40 copies sent to Dr Zube— balance destroyed 3/27/79

A Comprehensive Analysis of a Major Storm and Associated Flooding in Arizona

Technical Bulletin 202

Agricultural Experiment Station
The University of Arizona
Tucson

A Comprehensive Analysis of a Major Storm and Associated Flooding in Arizona

BY

DAVID B. THORUD

AND

PETER F. FFOLLIOTT*

May 1973

Technical Bulletin 202

Agricultural Experiment Station

*HEAD AND ASSOCIATE PROFESSOR, RESPECTIVELY, DEPARTMENT OF WATERSHED MANAGEMENT, COLLEGE OF AGRICULTURE, UNIVERSITY OF ARIZONA.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The 1970 Labor Day Weekend Storm caused more loss of human life than any other storm in Arizona's recent history. In addition, many dwellings, roads, bridges, and other structures were damaged by record flooding. Consequently, the meteorological and hydrological features of this event, and the resulting damage to human, cultural, and natural resources should be documented and analyzed.

The Storm caused periodic rainfall at various locations in Arizona over essentially a four-day period beginning on September 3rd. However, in the interest of simplicity, the event is hereafter referred to as "the 1970 Labor Day Storm" or, "the Storm."

Based on a suggestion from the Arizona Water Resources Committee,[1] Governor Jack Williams requested the Water Resources Research Center at the University of Arizona to arrange a review study of the 1970 Labor Day Storm. This study was designed to be an over-all collation of reports and data summaries prepared by federal, state, and local agencies and organizations concerned with the Storm and its consequences in Arizona. With the help of Governor Williams, appropriate offices were contacted for available reports and data summaries.

Preliminary reports on the Storm and its effects in Arizona were given at the 1971 Arizona Watershed Symposium (Thorud and Ffolliott, 1971) and the 1972 Western Snow Conference (Thorud and Ffolliott, 1972). This final report includes additional information not available for the preliminary reports.

---

[1] The Arizona Water Resources Committee is a private, nonprofit corporation, organized in 1957, to promote the development of Arizona's water resources with particular emphasis on water yield from wildland watersheds.

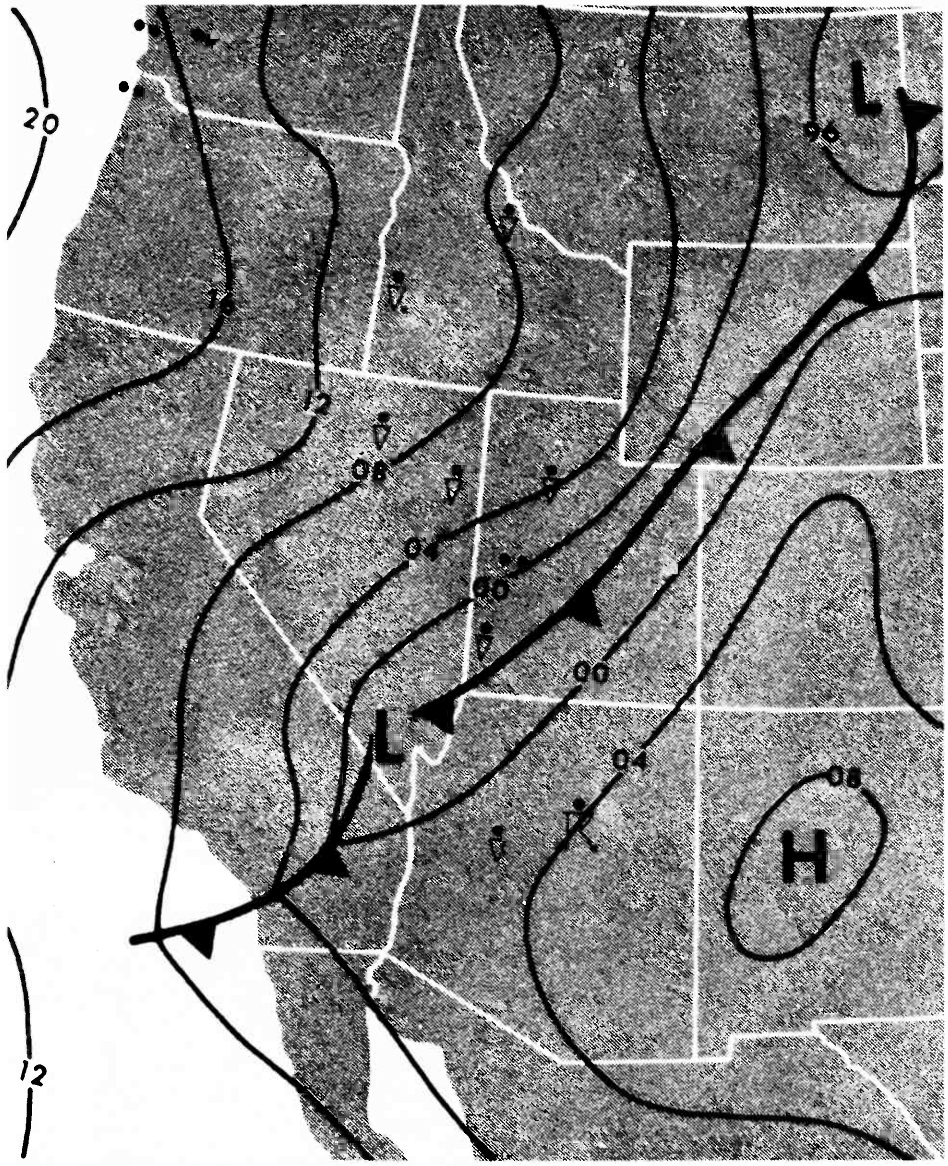


FIGURE 1. SURFACE WEATHER CHART FOR 5 A.M. MST, SEPTEMBER 5, 1970 (ZIMMERMAN, 1971).

ANALYSES

Meteorological Event

Synoptic Features — The complex meteorological events involved in the 1970 Labor Day Storm began on September 2 when moist air, associated with tropical storm **Norma,** flowed into Arizona from the Pacific Ocean and the Gulf of California (National Oceanic and Atmospheric Administration, 1970). This air mass extended over the State during the next two days, and reached sufficient depth to allow the formation of thunderstorms over southeastern Arizona on the 3rd. Thunderstorms spread northwestward into the Phoenix area by evening, and continued to spread northwestward over the State at night.

A convergent flow of air in the lower atmosphere over southern Arizona on the 4th caused heavy rainfall to occur on the east side of the Baboquivari Mountains and northward to Tucson and the Avra Valley. This rainfall ended late on the 4th.

On the morning of the 5th, a cold front had extended from southwestern Utah into southern Nevada (Figure 1), and an associated deep upper trough was located over Nevada and southern California. Simultaneously, in advance of the cold front, a surface trough was oriented from Las Vegas, Nevada to Palm Springs, California. Strong, southerly winds developed in the lowest 10,000 feet of the atmosphere early on the 5th. Orographically induced rainfall increased sharply over the mountains of central Arizona as the troughs approached from the west. In addition, a combination of the eastward advancing trough and normal daytime heating

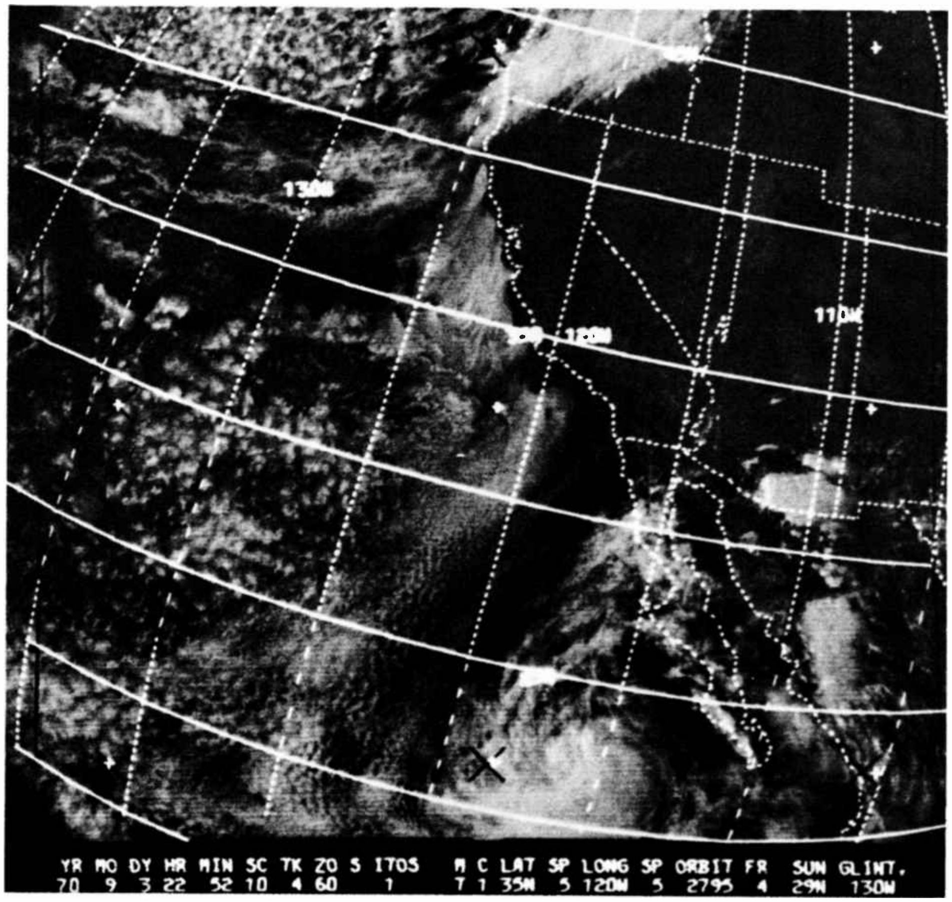


FIGURE 2A. AUTOMATIC PICTURE TRANSMISSION FROM THE ITOS 1 SYSTEM AT 3:52 P.M. MST, SEPTEMBER 3, 1970.

generated lines of thunderstorms in the desert valleys of western Arizona by midafternoon. These thunderstorms progressed eastward and intensified, resulting in heavy rainfall by late afternoon and evening in the Salt River Valley.

Most of the activity associated with the lines of thunderstorms had weakened by late evening on the 5th, and precipitation ended over the central mountains and the northeastern plateau. However, the eastward movement of the surface trough had slowed during the day, causing renewed storm activity throughout the evening in the desert valleys east of the Buckeye area.

The original cold front dissipated by the evening of the 5th, and the surface trough, which was now located east of Phoenix, acquired the characteristics of a cold front. This newer and weaker cold front progressed southward to a position between Tucson and Douglas on the morning of the 6th. Strong, southerly winds continued south of the front, and there was more orographic rainfall over the mountains of southeastern Arizona. Late on the 6th, all atmospheric disturbances had weakened and most of the precipitation ceased, bringing the Storm to an end.

Thus, conditions which led to the 1970 Labor Day Storm initially developed with a strong northward advance of moist, unstable air from the eastern Pacific Ocean and the Gulf of California. Following this air mass invasion, the triggering mechanisms that contributed to heavy rainfall included orographic uplift associated with strong southerly winds in the lower atmosphere, the invasion of an unusually intense early-fall cold air mass from the Pacific Northwest with its associated frontal activity, and heating at the desert surface.

Several synoptic features of the Storm are illustrated by pictures obtained with the Improved Tiros Operational Satellite (ITOS 1) system. On September 3 a cloud cover associated with thunderstorm activity was present in southeastern Arizona (Figure 2a). Also, clouds associated with tropical storm **Norma** off Baja California and a cold front system in the Pacific Northwest were evident. The cold front in the Pacific Northwest eventually moved southeastward into Arizona and contributed to heavy rainfall on the 5th. Precipitation was relatively light and confined largely to southern Arizona on the 3rd. In most cases, the total rainfall for this observational day[2] was less than 0.75 inch (National Oceanic and Atmospheric Administration, 1970).

Cloud cover was general over Arizona on the 4th (Figure 2b). The spiral cloud cover associated with **Norma** was still evident, and the cold front system originating in the Pacific Northwest had moved over Nevada. Also, the apparent "eye" of the tropical storm was visible slightly west of longitude 115W and south of latitude 25N. Rainfall was more general and heavier on the 4th than on the 3rd. Thirty-seven official National Weather Service stations reported at least one inch of rainfall for this observational day, and six stations reported 2.5 inches or more (National Oceanic and Atmospheric Administration, 1970).

On the 5th, the cloud cover over central and southern Arizona (Figure 2c) was associated partly with the strong cold front system and a cold trough that had entered the State, and partly with orographic uplifting of moist unstable air, primarily along the southern side of mountain ranges and the Mogollon Rim escarpment (Zimmerman, 1971). **Norma** was still visible, but much less so than on the 4th. The satellite picture on the 5th was obtained at 3:50 p.m. MST, when rainfall was heavy and subsequent flooding was particularly damaging in central Arizona. Precipitation was widespread in Arizona on the 5th. Rainfall totals for this observational day equalled or exceeded two inches at 32 official stations, and 11 stations reported at least four inches (National Oceanic and Atmospheric Administration, 1970).

---

[2] The total rainfall for an observational day usually means the greatest precipitation observed in the 24-hour period ending at the regular time of observation of a station taking only one observation per day. These data should be interpreted carefully. Time periods representing an observational day start and end at different times depending on the station. To illustrate, some stations have observation periods from 8 a.m. to 8 a.m., while others are from 7 p.m. to 7 p.m.

By midday on the 6th, cloud cover was present in southeastern and northern Arizona, and **Norma** had weakened considerably (Figure 2d). Rainfall totals equalled two inches or more at 25 stations and at least 4.0 inches at four stations (National Oceanic and Atmospheric Administration, 1970). All stations reporting four inches or more rainfall were measured from 8 a.m. to 8 a.m.; consequently, some of the reported rainfall for the 6th at these stations may have occurred on the 5th.

Skies were mostly clear over all of Arizona in late afternoon on the 7th (Figure 2e), and relatively little rainfall was reported for this observational day (National Oceanic and Atmospheric Administration, 1970).

Total Storm Rainfall — An isohyetal map of total rainfall during the Storm shows prominent orographic effects (Figure 3). Higher rainfall totals (five inches and more) were mainly associated with the Mogollon Rim northeast of Payson, the Sierra Ancha Mountains southeast of Payson, the Mazatzal Mountains south and southwest of Payson, the Bradshaw Mountains south of Prescott, the Black Hills east of Prescott, the high country south of Flagstaff, the Santa Catalina Mountains northeast of Tucson, and the Baboquivari Mountains and Kitt Peak southwest of Tucson.

New precipitation records for a 24-hour observational day were established at many National Weather Service stations in Arizona (Table 1). Perhaps the most spectacular record was established at Workman Creek 1, located in the Sierra Ancha Mountains of central Arizona. Here, an official rain gage recorded 11.4 inches of precipitation between 10:00 p.m. September 4 and 10:00 p.m. September 5, establishing a new 24-hour record for Arizona (National Oceanic and Atmospheric Administration, 1970). The previous official National Weather Service record for a 24-hour observational day was six inches, recorded at Crown King on December 19, 1967.

At the Payson Ranger Station, the 6.2 inches recorded during the Storm was the greatest amount recorded at this station since its early establishment in 1892.

