IMPACTS OF VEGETATIVE PRACTICES ON SUSPENDED SEDIMENT FROM WATERSHEDS OF ARIZONA

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ABSTRACT: Effects of vegetative practices on suspended sediment discharge from ponderosa pine forests and piñon-juniper woodlands in north-central Arizona are examined. Sediment-rating curves were developed to analyze the impacts. Disturbance from vegetative practices generally increased suspended sediment transport above those of control (reference) watersheds. Completely cleared and strip-cut ponderosa pine watersheds produced higher sediment concentrations than did a control watershed. Likewise, cabled and herbicide-treated piñon-juniper watersheds yielded higher sediment-laden streamflows than did a control. Sediment transport regimes are also related to streamflow-generation mechanisms and hydrograph stages. Although about 85% of the data analyzed represented snowmelt-runoff events in both vegetative types, derivation of sediment-rating curves based on streamflow-generation mechanisms improved the sensitivity of the analysis. Sediment data collected during rising and falling hydrograph stages varied between the two vegetative types. Sediment concentrations were generally higher in the rising stage than in the falling stage for ponderosa pine watersheds. There was no clear evidence of higher sediment concentrations in the rising stage of the hydrograph as compared to the falling stage in the piñon-juniper watersheds.

INTRODUCTION

Estimating sediment generation and export from watersheds is a useful way of predicting on-site and off-site environmental impacts of land management practices. Besides causing siltation in downstream reaches and deposition in reservoirs (Grenney and Heyse 1985), sediment is a major pollutant and a carrier of nutrients, pesticides, and other chemicals (Osterkamp and Parker 1991; Johansson et al. 1995; Duff et al. 1996; U.S. 1996). Sediment has been identified as being responsible for up to 80% of the water quality degradation in the United States (Anderson et al. 1976). While sediment discharge is an important parameter for estimating sediment buildup in reservoirs, sediment concentration is a primary factor of environmental concern to land managers (Wetzel 1983; Grenney and Heyse 1985).

Factors controlling sediment generation and export from a watershed include geologic structure, soil properties, topography, vegetation, land use, temporal and spatial distributions of precipitation, and streamflow generation mechanisms. However, it is difficult to combine all of these factors into one reliable expression for estimating sediment discharge from a watershed, or to isolate the individual effects of these factors on sedimentation processes (Lopes and Ffolliott 1992, 1993a). One method of analyzing the effects of land-use practices on sediment discharges is through interpretations of a sediment-rating curve relating sediment concentration to streamflow discharge (Shen and Li 1976; Lopes and Ffolliott 1993b; Brooks et al. 1997).

A sediment-rating curve reflects the pattern of soil erosion and sediment delivery operating in a watershed, and provides a readily accessible starting point for investigating the impacts of land-use practices on sediment discharge. Sediment-rating curves have been used for estimating sediment discharges from large watersheds (Livesey 1975; Elliott and DeFeyter 1986; Hansen and Bray 1993) and small-to-medium-size watersheds (Piest 1963; Sidle and Campbell 1985; Lopes and Ffolliott 1993b). These curves can be used along with streamflow-frequency data (flow duration curves) to calculate sediment yields by the flow duration–sediment-rating curve method (Crawford 1991). Since little is known about the sediment transport regime on ponderosa pine and piñon-juniper watersheds of north-central Arizona, the objective of this study was to evaluate the applicability of the sediment-rating curve method to estimate the impacts of vegetative practices on sediment discharges from ponderosa pine and piñon-juniper watersheds in north-central Arizona.

STUDY AREA

The Beaver Creek watersheds, encompassing 100,000 ha on the Coconino National Forest in north-central Arizona, are about 80 km south of Flagstaff, in the Salt-Verde River Basin of the Colorado Plateau physiographic province. The Salt-Verde River Basin is a major surface-water production area in north-central Arizona. Ponderosa pine forests and piñon-juniper woodlands occupy nearly 50% of the basin. Ponderosa pine watersheds yield nearly 50% of the total streamflow in the basin, and piñon-juniper watersheds yield approximately 10% (Barr 1956). The watersheds studied were chosen because they were representative of extensive areas of ponderosa pine forests and piñon-juniper woodlands found in the southwestern United States. Descriptions of the habitats of the tree species, overstory density conditions, and growth and yield characteristics of the ponderosa pine forests and piñon-juniper woodlands on these watersheds have been presented earlier by Brown et al. (1974), Clary et al. (1974), Ffolliott and Thorud (1975), and Baker (1982).

