Glancy + Harmsen, 1975

A Hydrologic Assessment of the September 14, 1974, Flood in Eldorado Canyon, Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 930

Prepared in cooperation with the U.S. National Park Service

Aerial view of Eldorado Canyon looking upstream (west) on September 30, 1974.

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By PATRICK A. GLANCY and LYNN HARMSEN

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A presentation of hydrologic data and interpretations, eyewitness accounts of destruction, and documentation of flooding

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CONVERSION FACTORS

For those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
Length		
inches (in.)	25.4	millimetres (mm)
	.0254	metres (m)
feet (ft)	.3048	metres (m)
yards (yd)	.9144	metres (m)
miles (mi)	1.609	kilometres (km)
Area		
square feet (ft^2)	.0929	square metres (m^2)
acres	4047	square metres (m^2)
square miles (mi^2)	2.590	square kilometres (km^2)
Volume		
cubic feet (ft^3)	28.32	cubic decimetres (dm^3)
	.02832	cubic metres (m^3)
cubic yards (yd^3)	.7646	cubic metres (m^3)
acre-feet (acre-ft)	1233	cubic metres (m^3)
Flow		
feet per second (ft/s)	.3048	metres per second (m/s)
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
miles per hour (mi/hr)	1.609	kilometres per hour (km/hr)
Mass		
tons (short)	.9072	tonnes (t)
Density		
pounds per cubic foot (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)

A HYDROLOGIC ASSESSMENT OF THE SEPTEMBER 14, 1974, FLOOD IN ELDORADO CANYON, NEVADA

By Patrick A. Glancy and Lynn Harmsen

ABSTRACT

A devastating flash flood of thunderstorm origin struck Eldorado Canyon, a 22.9-square-mile drainage with a history of flooding, in southern Nevada, at about 2:30 p.m., September 14, 1974. The flood killed at least 9 people, destroyed 5 trailer homes and damaged many others, obliterated a restaurant, destroyed 38 vehicles, 19 boat trailers, 23 boats, half of the boat-docking facilities, and the gas dock. The severe runoff resulted from intense basinwide rain and hail at rates up to 3 inches of precipitation per half an hour. The storm moved downbasin and generally increased in intensity, which compounded runoff rates. Peak discharge was estimated to be 76,000 cubic feet per second just upstream from the developed area near the canyon mouth. About 2,000 acre-ft of runoff reached Lake Mohave, the canyon terminus. Runoff dumped an estimated 70,000 cubic yards (about 100,000 tons) of inorganic sediment in Lake Mohave and throughout the lowermost canyon reach. It also delivered an estimated 4 acre-ft of organic or floating debris to Lake Mohave. The inorganic sediment was estimated to be less than 1 percent boulders, 40 to 60 percent gravel, 20 to 40 percent sand, and 10 to 25 percent silt-clay. Although the recurrence interval for this magnitude runoff is great, a similar flood could occur in any given year. These types of flash floods, although common in the desert southwest, are not fully understood and are frequently ignored, and therefore the danger to developed areas is not decreased. With proper understanding and informed planning, the risk of damage from similar floods in the future can be greatly reduced.

INTRODUCTION

"It first looked like a dark heavy cloud of dust. Looked like a solid wall moving down. As it came down, every vehicle was pulled into this muck. I saw 4–6 vehicles in the debris. The wall of muck appeared to go under the lake when it hit the water, causing a swell of water at the surface." Lemuel Washington, a weekend fisherman from Las Vegas, vividly described his impression of the onrushing flash flood of September 14, 1974, at the mouth of Eldorado Canyon. In many ways the flood Mr. Washington witnessed probably resembled a dozen or more similar floods that occurred throughout Nevada during the summer of 1974. Hundreds of these floods have occurred during historic times though many have not been observed by man. The Eldorado Canyon flood was unique because it occurred in a popular recreation area, and several accounts by witnesses have helped to document the event.

Although hydrologists tend to refer to the Eldorado Canyon flood as "a spectacular hydrologic event," Dick Mayne, Clark County Coroner, and other members of the local search-and-rescue squad call it "a catastrophe." Without its disastrous consequences, the flood probably would have gone generally unnoticed except by those who are interested in "spectacular hydrologic events." Everyone agrees that the loss of life and property damage was a regrettable tragedy; however, the tragedy has triggered renewed efforts by individuals and agencies to reduce the risks involved through better planning based in part on data obtained from the Eldorado Canyon flood. These data should help those concerned to reach an improved understanding and knowledge of the forces, power, and characteristics of natural processes.

Losses resulting from the flood of September 14, 1974, at Eldorado Canyon are difficult to determine accurately. The complex array of physical losses and expenditures will ultimately be resolved; however, damages caused by the loss of life can never be accurately assessed or compensated.

Almost all significant flood damage, with the exception of highway damage along Techatticup Wash, occurred within the Eldorado Canyon Resort area near the canyon mouth. At least nine people lost their lives and several others may still be missing. Known dead include four men, three women, and two children. The first three bodies were recovered from floating debris at the canyon mouth during the first three days of search operations. Five other victims were recovered between 14 and 38 days after the flood. Their bodies were discovered floating in Lake Mohave as much as 2½ miles north or south of the former boat landing.

The restaurant was totally destroyed. Five trailer houses were totally destroyed, some have not been found, and a number of others were seriously damaged. Nine cabins near the base of the north canyon wall were destroyed, and 38 vehicles and 19 boat trailers were lost. Twenty-four boat-docking slips were obliterated and 23 boats were lost. Figure 12 shows changes to the boat docks, the general location of a number of other specific cultural features, and qualitatively describes the nature of the damage sustained. Several photographs of damage to structures and vehicles near the canyon mouth are shown in figure 1. Figure 16 shows an overall view of the heavily damaged trailer park area. When viewing the damage shown in figures 1 and 16, keep in mind that the vehicles and structures receiving the greatest damage are not visible because they were either totally demolished or buried in Lake Mohave. Therefore, the photographs give a somewhat conservative view of the effects of the flood.

Flooding is no newcomer to Eldorado Canyon. Ample evidence of past flooding was known to local inhabitants (see section on "History"). Recent (1973) efforts by the National Park Service to revise and rearrange recreational and residential facilities at the site, reportedly to alleviate flood hazards, are a matter of public record.

THE SETTING

Eldorado Canyon is an arid, barren, rugged 22.9-mi^2 area tributary to Lake Mohave on the Colorado River. It lies in the Sonoran Desert section of the Basin and Range physiographic province as defined by Fenneman (1931). The general location of the basin and its relation to surrounding cultural features is shown in figure 2. General basin character is shown in the frontispiece. The lower end of Eldorado Canyon is also pictured in figure 5. Figure 10, another aerial photograph, shows physical characteristics of the Eldorado Canyon ter-

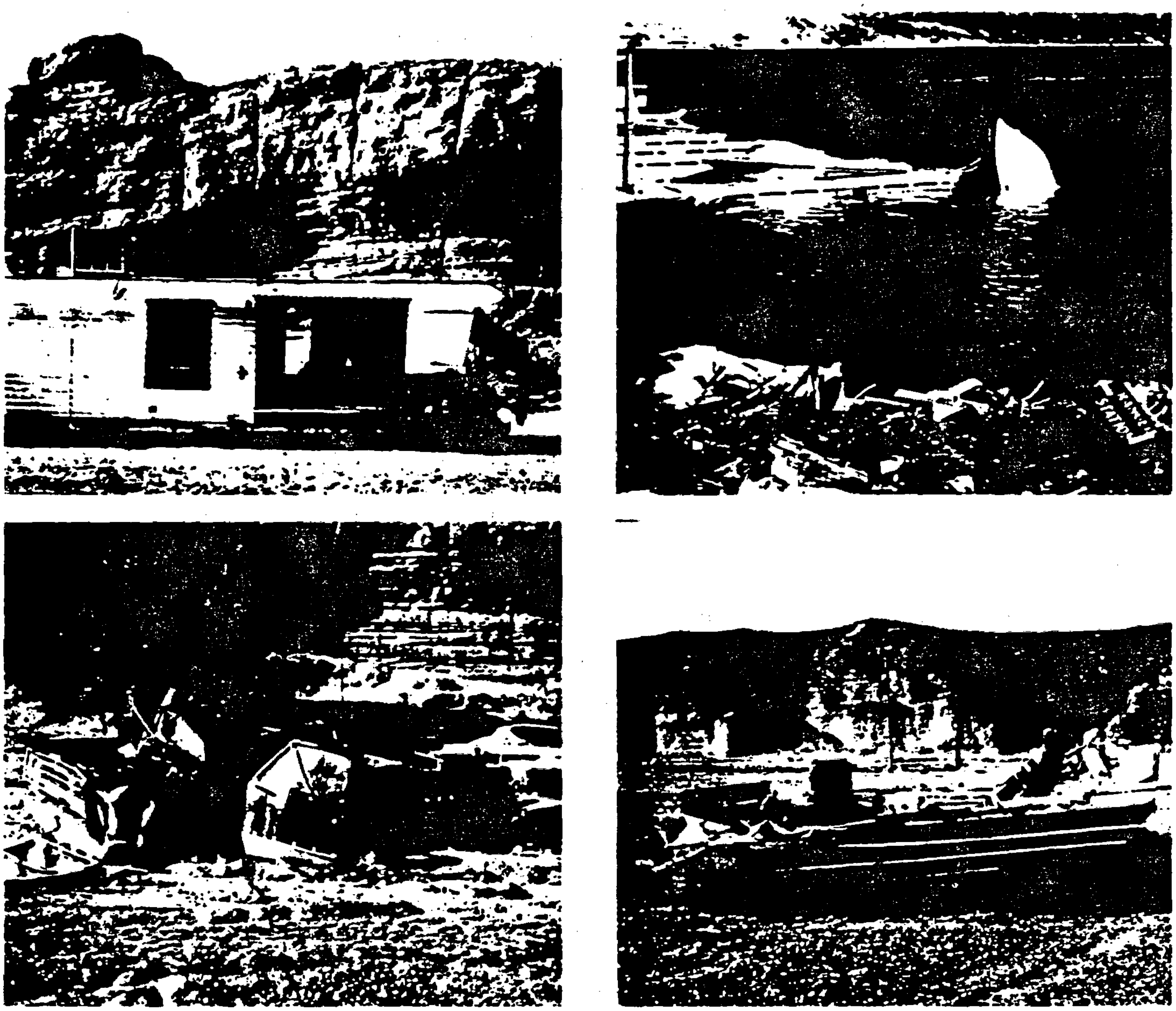


FIGURE 1.—Flood-damaged trailer, truck, and boats.

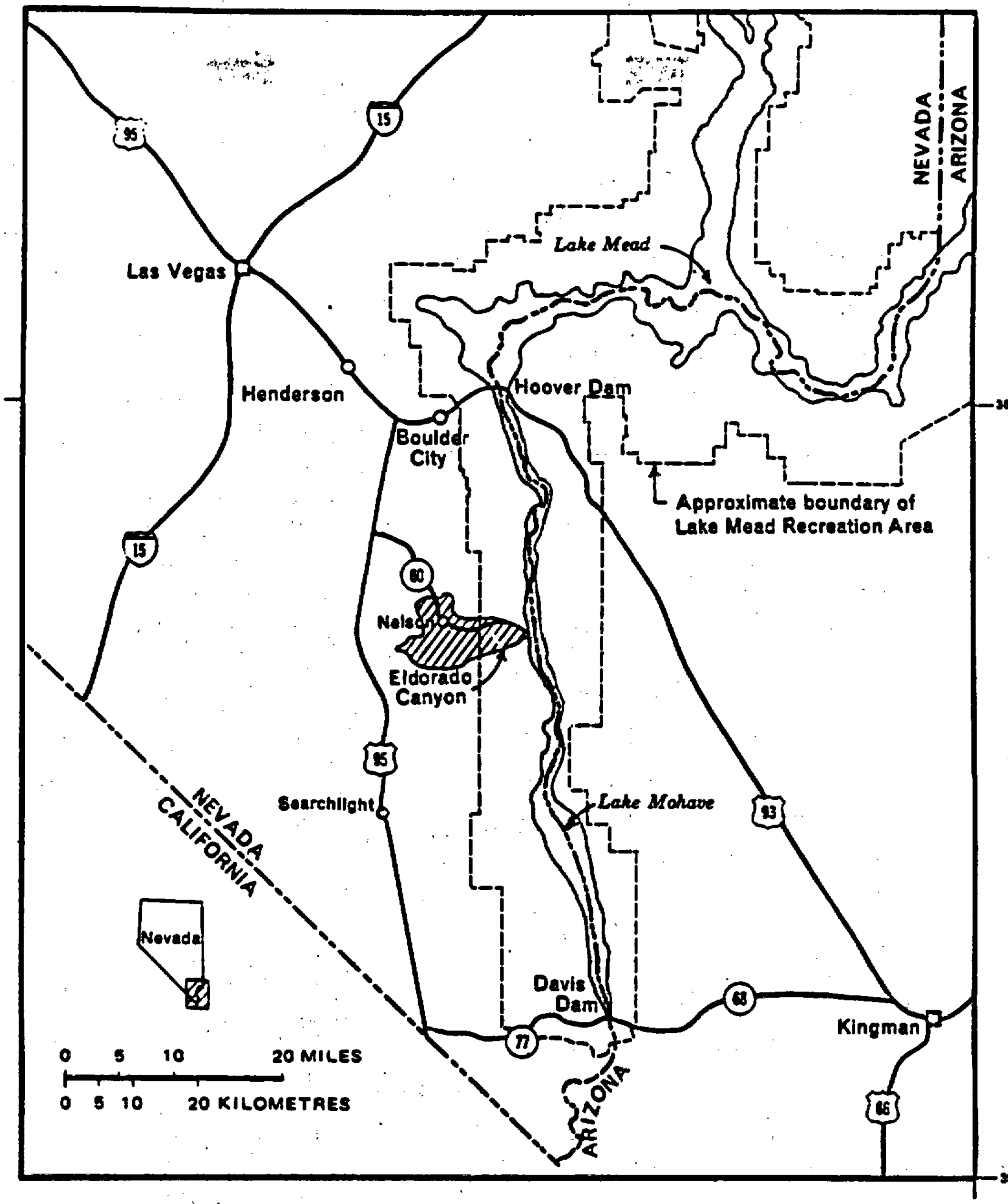


FIGURE 2.—Location of area described in this report.

minus as well as drainages to the north and south.

