#327

VOLUME 9

HYDROLOGY and WATER RESOURCES in ARIZONA and the SOUTHWEST

PROCEEDINGS OF THE 1979 MEETINGS
OF THE
ARIZONA SECTION —
AMERICAN WATER RESOURCES ASSN.
AND THE
HYDROLOGY SECTION —
ARIZONA - NEVADA ACADEMY OF SCIENCE

APRIL 13, 1979, TEMPE, ARIZONA

TESTS ON ARIZONA'S NEW FLOOD ESTIMATES

Brian M. Reich, Herbert B. Osborn and Malchus C. Baker, Jr.[1/]

ABSTRACT

A method for estimating regional flood frequency was prepared by R. H. Roeske of the U.S. Geological Survey (USGS) in 1978 for the Arizona Department of Transportation. Hydrologists may wish to use these regression equations for estimating flood peaks or for other purposes in development or flood control engineering. Many of those needs are for watersheds smaller than 10 sq. mi., however, for which USGS measurements are scarce. Records from two groups of small experimental watersheds near Tombstone and Flagstaff, one gaged by the U.S. Department of Agriculture's (USDA) Science and Education Administration and the other by the Forest Service, were used to independently evaluate the generalized Arizona relationships in specific applications to small watershed work. The new design floods for each experimental watershed were compared with estimates made using the USGS equation for two of the six flood frequency regions (FFR) in Arizona. The study showed that use of the generalized regional curve may underestimate flood peaks. Deviations from the curve can be caused by land use changes, differences in analytical methods, and use of short records.

INTRODUCTION

The users of an equation need to have a feel for the accuracy within which that equation simulates the natural behavior that it attempts to model. This is particularly true with flood peaks, whose magnitudes are the result of the joint action of many random hydrologic processes upon infinitely complex groupings of soils, land use, and watershed geometry. In the Southwest, flood peaks per unit area decrease with increasing watershed size because of the limited areal extent of the storms and the flow abstractions in the normally dry channels. Keppel and Renard (1962) examined hydrographs at progressive stations and verified that these combined hydrologic processes become particularly important for desert watersheds of 20 sq. mi. or more. Thus it may be beneficial to stratify Arizona watersheds into large and small subgroups before trying to fit flood peak (Q) area curves.

Fig. 1. USGS crest-gage station.

The U.S. Geological Survey (USGS) collects flood data in Arizona with financial support from groups within the state such as the Arizona Department of Transportation (ADOT). Roeske (1978) of USGS prepared a method for estimating regional flood frequency in six flood frequency regions (FFR) for Arizona. The present streamflow network is composed of 245 unregulated sites along Arizona's rivers and streams; the state-wide average is 463 sq. mi. per gage. This sparse network, particularly in the desert environment where the spatial and temporal variations of the rainfall input far exceed those in more humid parts of the U.S.A., results in a large error component when the data are used to prepare regional flood frequency prediction equations.

Moreover, 79 of Arizona's gages (32%) are of the crest-stage type, which estimate flood peaks less accurately than the other continuous recording stations. Photographs of two such installations are shown in Fig. 1. Of 32 USGS stations used by Roeske (1978) in the San Pedro and Santa Cruz basins alone, 65% were equiped with crest-stage gages.

The hydrologic processes at work on small areas are different from those operating upon the larger desert watersheds,

[1/] The authors are respectively: Manager, Planning and Resources Development, Pima County Flood Control District, Tucson; Supervisory Hydraulic Engineer, Southwest Rangeland Watershed Research Center, USDA, Tucson; and Hydrologist, Rocky Mountain Forest and Range Experimental Station, Flagstaff.

but the larger watersheds have overwhelming weight in the USGS data base. In the Santa Cruz and San Pedro basins, all but one of the 19 stations on watersheds smaller than 100 sq. mi. had crest-stage gages. Furthermore, at these small watersheds the average length of record was only 12 years, in contrast with the 32 years for larger watersheds. Short records and questions about whether such records represent longer climatic extremes may further reduce confidence in the accuracy of predictions for small watersheds.

Reich (1979) examined in detail the prerequisite statistical analysis of individual flood series from each stream gage. We combined his graphical analyses with the latest theory (Cunnane, 1978) on plotting positions and applied them to small watersheds in Arizona.

