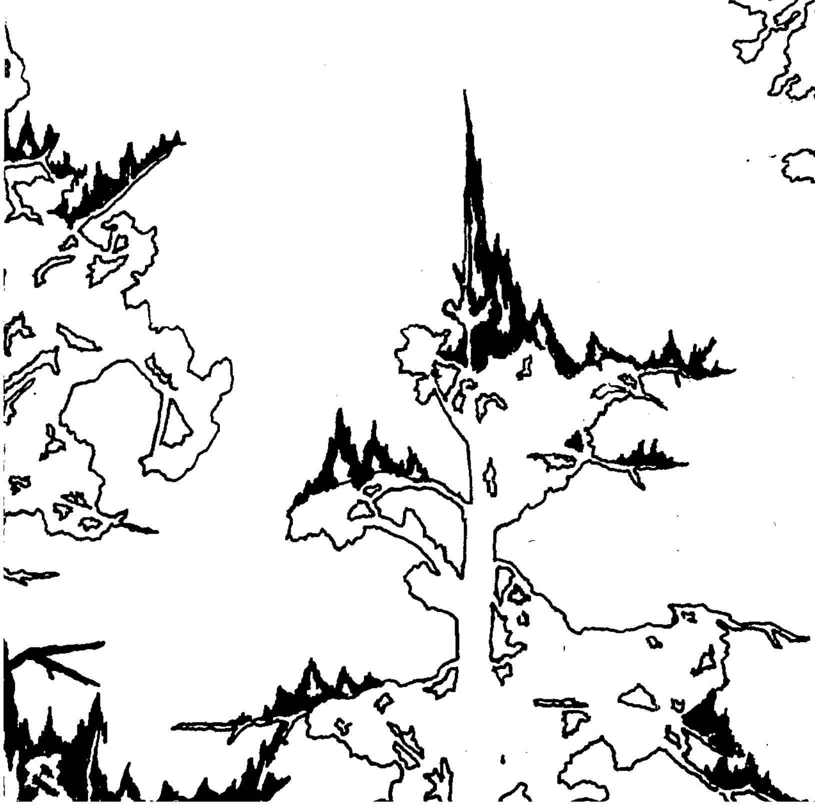

Abstract

A wildfire of variable severity swept through 717 acres (290 ha) of ponderosa pine forest in north-central Arizona in May 1972. Where the fire was intense it killed 90% of the small trees and 50% of the sawtimber, burned 2.6 in (6.5 cm) of forest floor to the mineral soil, and induced a water-repellent layer in the sandier soils. The reduced infiltration rates, which greatly increased water yield from severely burned areas during unusually heavy fall rains, caused soils to erode and removed some nutrients which had been mineralized by the fire. Water yields have declined each year toward prefire levels. Soluble nutrients leached into the surface soil during fall rains were subsequently removed by a record snowmelt. Successional changes provided up to 1,650 lb/acre (1,850 kg/ha) of herbage production compared to about 515 lb/acre (577 kg/ha) in unburned forest.

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Contents

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Management Highlights

The effects of a wildfire which burned in a north-central Arizona ponderosa pine forest in May 1972 were evaluated on watersheds with three burn conditions: unburned, moderately burned, and severely burned.

Approximately 50% of the pulpwood-size trees and 7% of the sawtimber were killed on the moderately burned watershed. On the severely burned watershed, 90% of the pulpwood and 50% of the sawtimber trees were killed. No natural tree regeneration is evident after 4 yr.

Herbage production, between 450 and 560 lb/acre (500 and 650 kg/ha) on all three watersheds the year of the fire, increased in 1974 to 1,275 lb/acre (1,430 kg/ha) on the moderately burned watershed, and 1,650 lb/acre (1,850 kg/ha) on the severely burned watershed. Grasses predominate in the understory on the moderately burned watershed, whereas forbs predominate on the severely burned watershed; species change from year to year. As a result of the fire, the ground cover (vegetation and litter) decreased from 92% on unburned to 39% and 23% on the moderately and severely burned watersheds, respectively.

Runoff was over eight times greater on the severely burned watershed than on the unburned area during heavy autumn rains. In the following year, water yields from the moderately burned and severely burned watersheds were respectively 3.1 and 3.8 times greater than from the unburned watershed. Differences decreased substantially in subsequent years.

Initial runoff from the severely burned watershed contained Ca, Mg and K ionic concentrations 2.8, 2.0 and 7.5 times greater than from the unburned watershed. Concentrations decreased in later autumn runoff. Sodium levels remained relatively unchanged. Nitrogen concentration, however, increased from 0.1 ppm (mg/l) in runoff from the unburned watershed to 1.4 ppm in initial summer runoff from the severely burned watershed, then declined to 0.6 ppm.

In the year following the fire, runoff carried about 1.7 tons per acre of suspended and bedload sediment from the severely burned watershed, as compared to a few pounds from the moderately burned and unburned watersheds. With restoration of ground cover, erosion hazard reduced appreciably in subsequent years.

Total soluble salts and Ca + Mg in the saturated soil extract of the surface 12 in (30 cm) of soil were appreciably higher in soils of the severely burned area than in the unburned areas. This effect was not evident 1 yr later. K and total N were lower in the soil of the burned watershed both immediately after the fire and 1 yr later.

Surface soil of the severely burned watershed dried rapidly by evaporation immediately after the fire, but because of reduced transpiration the total moisture demand was less than on the unburned site. Differences between sites lessened as herbaceous cover developed and as differences in the runoff regimes became less.

