Sediment Rating Curves in Ephemeral Streams

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SEDIMENTATION data are essential for the planning, design, construction, and maintenance of watershed conservation and control measures. Such data are scarce for the arid and semiarid regions of the southwestern United States. The complexities of the hydrologic phenomena producing and moving sediment make interpretation of existing information difficult.

Two major types of runoff-producing storms occur in the southwestern area of the United States, and are known as convective storms and frontal storms. The convective storms (1, 2)° are generally of limited areal extent, short duration, and high short-term intensity. The frontal storms, in contrast, are generally of wide areal extent, low intensity, and long duration.

On the Walnut Gulch experimental watershed described below, most runoff results from convective thunderstorms. During its course downstream, runoff from a convective storm usually flows over dry alluvial streambeds. A large volume of water is lost by transmission losses (stream-bed absorption) which reduces the possibility of sediment movement from the watershed. Because of variations in the distance of channel traversed, as well as physical and hydrologic variability of the watershed, water-sediment relationships are extremely variable.

Description of Study Area

Walnut Gulch is a 58-sq mile ephemeral tributary of the San Pedro River in southeastern Arizona (Fig. 1). The elevation of the measuring station at the watershed outlet is approximately 4,200 ft above mean sea level, while elevations range to about 6,000 ft at the headwater. The mixed grass-brush area is typical of most of the rangelands in southeastern Arizona and southwestern New Mexico. Approximately two-thirds of the 14-in. annual precipitation occurs during the July-through-September period of convective thunderstorms and produces essentially all of the annual runoff. The remaining one-third of the precipitation occurs primarily as low-intensity rains of wide areal extent during the winter months. These winter storms have produced runoff on very small watersheds within Walnut Gulch but have not produced flows at the large watersheds.

A sediment-sampling program was initiated in 1963 at flumes Nos. 6 and 1 (Fig. 2) on the main stem of Walnut Gulch. Samples are collected at these stations at a section about 100 ft above the flume using a US D-49, US P-61, or a US D-48 hand sampler. Water discharge is measured with water-level recorders in Walnut Gulch critical-depth flumes (3, 4). These permanent control structures are especially designed to measure the "flashy" runoff from debris-laden and sediment-laden ephemeral streams such as Walnut Gulch.

Ephemeral streams such as Walnut Gulch offer many difficulties when attempting to determine sediment parameters. Water velocities are high and often near the critical-depth velocity in many channel segments. Water depths in the main channel often change rapidly in terms of feet per minute, thus making sampling at more than one cross section difficult. Debris loads in these streams are often very high. On flows early in the runoff season or on large flows from channel reaches with a long time lapse since the last previous big flow, the runoff front actually resembles a broom sweeping organic matter and debris which has accumulated on the dry bed. Under these conditions, the sampling program is very sporadic.

Rating curves for the suspended-sediment sampling stations are needed to eliminate extensive sampling programs. The total flow duration in a year is very short at many locations, generally totaling less than 100 hr. The sampling program under these conditions is often very sporadic. To insure continuous samples during a runoff event, personnel would have to be stationed at the site throughout the runoff season.

In most areas of the country, a water-sediment relationship for a gaging station can be developed by plotting water discharge versus sediment concentration on a log-log graph. The result of such a plot at the watershed outlet of Walnut Gulch is shown in Fig. 3 for samples collected in 1964. The least-squares regression line was found to be:

$$Y = 2.25\ X^{0.027} \quad [1]$$

with a correlation coefficient r of 0.0226, which is not significant at even the 5 percent level. Similar results were obtained at flume No. 6, although the correlation coefficient was 0.322, which was highly significant. The least-squares regression line for a plot similar to Fig. 3 was found to be:

$$Y = 0.592\ X^{0.166} \quad [2]$$

Samples collected consecutively during an individual runoff event seemed to agree very well and to define a suspended-sediment concentration graph that seemed reasonable.

Multiple Linear Regression

In an effort to relate some possible watershed and hydrologic variables to the observed sediment concentration ("sediment concentration" hereafter means "suspended sediment"), a stepwise, multiple-regression analysis was performed on the data. More specifically, a regression equation was developed relating the sediment concentration (the dependent variable) to the so-called independent variables believed to be necessary to describe the flow conditions at the time the sample was collected. The stepwise, multiple-regression procedure adds one independent variable at a time into the regression equation (5). It automatically selects the next variable in combination with those variables previously included in the regression that will reduce the unexplained variance the most in a single step. Output from the computer contains the regression equation applicable at each step.