Figure 3 shows the areal extent of the drainage basin, its topography, and the main cultural features, and delineates major tributary subareas that converge to form a single channel only a short distance above the canyon mouth.

The topographic contours of figure 3 show the basin as hilly to mountainous in upstream areas. Near its mouth, the basin contains a series of east-west-alined, canyonlike, wide-bottomed arroyos incised into a moderately steep, eastward-sloping alluvial surface.

Nelson, a village of only a few tens of permanent residents, is in the upstream, northwestern part of the drainage. Eldorado Canyon Resort, with a few permanent residents and a highly variable population of visitors, is at the downstream, eastern terminus of the basin.

Eldorado Canyon Resort, within the Lake Mead National Recreation area, lies about 50 highway miles southeast of Las Vegas. Therefore, the area is a popular recreation attraction to many water sport enthusiasts, and the canyon-mouth cove provides a major boat land-

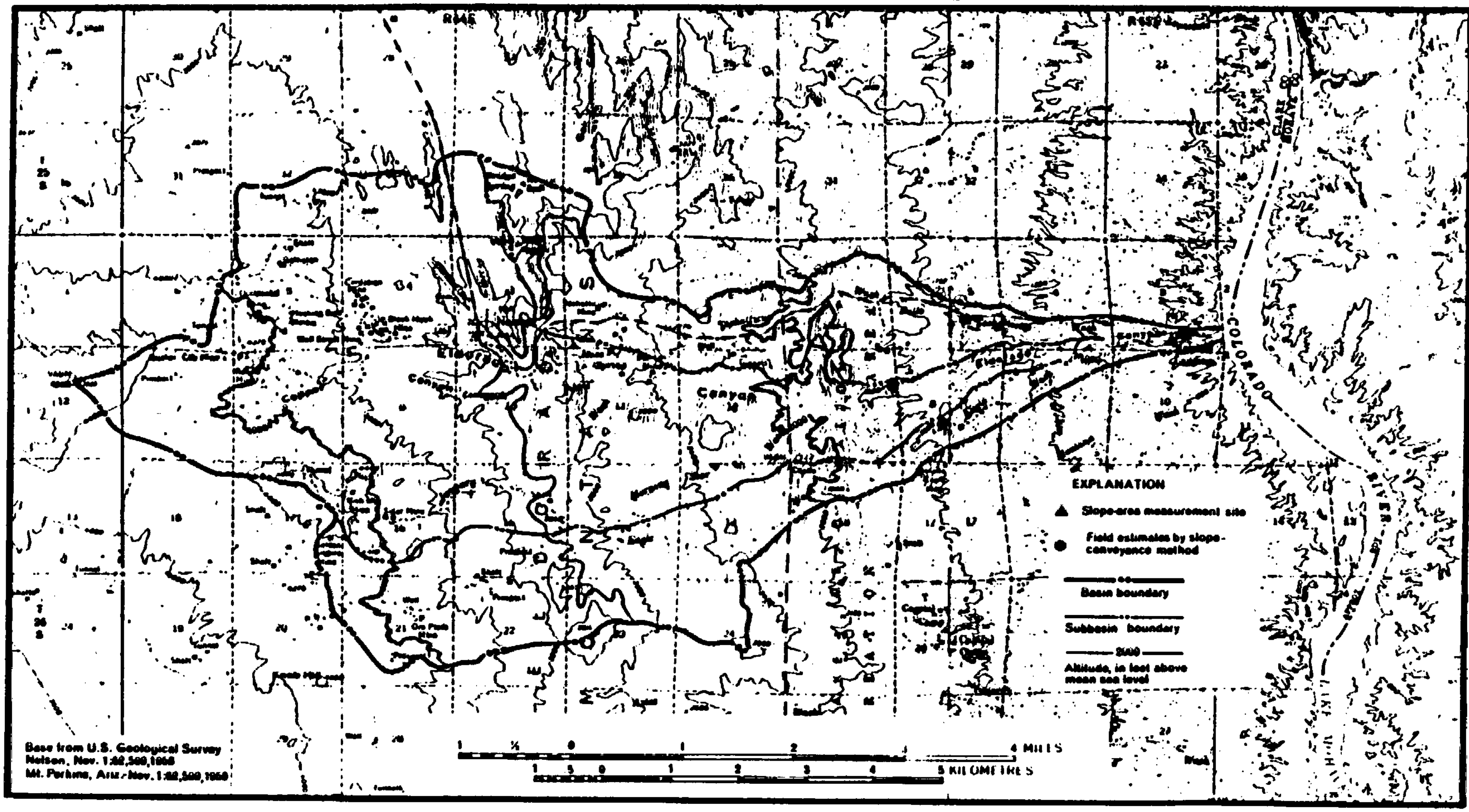


FIGURE 3.—Eldorado Canyon basin showing major tributary subbasins, area-altitude distribution, and location of streamflow estimate sites.

ing site for Lake Mohave. Most of the facilities are on the main canyon floor, within an obvious flood plain. This subjects most residents, employees, and visitors to a high degree of risk during major floods. However, floods mainly occur during relatively short and infrequent periods of intense rainfall and runoff; the short periods of hazard contrast sharply with generally prolonged periods that are undeniably safe.

HISTORY

Eldorado Canyon was the site of some of the earliest settlements in what is now southern Nevada. It was first settled by early miners, prospectors, and mill operators in about 1861, and in 1867 Camp Eldorado was established at the canyon mouth on land now beneath the surface of Lake Mohave as an outpost of the U.S. Army (Casebier, 1970, p. 1 and 19). The canyon has since been the site of several mining booms and busts, accompanied by erratic fluctuations in population. During recent times, it has been popular mainly as a recreation area.

Eldorado Canyon flooding is the most important aspect of the basin's history related to this report. Numerous floods are rumored to have occurred, but almost no known hydrologic data relating to these floods have been discovered. A search of available newspaper files for information on dates and details of flooding was beyond the practical scope of this investigation. Several persons recently interviewed generally recall floods in Eldorado Canyon as follows: Mr. G. F. Gatzke, National Park Service employee, and resident of the area since 1947, recalls flooding in about 1952, 1959, 1960, 1970, and 1972 (oral commun., September 1974). Mr. M. Emry, longtime resident (oral commun., September 1974), recalls reports of a very large flood in 1904 that caused heavy damage to the ore milling works at the canyon mouth, and a major flood in 1960 that heavily damaged the concessionaire's store-restaurant he operated in the canyon mouth (a similar store-restaurant was completely destroyed by the Sept. 14, 1974, flood). Photographs of flood damage provided by the National Park Service (written commun., October 1974) document a flood on November 6, 1960, with evidence of severe damage and extensive sediment deposits (13,000 yd^3, according to one of the photograph captions).

The scanty, incomplete, possibly inaccurate, and generally unverified reports listed above nonetheless categorize at least the canyon mouth area as one that has had a number of floods during the relatively short historical (about 70 years) period. A search of newspaper files would probably add more floods to those listed above.

BASIN CHARACTERISTICS

SLOPE

The Eldorado Canyon drainage slopes generally from west to east. Quantitative data on the area-altitude distribution are summarized in table 1. Both figure 3 and table 1 show that about 70 percent of the basin's area is concentrated in the 2,000- to 4,000-ft altitude zone

TABLE 1.—*Approximate area-altitude distribution of Eldorado Canyon basin*

Altitude zone (ft)	Area (mi^2)	Percentage of total basin area
4,000–4,898	2.7	11.8
3,000–4,000	9.3	40.6
2,000–3,000	7.0	30.6
1,000–2,000	3.6	15.7
647–1,000	.3	1.3
Total	22.9	100.0

Slope data were compiled from U.S. Geological Survey 15-minute 1:62,500-scale Nelson and Mt. Perkins quadrangle maps. These data are plotted in figure 4. The figure shows that average basin slope and mean channel slopes of the three major tributaries are very similar, and are generally quite steep. The profiles show that all three tributaries have similar, generally uniform slopes throughout their lower 4 mi of reach. This uniformity of slope also continues upstream throughout most of the length of Eagle Wash and Eldorado Canyon; Techatticup Wash is noticeably irregular in slope and profile above the lower 4-mi reach. The generally continuous steep slopes, and lack of a pronounced profile concavity, are anomalous compared with most stream systems. All three tributary profiles generally adhere to a 300- to 400-ft/mi slope, or greater, throughout most of their length, including the terminal reach of Eldorado Canyon that carries their combined flow. These consistently steep channels, with only minimal flattening in the drainage terminus, are an efficient flushing system that produces rapid runoff.

A view of overall topography including hillside slopes, minor tributaries relative to major channel slopes, and general landscape character in the lower part of the basin is shown in the frontispiece and in figure 5.

GEOLOGY

Geology of the drainage basin was mapped by Longwell (1963); his map, in condensed form, is also reproduced as part of the Clark County geologic map of Longwell, Pampeyan, Bowyer, and Roberts (1965). These publications indicate that geologic units in the

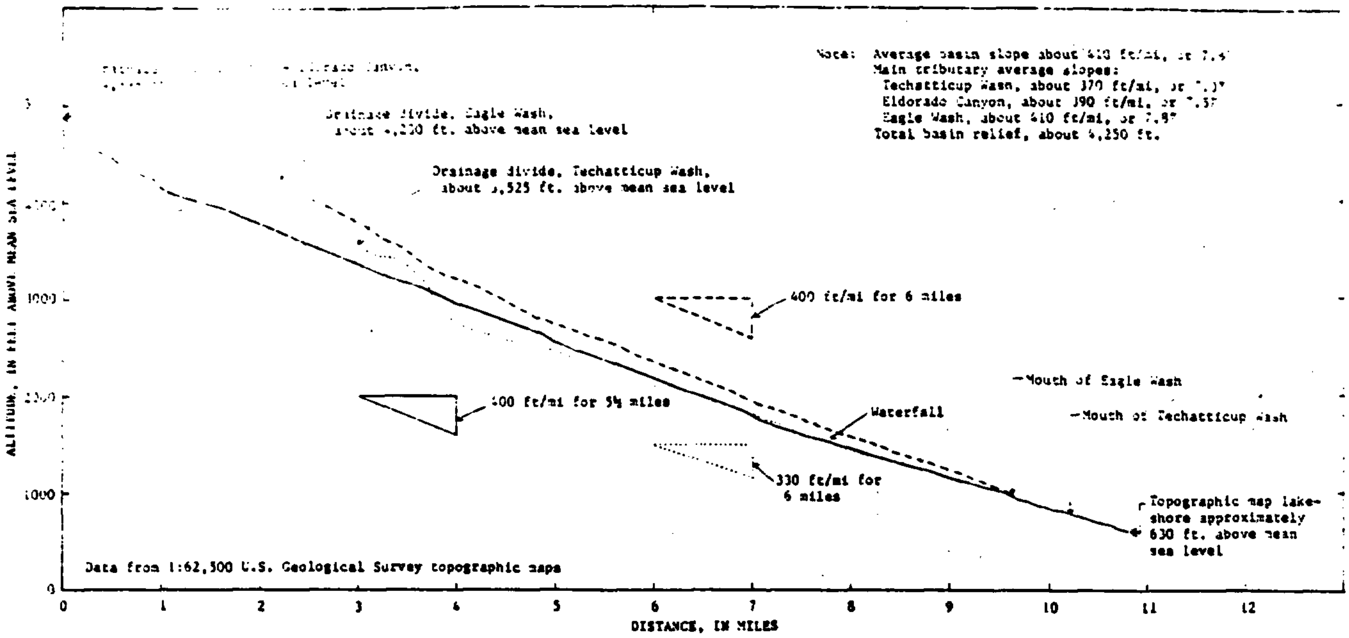


FIGURE 4.—Longitudinal profiles of main drainage channels.

