

Effects of Watershed Management Practices on Sediment Concentrations in the Southwestern United States: Management Implications

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Abstract.—Effects of watershed management practices on suspended sediment concentrations from ponderosa pine forests and pinyon-juniper woodlands in the Southwestern United States are examined. Completely cleared and strip-cut ponderosa pine watersheds produced higher sediment concentrations than the control. Likewise, cabled and herbicide-treated pinyon-juniper watersheds yielded higher sediment-laden streamflows than the control. Soil disturbances associated with vegetative manipulations on these watersheds are the assumed causal factor. Management implications of the reported effects are described.

Introduction

One method of analyzing effects of vegetative treatments on sediment concentrations is through interpretations of sediment rating curves relating suspended sediment concentration to streamflow discharge (Lopes and Ffolliott 1993, Lopes et al. 1996). A sediment rating curve reflects the pattern of soil erosion and sediment delivery operating on a watershed, and provides a readily accessible starting point for investigating the impacts of vegetative treatments on in-stream sediment discharge. This paper reports on the derivation of sediment rating curves to estimate impacts of vegetative treatments on suspended sediment concentrations from the Beaver Creek watersheds in north-central Arizona.

Study Area

The Beaver Creek watersheds, located about 80 km south of Flagstaff, are situated in the Salt-Verde River Basin of north central Arizona. These watersheds are

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representative of extensive areas of ponderosa pine forests and pinyon-juniper woodlands found in the southwestern United States. Descriptions of vegetative characteristics, physiological features, and precipitation-streamflow regimes of these watersheds have been presented by Brown et al. (1974), Clary et al. (1974), and Baker (1982) and, therefore, will not be detailed here.

The most important precipitation from a streamflow-generation standpoint is that originating from frontal storms during October through April, when about 60% of the annual precipitation falls. A second precipitation season is July through early September, when high-intensity, short-duration, localized convectional storms are common. Most annual runoff is produced from melting snowpacks in March or April. Winter runoff accounts for 85% of the annual water yield (Baker 1982). Suspended sediment discharges are 75 to 80% of the total sediment discharge from the watersheds studied.

Vegetative Treatments Evaluated

Ponderosa Pine Watersheds

Vegetative treatments evaluated on ponderosa pine watersheds consisted of creating cleared openings in the forest overstories and reducing forest overstory densities. WS 12 (184 ha) was completely cleared. All merchantable timber was removed and the remaining non-merchantable wood, and all intermingling Gambel oak and alligator juniper, were felled in 1966-67. Residual slash and debris was machine windrowed to trap and retain snow, reduce evapotranspiration losses, and increase surface drainage efficiency. The windrows were burned in 1977 to determine whether their removal would influence water yield (Baker 1983). Ponderosa pine, Gambel oak, and alligator juniper were allowed to seed themselves or sprout and grow following the clearing treatment. Because hydrologic changes caused by the treatment cannot be separated from those caused by the windrows, the treatment evaluated consists of complete forest clearing; soil disturbances

due to timber harvesting operations; and soil disturbances due to the presence of windrows. The treatment resulted in an average increase in annual water yield of about 30% (44.5 cm) for 7 years after treatment, at which time the post-treatment response became insignificant.

On WS 14 (546 ha), one-third of the ponderosa pine forest was cleared in irregular strips averaging 18 m wide in 1970. Slash was piled and burned in the cut strips. The forest overstory in the intervening leave strips, which averaged 37 m wide, was reduced by thinning to about 25% or 18 m² ha⁻¹ of basal area, a density level thought optimal for subsequent growth. Slash and debris were piled and burned in the cleared strips. This treatment resulted in a 57% reduction in basal area on the watershed. Gambel oak was retained throughout the watershed for mast and browse production, important to indigenous wildlife. Annual water yield increased about 20% (24 cm) in the first four post-treatment years, after which the response was insignificantly low or negative.

WS 13 (369 ha) served as a control against which the completely cleared and strip-cut treatments were evaluated. While some commercial timber had been harvested in the early 1950s, conditions on this watershed at the time of this study represented those obtained through minimal managerial inputs.

Pinyon-Juniper Watersheds

Treatments on the pinyon-juniper watersheds consisted of converting the woodland overstories to covers of less water-consuming herbaceous plants. On WS 1 (131 ha), a cabling treatment was applied in 1963. Larger trees were uprooted by a heavy cable pulled between two bulldozers. Smaller trees missed by cabling were hand-chopped, slash was burned, and the watershed seeded with a mixture of forage species. This treatment did not result in significant increases in annual water yields.

On WS 3 (147 ha), a mixture of picloram (2.8 kg ha⁻¹) and 2,4-D (5.6 kg ha⁻¹) was applied by helicopter to 114 ha in 1968; the remaining 33 ha were either not treated or the trees were sprayed with a backpack mist-blower. This treatment resulted in a significant increase in annual water yields of about 160% (4.4 mm) for 8 post-treatment years, after which the residual dead trees were removed in a firewood sale.

WS 2 (51 ha) was a control against which the cabling and herbicide treatments were evaluated. Conditions on this watershed represented those obtained through minimal managerial inputs.

Methods

Suspended sediment concentration and streamflow data obtained from 1974 through 1982 were the source data for this study. Data sets reflecting immediate impacts of the vegetative treatments were excluded from the analysis to better describe long-term impacts of the treatments on sediment concentrations. Either grab samples, integrated samples obtained with a DH-48 hand sampler, or pumping samples were analyzed by filtration to determine sediment concentrations. Streamflow was measured in concrete trapezoidal flumes. When a sample of suspended sediment was collected, the time was indicated on a digital tape on the continuous water-level recorders at the gauging stations. Sediment data used in the development of the sediment rating curves were collected for streamflow discharges in excess of 0.05 m³ s⁻¹ and at time intervals greater than 1 hr to reduce possible effects of serial correlation.