Example:

$$Y = a_1 + b_1 X_1 \quad [3]$$

$$Y = a_2 + b_2 X_1 + c_2 X_2 \quad [4]$$

As shown in the example (equation [3]), the coefficients and the constant will change with the addition of each new variable (equation [4]).

It is entirely possible that a dependent variable is closely correlated with three independent variables, but could nevertheless not be predicted by a

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° Numbers in parentheses refer to the appended references.

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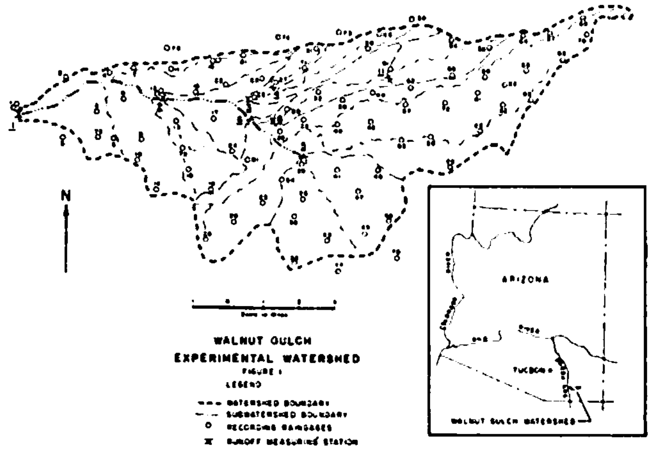

FIG. 1 Walnut Gulch experimental watershed.

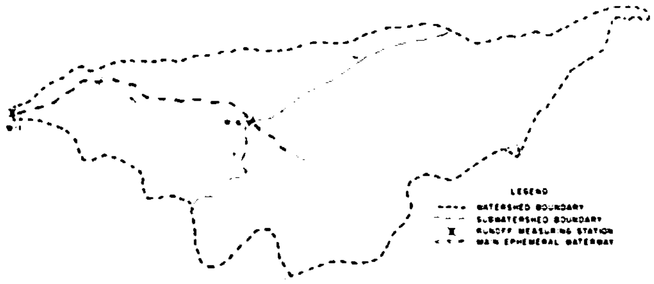

FIG. 2 Suspended sediment sampling stations on Walnut Gulch experimental watershed.

linear relationship such as that in equation [4]. The true relationship may rather be multiplicative, involving different exponents as shown in equation [5].

$$Y = aX_1^bX_2^cX_3^d \quad \ldots\ldots\ldots [5]$$

$$\log Y = \log a + b \log X_1 + c \log X_2 + d \log X_3 \quad \ldots\ldots\ldots [6]$$

Equation [6] shows how the multiplicative type of relationship can be evaluated using linear regression analysis. The variables (dependent and independent) for the analysis reported in this paper were transformed into logarithms before analysis, which results in the multiplicative form of equation [5] by taking the antilogarithm of equation [6]. The analyses were greatly facilitated by the use of electronic computers.

Eight independent variables were included in the analysis as follows:

X_1 lapse time from beginning of flow at sampling station until time at which the sample was collected, minutes

X_2, type of sample using the following coding:

1 for a depth-integrated sample from cableway
2 for a depth-integrated sample by wading
3 for a sample collected with the experimental pumping sampler of the Inter-Agency Sedimentation Project

X_3, rate of change of stage, which was taken as either positive or negative (+ on rising side of hydrograph) in ft per min

X_4, antecedent moisture conditions of channel alluvium. An exponential decay curve was used.

$$AM = \sum_{t=1}^{20} K^tQ_p^2 \quad \ldots\ldots [7]$$

where

K = 0.70 (arbitrary constant)
t = time to previous runoff in days
Q_p = peak discharge for flow on day t in cfs (cu ft per sec)

Q_p^2 was used for this variable because the area of channel wetted was much larger for the higher events, and it was believed that such an arbitrary procedure would better indicate true moisture levels.

X_5, distance in miles along the channel from the moving center of the runoff-producing thunderstorm (arbitrarily assumed as the rain gage with the maximum measured precipitation) to the runoff-measuring station.

X_6, peak discharge for the runoff event being sampled, cfs.

X_7, the storm position on the watershed in relation to vegetation cover. If the storm occurred on a brush area, it was assigned the No. 1; if on a grass area, it was assigned No. 3, and if it was on a mixed grass-brush area, the No. 2 was assigned.

X_8, water discharge as measured at the flume at the time the sediment sample was collected, cfs.