Topography of Beaver Creek watersheds includes plateaus, sloping mesas and breaks, steep canyons, and valleys. Underlying bedrock consists of igneous rocks of volcanic origin, with sedimentary rocks of Kaibab, Coconino, and Supai Formations below them. The soils, developed on basalts and cinders, are mostly silty clays and silty clay loams (Williams and Anderson 1967). The clays are primarily montmorillonite, which swell and shrink during each wet and dry cycle (Baker 1984), but long-term permeability rates of the A horizon can be 1–5 $mm \cdot h^{-1}$. Infiltration rates range between 2.0 and 6.4 $mm \cdot h^{-1}$ (Baker 1982). Stream channels have a southwesterly aspect and range in elevation from almost 1,000 to 2,450 m.

Precipitation varies from year to year, a characteristic of the precipitation regimes in the arid and semiarid southwestern

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United States. On the average, high elevation ponderosa pine forests receive between 500 and 635 mm, and the piñon-juniper woodlands about 450–500 mm, a year as rain and snow. The most important precipitation, from a streamflow-generating standpoint, is that originating from the 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, largely in March or April. However, annual snowpack accumulations are variable, and therefore result in variable patterns and amounts of runoff (Ffolliott et al. 1989). Average winter runoff accounts for 85% of the total annual water yield (Brown et al. 1974; Baker 1982). Suspended sediment discharges are 75–80% of the total sediment discharge from the watersheds studied (Brown et al. 1974; Lopes and Ffolliott 1993b).

VEGETATIVE TREATMENTS

Twenty watersheds were established between 1957 and 1962 to evaluate the effects of vegetative management practices on water yields, sediment discharges, and other natural resources (Brown et al. 1974; Clary et al. 1974). Of the 20, 18 were "experimental watersheds" from 26 to 824 ha in size; 12 were in the ponderosa pine type of forest, three were in the alligator juniper type, and three were in the Utah juniper type. An array of uniformly imposed vegetative treatments designed largely to increase water yields and other multiple use values were tested on these watersheds. The other two basins —encompassing 4,900 and 6,650 ha—were set aside to demonstrate the effects of vegetation management practices on areas of the size that managers work with operationally. Data from three experimental watersheds in ponderosa pine forests and three experimental watersheds in the Utah juniper type were analyzed in this study.

Ponderosa Pine Watersheds

Two general types of vegetative treatments were evaluated on the watersheds in ponderosa pine forests—creation of cleared openings in the forest overstories and reductions in forest overstory density levels. WS 12 (184 ha) was completely cleared. All merchantable timber was removed and the remaining nonmerchantable wood was felled in 1966–67. Residual slash and debris were machine windrowed to trap and retain snow, reduce evapotranspiration losses, and increase surface drainage efficiency. The windrows were subsequently burned in 1977 to determine whether their removal had any influence on water yield (Baker 1983). Ponderosa pine and intermingling minor tree species, dominantly Gambel oak and alligator juniper, were allowed to sprout or seed themselves and grow following the clearing treatment. Because the hydrologic changes caused by the clearing treatment cannot be separated from those caused by the windrows, the treatment evaluated on this watershed consists of complete forest clearing, soil disturbances due to timber harvesting, and the creation windrows (Baker 1986a). This clearing treatment, representing the most drastic form of vegetative practice considered in a ponderosa pine forest, resulted in an average increase in annual water yield of nearly 30% (44.5 mm) for seven years after the treatment, at which time posttreatment response became hydrologically insignificant.

On WS 14 (546 ha), 33% of the ponderosa pine forest was cleared in 1970 in irregular strips averaging 18 m wide. Slash and debris were piled and burned in the cleared strips. The forest overstory in the intervening leave strips, which averaged 37 m wide, was reduced by thinning to about 25% or 18 $m^2 \cdot ha^{-1}$ of basal area, a density level thought to be optimal for subsequent growth (Baker 1986a). Overall, 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 mm) in the first four posttreatment years, after which the response was insignificantly low or negative.

