Reprinted from Hydraulics/Hydrology of Arid Lands
Proceedings of Int'l. Symposium
HY & IR Div./ASCE
San Diego, CA/July 30-August 2, 1990

Alignment of Large Flood-Peaks on Arid Watersheds

B.M. Reich[1] , K.G. Renard[2], F. ASCE and F.A. Lopez[2]

Abstract: Bridge and culvert design requires estimates for 25- to 100-year return period flood peaks (Q). Floodplain delineation calls for 500-year (Q500) estimates. Arid western flood series are shorter and more variable than eastern ones (Reich, 1969). Even if about 30 years of good data exist, various statistical models will produce widely different estimates of flood frequency. This paper shows users how variable results may be because of natural variability, mathematical peculiarities, or different flood geneses in arid regions. It also suggests how close flood estimates may be from six engineers who select best fits of the larger floods from four graphical displays.

Background and Developments: Reich and Renard (1981) used King's table (1971), as a way of portraying the forms of flood series. This table comprised a 4-by-4 array of different probability papers. If a series of observed floods appeared linear on a particular paper, say Log-Normal (LN), then that theoretical distribution could serve best for extrapolating toward larger floods. This is useful for seeking the most appropriate distribution for each flood series. It comprised plotting annual maxima on LN, Extreme Value (EV), Log Extreme Value (LEV), and Weibull papers. Observed floods that curve down from a straight, rising alignment near large floods suggest a mismatch between the paper's model and empirical data. Theoretically, only one cell in King's table can produce a straight line. Twelve other elements of that graphical aid present convex or concave curves that would appear when the wrong paper was tried on various distributions. This expedites the search for the most appropriate plotting paper.

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[1]Consulting Engineer, 2635 E. Cerrada Adelita, Tucson, AZ 85718.
[2]Research Hydraulic Engineer and Hydrologic Technician, USDA-ARS, 2000 E. Allen Road, Tucson, AZ 85719.

Design Needs: Practitioners need estimates for return periods (RP) from 25 to 500 years. About 10 floods observed in an average 34-year history are likely to flow deep and swift enough to simulate conditions appropriate to a flood regime. The biggest observation from 34 years has a plotting position of 57 years according to Cunnane's (1978) theoretical work. The second largest recorded flood has an RP of 21 years; the following eight floods plot at RP's of 13, 9, 7, 6, 5, 4.5 and 3.6. More commonly, a flood record is only available for 20 years. It's six biggest items would have RP's of: 34, 13, 8, 6, 5, and 4 years. Search for linearity should emphasize the larger observations.

Bigger floods will usually be measured with large error. So it may be misleading to fit complex mathematical curves. The smaller half of the annual maxima do not interest design applications. In semiarid regions analysts need to indicate a preferred linear trend after testing common flood frequency papers. Positioning a straight line must recognize two possible occurrences; the chance measurement errors, and random occurrence of high or low "outliers". The selected frequency-plot should pass through about the largest 1/3 of the data and be free of systematic curvature.

An earlier test (Reich and Renard, 1981) involved seven watersheds from 2.5 to 56 square miles. They found that "straight-edge lines" were superior to statistically computed curves. Each flood series plotted into two straight lines that were separate from, and differently oriented to a large number of much smaller annual maxima. The 1982 Bulletin 17B of the Federal Inter-Agency Committee warned users that flood prediction requires more judgment than had always been used when computing flood frequencies from its 1967 Bulletin 15, Log Pearson (LP3) procedure.

Aron's multi-model PC program MINIEX (Aron, 1989) provides subroutines for implementing some of the flexibility now permitted in Bulletin 17B's text. Aron's output is limited to tabular information. However, manual plotting of floods, according to his three plotting formulae on various probability papers, is tedious and error-prone. de Roulhac's (1987) development of a PC program for plotting data and fitting classical curves was a step toward Q100. He was able to use only Cunnane's (1986) compromise plotting position formula on four probability papers in a study of short-duration rainfall intensity. He permitted us to use and modify his program.

