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A STUDY OF FLASH-FLOOD SUSCEPTIBILITY--A BASIN IN SOUTHERN ARIZONA

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ABSTRACT

Two commonly used methods of hydrologic analyses are parametric reconstruction and development of frequency distributions. Both techniques can be used to develop estimates of potential of damaging flash floods. However, under conditions of limited data, many areas may not have experienced enough flash floods to be recognized as prone to flash flooding. This paper gives a method to infer expected severity for flooding based on frequency analysis, which does not require a complete spectrum of data over a given basin. This method was used to estimate potential peak flows on Sabino Canyon, Arizona, and probability of occurrence of specified magnitudes was analyzed. These estimates indicate a strong possibility of damaging flash floods occurring in areas where none have occurred in several decades.

I. INTRODUCTION

Record-breaking floods and precipitation events are continual reminders of inadequacies in our analysis of hydrologic events. For example, peak flows from the Arizona 1970 Labor Day storm more than tripled previous maxima (Fogel, et al, [1]) and Hurricane Agnes produced flow data which resulted in the 100-year flood being changed to a 25-year flood (Reich [2]). Much hydrologic data do not fit a normal distribution curve, making the process to determine susceptibility of an area to flash flooding difficult.

To determine the potential for damaging flash floods, many techniques may be employed. The National Weather Service uses a technique from analysis of historical events as a basis for projecting future damages from flash floods, a method of parametric analysis. This is a good proven method, if data are available.

Another general technique is determination of the frequency distribution of floods. This method has not been used extensively for projections of potentially damaging flash floods, but it is a basic hydrologic tool for analysis of economics of structural design criteria. The Water Resources Council (1967) recommended the use of the log-Pearson Type III frequency analysis. Any statistical distribution procedure for extreme data is limited in successful application if data are insufficient. This paper presents an approach which combines available meteorological and hydrological data to assess flash-flood potential over areas with limited data.

This is not to infer that historical analysis of damaging flash floods is not a valuable tool or that community susceptibility to flash floods is not of paramount importance; merely, that lack of data is not a viable reason for not adequately assessing potential for damaging flash floods.

II. THE PROBLEM

If no damaging flash floods have occurred over a certain basin, why should we expect one to occur? This is a very valid argument against the possibility of a damaging flash flood occurring. Most areas susceptible to flash flooding surely would have experienced a number of damaging flash floods or at least one. Or would they?

Let's take the case of Sabino Canyon Creek near Tucson, Arizona. This creek drains an area of 35.5 square miles. The maximum peak in 42 years of record was less than 8,000 cubic feet per second (cfs). Could we expect this fairly small peak to occur on the average of once in 42 years? Data indicate that for the basin in the particular setting a 50-year storm would more than double this peak flow. Susceptibility of flash flooding seems very high. The problem is to prove that such a susceptibility exists. To do this, let's look at some past runoff data for some drainages in Arizona and nearby states and compare their characteristics to those of Sabino Canyon Creek.

To do this, determination of some runoff magnitude and frequency parameters must be made. These include:

1. The magnitude of runoff peaks likely to cause damage (10-year, 20-year, 50-year runoff event).
2. The expected distribution for this size of peak flow.
3. The likelihood of meteorologic conditions to cause this peak.
4. A comparison between past occurrences of this sized event and calculated return interval of this sized or larger event.

To make these determinations, some hydrologic tools are needed. These are:

1. A technique to determine a frequency distribution.
2. Relationships of peak flow rates, drainage area and expected return frequency.
3. An analysis of damaging flows on basins exhibiting similar hydrologic and meteorologic characteristics to the basin under study.

III. ANALYSIS OF SOME FACTORS INDICATING POTENTIAL FOR DAMAGING FLASH FLOODS ON SABINO CANYON CREEK

1. Recent Flash Floods Occurring in Arizona and Adjacent States

Damaging flash floods have occurred on many drainages in Arizona and contiguous states during the last several years, Table I. These locations were numbered from 1 through 9 and plotted on Figure 1.

