US Army Corps of Engineers
Hydrologic Engineering Center

Estimating Sediment Delivery and Yield on Alluvial Fans

June 1990

TP-130

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
June 1990

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Estimating Sediment Delivery and Yield on Alluvial Fans

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Dr. Robert C. MacArthur, Michael D. Harvey, Edward Sing

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-130

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Paper prepared for the International Symposium on the Hydraulics/Hydrology of Arid Lands, ASCE Hydraulics Division, San Diego, CA, 30 July – 3 August 1990.

14. ABSTRACT
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15. SUBJECT TERMS
alluvial fans, sediment production, sediment yield, transport capacity, geomorophology, single event floods, episodic flows, average annual sediment yield, flow duration methods, regional methods

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	14	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

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TP-130

ESTIMATING SEDIMENT DELIVERY AND YIELD ON ALLUVIAL FANS

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Abstract

This paper summarizes the procedures used for computing the basinwide annual yields and single event sediment production for ephemoral channels located on an incised alluvial fan in Central California. Unique geomorphic characteristics of the basin and alluvial fan are discussed in light of data and analytical methods necessary to compute sediment delivery and yield at a proposed damsite.

Introduction

A Sediment Engineering Investigation (SEI) of the Caliente Creek watershed (470 sq. mi.) in Kern County, California was conducted to determine the watershed sediment yield upstream from a proposed flood detention reservoir located on the Caliente Fan. Previous studies estimated annual sediment yields at the proposed reservoir site based on traditional soil loss methods and sediment accumulation rates observed in impoundments along the Sierra Nevada, Tehachapi and Transverse Mountain Ranges. Initial project feasibility was considered based on preliminary cost/benefit analyses using the rough sediment yield estimates. Further review of the potential annual maintenance requirements led to the conclusion that the economic viability of the project depended heavily on annual O & M costs potentially required to remove the yearly accumulation of sediment within the proposed reservoir. Accurate estimates for the average annual sediment yield and single event sediment delivery were essential.

Further studies were undertaken to (1) identify specific geomorphic characteristics of the stream channels and watersheds upstream from the proposed flood control reservoir that could effect the sediment yield at the damsite, and (2) to relate channel and basin processes to sediment production and yields for various frequency precipitation and flood flow events in the watershed. This paper summarizes the procedures used for computing the basinwide annual yields and single event sediment production, along with conclusions and recommendations for other project design modifications.

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Paper prepared for the International Symposium on the Hydraulics/Hydrology of Arid Lands, ASCE Hydraulics Division, July 30-August 3, 1990, San Diego, CA

Approach

A two element SEI was conducted to address the sediment yield question: (1) geomorphic analyses (Harvey et al., 1990) were conducted to determine those unique characteristics of the basin and channels important to estimating sediment yield, and (2) sedimentation analyses (HEC, 1990) were conducted to determine the sediment yield in light of the findings from the geomorphic analyses.

To determine the amount of sediment that can possibly enter the proposed reservoir during its design life (100 years), both the average annual sediment yield and single event sediment yields are estimated using a variety of sediment engineering procedures as reported in EM 1110-2-4000, "Sediment Investigations of Rivers and Reservoirs," (COE, 1989) and recommended by others. Available scientific and engineering literature was reviewed, a three-day field reconnaissance and sediment data collection investigation was conducted, persons familiar with the Caliente Creek Project and watershed were interviewed, and a series of sediment engineering analyses to determine the possible sedimentation characteristics of the drainage basin at the damsite were carried out. Morphometric data for the alluvial fan in the vicinity of the proposed reservoir site were obtained from 2-foot contour mapping. Sixteen bed and bank material samples and two Wolman Counts were collected at representative locations throughout the drainage basin.

Average Annual Sediment Yield - The possible range of average annual sediment yield at the proposed reservoir site is estimated from the results from eight different sources of data and/or methods for estimating sediment yield. The following sources of data and procedures were used: (1) Previous reports and publications were thoroughly reviewed, (2) U.S.D.A. (1977) reservoir sedimentation rates were examined, (3) recent COE reservoir sedimentation survey data were analyzed, (4) sediment yield maps for the Western United States (U.S.D.A., SCS, 1975) were examined, (5) the average annual sediment yield was estimated from computations of the total event sediment volumes for single events ranging from the 2-year event up to the PMF based on channel transport capacity rather than watershed sediment production and delivery, (6) a similar flow duration and sediment load curve integration method (see EM 1110-2-4000, COE, 1989) was used to estimate the average annual sediment production and yield to the reservoir site, (7) the Pacific Southwest Inter-Agency Committee (PSIAC) method was used to estimate basin-wide sediment yield from the entire watershed, and (8) the Dendy and Bolton (1976) Regional Analysis Method for sediment yield was applied. Results from these analyses are discussed next. Detailed procedures for conducting such investigations are presented in the references cited and in Engineering Manual 1110-2-4000 (COE, 1989).