Soils of sandy texture developed water repellency which persisted to some degree for at least 4 yr after the fire. Infiltration was 1.0 in/hr (2.6 cm/hr) on the severely burned watershed, as compared to about 2.7 in/hr (6.8 cm/hr) on the unburned watershed.

Deer use was greater on the moderately burned watershed in 1972, 1973, and 1974, and on the severely burned area in 1974, than on the unburned area. Numbers of trapped mice and ground squirrels increased and chipmunks decreased in the summer immediately following the fire in the burned watersheds.

The Rattle Burn was highly destructive to some aspects of the ecosystem. Timber production will be delayed for many years and, although some nutrients were mineralized to soluble salts, a considerable amount of the total plant nutrient capital, particularly nitrogen, was lost. Surface soils became less permeable and temporarily subject to erosion.

Except for these losses, however, the ecosystem is spectacularly flexible. Plants emerge and protect the soil surface from erosion. Insects and microorganisms attack the standing dead trees, which then fall in a few years and contribute to soil cover and organic matter. Rodent populations adjust upward and downward to match food supplies and habitat requirements. Grasses and forbs compensate for lost timber production.

Introduction

In addition to the stark, lifeless visual impact of burned vegetation, wildfire severely disorders a forest ecosystem. The timber resource is damaged; small trees and understory vegetation may be destroyed; the nutrient capital is depleted; the litter layer may be removed; microclimate immediately above the soil and in the surface soil is modified; the hydrologic behavior is affected; and the habitat for wildlife may be drastically changed. The purpose here is to document some of these changes which resulted from wildfire in a ponderosa pine (*Pinus ponderosa*) forest in the Southwest.

On May 7-9, 1972, a wildfire designated as the Rattle Burn swept through 717 acres (290 ha) of even-aged stands of ponderosa pine on the Coconino National Forest (fig. 1). This man-caused fire, about 18 mi (29 km) southwest of Flagstaff, Ariz., virtually destroyed some timber stands and left others relatively unaffected.

Three small watersheds, representing severe and moderate burns and an unburned control, were established to assess the effects of wildfire on hydrology, soils, timber and forage production, and wildlife populations. On the moderately burned watershed, 10 acres (4 ha), the fire was generally confined to the forest floor. The surviving trees provided some shade. On the severely burned watershed, 20 acres (8.1 ha), most of the trees were killed. The third watershed, an unburned area of 43.8 acres (17.7 ha) located adjacent to the severely burned watershed, was chosen as a control.

Background

The original pine forest mosaic of widely spaced, distinct groups of trees intermingled with pockets of grassland (Biswell et al. 1973) resulted from microenvironmental variation or other chance factors, as well as periodic fires (Cooper 1961).

Fire plays an important role in maintaining natural tree-understory patterns of the Southwest ponderosa pine ecosystem. In recent years, however, fire protection and suppression have been reasonably successful in eliminating large periodic fires. Forest fuels have accumulated; stands have become dense from lack of periodic thinning and removal of grass competition to tree seedlings. Tree crowns have become intermingled, creating a continuous chain of fuel capable of carrying fire from the forest floor into the crowns of the tallest trees. When these dense stands are logged, tremendous quantities of slash and cull logs are left to add to the accumulation.

Wildfires in stands of this type are disastrous. Crown fires are inevitable, and immediate and subsequent mortality is high. Trees with greater than 60% crown scorch are unlikely to survive 6 yr; trees with 50% crown scorch showing evidence of intensive ground fire nearby will

Figure 1.—Wildfire caused severe destruction in this ponderosa pine ecosystem. Only a layer of ash remains to cover the mineral soil.

also succumb (Herman 1954). Diameter growth of trees remaining in burned areas is likely to decrease as a result of crown scorch (Pearson et al. 1972).

Fire effects on watershed hydrology include increases in storm runoff, peak discharge, erosion, and downstream sedimentation (Ursic 1970, Rich 1962, Pase and Ingebo 1965, Harr et al. 1975, and Megahan and Molitor 1975). The magnitude of these effects is governed by the physiographic, edaphic, climatic, and vegetative condition of the watershed. Vegetation and the forest floor may be consumed, leaving soils exposed to raindrop impact and overland flow. On soils exposed by fire, infiltration rates are generally reduced (Zwolinski 1971) as surface compaction results from raindrop impact and plugging of surface pores by fine soil material. Infiltration may also be reduced by the formation of a hydrophobic layer in the soil during exposure to extreme heat (DeBano et al. 1970, Krammes and DeBano 1965, and Savage et al. 1972).

Wildfire in the Southwest may be devastating to the nutrient capital. Welch and Klemmedson (1975) estimated that 20% of the nitrogen (N) in an Arizona ponderosa pine ecosystem might be lost in a fire which destroys the N-rich forest floor.

Cole et al. (1975) found appreciable soluble oxides of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in ash immediately after a severe fire. N loss from the fuel was about 90%. Cation oxides were converted to carbonates and were leached into the soil. While leaching below the rooting zone was increased, the A and B horizons absorbed 70% to 90% of the cations entering the soil.

As a result of a severe wildfire in a coniferous ecosystem in north-central Washington, Grier (1975) found that 97% of the N in the forest floor, and 33% of the N capital of the A1 horizon—0-2.4 in (0-6 cm)—were lost. Considering the litter layer and soil to 14 in (36 cm) depth, losses of N, Ca, Mg, K and Na were 39%, 11%, 15%, 35%, and 83% respectively.