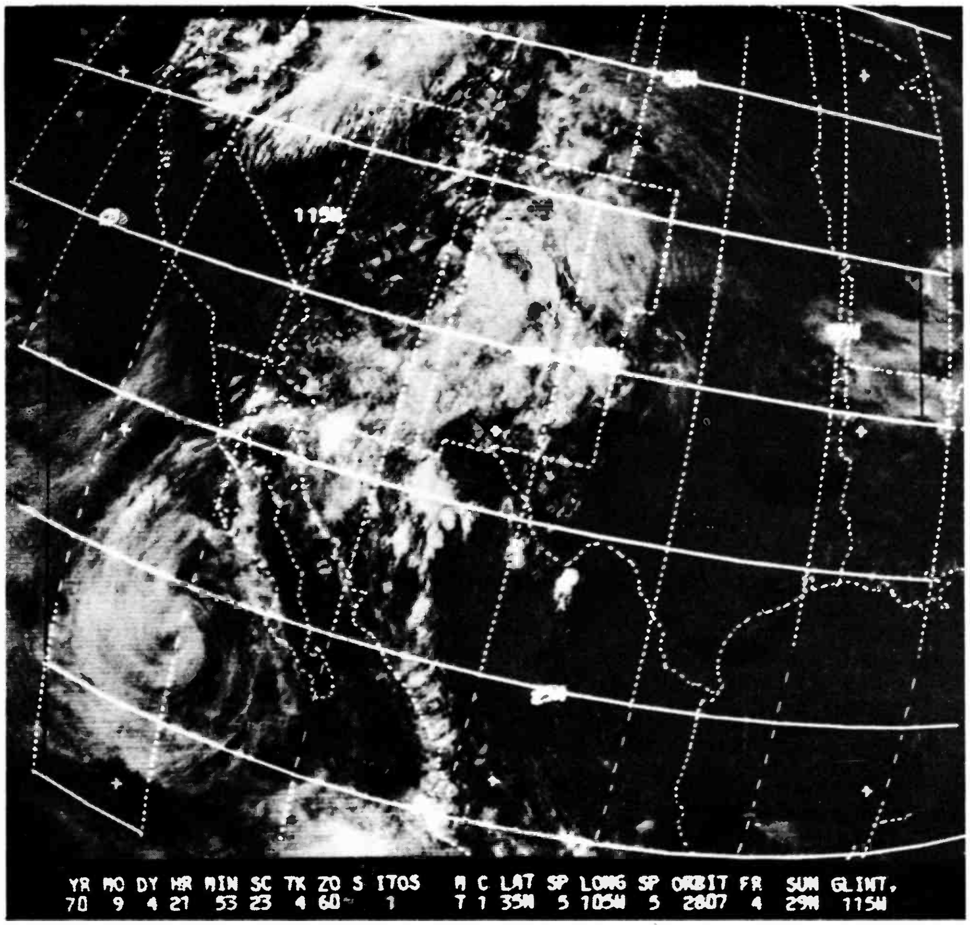


FIGURE 2B. AUTOMATIC PICTURE TRANSMISSION FROM THE ITOS 1 SYSTEM AT 2:53 P.M. MST, SEPTEMBER 4, 1970.

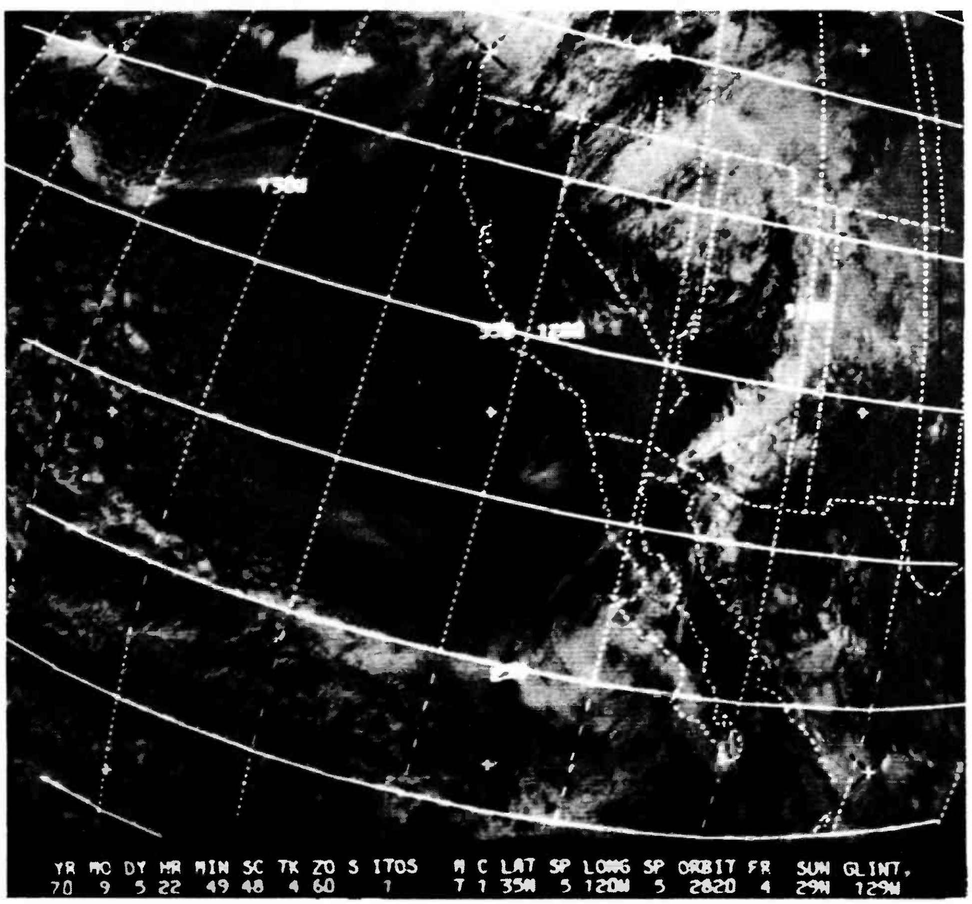


FIGURE 2C. AUTOMATIC PICTURE TRANSMISSION FROM THE ITOS 1 SYSTEM AT 3:50 P.M. MST, SEPTEMBER 5, 1970.

One analysis of total storm rainfall, based on computed estimates rather than actual rain gage measurements, suggested that up to 18 inches of precipitation may have occurred on the upper watershed of Tonto Creek along the Mogollon Rim from September 3rd to the 7th (Elson, 1971). However, this projected rainfall amount is based on streamflow determinations and cannot be verified.

Rainfall Intensity — Rainfall intensities greater than three inches in four hours were reported for several stations during the Storm (Roeske, 1971). Maximum rainfall intensities computed from a sampling of rain gage records for selected time intervals are presented in Table 2. These data were obtained in or near mountain ranges receiving large total rainfall amounts (Figure 3), but the intensities are not necessarily representative of entire mountain ranges.

Stations in the Sierra Ancha and Mazatzal Mountains northeast of Phoenix and on the plateau southeast of Flagstaff reported maximum 15-minute intensities exceeding 2.5 inches per hour. In Tonto Creek Basin, where loss of life and destruction from flooding were particularly severe, six inches of rainfall was estimated to have occurred over a one-hour period along the Mogollon Rim above the Tonto Creek Fish Hatchery (Elson, 1971). At the Diamond Two Ranch, about 20 miles south of Prescott, five inches of rainfall were observed in 1½-hour period (Williams and Russell, 1970).

Intensities of these magnitudes could easily exceed infiltration rates on some watersheds, particularly those with shallow storage over bedrock, and facilitate surface runoff and high peak streamflows. Infiltration rates are even more likely to be exceeded by high rainfall intensities when total storm precipitation is high, as observed at many locations during the Storm.

Return Period — A 24-hour rainfall total of five to six inches is a 100-year event at many locations in central Arizona (U.S. Weather Bureau, 1967). This amount was equalled or exceeded at several of these locations during the Storm. However, such a storm does not necessarily occur at 100-year intervals. Actually, the same event could occur

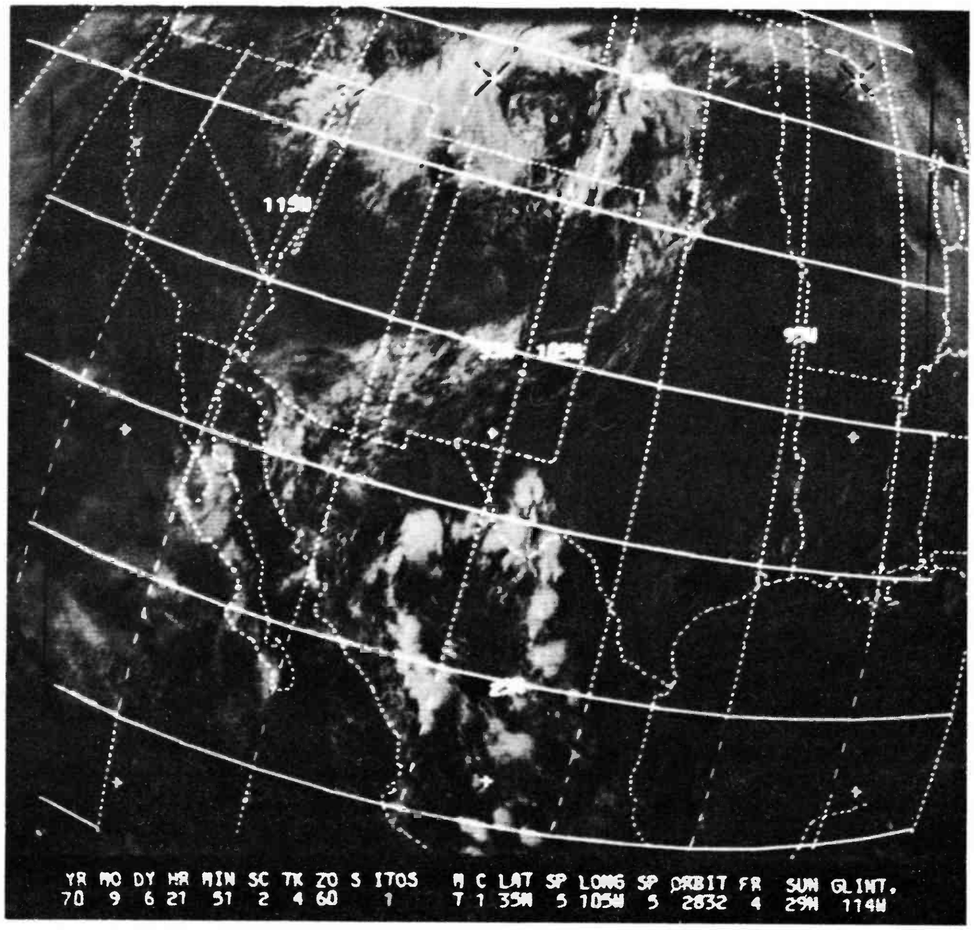


FIGURE 2D. AUTOMATIC PICTURE TRANSMISSION FROM THE ITOS 1 SYSTEM AT 2:51 P.M. MST, SEPTEMBER 6, 1970.

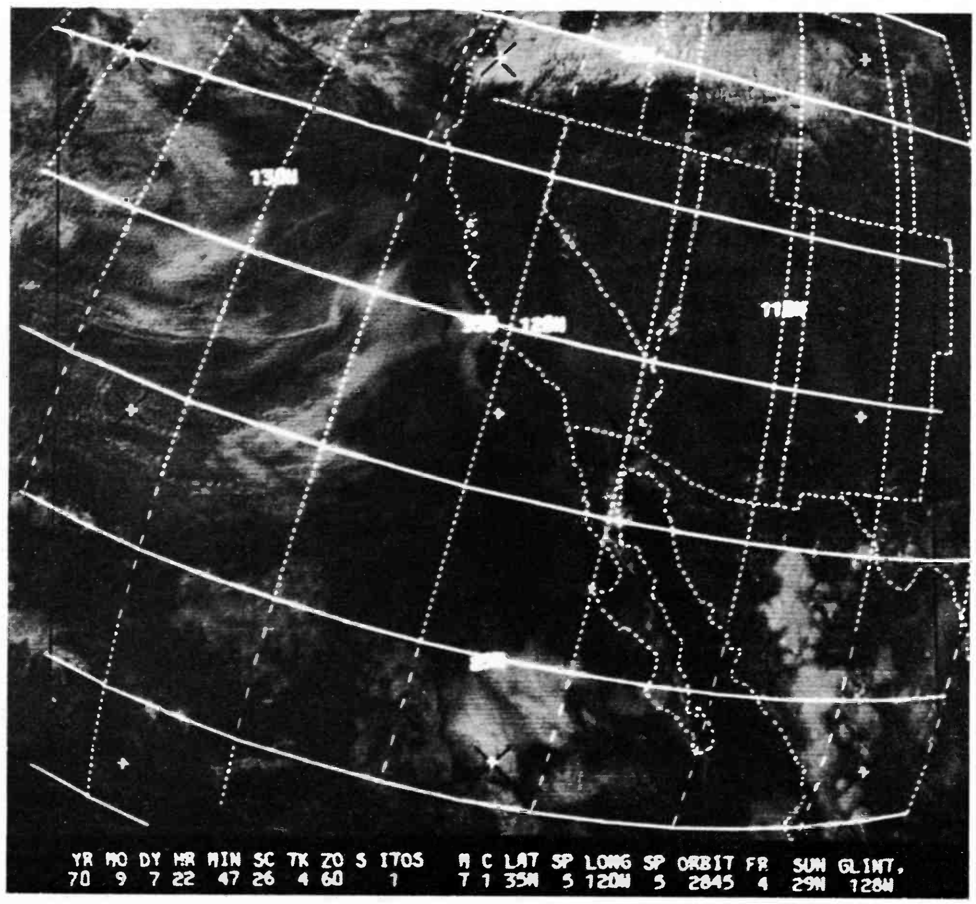
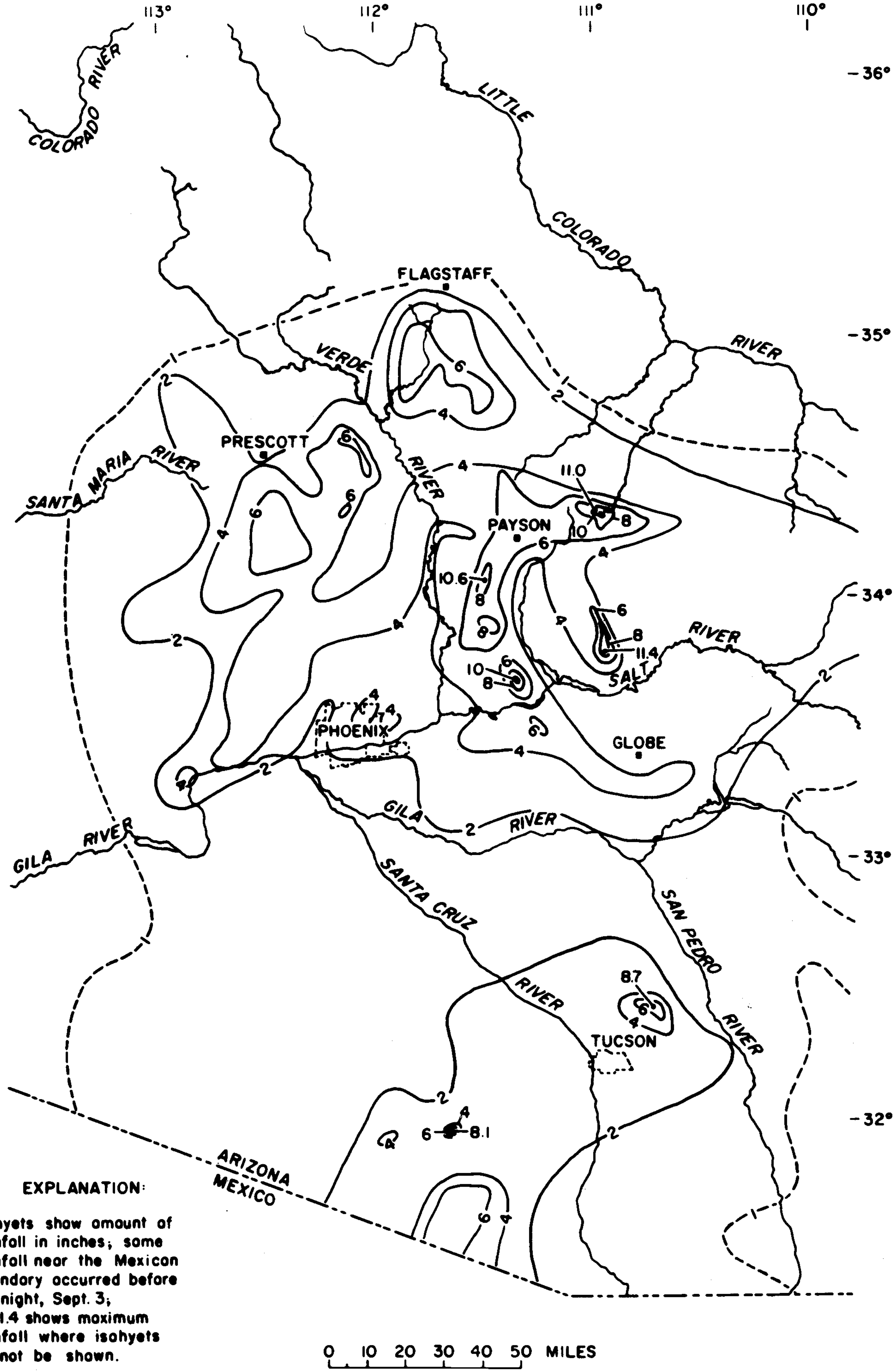


FIGURE 2E. AUTOMATIC PICTURE TRANSMISSION FROM THE ITOS 1 SYSTEM AT 3:47 P.M. MST, SEPTEMBER 7, 1970.