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

Piñon-Juniper Watersheds

Treatments in the piñon-juniper watersheds consisted of converting the woodland overstories to covers of less water-consuming herbaceous plants. However, the conversion treatments studied were carried out by different means. 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 was seeded with a mixture of forage species (Clary et al. 1974). This treatment did not result in significant changes in annual water yields.

On WS 3 (147 ha), a mixture of picloram (2.8 $kg \cdot ha^{-1}$) and 2,4-D (5.6 $kg \cdot ha^{-1}$) was applied by helicopter to 114 ha in 1968. Trees on the remaining 33 ha were either not treated or were sprayed with a backpack mist blower. The intent of this treatment was to reduce transpiration losses by killing trees, reducing evaporation losses from the soil by leaving the dead trees to provide shade, and reducing the amount of overland water flow trapped in the pits created when trees are uprooted by cabling (Baker 1984). The treatment resulted in a significant increase in annual water yields of about 160% (4.4 mm) for eight posttreatment years. The residual dead trees were then removed.

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.

ANALYTICAL PROCEDURES

Acquisition of Data Sets

Suspended sediment concentration and streamflow data obtained from 1974 through 1982 were the source data used in this study. Data sets reflecting immediate impacts of the vegetative practices on the respective sediment regimes were excluded from the analysis to describe long-term impacts of vegetative practices on sediment concentrations. Sediment samples obtained through grab samples, a DH-48 hand sampler, or automated pump were analyzed by filtration to determine sediment concentrations. Streamflow was measured in concrete trapezoidal flumes (Baker 1986b). 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 were collected for streamflow discharges in excess of 0.05 $m^3 \cdot s^{-1}$ and at time intervals greater than 1 h to reduce possible effects of serial correlation.

The following three types of events served as the basis for studying the effects of streamflow-generation mechanisms on sediment concentrations:

- Type 1—snowmelt-runoff events not preceded by precipitation, relatively slow response time to peak streamflow discharge, streamflow duration of several days or weeks, occurs in late winter to early spring.

- Type 2—high intensity, short-duration, mostly convectional rainfall events; rapid response time to peak streamflow discharge; streamflow duration of hours or a few days; occurs in late summer to early fall.
- Type 3—low-intensity, relatively long duration, essentially frontal rainfall events, mostly in the late fall and winter months; insignificant snow accumulations on the ground; moderate response time to peak streamflow discharge.

Event types 1 and 3 generated most of the streamflow events studied in the ponderosa pine forests, while event types 1 and 2 resulted in most streamflow events studied in the piñon-juniper woodlands. Rain-on-snow events, while major events in north-central Arizona when they occurred, represented less than 10% of the individual streamflow-generation mechanisms on the watersheds studied, and therefore were excluded from this analysis.

Derivation of Sediment-Rating Curves

A sediment-rating curve consists of a graph or equation relating sediment discharge or concentration to streamflow discharge. A study by Campbell and Bauder (1940) on the Red River in Texas provided an early documented example of the use of sediment-rating curves in the United States. The sediment-rating curve technique has been widely applied since in estimating sediment discharges for both large watersheds (Livesey 1975; Elliott and DeFeyter 1986) and small- to medium-size watersheds (Piest 1963; Sidle and Campbell 1985; Lopes and Ffolliott 1993b). Sediment-rating curves can be derived using either instantaneous or daily suspended sediment concentrations and streamflow discharge measurements; instantaneous data were used in this study.

Sediment-rating curves used in this study were derived by linear least squares of logarithmically transformed data. However, logarithmic transformation of data can result in bias when regression estimates are detransformed. Transformation bias is greater when the data sets are characterized by a relatively large number of measurements at low streamflow discharges, and when the variance is relatively large (Jansson 1985). However, if the curves are fitted through the points at the high end of the sediment-rating curves and the variance of the residuals is small, errors in estimating sediment concentrations caused by this bias should be small (Jansson 1985; Glysson 1987). In this study, a correction factor proposed by Duan (1983) was used to eliminate a major portion of the bias (Koch and Smillie 1986; Crawford 1991). The curves were expressed in the general form of a power equation

$$C = aQ^b \quad (1)$$

where C = suspended sediment concentration; Q = streamflow discharge; and a, b = constants for a particular stream. Multiplying both sides of (1) by Q, the suspended sediment discharged Q_s is obtained

$$Q_s = kaQ^{b+1} \quad (2)$$

where k contains the necessary unit conversions, and all other terms are as previously described.