Table 1 presents the estimated sediment yields computed using the various computational procedures listed above and from measured reservoir surveys conducted by the Corps of Engineers and SCS. Based on measured sediment accumulation rates recorded in the six Tulare, Kings, and Kern County reservoirs, the approximate range of observed sediment yields is from 0.2 AF/sq mi/yr to 2.2 AF/sq mi/yr with an average of approximately 1.0 AF/sq mi/yr. Sediment yield rates determined for the Western United States are reported by the U.S.D.A., SCS (1975). From the mapping of yield rates, it appears that the upper Caliente watershed area has sediment yield rates from 0.2 to 0.5 AF/sq mi/yr, with pockets as high as 0.5 to 1.0 AF/sq mi/yr. In the lower portions of the basin, on the valley floor and on portions of the broad alluvial fan, the estimated yields are reported to be in the 0.1 to 0.2 AF/sq mi/yr range. Using area weighting methods to sum the yields from contributing subbasins, the approximate annual yield appears to range from 0.2 to about 0.75 AF/sq mi/yr, with an average of about 0.47 AF/sq mi/yr for the entire watershed.

Harvey et al., (1990) determined that the sediment delivery and yield at the damsite depends on the channel transport capacity in the fan area upstream from the reservoir rather than the watershed production of sediment. The broad (3,000 to 6,600 feet wide) alluvial fan contains an unlimited supply of easily mobilized sediment materials. This result lead to the following approach based on the transport capacity of the channels in the supply reach. The supply reach is a 4-mile section of the channel considered to be representative of the channel hydraulic conditions and sediment transport characteristics

TABLE 1

Sediment Surveys for Reservoirs in the Vicinity of Caliente Creek, Kern County, California, and Estimated Sediment Yields Based on Various Computational Methods

Data Source	See References	Drainage Basin, Reservoir or Computational Method Used	Drainage Area (sq mi)	Yield (AF/sq mi/yr)
SCS	10	Blackburn	7.1	2.20
SCS	10	Antelope Canyon	4.4	1.50
CESPK	5	Isabella	2,074	0.37
CESPK	9	Pine Flat	1,542	0.20
CESPK	9	Success	393	0.76
CESPK	9	Terminus	560	0.75
SCS	8	SCS Yield Map of Western US (HEC)	470	0.47
Computed	7	Integration of the Event Volume vs. Frequency Curve (HEC)	470	0.55
Computed	7	Flow Duration Method (HEC)	470	0.90
Computed	7	Dendy & Bolton Method (HEC)	470	0.71
Computed	4	PSIAC Method (HEC)	470	0.75
Computed	6	Kern County Water Agency Study (SLA)	470	0.97

upstream from the dam site. Single event total sediment volumes were computed for each of the 2, 5, 10, 20, 50, 100, SPF, and PMF events. The total sediment production for each event was based on the sediment transport capacity of the alluvial channel (supply reach) upstream from the reservoir and the flow hydrographs used for each of the flood events evaluated.

A total sediment load versus percent exceedance curve was developed from these data and the area under the total load frequency curve was computed to give an estimate for the expected average annual sediment delivery to the reservoir based on channel transport capacity upstream from the reservoir. Two different transport relationships were used to develop the total load curves. The resulting average annual sediment delivery ranged from 0.1 AF/sq mi/yr to 1.0 AF/sq mi/yr due to the difference in transport capacity computed with the transport functions. Using these results as a representative range in expected yields based on channel capacity, an average of the two yields seems reasonable. Therefore, based on the channel transport capacity above the reservoir site and the estimated total sediment production from a range of single events, an approximate sediment yield at the reservoir is 0.55 AF/sq mi/yr. This method does not account for the additional contribution of sediment from dry ravel erosion, wind-blown sand transport into the channel or reservoir, channel bank caving, local scour, or toe failure that may occur along the Sand Hills. Therefore, the sediment yield to the reservoir may be as high as the higher of the two transport functions predicts, especially during periods of exceptionally wet years.