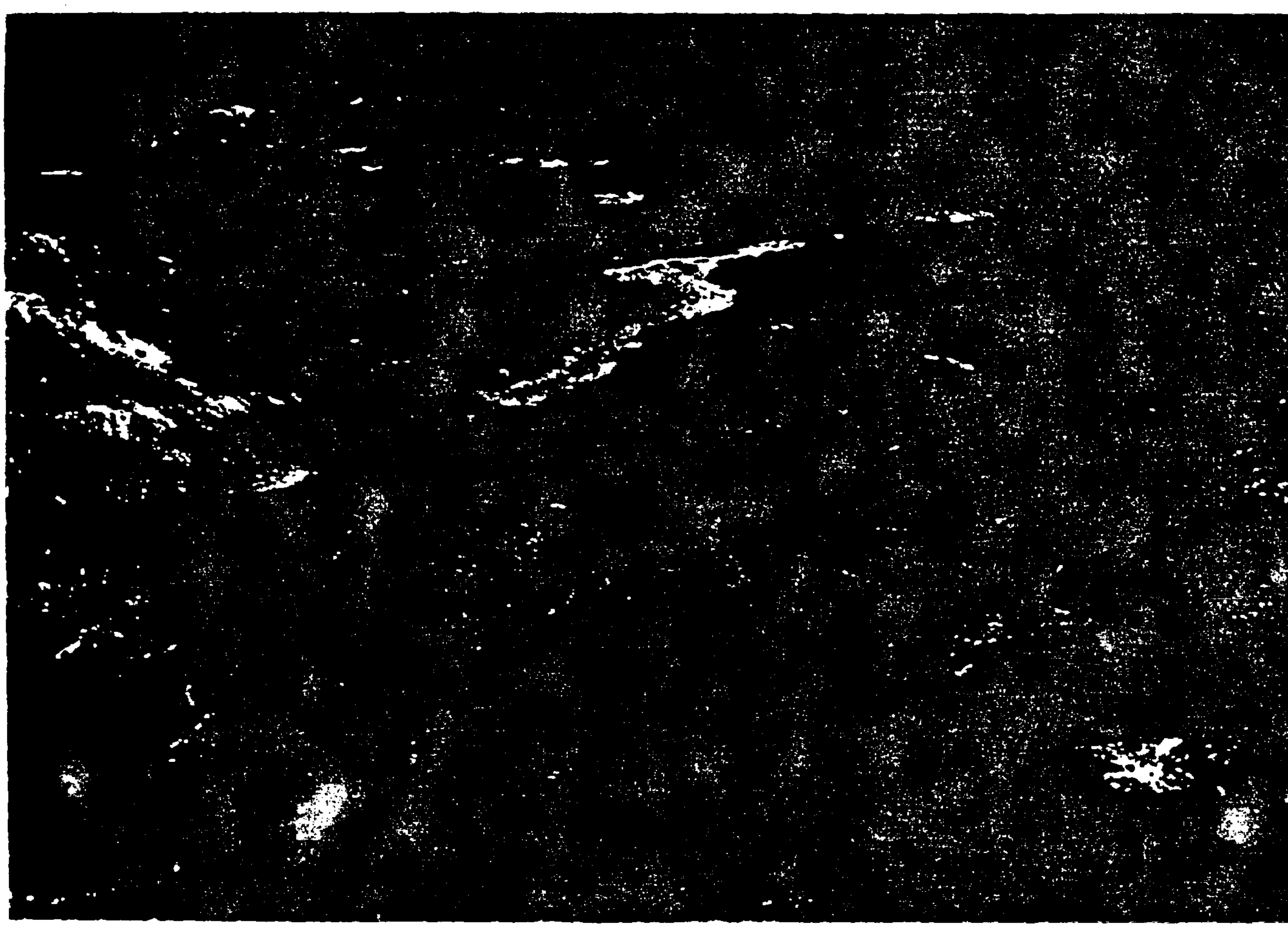


FIGURE 5.—Eastward aerial view of lower Eldorado Canyon. Lake Mohave in background.

basin include extensive exposures of consolidated rocks in the highlands of Eldorado basin, and a much smaller area of consolidated, semiconsolidated, and unconsolidated alluvium in the lower part of the drainage.

The consolidated rocks consist of Precambrian metamorphic and igneous rocks, some late Mesozoic and Tertiary igneous intrusive rocks, and a variety of Tertiary volcanic rocks. They are extensively deformed structurally, mainly by a system of north-south-trending faults. Consolidated-rock areas commonly consist of bare rock highland masses, or bedrock thinly mantled by soil or rock fragments derived from the underlying parent material. Steep slopes and lack of substantial vegetal cover render the thin soil and rock-fragment mantle very susceptible to erosion, particularly by intense runoff such as that which occurred during the storm of September 14, 1974.

Alluvium, as mapped by Longwell (1963, pl. 1), is exposed in only the lower 2 mi of the drainage basin. Much of this alluvium is consolidated to some degree and therefore is fairly resistant to erosion. However, unconsolidated alluvium also mantles all the main stream channels and many minor stream courses throughout most of their length. A thin mantle of unconsolidated alluvium also covers many upland areas. Therefore, a large volume of alluvium is concentrated along stream channels and on interfluvial slopes throughout the drainage where it is available for transport, depending on surface slope, vegetal cover, gravel armoring of the deposit surface, and intensity of the runoff.

VEGETATION

Vegetation is generally very sparse throughout the drainage basin. Plants include cholla and barrel cactus, creosotebush, some species of yucca, an occasional mesquite tree along arroyo floors, and other unidentified species, many of which probably belong to the *atriplex* genus. Greatest plant densities seem to occur in the highland areas of the basin (fig. 26), and lowest densities seem characteristic of the downstream areas (figs. 22–25). General views of vegetation densities in lower basin areas are shown in figure 5 and the frontispiece.

The general absence or scarcity of plants throughout the basin increases the speed and eroding ability of runoff.

THE STORM

The flood of September 14, 1974, in Eldorado Canyon was the direct result of an intense convective thunderstorm. A meteorological report of the storm is being prepared by the U.S. National Weather Service (Gerald Williams, written commun., October 1974). Therefore, this report will only briefly summarize known characteristics of the storm to set a stage of basic understanding for the following discussions of flooding and sediment transport.

Several characteristics of the storm had a critically important bearing on the nature of the flooding and its resultant catastrophic damage. These characteristics include: (1) time of occurrence, (2) total quantity of precipitation, (3) precipitation intensity, (4) storm track, and (5) nature of storm activity at the mouth of Eldorado Canyon during the early period of flooding.

Rainfall in the upper basin apparently began sometime around 1:00 p.m. (G. F. Gatzke, oral commun., September 1974), and the most intense rainfall at Nelson was around 1:45–2:00 p.m. (Thomas Jester, Nelson resident, oral commun., September 1974). Jester recalled a total storm duration of about 1½ hours at Nelson, which generally agrees with observations of A. R. Methvan, another Nelson resident. Methvan recorded 1.9 in. of total storm precipitation (oral commun., September 1974). According to Jester, storm clouds came into the Nelson area from the south. The clouds then apparently swung around near the north limits of the drainage divide when precipitation began, and subsequently passed over Nelson moving in a southeastward (downstream) direction during the period of intense precipitation. Several other observers also noted the general downbasin movement of the storm center. Both Jester and Methvan estimated the period of greatest precipitation intensity as less than half an hour. Eyewitness accounts near the canyon mouth indicate that greatest precipitation intensity spanned a quarter to half an hour.

Several excerpts from a preliminary draft of the U.S. National Weather Service report (Gerald Williams, written commun., October 1974) further characterize the storm as follows:

> This flash flood was caused by record-breaking rainfall from an isolated thunderstorm cell that moved slowly down the drainage channel in a way that maximized flooding. * * * Duration of rainfall was short, generally less than one hour. Intensities were very high—at least three inches per hour and as high as six inches per hour for ½ hour.
>
> The storm appears to have moved downstream at the rate of about 5 to 10 miles per hour, coinciding with the movement of surface runoff.

Highest rainfall intensities and quantities apparently occurred in middle to lower parts of the basin, rather than at the higher altitudes. On the basis of experience with other recent flash floods in Nevada, this characteristic is not uncommon, and may be more normal than abnormal. If true, hazard zoning for flooding probably should not relate flood potential strictly to altitude or differences in altitude, in the generally accepted "orographic influence" philosophy.

Eyewitness accounts describing the arrival of the very destructive leading edge of the flood front all describe it as being accompanied by intense rainfall.

thunder, and hail at the canyon mouth. The time of intense destructive flooding and precipitation at the canyon mouth is placed by most eyewitness accounts at about 2:30 p.m.

Therefore, four storm characteristics were critical to flooding and damage. The storm and flooding occurred during the early afternoon on a Saturday, presumably at a time of moderate use and occupancy at the canyon mouth. The high precipitation intensity, combined with the basinwide nature of the storm, yielded large quantities of rainfall during a short period and maximized the flooding. The downstream pattern of storm movement caused intense rainfall and runoff to be superimposed on downstream flood waves, compounding the peak intensity of surface runoff. Finally, the intense rainfall and hail at the canyon mouth probably caused people to run for or remain under shelter rather than leave the canyon floor.

RUNOFF

FLOW RATES

Peak flow rates are important to the process of understanding the hydrology of flash flooding, and to help categorize different flash floods according to magnitude and intensity. At Eldorado Canyon, the major damage to lives and property was caused by the leading edge of the flood runoff. Peak flow apparently followed, rather than coincided with, the initial surge of the flood. Therefore, peak flow estimates probably do not bear directly on damage and casualties. This is not always the case in general flooding or even in flash flooding, where peak flow can be a more important factor with regard to human losses. Peak flow rates are also important when establishing design criteria to cope with future floods. Peak flow rate is one of the few hydraulic parameters which generally can be computed or estimated with reasonable accuracy after the flood has passed. Therefore, we attempted to assess peak flow rates at Eldorado Canyon.

The peak discharge was computed for the main channel just above the trailer parking area (fig. 15 and table 2), using the standard U.S. Geological Survey indirect slope-area method (Dalrymple and Benson, 1967). This technique generally gives reasonable results when prevailing flow conditions are within the limitations for which the technique applies. Flow conditions in Eldorado Canyon may not have been ideal for proper application of the slope-area method; therefore, the peak flow computed may be considerably in error. Some factors that may have caused serious errors in the measurement include: (1) unsteady flow, (2) abnormally high sediment concentrations, causing high fluid viscosity, and (3) a cross-sectional flow area, at the time high-water lines were deposited, that differed from the area determined later at the time of the indirect measurement. These factors are generally influential to varying degrees in peak-flow measurements of most, or all, flash floods in the desert southwest. Nonetheless, the slope-area method is the best available technique.

The slope-area method was applied to a situation where steady-state flow may not have been dominant;, however, because the state of flow was unknown, a steady-state condition was assumed. Very high sediment concentrations were apparently associated with the initial flood surge (see section titled "Sediment Transport Characteristics"), but concentrations were probably much lower during later peak flows. In any event, high water lines, which provide the key basic data for slope-area determinations, were obviously created by flow much more dilute than a viscous mudflow.

After considering the factors discussed above, the 76,000 ft³/s computed is the best estimate available at present. The peak discharge plots close to a curve developed by Matthai (1969) for maximum discharges in relation to drainage areas in the United States (fig. 6).

There are at least two indications the estimate may be too high. (1) The mean velocities calculated for the two downstream cross sections of the slope-area measurement were 34 and 39 ft/s. These exceed the known mean

TABLE 2.—*Summary of hydraulic data resulting from peak-flow estimates*

Determination type and location[1]	Estimated peak discharge (ft³/s)	Measured cross-sectional area (ft²)	Estimated mean velocity (ft/s)	Approximate tributary area (mi²)	Estimated unit runoff (ft³/s/mi²)
Slope-area method					
Eldorado Canyon below Eagle and Techatticup Washes	76,000	(2) 3,030; 2,230; 1,920	(2) 25; 34; 39	22.8	3,300
Slope-conveyance method					
Eldorado Canyon above confluence with Eagle and Techatticup Washes	24,000	1,010	24	13.0	1,600
Eagle Wash near mouth	25,000	807	31	4.5	5,600
Techatticup Wash near mouth	11,000	421	26	3.2	3,400

[1]Measurement sites shown in figure 3.

[2]Values for individual cross sections.

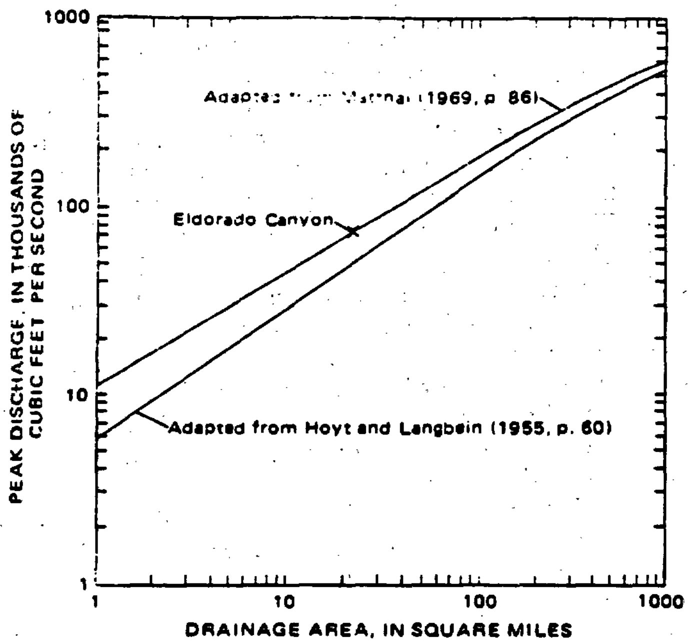


FIGURE 6.—Maximum water discharges in relation to drainage areas in the United States.

velocities, and most point velocities in natural channels except for some flood waves after dam failures. (2) At the time high water lines were created, an unknown quantity of sediment was passing through the slope-area reach as bedload. This bedload covered the channel floor to some unknown depth and thereby reduced the cross-sectional area if minimal channel scour is assumed to have prevailed at that time. The possible error in cross-sectional area would thereby have caused an indeterminate error in the peak flow estimate.

Field estimates were made of peak flow rates in the lower reaches of the three major tributaries, above the slope-area site, using the slope-conveyance technique. This technique is less accurate than the slope-area method. Results of these estimates are also shown in table 2. If the slope-conveyance estimates are added together, and their sum is adjusted for assumed flow pickup between these measurement sites and the slope-area site, a peak flow estimate of 70,000 to 80,000 ft^3/s is indicated. This mathematical approach is justified only if the peak flows of the tributaries contributed to the main trunk system with the proper timing to allow direct summation. Such a situation would normally be unlikely; however, the nature of this storm, with its downstream movement and the apparent occurrence of greatest rainfall intensities in the lower parts of the drainage basin, tend to favor a cumulative effect from the tributary peaks.

Flow velocity can be estimated in the canyon constriction above the site of the destroyed restaurant (fig. 12), if the estimated 76,000-ft^3/s peak flow is assumed to have occurred at that location. The high-water profile and preflood topographic map suggest an average flow depth of about 20 ft within this cross section. For this depth, the cross-sectional flow area would have been about 1,800 ft^2. The resultant mean velocity would have been about 42 ft/s, similar to velocities in the slope-area reach (table 2).