EXPLANATION:

Isohyets show amount of rainfall in inches; some rainfall near the Mexican boundary occurred before midnight, Sept. 3;
•—11.4 shows maximum rainfall where isohyets cannot be shown.

FIGURE 3. RAINFALL, SEPTEMBER 4-6, 1970 IN SOUTHERN AND CENTRAL ARIZONA (ADAPTED FROM ROESKE, 1971).

TABLE 1. NEW OBSERVATIONAL DAY RECORDS OF TOTAL RAINFALL RESULTING FROM THE 1970 LABOR DAY STORM, AND PREVIOUS RECORDS FOR SEVERAL STATIONS (NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1970).

Station[1]	New Record	Old Record	Date of New Record	Date of Old Record	Records Began
	inches	inches			
Bar T Bar Ranch	5.30	3.96	5th	6-14-55	1952
Bartlett Dam	4.50	4.00	6th	8-28-51	1939
Groom Creek	4.25	3.85	5th	12-26-66	1942
Junipine	5.28	4.71	5th	2- 7-37	1935
Mummy Mountain	3.94	2.29	5th	9-13-66	1955
Payson 12 NNE	4.29	3.53	5th	7-31-67	1950
Payson R.S.	6.20	4.37	5th	10-29-59	1892
Payson	5.36	3.74	5th	10-29-59	1948
Sasabe	4.36	2.75	4th	6-16-69	1959
Sedona R.S.	5.50	2.69	5th	9-12-58	1943
Sierra Ancha	4.77	4.58	5th	8-28-51	1935
Tonto Creek F.H.	5.63	4.30	6th	1-26-57	1944

[1]The exact locations of these stations can be obtained from National Oceanic and Atmospheric Administration (1970).

two or more years in a row at the same location, but such a sequence is unlikely.

A detailed analysis of the National Weather Service rainfall record obtained at Workman Creek 1 suggested that the return period or recurrence interval for the 1970 Labor Day Storm at this location exceeds 500 years, making it a highly unusual event (Kangieser, 1972). Data utilized in this analysis consisted of the greatest precipitation recorded during an observational day for each year of record. Since 1941, the greatest precipitation received in an observational day for each year exceeded five inches only twice prior to 1970, and exceeded six inches only during the 1970 Labor Day Storm.

TABLE 2. MAXIMUM RAINFALL INTENSITIES[1] FOR SELECTED TIME INTERVALS DURING THE 1970 LABOR DAY STORM AT SEVERAL LOCATIONS.

Station	Elevation (ft.)	Total Storm Amount (in.)	Time Interval 15 min.	30 min.	2 hours	6 hours
			(in. per hr.)			
Sierra Ancha Mts. (Upper Pocket Ck.)	4600	7.17	3.17	2.98	0.99	0.44
(S. Fork Workman Ck.)	6800	11.75	2.09	1.98	1.18	0.72
Mazatzal Mts. (Three Bar)	3700	8.04	2.52	1.65	1.15	0.61
Bradshaw Mts. area (Whitespar)	5700	2.64	1.12	0.95	0.49	0.26
Black Hills area (Mingus Mt.)	6300	2.18	0.80	0.56	0.31	0.12
Plateau SE of Flagstaff (Beaver Ck.)	7400	6.74	3.08	2.90	1.19	0.64

1/ Source data obtained from USDA Forest Service recording rain gages.

Hydrological Event

General Features — Arizona experienced high peak streamflows and flooding as a result of the 1970 Labor Day Storm. The peak discharge of several streams possibly exceeded the 20- to 25-year flood. On small watersheds of, say, less than 25 square miles, the return period may have been much higher. Flooding occurred near the border with Mexico on September 4, in the Mogollon Rim area and westward on the 5th, and along the Little Colorado River and near Tucson on the 6th. Thus,

TABLE 3. FLOOD STAGES AND DISCHARGES DURING THE 1970 LABOR DAY WEEKEND STORM (ROESKE, 1971).[1]

Location	Drainage Area	Beginning of Observation	Gage Height Previously Known Maximum	Gage Height September 1970	Discharge Previously Known Maximum	Discharge September 1970
	(mi^2)		(ft)	(ft)	(cfs)	(cfs)
Tonto Creek below Kohl's Ranch	24	--	--	--	--	18,400
Tonto Creek near Gisela	430	1964	19.0	29.2	30,000	38,000
Christopher Creek near Kohl's Ranch	24	--	--	--	--	11,900
Rye Creek near Gisela	122	1965	9.0	14.1	8,130	44,400
Tonto Creek above Gun Creek near Roosevelt	675	1940	16.7	18.2	--	53,000
Sycamore Creek near Fort McDowell	165	1959	15.0	19.7	15,800	24,200
East Verde River near Childs	328	1961	--	19.2	17,000	23,500
Dry Beaver Creek near Rimrock	142	1960	10.0	14.4	10,600	26,600
Oak Creek near Cornville	357	1885	23.0	16.5	--	24,700
Verde River below Tangle Creek, above Horseshoe Dam	5,872	1925	19.0	18.8	100,000	61,900
Hassayampa River at Box damsite near Wickenburg	417	1921	18.3	34.6	27,000	58,000
New River near Rock Springs	67	1962	10.7	13.5	10,600	18,600
Agua Fria River near Mayer	588	1940	--	14.9	13,000	19,800
Altar Wash near Three Points	460	1966	10.4	13.8	10,700	22,000
Brawley Wash near Three Points	776	1962	13.0	15.8	--	13,700
Sabino Creek near Tucson	36	1932	9.6	10.2	6,400	7,730
Little Colorado River at Holbrook	11,300	1870	--	13.9	60,000	19,700
Chevelon Creek near Winslow	994	1929	19.8	17.5	25,300	8,020
Clear Creek near Winslow, below Willow Creek	321	1947	21.5	20.6	16,400	15,800
Dinnebito Wash near Oraibi	261	1968	4.6	10.0	5,890	28,900

[1] These data were up-dated by personal communication with R. Roeske, USDI Geological Survey, Tucson, Arizona, November 16, 1972.

high peak flows were observed throughout the Storm period at various locations, but the most disastrous flooding occurred on the 5th.

As expected, much of the flooding was associated with areas receiving high rainfall amounts and high rainfall intensities. The spatial relationship between areas receiving at least five inches of rainfall during the Storm and several streams with high peak flows is shown in Figure 4.

The most serious flooding occurred in central Arizona, where large sudden flows occurred on Tonto, Sycamore, Dry Beaver, Wet Beaver, and Oak Creeks, and in the East Verde and Hassayampa Rivers (Roeske, 1971). New River and the Agua Fria River also had high peak streamflows. Flooding occurred in Altar and Brawley Washes in southern Arizona, primarily due to heavy rainfall near the border town of Sasabe; also, Sabino Creek near Tucson experienced a record peak streamflow. Additionally, flood flows occurred in the Little Colorado River, partly as the result of inflows from the Puerco River and Chevelon and East Clear Creeks.

Flood stages and peak discharges recorded at selected stations during the 1970 Labor Day Storm (Table 3) indicate new records for many locations (Roeske, 1971). In the Gila River Basin, at least 30 USDI Geological Survey streamflow gaging stations had record peak flows. Estimates of recurrence intervals for

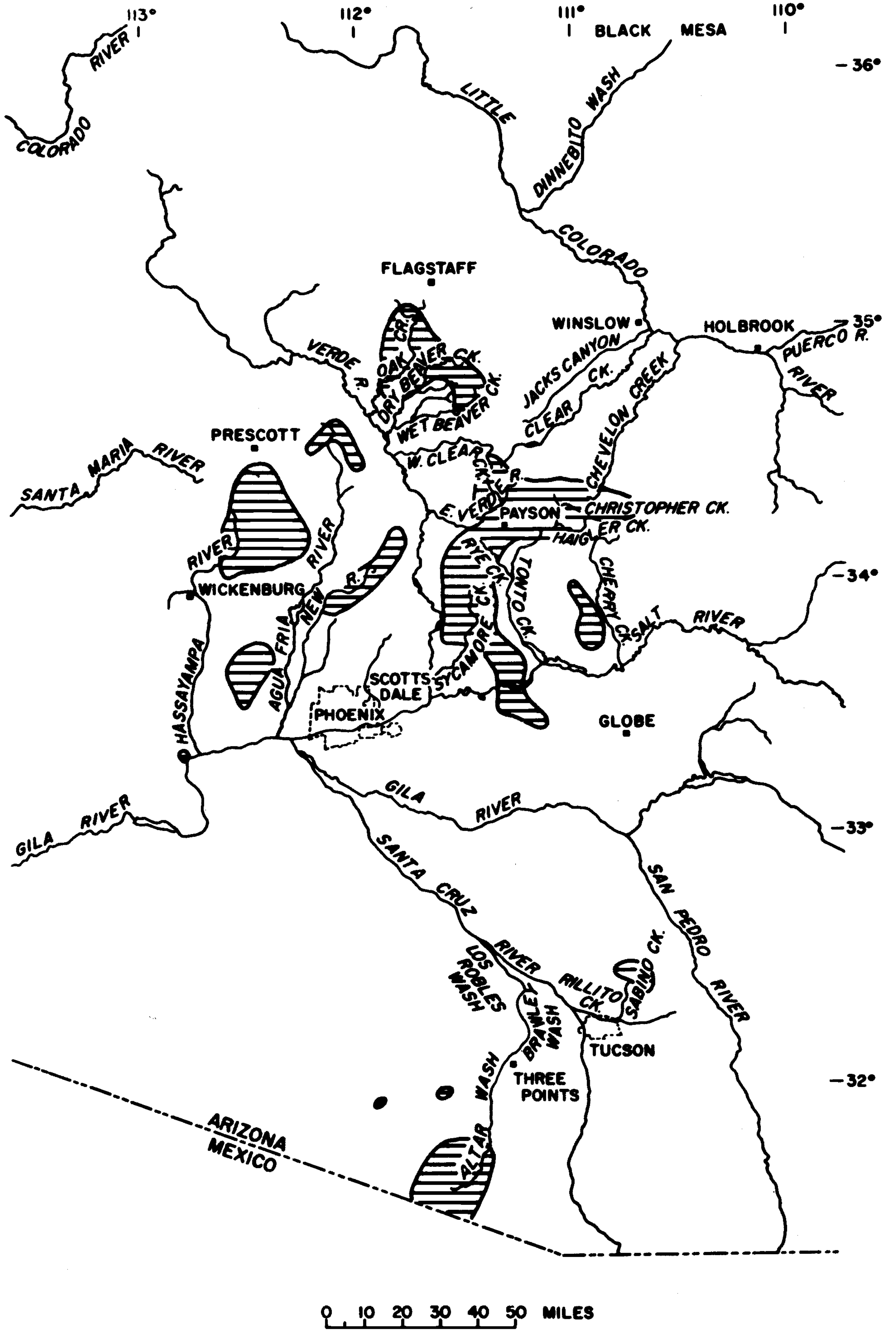


FIGURE 4. RIVER SYSTEM AND AREAS THAT RECEIVED A TOTAL RAINFALL OF FIVE INCHES OR MORE DURING THE SEPTEMBER 4-6 PERIOD OF THE LABOR DAY STORM OF 1970 IN ARIZONA. THE RAINFALL ZONES ARE CROSSHATCHED (ADAPTED FROM ROESKE, 1971).

TABLE 4. ESTIMATES OF RECURRENCE INTERVALS FOR PEAK STREAMFLOWS DURING THE 1970 LABOR DAY STORM (ROESKE, 1971).[1]

Location	Date	Peak Discharge (cfs)	Estimated Recurrence Interval[2] (years)
Tonto Creek near Gisela	5	38,000	10
Rye Creek near Gisela	5	44,400	20
Tonto Creek above Gun Creek near Roosevelt	5	53,000	40
Sycamore Creek near Fort McDowell	5	24,200	20
East Verde River near Childs	5	23,500	15
Dry Beaver Creek near Rimrock	5	26,600	20
Oak Creek near Cornville	5	24,700	25
Verde River below Tangle Creek, above Horseshoe Dam	6	61,900	10
Hassayampa River at Box damsite, near Wickenburg	5	58,000	1.2[3]
New River near Rock Springs	5	18,600	20
Agua Fria River near Mayer	5	19,800	40
Altar Wash near Three Points	4	22,000	10
Sabino Creek near Tucson	6	7,730	40
Little Colorado River at Holbrook	6	19,700	5

[1]These data were up-dated by personal communication with R. Roeske, USDI Geological Survey, Tucson, Arizona, November 16, 1972.

[2]Based on individual station records using the log Pearson Type III distribution.

[3]Ratio of discharge to 50-year flood.

peak streamflows (Table 4) further substantiate the significance of this hydrologic event.

Peak Flows and Recurrence Intervals

In central Arizona, the recreation areas near Kohl's Ranch on Tonto Creek were severely damaged by flooding (Elson, 1971), and it was here that more lives were lost than in any other area. At Kohl's Ranch, an estimated peak streamflow of 18,400 cfs (cu. ft. per sec.) occurred on the 5th. This flow, combined with high flows from two tributary streams, Christopher and Haigler Creeks, caused a peak flow of 38,000 cfs at Tonto Creek near Gisela on the 5th. Studies of recurrence intervals suggested that the peak streamflow of Tonto Creek near Gisela was a 10-year event (Table 4). This means that, on the average, a flood of this magnitude will be equalled or exceeded once in 10 years over the long run. Or, in other terms, there is a ten percent chance of a flood of this magnitude being equalled or exceeded in any given year.