Description of the Ecosystem

Geology and Soils

The Rattle Burn area is characterized by a flat to rolling plateau surface dissected by occasional deep, steeply walled canyons. Slopes range from 0% to 20%.

The three study watersheds are located south of the West Fork of Oak Creek at an elevation of 6,700 ft (2,040 m).

Soils were derived from the Kaibab limestone formation. About 40% of the soils in the Rattle Burn area were classified as either the Soldier or McVickers series, while about 50% of the area was designated as an unnamed, extremely stony, limestone outcrop complex (Schinzel and Meurisse 1972).

Climate

Climate of the area is described as "vigorous" because of its cold winters, mild, pleasantly cool summers, moderate humidity, and considerable diurnal temperature change. The growing season, based on a 32°F (0°C) temperature threshhold, averages about 120 days (NOAA 1975).

Annual precipitation has ranged from 16 to 44 in (420 to 1,122 mm) but for 3 yr averaged approximately 29 in (737 mm). Annual normal for the nearest established weather station at the Flagstaff airport is 20.1 in (511 mm). July and August receive the greatest precipitation; May and June are the driest months.

Vegetation

The area of the burn is within the ponderosa pine vegetation type, with an average prefire canopy coverage of 20% to 40%. Some dense stands with canopy cover of nearly 70% were found.

Some Engelmann spruce (*Picea engelmannii*), white fir (*Abies concolor*), and Douglas-fir (*Pseudotsuga menziesii*) are found in the steep, more moist canyon associations. There are also some Gambel oak (*Quercus gambelii*) and a few widely scattered alligator juniper (*Juniperus deppeana*).

Many grasses grow sparsely throughout the area. Among them are screwleaf muhly (*Muhlenbergia virescens*), squirrel-tail (*Sitanion hystrix*), pine dropseed (*Blepharoneuron tricholepis*), and muttongrass (*Poa fendleriana*). Bracken fern (*Pteridium aquilinum*) covers up to 30% of disturbed areas, following logging or fire.

Logging during the summer of 1971 removed an average of 2,389 ft^3/acre (167 m^3/ha). Slash was lopped and scattered or piled, leaving approximately 20 tons/acre (44,808 kg/ha) of material. The site is highly productive, with an average site index of 92 ft (28 m) in 100 yr (Minor 1964). Original stands prior to logging in 1971 averaged 198

ft^2/acre (46 m^2/ha) of basal area, and 5,297 ft^3/acre (371 m^3/ha) of timber volume (table 1).

Fire intensity was estimated using Byram's formula and estimates of fuel type, fuel loading, and rate of fire spread (Dietrich 1976). Fire intensity was computed as I=HWR BTU/sec/ft where H = heat content of fuel in BTU/lb, W = weight of fuel in lb/ft^2, and R = rate of fire spread in ft/sec.

Heat content of ponderosa pine fuel is assumed to be 8,500 BTU/lb (19,800 kjoules/kg). Fuel loading estimates, based on actual measurements in similar stands, were 53.5 tons/acre (120,000 kg/ha) of total fuel and 20.2 tons/acre (45,000 kg/ha) of available fuel, which is equivalent to 0.93 lb/ft^2 (4.5 kg/m^2). Available fuel is classified as fuel under 3 in (7.6 cm) diameter, the L and F layers of forest floor, and 25% of rotten wood on the ground. Windspeed at the fire was reported to be 13 mph (21 km/hr). The rate of fire spread was estimated as 0.3 ft/sec (0.10 m/sec) for the moderate fire and 1.3 ft/sec (0.4 m/sec) for the intense fire.

Intensity of the moderate fire was calculated to be 2,500 BTU/sec/ft (9,000 kjoules/sec/m); intensity on the severely burned areas was calculated to be 10,000 BTU/sec/ft (35,000 kjoules/sec/m).[2]

Effects and Responses

Vegetation

Overstory. Trees were inventoried on all three watersheds following the fire. A systematic set of 30 0.1-acre (0.04 ha) plots was established on each watershed. All trees on each plot were tallied and four trees from each plot were measured for height, diameter, age, and growth.

On the severely burned watershed, nearly two-thirds of the timber resource was destroyed, whereas about one-fourth was lost on the moderate burn (table 1). Mortality was greatest in smaller diameter classes. Almost 50% of the pulpwood but only 7% of the sawtimber was lost on the moderate burn, while 90% of the pulpwood and 50% of the sawtimber was lost on the severe burn.

Most killed sawtimber was salvaged, but all pulpwood was lost due to charring. In addition, growth of the remaining trees will be reduced because of severe crown scorch (Pearson et al. 1972). There is no evidence of natural tree regeneration.

Ponderosa seedlings were planted in some areas in spring 1975 with reasonable success. Survival after one growing season was 80%, and 68% after the second growing season.[3] Experimental direct seeding (Rietveld and Heidmann 1976) indicated that costs were high and results were variable. Planting stock from seed of local origin is recommended in preference to direct seeding (Schubert and Pitcher 1973).