The flow rate and velocity of the damaging initial flood surge at Eldorado Canyon cannot be determined because later flow apparently erased high water lines of the initial surge. The character and effects of the initial surge are discussed in greater detail in following sections.

FLOOD WAVE CHARACTERISTICS

Specific details of the flood waves are of special interest because they caused most of the property damage and apparently were instrumental in most of the deaths. Dramatic descriptions by eyewitnesses of the arrival of the initial flood wave are included in the section entitled "Sediment Transport Characteristics." However, the intensity of local runoff near the canyon mouth was apparently impressive prior to the arrival of the first damaging flood pulse. Eyewitness John Gallifent observed heavy runoff from his south-facing trailer window. The trailer was parked along the north canyon wall in the area just downstream from the point where the highway access road descends to the canyon floor (fig. 12). Gallifent became alarmed when he noted abnormally large flows of water pouring into the canyon from numerous rills and small gullies along the south canyon wall. He concluded that such heavy flows from minor tributaries of minimal drainage area foretold even greater runoff from upstream. He had just enough time to escape afoot to higher ground. Lemuel Washington also observed local runoff on the canyon floor near the canyon mouth prior to arrival of the initial flood surge. He characterized it as "a good stream * * * like a small river." Mrs. Kirby L. Koop described the local runoff along the canyon floor as knee- to thigh-deep before the first major wave arrived.

Kirby L. Koop watched the approach of the initial flood surge from near the icehouse area (fig. 12). He first saw it at a distance of about 100 yd. He recalled the dull thuds of cars caught up in the surge striking the canyon walls. According to Koop, when the mass of debris and water arrived at the preflood shoreline of Lake Mohave, it possessed such momentum that it appeared to "hydroplane" over the lake surface as far as the boat dock gangway (a distance of 100 to 150 ft, scaled from fig. 12). The mass then seemed to fall vertically into the lake.

Lemuel Washington's recollection is somewhat different. His statement to the National Park Service says, "* * * the wall of muck appeared to go under when it hit the water, causing a swell of water at the surface. Then I saw boats floating, bouncing, cracking, and saw a station wagon come to the surface and go back again."

Both Washington and Koop described great turbulence as the flood flow entered the lake. Washington mentioned "* * * the up-surge* * * coming back in full of debris." Koop's statement to the National Park Service described a truck in the flood flow ramming and breaking the boat dock. He said that the flood-surge turbulence then "* * * started to suck or pull the rest of the dock, boats, and all back into the oncoming water." Koop continued, "* * * a trailer * * * hit the lake, it was ground up. There were two boats trying to get out, one boat with four persons and one boat with one man in it. The force of the water pulled these boats back into the shore, pulled them stern first down and ground them up." Both accounts suggest a powerful destructive undertow near the lakeshore.

The mouth of Eldorado Canyon during the flood is shown in figure 7*A*, as photographed by Kenneth E. Beales of Las Vegas, Nev., during late stages of the flood recession. The same general view, about 2 weeks later, during excavation and cleanup of flood sediment deposits (fig. 7*B*), provides perspective on the approximate depth of flow at the time of Beales' photograph.

J. P. Monis and P. A. Glancy, U.S. Geological Survey, reconnoitered the east shore of Lake Mohave on September 19, 1974, for evidence of wave action caused by the flood surges entering the lake. Figure 8 shows the best noted evidence of possible flood wave action, at the base of a large sand dune across Lake Mohave about half a mile east and slightly south of the Eldorado Canyon mouth. The dune and its location relative to Eldorado Canyon are shown in the upper right part of figure 15. The horizontal cut in the sand above the flood debris (fig. 8), that was deposited before the lake was purposely drawn down to aid search-and-rescue operations, suggests a maximum wave height of about 1¾ ft. However, the horizontal cut may have originated from a higher preflood lake stand. In any event, no known evidence was observed of flood wave action greater than about 1¾ ft.

Apparent response of the stage of Lake Mohave at Davis Dam, about 35 mi downstream from Eldorado Canyon (fig. 2), to the flood wave is shown in figure 9. The figure indicates that lake stage rose approximately 0.45 ft shortly after 2:30 p.m. the day of the flood.

RUNOFF VOLUME

Total storm runoff into Lake Mohave was roughly estimated by the U.S. Bureau of Reclamation as about 2,000 acre-ft (G. B. Freeny, oral commun., 1974). This estimate was made on the basis of apparent change in contents of Lake Mohave caused by inflow and direct precipitation on the lake, and adjusted by preflood and postflood reservoir release trends. Aerial reconnaissance of the general area adjacent to Eldorado Canyon basin affirmed that the major share of inflow to Lake Mohave probably came from Eldorado Canyon. The generally undisturbed character of channel-bottom vegetation shown in figure 10 supports the conclusion that there was no heavy runoff in areas adjacent to Eldorado Canyon. Therefore, the flow to the lake from Eldorado Canyon itself was estimated at about 2,000 acre-ft. Figure 11 shows an estimated hydrograph of runoff to the lake from Eldorado Canyon. This hydrograph was constructed from the following data: (1) known zero flow before and after the flood, (2) an estimated peak flow rate of about 76,000 ft^3/s, (3) an estimated total duration of flow as described by eyewitnesses, and (4) the general shape of hydrographs for recorded flash floods in the same general hydrologic area. Runoff volume as determined from the hydrograph is also about 2,000 acre-ft.

MEASURED STREAMBED AND HIGH-WATER PROFILES

Figures 12, 13, and 14 show locations of flood boundaries, high-water profiles, streambed profiles, and a qualitative assessment of damage to some cultural features in Eldorado Canyon. Figure 15 shows the general flood plain extent and characteristics just above the developed area. The average slope of the profiles in the measured reach (fig. 12) is 280 ft/mi. The left-bank profile through the trailer park area indicates a 2- to 4-ft depth of water above the canyon floor (figs. 14 and 16), whereas the right-bank profile in the same section is defined by one piece of debris found on the vertical wall about 16 ft above the canyon floor. Assuming that this piece of debris actually represents the true water surface along the right bank, the difference in left- and right-bank elevations must be explained by the sloshing of water from bank to bank (figs. 12, 7*A*), and by local pileup of water caused by cars and boat trailers in the parking area. Downstream from the trailer parking area (fig. 14), the left- and right-bank profiles become very erratic and indicate water pileup due to the contraction of the reach. The momentum of the flowing water forced the water up and over the projecting bedrock ridges. The profiles (fig. 14) show that the water surface along the left bank was as much as about 25 ft above the canyon floor where the flow was pushed up and over the projecting rock ridge. Figure 16 shows the contrast between trailers caught within the left-bank high water line (damaged) and those on slightly higher ground (undamaged).

FLOOD FREQUENCY AND MAGNITUDE

No accurate definition of the recurrence interval for a flood peak of 76,000 ft^3/s in Eldorado Canyon is possible

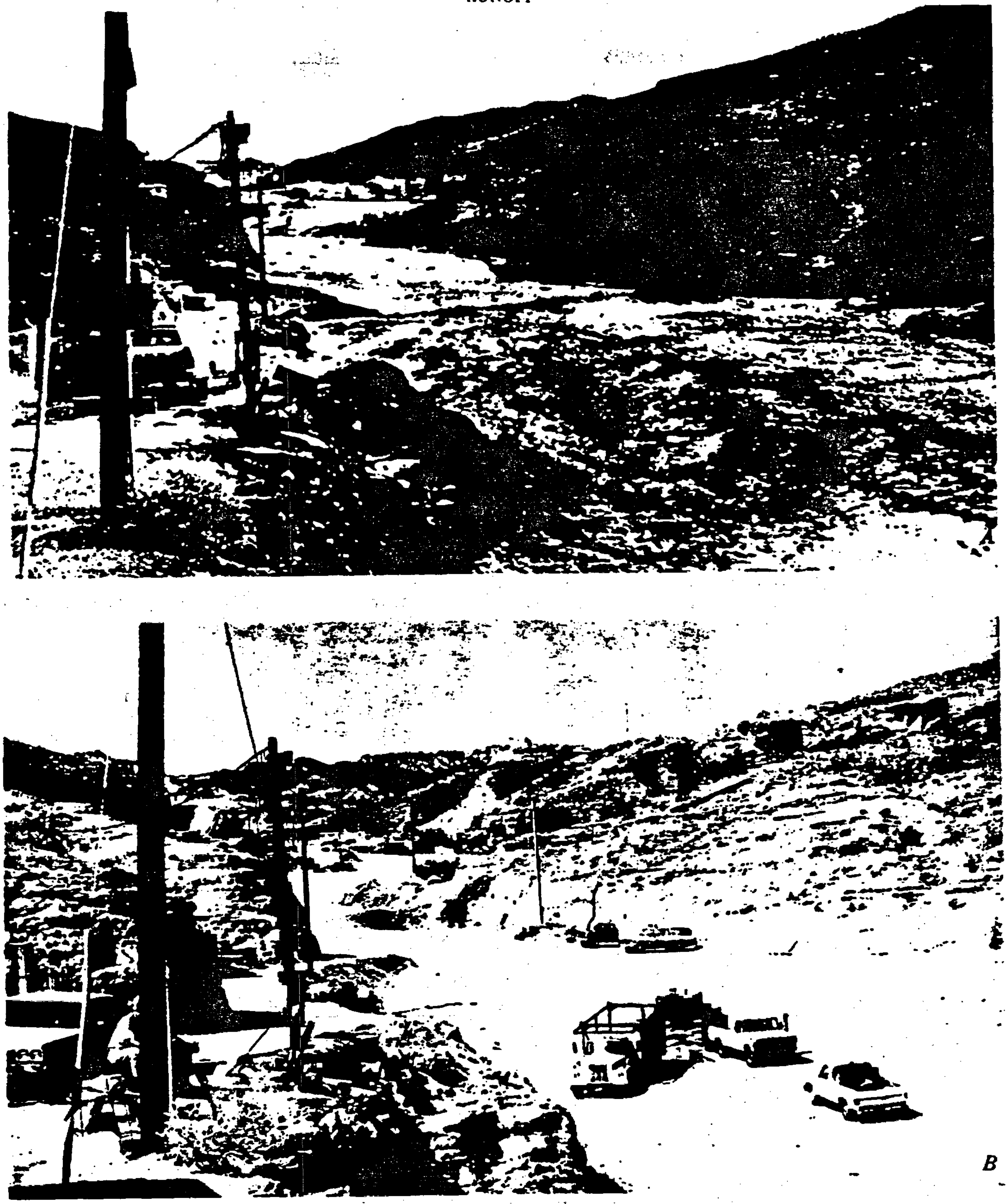


FIGURE 7.—Mouth of Eldorado Canyon. *A*. On September 14, 1974, probably during the late recession of flooding (photograph by Kenneth E. Beales, Las Vegas, Nevada). *B*. On October 1 during excavation of flood sediment deposits.

because of insufficient data. However, empirical methods being developed from data throughout southern Nevada (D. O. Moore, oral commun., 1974, and Moore, 1974) were used to estimate 10- and 25-year flood magnitudes for Eldorado Canyon near the canyon mouth. The peak flow estimates for the 10- and 25-year flood are 80 and 200 ft³/s, respectively. The 80-ft³/s flood, assuming an asphalt channel bottom through the trailer parking area (fig. 16) with the surface configuration as surveyed on September 16, 1974 (approximate profile stationing 1400, fig. 12), would be about 0.5 ft deep with an approximate mean velocity of 6 ft/s. The 200-ft³/s flood would be about 0.75 ft deep with an approximate mean velocity of 8 ft/s.

The scanty data and estimates described above suggest that a flood magnitude of 76,000 ft³/s would apparently have a large but unknown recurrence interval. However, it should be emphasized that flood magnitude and frequency are founded on the theory of probability. This introduces a risk factor. Also, long term data for floods in ephemeral stream channels in Nevada are very scarce. Therefore, a frequency analysis of major floods is based on little factual experience.

The magnitude of the September 14 flood gives no guarantee that another disastrous flood will not occur in the foreseeable future. Therefore, a reasonable course would be to assume such a flood can and may occur in any given year.

SIMILAR FLOODS

Areas in southern Nevada and nearby States known to have been subjected to high-intensity thunderstorms

FIGURE 8.—Wave-cut bench (above debris line) along east shore of Lake Mohave, possibly caused by flood surges entering the lake.

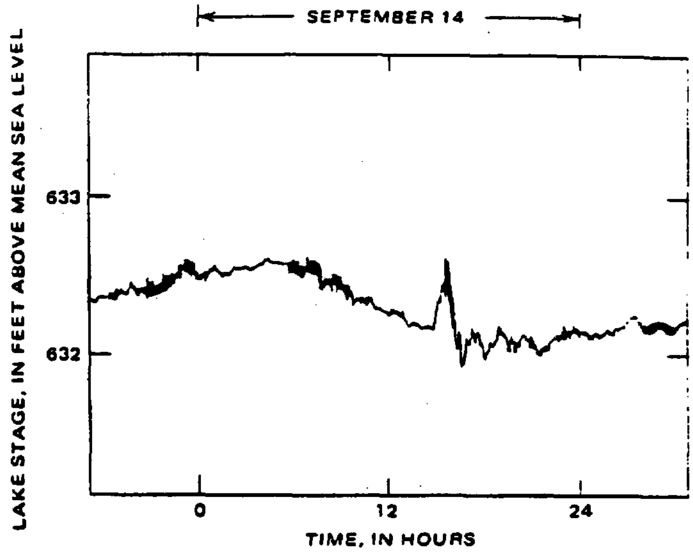


FIGURE 9.—Trace of Lake Mohave stage at Davis Dam, showing approximately 0.45-ft rise. Gage is about 35 mi downstream from mouth of Eldorado Canyon. Figure is reproduction of lake stage recorder sheet.

similar to that which struck Eldorado Canyon include the following:

1. An unnamed stream in the McCullough Range near Searchlight, Nev., in late August 1971.
2. Bullhead City, Ariz., area in late summer 1971.
3. Red Rock Wash near Las Vegas, Nev., on January 27, 1969, and July 23, 1974.
4. The McCullough Range between Henderson and Railroad Pass, Nev., in 1969 or 1970.
5. Grapevine Canyon in Death Valley, Calif., on August 14, 1968.
6. Black Canyon near Wickenburg, Ariz., on September 14, 1964.
7. Picacho Wash near Imperial Dam, Calif., on September 14, 1974.