Partitioning of Data Sets

Because of the differing significance of streamflow-generation mechanisms in the two vegetative types studied, and of the nature and relative severities of the treatments imposed on the two types, the data sets from the two vegetative types were analyzed separately. Derivation of sediment-rating curves began with the complete data set for each of the watersheds studied in the two vegetative types.

The data sets were subsequently partitioned into smaller data sets, initially by the types of streamflow-generation mechanisms (event types 1, 2, and 3), and then by hydrograph stage (rising stage and falling stage). These partitionings were made to account for two major influences on the sediment-rating curves—streamflow-generation mechanisms and variations in sediment discharge carried at similar streamflow discharges for the rising and falling limbs of the hydrograph (Walling 1977).

All pairs of data were weighed equally in deriving the sed-

TABLE 1. Sediment-Rating Curve Parameters, with 95% Confidence Limits, Standard Errors, Coefficients of Determination, and F Statistics, for Ponderosa Pine Watersheds

Watershed (1)	Event type (2)	N (3)	a (4)	95% Confidence Intervals: Group 1 (5)	95% Confidence Intervals: Group 2 (6)	b (7)	95% Confidence Intervals: Group 1 (8)	95% Confidence Intervals: Group 2 (9)	Standard error (SE) (10)	r^2_a (11)	F statistics (12)	Significance (13)
12	All	353	154.579	121.667	196.413	1.042	0.947	1.137	125.97	0.57	468.54	**
	1	326	155.234	120.370	200.224	1.066	0.964	1.167	125.39	0.57	426.87	**
	1r	148	170.847	114.559	254.700	1.027	0.877	1.177	169.38	0.55	182.82	**
	1f	131	141.415	99.093	201.393	1.198	1.058	1.399	64.91	0.69	282.32	**
	3	26	162.577	83.813	315.726	0.865	0.634	1.097	135.65	0.70	59.38	**
	3r	12	175.942	46.664	663.722	0.880	0.693	1.267	182.39	0.69	25.69	**
	3f	14	127.938	14.280	14.280	0.746	0.287	1.205	98.82	0.47	12.55	**
13	All	204	28.679	21.804	37.717	0.677	0.579	0.766	61.40	0.47	183.40	**
	1	179	26.272	19.909	34.678	0.665	0.560	0.770	64.44	0.47	156.44	**
	1r	44	39.853	15.288	103.837	1.030	0.745	1.315	94.37	0.55	53.35	**
	1f	71	21.670	12.754	36.782	0.608	0.425	0.790	56.86	0.38	44.01	**
	3	25	—	—	—	—	—	—	—	—	—	NS
	3r	8	76.552	10.800	121.456	0.537	0.512	1.164	24.14	0.46	6.94	**
	3f	12	36.196	44.945	70.906	0.938	0.886	1.062	73.24	0.74	32.77	**
14	All	473	56.590	43.335	68.681	0.974	0.919	1.097	74.94	0.50	475.87	**
	1	432	74.788	75.944	112.071	1.008	1.019	1.294	97.63	0.53	494.69	**
	1r	140	44.905	30.817	65.431	1.156	0.740	1.018	46.72	0.66	276.26	**
	1f	154	80.902	42.763	153.134	0.879	0.314	0.815	50.12	0.50	156.45	**
	3	41	112.158	54.425	231.101	0.578	0.245	0.746	55.15	0.37	24.31	**
	3r	20	—	—	—	—	—	—	—	—	—	NS
	3f	9	—	—	—	—	—	—	—	—	—	NS

Note: All = sediment-rating curve using all measurements; 1, 2, 3 = event types 1, 2, and 3, respectively; r = rising stage of event hydrograph; f = falling stage of event hydrograph; NS = not significant; N = sample size; ** = regression significance at $\alpha = 0.05$; F statistic—equation significant at $\alpha = 0.05$.