Using the two clusters of small research watersheds in Arizona where land use and hydrologic data are carefully monitored -- one in rangeland in southeastern Arizona near Tombstone (Walnut Gulch) the other in timber at higher elevations near Flagstaff (Beaver Creek) -- we examined Roeske's (1978) method to determine how well it applies to small watersheds in two of the six flood frequency regions (FFR) that he identified.

DESCRIPTION OF ROESKE'S EVALUATION

The six flood frequency regions (FFR) Roeske (1978) developed are shown in Fig. 2. The end product of his report was a set of seven regression equations for each FFR, each for a return interval of 2, 5, 10, 25, 50, 100, or 500 years. Table 1 presents the 100-year flood peaks (Q_{100}) in each region for a theoretical watershed having a 1-sq. mi. drainage, which were calculated using Roeske's method. The table also lists the size range of gaged watersheds upon which Roeske's equation was based and the standard error of estimate of the equation. Of the 200 watersheds used, 12% were less than 1 sq. mi., 24% between 1 and 10 sq. mi., 8% between 10 and 20 sq. mi., 8% between 20 and 50 sq. mi., 6% between 50 and 100 sq. mi., 8% between 100 and 200 sq. mi., and 13% between 200 and 1000 sq. mi. About two-thirds of the data used to develop these regression equations were from watersheds larger than 10 sq. mi. On the small watersheds included in the data base, the record length averaged less than 14 years, whereas for watersheds larger than 100 sq. mi. the records averaged about 26 years. In FFR 3 and 5, watersheds larger than 1,000 sq. mi. had average records of 38 years. The relative importance of differing storm types and channel abstractions lead to dichotomous flood behavior between large and small watersheds.

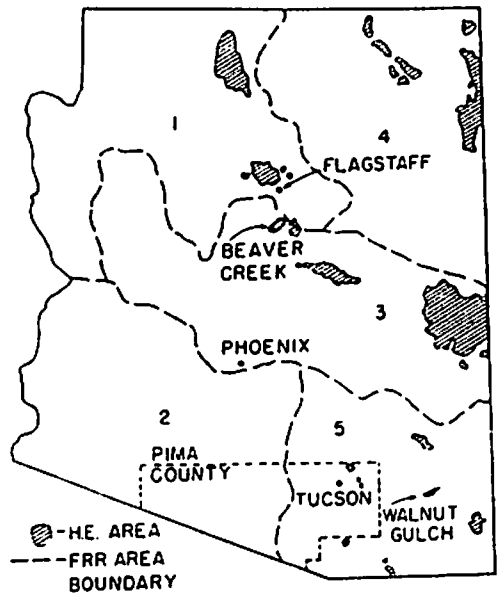

Fig. 2. Location map showing USGS flood frequency regions and the Walnut Gulch and Beaver Creek watersheds.

The practical meaning of the standard error of estimate is significant. In FFR 5, for example, Q_{100} is 1,230 cfs (Table 1). However, the 86% standard error of estimate should be interpreted to mean Q_{100} at one-third of similar watersheds could actually be outside 1,230 ± (86% of 1,230). The bounds -- 172 and 2,288 cfs -- represent a range within which two-thirds of the values lie. Moreover, the error around the estimate increases as one considers the very large or very small watersheds for which the regression relationship was derived.

In addition to the warning implied by the published standard errors of estimate, one must consider how much of the data came from small or large watersheds. One should be sure that the lower range of data upon which the equations were developed lend credence to the actual application. For example, the smallest watershed used in FFR 1 was 1.84 sq. mi. Similarly, for the high elevation (HE) FFR, where mean basin elevations are above 7,500 ft m.s.l., the smallest watershed was 1.61 sq. mi. The amount of data used to develop the regression relations for peak discharges are summarized in Table 2. The table shows again that the analysis of the HE region involved no watershed smaller than 1 sq. mi. In FFR 5, only seven of the 60 watersheds were within this smallest size class. Even more important, these seven very small watersheds added only 98 station-years of data, in comparison with the 339 station-years that came from nine watersheds larger than 1,000 sq. mi. Therefore, it would be unwise to apply these

Table 1. Estimates of Q_{100} (Roeske, 1978) with the standard error of estimate and size range of watersheds used to develop regression equations in each flood-frequency region.