Table 3 summarizes data for some floods in the western United States with peak flow rates per unit drainage area greater than that of Eldorado Canyon on September 14, 1974.

TABLE 3.—*Floods having peak flows per unit drainage area greater than that of Eldorado Canyon*

Location	Drainage areas (mi²)	Peak discharge (ft³/s)	Unit runoff (ft³/s/mi²)
Bronco Creek near Wikieup, Ariz.	20	73,500	3,700
Meyers Creek near Mitchell, Ore.	12.7	54,300	4,300
Trujillo Arroyo near Hillsboro, N. Mex.	6.9	45,000	6,500
South Fork Pine Canyon Creek near Waterville, Wash.	5.4	25,000	4,600
Little Pinto Creek tributary near Newcastle, Utah	.30	2,630	8,800
Lahontan Reservoir tributary No. 3 near Silver Springs, Nev.	.22	1,680	7,600
Eldorado Canyon, Nev.	22.8	76,000	3,300

FIGURE 10. Vertical aerial photo of the terminal reach of Eldorado Canyon drainage and adjacent drainages on September 20, 1974. Photograph courtesy of Nevada Division of Highways.

SEDIMENT

SEDIMENT DEPOSITS

Fluvial sediment transport was an important aspect of the September 14 flood. The greatest immediate impact of sediment deposition was the practical problem it posed for search-and-rescue crews. Sediment deposits at the canyon mouth and in Lake Mohave blanketed several acres to thicknesses of up to 12 ft. Much of this sediment had to be removed during the search for victims and missing property. Also, excavation of the material prolonged and increased lake turbidity near the landing and thereby hampered underwater search by divers. The cost of removing sediment deposits was great, and probably accounted for the major part of the search-and-rescue expense.

The sediment volume accounted for in known deposits is estimated to be 54,000 yd^3. Table 4 describes the location and distribution of the known sediment deposits; location of the depositional units is shown in figure 17. The estimate was made on the basis of postflood configuration of deposits and on some preflood topographic information. Estimates of deposits upstream from the preflood shoreline of Lake Mohave probably are reasonably accurate because detailed preflood topographic data were available. However, no recent preflood bathymetric data were available for the harbor or adjacent areas. Some general knowledge of preflood water depths is available from observations by the National Park Service staff and others. These sparse data are supplemented with estimates of the quantity of material actually excavated and removed, as well as evidence of depths to apparent preflood lake-bottom clays exposed during excavation.

The 54,000-yd^3 estimate does not account for an unknown silt-clay fraction of the total sediment load. This part of the load was probably dispersed widely throughout Lake Mohave because of its small particle size and inherent slowness of settling. Therefore, the 54,000-yd^3 deposit probably represents a lower limit of total sediment load.

A reconnaissance characterization of the sediment deposit according to particle-size distribution was attempted (extensive sampling and analysis was beyond the scope of the study). Six samples of excavated material were arbitrarily collected on September 30, 1974, when the large mass of available excavated material probably was representative of most of the recoverable sediment. Samples were collected by P. A. Glancy (U.S. Geological Survey), and standard sieve analyses were made by the Materials Testing Laboratory, Nevada State Highway Department, Las Vegas. Results of the sieve analyses are listed in table 5, and figure 18 pictures the material sampled at each site. Samples were collected from piles of excavated sediment dumped upstream from the trailer park area. The piles are clearly visible upstream from the access highway in the aerial photograph of September 20 (fig. 10). Samples were carefully collected to typify the mass of material excavated, and are believed to be generally representative of that mass, within limitations imposed by the small number of samples that could be collected feasibly.

On the basis of analytical results in table 5, the sediment excavated from the deposits can be characterized as follows: less than 1 percent boulders, about 60 to 80 percent gravel, about 10 to 30 percent sand, and less than 3 percent silt and clay. As described above, the silt-clay fraction of the sampled deposits probably is less than that contained in the total sediment load of the flood.

Seven additional samples were collected from drainage slopes and channel bottoms of Techatticup and

TABLE 4.—*Estimated nonorganic sediment deposits*

[Data regarding areal distribution and estimated thickness of deposits mainly provided by T. R. Gess, National Park Service Engineer (oral and written commun., September and October 1974). All quantities rounded because of nature of estimates]

Location of deposits	Map zone shown in figure 17	Approximate area (acres)	Estimated average thickness (ft)	Estimated volume (yd^3)	Estimated unit weight of deposits (lb/ft^3)[a]	Estimated dry weight of sediment (tons)
Upstream end of park development to upstream edge of boat landing	1	2.6	3	13,000	[b]130	
Upstream edge of boat landing to preflood shoreline	2	.6	4.5	4,700	[b]130	60,000
Preflood shoreline to postflood shoreline	3	1.1	9	16,000	[b]130	
Below postflood lake surface	4	2.3	5.5	20,000	[c]100	27,000
Subtotal		6.6		54,000		87,000
Somewhere in Lake Mohave beyond limits of known deposits	Not shown	unknown	unknown	[d]16,000	[e]80	17,000
Total (rounded)		(6.6)		70,000		100,000

[a] Unit weight estimates were adopted from data of Hough (1957, p. 30–31).
[b] Mainly moderately compacted gravel, sand, and small amounts of boulders and fines.
[c] Loosely compacted sand with small amounts of gravel and fines.
[d] Difference between crude estimate of total load transported (70,000 yd^3) and estimate of generally known deposits (54,000 yd^3).
[e] Probably very loosely compacted silt and clay with some fine sand and very small amounts of medium sand.

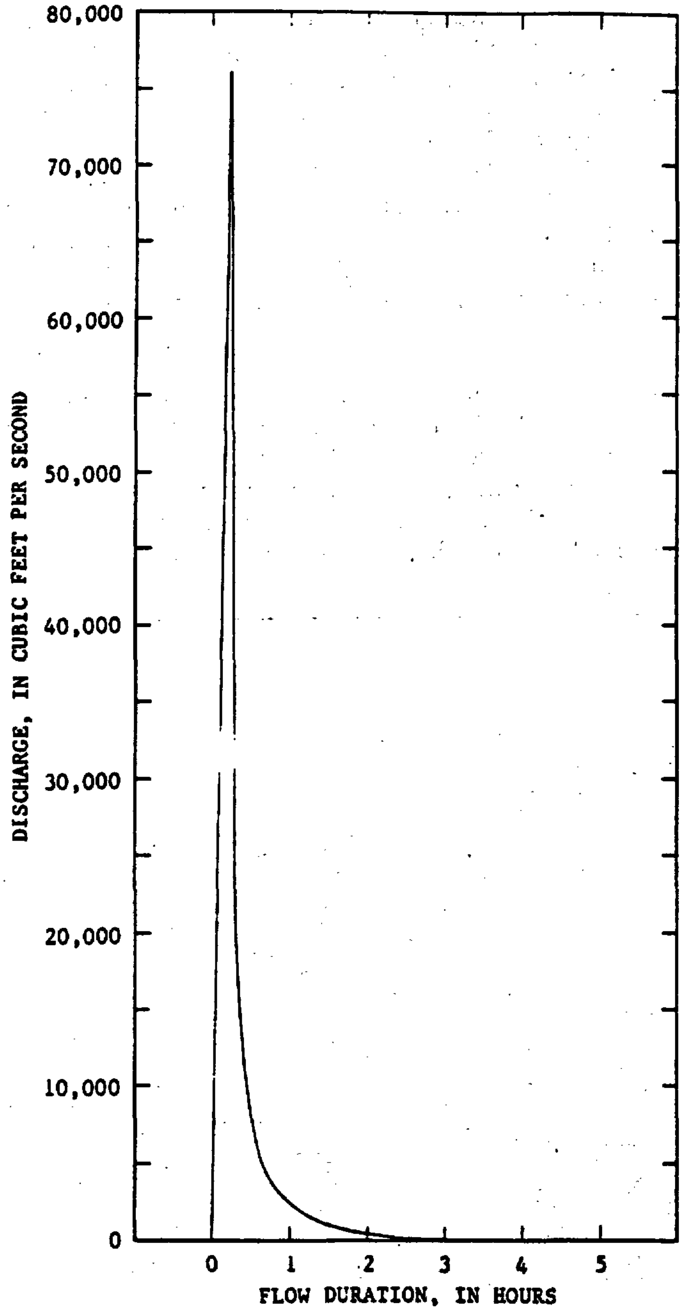


FIGURE 11.—Estimated flood hydrograph for September 14, 1974, near mouth of Eldorado Canyon.

Eagle Washes and Eldorado Canyon, 2 to 4 mi upstream from Lake Mohave, in an attempt to characterize particle-size distribution of sediment subjected to erosion. These samples all exhibited generally similar grain-size distribution, averaging about 50 to 70 percent gravel, 25 to 40 percent sand, and 4 to 8 percent silt-clay. However, because they represent postflood conditions and are not a statistically significant sampling of the overall drainage basin, they may not accurately represent sediment eroded, transported, and deposited by the flood. As with the flood deposits sampled, the silt-clay component of the upstream material may be underrepresented.

TABLE 5.—*Approximate particle-size distribution of sediment samples*

Size class	Approximate size of opening (mm)	U.S. standard sieve	Percent passing sieve, by weight					
			Sample number					
			EC-1	EC-2	EC-3	EC-4	EC-5	EC-6
Small cobbles (>64 mm)	100	4 in		100			100	
	75	3 in		83		100	97	
Gravel (2–64 mm)	50	2 in	100	79	100	96	72	
	37.5	1½ in	95	75	99	92	64	100
	25	1 in	89	65	95	82	55	97
	19	¾ in	81	58	91	73	46	91
	12.5	½ in	71	49	82	59	38	80
	9.5	⅜ in	63	43	73	51	32	72
	4.75	No. 4	48	31	53	35	21	50
Sand (0.062–2 mm)	2.00	No. 10	28	18	33	20	12	27
	1.18	No. 16	18	12	23	15	9	17
	0.425	No. 40	7	4	12	8	5	6
	0.300	No. 50	6	3	11	7	4	5
	0.150	No. 100	3	2	8	5	3	3
Silt-clay (<0.062 mm)	0.075	No. 200	3	1	6	4	3	2

However, the silt-clay fraction might be assumed to have made up less than one-fourth the total load, because sand was considerably less prevalent than gravel in the material recovered. Therefore, the total sediment load transported by the flood is roughly estimated at 70,000 yd^3 (purposely rounded to one significant figure) which allows a crude, but necessary, adjustment for the otherwise unaccounted fine-grained load component. Table 4 shows data for all known and assumed sediment deposits, except those for floating debris. The table also includes estimates of sediment weight for individual deposits. Total weight of all generally nonorganic sediment is estimated about 100,000 tons.

Particle-size distribution, by weight, of the estimated sediment load (less organics) can be roughly approximated from the data of table 4, using some arbitrary assumptions, as follows: boulders, less than 1 percent; gravel, about 40 percent to 60 percent; sand, about 20 percent to 40 percent; and silt-clay, about 10 to 25 percent.

Large boulders, common constituents of many intensive floods in the southwestern United States, were generally absent in the September 14 flood deposits. An occasional boulder was noted during excavation or observed in piles of excavated material. Selected examples of the measured triaxial diameters, in feet, of these observed boulders are as follows: 3×1.5×1.2; 3×1.5×1; 2.8×1.3×1.5; 2×1.5×0.5; 1.8×1.1×0.9; and 1.5×1×0.8. Another large boulder unearthed in the deltaic material (5.4×3.7×3.2 ft) may well have been deposited by some previous runoff event.

Figure 7 shows the approximate area of new land surface created in the harbor as a result of sediment deposition. New land surface was delineated on the basis of the preflood topography shown in the figure and postflood (Sept. 18 and 20, 1974) aerial photographs supplied by R. J. Gregory, Director, Nevada Civil Defense and Disaster Agency, and the Nevada Highway Department (fig. 10). Land surface was increased by about 1.1 acres, and the harbor shoreline was extended lakeward about 350 ft.

The in-place character of sediment deposits at the canyon mouth was only rarely disclosed during excavation because most steep slopes created by digging slumped almost immediately. Figure 19 pictures a rare near-vertical exposure of upper beds of material deposited along the right canyon wall near the shoreline of Lake Mohave. The photograph shows stratified sand and gravel probably deposited during the runoff recession.

Floating debris, mostly manmade artifacts and uprooted vegetation, temporarily covered a large area of harbor surface adjacent to the newly extended land surface. The extent of this debris is generally shown by figures 17 and 20. Most floating debris was restricted to about 1.1 acres of water-surface area by the afternoon of September 15 (fig. 20). A very rough estimate of floating debris is about 4 acre-ft, using the area shown in figures 17 and 20 and assuming an average 3 to 4 ft thickness of deposits (T. R. Gess, oral commun., 1974).

Removal of the floating debris (fig. 20) required about a week's labor, but the efforts yielded the bodies of three flood victims (fig. 17). The pulverized debris and the nude bodies testify to the tremendous energy expended by the flood in the terminal reaches of Eldorado Canyon.