The estimated peak streamflow in Christopher Creek near Kohl's Ranch was 11,900 cfs. Rye Creek, another tributary of Tonto Creek, had a peak flow of 44,400 cfs near the mouth, but, fortunately, the peak flows on these two streams occurred about two hours apart. Peak streamflow on Rye Creek was estimated to be a 20-year event. The highest discharge in Tonto Creek above Gun Creek was 53,000 cfs, which may be a 40-year flood.

Sycamore, Dry Beaver and Oak Creeks and the East Verde River had peak streamflows ranging from 23,500 to 26,600 cfs. These flows equalled or exceeded the 20-year flood on all but the East Verde. West Clear Creek did not experience serious flooding, and the peak streamflow in Wet Beaver Creek only slightly exceeded the previous record. Flows from tributary streams contributed to the highest peak flow in the Verde River above Horseshoe Dam (61,900 cfs) since a flooding event in August 1951, which was also associated with a tropical storm. However, the 1970 Labor Day flood on the Verde River above Horseshoe Dam was about a once-in-10-years event, and, in this sense, would not necessarily be considered a rare occurrence.

The Hassayampa River at the Box damsite experienced a peak streamflow of 58,000 cfs, which probably exceeded the 50-year flood. New River near Rock Springs and the Agua Fria River near Mayer had peak streamflows estimated to be 20- and 40-year floods, respectively.

In Altar and Brawley Washes, flood flows of 22,000 and 13,700 cfs, respectively, were observed near Three Points. A record peak streamflow of 7,730 cfs occurred in Sabino Creek, which drains from the Santa Catalina Mountains. This flow occurred two days after the flooding in Altar and Brawley Washes, and was estimated to be a 40-year event (Table 4).

The Little Colorado River at Holbrook had a peak streamflow of 19,700 cfs, which was estimated to be a 5-year flood (Table 4). Downstream from Holbrook, Chevelon and East Clear Creeks added to the volume of the Little Colorado River, which then caused flooding in Winslow on the 6th. Peak streamflows in Chevelon and East Clear Creeks near Winslow were 8,020 and 15,800 cfs, respectively.

Rainfall in northeastern Arizona was believed to be only one to two inches during the Storm, but reliable data are scarce (Roeske, 1971). Some runoff values were large enough to suggest greater rainfall at higher elevations. For example, Dinnebito Wash, which drains Black Mesa, had a peak streamflow of 28,900 cfs on the 5th. The previous known maximum flow was 5,890 cfs, although the period of record is short.

Reservoirs on rivers and streams reduced the damage potential of flood flows during the Storm. For instance, Roosevelt Reservoir on the Salt River stored all flow from the Tonto Creek Basin, and Horseshoe Reservoir on the Verde River absorbed the flows from upstream tributary streams (Roeske, 1971), preventing significant damage to major population centers. In addition, some small reservoirs or recreation lakes on upland watersheds, such as Chevelon Lake, Willow Springs Lake, Woods Lake and Black Canyon Lake on the Sitgreaves National Forest, had available storage space just prior to the flood, which may have prevented or reduced destruction downstream (USDA Forest Service, 1970). Blue Ridge Reservoir on East Clear Creek absorbed an estimated 9,000 acre feet of runoff (Morrison, 1970).

Some upland reservoirs received an influx of floating timber debris, such as Blue Ridge Reservoir which accumulated an estimated six to eight acres of this material during the flood (Nolan, 1970). The debris was considered potentially hazardous since it could jam spillways during future summer runoff and winter snowmelt events, and might, thereby, contribute to dam failure.

FIGURE 5. DEBRIS JAM ON TONTO CREEK (COURTESY USDA FOREST SERVICE).

Upland Watershed Damages — Many stream channels on upland watersheds were severely altered as a result of flooding during the Storm. Types of damage included accumulation of uprooted trees and other materials in debris jams at restriction points, deposition of boulder fields, channel scouring (to bedrock in some cases), and bank cutting. Damage in one or more of these categories was observed on the Coconino (Morrison, 1970), Prescott (Williams and Russell, 1970), Sitgreaves (USDA Forest Service, 1970), and Tonto (Arnolt, 1972) National Forests in north-central Arizona.

Debris jams resulted from high flows which uprooted live trees and carried them downstream along with other vegetative debris and rocks. At restriction points in channels, the churning mass of whole trees, parts of trees, and rocks tended to lodge and form the jams (Figure 5). Debris was deposited in narrow places, on sharp curves, in stands of trees, and around bridges and culverts (Arnolt, 1972). Evidently, debris jams caused at least two types of damage during the flooding. In some cases, channel diversion resulted as a head of water built up behind the debris; elsewhere, and more seriously, debris jams breached, sending a surge of destructive water, timber, and rock materials downstream in flood waves to the next restriction point where the process may have been repeated (Elson, 1971). Apparently, this sequential process led to larger debris jams with increasingly destructive potential upon release, which in turn, resulted in scoured channels to bedrock in some reaches and deposits of debris of all sizes at other locations (Arnolt, 1972).

The forces that uprooted and removed live trees during the flood were large. Whole trees were observed floating more-or-less upright in deep water during flooding (Elson, 1971). Trees left standing on the channel banks after the Storm were scarred and had sheared branches far above the high water mark (Figure 6). Damage to standing trees was evidently the result of contact from trees falling into the water and from trees and trash being carried along in the flow. Most of the trees in the debris were debarked, and branches and roots were abraded and broken almost flush with the trunks. In some cases, large trees were deposited on stream banks as high as 20 to 30 feet above the streambed (Elson, 1971). One report indicated that several large uprooted Douglas-fir trees were deposited on a bridge five miles downstream from the nearest known source of Douglas-fir trees (Williams and Russell, 1970).

Post-flood hazards, as a result of debris in channels, were considered potentially serious. During subsequent spring snowmelt periods and summer storms, debris left in channels might again plug channels, culverts and bridges, or divert flood waters into banks and cause more erosion (Arnolt, 1972). In addition, debris on unstable cut banks could eventually slough into channels, and downed timber might

FIGURE 6. TREE IN LEFT CENTER OF PHOTO SHOWING WHERE BRANCHES WERE SHEARED FROM THE RIGHT SIDE OF THE CROWN FOR APPROXIMATELY ONE-HALF THE CROWN LENGTH (COURTESY USDA FOREST SERVICE).

subsequently attract forest insects that could build up and spread to adjacent stands. Further, flammable flood debris constituted a potential fire hazard, particularly in recreation areas near fire-susceptible timber stands.

Massive boulder fields were deposited at various locations in channels (Figure 7). Some deposits were 10 to 30 feet in depth, extended the width of channels, and were up to ½ mile in length (Arnolt, 1972). Rock size varied, but larger boulders were six cubic yards in volume and possibly weighed up to 50 tons. In some places, streams flowed through or under the boulder fields; elsewhere, water was diverted laterally towards stream banks. Stream diversion was undesirable because it could lead to further bank erosion and attendant soil loss; also, more trees might be undermined and dropped into the channel (Arnolt, 1972). Future channel damage could be caused by some rock piles which were considered unstable and subject to new movement during subsequent high flows. Unstable boulder deposits were also potentially hazardous for recreation visitors.

Channel scour to bedrock occurred in some locations (Figure 8), such as on Dick Williams Creek, (a tributary of Tonto Creek) which was virtually swept clear of material above bedrock for much of its length (Elson, 1971). The scoured channel bottom of Dick Williams Creek was 50 feet below the high water mark and up to 100 feet in width in places. Elson (1971) remarked that the channel appeared "as if it had been scooped clean by some huge behemoth machine." Extensive channel scour was also observed on the Coconino National Forest (Morrison, 1970).

Vertical stream banks were another result of flood flows (Figure 9), particularly where debris deposits caused streamflow to be diverted against banks, at curves in channels, and where channel scouring was deep (Arnolt, 1972). Some vertical banks were unstable and constituted a potential source of sediment and timber debris if sloughing occurred during subsequent flooding. In addition, unstable banks were considered hazardous for recreation visitors. This hazard was accentuated where trees and large boulders were precariously suspended at high locations on or near the vertical face.

Damage to the fisheries resource was extensive throughout the flood area (Arnolt, 1972). Streams were sometimes split into multichannels by rock piles, each split with insufficient flow to support fish populations. In addition, conditions difficult to correct were created by channel scouring to bedrock, the filling of pools with boulders, sand, and silt, and the diversion of channels. Also, the frequent loss of streambank vegetation, which ordinarily shades the stream, could result in water temperatures too high for trout populations.

As would be expected, the severely damaged areas also experienced a change in appearance, which may be considered a reduction in natural beauty by some observers (Figure 10).

The large amount of channel and related damage that occurred on upland watersheds above the Kohl's Ranch area on Tonto Creek during the Storm received prompt attention from the USDA Forest Service (Arnolt, 1972) and the U.S. Army Corps of Engineers. Corrective measures undertaken included removal and disposal of timber debris, channel straightening, shaping of boulder fields to facilitate streamflow, shaping of cut banks, revegetation, and establishment of small pools in channels to help restore the fisheries resource (Figure 11).

Although channel damage was severe in many areas during the Storm and subsequent flood, minimal damage to side slopes on watersheds from erosion processes was noted. For example, little on-site damage was reported for the Tonto Creek area near the Mogollon Rim, where channel damage was particularly heavy (Elson, 1970). Likewise, only moderate on-site erosion was observed on the Coconino National Forest (Morrison, 1970). According to Williams and Russell (1970), most of the Storm damage on National Forest lands was confined to channels, while the contributing watersheds retained good litter cover. However, these reports should be considered tentative, recognizing the difficulty of surveying and quantifying sheet and rill erosion damage on large watersheds.

Debris flows, which constitute one form of on-site damage, occurred in at least five localities on the Tonto Creek watershed, and three debris flows deposited an estimated 14,000 cubic yards of soil and rock in the main channel of Dick Williams Creek (Elson, 1971).

Relation to Land Management Practices — The hydrologic response of the Beaver Creek Watershed, located on the Coconino National Forest in northcentral Arizona, may provide some insight to the effects of the 1970 Labor Day Storm in relation to different land management practices. On this study area, land management practices are being evaluated on test watersheds within the pinyon-juniper and ponderosa pine vegetation types (Brown, 1971).

Descriptions of selected test watersheds and specific land management practices under investigation on the Beaver Creek Watershed are presented in Table 5.

Total rainfall received as a result of the Storm ranged from 3.9 to 4.2 inches in the pinyon-juniper type, and from 4.7 to 6.7 inches in the ponderosa pine type (Baker **et al.,** 1971). Maximum point rainfall intensities are illustrated in Figure 12. Estimated recurrence intervals for these maximum point rainfall intensities ranged from 10 to over 100 years (Baker **et al.,** 1971).

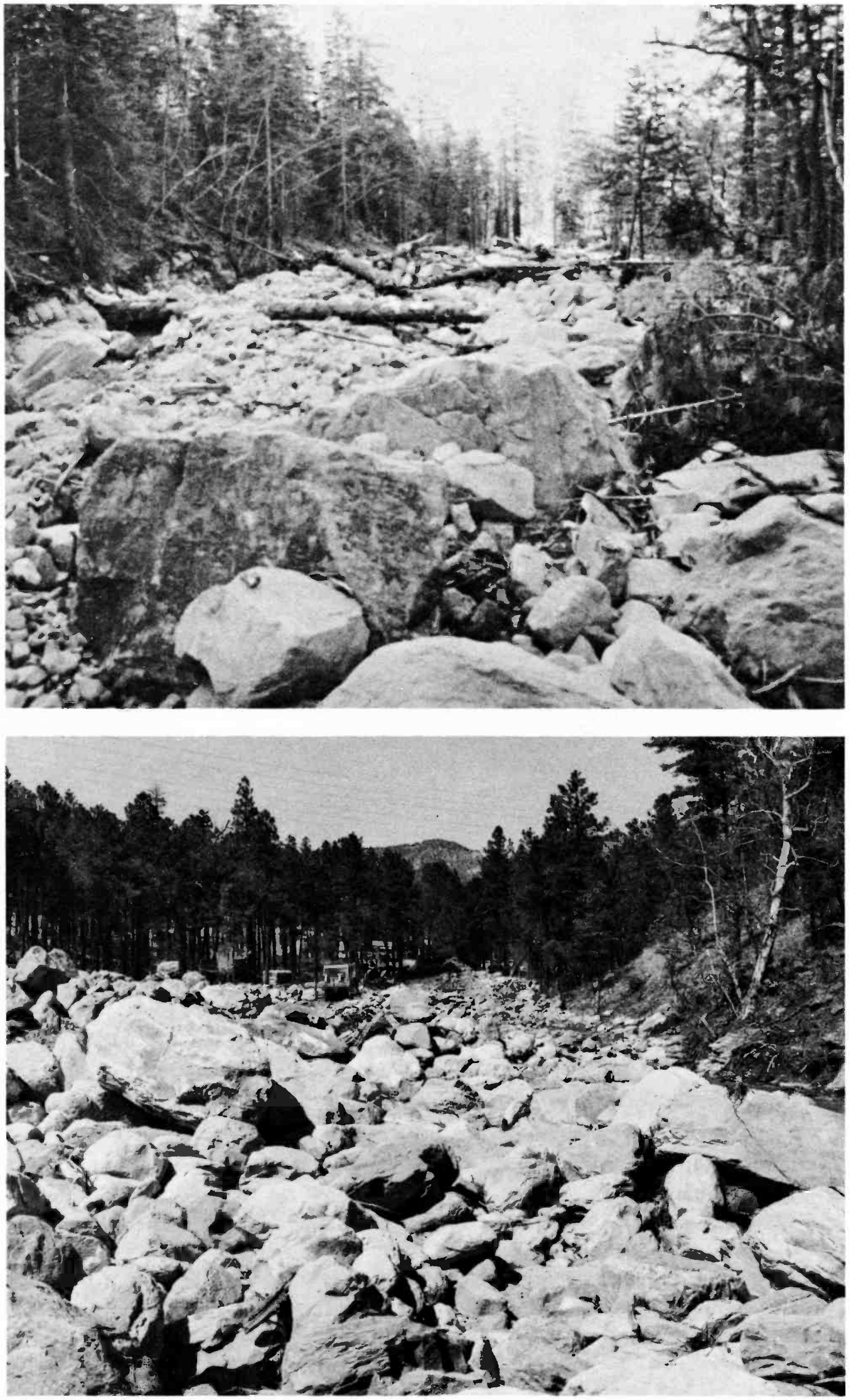


FIGURE 7. BOULDER DEPOSITS ALONG TONTO CREEK (COURTESY USDA FOREST SERVICE).

Total runoff for the Storm varied from 0.8 to 2.0 inches in the pinyon-juniper type, and from 1.2 to 4.0 inches in the ponderosa pine type (Baker **et al.,** 1971). Peak streamflow discharge ranged from 377 to 781 csm (cu. ft. per sec., per sq. mi.) in the pinyon-juniper type and from 71 to 1,777 csm in the ponderosa pine type (Baker **et al.,** 1971). The estimated recurrence intervals for peak streamflow discharges ranged from 15 to over 200 years (Baker **et al.,** 1971).