Five different dependent variables were used in the multiple-regression analysis as follows:

Y_1 = concentration of sand, percent by weight
Y_2 = concentration of silt, percent by weight
Y_3 = concentration of clay, percent by weight
Y_4 = $Y_1 + Y_2 + Y_3$ = total concentration
Y_5 = $Y_2 + Y_3$ = concentration of silt and clay.

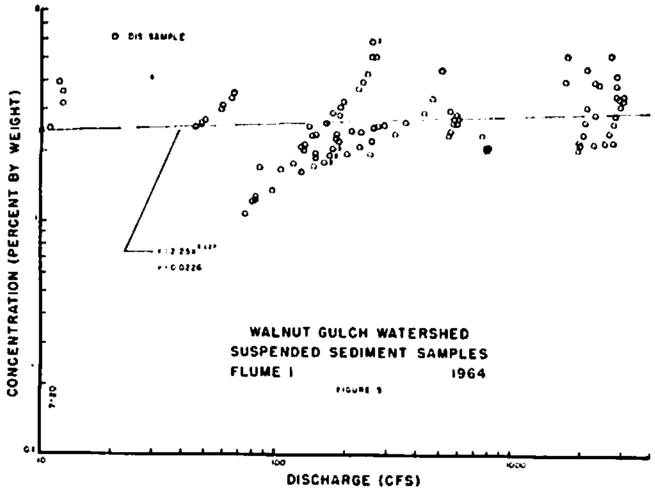

FIG. 3 Walnut Gulch watershed suspended-sediment samples, flume 1, 1964.

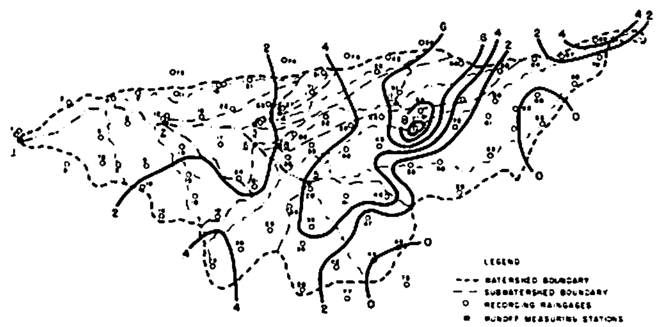

FIG. 4 Walnut Gulch watershed isohyetal map for storm of September 9, 1964. (Rainfall amount in inches).

While working with the logarithmic transformation of flume No. 6 data, it was found to be easier to transform the data. By transforming the data, it was not necessary to work with logarithms of numbers less than unity. The data transformation was the addition of a constant 2.00 percent by weight to all the observed sediment concentrations. Thus, for example, the resulting sediment concentrations from the regression equation contains a constant of 2.00 percent by weight, which must be subtracted from the regression equation when predicting the concentration for unmeasured periods.

The data at flume No. 6 were changed with and without the logarithmic transformation by adding a constant 2.00 to the rate of change of stage, independent variable X_3. This made all values of the variable X_3 positive, with numbers less than 2.00 signifying falling stages (hydrograph recession) and numbers greater than 2.00 signifying rising stages. This transformation was also used for the flume No. 1 data. Variable X_5, distance from the storm center to the measuring station, was changed by multiplying the observed distances by 100.

Tables 1 and 2 present, in summary form, the result of the stepwise multiple-regression analysis of the transformed data for flumes Nos. 6 and 1. Using the logarithmic transformation for the flume No. 6 data increased the R^2 (coefficient of determination) for the total suspended sediment (i.e., sand, silt, and clay fraction) from 0.29 to 0.49. The logarithmic transformation only increased the coefficient of determination from 0.63 to 0.70 at flume No. 1. The tables show the order of selection of the independent variable, the F level (for testing the statistical significance), the coefficient of determination, and the prediction equation for the addition of each independent variable. Tables 1 and 2 present the results of three of the five dependent variables included in the analysis. The results of the remaining two dependent variables are very similar to that for Y_5, the silt and clay combination.

The prediction equations shown in Tables 1 and 2 indicate the output from the computer resulting from addition of another independent variable to the multiple-regression equation. The coefficients and exponents change with the addition of each variable. The prediction equations are shown for the sand fraction, the silt and clay fractions, and for the total of the sand, silt, and clay fractions. The coefficients of determination for the dependent variables Y_1 and Y_5 are not appreciably better than that for the total sediment fraction, dependent variable Y_4. Thus, the equation for the total sediment concentration was used at both flumes Nos. 6 and 1 to predict the concentration during unsampled runoff periods.