	Q_{100} cfs	Std. error of estimate %	Watersheds used in developing the equations minimum (sq. mi.)	maximum (sq. mi.)	Q_{100} from hypothetical 1 sq. mile (cfs)
1	$584A^{.490}$	91	1.84	5,090	584
2	$1{,}100A^{.499}$	83	0.09	1,810	1,100
3	$553A^{.610}E^{-1.30}P^{.915}$	66	0.065	5,499	1,183
4	$0.0188A^{.369}E^{6.09}$	91	0.17	3,300	1,068
5	$1{,}230A^{.447}$	86	0.15	3,610	1,230
HE	$72.9A^{.795}$	45	1.61	747	73

A = Drainage area, in square miles

P = Mean basin elevation, in thousand feet above m.s.l.

E = Mean annual precipitation, inches

Table 2. Watershed size distributions and length of records used in Roeske's study.

Drainage areas in square miles	FFR 1		FFR 2		FFR 3		FFR 4		FFR 5		HE			
	Number of Watersheds	Station Years of Data	Number of Watersheds	Station Years of Data	Number of Watersheds	Station Years of Data	Number of Watersheds	Station Years of Data	Number of Watersheds	Station Years of Data	Number of Watersheds	Station Years of Data	% of Total Number	% of Station Years
Less than 1	0	0	4	53	11	152	5	66	7	98	0	0	13	8
1 - 9.99	5	66	8	98	17	246	6	77	18	266	2	18	24	15
10 - 19.99	2	23	4	51	2	26	2	26	6	104	2	18	8	6
20 - 49.99	2	26	2	28	6	84	0	0	5	80	4	43	8	6
50 - 99.99	0	0	3	53	6	94	2	26	1	11	2	51	6	5
100 - 199.9	1	50	2	25	11	173	0	0	2	34	3	78	8	8
200 - 999.9	2	22	1	12	24	591	3	140	12	301	5	101	20	28
More than 1,000	5	80	3	50	10	386	3	57	9	339	0	0	13	21
TOTALS	17	257	27	370	87	1752	21	392	60	1233	18	309	100	100

equations on watersheds smaller than 1 sq. mi. in FFR 1 or HE, and they should be used with care on other sized watersheds.

Consideration of the hydrologic processes at work during flood genesis in various regions and on different size watersheds should supplement the statistical results. Floods on large Arizona watersheds generally result from widespread frontal storms that occur in the cooler season. In contrast, extreme flood events on small semiarid watersheds result primarily from air-mass thunderstorms, which dominate the precipitation input in July, August, and September (Lane and Osborn, 1972; Osborn and Laursen, 1973). Flood peak reduction through channel transmission losses also has considerable impact in the desert (Keppel and Renard, 1962; Lane et al., 1971; and Lane 1972). In addition, the influence of heavy convective storms that typically cover less than 10 sq. mi. should be considered. Table 2 shows then that small watershed processes are virtually absent from the input data for FFR 1 and HE. The USGS equations for those regions are for large watershed relationships. It is not surprising, therefore, that the hypothetical 1 sq. mi. Q_{100}'s in Table 1 for FFR 1 and HE appear to be much smaller than for the other four FFR's.

DESCRIPTION OF STUDY AREAS

Walnut Gulch Research Watersheds

To test Roeske's equation for FFR 5 on the smaller basins, we selected a cluster of experimental rangeland watersheds at Walnut Gulch in southeastern Arizona (Fig. 2). Each subwatershed is equiped with rain gages and a laboratory calibrated flume-weir constructed and operated by the USDA-SEA-AR, Southwest Rangeland Watershed Research Center. There are 11 flume-weirs at Walnut Gulch which measure runoff from subwatersheds of 1 to 58 sq. mi. Eight of the subwatersheds are smaller than 10 sq. mi. A typical station is shown in Fig. 3.

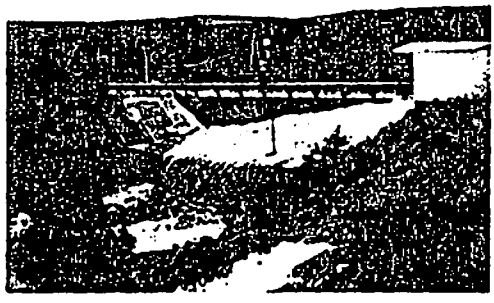

Fig. 3. Flow at a runoff-measuring station, Walnut Gulch, Arizona.