TABLE I

Some Recent Damaging Flash Floods in Arizona and Contiguous States [13]

Location	Year	Code No. on Figure 2
Tonto Creek, Arizona	1970	1
San Juan River, New Mexico, Colorado	1970	2
San Juan River, Colorado	1972	2
El Dorado Canyon, Nevada	1974	3
Lake Havasu City, Arizona	1974	4
Cottonwood Creek, Utah	1968	5
Morgan, Utah	1962	6
Upper Gila River, New Mexico and Arizona	1972	7
Little Colorado River, Arizona	1972	8
Bronco Wash, Arizona	1971	9
Sabino Canyon, Arizona	--	10

Most of these events occurred over drainages associated with steep mountain topography, and such occurrences are common.

Are these basins more susceptible to damaging flash floods than Sabino Canyon because they have experienced damaging flash floods? These events probably could be transposed over the Sabino Canyon Basin which would indicate similar potential for occurrence of large peak flows. The transposition of storms will be further explored, but first orientation of the basins to atmospheric moisture flow will be briefly discussed.

2. Basin Orientation and Moisture Flow Related to Large Amounts of Precipitation

Atmospheric moisture flow and its relation to physiography have an important influence on the amount of precipitation falling over any given basin. Meteorologic conditions may never be identical and each storm has a different potential for producing large amounts of precipitation. In an attempt to relate various factors to the potential to produce heavy precipitation, physiographic factors generally are considered. Miller, Frederick, and Tracy [3] developed a precipitation atlas used to estimate six-hour and 24-hour precipitation amounts for return periods of from two to one-hundred years for eleven (11) western states. The authors analyzed physiographic factors by regions considered to be meteorologically homogeneous. The extent of each region was determined from consideration of the weather situations that could be expected to produce large precipitation amounts. Among the questions asked and answered were: What is the source and from what direction does moisture for major storm come, and are there major orographic barriers that influence the precipitation process? Figure 1 shows some of the principal paths of moisture inflow for the western United States and the major orographic barriers to such flow.

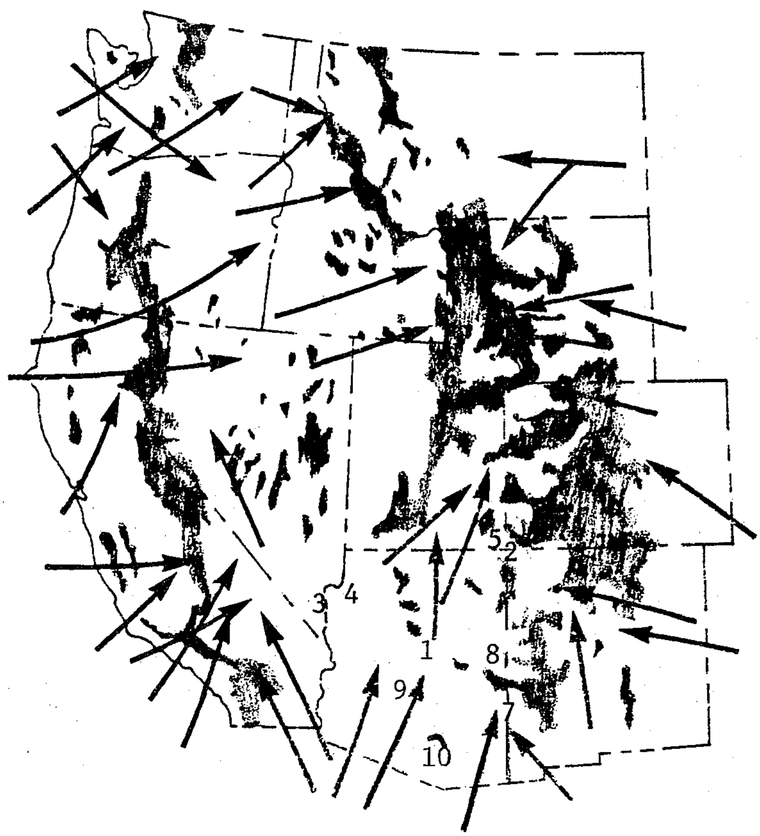

Figure 1. Principal Paths of Moisture Inflow in the Western United States for Storms Producing Large Precipitation Amounts. Toned Areas are Major Orographic Barriers.