The prediction equation for the untransformed data at flume No. 6 is not shown because of the low coefficient of determination. The low coefficient of determination ($R^2 = 0.29$) indicates that the linear model does not provide a good representation of the variability of the data. A higher coefficient of determination for the flume No. 6 data was obtained for the log-log graph of concentration versus instantaneous discharge.

TABLE 1. STEPWISE MULTIPLE LINEAR REGRESSION, LOGARITHMIC TRANSFORMED DATA, FLUME 6, 1964, WALNUT GULCH

Variable	F-level	R^2	Equation
			Dependent variable Y_1 (sand)
X_8	90.244**	0.32	$Y_1 = 0.289X_8^{(0.0326)}$
X_1	56.819**	0.48	$Y_1 = 0.366X_1^{(-0.0478)}X_8^{(0.0363)}$
X_6	14.530**	0.51	$Y_1 = 0.363X_1^{(-0.0655)}X_6^{(0.0219)}X_8^{(0.0235)}$
X_7	22.773**	0.57	$Y_1 = 0.153X_1^{(-0.0697)}X_6^{(0.0325)}X_7^{(0.298)}X_8^{(0.0216)}$
X_5	1.529	0.57	
X_4	1.062	0.57	
X_2	0.386	0.57	
X_3	0.192	0.57	$Y_1 = 0.147X_1^{(-0.072)}X_2^{(-0.0296)}X_3^{(0.0783)}X_4^{(-0.0014)}$
			$X_5^{(-0.0046)}X_6^{(0.0336)}X_7^{(0.318)}X_8^{(0.0239)}$
			Dependent variable Y_5 (silt + clay)
X_1	35.718**	0.16	$Y_5 = 0.724X_1^{(-0.110)}$
X_8	16.816**	0.23	$Y_5 = 0.665X_1^{(-0.122)}X_8^{(0.0355)}$
X_7	19.888**	0.30	$Y_5 = 0.131X_1^{(-0.111)}X_7^{(0.760)}X_8^{(0.0464)}$
X_4	18.837**	0.36	$Y_5 = 0.0115X_1^{(-0.139)}X_4^{(-0.0215)}X_7^{(1.09)}X_8^{(0.0586)}$
X_6	7.536**	0.39	$Y_5 = -0.116X_1^{(-0.172)}X_4^{(-0.0211)}X_6^{(0.0447)}X_7^{(1.26)}X_8^{(0.0347)}$
X_2	7.497**	0.41	$Y_5 = 0.0939X_1^{(-0.175)}X_2^{(-0.376)}X_4^{(-0.0174)}X_6^{(0.0509)}$
			$X_7^{(1.25)}X_6^{(0.0403)}$
X_3	3.396**	0.42	$Y_5 = 0.407X_1^{(-0.198)}X_2^{(-0.402)}X_3^{(-0.869)}X_4^{(-0.0183)}$
			$X_6^{(0.0602)}X_7^{(1.24)}X_8^{(0.035)}$
X_5	0.091	0.42	$Y_5 = 0.39X_1^{(-0.195)}X_2^{(-0.404)}X_3^{(0.836)}X_4^{(-0.0179)}$
			$X_5^{(0.00303)}X_6^{(0.0589)}X_7^{(1.24)}X_8^{(0.0349)}$
			Dependent variable Y_4 (sand + silt + clay)
X_1	34.162**	0.15	$Y_4 = 0.77X_1^{(-0.1157)}$
X_8	40.866**	0.30	$Y_4 = 0.676X_1^{(-0.135)}X_8^{(0.0562)}$
X_7	21.394**	0.37	$Y_4 = 0.115X_1^{(-0.123)}X_7^{(0.799)}X_8^{(0.0677)}$
X_4	16.695**	0.42	$Y_4 = -0.000211X_1^{(-0.150)}X_4^{(-0.0207)}X_7^{(1.12)}X_8^{(0.0795)}$
X_6	13.068**	0.46	$Y_4 = -0.169X_1^{(-0.194)}X_4^{(-0.0202)}X_6^{(0.059)}X_7^{(1.34)}X_8^{(0.0479)}$
X_2	6.287**	0.48	$Y_4 = 0.0258X_1^{(-0.196)}X_2^{(-0.348)}X_4^{(-0.0168)}X_6^{(0.0648)}$
			$X_7^{(1.33)}X_8^{(0.0530)}$
X_3	2.092*	0.49	$Y_4 = 0.274X_1^{(-0.214)}X_2^{(-0.369)}X_3^{(-0.689)}X_4^{(-0.0175)}$
			$X_6^{(0.0722)}X_7^{(1.32)}X_8^{(0.0489)}$
X_5	0.024	0.49	$Y_4 = 0.265X_1^{(-0.1213)}X_2^{(-0.37)}X_3^{(-0.672)}X_4^{(-0.0173)}$
			$X_5^{(0.00158)}X_6^{(0.0715)}X_7^{(1.32)}X_6^{(0.0488)}$