The Walnut Gulch subwatersheds are in brush-grass rangeland typical of much of Southeastern Arizona, Southwestern New Mexico, and Northern Sonora, Mexico. Major channels with slopes of about 1% are incised. All channels abstract large amounts of surface runoff. The average annual rainfall is 13 to 14 inches, and 70% occurs in the summer as intense, short-duration thunderstorms. All major flood peaks on Walnut Gulch have resulted from thunderstorm rainfall between April and October. Runoff records from the eight subwatersheds smaller than 10 sq. mi. range from 13 to 22 years. Flood peaks of up to 1,400 cfs per sq. mi. have been recorded on the smaller subwatersheds.

Beaver Creek Research Watersheds

To test Roeske's FFR 3 equation on small basins, we used watersheds with a wide variety of soils under various land uses. From 1957 to 1962, the U.S. Forest Service built stream gages on 18 watersheds near Flagstaff ranging in size from 66 to 2,036 acres. Vegetation representing the Utah and alligator juniper types as well as the ponderosa pine type were included. A high plateau, sloping mesas and breaks, steep canyons, and valleys characterize the topography of Beaver Creek. Because of a layer which impedes downward movement of water, the infiltration rate is slow -- from 0.05 to 0.2 inches/ hour when the soil is thoroughly wetted. Average precipitation varies from 12 to 25 inches across the research area, with 64% falling from October through April. Average peak snow water equivalent on Beaver Creek is about 3.4 inches. Fig. 4 shows an example of a Beaver Creek streamgage.

In testing the FFR 3 equation, we used 14 of the watersheds at Beaver Creek. They ranged in size from 0.1 to 3.2 sq. mi. On four of these, forest overstory was either thinned or clear cut so that data could be separated into before and after treatment series. These effects of forest treatment are indicated in Fig. 5. In some cases a combined series for the watershed was also subjected to flood frequency analyses. We studied the effects of various cover types and of thinning or clear cutting because any of these land uses can occur, alone or combined, at some future time on a watershed of interest to a hydraulic designer.

COMPARISON OF ESTIMATED FLOOD PEAKS

Walnut Gulch

The "best fit" in Fig. 6 represent the Q_{100} that we derived from the very best flood frequency analyses for 10 precisely gaged Walnut Gulch watersheds. The equation for this least-squares-fitted

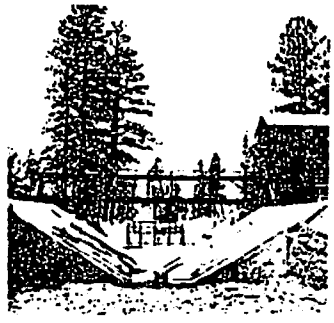

Fig. 4. A streamgaging station at Beaver Creek, Arizona.

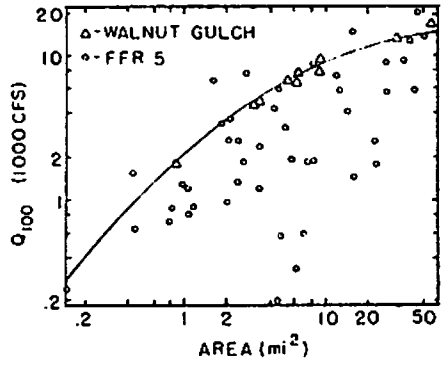

Fig. 6. Best fit (Δ) for Q_{100} at 10 samll watersheds at Walnut Gulch as compared with scatter found by Roeske (1978) in Pima County on the basis of his equation for FFR 5.

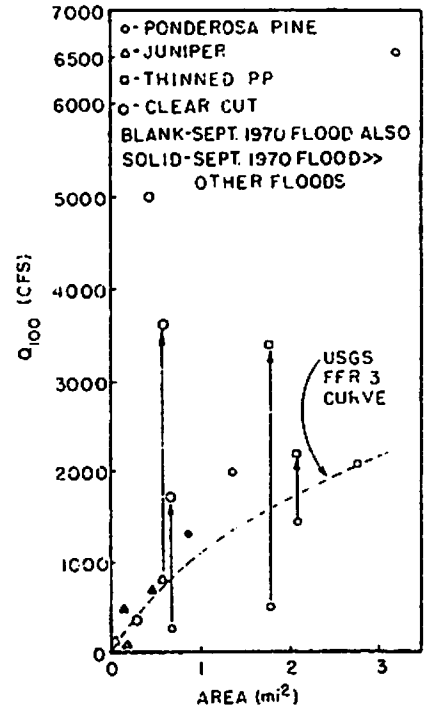

Fig. 5. Effects of forest treatment on runoff for selected Beaver Creek watersheds.