SEDIMENT TRANSPORT CHARACTERISTICS

The scarcity of boulders in deposits from the September 14 flood seems anomalous when field examination of upstream areas shows a large number of boulders on many hillslopes and in numerous small tributary channels. However, field reconnaissance shows that the boulders are characteristically scarce in the postflood

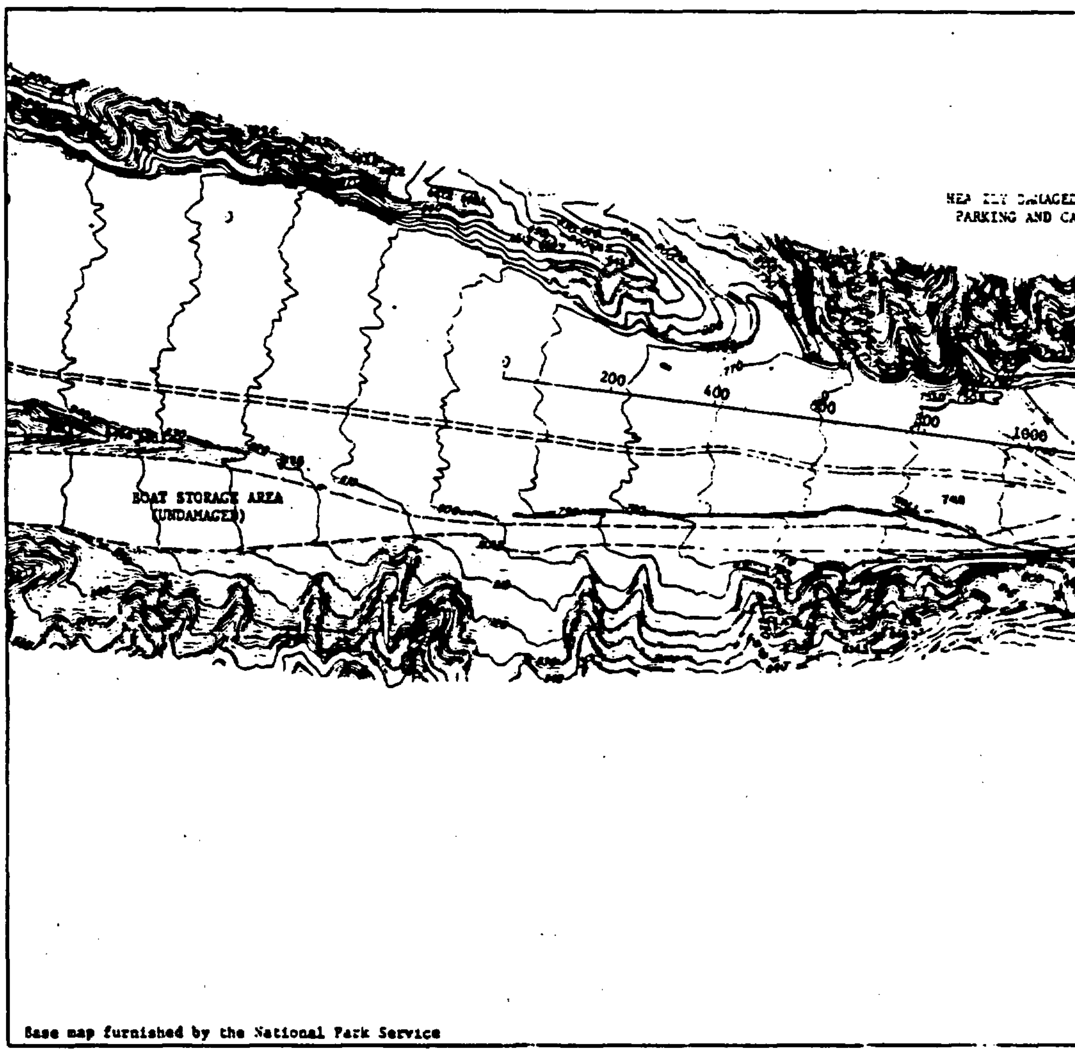


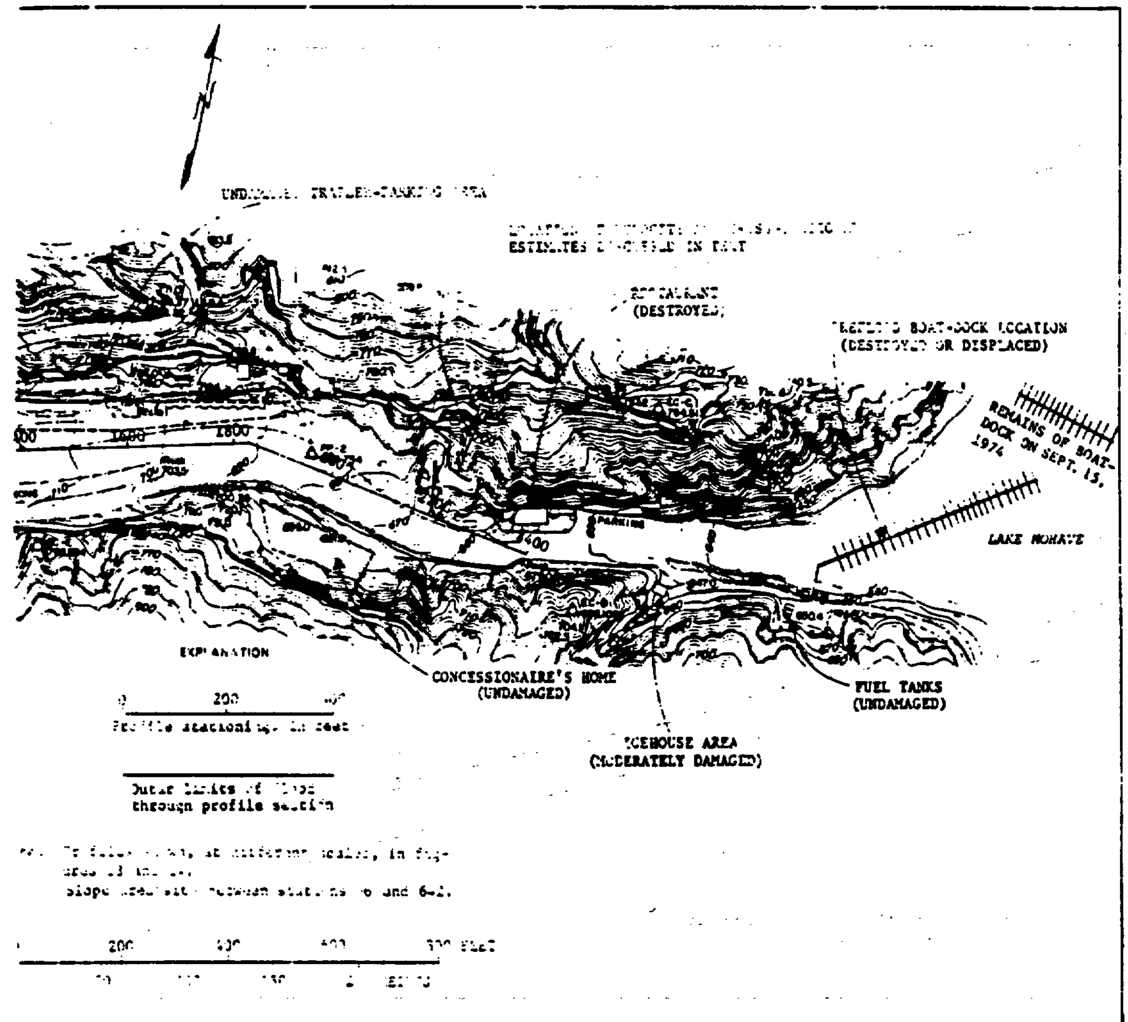
FIGURE 12.—Flood boundaries, streambed

surface dep... Eldorado Canyon and Eagle Wash, but Techatticup Wash contains a greater number of boulders scattered along its main channel. It is assumed preflood channel deposits were similar in particle-size distribution. Therefore, boulders observed on hillslopes and in small channels presumably were not subjected to streamflow intense enough, on or recently prior to September 14, to move them to the main channels where velocities on September 14 probably would have been adequate to have transported many of them long distances. As a result, the flows that collected in the three main drainage channels (Eagle and Techatticup Washes and Eldorado Canyon) transported only the available material, which was apparently dominated by gravel.

Evidence of at least some large-boulder movement in Techatticup Wash is suggested in figure 21. The boulders shown mantling the channel floor are in the extreme west center of sec. 5, T. 26 S., R. 65 E., just upstream from the waterfall of Techatticup Wash. They lie in a locally wide section of the wash, suggesting that they were deposited bec... rapidly decreasing flow velocities associated w... the channel expansion. Most of them were probably ... motion during the September 14 flood.

An exceptionally large boulder that may well have moved some distance during the flood is shown in figure 22; its dimensions are 6×4×2.5 ft. Figure 24 shows a boulder lodged under the front bumper of a car abandoned during the flood in the lower reaches of Eagle Wash. The boulder (dimensions 2×1.5×1 ft), overlying a live bush, obviously moved during the flood.

The rough estimate (70,000 yd³) of the total nonorganic sediment deposited at or near the mouth of Eldorado Canyon, plus the estimate of inflow to Lake Mohave from Eldorado Canyon, allow reasonable speculation on additional sediment-transport characteristics of the September 14 flood. The estimated dry weight of



... profile line, and specific cultural features sediment deposits is shown to be about 100,000 tons in table 4. Sediment deposits below the postflood lake surface are equivalent to about 12 acre-ft of solid rock on the basis of estimated volume and unit weight of the deposits. Pure water inflow, dismissing organic debris, was about 1,988 acre-ft (2,000 acre-ft total inflow minus 12 acre-ft of rock) or about 2,700,000 tons. Therefore, the overall water-sediment mixture delivered to the terminal reaches of Eldorado Canyon was water-dominated (about 3½ percent sediment, by weight). The mean sediment concentration for the total water-sediment mixture, not counting organics, may have been about 36,000 mg/l (milligrams per litre). Recognizing limitations on estimates of total streamflow and sediment, as well as unknown weight of organics, a mean total-sediment concentration of 30,000 to 40,000 mg/l seems reasonable. This statistic also indicates that sediment transport during the flood was important, but the material delivered to the canyon terminus was nonetheless a water-dominated mixture. The water-sediment composition probably varied greatly with time and location, and probably was rarely equal to the mean concentration.

Several persons witnessed the flood flows in the vicinity of the boat landing at the canyon mouth. Lemuel Washington of Las Vegas, Nev., and Kirby L. Koop of Placentia, Calif., both describe the initial flood surge as being very heavily laden with sediment having a consistency generally equivalent to freshly mixed concrete (Washington) and not quite as viscous as freshly mixed concrete (Koop). Both witnesses describe the initial flow definitely as a vertical wall of water mixed with sediment and manmade artifacts. Unfortunately, both witnesses were observing the oncoming flood along a line of sight parallel to the direction of movement, which is a disadvantageous position from which to accurately judge whether the leading edge was near-vertical. It is certain, however, that the mixture arrived as a sudden onrush of streamflow carrying a very high concentration of sediment; that it had picked up a conspicuous

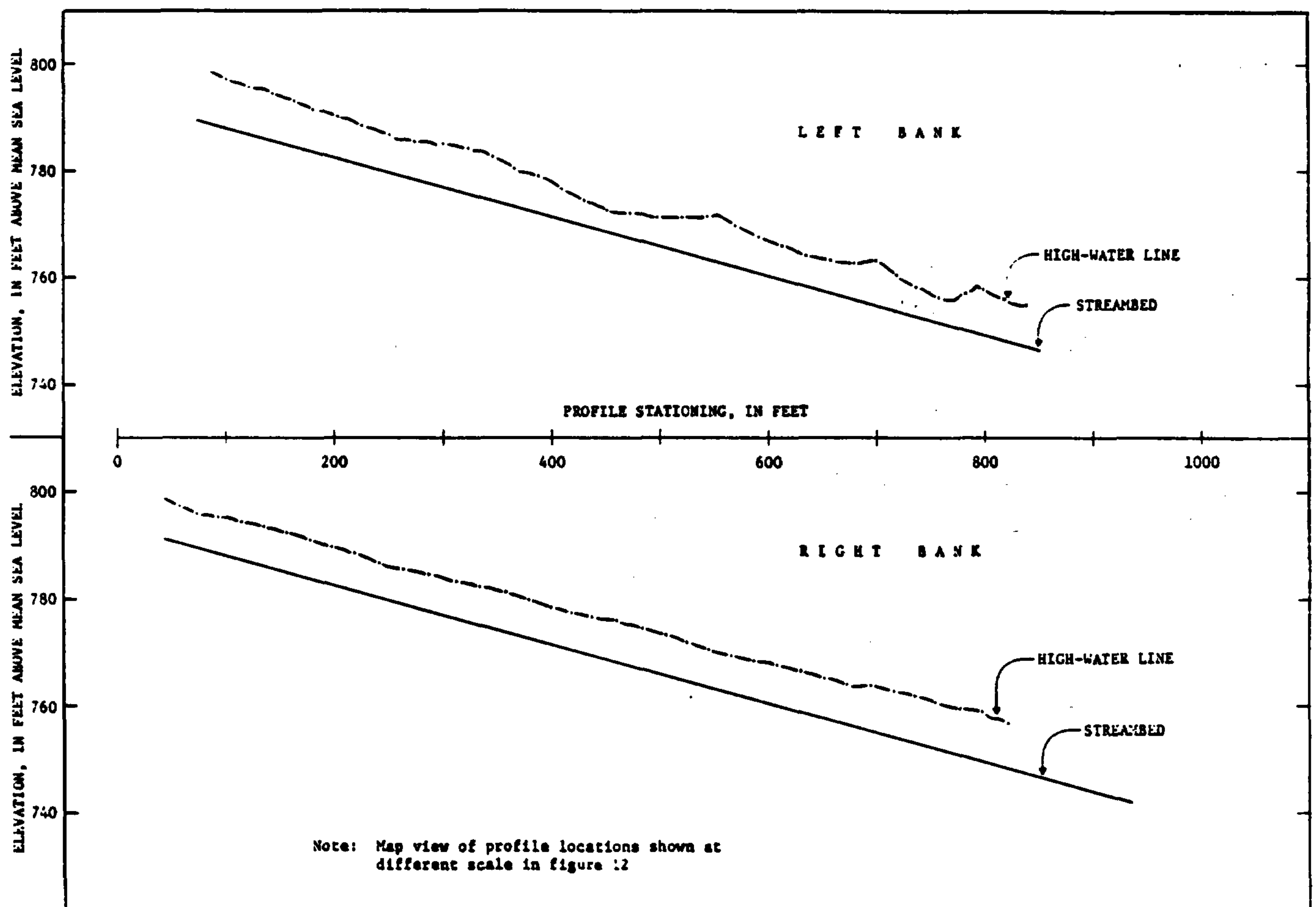


FIGURE 13.—Profiles of peak discharge high water lines and streambed at slope-area site in Eldorado Canyon.

array of manmade artifacts from the upstream parking lots, trailer village, and campground facilities, and that it probably contained an appreciable amount of uprooted vegetation. Koop further describes the leading edge of the onrushing mixture as raining or spraying out gravel as large as several inches in diameter. He characterized the flow as dark brown in color, but indicated that the oncoming flow was not audible. Mrs. Koop, also an eyewitness with her husband, described the initial flow as so abrupt that at first she thought a dam must have burst somewhere upstream. Mr. Koop's impression of the oncoming mass of material was described in a statement to National Park Service personnel, as follows:

> When I got around the small nose which was behind the block-ice machine and started walking toward the coffee shop, I looked up for a second. I became disoriented because I thought the mountain had moved. Then I realized what we were seeing was a wall of water about 20–25 feet high stacked with cars, trailers, etc., smash into the coffee shop, post office, and they exploded like there was dynamite inside.