TABLE 2. Sediment-Rating Curve Parameters, with 95% Confidence Limits, Standard Errors, Coefficients of Determination, and F Statistics, for Piñon-Juniper Watersheds

Water-shed (1)	Event type (2)	N (3)	a (4)	95% Confidence Intervals Group 1 (5)	95% Confidence Intervals Group 2 (6)	b (7)	95% Confidence Intervals Group 1 (8)	95% Confidence Intervals Group 2 (9)	Standard error (SE) (10)	r_a^2 (11)	F statistics (12)	Signifi-cance (13)
1	All	525	7.362	5.297	10.257	0.233	0.143	0.324	7.03	0.05	39.33	**
	1	429	6.982	4.831	10.069	0.216	0.114	0.318	7.37	0.04	17.26	**
	1*r*	93	66.222	26.122	105.925	0.779	0.632	0.956	9.79	0.54	11.01	**
	1*f*	333	—	—	—	—	—	—	—	—	—	NS
	2	90	6.668	3.013	14.757	0.231	0.025	0.438	4.17	0.04	4.94	**
	2*r*	20	38.905	10.116	149.624	0.529	0.190	0.868	2.92	0.34	10.77	**
	2*f*	70	—	—	—	—	—	—	—	—	—	NS
2	All	519	5.129	3.664	7.161	0.193	0.112	0.274	2.98	0.04	22.01	**
	1	448	4.335	3.013	6.237	0.168	0.081	0.256	3.13	0.03	14.24	**
	1*r*	153	13.772	6.730	28.119	0.438	0.253	0.625	4.23	0.12	21.82	**
	1*f*	288	—	—	—	—	—	—	—	—	—	NS
	2	65	14.125	6.124	32.509	0.363	0.157	0.568	2.74	0.15	12.37	**
	2*r*	12	16.672	10.789	25.763	0.172	0.073	0.270	1.22	0.51	15.16	**
	2*f*	53	29.923	—	—	0.613	—	—	—	0.46	45.88	**
3	All	611	8.091	5.916	11.066	0.245	0.168	0.321	4.67	0.06	25.76	**
	1	572	8.147	5.984	11.092	0.244	0.168	0.320	4.95	0.06	40.13	**
	1*r*	203	29.174	17.179	49.431	0.547	0.408	0.685	6.66	0.23	60.46	**
	1*f*	362	4.457	3.097	6.412	0.120	0.034	0.206	2.31	0.02	7.48	**
	2	33	—	—	—	—	—	—	—	—	—	NS
	2*r*	9	—	—	—	—	—	—	—	—	—	NS
	2*f*	23	—	—	—	—	—	—	—	—	—	NS

Note: All = sediment-rating curve using all measurements; 1, 2, 3 = event types 1, 2, and 3, respectively; r = rising stage of event hydrograph; f = falling stage of event hydrograph; NS = not significant; N = sample size; ** = regression significance at $\alpha = 0.05$; F statistic—equation significant at $\alpha = 0.05$.

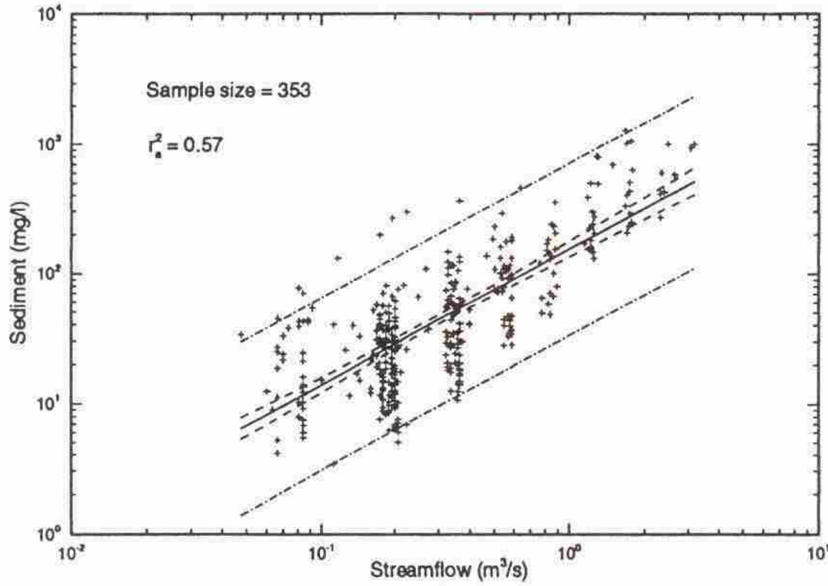

FIG. 1. Sediment-Rating Curve (Solid Line) and 95% Confidence (Dashed Lines) and Prediction (Dashed-Dotted Lines) Intervals for Completely Cleared Ponderosa Pine Watershed (WS 12)