curve derived at Walnut Gulch is:

$$Q_{100} = 2360\ A^{(.688-.128 \log A)}$$

where A is the drainage area in square miles. The deviations about the curve in Fig. 6 are unusually small. These 10 Walnut Gulch subwatersheds are very close together, and similarity of climate and geomorphology might be partly responsible for the scatter-free peak area relationship. We also suspect that there is interstation correlation of the flood values in these separate series. This property is found among other clustered experimental subwatersheds in the U.S.A., where runoff results from large area storms.

Cross correlation of Walnut Gulch annual flood series showed less dependence than might be expected, however, presumably because of the small size and random positioning of intense summer storms in southeastern Arizona. Correlation between concurrent peak discharges for 10 Walnut Gulch subwatershed stations are shown in Table 3. As might be expected, successive stations on the same drainage -- subwatersheds 11 and 8, 6 and 2, 9 and 6, 2 and 1 in Fig. 7 -- show the highest correlations ($r = 0.76$ to 0.88) between runoff peaks (Table 3). Also, runoff peaks from some adjacent watersheds -- 8 and 10, 9 and 10, and 10 and 11 -- are correlated ($r = 0.66$ to 0.77). On the other hand, for 95% confidence limits, an r of 0.2 or less can result from random selection. Therefore at least stations 7, 11, and 15 may be considered as independent sampling points, or stations 7 and 3, 6, 8, 9, 10, 11, and 15, respectively, are independent sampling points. Stations 7, 11, and 15 have a combined record of 46 years, or an equivalent 46-year record, if the period of record on Walnut Gulch can be considered as a good sample of a longer period. If pairs of stations with correlations of less than 0.3 are considered independent sampling points, the record would be the equivalent of about 65 years.

Fig. 7. Walnut Gulch subwatersheds used in best fit analysis.

Table 3. Correlation (r) between concurrent peak discharges for 10 Walnut Gulch subwatershed stations. Location of subwatersheds is shown in Fig. 2.

Subwatershed station	1	2	3	6	7	8	9	10	11	15
1	1.0	.76	.41	.57	.63	.47	.46	.54	.34	.27
2		1.0	.69	.88	.29	.69	.77	.72	.37	.52
3			1.0	.55	.03*	.55	.42	.39	.06	.46
6				1.0	-.04	.80	.85	.87	.57	.55
7					1.0	-.12	-.11	-.09	-.11	.03
8						1.0	.59	.76	.77	.30
9							1.0	.78	.41	.29
10								1.0	.66	.29
11									1.0	.02
15										1.0

*Underlined values indicate station pairs with no statistical correlation.

The data and amounts for annual maximum peak discharges (cfs) for the same 10 Walnut Gulch subwatershed stations for 1963-1974 are shown in Table 4. Many maxima are recorded on the same dates on Walnut Gulch which indicates strong interdependence between some stations. However, annual maxima occur only occasionally on the same date at other stations - (7 and 8, and 11 and 15, for example. Also, examination of isohyetal maps of major thunderstorm rains (producing the major peaks) shows large differences in amount and areal variabilities between watersheds.

The storm of September 10, 1967, is shown in Fig. 8. The storm's maximum of 3.45 inches was recorded in 45 minutes. Annual maximum peak discharges were recorded on watersheds 8, 9, 10, and 11 during this storm, but there were large differences on the three watersheds. Also, in spite of the magnitude of this "record" event, maximum annual peak discharges were recorded on other dates in 1967 at three stations on Walnut Gulch.

Walnut Gulch represents one locality within FFR 5 where the Roeske method could be tested. In FFR 5 the curve for Walnut Gulch (Fig. 6) is about 70% higher than the USGS curve over the range from two to 10 sq. mi. Thus, for small watershed work, the FFR 5 equation should be multiplied by a safety factor of about 1.7. In other parts of the region, for example the steep-rock faces of the Catalina Mountains in Pima County a safety factor greater than 1.7 might be needed.