Herbage Production. Annual herbage production was determined by weight-estimates on three 9.6-ft^2 (0.9 m^2) plots centered around each timber inventory sample plot in 1972 and 1974.[4]

[2] *Dieterich, John H., Rocky Mt. For. and Range Exp. Stn., Tempe, Ariz. Personal communication.*

[3] *Broyles, W. K., Flagstaff Dist. Coconino Nat. For. Personal communication.*

[4] *Fitzhugh, E. Lee and J. T. Beaulieu. 1976. Wildfire effects on plant and animal communities in Arizona ponderosa pine forests. Mimeo rep. Eisenhower Consortium Coop. Agreement 16-454-CA, on file at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

Table 1.—Ponderosa pine timber: prefire condition and effects of wildfire on basal area and volume, Rattle Burn watersheds

Watershed	Time of inventory	Basal area	Timber Volume		
		ft.²/acre (m²/ha)	*ft³/acre (m³/ha)*	*bd ft/acre*	*cords/acre*
Unburned	Prelog	211	6215	29333	7.0
	Postlog	121	2944	11665	6.9
Moderate burn	Prelog	194	4773	20224	8.3
	Postlog	133	2714	8962	8.0
	Postfire	103	2227	8356	4.9
	Postsalvage	73	1658	6532	3.1
Severe burn	Prelog	190	4903	20892	8.4
	Postlog	129	3067	11138	8.2
	Postfire	40	1159	5589	0.8
	Postsalvage	7	194	784	0.4
Average	Prelog	198 (46)	5297 (371)	23483	7.9
	Postlog	128 (36)	2908 (203)	10588	7.7

Mean annual herbage production on the three watersheds in 1972 and 1974 was:

Watershed	1972	1974
	lb/acre	*lb/acre*
Unburned	474	559
Moderate Burn	452	1,275
Severe Burn	582	1,651

There were no significant differences in herbage production among watersheds in 1972. Herbage production on both the moderately and severely burned watersheds had increased threefold by 1974, however. Composition of herbaceous species on the moderately burned watershed had approached that of the control by 1974; composition on the severely burned watershed continued to show successional changes, with an initial predominance of forbs and grasses increasing each year.

Ground Cover. Depth of the forest floor on the unburned watershed was evaluated as an index of the preburn condition of burned areas. Averages of 200 measurements were: 0.83 in (2.1 cm) of L layer, 1.02 in (2.6 cm) of F layer, and 0.71 in (1.8 cm) of H layer, with a total forest floor depth of 2.56 in (6.5 cm). The proportion of ground cover by various components, such as vegetation and litter, charred debris, ash, rock, and exposed soil was estimated in 9.6-ft^2 (0.9 m^2) plots in the fall of 1972 (table 2). Followup measurements of ground cover were not taken.

Table 2.—Percent ground cover as affected by wildfire, Rattle Burn watersheds. August 1972

Component of cover	Unburned	Moderate burn	Severe burn
Vegetation and litter	92	38	23
Charred debris	0	15	4
Ash	0	3	1
Rock	1	8	2
Exposed soil	7	36	70

Fire reduced ground cover on the moderately and severely burned watersheds, while exposed soil, charred debris, and ash increased. The percentage of exposed soil on the severely burned watershed was twice as great as that on the moderately burned watershed. Charred debris (material not completely consumed by fire) was greater on the moderately burned watershed than on the severely burned watershed.

Streamflow

Streamflow was measured by means of 2-ft H-flumes instrumented with automatic stream stage recorders at the outflow points of each watershed. Mean annual water yields in 1973-1975 averaged from 0.2 in (6 mm) on the unburned watershed to 0.8 and 1.1 in (20 and 27 mm) on the moderately and severely burned watersheds, respectively. Streamflow and precipitation are usually based on a water year which runs from October 1 to September 30. Winter season storm patterns are generally established in October and run through April, with summer storm patterns evident during the remaining months.

Average seasonal runoff efficiencies (ROE), defined as the ratio of runoff to precipitation, generally increased with severity of burn (table 3). Runoff efficiencies for 1973-1975 averaged from 0.8% on the unburned watershed to 2.8% and 3.6% on the moderately and severely burned watersheds, respectively. The rain season is defined as June through October because most of the runoff during these months is the result of rainfall events; snowmelt contributes most of the runoff during the remaining months. The severely burned watershed had 357% higher ROE for the rain season, but had 51% lower ROE than the moderately burned watershed during the snow season. During rain events, the reduced timber basal area, litter cover and hydrophobic soil apparently resulted in reduced evapotranspira-

Table 3.—Average seasonal precipitation and runoff on Rattle Burn watersheds, water years 1973-75 inclusive

Precipitation form	Unburned			Moderate burn			Severe burn		
	Precipitation	Runoff	ROE	Precipitation	Runoff	ROE	Precipitation	Runoff	ROE
	in		%	*in*		%	*in*		%
Snow	17.7	0.16	0.9	17.2	0.63	3.7	17.7	0.31	1.6
Rain	11.7	0.08	0.7	11.1	0.16	1.4	11.7	0.75	6.4
Total	29.4 (747 mm)	0.24 (6 mm)	0.8	28.3 (718 mm)	0.79 (20 mm)	2.8	29.4 (747 mm)	1.06 (27 mm)	3.6

tion rates and larger water yields. During winter, however, reduced timber basal area allowed more snowpack to be lost to evaporation, and less runoff occurred than on the more shaded, moderately burned area.

Seasonal Distribution. Runoff from snowmelt accounted for 67% of the annual streamflow on the control watershed and 80% and 30% on the moderately and severely burned areas, respectively (table 3). Data from the control watershed indicate that runoff occurred only during April and May as a result of spring snowmelt; and in October 1972, the wettest October on record in Flagstaff, as a result of rainfall.

