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APPLICATION OF ADVANCES IN FLOOD  
FREQUENCY ANALYSIS<sup>1</sup>*Brian M. Reich and Kenneth G. Renard<sup>2</sup>*

**ABSTRACT:** Flood frequency analyses are frequently being made using widely available computer programs. Serious errors can result from blind acceptance of such results. Visual interpretation of observed flood series can be used for evaluation on frequency paper with compatible scales. Such frequency papers are presented in the paper. In ephemeral streams, more infrequent floods may constitute a separate set from the more frequent floods because (a) runoff producing storms cover only a portion of the contributing area, (b) transmission losses in the normally dry streambed may reduce the peak flow, and (c) some runoff may be stored in stock water ponds which therefore leads to partial area runoff. The Cunnane plotting position used in this paper is superior to the more widely used Weibull equation, having a mathematically sound basis for locating observed floods on an assumed probability.

(KEY TERMS: flood frequency; plotting position; frequency distributions; runoff; computer.)

## INTRODUCTION

An avalanche of "advances" in analytical methods found the already advanced approaches for estimating a design flood maximum. It is not surprising that the Water Resources Council (WRC) tried to standardize methodology with a handbook in 1967. Some casual applicers of the more sophisticated computer programs, arising from the WRC (1977) Bulletin 17-A, may consider such expedited calculations as another "advance" in these analytical tools. Scientific literature (Colorado State Univ., 1972) is replete with applications of stochastic hydrology for analyzing a river's flood series. In this decade, many texts (Benjamin and Cornell, 1970; Haan, 1977) have been published with comprehensive presentations of statistical theory useful to civil engineers and hydrologists. Well documented computer programs for large electronic computers (Corps of Engineers, 1976), and for personal programmable calculators (Croley, 1977; Eggert and Simons, 1979) are available. All of these efforts represent considerable advances since 1914 when Hazen suggested plotting annual maximum floods on log-normal paper, or since 1954 when Chow introduced a parameter (K-values) for mathematically

applying various statistical distributions to the analysis of flood series.

Theoretical sophistication and the ease with which computers can perform complex, repetitive arithmetic seem to have diverted attention away from the merits of some graphical techniques. We may overlook the value judgments made by experienced hydrologists who recognize causative physical processes that produce flood peaks in our fascination with new statistical and computational tools. Everyone knows the adage "Garbage in, garbage out." Before we rush to the electronic wizard, we should also remember the constraints and mathematical assumptions hidden within any computer code that we borrow.

The particular advances discussed below are actually graphical simplifications that return men "back into the driver's seat." They pertain to applying 1978 theoretical advances (Cunnane, 1978) and the preparation of compatible probability papers. Arguments are also presented for fitting frequency lines to larger floods, which is the class from which designers may more safely extrapolate to rare events. The dichotomy between these larger and smaller peaks in a flood series were studied on seven research watersheds in southeastern Arizona. Hydrologic processes of arid zones were examined to account for the distribution of floods within each of these series. Blind computer fitting of a frequency curve to all peaks in a series can produce a 100-year flood estimate that is incompatible with trends established by the five or more major flows. Rationale presented for reviewing improved visual analysis of flood series could be applied elsewhere. Computer graphics and the recently available plotters for desk top calculators can be used to improve upon the past decade's experience with statistics, which always presented the dilemma: "Is the assumed probability distribution bad, or is the misfit simply an outcome of data sampling?"

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## COMPATIBLE PAPERS FACILITATE VISUAL CHOICE AMONG DISTRIBUTIONS

Probability papers previously available for applying various separate *a priori* distributions have each contained different arithmetic spacing for flood magnitude and for probability. Thus, for example, the same flood series plotted separately on extreme value (EV), on log extreme value (LEV), and on log normal (LN) paper did not simplify visual comparison among these various statistical distributions. The unachievable perfect linearity would, of course, provide indisputable proof that the statistical model represented in that paper was appropriate. A more common and vexing problem is the selection between two or three graph papers, on each of which various different observed points deviate from the straight lines that presumably describe data with such a distribution. Reading the deviation of observed discharges above or below the straight line is tedious. Moreover, a large discharge deviation in the upper part of a logarithmic scale is compressed and will create an optical favorable bias as compared with a smaller discharge deviation in the lower range of discharges that are represented by a greater physical distance from the straight line. Differently proportioned papers for each statistical model further complicate comparisons. The problem is compounded by the eye fitted lines themselves being located with various alignments on various papers. To overcome this problem, the Pima County Flood Control District (PCFCD) prepared probability papers (Figure 1) with identical vertical discharge scales for log normal (LN) and log extreme value (LEV) distributions, which are shown in Figures 1b and 1c. On extreme value (EV) and LEV papers, the horizontal scales have been made equal in Figures 1a and 1c.

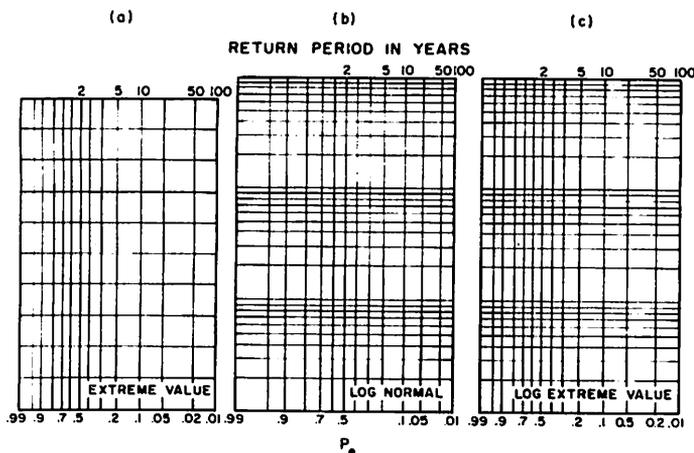


Figure 1. Three Compatible Sheets of Probability Paper Facilitate Choice Among Distributions.