Table 4. Date and amount for maximum annual peak discharges (cfs) for selected Walnut Gulch Watersheds (1963-1974).

Year	Date and maximum peak discharge at -- 1 (58 mi^2)	2 (44 mi^2)	3 (3.5 mi^2)	6 (37 mi^2)	7 (5.2 mi^2)	8 (6.0 mi^2)	9 (9.1 mi^2)	10 (6.4 mi^2)	11 (3.2 mi^2)	15 (10 mi^2)
	cfs									
1963	19 Aug 2,710	25 Aug 1,370	22 Aug 85	19 Aug 2,025	--	19 Aug 740	--	--	19 Aug 750	31 Aug 680
1964	22 Jul 4,290	22 Jul 4,070	9 Sep 465	22 Jul 6,590	--	22 Jul 4,060	--	--	22 Jul 4,390	8 Sep 340
1965	4 Sep 840	4 Sep 1,100	4 Sep 144	4 Sep 1,480	--	4 Sep 1,020	--	--	4 Sep 1,050	4 Sep 20
1966	28 Jul 1,570	28 Jul 1,900	29 Jul 120	28 Jul 2,100	14 Aug 430	30 Jul 670	--	--	30 Jul 960	19 Aug 1,140
1967	10 Sep 4,680	10 Sep 3,180	24 Sep 60	10 Sep 4,640	3 Aug 340	10 Sep 1,800	10 Sep 2,350	10 Sep 2,220	10 Sep 1,700	3 Aug 950
1968	25 Aug 810	31 Aug 880	25 Aug 140	25 Aug 820	25 Aug 1,080	5 Aug 570	31 Aug 90	3 Aug 8	5 Aug 880	31 Aug 1,080
1969	7 Aug 1,680	7 Aug 110	15 Sep 8	15 Sep 120	17 Jul 100	15 Sep 170	13 Aug 170	15 Sep 70	13 Aug 260	28 Jul 8
1970	8 Sep 670	16 Aug 1,180	8 Sep 290	20 Jul 1,110	29 Jul 90	16 Aug 530	20 Jul 1,080	16 Aug 460	20 Jul 490	17 Aug 870
1971	10 Aug 3,610	10 Aug 3,810	10 Aug 1,040	10 Aug 3,600	20 Aug 220	10 Aug 1,280	10 Aug 2,110	10 Aug 1,160	18 Aug 430	10 Aug 1,260
1972	12 Aug 6,060	24 Jul 1,710	6 Sep 50	24 Jul 1,810	12 Aug 2,590	24 Jul 190	24 Jul 2,640	24 Jul 260	28 Jul 65	6 Jun 110
1973	27 Jul 2,980	27 Jul 1,940	27 Jul 120	21 Aug 200	27 Jul 2,540	21 Aug 380	21 Aug 20	21 Aug 20	21 Aug 490	19 Mar 90
1974	5 Aug 640	2 Sep 820	1 Aug 140	2 Sep 1,120	5 Aug 1,080	15 Aug 210	18 Aug 820	2 Sep 420	24 Sep 180	5 Aug 610

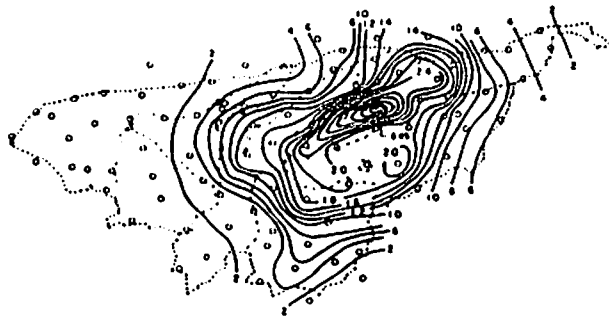

Fig. 8. Isohyetal map of storm rainfall on 10 Sept. 1967, Walnut Gulch, Arizona.

Pima County

The flood frequency plots that result from short records at two creststage gages in Pima County are shown in Fig. 9. The 13 observations on Geronimo Wash gave an inadequate but general indication that the flood which has a probability of 0.01 of being exceeded each year is about 3000 cfs. The best that could be derived from the Anklam Wash data was even less reliable. Two frequency lines on the graph suggested inadequate estimates of 3,000 or 6,000 cfs.