Sediment rating curves are frequently expressed in terms of a power function form, such as $C = aQ^b$, where C = suspended sediment concentration (mg/L), Q = streamflow discharge (m³/s), and a , b = regression coefficients for a particular stream. Sediment rating curves to be derived in a power function form are often approximated by least-square linear regressions of logarithmic-transformed data (Walling 1977); this transformation was used in this study. The procedure to overcome the possibility of bias when the regression estimates were detransformed and to minimize spurious conditions was outlined earlier by Duan (1983). Parameters “ a ” and “ b ” of the sediment rating curves for the sediment rating curves, with the 95% confidence limits, fitted standard errors, coefficients of determination, and F statistic, are presented in table 1.

Results

Ponderosa Pine Watersheds

There were significant differences in sediment rating curves among the treated ponderosa pine watersheds and control watershed. These differences indicated that for a similar streamflow discharge, sediment concentrations from the completely cleared watershed (WS 12) were significantly higher than those from the strip-cut watershed (WS 14), and that sediment concentrations from the

Table 1. Sediment rating curve parameters, with 95% confidence limits, standard errors, coefficients of determination and statistics for ponderosa pine and pinyon-juniper watersheds.

Watershed	N	a	95% Confidence Intervals		b	95% Confidence intervals		Standard error SE	r_a^2	F Statistics	Significance
Ponderosa Pine											
12	353	154.579	121.667	196.413	1.042	0.947	1.137	125.97	0.57	468.54	**
13	204	28.679	21.804	37.717	0.677	0.579	0.776	61.40	0.47	183.40	**
14	473	56.590	43.335	68.681	0.974	0.919	1.097	74.94	0.50	475.87	**
Pinyon-juniper											
1	525	7.362	5.297	10.257	0.233	0.143	0.324	7.03	0.05	39.33	**
2	519	5.129	3.664	7.161	0.193	0.112	0.274	2.98	0.04	22.01	**
3	611	8.091	5.916	11.066	0.245	0.168	0.321	4.67	0.06	25.76	**

N=Sample size

F Statistic:Equation significant at $\alpha=0.05$

*Significance:Regression significance(**) at $\alpha=0.05$*

strip-cut watershed were higher than those from the control watershed (table 2).

WS 12 experienced watershed-wide soil disturbance from the complete clearing treatment, simultaneous breaking-up of the herbaceous ground cover by the clearing operation, and follow-up pushing of the residual slash and debris into windrows. Soil disturbance on WS 14 was less extensive and more localized than what took place on WS 12. The most destructive portion of the disturbance on WS 14 occurred on the one-third of the watershed that was cut into irregular strips, where much of the protective herba-

ceous plant cover was disturbed, and where the residual slash and debris were piled and burned. Larger snowpack accumulations occurred in the strip-cuts in comparison to those in intervening leave strips. These strip-cuts had up-down-slope orientations, causing the increased overland water flows originating from melting of the larger snowpack buildups to be concentrated in the strips, where most of the sediment production on WS 14 took place.

Pinyon-Juniper Watersheds

There were differences in sediment rating curves among the treated pinyon-juniper watersheds and the control watershed (Lopes et al. 1996). The main difference was higher sediment concentrations from the cabled watershed (WS 1) than the control watershed for similar streamflow discharges. Higher concentrations of suspended sediment on WS 1 were likely a reflection of the soil disturbances caused by uprooting trees in the cabling treatment.

There was also a difference between sediment rating curves derived for the watershed treated with herbicides (WS 3), which experienced little soil disturbances as a result of treatment, and the control watershed. However, soil disturbance caused by the follow-up removal of merchantable firewood, and piling and burning the residual slash 8 years after the herbicide treatment, was significant in terms of affecting suspended sediment discharge.

Table 2. Minimum, mean, and maximum values of streamflow and suspended sediment concentration for ponderosa-pine and pinyon-juniper watersheds.

Water-shed	Flow(m ³ /s)			Sediment (mg/l)		
	Min	Mean	Max	Min	Mean	Max
Ponderosa pine						
WS12	0.048	0.456	3.198	6.53	68.20	519.08
WS14	0.048	0.528	6.679	2.94	30.38	359.76
WS13	0.034	0.693	5.009	2.91	22.37	85.37
Pinyon-juniper						
WS1	0.004	0.041	0.261	2.03	3.50	5.38
WS3	0.003	0.026	0.151	1.95	3.31	5.09
WS2	0.001	0.025	0.216	1.35	2.52	3.82

Management Implications

Soil disturbances from vegetative treatments on Beaver Creek watersheds in both vegetative types generally increases sediment concentrations above those of control watersheds. This response is reflected by their respective sediment rating curves. Completely cleared and strip-cut ponderosa pine watersheds produced higher suspended sediment concentrations than did the control watershed. Likewise, cabled and herbicide-treated pinyon-juniper watersheds yielded higher sediment-laden streamflows than did the control.

While significantly different, suspended sediment concentrations on the Beaver Creek watersheds are relatively low. This finding is not surprising, because erodibility of the volcanic soils on Beaver Creek is inherently low and, therefore, the sediment supply is limited (Lopes and Ffolliott 1993, Baker 1999). More than 50% of the ponderosa pine forests and pinyon-juniper woodlands in the Southwestern United States are found on soils of similar parent materials cover.

It is concluded that the watersheds studied can be severely disturbed by vegetative treatments and still yield relatively little sediment. Furthermore, effects of the disturbances decrease rapidly with time. These watersheds, therefore, appear to be resilient in terms of their soil/site stability and function.

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