

Hydrologic Impacts of Oak Harvesting and Evaluation of the Modified Universal Soil Loss Equation¹

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Abstract: Two Sierra foothill watersheds were monitored to learn what effects selective oak removal would have on watershed hydrology and water quality. We also used the data to generate sediment rating curves and evaluate the modified universal soil loss equation (MUSLE). Annual sediment rating curves better accounted for the variability in precipitation events from year to year, which may be at least as important as total rainfall, on the amount of runoff and sediment yield. Measurements before and after oak removal indicated small but not statistically significant increases in the runoff/rainfall ratio and fewer tons of sediment leaving the watershed after cutting. The MUSLE predicted quite accurately when calibrated for these watersheds.

Resource agencies, professionals and the public, concerned with soil erosion, water quality and maintenance of wildlife habitat, have been alarmed about the potential loss of valuable oak stands due to commercial firewood harvesting or to land clearing practices (Passof and others 1985).

Accelerated erosion in the wake of efforts at improving water yields through vegetative type conversion has been a major problem (Pitt and others 1978; Rice 1974). Rowe and Reimann (1961) concluded that the amount of increase in water yield obtained depends on depth and storage capacity of the soil, amount and distribution of annual rainfall, as well as the vegetation occupying the site before and after conversion. Furthermore, any disturbance that increases runoff and subsequently flow rate should also effect the rate of sediment movement within the watershed (Flaxman 1974).

Analytical tools for measuring erosion and sediment yield can be valuable aids to assess the changes brought about by vegetation manipulation. The importance of water quality planning as a result of section 208 of the Federal Water Pollution Control Act of 1972 and additional pressures for more intensive management of western rangelands has created the need for soil erosion and sediment yield models. An important need can be met by coupling a hydrologic model to water quality data for validation and improvement. The Modified Universal Soil Loss Equation (MUSLE) is a logical place to start for rangeland use. Williams (1975) modified the USLE to predict sediment yield

for watersheds by replacing the rainfall energy factor with a runoff energy factor. The runoff factor represents energy used in transporting as well as in detaching sediment.

This investigation addresses three oak management issues: 1) Does selective oak harvesting result in increased water yield? 2) Is water quality lowered by the addition of sediment after selective harvesting? 3) Can the processes be modeled and predictions be generated which accurately answer these questions?

STUDY SITE

The study area is part of the University of California Sierra Foothill Range Field Station (SFRFS) located 60 miles (96 km) northeast of Sacramento. The 64 acre (26 ha) Schubert 1 (S1) and 254 acre (103 ha) Schubert 2 (S2) Watersheds are representative of the oak-woodland rangeland on the lower western slopes of the Sierra Nevada. Precipitation is dominated by low intensity, short duration rainfall from about October 1 to March 30. Average annual rainfall for the last 20 years has been 29 inches (732 mm).

Elevation ranges from 500 ft to almost 1400 ft (152 m to 427 m) above sea level with 2 to 50 percent slopes. The watersheds have ravines containing both ephemeral (S 1) and perennial (S2) streams that are tributary to the Yuba River below Englebright Reservoir. Soils are red, medium textured, gravelly and rocky, shallow to moderately deep, in the Auburn-Sobrante-Las Posas Association.

PROCEDURE

Oaks were clearcut from small selective stands on 44 percent of the 64 acre Schubert 1 beginning January 1984 and ending May 1985. Oaks were similarly cleared from about 14 percent of the 254 acre Schubert 2 beginning July 1984 and ending May 1986. Approximately 831 trees on S 1 and 1350 trees on S2 were harvested. Cutting and removal of the trees was done primarily during the dry summer months to minimize watershed disturbance. Average blue oak density, at sites representative of the areas harvested was 68 trees per acre.

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Water measurements began in 1980 before the selective removal of oak trees. Two rain gauges measure precipitation. Each stream is equipped with a Parshall flume for measuring the quantity and flow rate of runoff from high flows and a 90° "V" notch weir for measuring low flows. Automatic water samplers installed upstream from the waterflow gages periodically collect water samples for suspended sediment concentration determination.

Sediment-rating curves for computing annual sediment yield as a function of runoff volume were estimated by linear regression analysis.

The Modified Universal Soil Loss Equation (MUSLE) was evaluated by calibrating the MUSLE coefficients for the Schubert Watersheds. Measured sediment yield values were compared to estimated values using calibrated and published coefficients. Published MUSLE coefficient $\alpha=95$ and $\beta=0.56$ were used as specified in the USDA-SCS (1980) Geology Note No. 2 for predicting the concentration of fine sediment in short tons from channels for single-storm events.

Data for every other storm throughout the year was fit to the model and put through a calibration procedure. The procedure rests heavily on linear regression analysis after logarithmic transformation of the original MUSLE to determine a best fit series of model coefficients for the storms. The remaining half of the measured sediment data was used for validation of the calibrated equation. A paired t-test determined the strength of the null hypothesis that the mean differences between the measured and the predicted storm sediment using both the calibrated and published parameters was equal to 0.