** Significant at 1% level.
* Significant at 5% level.

TABLE 2. STEPWISE MULTIPLE LINEAR REGRESSION, LOGARITHMIC TRANSFORMED DATA, FLUME 1, 1964, WALNUT GULCH

Variable	F-level	R^2	Equation
			Dependent variable Y_1 (sand)
X_2	179.629**	0.620	$Y_1 = 3.06X_2^{(-2.25)}$
X_5	22.123**	0.684	$Y_1 = 2.07X_2^{(-2.60)}X_5^{(0.959)}$
X_3	9.155**	0.709	$Y_1 = -0.574X_2^{(-2.44)}X_3^{(8.60)}X_5^{(0.972)}$
X_4	1.278	0.712	
X_6	2.732	0.720	
X_1	2.342	0.726	
X_8	1.136	0.729	
X_7	1.157	0.732	$Y_1 = -0.929X_1^{(-0.0984)}X_2^{(-1.68)}X_3^{(8.61)}X_4^{(0.0296)}$
			$X_5^{(0.888)}X_6^{(0.0921)}X_7^{(-0.515)}X_8^{(0.0716)}$
			Dependent variable Y_5 (silt + clay)
X_1	130.123**	0.542	$Y_5 = 3.67X_1^{(-0.204)}$
X_2	16.725**	0.603	$Y_5 = 3.61X_1^{(-0.210)}X_2^{(0.288)}$
X_7	10.804**	0.639	$Y_5 = 3.51X_1^{(-0.213)}X_2^{(0.288)}X_7^{(0.352)}$
X_6	6.910**	0.661	$Y_5 = 3.62X_1^{(-0.197)}X_2^{(0.158)}X_6^{(-0.0484)}X_7^{(0.488)}$
X_4	9.355**	0.688	$Y_5 = 3.75X_1^{(-0.187)}X_2^{(-0.0117)}X_4^{(-0.0141)}X_6^{(-0.0794)}$
			$X_7^{(0.646)}$
X_8	1.973	0.694	
X_5	3.479	0.704	
X_3	0.158	0.704	$Y_5 = 3.33X_1^{(-0.210)}X_2^{(0.0142)}X_3^{(0.497)}X_4^{(-0.0152)}X_5^{(0.318)}$
			$X_6^{(-0.0926)}X_7^{(0.280)}X_8^{(0.0416)}$
			Dependent variable Y_4 (sand + silt + clay)
X_1	131.573**	0.545	$Y_4 = 3.74X_1^{(-0.194)}$
X_8	17.445**	0.607	$Y_4 = 3.66X_1^{(-0.214)}X_8^{(0.0478)}$
X_5	6.768**	0.631	$Y_4 = 3.43X_1^{(-0.277)}X_5^{(0.213)}X_8^{(0.0558)}$
X_6	6.700**	0.652	$Y_4 = 3.44X_1^{(-0.226)}X_5^{(0.265)}X_6^{(-0.0451)}X_8^{(0.0813)}$
X_3	8.857**	0.679	$Y_4 = 2.37X_1^{(-0.213)}X_3^{(3.45)}X_5^{(0.291)}X_6^{(-0.052)}X_8^{(0.0809)}$
X_2	1.890	0.685	
X_4	4.186	0.697	
X_7	0.960	0.700	$Y_4 = 2.70X_1^{(-0.193)}X_2^{(-0.356)}X_3^{(2.75)}X_4^{(-0.0109)}X_5^{(0.365)}$
			$X_6^{(-0.0819)}X_7^{(0.191)}X_8^{(0.0513)}$

** Significant at 1% level.
* Significant at 5% level.

TABLE 3. ORDER OF SELECTION OF INDEPENDENT VARIABLES
Flume 6, Walnut Gulch, 1964 Data

	Y_1		Y_2		Y_3		$Y_4 = Y_1+Y_2+Y_3$		$Y_5 = Y_2+Y_3$	
	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.
	8°	8	1	1	1	1	1	1	1	1
	1	1	5	8	5	7	5	8	5	8
	6	6	7	7	7	6	7	7	7	7
	3	7	4	4	4	4	6	4	4	4
	4	5	6	6	6	3	4	6	6	6
	7	4	2	2	8	2	2	2	2	2
	5	2	3	3	2	5	3	3	8	3
	2	3	8	5	3	8	8	5	3	5
R^2	0.28	0.57	0.31	0.48	0.28	0.34	0.29	0.49	0.30	0.42

═ Variables significant at 1 percent level.
— Variables significant at 5 percent level.
° Independent variable number.
Y_1 = sand concentration.
Y_2 = silt concentration.
Y_3 = clay concentration.
R^2 = coefficient of determination.