TABLE 5. DESCRIPTION OF BEAVER CREEK WATERSHEDS.[1]

Watershed number	Area, acres	Vegetation and soils	Pretreatment: Mean annual precipitation, inches	Pretreatment: Mean annual streamflow, inches	Description of treatment (percentage refers to portion of area treated)
1	332	Utah juniper and single-leaf pinyon pine. Parent material basalt, soil clay < 2 ft deep.	18	0.99	1963, 100% cabled, slash burned, regrowth
3	362	Similar to Watershed 1	18	0.87	1968, 100% herbicide treated, no removal or burning
6	104	Alligator juniper, Utah juniper, and ponderosa pine. Parent material basalt, soil silty clay < 2-1/2 ft deep.	20	3.17	1965, 100% clearcut, no removal or burning, regrowth restricted
9	1121	Ponderosa pine and Gambel oak. Basalt and cinders, silty clay loam < 2 ft deep.	27	6.77	1967-8, 33% completely clearcut in uniform 60-ft strips; slash partially burned
11	188	Perennial. Parent material basalt, soil silty clay < 2-1/2 ft deep.	22	3.05	1967+, 50% utilization of perennial grasses every spring and fall
12	455	Ponderosa pine, Gambel oak, and alligator juniper. Parent material basalt and cinders, soil silty clay < 2 ft deep.	24	5.97	1966-7, 100% clearcut, slash windrowed, partial sprout control
14	1349	Ponderosa pine and Gambel oak. Parent material basalt and cinders, clay loam < 2 ft deep.	25	4.61	1970-71, clearcut in irregular strips averaging 60-ft wide, thinned to intervening strips to 80 sq ft/A; slash burned and clearcut strips planted in ponderosa pine
17	299	Ponderosa pine and Gambel oak. Basalt and cinders, silty clay loam < 2 ft deep.	28	7.63	1969, 75% thinned in even-aged groups; slash windrowed

[1] Adapted from Baker et al., 1971.

Relationships between total rainfall and total runoff for the Storm on six watersheds, including four watersheds subjected to specific land management practices, are given in Figure 13. Runoff efficiencies illustrated by these relationships may reflect hydrologic performances associated with the different land management practices being investigated on the Beaver Creek Watershed.

The effects of land management practices on total runoff and peak streamflow discharge were assessed by comparing treated watersheds with untreated control watersheds; additionally, a graphical analysis of hydrologic response was made using relationships between peak streamflow discharge and maximum (weighted) 60-minute rainfall intensity (Baker **et al.**, 1971). Total sediment yields associated with the Storm were measured with catchment basins and splitting devices on a sample of test watersheds (Brown **et al.**, 1970).

Estimates of land management practice effects on total runoff and peak streamflow discharge are summarized in Table 6. Total sediment yields on selected Beaver Creek Watersheds are presented in Table 7.

In the pinyon-juniper type, total runoff and peak streamflow discharge were estimated to have increased most on a 6-year old cabled watershed (Watershed 1) and less on a 2-year-old chemically treated watershed (Watershed 3); there was no apparent effect of a 5-year-old treatment (Watershed 6) where trees had been felled and left in place (Baker **et al.**, 1971). Total sediment yield was greater on a 6-year-old

TABLE 6. ESTIMATED INCREASES IN PEAK RUNOFF DISCHARGE AND TOTAL SURFACE RUNOFF DUE TO TREATMENT.[1]

Watershed treated vs control	Treatment	Estimated Increase					
		Peak discharge				Total runoff	
		Control watershed analysis		Graphical analysis		Control watershed analysis	
		Csm	Percent	Csm	Percent	Inches	Percent
1 vs 2	Cabled pinyon-juniper	400	207	300	160	0.8	210
3 vs 2	Chemically treated pinyon-juniper	100	126	100	126	0.2	130
6 vs 5	Clearcut pinyon-juniper	0	0	0	0	0	0
9 vs 8	1/3 stripcut ponderosa pine	200	145	100	120	0.2	114
11 vs 10	Old clearcut ponderosa pine	0	0	350	170	0	0
12 vs 14	Recent clearcut ponderosa pine	600	218	750	300	2.1	226
17 vs 18	3/4 thinning ponderosa pine	400	216	500	300	1.9	190

[1] Adapted from Baker et al., 1971.

FIGURE 8. CHANNEL SCOUR IN TONTO CREEK DRAINAGE (COURTESY USDA FOREST SERVICE).

cabled watershed (Watershed 1) than on a 2-year-old chemically treated watershed (Watershed 3).

Land management practices which may have increased both total runoff and peak streamflow discharge in the ponderosa pine type were a 3-year-old clearcut (Watershed 12), a 1-year-old thinning (Watershed 17), and a 3-year-old strip cut (Watershed 9). A 3-year-old clearcut (Watershed 12) appeared to be the only practice in this vegetation type that increased total sediment yield (Baker **et al.**, 1971).

Although strictly limited to conditions on the Beaver Creek Watershed, the information presented above may be helpful in attempting to understand the relation of the 1970 Labor Day Storm to some of the land management practices imposed on forest lands in Arizona.

Hydrologic relationships between specific land management practices and overwhelming meteorologic events such as occurred during the 1970 Labor Day Storm are difficult to isolate and quantify. For example, if a large rainfall occurs, particularly in a short period of time, flooding may result regardless of the current land management practice. However, if a watershed, for whatever reason, is largely denuded of vegetation and has bare soil exposed to the elements, then rates of overland runoff, erosion, and sedimentation may be higher than would be expected if the watershed were in a more protected condition.

Forecasts and Warnings — For any major disaster such as the 1970 Labor Day Storm, the forecast and warning system in use at the time has an important public function, and should, therefore, be considered and described in post-storm analyses.

National Weather Service Offices (WSOs) are primarily responsible for distributing weather forecasts, including severe weather warnings, to the local public for designated areas (Zimmerman, 1971). In Arizona the WSO's base weather forecasts and warnings on recent observations and guidance from two higher echelon offices, the National Meteorological Center (NMC), Suitland, Maryland, and the Weather Service Forecast Office (WSFO), Albuquerque, New Mexico.

TABLE 7. SEDIMENT STATISTICS FROM SELECTED BEAVER CREEK WATERSHEDS DURING THE 1970 LABOR DAY STORM.[1]

Vegetation type	Watershed number	Area	Bedload[2]				Suspended		Total amount
			Amount	Percent of total	Size of material Over[3] 2 mm	Size of material Under 2 mm	Amount	Percent of total	
		Acres	Tons/A		-- Percent --		Tons/A		Tons/A
Utah juniper	1	332	0.3	27	0	100	0.8	73	1.1
	3	362	0.01	20	0	100	0.04	80	0.05
Alligator juniper	4	346	0.04	13	0	100	0.23	87	0.3
Ponderosa pine	9	1121	0.2	14	100	0	1.1	86	1.3
	10	571	1.1	10	100	0	9.6	90	10.7
	12	455	0.9	10	100	0	7.9	90	8.8
	14	1349	0.1	10	90	10	1.1	90	1.2
	16	252	Trace[4]	--	0	100	--	--	--
	17	299	0.8	40	0	100	0.12	60	0.2

[1]Adapted from Baker et al., 1971.

[2]Bedload is defined as proportion of sediment which is deposited in sediment basin (Brown, Hansen, and Champagne, 1970).

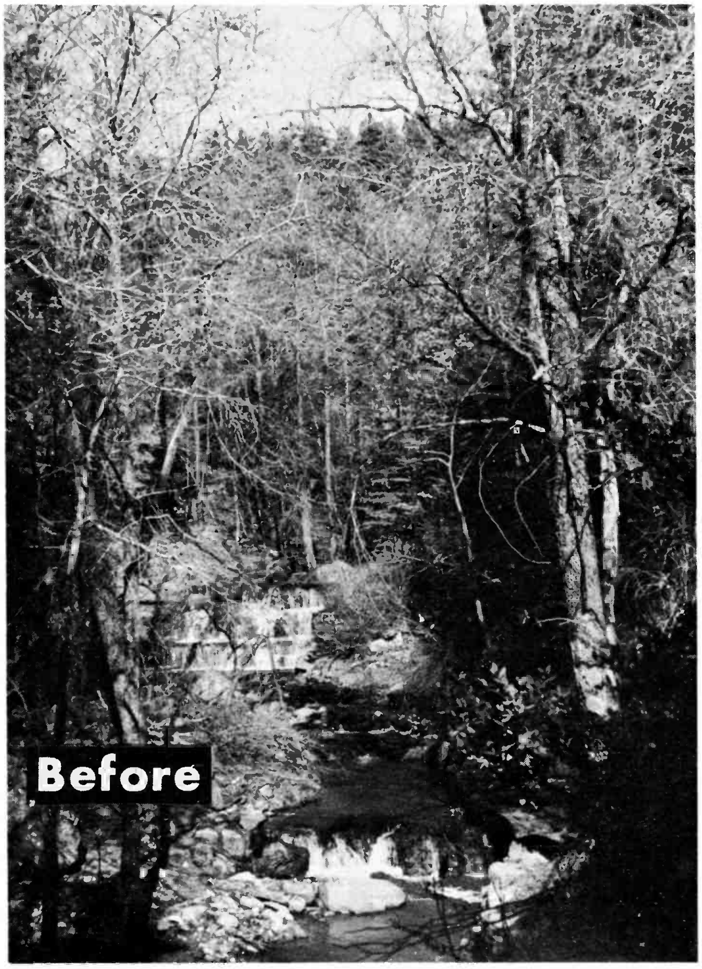
[3]Maximum material sizes were 24, 18, 15, 12 inches, respectively, on Watersheds 10, 14, 9, and 12.

[4]Trace equals less than 0.001 ton/acre.

FIGURE 9. VERTICAL STREAM BANK ALONG CHRISTOPHER CREEK (COURTESY USDA FOREST SERVICE).

The National Weather Service is also developing a capability to provide river and flood forecasts by means of River Forecast Centers (RFCs) and River District Offices (RDOs). The WSO in Phoenix is designated as the RDO for all of Arizona except for a small area in the northwest corner of the State. The RFC for Arizona is in Salt Lake City, Utah. Unfortunately, at the time of the 1970 Labor Day Storm, the RFC was just newly established and could not provide the RDO in Phoenix with much assistance (Zimmerman, 1971). Telephone contact between the two offices was made on the morning of September 4, however, and it was agreed that forecasts and weather statements should stress a high flash flood potential in Arizona for the next couple of days (Zimmerman, 1971).

The NMC predictions made prior to September 5 indicated that shower activity was expected to diminish over Arizona on the 5th (Zimmerman, 1971). This incorrect information had an undesirable effect on WSFO and WSO forecasts, which are based partly on



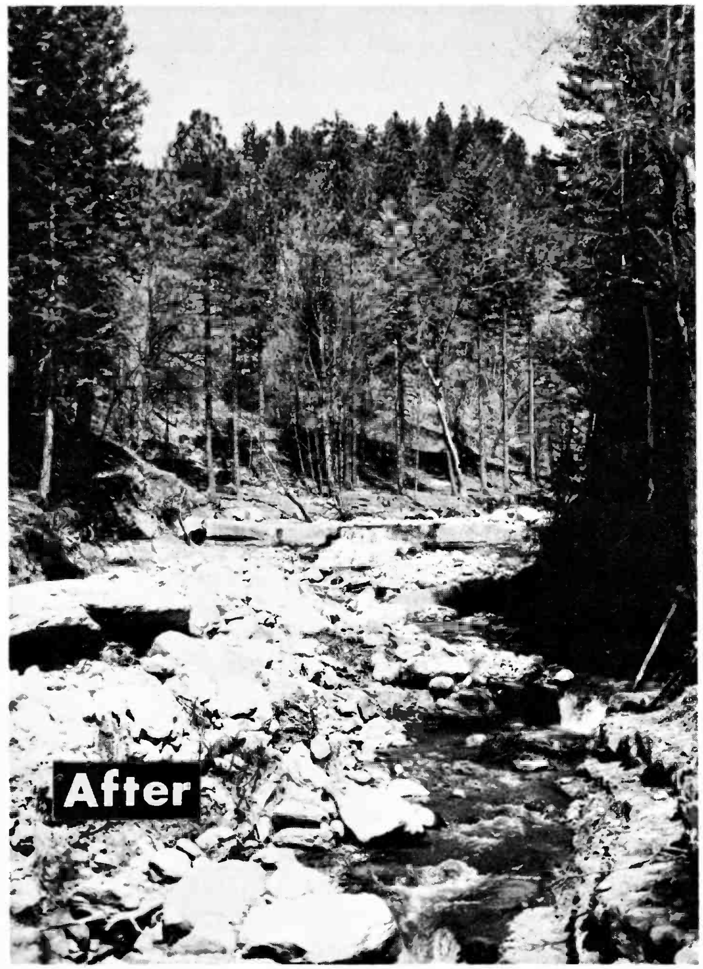


FIGURE 10. APPEARANCE OF TONTO CREEK BEFORE AND AFTER THE 1970 LABOR DAY FLOOD (COURTESY USDA FOREST SERVICE).

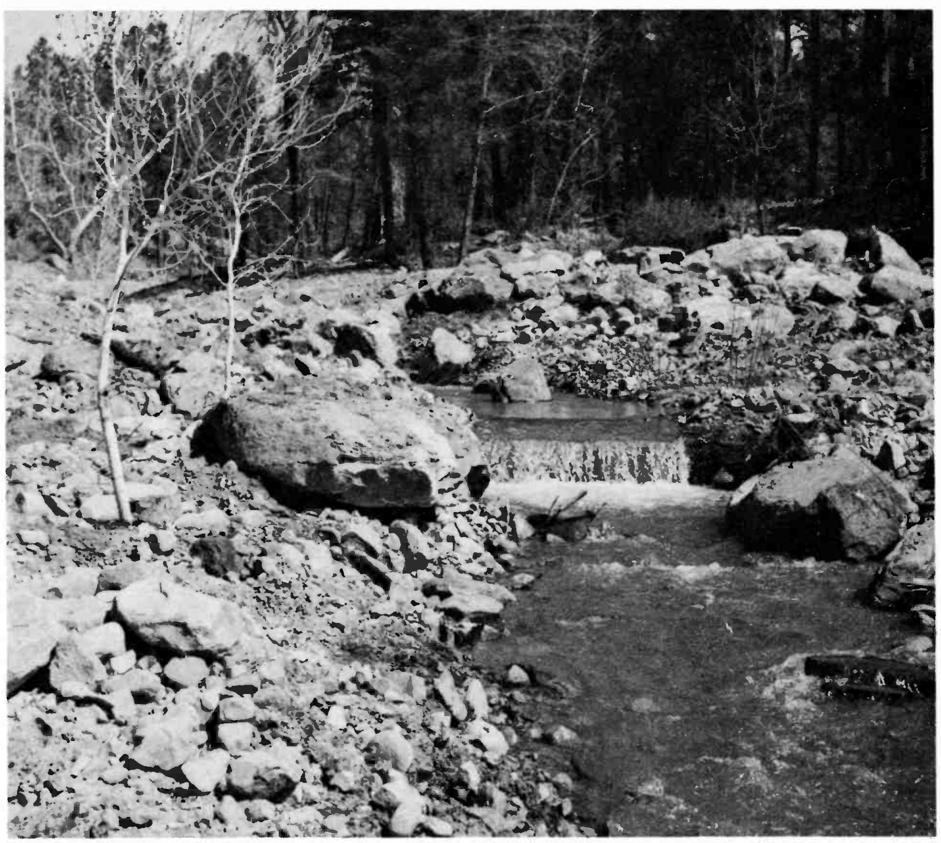


FIGURE 11. A REACH ALONG TONTO CREEK AFTER CLEAN-UP SHOWING PLANTED COTTONWOODS AND ARTIFICIAL POOL (COURTESY USDA FOREST SERVICE).