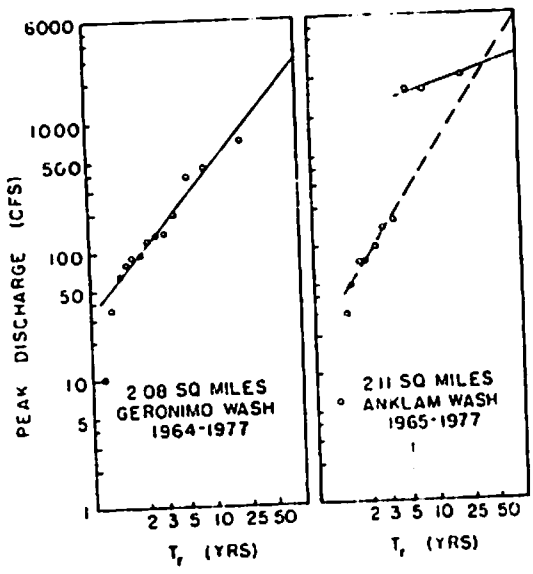

Fig. 9. Flood frequency plots for short records at two selected crest-gage stations in Pima County.

Separating variations from types of installation and the short record is difficult. Data were obtained from 45 USGS gages in and around the county. A complete flood frequency analysis was performed on each of these using three types of probability paper (Reich, 1979). The best estimates of Q_{100} for each time series for the 45 watersheds were plotted in Fig. 6. The huge scatter of these estimates may be partially due to physical differences between these diverse watersheds. If it were possible to separate them into sets of recognizable similar hydrologic systems, one would hope to distinguish a family of curves, somewhat concentric to the Walnut Gulch curve, fitting through each of these subsamples. Attempts to do this by means of four descriptive flood producing features (channel roughness, channel type, watershed slope, and runoff potential) failed. Therefore, much of the scatter in Fig. 6 may be due to inadequate data.

Beaver Creek

An indication of how much land use may alter peak flows within one FFR would be most valuable to hydrologists. A general equation like one of Roeske's in Table 1 represents only average conditions. Features like soil, cover, tributary configuration, etc. make peak discharges on a specific watershed higher or lower than average.

The effects of the forest treatment on runoff at Beaver Creek are shown in Fig. 5. In both cases where the ponderosa pine was thinned, Q_{100} increase significantly after treatment in the subseries of floods shown by the line and arrow in Fig. 5. The fact that Q_{100} for the intermediate size watershed

before the thinning treatment is far below that for the slightly larger watershed emphasizes the expected range of estimation from short records. Perhaps some intermediate value before thinning of about 1,000 cfs is a more reliable indicator. Similarly, although Q_{100} values at the intermediate sized and larger watershed after thinning differ -- over 2,000 and over 3,000 cfs -- indicating a general after-treatment Q_{100} of about 2,7000 cfs, which means in increase in Q_{100} of about a factor of 2.7 times.

On the 0.7 sq. mi. watershed, the smallest, clear cutting ponderosa pine changed the Q_{100} from 235 cfs to 1,700 cfs. However, because of the relatively short period of record, the flood frequency plots for these values are uncertain. More correct pre-and post-treatment Q_{100}'s might be closer together, and the treatment may be responsible for less than the large change indicated in predicted peaks.

All of the data after clear cutting included the flood of September 5, 1970, but this flood did not plot off the general trend of other floods. Very similar Q_{100}'s would have been estimated even without the 1970 event. The 1970 event, the largest in the 20 year record for this 2.8 sq. mi. watershed, lies along the line established by the rest of the peak discharges (Fig. 6). Notice also that peak discharges in ponderosa pine or thinned ponderosa pine make up four of the six largest from the entire series. The average of the two larger thinned ponderosa pine, 2,600 cfs, is about 40% greater than would be estimated with the FFR 3 equation. Four watersheds, (solid symbols) in Fig. 5 did show that the 1970 flood plotted markedly above the general trend in each flood frequency plot (not shown). In such cases, the 1970 event had to be treated somewhat as an outlier when eye-fitting a line on each frequency plot. The Q_{100} estimates were not inflated as much as they would have been with computer analysis, and as a result these four points lie fairly close to the USGS curve for FFR 3 shown on Fig. 6.