Order of Independent Variable Selection

Tables 3 and 4 list the independent variables (X_1 through X_8) in the order of their importance in reducing the unexplained variance of the data as determined by the computer. The order of selection of the independent variables is shown for both the transformed and untransformed data and for the three dependent variables, as well as two combinations of these dependent variables. The levels of statistical significance as shown in the tables were determined in the computer program using the F-level test.

Lapse time (independent variable X_1) was the variable selected as explaining the greatest amount of variance in almost every instance on these two tables. As shown in the prediction equations of Tables 1 and 2, the negative exponent for this variable means that the sediment concentrations on the falling portion of the hydrograph are less. This agrees well with field observations of higher concentrations in the rising portion of the hydrograph.

Instantaneous water discharge at the time of sampling (independent variable X_8) was quite variable in its importance for reducing the variance of the measured data. For example, at flume No. 6 it was the most important variable for the variance associated with the sand fraction but was the least important variable for the clay fraction as predicted using the transformed data. At both flumes, X_8 was the second variable selected for the transformed data, i.e., the multiplicative prediction equation form.

Storm position on the watershed, independent variable X_7, was included in the analysis, although in an admittedly crude way, because of previous experiences on the project. Kincaid *et al* (6) showed that the sediment yield, as measured in stock tanks, "is two or more times as great from the brush-covered watersheds as from grass-covered ones." At the same time there was no evidence of greater runoff from the brush areas. This variable, which was the third variable selected at flume No. 6 for the total suspended concentration, has exactly the opposite effect to that presented by Kincaid *et al.* The regression prediction equation (Table 1) indicates higher concentrations from the grass areas than from the brush area. The same relationship was observed for the untransformed data at flume No. 6, i.e., higher concentrations from the grass areas. Explanations for this can perhaps be that different kinds of erosion are occurring between some grasslands and the brushland areas. The storm-position variable was not significant for the flume No. 1 data for the total concentration with the multiplicative form of the prediction equation.

Antecedent moisture conditions in the channel alluvium, independent variable X_4, was significant at the 1 percent level for the silt and clay predictions at both flumes and for both the additive and multiplicative prediction equation forms. The variable acted to reduce the concentration with an increasing antecedent moisture index. This would seem to agree with qualitative observations on the watershed. Transmission losses in ephemeral channels such as Walnut Gulch are closely related to the antecedent moisture levels, i.e., high loss rates are associated with drier channels. Sediment concentrations have been observed to increase as runoff traverses dry beds. Whether the increase is a result of greater availability of sediment or whether the loss of water (transmission losses) is not accompanied by a proportionate loss of sediment quantity remains to be demonstrated. The prediction equation would tend to support the latter explanation.

Further refinement of variable X_4 seems warranted. For example, various values of the constant in the summation could be used. Because the moisture conditions were intuitively felt to be a function of more than just an amount, such as is used in many types of hydrograph analysis (7), the peak discharge was squared. Perhaps a more realistic approach would be some combination of peak discharge and runoff duration, or perhaps some direct determination of the moisture level such as with tensiometers or moisture blocks.

Distance of travel of the runoff from the center of the storm to the measuring station (independent variable X_5) was thought to be of possible importance prior to this analysis because of its role in the quantification of the transmission-loss phenomenon. Transmission losses are proportional to the distance of streambed traversed, and the sediment concentration increases with increasing transmission losses. Therefore, variables X_4 and X_5 are intended to reflect these losses. The success of this variable X_5 in the prediction equations for explaining the variance was generally low for the flume No. 6 data but quite important at flume No. 1. In the multiplicative equation form, it was the last variable selected at flume No. 6, but the third variable selected at flume No. 1 for the total concentration prediction. The variable was also intended to reflect the opportunity for the sediment concentration of the runoff to increase by picking up material from the