NMC guidance. The WSFO in Albuquerque issues forecasts and guidance messages every six hours (9:10 p.m., 3:10 a.m., 9:10 a.m., and 3:10 p.m.).[3] On September 4, the morning and afternoon statements by the Albuquerque WSFO indicated, as the NMC had suggested, that shower activity would diminish over Arizona on the 5th. However, a 9:10 p.m. forecast discussion on September 4 indicated a potential for heavy showers on the 5th. But the 3:10 a.m. statement on September 5 indicated only scattered showers for this day, decreasing on the 6th, with no mention of heavy rainfall. It was not until the 9:10 a.m. and 3:10 p.m. forecasts on September 5 that the WSFO correctly indicated heavy rainfall through the night of the 5th. This more adequate information was issued to Arizona WSOs only a few hours before or during the heavy rainfall of September 5.

[3] All references to time in terms of MST.

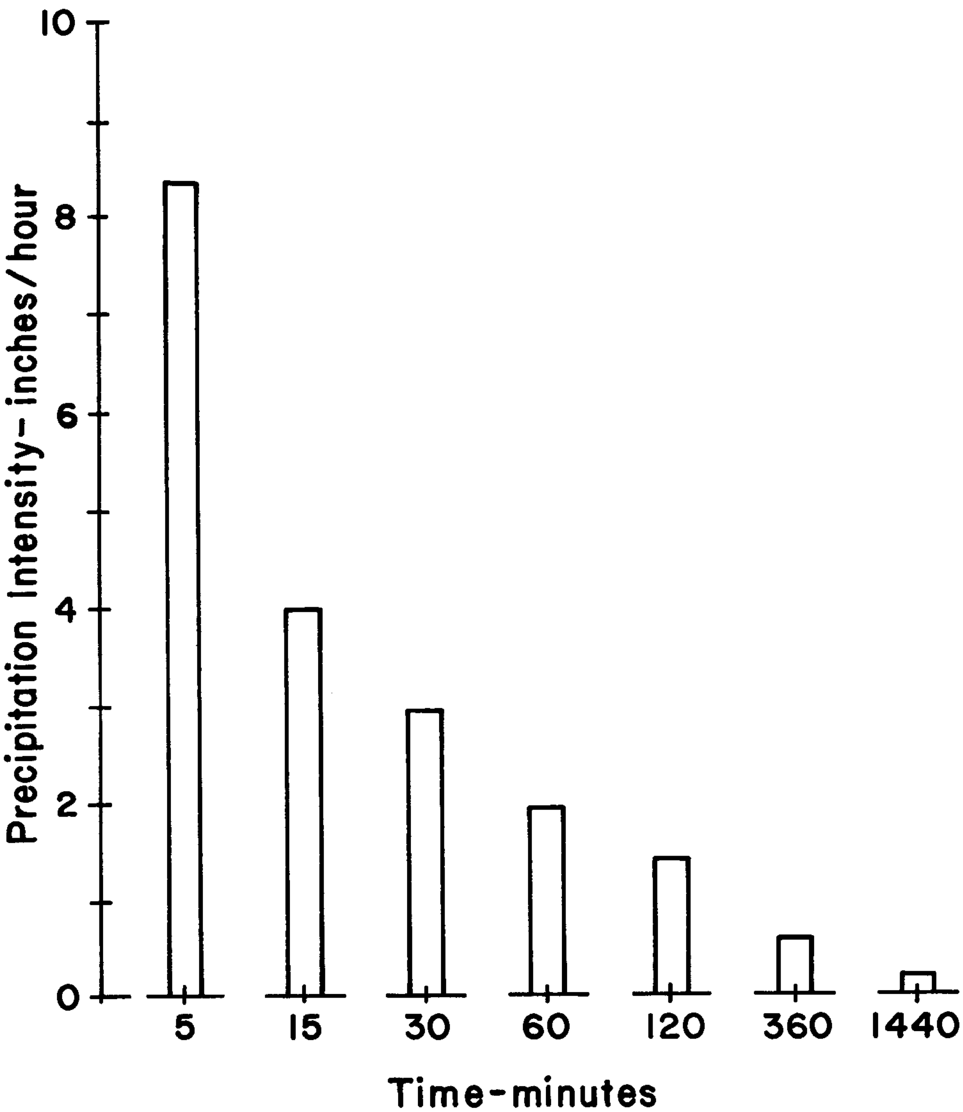


FIGURE 12. MAXIMUM POINT RAINFALL INTENSITIES FOR THE BEAVER CREEK EXPERIMENTAL WATERSHEDS (ADAPTED FROM BAKER ET AL., 1971).

Fortunately, the Phoenix WSO had decided to preface forecasts issued by the WSFO on September 4 and 5 with the statement "Flash Flood Potential High (or Very High)" with one exception, the 4:00 a.m. forecast on September 5, which did not stress this hazard (Zimmerman, 1971). The added information on flash flood potentials, which was disseminated to the public along with the forecasts, may have caused some travelers and recreationists to avoid hazardous areas or to stay home for this Labor Day Weekend.

The Phoenix WSO prepares weather summaries for the entire State every three hours, in addition to issuing forecasts from the WSFO every six hours for Phoenix and its vicinity. The summaries are widely distributed in Arizona, and are used by the press, wire services, and other disseminators of weather information. The 8:00 a.m. weather summary on September 4 indicated:

> **". . . Flash-flood potential is very high, and there may be some sustained heavy rains in the mountains resulting in prolonged periods of runoff into some streams and washes." (Zimmerman, 1971).**

Other summaries through the evening of September 4 also indicated that the flash flood potential was high. However, the summaries released on the night of September 4 and the early morning of the 5th reflected the "drier" forecasts issued by the NMC and WSFO, and it was not until 5:30 a.m. on September 5 that very high flash-flood potentials were again identified in the summaries.

The preface statements concerning flash flood potentials which were attached by the Phoenix WSO to forecasts prepared by the WSFO, and those included in WSO weather summaries for Arizona, are not considered official National Weather Service flood warnings. It was not until 2:00 p.m. on September 5 that the first in a sequence of official flood warnings was issued by the Phoenix RDO, as follows:

> **". . . effective immediately until 10 pm for Verde Valley and Oak Creek, Beaver Creek area, Cottonwood, Cornville, Camp Verde and Sedona area.**
>
> **Continued heavy rains over the Oak Creek and Sycamore Creek Basins and Beaver Creek Basin have caused flooding on these streams. Oak Creek is running almost up to the base of the bridge at Sedona and still rising.**
>
> **Several crests are likely on the Verde from each of these streams this evening and tonight. At present it is not possible to determine the exact timing or height of each crest.**
>
> **All interests along the Verde from Cottonwood to Camp Verde and on its tributaries in this area should expect the river to rise during the evening and night . . . probably above flood stage.**
>
> **All interests should listen for later warnings and bulletins" (Zimmerman, 1971).**

The Phoenix RDO issued flood warnings for the Agua Fria River and New River at 3:30 p.m. on September 5, and for the Hassayampa River from Wickenburg south to the Gila River at 6:30 p.m. On September 6 at 8:00 a.m., flash flood warnings were continued for eastern sections of Pinal and Maricopa Counties and for all of Pima, Santa Cruz, Cochise, Graham, and Greenlee Counties, and southern portions of Navajo and Apache Counties for the rest of the day. Flood warnings were

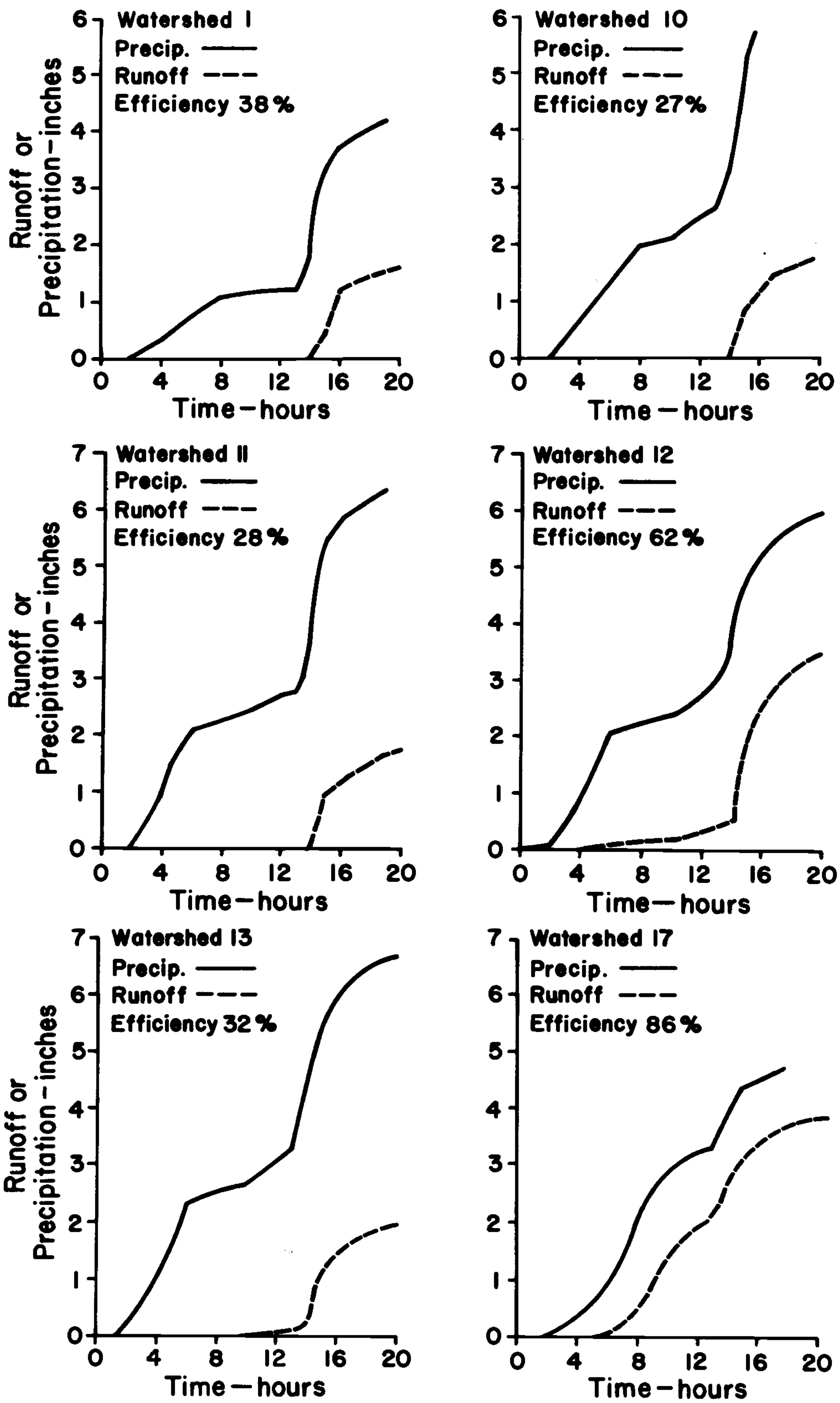


FIGURE 13. RUNOFF EFFICIENCY FOR SELECTED BEAVER CREEK EXPERIMENTAL WATERSHEDS (ADAPTED FROM BAKER ET AL., 1971).

issued for the Little Colorado River above Holbrook to the mouth at 10:00 a.m. on September 6 (Zimmerman, 1971).

The Flagstaff WSO was also involved in the events of the 1970 Labor Day weekend. At 7:10 a.m. on September 5, this office stressed continued rainfall throughout the day, heavy at times, by means of direct broadcast over two radio stations (Zimmerman, 1971). At 9:00 a.m. the Flagstaff WSO contacted the Phoenix WSO about flood warnings, but a lack of information on the heavy rainfall and the recent forecast guidance from the WSFO in Albuquerque discouraged the Phoenix WSO forecaster on duty from issuing flood warnings. At 12:10 p.m., after contacts with the Arizona Highway Patrol and the Coconino County Sheriff's Office, the Flagstaff WSO made direct radio broadcasts in which travelers and motorists were advised to seek higher ground, to stay where they were if safe and to restrict travel. At 2:00 p.m. a flood warning was issued as follows:

> **"Flooding expected all drainages Coconino County. All streams rising rapidly. Two to five inches of rain received so far — at least one more expected this afternoon. Heavy runoff continuing for 12 to 18 hours" (Zimmerman, 1971).**

The weather service area for the Winslow WSO was on the fringe of the main heavy rainfall area. However, when flood warnings for the Little Colorado River were received from the Phoenix RDO, the Winslow office advanced the warnings to radio stations and city officials (Zimmerman, 1971).

Weather statements and warnings pertaining to heavy rainfall and flooding, once available, were disseminated promptly (Zimmerman, 1971). The Phoenix and Flagstaff WSOs supplemented the formal written statements with telephone calls to officials who have responsibility for emergency actions. Apparently, Arizona Police agencies, the Office of the Governor-Division of Emergency Services, and the USDA Forest Service generally received the information once it was released by the National Weather Service. There were exceptions, however, especially in remote localities, where flood warnings did not uniformly reach some officials such as USDA Forest Service and public safety personnel.

Perhaps the most serious limitation in the sequence of weather statements

FIGURE 14. VIEW OF DOWNSTREAM FACE OF TONTO CREEK-HORTON CREEK BRIDGE AFTER THE 1970 LABOR DAY FLOOD. SEVERAL LIVES WERE LOST AT THIS LOCATION. (COURTESY USDA FOREST SERVICE).

and flood warnings concerned with the 1970 Labor Day floods was the ambivalence and inconsistency in releases on September 4 and early on September 5. The WSFO forecast of 3:10 a.m. September 5 was particularly deficient in that it did not identify the seriousness of the impending storm. The guidance provided by this forecast, being more up-to-date, may have negated in the minds of recreationists and travelers, the earlier more correct guidance on conditions to be expected. The 3:10 a.m. forecast may also have helped delay official flood warnings until 2 p.m. on September 5. Since much of the most disastrous flooding in some areas occurred within three to four hours of the 2:00 p.m. release, the opportunities for warnings to reach campers and other recreationists in relatively remote localities may have been limited.

Losses, Damages and Expenditures

The heavy rainfall associated with the 1970 Labor Day Storm brought subsequent flooding throughout central and northeastern Arizona, southeastern Utah, and southwestern Colorado (Roeske, 1971). This flooding caused widespread and unprecedented losses and damage to human, cultural, and natural resources in Arizona.

Losses and Damages — Tragically, 23 lives were reported lost in central Arizona (Russell, 1970). The greatest loss of life occurred in Gila County, where 14 lives were lost in the Kohl's Ranch area on Tonto Creek (Figure 14), and one life was lost in Camp Creek Wash north of Carefree, three in Mesquite Wash east of Canyon Lake, three in Sycamore Creek near Sunflower, and one in the New River drainage inside of the Phoenix metropoltian area.

The number of people injured or hospitalized as a direct result of the Storm is unknown, but presumed many.

On the night of the Storm (in the Phoenix area), the Maricopa County Chapter of the American National Red Cross opened two shelters and feeding centers in affected areas of Scottsdale: one on Granite Reef Road near a break in the Arizona Canal, which remained open over night, and one near the Indian village of Vista del Camino, which remained open for four days. Emergency assistance (food, clothing, household furnishings, medical and nursing aid, etc.) was provided to approximately 400 families victimized by the Storm at these locations (Krebs,

FIGURE 15. DAMAGE TO CABINS ALONG TONTO CREEK DRAINAGE (COURTESY USDA FOREST SERVICE).

1971). In other affected communities, the Red Cross housed a few families in motels. The majority of the victims were able to find shelter with friends or relatives, however.

The Arizona National Guard also provided emergency services to flood victims during the Storm.