Because of future development, many watersheds will be cleared of vegetation for harvest, roads, or urbanization. Design values might therefore be expected to be closer to the top of the arrows in Fig. 6 than to the generalized FFR 3 curve.

In fact, a 1.4 sq. mi. watershed in ponderosa pine gaged for 20 years gave a Q_{100} almost 50% higher than the USGS curve. Another watershed in ponderosa pine, this one 3.2 sq. mi. with 16 years of record, indicated a Q_{100} of 6,400 cfs from a very good flood frequency plot. This is three times the value from the USGS equation.

It appears from Fig. 6, therefore, that small watershed designers in FFR 3 should multiply the equation by a safety factor of about 3. This value is compatible with the example we presented on Roeske's published errors of estimate.

Structural engineers often do use such safety factors and their calculations are much more deterministic than those computed using indadequate hydrologic data.

SUMMARY

The regional flood frequency method developed by Roeske (1978) appears to underestimate flood peaks for small rural watersheds. Evaluation of runoff records from controlled measuring structures on the USDA-SEA Walnut Gulch experimental Watershed and the USDA Forest Service Beaver Creek Watersheds in Arizona suggested that the Roeske method may underestimate flood peaks. Although of excellent quality, the USDA runoff records in Arizona are relatively short, and the Walnut Gulch watersheds are spaced quite closely. Therefore, flood peak predictions based on these records are also uncertain. However, the study suggested that Roeske's method should be applied to small watersheds with caution, because for small watersheds in Arizona, the curves are based on a few short records of questionable accuracy. If the method is used, a resonable safety factor should be applied until longer and more accurate records are available.

REFERENCES

Brown, H.E., Baker, M.B., and Rogers, J.J. 1974. Opportunities for Increasing Water Yields and Other Multiple Use Values on Ponderosa Pine Forest Lands. USDA Forest Service Research Paper RM-129, Fort Collins, CO, 36 p.

Clary, W.P., Baker, M.B., and O'Connel, P.F. 1974. Effect of Pinyon-Juniper Removal on Natural Resource Products and Uses in Arizona. USDA Forest Service Research Paper RM-128, Fort Collins, CO, 28 p.

Cunnane, C. 1978. Unbiased Plotting Positions - A Review. Journal of Hydrology. Vol. 37. No. 3, p. 205-222.

Keppel, R.V., and Renard, K.G. 1962. Transmission Losses in Ephemeral Stream Beds. J. Hydraulics Div., Proc. ASCE 88(HY3):59-68.

Lane, L.J. 1972. A Proposed Model for Flood Routing in Abstracting Ephemeral Channels. Hydrology and Water Resources in Arizona and the Southwest, Am. Water Res. Assoc., Ariz. Sec. Ariz. Acad. Sci., Hydrology Sec. Proc. 2: 439-453.

Lane, L.J., Diskin, M.H., and Renard, K.G. 1971. Input-Output Relationships for an Ephemeral Stream Channel System. J. Hydrology 13:22-40.

Lane, L.J., Osborn, H.B. 1972. Hypotheses on the Seasonal Distribution of Thunderstorm Rainfall in Southeastern Arizona. Proc. Second International Symposium in Hydrology, Fort Collins, CO, p. 83-94.

Osborn, H.B., and Laursen, E.M. 1973. Thunderstorm Runoff in Southeastern Arizona. J. Hydraulics Div., Proc. ASCE 98(HY7):1129-2245.

Reich, B.M. 1976. Magnitude and Frequency of Floods. Critical Reviews in Environmental Control, Vol. 6, Issue 4, p. 297-348.

Reich, B.M. 1979. Rainfall Intensity-Duration-Frequency Curves Developed From, Not By, Computer Output. Transportation Research Record. 9 p.

Roeske, R.H. 1978. Methods for Estimating the Magnitude Frequency of Floods in Arizona. Final Report ADOT-RS-15-121 U.S. Geological Survey, Tucson, AZ. 82 p.

Williams, G., Gifford, G.F., and Coltharp, G.B. 1969. Infiltrometer Studies on Treated Versus Untreated Pinyon-Juniper Sites in Central Utah. J. Range Manage. 22(110-114).

Williams, G., Gifford, G.F., and Coltharp, G.B. 1972. Factors Influencing Infiltration and Erosion on chained Pinyon-Juniper Sites in Utah. J. Range Manage. 25(201-205).