TABLE 4. ORDER OF SELECTION OF INDEDENDENT VARIABLES
Flume 1, Walnut Gulch, 1964 Data

	Y_1		Y_2		Y_3		$Y_4 = Y_1+Y_2+Y_3$		$Y_5 = Y_2+Y_3$	
	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.	Untrans.	Trans.
	2°	2	1	1	1	1	1	1	1	1
	3	5	7	8	8	8	3	8	5	2
	5	3	6	2	5	7	7	5	4	7
	8	4	4	6	4	4	6	6	6	6
	7	6	3	5	7	3	2	3	3	4
	1	1	2	4	2	6	5	2	8	8
	4	8	8	3	6	2	4	4	7	5
	6	7	5	7	3	5	8	7	2	3
R^2	0.80	0.73	0.54	0.75	0.73	0.77	0.63	0.70	0.66	0.70

═ Variables significant at 1 percent level.
— Variables significant at 5 percent level.
° Independent variable number.
Y_1 = sand concentration.
Y_2 = silt concentration.
Y_3 = clay concentration.
R^2 = coefficient of determination.

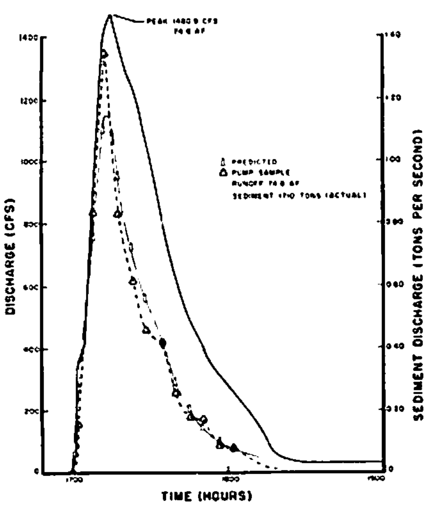

FIG. 5 Walnut Gulch watershed, flume 6, September 9, 1964.

streambed. The positive exponent for the transformed data at flume No. 1 indicates the concentration increases with the greater distance of dry bed traversed.

Peak discharge (variable X_6) for the event being sampled was highly significant at the one percent level for predicting the total concentration at both flumes and with both forms of the prediction equation. In streams such as Walnut Gulch, bank sloughing provides large amounts of material which are moved during bigger flows. Many of the flow events are so small that only a portion of the channel bottom is wetted. The materials at the stream edge are not picked up by these small flows. The positive exponent of variable X_6 at flume No. 6 indicates that higher concentrations are associated with larger peak-discharge flows. The opposite relationship was found at the watershed outlet, i.e., larger peak flow gave a lower concentration from the prediction equation.

Independent variable X_2, an indexing of the type of sample, was statistically significant at flume No. 6 in the multiplicative form of prediction equation except for the sand fractions. Three types of samples were collected at this station. During the higher discharges, depth-integrated samples were collected near the stream centerline from a cableway using a US D-49 sampler. During lower discharges, depth-integrated samples were collected from the entire cross section by wading the stream using a US D-48 hand sampler. For the analysis, these samples were coded 1 and 2, respectively, because it was felt that the cableway samples at the stream centerline would probably contain a slightly higher concentration than would the wading samples. The third group of samples, which were coded 3 for the analysis, were collected at the edge of the channel using a pumping sampler (8) with an intake approximately 6 inches above the streambed. The prediction equation at flume No. 6 showed that the concentrations were in the order of cableway samples, wading samples, and pump samples.

At the watershed outlet, flume No. 1, only cableway and wading samples were collected, and here also the multiplicative prediction equation showed the concentrations to be lower for the wading samples. This variable was the most important variable selected by the computer to explain the variance of the sand fraction, with the highest concentration coming from the cableway samples.

Independent variable X_3, the rate of change of stage, was felt to be of importance because of the rapid changes in depth commonly experienced in ephemeral streams such as Walnut Gulch. This variable was of little importance in explaining the observed variance as determined by the computer. The variable on the multiplicative form of prediction equation gave higher concentrations on the rising than on the falling stages at flume No. 1, but for some unexplained reason gave the opposite relationship at flume No. 6.

September 9, 1964, Storm

A storm on September 9, 1964, on the upper portion of Walnut Gulch centered at rain gage No. 57 (Fig. 4) with 1.01 in. of precipitation in the 25-min. duration. The maximum 5-min intensity for this storm was 4.56 in. per hr. This storm with all of the runoff originating above flume No. 6 produced a sharp hydrograph at this flume (Fig. 5) with a peak discharge of 1480 cfs and 74.8 acre-ft of runoff. On traversing the 6.8 miles of dry streambed between flumes Nos. 6 and 1, the hydrograph was reduced to a peak discharge of 630 cfs and a volume of 53.6 acre-ft. The transmission losses of 21.2 acre-ft for this flow event are not especially large for such an event (9) because the channel was quite wet from a runoff event only 20 hours prior to this event.