Table 1. Six engineers' straight-line Q250 estimates.

	Engineer Number 1	2	3	4	5	6	Average	Range
LN	18.0*	18.0	30.2	22.0	17.0	20.0	20.9	17.0-30.2
EV	11.5	10.5	10.2	12.6	13.0	20.0	13.0	10.2-20.0

*Discharge peak in 1000 cfs.
Computer predicted Q250: 93,000 cfs for LN; 10,900 cfs for EV.

and spatial precipitation variability. This is not common in the eastern United States. Fig. 2 shows how the solid-line Log Pearson III (LP3) flattens off for RPs greater than 10 years at less than 5,000 cfs, even though a 32-year record contained three observations from 5 to 12 thousand cfs. Fitting a straight line (dashed) through the larger half of the observations seems more satisfactory. To judge the variation between analysts in using such eye-fitted straight lines, two of us undertook independent drawing of straight lines through the data-plots for six watersheds.

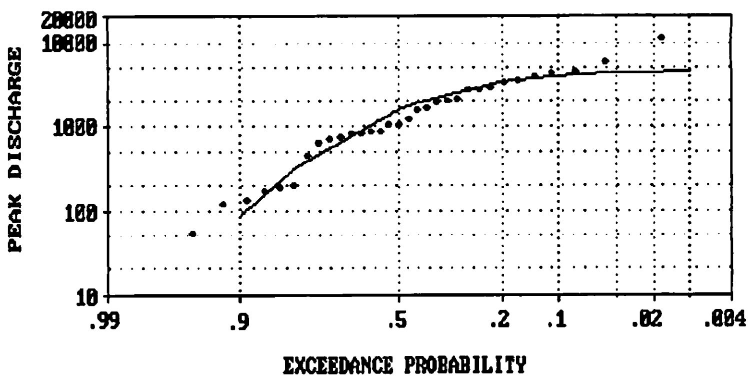

Fig. 2. LP3 math curve does not climb toward four observations between 5,000 and 12,000 cfs.

Table 2 summarizes the analyses completed by the first two authors for the six watersheds. The first three columns list some watershed information. All but Alamogordo Creek (a discontinued ARS watershed in eastern New Mexico near Santa Rosa) are located in southeastern Arizona. The Walnut Gulch watersheds, operated by ARS, have the two smaller ones as subwatersheds of the larger one. The last two on the list are operated by USGS.

Verification by Six Hydrologists: Four other engineering hydrologists joined the first and second authors to test our method of estimating design-sized floods from an observed series of annual maxima. These six scientists brought about 200 years of arid runoff experience into the evaluation. de Roulhac's (1987) software and automated plotting was applied to 33 yearly maxima from a 56 square mile, southeastern Arizona rangeland watershed known as the Walnut Gulch Experimental Watershed (Renard, 1970). One of their results is shown in Fig. 1. The scientists were requested to separately fit a straight line for each series on EV, Normal, LN, and LEV paper "through as many floods that each felt should influence the 25-, 100-, and 250-year estimates". They were instructed to assign a zero to a plot they felt fitted unacceptably. Four gave zero to Normal paper. The other two only graded Normal papers as 1 out of 9. In contrast, four of the six raters considered LN eye-fits the best, and the other two raters called it second best. EV eye-fits came second for five judges. Two raters called EV best.

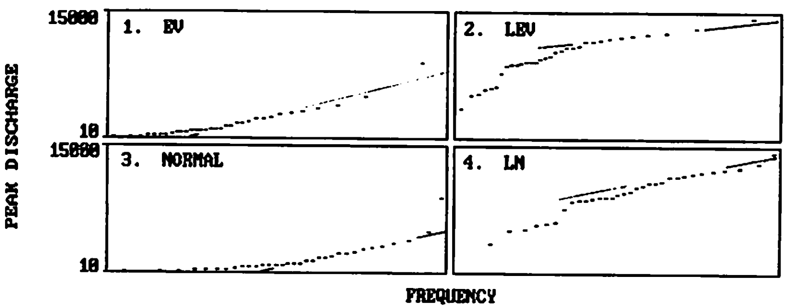

Fig. 1. Annual maximum floods plotted according to Cunnane's formula on N, LN, EV, and LEV graph papers.