Figure 23 shows the location of high water lines just upstream from the coffee shop site, where the canyon narrows abruptly. Flow depths at this point, approximately where the oncoming surge of water was observed by Koop, generally support his estimate of surge height.

Lemuel Washington, in his statement to the National Park Service, described the approaching streamflow as follows: "It first looked like a dark heavy cloud of dust. Looked like a solid wall moving down. As it came down, every vehicle was pulled into this muck. I saw 4 to 6 vehicles in the debris. The wall of muck appeared to go under the lake when it hit the water, causing a swell of water at the surface." Washington indicated that he first sighted the approaching flow when it was above the trailer court; at that point, it appeared as an approaching wall about 6 to 8 ft high. Koop apparently first observed the surge as it was entering, or had just entered, the canyon narrows immediately upstream from the coffee shop (restaurant).

The foregoing accounts strongly imply that sediment concentration of the initial flood surge was considerably higher than the estimated mean concentration of 30,000–40,000 mg/l. The statements generally characterize the onrush as a highly charged debris flow that may have had the general consistency of a mudflow. Koop (oral commun., 1974) described the initial "wave" as being followed by several wavelike surges, none of

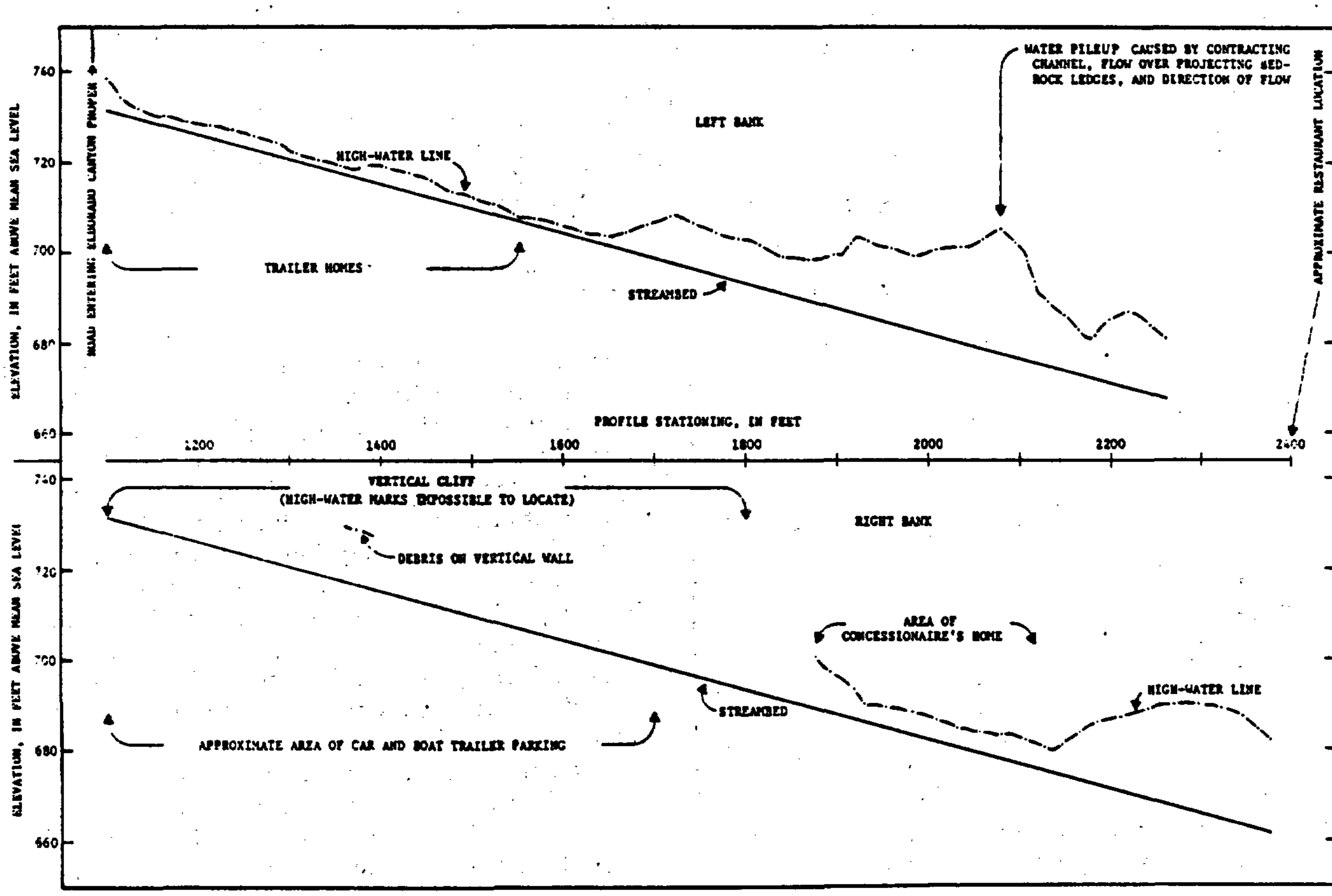


FIGURE 14.—Profiles of peak discharge high water lines and streambed, Eldorado Canyon Resort.

FIGURE 15.—Downstream (eastward) aerial photograph of Eldorado Canyon terminus taken September 17, 1974. Boat-storage area to right. Horizontal lines show approximate slope-area site

FIGURE 16.—Heavily damaged trailer park at Eldorado Canyon Resort. Afternoon, September 19, 1974.

which he observed to noticeably recede before a subsequent surge further increased the flow depth. If correct, Koop's description may explain why no mudline marked passage of the initial surge.

Neither the Koops nor Mr. Washington observed any movement of large boulders during the flood.

The foregoing description of sediment transport characteristics of the initial flood surge suggests that the moving flood front tended to pick up debris from the stream channel during its flow downstream. This progressive debris pickup of the leading flow edge pr bly created a front laden with sediment that moved r dly but slower than the water behind it. The result was the abrupt arrival of a tremendous mass of debris and water. This type of debris-laden flood front has been described to the authors by several eyewitnesses of other flash floods. Field evidence of numerous other similar floods in Nevada also suggests this debris-laden front is a common characteristic of flash flooding in this environment. However, somewhat less common, in our experience, is the apparent increasing stage of more dilute streamflow following the initial debris-laden surge. This characteristic may be related to very intense flash flooding in a relatively large watershed having a complex major-tributary system wherein peak flows are more likely to occur sometime after the initial surge. This appears to have been the situation at Eldorado Canyon.

In summary, throughout the terminal reaches of Eldorado Canyon below the junction of the three major washes, the sediment transport characteristics of the major floodflow appear to have been generally as follows: (1) the initial surge was highly charged with sediment, artifacts, and uprooted vegetation; (2) the initial surge was followed by several succeeding surges, some of which were of higher stage than the initial surge; (3) surges following the initial onrush probably had a generally lower sediment concentration than the initial surge

Dr. J. H. Sessums, Bishop, Calif., observed the flooding from quite a different vantage point, in Eagle Wash about 2 mi upstream from the trailer court (oral commun., 1974). Sessums was driving up Eagle Wash during the intense rain and hailstorm. His first encounter with floodflow in Eagle Wash came as his moving car met several small pulses of flow. These pulses cumulated and increased the overall depth to a degree that prompted him to abandon his car. He did not observe any initial "wall" of water in Eagle Wash, nor any debris-clogged initial flow surge. He described the runoff as turbid, but definitely not a mudflow.

Flow surges continued and added to the stream stage until Sessums' car was swept downstream about a mile. It was subsequently deposited on the floor of the wash by the receding streamflow. Figure 24 pictures Sessums' car on the afternoon of September 20 at its final resting place. The boulder deposited in front of the car was discussed earlier (p. 16). The car paint was unscratched in spite of the fact the car was partly inundated by rapidly flowing turbulent water for a substantial period of time. The flow apparently did not abrade or damage the paint surface, nor were there any visible signs of damage by large moving rocks. This evidence suggests that sediment transport in Eagle Wash apparently was dominated by gravel-size bedload that passed beneath the painted surface of the auto. The apparent dominance of gravel-size sediment agrees with the particle-size data of table 5. Absence of any scouring of the paint surface by suspended sand remains somewhat mysterious to the authors.

Sessums described his recollections of peak-flow conditions from his vantage point along Eagle Wash as a flow section 400 to 600 ft wide and about 4 to 6 ft deep. His description of the mobilization and transport of his car by the streamflow might provide useful evidence regarding the apparent absence of vehicles among the coarse-grained deposits at the mouth of Eldorado Canyon. He observed his car being initially mobilized by a surge of flow that at some critical depth caused the front of the auto to pitch upward like the prow of a boat and begin moving downstream. Thereafter, the car appeared to bob along in the flow like a cork, aided by buoyancy caused by air trapped inside the body. This buoyancy may also have prevented prolonged submergence with associated paint abrasion. If cars near the canyon mouth were likewise buoyed up by entrapped air, they would be less likely to settle with coarse-grained sediments and would more likely be found considerably farther lakeward, among the finer-grained deposits.

The fact that Sessums' car moved downstream only 1 mi before being set down attests to the very short period of peak flow in Eagle Wash.

EROSION

Postflood air and ground reconnaissance of the drainage basin disclosed abundant evidence of fresh erosion of rills, small tributary channels, and main channels throughout most of the basin. Generally, drainage areas upstream from main-channel reaches that experienced heavy runoff are relatively devoid of intensive rill-erosion scars. This relation between rill erosion and estimated peak flow rates in main channels generally agrees with apparent areal trends of total precipitation. All data suggest that precipitation, runoff, and erosion apparently were lowest in the headward parts of the basin. Intensities generally increased in a downstream direction and probably reached a maximum in the lower one-third of the basin.

The most intense observed rill erosion was in a lower basin area (SE¼NW¼ sec. 8, T. 26 S., R. 65 E.) shown in figure 25. In contrast, rill erosion is virtually absent in many parts of upstream areas such as that shown in figure 26, photographed approximately in the N½ secs. 8 or 9, T. 26 S., R. 64 E. Figure 26 shows that a minor amount of main-channel streamflow and erosion did occur at the site, in spite of the lack of flow evidence on

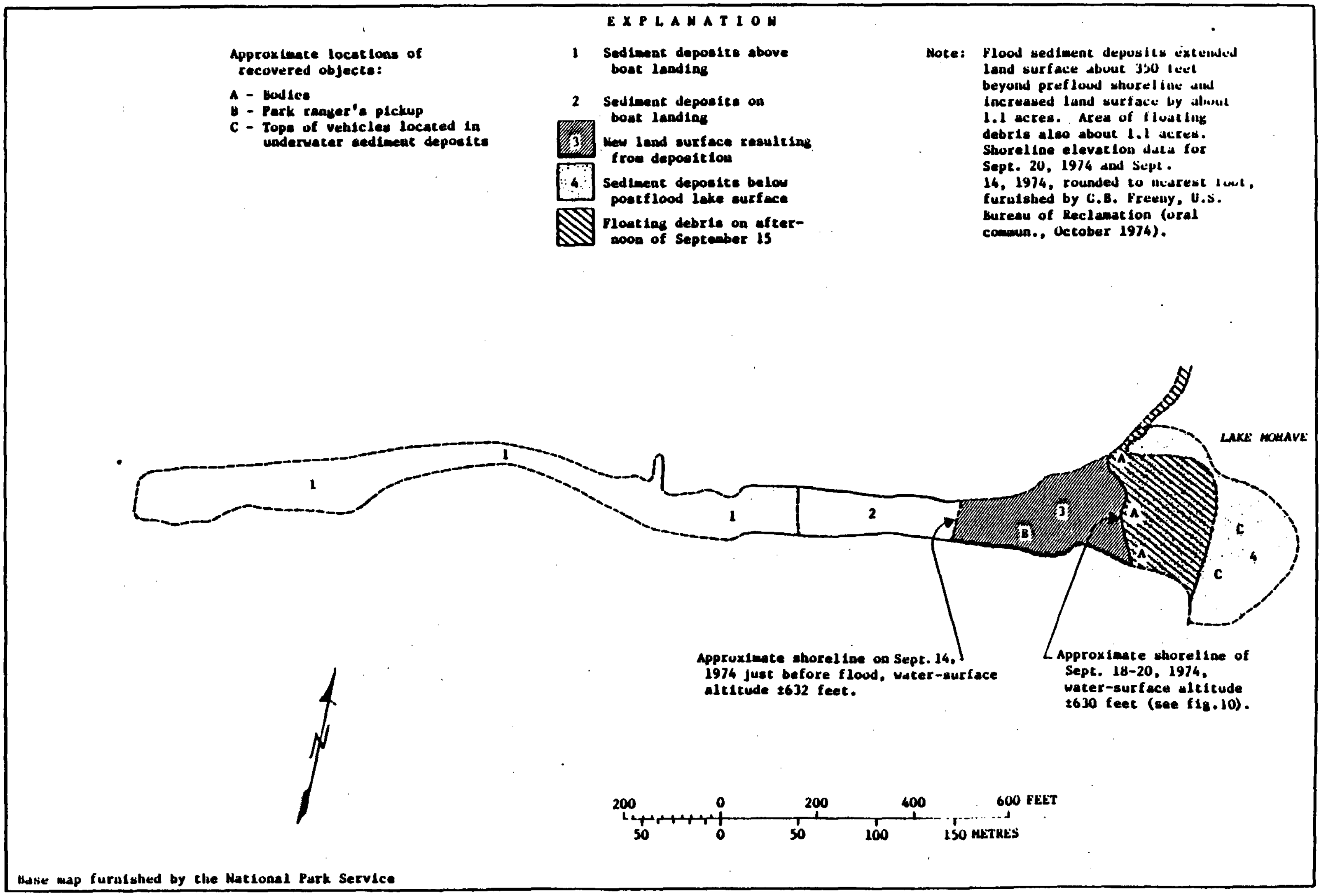


FIGURE 17.—Sediment deposits and locations of preflood and postflood shorelines.

