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MAJOR FLOODS, POOR LAND USE DELAY RETURN OF SEDIMENTATION TO NORMAL RATES

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Abstract: Recovery from flood-accelerated sedimentation affects both estimates of long-term average deposition and short-term monitoring of changes. "Years to return to normal" for 10 watersheds in northern California after a major flood accelerated sediment concentrations were analyzed. Returns to normalcy took from 0 to 9 years; rate of decline was related to both amount of initial acceleration by the flood and differences in watersheds. Years to recovery increased with these four factors: coefficient of path lengths in the watershed, area of poor logging, area of steep grassland, and percent of area in sedimentary rock types Cenozoic or younger.

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To estimate damaging sediment deposition and monitor deteriorating water quality, the land manager samples reservoirs or streams. But what he measures may not be representative of expected amounts in the future. A major flood can, for example, cause biased samples by temporarily accelerating sediment transported by streams in the years thereafter.[1] How long does it take for sediment discharge to return to normal after a major flood? Is that recovery related to watershed characteristics and conditions?

This note offers some answers from sediment samples taken in 10 northern California streams before a major flood in December 1964 and similar sampling of sediment rates in the subsequent 5 years.

USE OF SEDIMENT SAMPLES

Streamflow is sampled to determine sediment concentration, but each year's results are different because each year's streamflow regime differs from that of other years. How can such varying results be compared? Such a comparison can be made only by converting the data to some "normalized"series of streamflow events. One technique is known as the "flow duration-sediment discharge method" of computing sediment discharge from watersheds.[2] Sediment concentration is related to streamflow discharge and then multiplied by the long-term probability of streamflow discharges for a given watershed and a given condition in that watershed. Since the sediment concentration measurements for a given year are weighted by the long-term expected flow duration, each year's sediment can be compared with measurements in other years, and changes in sedimentation can be determined. The result is a weighted average of sediment concentration in a stream, with the weighting being the expected streamflow frequency. If the concentration is multiplied by average streamflow, the result is "normalized" total suspended sediment discharge for a watershed and a given year.

Using this technique, I determined the sediment discharge in the period before the 1964 flood, the first year acceleration of sediment discharge (for equal flows) by the flood, and the rate of recovery of sediment discharges to pre-flood rates after the flood. Data were available for 10 watersheds (see table for names).

For pre-flood sediment discharge, I took the average annual sediment discharges for the 3 years 1960 to 1962. For the initial acceleration of sediment discharge by the flood, I used the sediment-concentration measurements during the period January to September 1965. Then, the year-to-year sedimentation rates for the years 1966 through 1969 were used to determine recovery.

Pre-flood sediment amounts varied widely between the 10 watersheds ranging from 130 to 4,400 tons per square mile per year (46 to 1,535 metric tons per square kilometer per year). Post-flood acceleration (normalized 1965 sedimentation) ranged from no acceleration to 4.6 times as much sediment as in the preflood period. Recovery of sedimentation was taken as the number of years for the sediment rate to return to the 1960 to 1962 normalized period or for the projected recovery to return to that rate for each watershed *(fig. 1)*. Projected recovery, of course, assumes no recurrence of a major flood in the recovery interval.

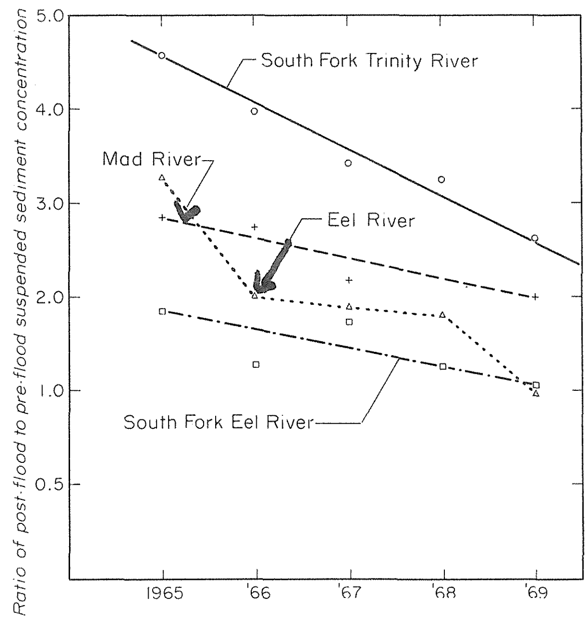

Figure 1—The years it took for sedimentation rate to return to normal after the December 1964 flood in California varied widely among four watersheds.