The highest peak annual discharge on the control watershed was only 0.92 $ft^3/sec/mi^2$ (csm) (0.07 $m^3/s/km^2$) (table 4). On the moderately burned watershed, peak discharge reached 21.5 csm (0.24 $m^3/s/km^2$), while on the severely burned area the peak discharge exceeded 366 csm (4.067 $m^3/s/km^2$). The highest flows recorded on the severe burn were in September and October following the wildfire, and indications are that the peak flows probably will not approach this magnitude again under normal rainfall conditions.

The number of runoff events resulting from rainfall also increased significantly with severity of burning:

Year	Unburned	Moderate burn	Severe burn
1972	0	2	5
1973	4	6	11
1974	0	6	4
1975	2	1	5
Total	6	15	25

The number of events on the moderately and severely burned watersheds was, respectively, 2.5 and 4 times greater than on the control. Removing litter cover and production of hydrophobic substances clearly increased surface runoff efficiencies.

Water Quality

A limited analysis of 15 water samples showed that chemical quality of water runoff was not greatly affected by the fire. In the first postfire runoff events in July and early October, concentrations of Ca, Mg, and K were about 11, 3 and 3 ppm, respectively. After the first flush, and as the flow increased, concentrations of these ions decreased to about 5, 0.6 and 0.7 ppm. Sodium concentration of about 5 ppm appeared to be relatively unaffected by the fire or by changes in rate of flow. Concentration of ions from the unburned watershed was about 4, 1.5, 0.4 and 5 ppm of Ca, Mg, K and Na, respectively.

The combined organic-inorganic nitrogen concentration was about 1.4 ppm in the initial postfire runoff, and decreased to about 0.6 ppm. The nitrogen concentration in the runoff from the unburned watershed was 0.1 ppm.

Suspended Sediment. During the 1973 water-year, in which an all-time precipitation record was set, sediment yield was about 3 lb/acre (3 kg/ha) from the undisturbed watershed compared to a high 1,254 lb/acre (1,406 kg/ha) from the severely burned watershed. In subsequent years, the amounts decreased drastically:

Water Year	Unburned	Moderate burn	Severe burn
		lb/acre	
1972	0	1	136
1973	3	16	1254
1974	0	0	1
1975	0	1	1

In contrast to the other two watersheds, the severely burned watershed with its disordered ecosystem of exposed soil and decreased tree canopy protection, was vulnerable to abnormally heavy summer and fall rains. In the 6 months following the fire, 2.4 in (6.2 cm) of runoff carried approximately 13.8 tons (12,600 kg) of suspended sediment, or about 0.70 tons/acre (1,560 kg/ha) from the watershed. In addition, 24 tons (22,000 kg) of bedload material, 1.2 tons/acre (2,770

Table 4.—Peak annual discharge from Rattle Burn watersheds for the period 1972-75

Unburned			Moderate burn			Severe burn		
Date	Rate	Volume	Date	Rate	Volume	Date	Rate	Volume
	cfs	*csm*		*cfs*	*csm*		*cfs*	*csm*
[1]	0	0	9/2/72	0.25	12.5	9/2/72[2]	10.98	366.0
10/17/72	0.43	6.1	10/19/72	0.43	21.5	10/17/72[2]	10.98	366.0
7/7/74	0.06	0.9	7/7/74	0.43	21.5	7/7/74	5.31	177.0
10/27/74	0.01	0.2	7/16/75	0.13	6.5	7/14/75	1.43	47.3

[1]*Summer only, 1972.*
[2]*Flow exceeded capacity of the flume.*

kg/ha), was moved out of the watershed. With the restoration of ground cover and reduction in water repellency, sedimentation appears to have stabilized.

The moderately burned watershed, with more vegetative ground cover and tree canopy remaining after the fire, was much more stable than the severely burned one. During the first 6 months following the fire, this watershed produced only an estimated 44 lb (20 kg) of sediment—4 lb/acre (5 kg/ha).

Soil Factors

Soil Nutrients. Soil nutrient changes were investigated by sampling the mineral soil in 4-in (10 cm) increments to a depth of 12 in (30 cm) in the severely burned and unburned watersheds. Samples were taken shortly after the fire, on July 20, 1972, and again on June 5, 1973, within the same transects used for soil moisture determinations.

Electrical conductivity of the saturated soil extract was measured. The EDTA titration procedure was used to determine Ca + Mg, and concentration was calculated on the assumptions that the Ca/Mg weight ratio was 2.85 and that the saturation moisture content of the soil was 40% by weight. K was extracted with water and determined by flame photometry. The pH of the saturated soil paste was determined with a glass electrode. NO_3, and CO_2 extractable PO_4, were determined using titration methods in the Technicon Autoanalyzer. Total N was determined by the Kjeldahl method.

