DEBRIS FLOWS FROM TRIBUTARIES OF THE COLORADO RIVER, GRAND CANYON NATIONAL PARK, ARIZONA: EXECUTIVE SUMMARY

Robert H. Webb

U.S. GEOLOGICAL SURVEY

Open-File Report 87-117

Prepared in cooperation with the

U.S. BUREAU OF RECLAMATION

Tucson, Arizona
September 1987

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Federal Building, Box FB-44
300 W. Congress Street
Tucson, Arizona 85701-1393
Telephone (602) 629-6671

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Bldg. 810
Box 25425
Denver, Colorado 80225
Telephone: (303) 236-7476

CONTENTS

FIGURES

CONVERSION FACTORS

For readers who prefer to use the metric (International System) units, the conversion factors for the inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
cubic foot (ft^3)	0.2832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton	0.9072	megagram (Mg)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

DEBRIS FLOWS FROM TRIBUTARIES OF THE COLORADO RIVER, GRAND CANYON NATIONAL PARK, ARIZONA: EXECUTIVE SUMMARY

By

Robert H. Webb

ABSTRACT

Debris flows are a major process of sediment transport to the Colorado River from ungaged tributaries in Grand Canyon National Park, Arizona. Debris flows are slurries of clay- to boulder-sized particles of large magnitude and short duration that occur infrequently. They are the source for potential large volumes of sand for beaches on the Colorado River. Debris flows create and maintain hydraulic controls (rapids) on the Colorado River at tributary mouths.

INTRODUCTION

A potentially large source of sand for Colorado River beaches in Grand Canyon National Park, Arizona, is derived from sediment transported from small drainages (fig. 1). Little is known about the annual sediment yield from these drainages, and existing methodology for predicting sediment yields from small basins is not designed for high-relief basins with a large potential for slope failures. The key to estimating sediment transport is an understanding of the sediment-transport process.

A previous flood report (Cooley and others, 1977) and recent mapping of alluvial deposits in tributary canyons during this project indicate that debris flows are the dominant process of sediment transport in small drainages in Grand Canyon National Park. Debris flows are common in arid and semiarid regions, but their importance in supplying sediment to the Colorado River has not been previously recognized. The purpose of this report is to document the occurrence of debris flows in Colorado River tributaries. Three tributary canyons were studied in detail for debris-flow frequency and the magnitude of recent events.

METHODS

Debris flows are flowing water-based slurries of poorly sorted clay- to boulder-sized particles (Costa, 1984). Debris flows typically have volumetric water content of 15 to 40 percent compared with 40 to 80 percent for hyperconcentrated flow and 80 to 100 percent for streamflows (Beverage and Culbertson, 1964). Debris-flow deposits were identified in tributary canyons on the basis of poor sorting of particle sizes, lack of sedimentary structures, and matrix support of cobbles and boulders.

