Effect of Prescribed Burning on Sediment, Water Yield, and Water Quality from Dozed Juniper Lands in Central Texas

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Highlight: *Prescribed burning was applied to six mini-watersheds that were each paired with an unburned watershed. Erosion losses, runoff, and water quality were unaffected on level areas, but adverse effects lasted for 9 to 15 months on moderate slopes and for 15 to 30 or more months on steep slopes. Rates of erosion losses stabilized within 18 months on all slopes when vegetative cover reached 63 to 68%.*

During the last 70 years, Ashe juniper (*Juniperus ashei*) has invaded extensive areas of the mixed prairie in central Texas. Since fire is the only economical method to remove piles of dozed juniper and to kill invading young juniper trees (Wink and Wright, 1973), this study was undertaken to measure how long it would take for overland flow, soil loss, cover, and water quality to return to preburn status in an Ashe juniper community.

Removal of brush and trees from pinyon (*Pinus edulis*)-juniper (*Juniperus* sp.) communities in Arizona and Utah does not generally affect water or sediment yield (Brown, 1965, 1971; Collings and Myrick, 1966; Gifford et al., 1970), except following 25-year storms (Baker et al., 1971) and occasionally following slash burning or excessive soil disturbance treatments (Myrick, 1971; Gifford, 1973). These data, however, were collected in 12 to 20-inch precipitation zones. In central Texas the annual precipitation is 26 to 28 inches, which could affect water and sediment yield quite differently, as indicated by prescribed burning tests in a similar precipitation zone in the Black Hills of South Dakota (Orr, 1970).

Following burning, soil movement is usually related to the intensity of the fire. Intense fires increase runoff and/or erosion (Connaughton, 1935; Holland, 1953; Rowe, 1955; Hussain et al., 1969), whereas low intensity fires leave some litter on the soil surface and have little or no effect on surface runoff and erosion (Biswell and Schultz, 1957; Agee, 1973). Thus, it appears that cover (live vegetation plus litter) is by far the most important variable related to soil erosion (Packer, 1951; Bailey and Copeland, 1961; Orr, 1970) and will account for as much as 76% of the variance of the logarithm of the weight of eroded soil (Meeuwig, 1970). A cover of 60 to 70% is considered necessary for soil stability (Bailey and Copeland, 1961; Packer, 1963; Orr, 1970), which on steep watersheds is generally reached in 2 to 4 years after burning (Glendening et al., 1961; Orr, 1970, DeByle and Packer, 1972).

Other factors that affect sediment production include intensity of storms, size and frequency of bare areas, and wettability of the soil. Orr (1970) found that summer storm runoff and sediment production were closely related to precipitation in excess of 0.36 inch/hour. Size of bare areas substantially affects the influence of a given ground cover (Packer, 1951). As the size of the bare openings increases, the influence of ground cover decreases. Bare soils in natural plant communities or following burns are generally hydrophobic (Adams et al., 1970).

The effects of rangeland treatment practices on water quality are essentially unknown (Branson et al., 1974), but sediment is the major pollutant that lowers water quality (Robinson, 1971; Grant, 1971). Another important indicator of water quality is its calcium and magnesium content, which is usually expressed in terms of hardness (Hem, 1970). Calcium and magnesium consume soap, thus reducing its sudsing ability. Calcium carbonate ($CaCO_3$) content for soft, moderately hard, hard, and very hard water is 0-60, 61-120, 121-180, and > 180 mg/liter, respectively (Durfor and Becker, 1964). However, for ordinary domestic purposes, hardness does not become particularly objectionable until it reaches 100 mg/liter (Hem, 1970). Hem states that total hardness, calcium plus magnesium hardness, and hardness as $CaCO_3$ are all synonymous terms.

The average concentration of sodium in river waters is 6.3 mg/liter (Livingstone, 1963), but is generally below this level in water from limestone formations. Potassium and pH are also of interest in relation to water quality. In most natural waters the concentration of potassium is much lower than the concentration of sodium (Hem, 1970), but if increased by burning treatments, both concentrations will drop to preburn levels in the second year after burning (DeByle and Packer, 1972). pH of ground waters varies from 6.0 to 8.5 (Hem, 1970), but is not of much concern in hard waters used by municipalities because the water purification process usually controls pH.