The results of the analyses are summarized in table 5. Soil pH averaged 5.9, but was not affected by burning. This pH is lower than that given by Schinzel and Meurisse (1972). Electrical conductivity in the surface soil layer was substantially higher immediately after the fire in the burned watershed than in the unburned watershed. Approximately 3.4 in (8.5 cm) of rain fell between the time of the fire and the first sampling, which was sufficient to leach substantial quanti-

Table 5.—Wildfire effects on soil chemical constituents, Rattle Burn watersheds

Item		Depth	Unburned 1972	Unburned 1973	Burned 1972	Burned 1973
		in				
Conductivity		0- 4	374	332	572	257
Sat. ext.		4- 8	350	290	456	226
EC x 10^6		8-12	343	204	389	225
		Mean[1]	356b	306b	472a	237b
	Difference (1972-73)		50b		235a	
Ca + Mg		0- 4	25.8	18.5	37.1	11.6
ppm		4- 8	21.9	15.1	29.9	6.3
		8-12	20.9	17.4	29.5	7.3
		Mean	22.8ab	17.0bc	32.2a	8.2c
	Difference (1972-73)		5.8b		23.9a	
K		0- 4	36.1	28.6	27.2	18.3
ppm		4- 8	26.5	22.5	18.2	14.6
		8-12	23.8	20.1	13.9	12.0
		Mean	28.8	23.7	19.8	15.0
	Difference (1972-73)		5.1		4.8	
PO_4		0- 4	5.89	3.59	7.26	5.18
ppm		4- 8	5.62	4.04	5.75	5.36
		8-12	6.23	4.06	5.67	5.88
		Mean	5.91	3.90	6.23	5.47
	Difference (1972-73)		2.01		0.76	
Total N		0- 4	1426	1386	806	817
ppm		4- 8	1090	917	654	636
		8-12	737	719	509	523
		Mean	1085	1007	656	658
	Difference (1972-73)		78		-2	
NO_3		0- 4	0.17	0.91	1.13	1.13
ppm		4- 8	0.45	0.64	1.01	1.00
		8-12	0.51	0.48	0.69	0.93
		Mean	0.38	0.67	0.94	1.02
	Difference (1972-73)		0.08		0.29	

[1]*Means and differences followed by unlike letters are different (at the 0.05 level) from others within the same group.*

ties of soluble salts from the ash layer into the mineral soil. By the following June, conductivity of soil at the burned site decreased significantly while that of the unburned area decreased only slightly. The change in conductivity at the unburned site may be attributed to record high precipitation for the 1972-73 water-year.

Concentrations of Ca + Mg were greater in the surface 4 in (10 cm) than in the lower levels in both soils, but were higher in the newly burned soils. During the following year, however, this initial pattern reversed to a lower level of Ca + Mg in the burned area.

The water-soluble K concentration was lower in soil of the burned area than in the unburned, both immediately after the fire and a year later; the concentration declined between samplings about equally in both soils. The unexpectedly low amount of K detected in the surface soil of the burned area may have resulted from loss by convection or volatilization during the fire. Grier (1975) reported 79% less K in the ash than in the unburned litter layer after an intense fire. He also found less K in the surface soil of a burned site compared to unburned. This K loss causes us to speculate that temperatures in this intense fire may have exceeded 1000°C at the surface. Smith (1970) reported surface temperatures exceeding 1000°C in a fire which burned most of the surface litter but not all the humus.

Total N was significantly lower in soils from burned than unburned areas. Total N from both areas did not vary significantly between years. The decrease in total N by depth was suppressed in the burned area compared to the unburned. We have no measure of soil temperatures during the burn, but speculate that they were sufficiently high to affect the total N content in the 0-4 in (0-10 cm) depth.

NO_3 levels varied considerably among samples. Mean differences by depth approached significance at the 95% level. The treatment by year by depth interaction was significant at the 95% level because soil NO_3 for the unburned area was extremely low in 1972. The NO_3 in the burned plots tended to be slightly higher than in the unburned plots. This condition probably reflects higher nitrification rates in the burned areas, and reduced demand for NO_3 by microorganisms that decompose organic materials with high C/N ratio (which had been destroyed by fire).

Soil Moisture. Patterns of soil moisture use were monitored for the three summers following the fire.

Soils were sampled in 4-in (10 cm) increments to 12 in, on 10 plots in each of 3 blocks (transects) on all three watersheds. Samples were taken with an Oakfield probe, and soil water was determined gravimetrically. Sites similar to those on the unburned area were selected for all watersheds. The sites were on Soldier sandy loam soil, with less than 5% slope, in large-pole stands of ponderosa pine with approximately 3 in (8 cm) of litter. Litter was assumed to have been present on the burned area because of remaining ash and other similarities between the burned and unburned areas.

Because data from the moderately burned watershed were extremely variable, they are not reported here. In all 3 postfire years, evaporational loss from soil of the severely burned watershed exceeded that from the undisturbed forest, where less water was used from the surface 10-cm than from the 20- to 30-cm depth (fig. 2). During July and August following the fire, the 4- to 8- and 8- to 12-in (10- to 20- and 20- to 30-cm) depths of the burned watershed were wetter than the surface 4 in (10 cm), and all depths of the undisturbed soil. Summer rains moistened the surface 4 in of soil in the burned watershed to levels of the lower depths. The data indicate little transpiration use of water during this period in the burned area.

When sampling was resumed in early June 1973 after a very wet winter and spring, soil from the burned area contained less water (23% by volume) than that from the undisturbed area (30%). This difference in soil moisture reflected greater winter runoff from the burned watershed. Loss of soil moisture by evaporation from the burned area was again more pronounced when compared to the undisturbed area, particularly from mid-June to early July. The data indicate that, a year after the fire, soil moisture was more quickly depleted in the surface 12 in from the burned area than from the undisturbed area. This pattern of profile drying in the burned area persisted through 1973. By 1974 the drying patterns were similar for both areas, except that the burned watershed was slightly more responsive to evaporative conditions.

In summary, immediately following the fire, the surface soil in the burned area dried quickly by evaporation, but total moisture demand was less than on the undisturbed site. By the second summer, understory vegetation increased moisture demand but, with the absence of a forest litter cover, soils in the burned area were more susceptible to evaporative water loss than those from the undisturbed forest. Differences lessened in the third year following the fire.