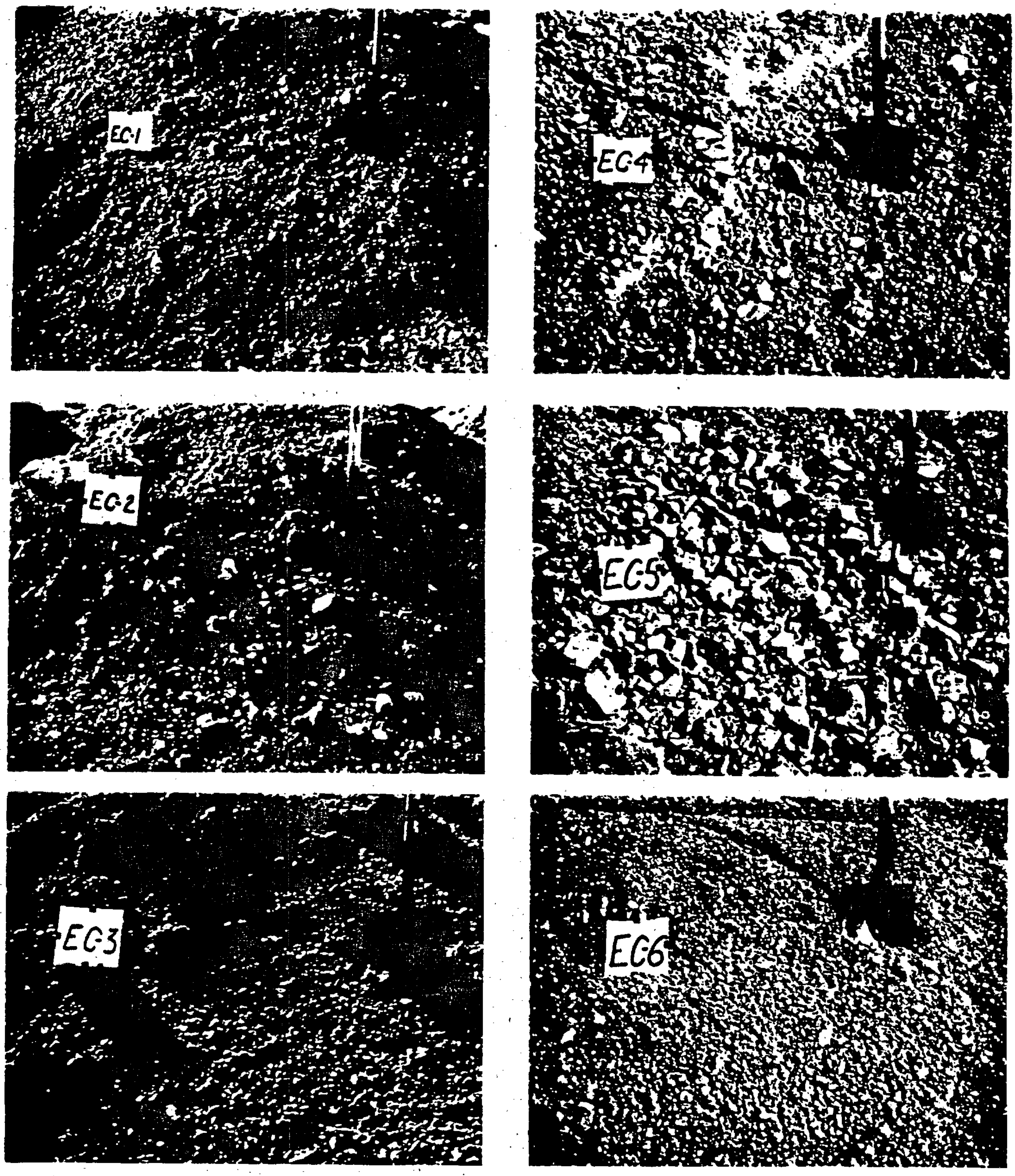


FIGURE 18.—Excavated sediments quantitatively described in table 5.

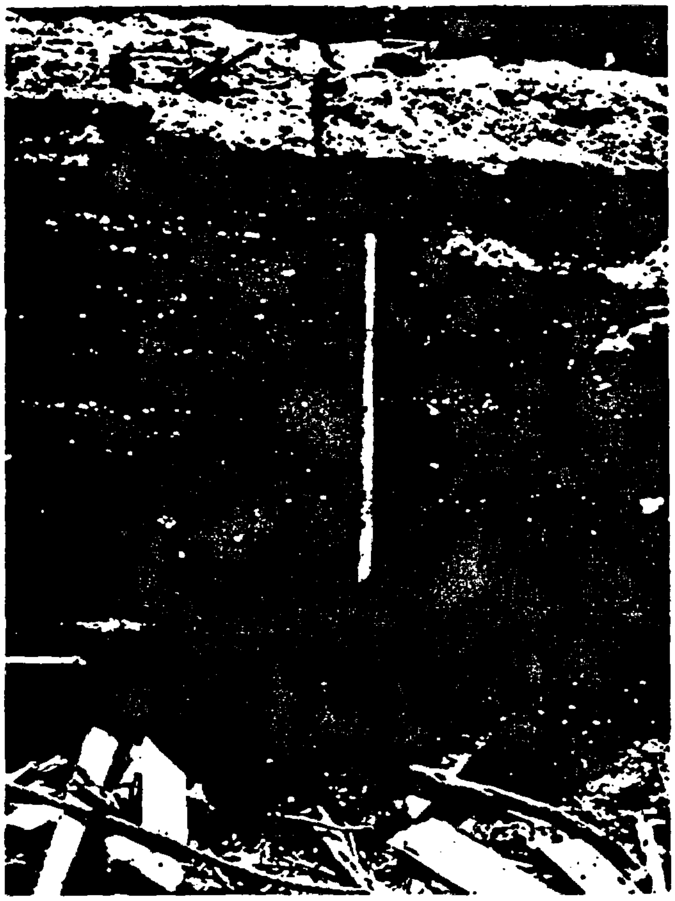


FIGURE 19.—Stratified sediment deposited at the mouth of Eldorado Canyon. Note alternating layers of mixed particle sizes with only a general impression of coarsest sediment in lowest strata.

the adjacent hill. Figure 5, an aerial view of lower basin terrain, shows distinctive rill-erosion scars. Intensive rill erosion is also clearly visible in figure 24, a photograph taken in NE¼ sec. 9, T. 26 S., R. 65 E., lower Eagle Wash. Large amounts of sediment derived by rill erosion were delivered to main channels and transported further.

Much of the sediment transported by the September 14 flood, particularly the coarser grained fraction, probably was derived by erosion from within the larger stream channels. Evidence of local vertical scour, generally less than 1 ft in depth, was common. Deeper scour may have occurred in some places, followed by later redeposition. Figures 15, 22, and 24 show traces of rooted vegetation within high-intensity flow reaches. This evidence precludes any overall deep scouring.

Severe lateral scour did occur in some places along major channels. Figure 27 shows examples of highway damage caused by this type of erosion.

Although the flood of September 14 is believed to have been the most severe in Eldorado Canyon during historic times, field reconnaissance disclosed some evidence of even more intensive erosion locally in at least one drainage tributary. Figure 28 shows a severe erosion scar on the steep southwest-facing slope of a hill in about SW¼SW¼ sec. 1, T. 26 S., R. 64 E., tributary to Techatticup Wash. The deeply furrowed channel is laterally bounded by windrow-shaped ridges of sizeable boulders that indicate very intense runoff and erosion. Vegetation growing within the furrowed channel and among the deposits indicate this feature substantially predates the September 14 flood. It does, however, show that other violent runoff events have occurred during the past within the drainage. The hillslope in the background of figure 28, across the highway, shows additional severe rill erosion of the September 14 flood.

ESTIMATED LANDSCAPE DENUDATION

The estimate of total sediment deposited during the flood can be used to describe the effects of the flood in terms of overall landscape denudation. If the 100,000-ton estimate of deposits (table 4) is converted to a solid-rock equivalent and prorated uniformly over the 22.9-mi^2 drainage basin, a mean basin denudation rate of about 0.002 ft is indicated for the flood. However, if the majority of eroded material was derived by main-channel erosion of temporarily stored alluvium, prorating the sediment over the total basin would not be meaningful. Another approach, assuming dominant main-channel supply of detritus, would be to prorate the total sediment volume uniformly over the total length of mainstem channel. The sediment deposits above the postflood shoreline are about 34,000 yd^3. The sub-lake-surface deposits (36,000 yd^3) can be reduced to a land-surface volume equivalent of 25,000 yd^3 by ratios of their unit weights. The resultant volume of equivalent main-channel deposits is about 60,000 yd^3. Dividing that volume by the sum of main-channel lengths (25 mi) derived from figure 4 (Eldorado Canyon, 10.8 mi; Eagle Wash, 7.4 mi; and Techatticup Wash, 6.7 mi), the uniform channel-denudation rate would be about 2,400 yd^3/mi. Further, assuming the average channel width to be 100 ft, uniform vertical scour needed to supply the sediment from the main-channel system would require about 0.12 ft of average downcutting. Obviously, none of the above statistical manipulations satisfy the true erosion picture; however, they may provide a crude reference for regional comparison with other runoff events.

ACKNOWLEDGMENTS

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FIGURE 20.—Floating debris at the mouth of Eldorado Canyon. Photograph on afternoon of September 15, about 24 hours after flood and before any significant cleanup of debris.

FIGURE 21.—Downstream view of boulder deposits that probably moved on September 14 in Techatticup Wash.

FIGURE 22.—Large boulder that probably moved during flood in lower reaches of Eldorado Canyon.

FIGURE 23.—Position of high water line at canyon narrows just upstream from former restaurant. Note people standing on high water line for scale.

Service in the investigation and the preparation of this report.

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FIGURE 24.—An automobile at rest in lower Eagle Wash after about a 1-mile transit in flood.

FIGURE 25.—Evidence of intense rill erosion in unnamed tributary to lower Eldorado Canyon.

FIGURE 27.—Highway damage in Techatticup Wash caused mainly by lateral channel scour.

neth E. Beales, for permission to publish his photograph of flood flow; and John Gallifent, Lemuel Washington, Mr. and Mrs. Kirby L. Koop, and Dr. J. H. Sessums, eyewitnesses to the flood.

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FIGURE 29.—Evidence of minor channel flow and only minimal rill erosion in Copper Canyon.

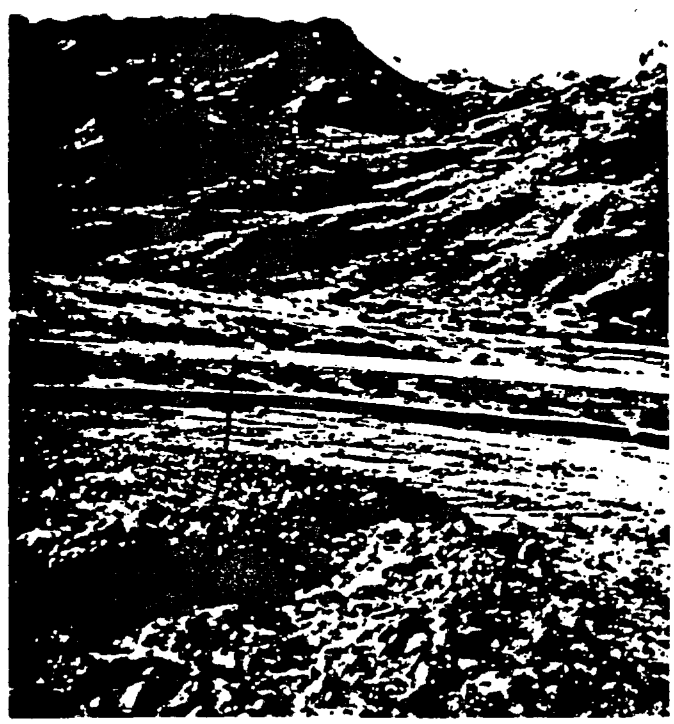

FIGURE 28.—Windrows of boulders bordering a pre-September 4, 1974 erosion scar.

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