Methods

This study was conducted on the Beckham Ranch in Callahan County, Tex., 15 miles southeast of Baird. The area is

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on limestone derived soils in the southern mixed prairie on the north end of the Edwards Plateau in central Texas. Average annual precipitation is 26 to 28 inches. Topography is level to undulating with slopes up to 60% at an elevation of 1,400 to 2,100 ft above sea level. The average minimum January temperature is 23°F; average maximum July temperature is 95°F. The growing season averages 232 days.

Table 1. Characteristics of watersheds on Beckham Ranch near Baird, Tex.

Watershed number	Surface area (acre)	Average slope (%)	Soil[1] series
1	0.066	3.7	Krum
2	0.062	2.7	Krum
3	0.086	3.3	Krum
4	0.089	3.0	Krum
5	0.268	7.8	Brackett
6	0.194	14.8	Brackett
7	0.043	18.3	Hext
8	0.082	20.1	Shep
9	0.478	37.3	Somervell
10	0.246	44.9	Somervell
11	0.410	60.6	Somervell
12	0.308	52.8	Somervell

[1] Soil classifications were based on tentative and established series data from U.S. Department of Agriculture, Soil Conservation Service, Fort Worth, Tex.

Twelve mini-watersheds were selected for study, which varied in size from 0.06 to 0.48 acre (Table 1). They were paired on the basis of soil type and classified as level (1–4% slopes), moderate (8–20% slopes), and steep (37–61% slopes). One watershed of each pair was picked at random to be burned. Three were burned on March 24 or 25, 1972; and three were burned on December 13 or 16, 1972. They were burned without any prepared firelines when the wind was 4 to 5 mph, relative humidity was 26 to 50%, and air temperature was 37 to 51°F.

The level watersheds were bounded by a strip of 8-inch sheet metal, whereas the moderate and steep watersheds had natural boundaries. Where necessary, a dyke was constructed on the upper end of some watersheds so that no overland flow from upslope could enter the test areas.

At the base of all watersheds, a metal dyke was installed. Flush with the soil surface, a 1-ft^2 opening in the dyke was connected to a trough that led to a collection tank (Fig. 1). The collection tanks varied from 750 to 3,000 gal, depending on the size of the watersheds. The tanks and troughs were not covered, so the quantity of runoff water was always corrected for rainfall. Runoff samples were collected 24 hours after each storm. Sediment and sediment samples were collected every 1 to 3 months after the tanks were drained and had dried out.

Water samples, taken 24 hours after most sediment had settled out, were analysed for calcium, magnesium, sodium, turbidity, hardness, and pH. Calcium and sodium were determined as mg/liter on a flame photometer. Calcium plus magnesium (mg/liter) was determined by the official methods of analysis (Ass. Off. Anal. Chem. 1970: p. 671). Then mg/liter of magnesium was determined by subtracting mg/liter