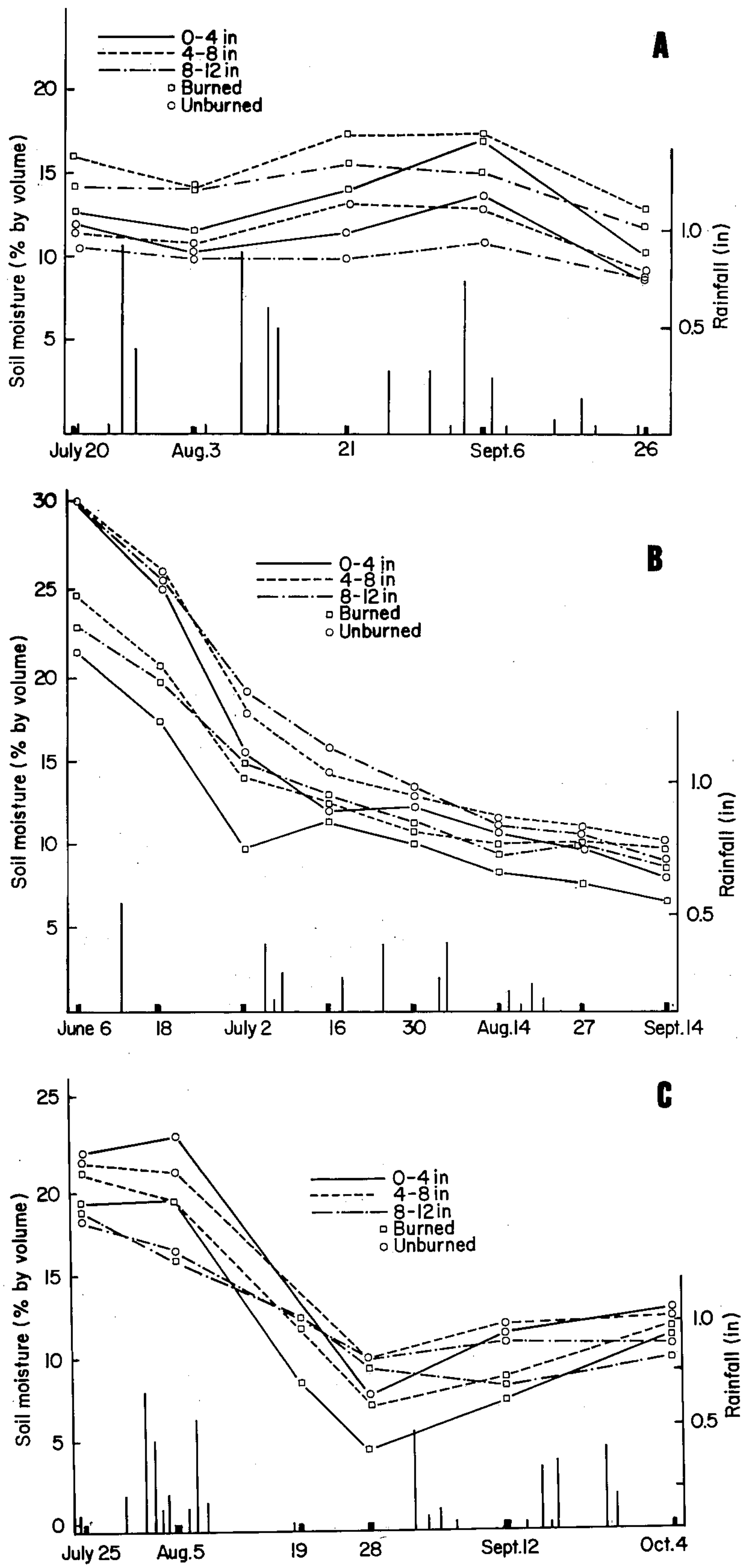

Figure 2.—Soil moisture on Rattle Burn watersheds as affected by wildfire:
(A) (1972), (B) (1973), (C) (1974).

Infiltration. Rates of infiltration into soils were determined in August following the fire and in June, July, and August the following year. The technique and infiltrometer developed by Meeuwig (1971) were used. The infiltrometer consisted of a rainfall simulator which applied water to a 3.7-ft² (0.344 m²) plot from which runoff was caught by a trough at the downhill edge of the area of application.

Infiltrometer plots were established adjacent to transects used for sampling soil moisture. Values shown are means of 12 runs on the moderately burned and unburned watersheds and 14 runs on the severely burned area:

Unburned	2.7 in (6.9 cm)/hr
Moderate burn	1.5 in (3.7 cm)/hr
Severe burn	1.0 in (2.6 cm)/hr

Reduced infiltration rates on the burned areas reflect severity of the fire, and are attributed to fire-induced water repellency in the soil and to puddling and subsequent sealing of the unprotected surface soil.

Most of the infiltration plots on the burned areas had a layer of litter by the second year. This provided a small degree of protection to the soil surface, but, the rate of infiltration did not increase appreciably. A layer of water-repellent soil was found on plots with extremely slow infiltration rates. These facts led us to conclude that fire-induced repellency was an important factor in reducing infiltration rates.

Water Repellency. The presence of water repellency was tested by a method similar to that described by Savage et al. (1969). Drops of distilled water were placed on the smoothed side of a soil core immediately after it was drawn from the soil. If a waterdrop failed to penetrate after 30 sec, the soil layer was judged to be repellent. Thirty samples per watershed were tested on each of five dates in 1972 and three dates in 1973. The most striking feature of the data was its extreme variability and inconsistency from one sampling date to another, part of which may have been attributable to surface soil moisture variation. However, some revealing patterns did emerge.