The "flow duration sediment discharge rating curve method," (COE, 1989) is a simple method where the flow duration curve is integrated with the sediment discharge rating curve developed for the damsite. It is very similar to the method just described, however, the average annual sediment yield is based on the transport capacity and flow duration relationship at the damsite rather than the total event volume frequency. The resulting annual sediment yield is approximately 438 AF/year, or 0.9 AF/sq mi/yr.

Further examination of the U.S.D.A., SCS (1975) "Sediment Yield Rates for the Western United States" shows areas in the vicinity of the proposed damsite with estimated yields from 0.5 to 1.0 AF/sq mi/yr. These areas may correspond to the broad floodplain channels (4000 to 6500 feet wide) immediately upstream from the proposed reservoir site. If that is the case, then the higher yield values estimated with the channel transport capacity method (1.0 AF/sq mi/yr) and the flow duration method (0.9 AF/sq mi/yr) are supported by SCS yield mapping estimates.

The Dendy and Bolton (1976) method produces an average annual sediment yield of approximately 0.71 AF/sq mi/yr for the Caliente Basin at the Sivert damsite, while the application of PSIAC procedures to the Caliente Creek watershed produces an estimated average annual sediment yield of 0.75 AF/sq mi/yr at the dam site. These values are right in line with the range of values predicted from the channel capacity approach and the measured reservoir accumulation results from Tulare County.

Others (Simons, Li & Associates, 1989) conducted an independent assessment of the proposed Caliente Creek Project. The authors report the arithmetic average of their yield estimates **(0.97 AF/sq mi/yr)** in **Table 1. Figure 1** shows all thirteen yield values and the drainage basin area associated with each yield. A best fit line through these data points gives an average annual sediment yield of **0.75 AF/sq mi/yr.** This is more than twice the original annual estimate.

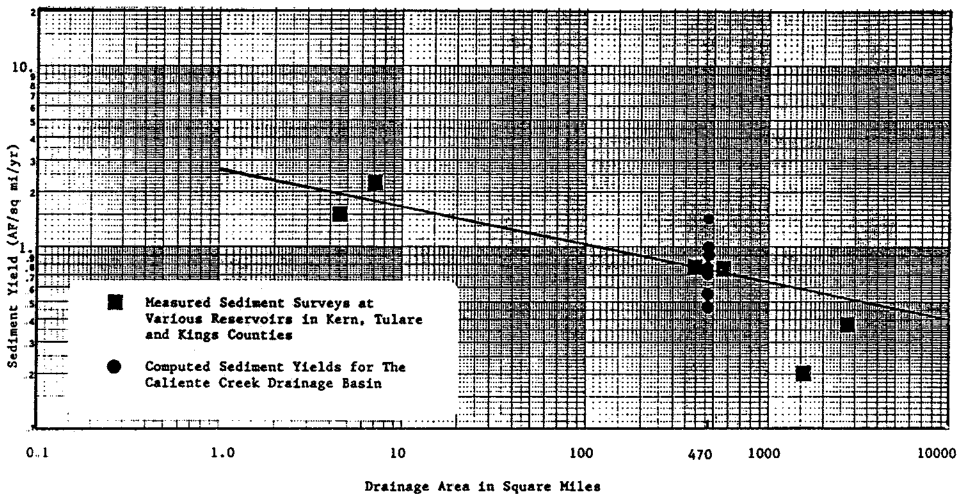

Figure 1

Measured and Computed Values of Average Annual Sediment Yield Versus Drainage Basin Area

It is important to note that arid and semi-arid basins, such as Caliente Creek, are very episodic in nature. During dry years (perhaps even normal years) the sediment production and delivery (and, therefore, annual yield) is small. During large runoff events the sediment production and delivery can produce tremendous loads of sediment in the channels. The annual yield during an excessively wet year can be quite high. Therefore, the presentation of a single average annual yield value may be misleading. For planning purposes, the consideration of the range of possible annual yields is more meaningful.

Single Event Analyses

In addition to the average annual sediment yield, it is important to estimate the sediment production and delivery from possible single events ranging from small 5-year flows to the design event (100 year flood) and, perhaps the SPF and PMF. It is possible that one or more single events during the design life of the project can significantly affect the operation and maintenance of the reservoir.

The study reach upstream from the proposed damsite was partitioned into four different zones or subreaches based on distinct hydraulic and geomorphic characteristics. The transport capacity is computed for each reach and is compared to the others with different hydraulic and geomorphic characteristics. The channel averaged sediment grain size and averaged channel hydraulic conditions for a range of discharges are used with several different total bed material load transport functions to develop representative water discharge versus total bed material load relationships for each of the subreaches and flow conditions.