The equation's USLE factors were obtained using appropriate guides (USDA-SCS, 1977; and Wilson, 1986). Curve generation and MUSLE evaluation were conducted using Statistical Analysis Systems (SAS) programs (Ray 1982) and the standard linear regression procedures outlined in Affifi and Clark (1984) and Neter and Wasserman (1974).

RESULTS AND DISCUSSION

Runoff and Sediment Yield

A comparison of post-cut measured runoff values with those estimated by simple linear regression of pre-cut runoff on rainfall indicated no significant difference (95 percent confidence level) in the annual runoff response after harvesting. Comparisons between similar years show an apparent increase in runoff for the same rainfall on Schubert 2 after oak harvest. In the 1980-81 pre-cut year, 21 inches of precipitation generated 3 inches of runoff, while in the 1987-88 post-cut year, 19 inches produced 11 inches of runoff (table 1).

A possible reason for the higher runoff in the post-cut year may not be cutting, but rather the distribution of rainfall, particularly the "priming" effect of the November and December storms which were followed by heavy rainfall in January. The

early winter storms refilled the depleted soil moisture storage so the January precipitation quickly saturated the soil and produced runoff.

Fewer tons of sediment left Schubert 2 after cutting and tons per inch of runoff decreased about 60 percent (table 1) but the difference was not statistically significant. Year-to-year comparisons between similar rainfall years are less clear for sediment production than for runoff. The distribution and intensity of precipitation events may be at least as important as total rainfall in determining sediment yield. In the post-cut year 1987-88, tripling the runoff tripled the total sediment load compared with the sediment load for the pre-cut year 1980-81 (Table 1). But the 35 percent greater runoff in 1988-89 produced nearly 2 tons less sediment than the pre-cut 1983-84 year.

Sediment Rating Curves

Equations 1 and 2 are the rating curves for the combined 1981-1986 water years on Schubert 1 and 2, respectively. The value 0.2 was added to all Schubert 2 suspended sediment concentration (C_s = milligrams per liter) values so that real values equal to 0, which have no logarithmic equivalent, would not be lost from the data base. The value 0.02 was added to the runoff volume (cfs = cubic feet/second) data to compensate for the adjustment to the C_s data. Both values are the smallest measured C_s and cfs values.

$$\begin{array}{ll} \text{SCHUBERT 1 RATING CURVE} & (\text{Eq. 1}) \\ \log_{10}(C_s) = 1.6 + 0.5 \log_{10}(cfs) \end{array}$$

$$\begin{array}{ll} \text{SCHUBERT 2 RATING CURVE} & (\text{Eq. 2}) \\ \log_{10}(C_s+0.2) = 1.2 + 0.8 \log_{10}(cfs+0.02) \end{array}$$

On Schubert 1 and 2, respectively, 43 percent and 48 percent of the variation in the sediment concentration was explained by the runoff volume for water years 1981-1986 as indicated by the coefficient of determination (r^2) from regression analyses (table 2). Often, separate curves for individual years performed better than one curve for all six years on each watershed. For example, r^2 was 0.80 for 1980-81 and 0.73 for 1984-85 (table 2). As a result, separate rating curves for individual years were chosen for estimating the suspended sediment concentration from runoff.

MUSLE Evaluation

The residual plot of sediment yield predicted by the calibrated MUSLE indicated multiplicative error terms or an increase in the error variance as the predicted values increased. As a result, the model was logarithmically transformed and a linear regression method for a least squares estimate of single-storm sediment yield was employed (Eq. 3). The USLE C, P and K factors were held constant at 0.003, 1.0 and 0.4, respectively, for calibrating the MUSLE. LS values used were 8.44 for S1 and 8.96 for S2.

Table 1—Annual rainfall (RF), runoff (RO), runoff/rainfall ratio (ROIRF), total suspended sediment load (SED), and total suspended sediment load/runoff (SED/RO) for Schubert 2 Watershed, Sierra Foothill Range Field Station, 1980-1989.

Year	RF	RO	RO/RF	SED	SED/RO
	in/yr		short tons		
PRE-CUT					
80-81	21	3	0.14	1	.33
81-82	47	26	0.55	32	1.23
82-83	40	31	0.78	25	.81
83-84	29	14	0.48	12	.86
MEAN	34	18	0.49	18	.81
POST-CUT					
84-85	18	7	0.39	2	.29
85-86	33	21	0.64	8	.38
86-87	13	10	0.77	10	1.00
87-88	19	11	0.58	3	.27
88-89	28	19	0.68	10	.53
MEAN	22	14	0.61	6	.49
9-Yr MEAN	28				
20-Yr MEAN	29				

NOTE: Rainfall and runoff values are rounded to the nearest whole numbers.

$$\log_{10} (Y/k) = \log_{10} (\alpha) + \beta \log_{10} (Q * q_p) \quad (\text{Eq. 3})$$

Y=sediment yield from the basin (tons);

Q=storm-event surface runoff volume (ft³);

q_p storm-event peak flow rate (ft³/s);

k=USLE K, C, P, and LS factors;

α,β=coefficients.