The water-repellent layer was thickest and most prevalent in soils from the severely burned area. The repellent layer in soil of the unburned area was at the surface; the repellent layer in soil of the burned areas occurred below a wettable layer in many of the samples, and was generally deeper in soil of the severely burned area.

The proportion of samples exhibiting water repellency was consistent with severity of the burn. At any sampling date, more samples from severely burned plots contained a repellent layer than samples from either moderately burned or unburned plots. The prevalence of water repellency in the soil, particularly from the unburned site, was generally inversely related to soil moisture content of the surface soil.

The sites were sampled again in the summer of 1976. Some repellency still persisted in the severely burned areas. The data, combined with general observations, support the findings of DeBano (1969), DeBano and Rice (1973), Savage et al. (1969), Miyamoto et al. (1972), and several others in respect to fire-caused and naturally occurring water repellency. The repellency persisted in sandy loam soils, but was less evident in finer textured soils.

Animal Life

Large Herbivores. Because movements of large animals could not be restricted to the study watersheds, use by these animals was measured on larger areas. Approximately 300 sample plots 109 ft² (10 m²) were established on sites representing the two burned conditions and the control. Fecal deposits were counted in October 1972, 1973, and 1974. Data obtained in 1972 represented only a 2.5-month accumulation period, while 1973 and 1974 data represented 12-month periods.[4]

Deer use on the moderately burned areas was greater than on the unburned areas in all 3 yr (table 6), while use was greater on the severely burned areas than on the unburned ones in 1974. The pattern of deer use in different years and on different sample areas appeared to be related to the production of palatable herbage species (Neff 1974). Counts of elk and cattle fecal deposits were confounded by management changes for cattle. Elk pellet densities were low, and patterns of use could not be verified statistically.

Rodents. A trapping grid using 30 systematically located plots was established on each of the three watersheds to index population changes among small rodents. In July 1972, three live traps were placed at each sample plot. Rodents were trapped for two separate 3-day periods. In 1973 and 1974, 60 traps were set for 14 consecu-

[4]Fitzhugh, E. Lee and J. T. Beaulieu. 1976. Wildfire effects on plant and animal communities in Arizona ponderosa pine forests. Mimeo rep. Eisenhower Consortium Coop. Agreement 16-454-CA, on file at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.

Table 6.—Use of burned and unburned ponderosa pine forest by large herbivores as indexed by fecal deposits/acre, Rattle Burn, 1972-74

Herbivore	Unburned			Moderate burn			Severe burn		
	1972[1]	1973	1974	1972[1]	1973	1974	1972[1]	1973	1974
Deer	672	267	116	1001	398	363	257	171	262
Elk	74	74	54	250	49	306	17	37	269
Cattle	353	250	250	465	245	324	427	398	818

[1]*Pellet plots were established in June to August, 1972 and cleared again in October, 1972. Thereafter, the accumulation period was 12 months*

tive days on each watershed. Traps baited with peanut butter and grain were checked early each morning and late each evening. They were set 24 hr/day in 1973 and 1974, but only from evening to morning in 1972. All captured rodents were toe-clipped for identification before release. Differences in numbers of animals caught were analyzed by species through Chi-square tests evaluated at the 90% level.

Seven rodent species were caught: golden-mantled ground squirrels (*Spermophilus lateralis*), deer mice (*Peromyscus maniculatus*), white-footed mice (*P. laucopus*), brush mice (*P. boylei*), gray-neck chipmunks (*Eutamias cinereicollis*), Mexican voles (*Microtus mexicanus*), and Mexican woodrats (*Neotoma mexicana*).

Mice were generally the most numerous rodents trapped. In 1972, more mice and ground squirrels and fewer chipmunks were caught on the burned watersheds than on the control; differences between severely burned and moderately burned watersheds were not significant. Since the patterns found in 1972 were no longer detectable in 1973 and 1974, the effects of the wildfire on rodent populations evidently were relatively short-lived. Insufficient numbers of voles and woodrats were caught to adequately evaluate the effect of fire on their populations.

Ground squirrel population increases on the burned watersheds were attributed to opening up of the forest by fire, and subsequent increases in grasses and forbs. These plants, and hypogeous fungi (mushrooms) comprise the ground squirrel's diet (Tevis 1953). Mice also increased after the burn, probably in response to increased food such as insects, seeds, and herbaceous vegetation (Hooven 1969, Jameson 1952). The similarity of mouse populations between the two burned watersheds may indicate that the cover differential was not important. Since chipmunks are more dependent on trees than the other rodent species caught, their decline was expected after the forest overstory was burned (Gashwiler 1959).

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A wildfire of variable severity swept through 717 acres (290 ha) of ponderosa pine forest in north-central Arizona in May 1972. Where the fire was intense it killed 90% of the small trees and 50% of the sawtimber, burned 2.6 in (6.5 cm) of forest floor to the mineral soil, and induced a water-repellent layer in the sandier soils. The reduced infiltration rates, which greatly increased water yield from severely burned areas during unusually heavy fall rains, caused soils to erode and removed some nutrients which had been mineralized by the fire. Water yields have declined each year toward prefire levels.

Keywords: Fire, *Pinus ponderosa,* herbage production, water repellency, water yield, sediment production.

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