The automatic-pumping sampler at flume No. 6 obtained 12 samples during this flow which defined a sediment discharge graph for this event. The multiplicative prediction equation for the total concentration of Table 1 was used to calculate the sediment load for this same storm. The agreement with the observed sediment graph seems good except in the vicinity of the peak where the predicted value is about 15 percent low. The sediment discharge for this event at flume No. 6 amounted to 1710 tons.

At the watershed outlet, the hydrograph and the suspended sediment-discharge graphs are shown for this same event (Fig. 6). The predicted and measured sediment-discharge graphs for these events differ appreciably on the recession. The indicated sediment discharge, by a combination of the actual data and the generated data on the recession when no samples were collected, is 1650 tons versus 2300 tons from the predicted data only. This 28 percent difference is considerably larger than desirable, but it represents one of the worst examples in the data collected.

This event demonstrates a phenomenon observed on other events, i.e., the runoff decreases because of transmission losses, but the sediment discharge remains nearly the same as that at an upstream point or, in some instances, may actually increase. On this storm of September 9, 1964, the sediment discharge of 1710 tons at flume No. 6 was about the same as the 1650 tons at flume No. 1.

Additional Considerations

An inherent limitation of an analysis, such as that reported here, results from the skewed distributions of some of the sample data and also because some of the independent variables are constant for a particular flow event. For example, independent variables X_4, X_5, X_6, and X_7 are constants for each particular flow event. The multiple-linear regression analysis, which included data for about ten different storms at flume No. 6, had unequal weighting for these four variables, depending on the number of samples collected for the various storms.

A more valid method of computation would be to determine a starting sediment concentration from these fixed independent variables and to compute

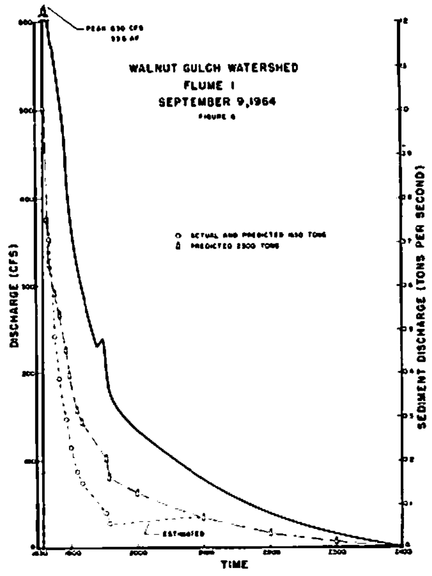

FIG. 6 Walnut Gulch watershed, flume 1, September 9, 1964.

the concentration at any time (Y_t) as a function of the initial concentration (Y_i) and the changing variables. In equation form, this might be given by:

$$Y_i = f(X_4, X_5, X_6, X_7) \quad \ldots\ldots \quad [8]$$

$$Y_t = f(Y_i) + f(X_1, X_2, X_3, X_8) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [9]$$

Future work will be directed toward this form of analysis, plus work for refinement of the eight independent variables used in the analysis.

There are additional variables which might be considered for reducing the unexplained variance in the equations developed in this paper. Obviously a parameter for channel erodibility is needed. Some channels erode more than others, and this availability of material for transport could be very important. Because of inadequate information to define the values of this variable, it was not included in the analysis.

Conclusions

Sediment concentration in an ephemeral stream where runoff is generated from only a portion of the contributing watershed, appears to be related to a number of independent variables, which is indicative of the flow and hydrologic conditions at the time of the sample. Although a large amount of unanswered variability remains, the multiple-linear-regression technique seems to answer some of the problems of a sediment-rating curve for semiarid ephemeral streams.

Sediment concentration does not seem to be predictable with a simple additive equation involving coefficients of the independent variables involved. A better relationship appears to be a multiplicative equation involving the products of the independent variables with different exponents.

Lapse time from the beginning of flow at the sampling station and the instantaneous discharge at the time of sampling were the two most important variables for predicting the sediment concentration. Other variables were important in reducing the unexplained variance but were more inconsistent between the stations considered in the analysis and were important rather for the sand, silt, or clay fractions of the total concentration.

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