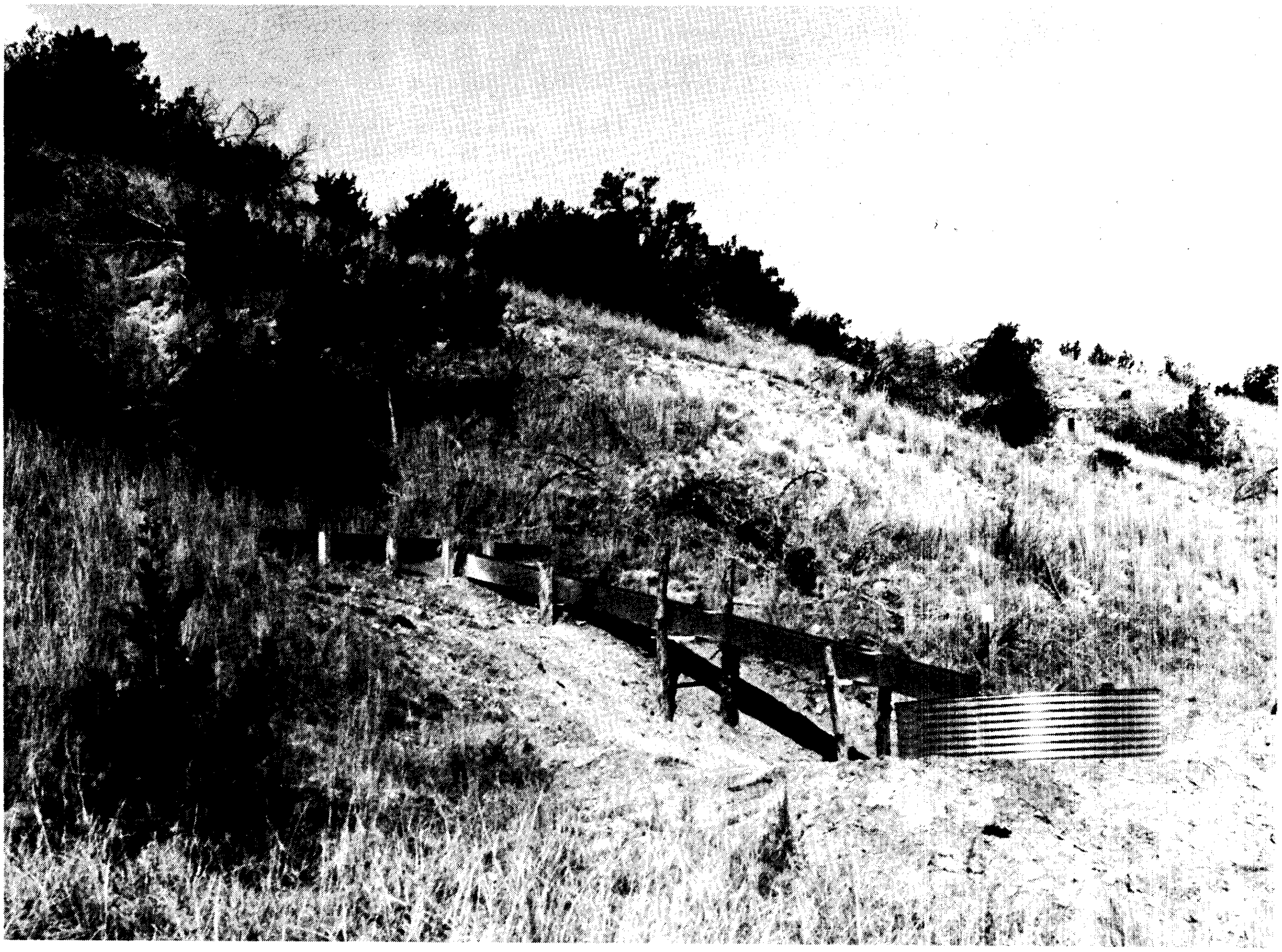

Fig. 1. *A metal dyke with trough and collection tank were installed at the base of each watershed.*

of calcium from mg/liter of calcium + magnesium. Using these data, water hardness was calculated from the following formula: mg/liter of Ca × 2.497 plus mg/liter of Mg × 4.116. Turbidity was measured in Jackson units (Rainwater and Thatcher, 1960) on a scale of 0 to 400 using a UV-Vis spectrophotometer. A reading of 0 would be obtained using distilled water with 100 transmittance, whereas a reading of 400 would be for very turbid water with no transmittance of light. pH was determined with a Sargent-Welch pH meter model LSX.

Sediment samples were oven dried for 24 hours at 220°F and analyzed for organic matter, nitrogen, phosphorus, and potassium. Organic matter was determined using the potassium dichromate method. Phosphorus and potassium were read on a photoelectric colorimeter using quinaldine red indicator for phosphorus and sodium cobaltinitrite as an indicator for potassium. Parts per million of nitrogen were determined by a standard formula: percent organic matter/2 × 1,000. This formula assumes an organic matter to nitrogen ratio of 20:1 (Buckman and Brady, 1961).

Volume of runoff and weight of sediment were determined in the field. Runoff was determined by measuring the depth of water in tanks, subtracting the correction for rainfall, and then calculating inches of runoff per acre. Sediment was weighed, corrected for water content and then calculated as tons per acre.

Cover (live vegetation plus litter), rock, and bare soil were determined by a vertical ocular estimate using fifty 2.4-ft^2 rectangular plots on each watershed. These data were taken before treatment and after the spring and fall growing seasons each year.

Soils on the 1 to 4% slopes are uniform Krum clay loams. The Krum series is a member of the fine, mixed, thermic family of Vertic Haplustolls. The C horizon contains segregated lime.