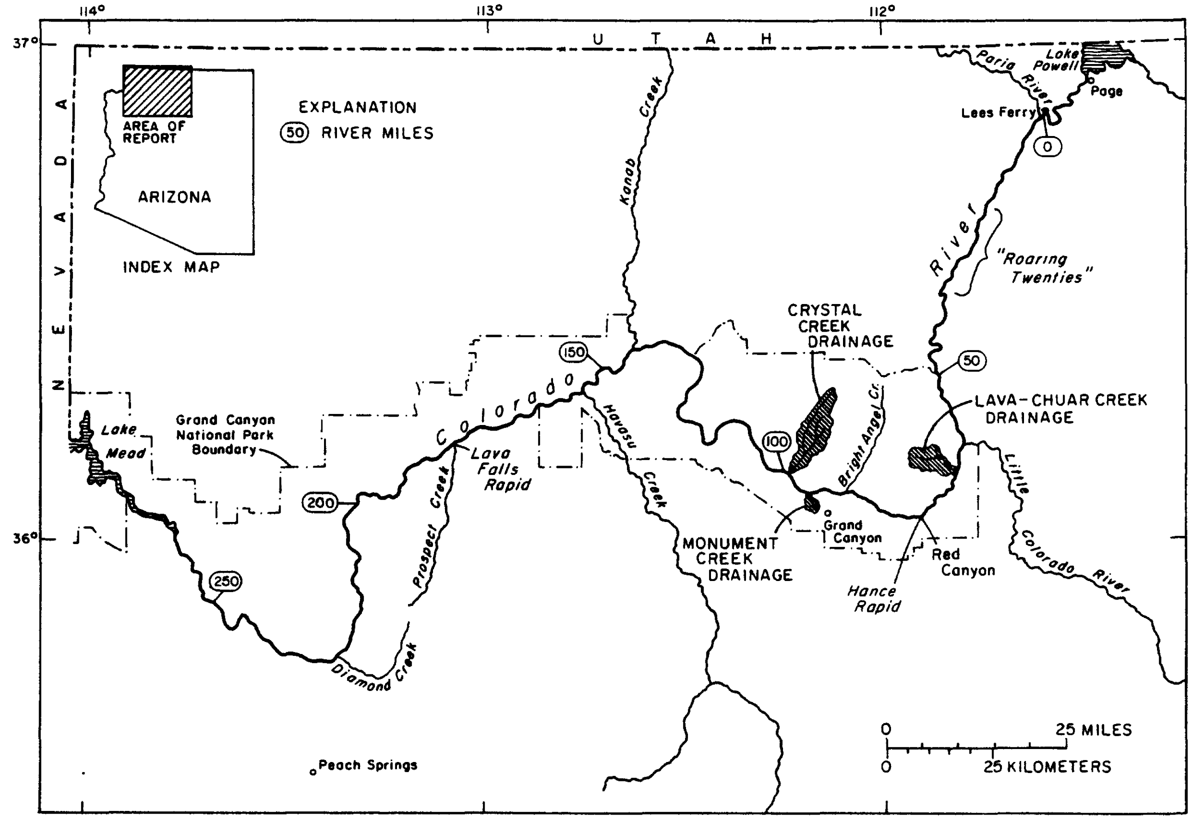


Figure 1.--Areas of study in Grand Canyon National Park, Arizona.

Debris-flow deposits were observed in 36 tributaries of the Colorado River during this study. Twenty-one of the 36 tributaries have evidence for recent debris flows. Three tributaries were selected for more detailed study on the basis of previous reports of debris flows. The tributaries studied in detail were the Lava-Chuar Creek, Monument Creek, and Crystal Creek drainages. The fieldwork for this project was completed in March and April 1986.

The frequency of past debris flows was determined from analysis of preserved stratigraphy in the tributaries. Sediments from discrete debris flows were traced longitudinally using characteristic color, lithology, and particle sizes of the preserved sediments. Radiocarbon dating and analysis of scarred trees and historical photographs provided a control on dating the ages of events. Evidence for all events was not necessarily preserved in the tributaries; therefore, estimates provide a minimum frequency of debris flows in the tributary canyons.

Simplified hydraulic formulas were used to calculate flow velocities and discharges for debris flows (Pierson, 1985). Velocities were calculated from runup evidence of the velocity head, which is preserved in sites where an obstacle is oriented perpendicular to the flow direction. Superelevation evidence, which is found where the flow surface is elevated on the outside of bends due to centrifugal forces, was also used to calculate velocities. The methods provide a conservative estimate of the actual velocity of debris flows (Pierson, 1985). Discharge was calculated as the product of velocity and cross-sectional area. Project personnel collected 5- to 10-pound samples of debris-flow matrix for reconstitution of the water content of the debris flow using methods described in Cooley and others (1977) and Gallino and Pierson (1985). Uncertainty in the reconstituted water content by volume for each sample was 1 to 2 percent. Particle-size distributions were obtained by combining sieve data with point-count data obtained in the field. The two methods yield numerically equivalent particle-size distributions (Kellerhals and Bray, 1971).