RECOVERY OF WATERSHEDS

The time to recovery also varied widely among the 10 watersheds. Recovery or projected recovery ranged from 0 to 9 years. Are these differences related to watershed conditions and are recovery rates predictable? To find the answers, I tested the "number of years to recovery" against these five variables: initial acceleration of sedimentation by the flood (AC 65); topographic path lengths (CV); indexes of land use before the flood—poor logging (L1), with roads next to channels and landings in draws, and area of steep grassland (IGS); and the geologic rock type, unconsolidated sediment (USED) *(table 1)*. The general model was:

Years to Recovery = f(AC 65, CV, L1, IGS, USED).

RESULTS

To determine the coefficients which relate the years to recovery to watershed variables, I used the technique of principal component analysis[3,4]; specifically, the computer program written by Wallis,[5] which uses the Varimax rotation of components,[6] starting with the correlation matrix. The technique has recently come into rather widespread use in hydrologic analysis since the development of large, fast computers.[7]

What factors were important in explaining the number of years to recovery of watersheds after a major flood? The factor contribution to explained variance was determined by retaining four factors or components. The results showed that of the 85 percent of explained variance (R^2), 10 percent was associated with the areas of poor land use in watersheds—poor logging (L1), and steep grasslands (IGS); 50 percent was associated with the degree of initial acceleration that had occurred (AC 65); 25 percent was associated with the topographic variable —the coefficient of variance of path lengths (CV); and a small percent was associated with the relative area in the watershed of unconsolidated sedimentary rock in contrast to other rock types. The standard error of estimate upon regressing on these principal components was 1.2 years. All of the variables were statistically significant as indicated by the standardized regression coefficients.

The regression equation which may be used for predicting the years to recovery is:

Years =	-15.2		Regression constant.
	+ 1.69	AC 65	Acceleration in sediment discharge after the December 1964 flood (sed. 1965/ sed. 1960-62) (mean 2.6, std. dev. 1.25).
	+ 0.31	CV	Coefficient of variance of path length in watershed, std. dev./mean path length (mean 45, std. dev. 4.1).
	+ .0161	L1	Area with poor logging in watershed, acres per square mile (mean 22.6, std. dev. 15.3).
	+ .0046	IGS	Area of grassland times slope of grassland, percent times percent (mean 136, std. dev. 105).
	+ .0238	USED	Area of sedimentary rocks Cenozoic or younger, percent (mean 23, std. dev. 31).

DISCUSSION

To test regression results I used data from 3 to 7 watersheds not included in the analysis. The ratio of normalized sediment discharge in 3 succeeding years was determined and compared with the predicted amounts:

	No. of watersheds	*Average ratio from regression*	*Average actual ratio*
Years:			
1967/66	3	0.84	0.87
1968/67	3	.81	.79
1969/68	7	.76	.74

The comparisons on the average seem satisfactory.

What do the regression results imply quantitatively? These results can be used to estimate recovery of a poorly logged area compared to a non-logged area. Recovery of the poorly logged area (that is, with 640 acres per square mile, poorly logged) would be delayed for (640 times 0.0161), for 10 years. Similar estimates can be made for other watershed differences. For example, watersheds with the greatest variance in path lengths (CV=50 vs. CV=39) may take longer to deliver flood-accelerated sedimentation—the regression results indicate about 3-1/2 years longer to recover to normal sediment discharge rates. The initial acceleration of sedimentation by the flood (AC 65) was important to recovery. For watersheds in