Two areas were studied on 8 to 20% slopes. One area has a Brackett gravelly loam soil with slopes from 8 to 15% and a northwest aspect. The Brackett series is a member of the loamy, carbonatic, thermic, shallow family of Typic Ustochrepts. Together the A and B horizons are less than 20 inches thick and are underlain by chalky limestones and calcareous earth. Water seeps from these soils after heavy rains. The second area studied on moderate slopes was classified as a Hext fine sandy loam on one watershed and a Shep loam on the other watershed. Both watersheds had 18 to 20% slopes with an east aspect and were adjacent to each other. The Hext series is a member of the coarse-loamy, mixed, thermic family of Rendollic Eutochrepts. The Shep series is a member of the fine-loamy, mixed, thermic family of Typic Ustochrepts.

The steep slopes varied from 37.3 to 60.6% with an east aspect. They are characterized by Somervell gravelly clay loams. The Somervell series is a member of a loamy-skeletal, carbonatic, thermic family of Ustochrepts. They contain over 50% gravel and cobble-size limestone fragments throughout the A and B horizons.

Vegetation on all watersheds consists of mixed prairie grasses interspersed with Ashe juniper and several species of oak (*Quercus* spp.). Little bluestem (*Schizachryium scoparium*) and sideoats grama (*Bouteloua curtipendula*) are the dominant decreasers. Buffalograss (*Buchloe dactyloides*), vine-mesquite (*Panicum obtusum*), Texas wintergrass (*Stipa leucotricha*), tall grama (*Bouteloua pectinata*), and meadow dropseed (*Sporobolus asper* var. *hookeri*) are important increasers. All large juniper trees were dozed in piles of 1 to 4 trees in 1967.

Results and Discussion

Soil losses following burning occurred only on the moderate and steep slopes (Table 2). The loss rates gradually

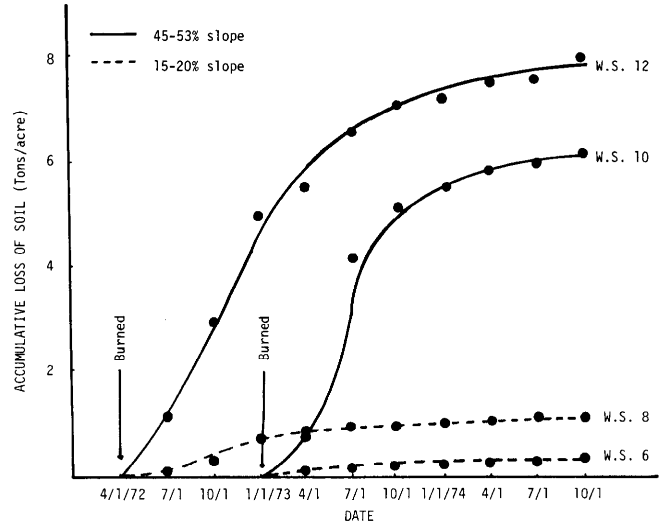

Fig. 2. *Accumulative loss of soil from burned watersheds for moderate and steep slopes in relation to date.*

declined after burning until soil material stabilized in 9 to 15 months on moderate slopes and in 15 to 18 months on steep slopes (Fig. 2). This stability was exhibited despite several intense rain storms (total of 17.4 inches) during the last 1.5 months of the study period. Some soil was still being lost from one steep watershed (No. 12) 2.5 years after burning, but it was only 0.125 ton/acre (part of the 0.218 value in Table 2) during the 1.5-month period in which we received 17.4 inches of rain. Most of this soil came off the watershed during a 2.44-inch storm that fell at an intensity of 2.36 inches/hour.

Table 2. Sediment (tons/acre) from mini-watersheds and associated precipitation (inches) on the Bob Beckham Ranch near Baird, Tex.

Measurement and watershed number	Dates of 6-month periods					
	4/1-9/30/72	10/1-3/31/73	4/1-9/30/73	10/1-3/31/74	4/1-9/30/74	Total
Sediment						
Level areas						
1[a]	0.010	0.003	0.008	0.001	0.005	0.027
2	0.008	0.003	0.008	0.002	0.004	0.025
3	0.005	0.003	0.006	0.001	0.003	0.018
4[b]	0.006	0.002	0.007	0.001	0.003	0.019
Moderate slopes						
5	0.014	0.020	0.007	0.002	0.003	0.046
6[b]	0.014	0.102	0.035	0.025	0.014	0.190
7	0.052	0.070	0.106	0.057	0.035	0.320
8[a]	0.304	0.532	0.167	0.044	0.024	1.071
Steep slopes						
9	0.002	T[c]	0.001	0.001	0.003	0.007
10[b]	0.005	1.203	3.917	0.663	0.141	5.929
11	0.005	0.001	0.001	T	T	0.007
12[a]	2.97	2.796	1.586	0.387	0.218	7.957
Precipitation	13.0	13.9	12.8	8.4	21.8	

[a]Burned in March, 1972.
[b]Burned in December, 1972.
[c]Trace (less than 0.0005 tons/acre).