For all years, comparing MUSLE estimates with measured values, equations 4, 5, and 6 gave the highest correlation (r² values were 0.90 and higher) on Schubert 1, 2 and the combined watersheds, respectively. The percentage error of the average estimate is 50 percent, 36 percent and 74 percent of the dependent variable's mean, respectively, for Schubert 1, 2 and the combined watersheds. The significant difference (99 percent

Table 2—Number of observations (n), and Coefficients of determination (r²) and variation (CV) for a simple linear regression of suspended sediment on runoff for Schubert 1 and 2, Sierra Foothill Range Field Station.

Year	n	r ²	CV (percent)
SCHUBERT			
1981-86	259	.43	48
1980-81	9	.80	24
1981-82	59	.44	51
1982-83	87	.39	46
1983-84	14	.73	62
1985-86	32	.38	40
SCHUBERT 2			
1981-86	585	.48	60
1980-81	49	.74	40
1981-82	85	.81	43
1982-83	94	.44	44
1983-84	201	.26	65
1984-85	74	.28	69
1985-86	82	.40	51

Table 3—Comparison of Schubert 2 annual storm sediment yield measured with the amount estimated using the published and calibrated MUSLElog₁₀ (Y/k+1)=log₁₀ (1.1) + 0.78 log₁₀ (Q*q_p +1). Sierra Foothill Range Field Station, 1980-86.

	Measured	MUSLE Published	MUSLE Calibrated
	Short Tons		
MEAN	.49	9.4	.45
Standard Deviation	1.4	21.9	1.4
Standard Error of Estimate		2.3	.04
Paired T-test probability ¹		.0002	.35*
r ² (for Y & O(Y,)) ²		.96	.92

¹(*) indicates no significant difference (99.5 percent confidence level) between means of measured and estimated yields

²Coefficient of Determination for means of measured (Y) and estimated (O(Y,)) yields

confidence level) between the calibrated coefficients and the published coefficients, α = 95 and β = 0.56 is related to the difference in watershed characteristics and the erosion rates of the sites presently investigated and those previously studied.

$$S1 \ Y = 2.1 (Q * q_p)^{0.76} k \quad (\text{Eq. 4})$$

$$S2 \ Y = (1.1 (Q * q_p + 1)^{0.78} - 1) k \quad (\text{Eq. 5})$$

$$S1 \& 2 \quad Y = 1.7 (Q * q_p)^{0.70} k \quad (\text{Eq. 6})$$

The mean differences between the measured and estimated storm sediment yield using the calibrated equation for Schubert 2 was not statistically significant as indicated by paired T-test results shown in table 3. Whereas, the mean difference between the measured and estimated storm sediment yield using the published MUSLE was significantly different (99.5 percent). On S2, the published MUSLE overestimated the storm sediment by about 1900 percent.

Table 4—Measured sediment yield for several single-storm events and the yields estimated using the published and calibrated MUSLE for Schubert 2 Watersheds, Sierra Foothill Range Field Station, 1980-86. Runoff volume and flow rate are given for each event.

DATE	VOLUME RUNOFF	RUNOFF RATE	STORM SEDIMENT YIELD		
			Measured	Calibrated Estimate	Published Estimate
	(inches)	(ft ³ /sec)	(short tons)		
11-30-80	.02	.05	.000	.001	.15
01-26-81	7.86	2.97	.34	.15	6.65
03-15-81	.28	.42	.004	.002	.35
03-25-81	5.24	4.12	.23	.14	6.37
11-22-81	.09	.82	.002	.002	.27
11-27-81	1.24	1.42	.01	.02	1.56
12-31-81	1.44	2.75	.02	.03	2.46
02-13-82	37.94	33.10	3.97	3.44	61.99
01-22-83	31.45	21.50	1.95	2.12	43.82
11-23-83	13.08	16.80	1.31	.88	23.38
02-06-85	27.76	27.30	3.05	2.32	46.71
02-12-86	159.88	48.20	8.98	14.19	171.21
03-15-86	13.67	11.60	.44	.68	19.46

Table 4 shows that the calibrated MUSLE performed quite satisfactorily in predicting the sediment yield for single-storm events compared to the estimations made with the published coefficients. There may be a tendency for the calibrated equation to underpredict small storms and overpredict large ones which is the reverse of the findings reported by Johnson and others (1985).

CONCLUSION

No evidence was found supporting the hypothesis that carefully controlled oak removal increased runoff or sediment yield.

Annual sediment-rating curves performed better than a single curve generated to predict sediment over several years. This is to be expected since there is less variability in one year compared to a six-year average. Annual curves better account for the variability in the distribution and intensity of precipitation events from year to year, which may be at least as important as total rainfall, on the amount of runoff and sediment yield.

We have shown that the MUSLE is useful for predicting single-storm sediment yield and can be used by watershed planners and managers for predicting the effects of management options on water quality, within a reasonable degree of accuracy. However, the accuracy of the model is improved when calibrated for our particular watershed sites.

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