Most of the recent extremely damaging flash floods in Arizona and adjacent states occurred over basins having upslope flow with the typical summer moisture flow pattern. The movement of moisture, causing high-intensity rainfall, is generally from a southerly or southwesterly direction. This moisture may be predominantly from the Pacific Ocean with the Gulf of Mexico being another major source (Hales [4], Sellers [5], and Brenner [6]. This generally occurs in the months of July, August, and September and is associated with a tropical disturbance south of the area and high pressure over the lower Rocky Mountain states. In the Sabino Canyon drainage basin, this same orientation to moisture inflow may not be a critical factor due to local influences on weather. This possibly seems slight. Sabino Canyon is located on the south slopes of the Santa Catalina Mountains, the highest mountain range for several hundred miles in the path of the major moisture flow. However, it should be acknowledged that local flash floods may occur over all washes and canyons in Arizona regardless of topographic orientation. Ten Harkel [7] indicates that it is difficult to differentiate flood susceptibility between basins due to orography because of complex meteorologic phenomena.

3. Expected Return Interval for Certain-Sized Events Transposed Over Sabino Canyon Creek

The graph in Figure 2 can be used to determine peak discharge (cfs/sq. mi.) by extracting data from the "y" axis for a specified size of drainage basin given on the "x" axis. The relationships would be valid only for basins geographically located under similar conditions to those for which the graph was constructed. More credence is given to this particular graph when compared to similar graphs developed by Thomas, et al, [8]; Matthai [9]; Hoyt and Langbein [10]; Creager, Justin, Hinds [11]; and Fogel, et al, [1]. Evidence from these sources indicates that results obtained from Figure 2 would be applicable in the western United States.

The potential for an extremely damaging flash flood in Sabino Canyon seems real. The basin is in a topography setting very conducive to high-intensity rainfall; possibly even more so than Walnut Gulch watershed where much data used in Figure 2 originated. Fogel's [1] data for the 25 square-mile Atterbury watershed (in relatively flat topography near Sabino Canyon) showed expected peaks to be significantly greater than those presented in Figure 2. He shows that for a 10-year storm an expected peak flow would exceed 12,000 cfs and that for a 20-year storm--more than 15,000 cfs. These are much greater than measured for 42 years at Sabino Creek. Figure 2 is used because more data from various-sized drainage basins throughout Arizona were analyzed, giving it possibly a wider application. However, it is acknowledged that for Sabino Canyon the calculated, expected peaks are conservative.

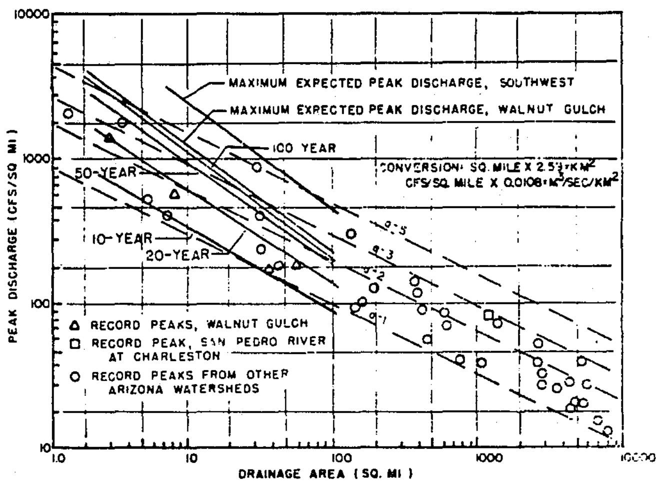

Figure 2. Comparison of Estimated Maximum Expected Peak Discharge and Estimated 10-yr., 20-yr., 50-yr., and 100-yr. Peak Discharges for Walnut Gulch with Peak Discharges Versus Drainage Area for Arizona Flood Peaks. (Excerpt from a Paper by Osborn and Laursen [12].)

In the 42 years of United States Geological Survey (USGS) [13] flow data for this basin, indications are that from chance alone no major flash-flood event has occurred. From the curves in Figure 2, the expected peak 10-year flow for Sabino Creek is about 200 cfs/mi^2 or 7,000 cfs. This compares with the observed maximum flow of 7,730 cfs or 218 cfs/mi^2. This particular event occurred in 1970. An event expected once in 10 years has occurred only once in 42 years; while an event expected once in 20 years or twice during the period of record has not occurred (300 cfs/mi^2 or 10,500 cfs peak). A 50-year event would exceed 15,000 cfs, which is not uncommon in small drainages (less than 50 square miles) throughout Arizona and the Southwest.