iment-rating curves. (That is, a data pair for measurements made during a high-flow discharge was assigned the same weight in deriving a sediment-rating curve as a data pair for measurements made during a low-flow discharge.) Parameters a and b of the sediment-rating curves for the ponderosa pine watersheds and the piñon-juniper watersheds, with the 95% confidence limits, fitted standard errors, coefficients of determination, and F statistics, are presented in Tables 1 and 2, respectively. The low values of the coefficient of determination for the piñon-juniper watersheds are due to insufficient data at the high streamflow range. Figs. 1 and 2 illustrate sediment-rating curves and 95% confidence and prediction levels for the completely cleared (WS 12) and control (WS 13) ponderosa pine watersheds; once again, the former represents the extreme in terms of soil disturbance, whereas the latter had not been disturbed since the early 1950s.

COMPARATIVE ANALYSIS AND DISCUSSION

A hierarchical statistical test was performed at three different levels to compare groups of sediment-rating curves. The purpose of the test was to determine the significance of changes in explained variations of sediment concentrations, expressed in terms of R^2, at the watershed level, streamflow-generation level, and hydrograph-stage level. The null hypothesis at each level was that the parameters a and b of two sediment-rating curves had not changed when the data sets were disaggregated. This null hypothesis was formulated as

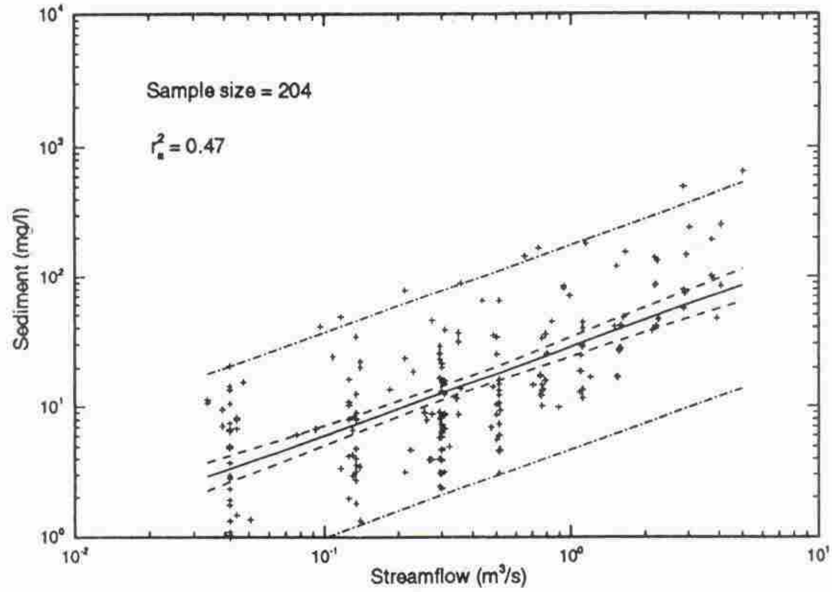

FIG. 2. Sediment-Rating Curve (Solid Line) and 95% Confidence (Dashed Lines) and Prediction (Dashed-Dotted Lines) Intervals for Control Ponderosa Pine Watershed (WS 13)

$$H_0: a_1 = a_2 = \cdots = a_m; \quad b_1 = b_2 = \cdots = b_m \qquad (3)$$

where m = number of equations tested. At each level, the "Chow test" (Kmenta 1986) was performed in a pair-wise fashion to test the null hypothesis that the parameters (a and b) of two sediment-rating curves had not changed significantly (at the 95% level of significance) due to partitioning. Test results are shown in Tables 1 and 2 for the ponderosa pine and piñon-juniper watersheds, respectively.

Ponderosa Pine Watersheds

Watershed Level

There were significant differences in the sediment-rating curves among the treated watersheds and the control watershed (WS 13). These differences indicated that for similar stream 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 strip-cut watershed were higher than those from the control watershed.

WS 12 experienced extensive watershed-wide soil disturbance from the complete clearing of the overstory trees, the simultaneous breaking up of the herbaceous ground cover by the clearing operation, and the 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 part of the disturbance on WS 14 occurred on the 33% of the watershed that was cut into irregular strips, where much of the protective herbaceous plant cover was destroyed, 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 yielding on WS 14 took place.