DEBRIS FLOWS FROM THREE TRIBUTARIES

Evidence for at least five prehistoric debris flows and three historic debris flows is preserved in the Lava-Chuar Creek drainage. Historic debris flows occurred between 1916 and 1966, in December 1966, and between 1973 and 1984. Debris flows have reached the Colorado River on an average of every 200 years during the last 1,500 years and every 20 to 30 years since 1916. Debris flows may reach the Colorado River more frequently because some prehistoric debris flows may not have overtopped the terraces to leave depositional evidence.

The debris flow of 1966 in the Lava-Chuar Creek drainage began as slope failures in the Permian Hermit Shale and Permian and Pennsylvanian Supai Group and traveled 6.5 mi downstream to the Colorado River. The debris flow had a velocity of 12 ft/s and a total discharge of about 4,000 ft^3/s near the Colorado River. The average water content of the flow was estimated to be 22.5 percent, hence the peak sediment and water discharges are estimated to be 3,100 and 900 ft^3/s, respectively. The debris flow was composed of 30 to 35 percent sand and carried boulders that were about 1 to 2 ft in diameter. The largest boulder measured that was transported during the debris flow weighed an estimated 9 tons.

Two debris flows occurred in the last 25 years in Monument Creek drainage. A storm on July 27, 1984, initiated an avalanche and subsequent debris flow that reached the Colorado River. Some evidence indicates an earlier debris flow that occurred in the early 1960's. Older debris-flow deposits were radiometrically dated at about A.D. 1780; however, lack of correlation with downstream deposits precluded any use of this date for determining frequencies of events.

The debris flow of 1984 in Monument Creek drainage began as an avalanche from the Permian Esplanade Sandstone of the Supai Group 2,000 ft above the channel. A 20-foot-high debris dam resulted and had not been breached as of 1986. The debris flow traveled 2.8 mi to the Colorado River at a velocity of 11 to 13 ft/s and had a peak discharge of about 3,800 ft^3/s. The water content of the flow ranged from 27 to 34 percent, and the flow was composed of 30 to 40 percent sand. One boulder that was transported during the flow weighed an estimated 37 tons.

The debris flow of 1984 created a new fan surface at the Colorado River that significantly constricted Granite Rapid. Volume of sediment transported onto the fan and into the river was estimated on the basis of four hypothesized scenarios of the fan geometry after deposition of sediments from the debris flow. The most likely volume of sediment transported onto the fan and into the river is 300,000 ft^3. The debris fan was completely devoid of particles less than 16 mm in diameter in 1986, which suggested that all finer particles (including sand) were transported quickly into the Colorado River. Assuming an average sand content of 35 percent, the estimated volume of sand entering the river is 84,000 ft^3 with a range for all scenarios of 56,000 to 150,000 ft^3. Estimates of the volume of transported sediment and the upstream discharge indicate that the fan was created in 1 to 3 minutes during the first pulse of the debris flow.

The Crystal Creek drainage averaged a minimum of one debris flow reaching the Colorado River every 50 years. A large debris flow in December 1966 (Cooley and others, 1977) has been the only debris flow to reach the Colorado River in this century. Small debris flows that did not reach the Colorado River significantly aggraded the channel and probably deposited sediments that caused larger debris flows to reach the river.

The debris flow of December 1966 in the Crystal Creek drainage began with 11 slope failures in the Hermit Shale and Supai Group and traveled 13 mi to the Colorado River. Calculated flow velocity ranged from 10 to 18 ft/s, and the discharge ranged from 9,200 to 14,000 ft^3/s. Water content of the debris flow ranged from 24 to 33 percent, and the sediments had a sand content of 10 to 15 percent. One boulder transported by the debris flow weighed an estimated 47 tons; transported boulders with diameters in excess of 5 ft were common. Upon reaching the Colorado River, the debris flow created a new fan surface that significantly constricted the Colorado River (Kieffer, 1985).