Damage to sewage collection and treatment facilities occurred in the immediate aftermath of the Storm in Phoenix, Scottsdale, Holbrook, and Wickenburg (Kossuth, 1970). In Phoenix, a sewer system serving a four-city area was uncovered by flood waters. Fortunately, the system did not discharge raw sewage. Flood waters also caused the caving in of a ditch above a recently installed sewer line in Scottsdale. This sewer line was not damaged, however. At Holbrook, the dikes of three sewage treatment ponds washed out, and the contents were discharged onto surrounding flats. Washed-out sections of the dikes were quickly repaired, and an intensive disinfection program was carried out on the effluent. The Wickenburg sewage treatment plant was severely damaged and 1,280 feet of sewer outflow leading to the plant were destroyed, resulting in a discharge of raw sewage into the Hassayampa River. To minimize public health hazards, immediate steps were taken to chlorinate the effluent and construct a temporary dike in the River bed to restrain the discharge of raw sewage.

The Arizona State Department of Health indicated that damage to sewage collection and treatment facilities had no known detrimental effect on public health (Kossuth, 1970). Prompt action by local officials undoubtedly minimized health hazards.

Flood waters caused damage to public water supply systems in Buckeye, Tempe, and Phoenix, and in the Payson area (Kossuth, 1970). The main well serving Buckeye was completely inundated, causing millions of gallons of flood water to enter the aquifer. Flood waters also entered the electrodialysis water treatment plant, reducing the mineral concentration in the water supply and causing extensive damage to the electrical equipment. In Tempe, the main water treatment plant was removed from service due to a break upstream in the Arizona Canal, which supplies water to this plant. A standby well system was used until repairs were finished. There were three areas of flood damage to the Phoenix water supply system: flood waters overflowed into the Salt River Pumping Station at the Verde Filter Plant, taking it out of service for a short time; the Squaw Peak and Deer Valley water treatment plants had to utilize extra coagulating chemicals to reduce the excessive turbidities in the Arizona Canal water; and, there was minor flood damage to several of the city wells, which were quickly returned to service following minimum repairs. Ten small water systems in the outlying area around Payson, but not including Payson, were damaged by flood waters. Fortunately, all systems were promptly restored to an adequate operating condition.

A complete and composite accounting, in physical units, of the losses and damages to private and public developments, to transportation and communication systems, and to croplands, range lands, and forest lands as a result of the Storm is not possible. It is known, however, that losses and damages were many and extensive.

Temporary and permanent residences, farming and ranching operations, business establishments, and recreational facilties were damaged or destroyed in many areas that experienced record flood stages and peak discharges (Figure 15). Areas that suffered extensive destruction include, but are not exclusive of, the following: Upper Tonto Creek, with considerable damage in the vicinity of Kohl's Ranch; portions of the Sycamore, Dry Beaver, and Oak Creeks and East Verde River watersheds; along the Hassayampa River above and including Wickenburg; many urban, suburban, and agricultural sites in central Arizona, particularly in Gila, Maricopa, and Yavapai Counties; and, along the Little Colorado River, especially near Holbrook.

Losses and damages in municipalities affected by the Storm took many forms. For example, sheet flow of flood waters occurred throughout Phoenix, and, although drainage systems functioned well, extensive property damage was reported (Attebery, 1971). Residential damages included approximately 200 homes experiencing flooding; minimum commercial and industrial damage occurred, although 16 business establishments sustained flooding; and, damage to utilities, streets, and highways was widespread, with damage to sewage and water supply facilities, silting of streets, pavement breakup, etc. In Scottsdale, flood waters overflowed in Indian Bend Wash and caused considerable damage in the Vista del Camino (the Yaqui Village) subdivision, with flood water up to four feet deep in many homes (Evans, 1971). Flood waters from a break in the Arizona Canal also damaged many homes in the Scottsdale area. Flood waters washed out a portion of a dike along the Little Colorado River at Holbrook, and poured into approximately 40 to 45 homes (Carpenter, 1971). Further damage was done to septic tanks, streets, and roads, and to the main sewage disposal system.

Damage to highways and roads, including interstate, primary, secondary, and private systems, was widespread throughout central and northeastern Arizona (Figure 16). Landslides blocked the access to many right-of-ways, culverts plugged with debris caused many washouts, and road surfaces were often eroded by flood waters. An indication of the extent of damage to highways and roads may be derived from a listing of Emergency Relief Fund projects administered through the Arizona Highway Department (Hendrick, 1972).

FIGURE 16. DAMAGE TO FOREST ROAD ON THE COCONINO NATIONAL FOREST (COURTESY USDA FOREST SERVICE).

ARIZONA STATE HIGHWAY SYSTEM

Rte.	Description
SR-86	Brawley Wash Bridge
SR-87	Maricopa County Line-Payson
SR-87	East Verde Branch-Strawberry Junction
SR-87	Sycamore Creek Section
SR-88	Pinal County Line-SR-188
SR-188	Maricopa County Line-Tonto Basin
SR-260	Payson-Navajo County Line
SR-264	Indian Reservation Roads
SR-286	Altar Wash Section
SR-386	Kitt Peak Highway
I-17	Hog Tank Wash-Rattlesnake Canyon
Alt. 89	Midgley Bridge-North
US 60	Wickenburg-Monarch Wash
US 80	Kimball Road-Avondale

COUNTY PROJECTS FAS

County	Description
Coconino	West Side Mormon Lake
Maricopa	Indian School Road-Agua Fria Bridge
Maricopa	McDowell Road-Agua Fria Crossing
Maricopa	Cotton Lane-Waddell-US 80
Maricopa	Olive Avenue-New River Crossing
Maricopa	Broadway Road-Ogelsby Road-Perryville
Maricopa	Shea Blvd-Junction SR-87-West

The use of power transmission and telephone systems was interrupted in some areas affected by the Storm, although, in most instances, service was quickly restored.

Flood waters inundated fields planted to sugarbeets, grains, and other agricultural crops in central Arizona. On farm lands in the Roosevelt Irrigation District, for example, approximately 2,500 acres had been plowed, and farmers were in the process of preparing the land for sugarbeets, grains, and other crops. But flood waters covered these plowed fields, cutting gullies and washes through the land and eroding topsoil (Lamoreaux, 1970; Pugh, 1970). Also, approximately 8,000 acres in the District had been planted to cotton, and damage to this crop due to inundation was estimated to be ½ bale per acre. Damages to irrigation facilities, including deposition of sand and rock in the main canal and lateral system, numerous leaks along the sides of the main canal, etc., compounded the losses and damages to croplands in this area (Figures 17 and 18).

Extensive damage to farm lands and irrigation systems was also reported on the Fort McDowell and Salt River Indian Reservations (Cole **et al.,** 1970), and there was considerable damage to farm lands, range lands, diversion dams, and dikes on the Hopi Indian Reservation (Anonymous, 1970). Fortunately, there was no reported damage or loss to farm lands on the other reservations in Arizona, although some areas did receive heavy rainfall amounts (LeCrone, 1971).

Soon after the Storm, the USDA Agricultural Stabilization and Conservation Service surveyed and estimated the damage that had occurred to farm lands prerequisite to administering funds available under the Agricultural Conservation Program (Public Law 85-28). These funds are to be used to rehabilitate farm lands damaged by floods, drouths, etc. The results of this survey (Faltis, 1971), which suggest the extent of the damage to farm lands in affected areas, included:

County	Number of Farm Units Damaged
Coconino	50
Gila	20
Maricopa	200
Navajo	70
Yavapai	40
Total	380

Additionally, the USDA Agricultural Stabilization and Conservation Service submitted damage information to Washington, D.C. in conjunction with a request for funds made available to farmers and ranchers by the Office of Emergency Preparedness. These funds are to be used for the removal of flood debris to restore the productivity of the land to its original state. This damage information (Faltis, 1971) included:

County	Number of Farm Units Damaged
Coconino	35
Gila	20
Maricopa	350
Navajo	30
Yavapai	20
Total	455

FIGURE 17. IRRIGATION CANAL FILLED WITH SAND AND SILT IN THE ROOSEVELT IRRIGATION DISTRICT (COURTESY USDI BUREAU OF RECLAMATION).

While the rainfall received as a result of the Storm furnished some short-term additional livestock water, the accumulation of sediments and other debris reduced the capacities of many permanent livestock water impoundments. Extensive damages to allotment fences and livestock driveways also occurred across many range lands, although the extent of these damages is difficult to ascertain. The lateness of the Storm in the growing season probably prevented any significant increases in usable forage for livestock consumption.

The number of livestock and wildlife animals lost as a result of the Storm is largely unknown. Damage summaries prepared by USDA Soil Conservation Service personnel (Lamoreaux, 1970; Parsons, 1970; Tobin, 1970) indicated approximately 35 to 40 cattle and horses were killed, however, and many animals were reported missing.

Sediments and debris were deposited in several reservoir systems, particularly along the Mogollon Rim. Three recreation reservoirs in the Chevelon drainage (Bear Canyon, Black Canyon, and Chevelon Canyon) and the Blue Ridge Reservoir on East Clear Creek received accumulations of debris that endangered spillway operations (USDA Forest Service, 1970). Since urban developments are situated in the flood plains below some of these reservoirs, an even greater disaster was possible if additional rainfall and flooding had occurred.

High flood stages and peak discharges drastically altered the character of many waterways throughout the Storm affected area. Often, trees growing along channels were uprooted and piled downstream, which frequently prevented free movement of water in the channel. The scouring action of flood waters also caused many stream improvements and diversion channels to be lost or severely damaged. Again, with these conditions, there existed the possibility for additional serious destruction if subsequent storms had occurred before repairs were completed.

Losses and damages were extensive on many lands under the jurisdiction of the USDA Forest Service. On the Tonto National Forest, an area particularly hard hit by the Storm, damages included loss of life, as reported above, destruction to cultural developments (private residences, business establishments, personal property, roads and trails, stock tanks, allotment fences, etc.), and loss of natural resources (riparian timber, wildlife and fisheries habitat, etc.) (Russell, 1970). Damages on the Coconino National Forest included washed out roads, culverts, and bridges on FS system roads, approximately ten miles of fence line destroyed, between 400 and 500 water gaps washed out, and damaged picnic and campground facilities in Oak Creek Canyon, and at Kinnikinick and Ashurst Lakes (Morrison, 1970). Also, damage occurred to research installations on the Beaver Creek Watershed, a study area established to determine the effects of different land management practices on natural resource values (Baker, **et al.**, 1971). On the Sitgreaves National Forest, damages included debris moving across lakes and plugging spillways, accumulations of trees and man-made structures in many waterways, washed out sections on FS system roads, and large gullies formed by flood waters on erodible soils (USDA Forest Service, 1970). Flood damage on the Prescott National Forest included stream bottoms choked in many places with logs and other debris, washed out roads and trails, damage to contour ditches and sediment dams on Forest System Watersheds, and destruction to ranch properties (Williams and Russell, 1970). On the Coronado National Forest, flood damage was concentrated in the Santa Catalina Mountains, with destruction reported to the road systems in Sabino Canyon and on Mt. Lemmon (Nolan, 1970). No losses or damages were reported on the Kaibab (Dezell, 1971) or on the Apache (Buck, 1971) National Forests.

FIGURE 18. STRUCTURAL DAMAGE TO IRRIGATION CANAL SYSTEM IN THE ROOSEVELT IRRIGATION DISTRICT (COURTESY USDI BUREAU OF RECLAMATION).

Expenditures — On September 22, at the request of Governor Williams, President Nixon declared the flood-damaged areas of Arizona a major disaster. This action permitted political jurisdictions and, in a restricted sense, private parties to be reimbursed by the Federal Government for eligible expenditures made as a result of the Storm.

The Office of the Governor — Division of Emergency Services advised leaders of political jurisdictions affected by the Storm of the financial assistance available, as specified in Public Law 91-606, and assisted them in the preparation of applications for funds to be forwarded to the Office of Emergency Preparedness, Washington, D.C. Categories of eligible work under the Public Law include debris removal from private and public properties, protective, health, and sanitation measures, and emergency repairs and temporary replacement of (a) streets, roads, and bridges, (b) dikes, levees, and drainage facilities, (c) public buildings and related equipment, and (d) public utilities.

The amount of financial assistance approved by the Office of Emergency Preparedness, as of June 30, 1972, was $1,085,458 (Table 8). Final reimbursements to applicants as of this date have not been completed and are subject to both state and federal audits (Smith, 1972).

It is necessary to add financial assistance and expenditures provided through media other than the above-mentioned to obtain a monetary estimate representing the total losses and damages for the 1970 Labor Day Storm.

For example, a state and its political jurisdictions must expend, within a 12-month period immediately preceding a request for a Presidential declaration of a major disaster, a certain amount before a request to the President will be honored. Arizona's obligation of $750,000 was satisfied (Smith, 1971), and this figure should be included in the total loss and damage.

TABLE 8. FINANCIAL ASSISTANCE,[1] AS SPECIFIED BY PUBLIC LAW 91-606.

Applicant	Categories of Eligible Work[2]							Total Funds Approved[1]
	Ap	A	B	C	D	E	F	(dollars)
Coconino County		*		*				81,146
Gila County	*			*				220,179
Maricopa County	*	*		*	*			84,122
Navajo County		*	*	*	*			98,450
Yavapai County	*	*	*	*				23,814
City of Flagstaff		*		*				4,835
City of Phoenix		*	*	*	*			133,156
City of Scottsdale		*	*	*		*	*	35,530
City of Tempe	*		*	*			*	8,903
Town of Buckeye							*	40,205
Town of Holbrook		*	*	*	*		*	59,549
Town of Wickenburg			*	*			*	67,536
Arizona Game & Fish Dept.		*	*	*	*		*	64,898
Buckeye Water Conservation and Drainage Dist.					*			13,000
Roosevelt Irrigation Dist.		*			*			150,135
Total								1,085,458

[1]Records available to the Office of the Governor - Division of Emergency Services, as of June 30, 1972.

[2]Categories of Eligible Work:

Alphabetical Identification	Eligible Work
Ap	Debris removal from private sectors
A	Debris removal from public sectors

Alphabetical Identification	Eligible Work
B	Protective, health, and sanitation measures
C	Emergency repairs and temporary replacement of streets, roads, and bridges
D	Emergency repairs and temporary replacement of dikes, levees, and drainage facilities
E	Emergency repairs and temporary replacement of public buildings and related equipment
F	Emergency repairs and temporary replacement of public utilities

Emergency assistance provided to victims of the Storm by the Maricopa County Chapter of the American National Red Cross approximated $65,000 (Krebs, 1971). Administrative costs (salaries, T & M, etc.) increased the total expenditures by the Red Cross to $77,000.

A record of disbursements by federal agencies operating within Arizona must also be considered to assess total expenditures.

The Small Business Administration approved 171 disaster home loan applications for $571,350 and 28 disaster business loan applications for $468,400, for a total of 199 loan applications in the amount of $1,039,750 (White, 1972).

Total expenditures by the Corps of Engineers relative to the Storm was $713,072, which included costs involved in contracts for stream channel restoration, primarily in Coconino, Gila, and Yavapai Counties, plus government costs (Coker, 1972).

Although the USDI Geological Survey is responsible for collecting streamflow data of all magnitudes and, therefore, expects and budgets for a certain amount of extra expense, above normal expenditures attributed to the Storm did occur (Click, 1972). These expenditures included:

Replacement and repair of destroyed and damaged streamflow gages	**$22,000**
Above normal travel expenses	**10,000**
Preparation of flood reports	**16,000**
Total	**$48,000**

Emergency funds of $63,575 were made available to the USDI Bureau of Land Management, primarily for the repair of water control structures installed for erosion control purposes and of access roads to these areas (Fallini, 1971).

The USDA Farmers Home Administration approved six loans, totaling $64,120 (Barney, 1971). The USDA Soil Conservation Service reported expenditures of $11,358 for engineering services in connection with the Storm (Cavallo, 1971). The USDA Agricultural Stabilization and Conservation Service spent $465,384 in Emergency Conservation Measures funds as a result of the Storm (Golding, 1971).