Streamflow-Generation Level

Two types of streamflow-generation mechanisms were considered in the ponderosa pine watersheds—snowmelt runoff (type 1) and frontal rainfall (type 3). Sediment-rating curves derived at the watershed level were not significantly different from those derived for frontal rainfall events for WS 13, but they were different for WS 12 and WS14. This result was expectable, as the process of dislodging and transporting soil particles by low-intensity, relatively long duration, frontal rainfall events (type 3) is ineffective on vegetated watersheds (WS 13). It follows that estimates of sediment concentrations from sediment-rating curves for the ponderosa pine watersheds are improved by separating sediment data derived from snowmelt runoff from those derived from the complete data sets.

Hydrograph-Stage Level

The hydrographs were partitioned into rising stage and falling stage to investigate the effect of hydrograph stage on sediment concentration–streamflow discharge relations. This separation was made to evaluate the commonly reported observation that the rising stage of a hydrograph is generally associated with higher rates of suspended sediment transport than is the falling stage (Elliott and DeFeyter 1986; Glysson 1987; Brooks et al. 1997).

The results from the ponderosa pine watersheds indicated a greater difference between sediment-rating curves derived after the data sets were partitioned into rising-stage and falling-stage hydrographs. Sediment concentrations for the rising stage of a hydrograph were generally higher than those for the falling stage. This reinforced the previous findings that higher rates of sediment transport during stormflow events are found with the rising limb of a hydrograph, and that the amount of sediment in suspension drops after the flood peak passes.

Piñon-Juniper Watersheds

Watershed Level

There were differences in the sediment-rating curves among the treated piñon-juniper watersheds and the control watershed (WS 2). The main difference was higher sediment concentrations from the cabled watershed than from the control watershed for similar streamflow discharges. The higher concentrations of suspended sediment on WS 1 were likely a reflection of the soil disturbances caused by uprooting trees in the cabling treatment (Clary et al. 1974). Earlier studies on Beaver Creek also indicated that the uprooting of piñon and juniper trees by cabling can increase soil loss by the resultant overland flow (Skau 1960, 1961).

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

Streamflow-Generation Level

There were significant differences in the sediment-rating curves derived from the total data sets and the curves derived from the data sets after they had been partitioned by streamflow-generation mechanisms for WS 1 and WS 2. However, there was no significant difference in sediment concentration when streamflow-generation mechanisms were considered on WS 3. Similar to observations on the ponderosa pine watersheds, a large portion (85%) of the data sets were associated with snowmelt-runoff events; therefore, these latter events dominated the statistical properties.

Hydrograph-Stage Level

Sediment-rating curves derived from data sets partitioned into rising-stage and falling-stage hydrographs were different from those derived at the streamflow-generation levels of analysis for convectional rainfall events (type 2) on WS 2 and snowmelt-runoff events (type 1) on WS 3. There were no differences between suspended sediment concentration for the rising and falling limbs of the hydrograph for the other cases. Therefore, with the exception of hydrographs generated by convectional rainfall events (type 2) on WS 2 and by snowmelt-runoff events (type 1) on WS 3, results from the piñon-juniper watersheds do not support the often-stated hypothesis that higher rates of sediment transport during stormflow events are found with the rising limb of a hydrograph.

CONCLUSIONS

The following conclusions may be drawn from the present research:

1. Soil disturbances from implementing vegetative practices on watersheds in both ponderosa pine forests and piñon-juniper woodlands generally increase sediment concentrations significantly above those of control watersheds. This response is reflected by their respective sediment-rating curves.
2. Completely cleared and strip-cut ponderosa pine watersheds produced higher suspended sediment concentrations than did the control watershed. Likewise, cabled and herbicide-treated piñon-juniper watersheds yielded higher sediment-laden streamflows than did the control.
3. Although about 85% of the data analyzed in this study represented snowmelt-runoff events in both vegetative types, derivation of sediment-rating curves based on streamflow-generation mechanisms improved the sensitivity of the analysis. This improvement was especially true for watersheds that had higher levels of disturbance.
4. Sediment data collected during the rising and falling stages of the hydrographs varied between the two vegetative types. Sediment concentrations were generally higher in the rising stage than in the falling stage for ponderosa pine watersheds. There was no clear evidence of higher sediment concentrations in the rising stage of the hydrograph as compared to the falling stage in the piñon-juniper watersheds.

APPENDIX. REFERENCES

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