Table 2 presents the computed sediment inflow to the proposed damsite for the various flood events. The 100 year flood event can possibly produce enough sediment during the single design event to remove 43.7 percent of the gross pool storage capacity (6992 AF). It also suggests that events greater than about the 15 year event can possibly remove 10 percent or more of the gross pool storage in one 5 day period. This indicates that the present design capacity of the reservoir may be undersized. The computed total sediment loads account for the total bed material load with an additional 15 percent estimated for the wash load. Typical wash loads can account for as much as 90 to 95 percent of the total load in most sand bed rivers (Vanoni, 1975). However, in the Caliente River Basin the availability of fines (silts and clays) may be limited due to the nature of the granitic parent materials throughout the basin (see Harvey et al., 1990). The authors postulate that the wash load near the damsite will have an inverted bed load/wash load relationship, and may only account for approximately 15 percent of the total sediment load being transported by each event.

TABLE 2

Computed Single Event Sediment Inflow to the Proposed Reservoir and Comparison to Planned Detention Storage Volume of 16,000 Feet

Event	Total Load Per Event (acre-feet) [dry volume]	Percent of the Planned Detention Storage Volume Associated with Single Event Sediment Delivery
5	245	1.5%
10	760	4.8%
20	1,794	11.2%
50	4,709	29.4%
100	6,992	43.7%
SPF	11,615	72.3%
PMF	29,440	184.0%

Harvey et al., (1990) estimate that there may have been approximately 9 inches of sediment deposited in the reach upstream from the Highway 58 crossing during the 1983 flood event. That event is estimated to be approximately a 50 year event according to the Kern County Water Agency. Comparing the total sediment loads entering and leaving the reach it is seen that there is approximately 575 acre feet more sediment transported into the reach from the upstream supply reach than leaves the reach. The approximate surface area of the reach is one square mile (640 acres). Assuming that the 575 acre feet of sediment deposits uniformly over the reach, this gives an approximate sediment deposition thickness of 10.8 inches. This matches the observed deposition depth for a 50 year event reasonably well.

Large events such as a 50 year flood or greater may produce large amounts of sediment material that enter the water course due to mass wasting, channel bank failure and erosion of prograded alluvial fans that often extend into the channel in the upper basin. It may be that single event sediment production can contribute significant quantities of sediment materials to the reservoir in a short period of time (a few days) and affect the operation and storage characteristics of the project.

Conclusions

The following conclusions are drawn from the results of this investigation:

1) The morphology of the Caliente Creek drainage basin and the nature of the sediments delivered to the channels and the potential for sediment storage within the drainage basin are controlled by the basin geology (Harvey et al., 1990).
2) Sediment transport in the basin is episodic and is governed by the occurrence of large runoff events. Sediment is stored in the broad valley washes (3000 to 6600 feet wide) in the lower portions of the Caliente Basin. There is sufficient material located in these expansive washes to provide sediment supply to the lower fan areas somewhat independently of the production and delivery of sediments from the upper watershed areas. Therefore, sediment yield at the proposed damsite may be more dependent upon the transport capacity of the channels and washes upstream from the damsite, than the watershed production of sediment materials during a flood event.
3) Examination of eight different sources of yield data and methods for estimating yield at the damsite concludes that the approximate average annual sediment yield at the Sivert Reservoir is 0.75 AF/sq mi/yr. This is more than twice the initial yield estimate developed during the planning studies. Annual sediment yields can range from 0.47 AF/sq mi/yr to approximately 1.5 AF/sq mi/yr.
4) Single event floods may produce significantly more sediment per event than the annual sediment yield would indicate. As much as 43 percent of the total gross pool storage volume (16,000 AF) may be lost due to sediment deposition during a 100 year event. This would necessitate the removal of approximately 7,000 AF of sediment material (dry volume) from the reservoir prior to the next flood season. It also indicates that the design capacity of the reservoir may be undersized.

Acknowledgements

The study reported herein was conducted by the Hydrologic Engineering Center, Davis, California at the request of the Sacramento District, Corps of Engineers. The views expressed herein are those of the authors and not necessarily those of the U.S. Army Corps of Engineers.

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TP-160 Application of Risk-Based Analysis to Planning Reservoir and Levee Flood Damage Reduction Systems
TP-161 Corps Water Management System - Capabilities and Implementation Status