Cover (live vegetation plus litter), the size of bare areas created by burning the juniper piles, and loose piles of soil where juniper trees had been dozed and pushed together, all affected soil losses from the watersheds. Most sediment during the first 18 months after burning probably came from loose piles of soil on bare areas. Soil from these areas on steep areas eroded rapidly. There was almost no evidence of pre-existing piles 18 to 24 months after burning.

Cover reached 66 to 68% on the moderate slopes after two spring growing seasons (15 months). By comparison, the steep slopes had only 58% cover after two spring growing seasons and required 21 to 30 months to achieve a 63 to 68% cover. Even with more than 60% cover, the steep, burned watersheds lost some soil (Table 2). Revegetation was slow on steep slopes where bare areas were from 3 X 6 ft to 12 X 15 ft in size.

Nutrient and organic matter losses due to erosion of soil, were relatively low in proportion to the amount available in the upper 6 inches of the soil profile. Losses of N, P, K, and organic matter (O.M.) from the upper 6 inches of soil were less than 2% for all elements during the 2.5-year period following the burn on moderate and steep-sloped watersheds. Below is a tabulation of percent nutrient and organic matter losses from the watersheds:

	N	P	K	O.M.
Moderate	0.13	0.25	0.12	0.08
Steep	0.53	1.78	1.13	0.56

Only traces of elements were lost from level areas and from the controls. Phosphorus was the element most susceptible to loss. These losses do not include nutrients lost in runoff water as organic particulate or dissolved organic or inorganic nutrients.

After 12 to 18 months, overland flow (Table 3) on moderate slopes was similar to that of the controls, but was higher on the steep slopes than that of the controls after 30 months. Thus, on the steep slopes, overland flow appears to be a function of the rate at which bare areas heal.

Watersheds 5 and 6 were on a Brackett gravelly loam soil, and water seeped from them following several 1.5 to 5.1-inch storms. This complicated the interpretation of the effect of cover on overland flow. Thus, when seepage or saturated overland flow influenced runoff on level and moderate-sloped watersheds, data from those storms was excluded from total overland flow (data in parentheses in Table 3). This helped us to interpret the effect of cover on overland flow for several watersheds.

Water did not seep from watersheds 7 and 8, but watershed 7 had a shallow A and B horizon, which minimized infiltration after several inches of rain had fallen. The level areas were saturated occasionally following 8 to 9 inches of rainfall within a 10-day period. Once the soils were saturated, water rapidly ran off all level and moderate slopes. The unburned steep slopes (Somervell gravelly clay loam) produced little overland flow, except on rare occasions when the saturated soils produced temporary springs. Thus, these steep slopes, because of their high infiltration and percolation rates, usually help stabilize runoff during peak overland flow periods. This could be a good reason for not burning steep slopes until we know how to stabilize them more quickly.

Quality of water following burning on limestone soils, as indicated by turbidity, was good on level areas, fair on moderate slopes, and poor on steep slopes (Table 4). Turbidity

Table 4. Turbidity (Jackson Units) of runoff water 24 hours after storms for the first 12 months after treatment near Baird, Tex.

Slope	Treatment	
	Burned	Control
Level	12	12
Moderate	53	20
Steep	132	12

of runoff from moderate slopes is comparable to that of the control in 1.5 years after burning. On the steep slopes, turbidity did not change until 2 years after burning. Then it declined rapidly to 60 Jackson units on burned areas compared to 18 on the control. Turbidity of runoff from steep slopes may not reach the level of control watersheds until 3 to 4 years after burning.

Total hardness (mg/liter of Ca X 2.497 plus mg/liter of Mg X 4.116) of water was not affected as seriously by burning as turbidity. Neither runoff from the level areas nor runoff from moderate slopes on brackett gravelly loam soils changed in water hardness (25) due to burning, but water from the Brackett gravelly loam soils was always moderately hard (80). Runoff from moderate slopes with Shep loam and Hext fine sandy loam soils was soft (< 60) within 6 months after burning, but it was not comparable to the controls until 18 months after burning (48). Water from steep slopes was moderately hard for 30 months (95 vs 32 for control). Calcium accounted for 57% of the water hardness on all watersheds; the remainder was due to magnesium.