Table 1—*Characteristics of 10 northern California watersheds used in regression analysis*[1]

Watershed	Area[1]	AC65[2]	L1[3]	CV[4]	IGS[5]	USED[6]	Yrs.[7]
	Sq. mi.	*Ppm./ppm.*	*Ac./sq. mi.*	*Mi./mi.*	*Pct. x pct.*	*Pct.*	
Naciemento	140	1.10	0	46	120	52	3
Consumnes	537	1.02	6	42	92	0	0
Middle fork of Cottonwood	249	1.74	0	40	118	46	3
Thomes Creek	194	4.37	0	39	111	0	4
North fork of Casper Creek	2	1.43	0	49	0	100	4
South fork of Eel River	44	1.85	51	50	82	4	4
Eel River at Scotia	3113	3.26	38	41	351	8	4
Mad River at Arcata	484	2.84	58	50	322	7	9
South fork of Trinity	899	4.58	0	42	81	5	7
Trinity	2848	3.43	0	48	88	11	6

[1]Drainage area of watershed above gaging station.

[2]Ratio of weighted sediment concentration in 1965 to average of 1960-1962.

[3]Area in "poor logging," with roads next to channels and landings in draws.

[4]Coefficient of variation of path lengths, determined by method of Busby and Benson.[9]

[5]Product percent of watershed in grassland time slope of grassland.

[6]Unconsolidated sediment, watershed area with unconsolidated sediment geologic rock type (Cenozoic and younger).

[7]Number or projected number of years for sedimentation to return to average 1960-1962 rate.

which AC 65 cannot be determined directly it can be estimated.[8]

Recovery from acceleration must be known if land managers are to estimate long-term expected sedimentation or to monitor properly sediment changes in watersheds. Long-term expectation can be illustrated by an example from the Eel River watershed above Scotia, California (drainage area: 3,100 square miles). If it is assumed that the 1964 flood had an expected return interval of 75 years, and a 10-year period is sampled which included the flood and its post-flood acceleration, an estimate of long-term mean annual sediment discharge would be about twice the actual amount. Such overestimates have happened in practice, so recent estimates of sediment discharge of the Eel River of 30 million tons per year are probably too high by a factor of nearly 2. On the other hand, if only non-flood periods were sampled, the long-term average sediment discharge would be underestimated by 24 percent. Since the 1964 flood varied in relative discharge by a factor of 5 among northern California watersheds, clearly no blanket adjustment is suggested. However, the effects of temporary acceleration of sedimentation by major floods must be accounted for in estimating long-term expected sedimentation.

The impact in short-term monitoring of sediment discharge and sediment impairment of water quality is even more crucial. A management activity could be blamed for accelerating sediment, when the principal cause was flood acceleration. On the other hand a management activity could be credited with a drop in sedimentation or with no acceleration, when "natural recovery" should be accorded the credit.

The equation offered in this note may aid in predicting the rate of recovery of individual watersheds. Such predictions may result in better estimates of long-term sedimentation rates, and more valid monitoring of changes in sediment production from watersheds.

NOTES

[1]Anderson, Henry W. *Principal components analysis of watershed variables affecting suspended sediment discharge after a major flood.* Int. Assoc. Sci. Hydrol. Publ. 96, 405-416. 1970.

Brown, W. M., III, and Ritter, J. R. *Sediment transport and turbidity in the Eel River basin, California.* U.S. Geol. Surv. Water-Supply Paper 1986, 70 p. 1971.

[2]Perhaps a dozen people have "invented" this procedure, including me (see Anderson, Henry W. *Suspended sediment discharge as related to streamflow, topography, soil, and land use.* Trans. Am. Geophys. Union 35(2): 268-281. 1954). A computer program is available to compute frequencies of turbidity, by classes, from the same data. Basically, the method utilizes, for each year, the relation of sediment concentration to stream discharge. Sediment discharge is the product of sediment concentration and streamflow; however, instead of using each year's streamflow, the long-term frequency of streamflow is used; giving average yearly sediment discharge.

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