DISCUSSION AND CONCLUSIONS

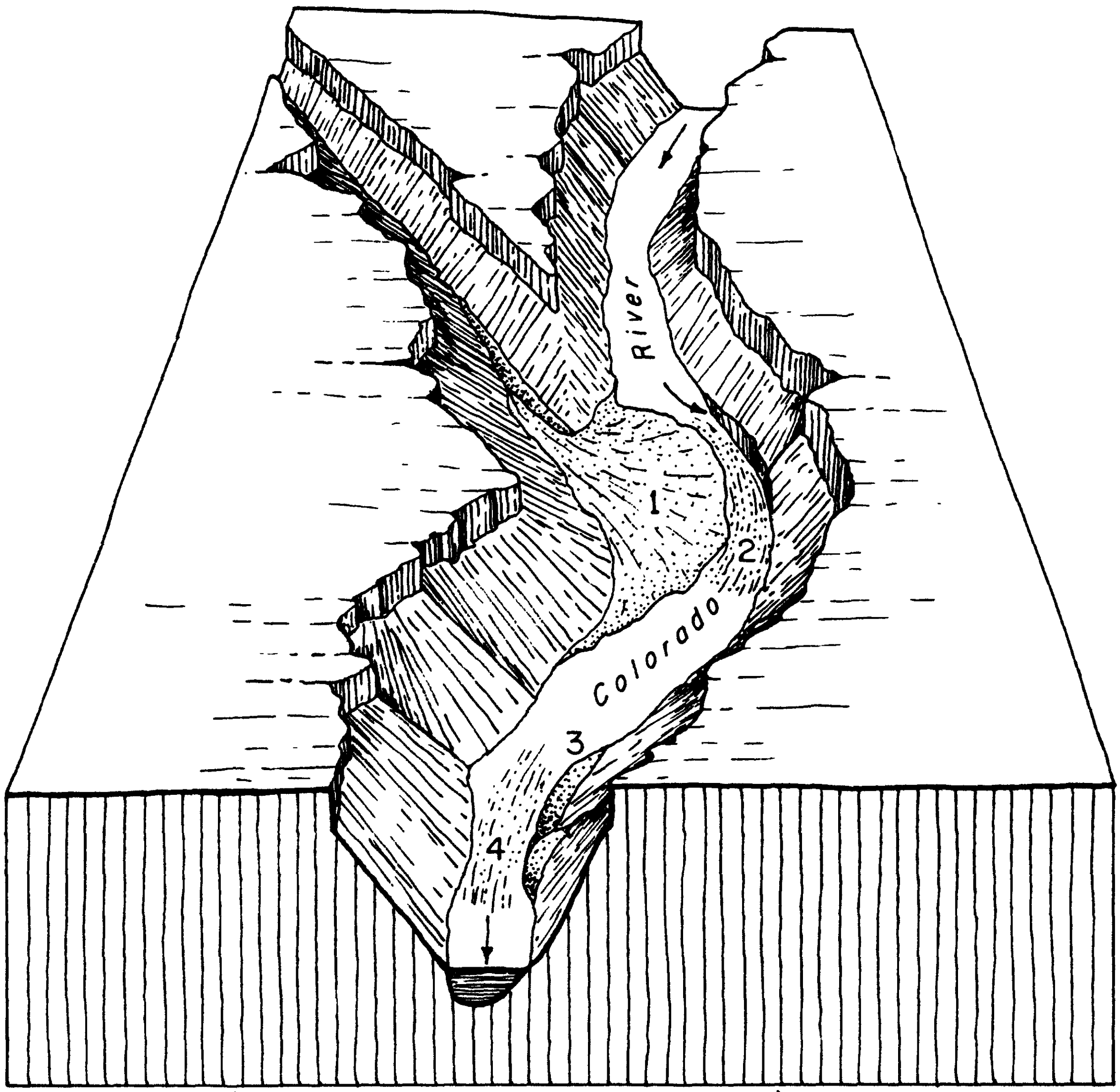
The debris flows had similarities indicative of the cause and nature of debris flows in Grand Canyon National Park. All three debris flows were initiated at slope failures in the Hermit Shale and Supai Group, especially the Esplanade Sandstone in the Supai Group. All debris flows transported a poorly sorted mixture of clay- to boulder-sized particles with water contents that ranged from 23 to 33 percent by volume. The largest boulders transported ranged from 9 tons in the Lava-Chuar Creek drainage to 37 and 47 tons in the Monument Creek and Crystal Creek drainages, respectively. Two of the three debris flows significantly constricted the Colorado River at the tributary mouths. The frequency of debris flows reaching the Colorado River is tentative; however, available data suggest that one debris flow reaches the Colorado River every 20 to 50 years in these drainages. A compilation of historical information on flow events from Grand Canyon tributaries, however, indicates that debris flows occur more frequently throughout the park.