One individual received $150 in Disaster Unemployment Assistance due to unemployment as a direct result of the Storm (Taylor, 1971).

Emergency Relief Fund projects resultant from the Storm, and administered through the Arizona Highway Department (Hendrick, 1972), required $1,254,650 in expenditures.

A summary of expenditures by the USDA Forest Service included $1,977,600 on the Tonto National Forest (Wirth, 1972), $108,500 on the Coconino National Forest (Seaman, 1972), $390,838 on the Sitgreaves National Forest (Tixier, 1972), $48,920 on the Prescott National Forest (Kimball, 1972), and approximately $280,000 on the Coronado National Forest (Nolan, 1972).

It is difficult to ascertain the total dollar cost of the 1970 Labor Day Storm. However, based on analyses of existing reports and data summaries, actual expenditures have exceeded $8,200,000. Furthermore, with possible changes due to final reimbursements to applicants for financial assistance by the Federal Government, additional expenditures contemplated by some agencies and organizations affected by the Storm, and incomplete knowledge relative to total expenditures by all agencies and organizations affected by the Storm, the final figure may approach $8,500,000.

DISCUSSION

In terms of safety hazards to human well-being, the most important flooding during any event such as the 1970 Labor Day Storm may occur on small, remote streams that are utilized for recreation. The unwary picnicker, camper, or cabin dweller may not appreciate the vulnerability of his location should a rapid rise in water level occur. These streams can respond quickly to a precipitation event with little advance warning, especially if breached debris jams release surges of water downstream. Furthermore, structures for safely containing flood waters are uncommon in Arizona. In recognition of the increasing use of riparian environments for recreation, hydrologists along with other professionals should participate in the design and location of streamside facilities. Also, perhaps consideration should be given to a moderate program of slash and debris removal along selected high risk streams where channel flow might be impeded by debris jams during flooding.

The debris jam phenomena may have produced higher peak streamflows and associated stages than would be expected from equivalent runoff volumes in the absence of debris jams. This conclusion, if valid, may have engineering design implications where runoff estimating techniques that do not recognize the potential of debris jams to produce fast moving surges of high energy water and debris mixtures are utilized. Additionally, such flood surges conceivably could trap unsuspecting people attempting to cross bridges or ford channels where the streamflow level appears to be rising regularly during a flood event. In many cases, these individuals are probably not prepared to encounter a more-or-less instantaneous flood wave.

It is suggested that consideration be given to an expanded educational program to help inform the public of appropriate safety measures during a flood situation. People should also learn to identify potentially hazardous locations on or near streams. Such educational programs might utilize schools, pamphlets, radio broadcasts, and other techniques employing the mass media. In addition, high risk areas such as certain bridges and campgrounds could perhaps be identified with a universal flood symbol or sign to remind the public of potentially hazardous situations.

Emergency warning systems concerned with immediate flood hazards in remote, high-use localities should be perfected, especially for critical times such as holidays and to some extent at all times (Zimmerman, 1971). Such systems would certainly be an extension of the National Weather Service warning system. This extension may involve the coordinated use of law enforcement and land management personnel (such as the USDA Forest Service); perhaps private individuals or volunteer groups could also be enlisted and organized for such an effort.

Another flooding problem caused by storms such as reported herein may occur in localities which have experienced a rapid growth. For example, transportation systems (highways, railways, etc.) built prior to full development of many localities often become dikes which interfere with normal functioning of channels that formerly conducted flood waters through developed areas (Harenberg, 1971). Control of the problem, unfortunately, may be beyond the economic ability of the affected localities. Thus, better urban, rural and wildland planning may be needed to avert or alleviate such losses and damages.

Although no amount of benefit can compensate for the loss of human, cultural, and natural resources, the 1970 Labor Day Storm did cause increased storage in surface water reservoirs. The total combined gain to reservoirs on the Salt-Verde River Basin, for instance, was estimated to be in excess of 160,000 acre-feet. This water gain may have been particularly significant since below normal precipitation and runoff characterized the months following the Storm. In fact, the winter-spring runoff of 1970-71 was the lowest in 12 years on the Salt River Basin and the lowest in eight years on the Verde River Basin (Enz, 1971).

The 1970 Labor Day Storm probably increased groundwater supplies, but estimates of recharge are unknown.

Conceivably, downstream water users may benefit in the long-run from a degree of channel scour and clearing which may create stream conditions that transport runoff more efficiently, resulting in less transmission loss of the water resource.

A potential problem of replication in reporting was encountered in collating losses and damages and subsequent expenditures. Some information provided by one agency or organization could also have been included in the appraisals of others. Undoubtedly, some duplication did occur; however, it was not always possible to sort-out, identify, and categorize losses, damages, and expenditures as reported.

Another problem involved reports and data summaries that expressed losses and damages attributed to the Storm only in terms of monetary units in arbitrary categories. Without knowledge of losses and damages in physical units, or of the appraisal procedures used in the development of monetary estimates, it is difficult to assess, interpret, and combine on a common basis the information provided by the different agencies and organizations. In addition, data presented in monetary units alone have the disadvantage of being time-dated by current costs for labor, equipment, materials, etc.

The question may arise as to why a storm with an estimated 100- to 500-year return period, as measured at some rainfall stations, was associated with flood peaks having estimated return periods of 20 to 40 years. Part of this discrepancy may be due to the dampening effect that large watersheds can have on rainfall inputs which are localized on relatively small portions of the watershed. Estimates of return periods for rainfall totals are based on point samples (raingages), whereas the streamflow response is partly a function of the entire watershed area. Thus, even if high rainfall totals and intensities are observed at some point locations, as occurred during the 1970 Labor Day Storm, lag and storage effects in the runoff system may cause the streamflow response to be dampened downstream, particularly on large watersheds. On relatively small watersheds, however, recurrence intervals for total rainfall and peak streamflow may be more similar in magnitude for large storms.

Antecedant moisture conditions on watersheds may also partly explain discrepancies between estimated rainfall and runoff return periods for a common event. To illustrate, if soil water storage and groundwater levels are comparatively low prior to a storm, even an exceptionally heavy rainfall may be largely retained or detained without producing a particularly spectacular runoff event.

Thus, a relatively high return period for total rainfall amount is not necessarily expected to be associated with a similar return period for the resulting runoff event, although flooding can still be serious in localized areas as observed during the 1970 Labor Day Storm.

The 1970 Labor Day Storm was not the first tropical storm to be associated with flooding and damage in Arizona. Other examples include **Claudia** (September 1962) and **Tillie** (September 1964); another storm of apparent tropical origin produced heavy flooding in August 1951. Conditions seem to be right for such storms to produce some degree of flooding perhaps once every four or five years in Arizona (Sellers, 1960). It is recommended that a generalized and integrating analysis of the meteorological and hydrological characteristics associated with these storms be undertaken. A comprehensive study involving meteorology, hydrology, and engineering skills should yield useful design and safety information. Such information could be particularly important in central and southern Arizona, where settlement and construction continue at a rapid pace, and where storms of tropical origin seem to have great impact.

ACKNOWLEDGMENTS

This study was supported, in part, by the Office of Water Resources, Department of the Interior, as authorized under the Water Resources Act of 1964, Public Law 88-379.

The assistance of Dr. A. R. Kassander, Vice President for Research (formerly Director, Water Resources Research Center), University of Arizona, and Mr. Joseph F. Arnold, USDA Forest Service, Phoenix, is gratefully acknowledged.

The study was based on information provided by many agencies and organizations concerned with the 1970 Labor Day Storm and its consequences in Arizona. The assistance of the following agencies and organizations is acknowledged — USDC National Oceanic and Atmospheric Administration, USDI Geological Survey, USDI Bureau of Reclamation, USDI Bureau of Land Management, USDI Bureau of Indian Affairs, USDA Forest Service (including Region 3 and the Rocky Mountain Forest and Range Experiment Station), USDA Soil Conservation Service, USDA Agricultural Research Service, USDA Agricultural Stabilization and Conservation Service, USDA Farmers Home Administration, Federal Highway Administration, Small Business Administration, and the Corps of Engineers; Arizona Department of Health, State Land Department, Highway Department, Game and Fish Department, Employment Security Commission of Arizona, and the Office of the Governor — Division of Emergency Services; the Counties of Maricopa, Pima, and Yavapai; the Localities of Wickenburg, Phoenix, Globe, Chandler, Tempe, Mesa, Holbrook, Flagstaff, Casa Grande, Scottsdale, and Prescott; the American National Red Cross; the Salt River Project; and the San Carlos Irrigation and Drainage District.

REFERENCES

Anonymous.
1970. Report of Flood Damage, District 6 of the Hopi Reservation, September 5 and 6, 1970. Hopi Agency, Ariz., 13 p.

Arnolt, Fred M.
1972. Project Ringtail. USDA Forest Service, Tonto National Forest, Phoenix, Ariz., 107 p.

Attebery, James E.
1971. Flood Damage Report — Storm and Flood of Sept. 4-6, 1970, City of Phoenix. Engineering Department, City of Phoenix, Phoenix, Ariz., 20 p.

Baker, Malchus B., Jr., Harry E. Brown, and Norman E. Champagne, Jr.
1971. Hydrologic Performance of the Beaver Creek Watersheds During a 100-Year Event. Paper presented at A.G.U. Meeting, San Francisco, California, December 1971, 26 p.

Barney, Richard R.
1971. Correspondence. USDA Farmers Home Administration, Phoenix, Ariz.

Brown, Harry E.
1971. Evaluating Watershed Management Alternatives. J. Irrig. & Drain ASCE Vol. 97 No. IR1, Proc. Pap. 1952, pp. 93-108.

Brown, Harry E., E. A. Hansen, and N. E. Champagne, Jr.
1970. A System of Measuring Total Sediment Yield From Small Watersheds. Water Resources Res. 6:818-826.

Buck, Bill.
1971. Correspondence. Apache National Forest, USDA Forest Service, Springerville, Ariz.

Carpenter, W. S.
1971. Correspondence. Town of Holbrook, Holbrook, Ariz.

Cavallo, Robert J.
1971. Correspondence. USDA Soil Conservation Service, Phoenix, Ariz.

Click, David E.
1972. Correspondence. USDI Geological Survey, Tucson, Ariz.

Coker, Raymond L.
1972. Correspondence. Corps of Engineers, Department of the Army, Phoenix, Ariz.

Cole, Norris M., Samuel L. Hilliard, and Lawrence E. Hanline.
1970. Narrative Report. Branch of Land Operations, Salt River Agency, Scottsdale, Ariz., 21 p.

Dezell, J. W.
1971. Correspondence. Kaibab National Forest, USDA Forest Service, Williams, Ariz.

Elson, T. E.
1971. The 1970 Labor Day Weekend Flood in the Vicinity of Upper Tonto Creek, Arizona. USDA Forest Service. Albuquerque, New Mexico. 80 p.

Enz, Richard W.
1971. Water Supply Outlook for Arizona (as of April 1). USDA Soil Conservation Service, Phoenix, Ariz., 15 p.

Evans, David R.
1971. Correspondence. City of Scottsdale, Scottsdale, Ariz.

Fallini, Joe T.
1971. Correspondence. USDI Bureau of Land Management, Phoenix, Ariz.

Faltis, Steve.
1971. Correspondence. USDA Agricultural Stabilization and Conservation Service, Phoenix, Ariz.

Golding, Dodge C.
1971. Correspondence. USDA Agricultural Stabilization and Conservation Service, Phoenix, Ariz.

Harenberg, Sylvan L.
1971. Correspondence. City of Flagstaff, Flagstaff, Ariz.

Hendrick, Ivan, Jr.
1972. Correspondence. Arizona Highway Department, Phoenix, Ariz.

Kangieser, P. C.
1972. Unusually Heavy 24-hour Rainfall at Workman Creek 1, Arizona, Monthly Weather Review 100:206-207.

Kimbell, James L.
1972. Correspondence. Prescott National Forest, USDA Forest Service, Prescott, Ariz.
Kossuth, Louis C.
1970. Correspondence. Arizona State Department of Health, Phoenix, Ariz.
Krebs, Lee D.
1971. Correspondence. Maricopa County Chapter, American National Red Cross, Phoenix, Ariz.
Lamoreaux, Marvin G.
1970. Buckeye Watershed — September 1970 Flood. USDA Soil Conservation Service, Buckeye, Ariz., 2 p.
LeCrone, D. E.
1971. Correspondence. USDI Bureau of Indian Affairs, Phoenix, Ariz.
Morrison, Douglas C.
1970. Flood Damage Report. Coconino National Forest, USDA Forest Service, Flagstaff, Ariz., 10 p.
National Oceanic and Atmospheric Administration.
1970. Climatological Data — Arizona. USDC Environmental Data Service, 74:159-181.
Nolan, M. E.
1970. Correspondence. Coronado National Forest, USDA Forest Service, Tucson, Ariz.
Nolan, M. E.
1972. Correspondence. Coronado National Forest, USDA Forest Service, Tucson, Ariz.
Parsons, C. F.
1970. Flood Report Work Sheet. USDA Soil Conservation Service, Flagstaff, Ariz., 2 p.
Pugh, C. A.
1970. Correspondence. USDI Bureau of Reclamation, Phoenix, Ariz.
Roeske, R. H.
1971. Floods of September 1970 in Arizona, Utah, and Colorado. Arizona State Land Department, Water-Resources Report 44, 20 p.
Russell, William L., Jr.
1970. Flood Damage Survey Report — Tonto National Forest. USDA Forest Service, Phoenix, Ariz., 23 p.
Seaman, Don D.
1972. Correspondence. Coconino National Forest, USDA Forest Service, Flagstaff, Ariz.
Sellers, William D.
1970. Arizona Climate. The University of Arizona Press, Tucson, Ariz., 60 p.
Smith, Carl N.
1971. Correspondence. Department of Civil Defense and Emergency Planning, Phoenix, Ariz.
Smith, Carl N.
1972. Correspondence. Office of the Governor — Division of Emergency Services, Phoenix, Ariz.
Taylor, C. B.
1971. Correspondence. Employment Security Commission of Arizona, Phoenix, Ariz.
Thorud, David B., and Peter F. Ffolliott.
1971. The 1970 Labor Day Storm. Ariz. Watershed Symp. Proc., 15:46-55.
Thorud, David B., and Peter F. Ffolliott.
1972. The Labor Day Storm of 1970 in Arizona. Proc. Western Snow Conf., 40:37-42.
Tixier, J. S.
1972. Correspondence. Sitgreaves National Forest, USDA Forest Service, Holbrook, Ariz.
Tobin, Robert F.
1970. Flood Report and Precipitation. USDA Soil Conservation Service, Prescott, Ariz., 2 p.
USDA Forest Service.
1970. Flood Damage Report. Sitgreaves National Forest, Holbrook, Ariz., 31 p.
U. S. Weather Bureau.
1967. 100-Year 24-Hour Precipitation — Arizona-USDC Environmental Science Services Admin., 1 p.
White, Cletha
1972. Correspondence. Small Business Administration, Phoenix, Ariz.
Williams, J. W., and T. E. Russell.
1970. Flood Damage Report. Prescott National Forest, USDA Forest Service, Prescott, Ariz.
Wirth, Fred J.
1972. Correspondence. Tonto National Forest, USDA Forest Service, Phoenix, Ariz.
Zimmerman, A. L.
1971. Arizona Floods of September 5 and 6, 1970. USDC National Oceanic and Atmospheric Administration. Natural Disaster Survey Rpt. 70-2, 39 p.