Rillito Creek, which drains basins surrounding Tucson, Arizona, and of which Sabino Creek is a tributary, contains 892 square miles drainage area. During 57 years of data (records began in 1917), the peak flow on Rillito Creek at Tucson was 24,000 cfs. This event would be expected more than once in 20 years. The maximum expected flow would be near 50,000 cfs; not 24,000 cfs. Rillito Creek and Sabino Creek are oriented in such a way that maximum flow may be expected and extrapolated from these given relationships.

4. Frequency Analysis

We have discussed the potential for damaging flash floods occurring from:

(a) The standpoint of orientation to meteorologic influence, and (b) the standpoint of occurrences for various return intervals. If a basin has not experienced a damaging flash flood and if evidence seems to indicate that such a potential is high, what could be the reason? Could the basin shape, configuration, or aspect be such that the peak is attenuated and a 20-year event is comparatively small? This seems unlikely over the Sabino Canyon Creek basin. It seems very prone to a damaging flash flood. The basin is fan-shaped, conducive to converge runoff to form a high peak.

This may indicate the likelihood that only one 10-year event may have occurred on Sabino Creek, and not that the maximum recorded is an extreme event. Meteorological and hydrological data indicate that the maximum recorded event is a relatively common event--probably a 10-year event. Let's analyze this concept from a probability aspect.

Hydrologic events exhibit a skewed distribution function. The common hydrologic statistics of median and extreme events cannot be reliably predicted using normal distribution functions. This is particularly true when desert areas are analyzed. For example, from analysis of 33 years of November - June flow (1939-1972) on the San Francisco River near Clifton, Arizona, 20 years had flow lower than the mean flow value. Values ranged from less than 20,000 acre-feet to more than 340,000 acre-feet, a 17-fold difference. These statistics may be even more exaggerated when phenomena of flash floods are considered.

Fogel, et al, [1] strongly justified use of the Poisson frequency distribution in fitting hydrologic data. For valid use of Poisson distribution, events must be statistically stationary and independent. Evidence is substantial to justify validity of this distribution function, especially in the Southwest (Duckstein, et al, [14] and Brooks and Corruthers [15]). The Poisson distribution is written as:

$$F\,(n) = \frac{m^{n}\ e^{-m}}{n!}\ .$$

Where m = Average number of events occurring in a given time period (or probability x number of trials).

Where n = Occurrences of event.

F (n) = Probability of occurrence of "n" events.

This distribution can be used to determine probability for a given number of occurrences of specified sized events or, conversely, the probability of a specified event not occurring can be determined. Integration of the Poisson distribution function allows these calculations. The probability of one 10-year event occurring plus the probability of no 10-year event occurring in a 40-year period is .09 or about 10 percent, while the probability of at least four 10-year events occurring in a 40-year period is .567 or about 60 percent. This is logical because during a 40-year period several 10-year events would be expected. Therefore, under conditions where this Poisson distribution is valid, the probability is that one basin in ten would have experienced only one or no 10-year event during a 40-year period. There are hundreds of flash-flood-prone areas in the western United States, and 10 percent of these would be a significant number. Furthermore, runoff records cover less than 40 years for many flash-flood-prone basins. This illustrates the danger of depending upon limited records or the memory of local citizens in determining flash-flood danger.

IV. SUMMARY AND CONCLUSIONS

Many basins located in the Southwest may not have experienced damaging flash floods in the recent past. Consequently, the apparent potential for damaging flash floods may be small. In actuality, a high potential for damaging flash floods may exist. A basin situated in a geographical area where flash floods occur frequently should be analyzed carefully for likelihood of flash flooding. Even though no particularly damaging flash floods have occurred during the period of record available for the basin.

This technical memorandum presents a method where potential damage can be determined even though past evidence is lacking. The following factors must be analyzed: (1) Magnitude of events for various return intervals, (2) Probability of occurrence, (3) Size of past events, and (4) Community susceptibility to damages. Current meteorological and hydrological potential must be considered, not merely history of events.

An example utilizing Sabino Creek near Tucson, Arizona, is given: Where the 20-year event may be 50 percent greater than any event which has occurred during the 42-year period of record studied.

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