The bedrock geology of Grand Canyon National Park provides an ideal location for the initiation of debris flows. The high relief combined with differential strength properties of the rocks results in a high potential for slope failures. The most common sources of mobilized sediments for debris flows are the Permian Hermit Shale and underlying Esplanade Sandstone of the Supai Group. Other sources include in descending order the Permian Kaibab Limestone, Toroweap Formation, and Coconino Sandstone (sequence overlies the Hermit Shale); Cambrian Muav Limestone and underlying Bright Angel Shale; and Quaternary basalts in the western Grand Canyon. Dispersive and swelling clays in some of these formations aid in the initiation of debris flows.

The magnitude and frequency of debris flows control the hydraulics of the Colorado River in Grand Canyon National Park. Debris flows from the small tributaries aggrade fans that typically force the river against the opposite wall of the canyon (fig. 2). The ability of small drainages, such as Monument Creek, to form hydraulic controls (rapids) on one of the largest rivers in the United States is hydrologically significant. The debris fans also cause flow separation zones conducive to deposition and storage of sand on beaches. Reworking of debris fans by discharges of the Colorado River creates secondary riffles or rapids (fig. 2). Debris flows are the source of large volumes of sand entering the river at discrete points, although the debris flows occur infrequently. Knowledge of the magnitude and frequency of debris flows is necessary for any understanding or long-term estimates of sediment transport in the Colorado River in Grand Canyon National Park.

REFERENCES CITED

Beverage, J. P., and Culbertson, J. K., 1964, Hyperconcentrations of suspended sediment: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 90, p. 117-126.



(Modified from Hamblin and Rigby, 1968)

EXPLANATION

1 TRIBUTARY DEBRIS FAN

2 RAPID CONTROLLED BY LARGE IMMOBILE BOULDERS

3 DEBRIS BAR (synonymous with "island" or "rock garden")

4 RIFFLE OR RAPID CAUSED BY DEBRIS BAR

Figure 2.--Geomorphic features of a typical rapid controlled by debris flows on the Colorado River.

Cooley, M. E., Aldridge, B. N., and Euler, R. C., 1977, Effects of the catastrophic flood of December, 1966, North Rim area, eastern Grand Canyon, Arizona: U.S. Geological Survey Professional Paper 980, 43 p.

Costa, J. E., 1984, Physical geomorphology of debris flows, in Costa, J. E., and Fleisher, P. J., editors, Developments and applications of geomorphology: Berlin, Springer-Verlag Publishing Co., p. 268-317.

Gallino, G. L., and Pierson, T. C., 1985, Pollalie Creek debris flow and subsequent dam-break flood of 1980, East Fork Hood River basin, Oregon: U.S. Geological Survey Water-Supply Paper 2273, 22 p.

Hamblin, W. K., and Rigby, J. K., 1968, Guidebook to the Colorado River, Part 1, Lees Ferry to Phantom Ranch in Grand Canyon National Park: Provo, Utah, Brigham Young University Geology Studies, v. 15, part 5, 84 p.

Kellerhals, R., and Bray, D. I., 1971, Sampling procedures for coarse fluvial sediments: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 97, p. 1165-1180.

Kieffer, S. W., 1985, The 1983 hydraulic jump in Crystal Rapid—Implications for river-running and geomorphic evolution in the Grand Canyon: Journal of Geology, v. 93, p. 385-406.

Pierson, T. C., 1985, Initiation and flow behavior of the 1980 Pine Creek and Muddy River lahars, Mount St. Helens, Washington: Geological Society of America Bulletin, v. 96, p. 1056-1069.