The 250-year estimates from the six engineers' straight lines for LN and EV appear in Table 1. LN estimates were frequently 75% greater than EV's. Estimates by different "experts" differed by two times. Thus flood professionals may consider safety factors which are used by structural engineers.

Study of Six Western Rangeland Watersheds: Arizona and New Mexico watersheds ranging in size from 3.1 to 82 square miles were analyzed. The watersheds had record lengths of 57, 40, 33, 32, 27 and 24 years. Fig. 1 shows one station's annual maxima plotted according to Cunnane's formula on N, LN, EV, and LEV graph papers. They display "dog's legs" which seem to be characteristic of semiarid rangelands, reflecting transmission losses

Table 2. Summary of computer and straight-line frequency estimates for six southeastern Arizona "desert watersheds".

Watershed	Drainage Area sq. mi.	Record Length Years	Straight Line Q100 cfs				Computer Estimate Q100 cfs			
				Reich		Renard	LN	EV	LEV	LP3
Walnut Gulch 11	3.18	27	LN	7,500	LN	7,000	10,800	4,400	43,700	5,200
Walnut Gulch 03	3.47	32	EV	1,800	LN	2,000	2,900	1,310	10,900	1,420
Walnut Gulch 01	57.7	33	EV	9,900	LN	16,000	59,000	9,420	334,000	4,500
Alamogordo Creek (near Santa Rosa, NM)	67.0	24	LN	14,000	LN	15,000	22,400	8,700	91,000	9,770
Santa Cruz @Lochiel	82.2	40	LN	13,500	LN	13,500	23,700	10,700	75,300	5,140
Sabino Canyon	35.5	57	EV	8,000	LN	12,000	13,400	7,580	36,400	9,700

LN = log normal, EV = extreme value, LEV = log extreme value, and LP3 = log-Pearson 3.

Columns 4 to 7 show the 100-year estimates using the distribution selected by each of the two engineers as best fitting data influencing the 25- through 250-year frequency domain. The LN distribution gave the best result in most instances. One of the engineers preferred EV in 3 of the 6 watersheds.

The ratios of Renard's to Reich's Q100s were 0.93, 1.11, 1.62, 1.07, 1, and 1.5. LP3 computations produced Q100s that were only 72, 75, 35, 68, 38, and 97% of the mean of two linear straight lines through larger floods. In contrast, estimates by the two engineers were within 10% for four watersheds. Two Renard estimates are 1.6 and 1.5 times Reich's.

The last four columns show the computer estimated 100-year discharges for four models. Estimates from LN, EV, LEV, and LP3 computations deviate by several orders of magnitude. It is interesting to note that the EV computed Q100 agrees quite well with the "straight-line eye-fit" estimates for EV.

Walnut Gulch watersheds 3 and 11 which have about the same size drainage areas and are in very close proximity, show flood estimates that differ by three times. Although there are some differences in soils and vegetation, the primary explanation involves chance rainstorm position with greater storm depths and intensities on watershed 11. Thus, the two contiguous watersheds with relatively short records produce greatly different 100-year peak discharge estimates; i.e., an illustration of the variability to be expected in semiarid ephemeral streams.

<u>Summary</u>: Annual maximum flood series in ephemeral streams of semiarid areas comprise different populations for the less frequent larger and more frequent smaller

storms. Spatial precipitation differences and transmission losses affect small floods differently from large floods.

Flood estimates such as the Q100 estimate exhibit large differences. Theoretical curves or eye-fit straight-line fitting should emphasize the larger discharge observations. The authors have argued that care must be taken in accepting computer-generated flood estimates without careful examination of the observed data. The straight-line eye-fit interpretation of the data produce consistent results.

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