Sodium was always low in the runoff water from these

Table 3. Overland flow (inches) from mini-watersheds and associated precipitation (inches) on the Bob Beckham Ranch near Baird, Tex.[c]

Measurement and watershed number	Date				
	4/9-9/30/72	10/1/72-3/31/73	4/1-9/30/74	10/1/73-3/31/74	4/9-9/30/74
Overland flow					
1[a]	0.000	0.064	0.031	0.022	0.116 (0.039)
2	0.005	0.065	0.048	0.030	0.403 + (0.082)
3	0.002	0.046	0.189 (0.060)	0.016	0.266 + (0.025)
4[b]	0.000	0.046	0.298 (0.056)	0.004	0.376 + (0.142)
5	0.038	0.897 (0.366)	0.423 (0.050)	0.230 (0.036)	1.476 (0.108)
6[b]	0.008	1.085 (0.512)	0.349 (0.109)	0.329 (0.156)	0.655 (0.181)
7	0.072	1.512 (0.300)	0.456 (0.062)	0.248	0.068 (0.215)
8[a]	0.304	0.913 (0.300)	0.560 (0.210)	0.347	0.655 (0.179)
9	0.008	0.012	0.006	0.002	0.004
10[b]	0.008	0.064	0.690	0.496	0.303
11	0.010	0.014	0.006	0.002	0.008
12[a]	0.600	0.484	0.469	0.278	0.391
Precipitation	13.0	13.9	12.8	8.4	21.8

[a]Burned in March, 1972.
[b]Burned in December, 1972.
[c]Data in parentheses exclude values obtained when seepage or saturated overland flow influenced runoff.

limestone-derived soils. Over a period of 2.5 years, it was below 1.0 mg/liter on all watersheds during eight out of ten 3-month periods. During the other two periods, which were dry spring or summer months, the average sodium concentration varied from 0.2 to 6.3 mg/liter. The highest readings were associated with unburned plots, so burning did not increase salinity of water.

Burning affected pH of runoff water slightly. On control watersheds with level, moderate, and steep slopes pH was 7.3, 7.6, and 7.4, respectively. On burned watersheds it was 7.3, 7.7, and 7.7 for the same slopes over an 18-month period. Differences in pH on the moderate and steep slopes were significant, but of little biological importance. No differences in pH were detectable after 16 months from runoff water on the moderate slopes, but they were still detectable after 30 months on steep slopes.

Conclusions

Prescribed burning in central Texas significantly affected hydrologic properties of limestone derived soils with 15 to 53% slopes. Soil losses (1 ton/acre on 15% slopes and 8 tons/acre on 53% slopes) stabilized in 9 to 15 months on moderate slopes and in 15 to 18 months on steep slopes. Nutrient losses in the upper 6 inches of soil did not exceed 0.53, 1.78, and 1.13% for nitrogen, phosphorus, and potassium, respectively, on the most severely eroded sites. Based on observations, most eroded soil was derived from piles of loose soil beneath dozed juniper trees that burned.

Cover reached 66 to 68% in 15 months after burning on moderate slopes but it took 21 to 30 months to reach a similar ground cover on steep slopes. Ground cover and the number and size of bare spots (where piles of juniper burned) seemed to be the controlling factors influencing overland flow.

Water quality, primarily turbidity and total hardness, was related to vegetative cover. Following burning, water was soft from level areas, moderately hard for 6 months on 15 to 20% slopes, and moderately hard for more than 30 months on 53% slopes. Water from burned watersheds was more turbid than water from controls for 1.5 years on moderate slopes and for at least 2.5 years on steep slopes. Sodium was always low, and pH increased only slightly after burning moderate and steep watersheds.

This study indicates that slopes less than 20% can be tree-dozed and left to heal naturally after burning without serious soil or water quality losses. Slopes over 45%, however, on the Somervell soil series lose 6 to 8 tons/acre of soil if burned, and water quality is lowered. In the unburned condition this soil imbibes almost all water and produces no sediment. As a management alternative, steep slopes might be left alone and used for wildlife cover to preserve the watershed values of the range.

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