In older papers, considerably different physical spacing was often used along the probability axis. For example, one type of log normal probability paper had two inches between its probability lines for the exceedance probabilities ( $P_e$ ) of 0.1

and 0.01. Another log normal paper used 0.8 inches for the same range. The illusion of horizontal closeness of plotted points to a line will differ on two such papers. Another possible visual distortion when probabilities are more widely spaced physically is that the same data may seem to tie down a line over a wider range on one probability paper than over another. In regard to this problem, the deviation between LN and LEV or EV papers for probabilities smaller than 0.1 is relatively unimportant.

A more difficult problem arises when one tries to achieve linearly compatible probability scales between LEV and LN papers. This is because the former's probability distribution is skewed to the right and, therefore, has widening spacing towards the smallest probabilities (Figure 1c). The LN and LEV papers were designed with as closely similar physical spacing as was mathematically valid across the range of  $P_e$  from 0.5 to 0.1. Physical reasons suggest that flood hydrologists should pay strong attention to observations whose probabilities of being exceeded are less than 0.5. This dictates that the larger half of the observations, which should influence the estimate of a large design flood (like  $Q_{100}$ ) must be plotted in closely comparable horizontal positions on different papers. The larger half of observed floods plot mostly within the range from  $P_e = 0.5$  to 0.1. For example, in a 16-year record, all but the largest of the top half of the observations will plot within this important range.

The largest observation of a 16-year record should be plotted at  $P_e = 0.059$ . For many stations, the largest flood, generally, is observed with the most error. When current meter measurements are used to develop a rating curve for the station, these measurements are generally made at lower stages and the depth discharge relationship is extrapolated to the largest stage. Thus, the magnitude of the largest flood of each series has more uncertainty in cubic feet per second (cfs) than the smaller ones for which stage can be translated to discharge with less error. Moreover, the position along the horizontal probability axis of the largest observed flood also may be misleading because of a sampling abnormality. One watershed may experience a very rare event, like a 300-year flood ( $P_e = 0.003$ ) within, say, a 25-year record; whereas, another watershed, for that same record period, may experience no flood larger than a true 15-year ( $P_e = 0.067$ ) magnitude. In both instances, the peak flood is plotted at  $P_e = 0.024$ . Thus, the difference between LN and LEV or EV papers for probabilities smaller than 0.1 is relatively unimportant.

## UNIVERSAL PLOTTING POSSIBLE WITH NEW FORMULA

The early formulae proposed for locating observed floods according to the probability spacing were gradually replaced by Weibull's (1939) equation

$$P_e = \frac{m}{N+1} \quad (1)$$

where:

$m$  = rank, with 1 for the largest flood

$N$  = total number of floods in the series.

This choice was arbitrarily suggested by Gumbel (1954), and has been frequently cited in text books and computer programs since the 1950's. A mathematically sound plotting position equation for EV or LEV data was presented by Gringorten (1963). It is:

$$P_e = \frac{m-a}{N+1-2a} \quad (2)$$

where the constant  $a$  varies with sample size approximately as follows:

$N$	10	20	40	60	100
$a$	0.448	0.443	0.441	0.440	0.439

For common situations, an adequate approximation is

$$P_e = \frac{m-0.44}{N+0.12} \quad (3)$$

Use of Gringorten's formula for EV and LEV papers, along with Weibull's formula for LN plotting, required an extra computation. More serious was the objection to the resulting difference in horizontal spacing of the largest floods and its influence upon linear fitting and extrapolation towards the 100-year estimate,  $Q_{100}$ .

Cunnane's theoretical work (1978) permits the use of one compromise formula

$$P_e = \frac{m-0.4}{N+0.2} \quad (4)$$

to be applied to EV, LEV, LN, and normal distributions alike. Notice the close resemblance between Equation (3) and (4). For example, the largest flood in a 20-year series will now be plotted at  $P_e = 0.0297$ , instead of at Gringorten's value of 0.0278, which is theoretically perfect for EV or LEV data. The difference on Figures 1a and 1c is imperceptible. The Weibull formula, which Cunnane proved to be theoretically inappropriate for LN or normal distributions, is significantly different for large and small floods. Our 20-year example would have the largest flood plotted at  $P_e = 0.048$  by Weibull's Equation (1), whereas it should be located at  $P_e = 0.030$  with Cunnane's Equation (4). This comprises considerable displacement on LN paper in Figure 1b.

Development of this one plotting formula, and the compatible papers described in the previous section, provide further advantages for graphical frequency analysis (Reich, 1976 and 1978).

## PLOTTING ASSISTS THE SELECTION OF BEST DISTRIBUTION

One problem involved in mathematically fitting a frequency curve to a flood series by moments, maximum likelihood, or any other statistical method is the need for selecting an *a priori* mathematical distribution describing the true population from which observed floods are a small sample. Rademaker (1974) discussed theoretical methods for testing two different distributions at the same time by considering estimation error in each of their two parameters. However, application of such tests is too complicated for the generalist in water resources. Moreover, our choice may require selection from more than two probability functions. Sometimes, floods have been modeled with the following mathematical functions:

- extreme value,
- log extreme value,
- log normal,
- three parameter gamma,
- two parameter gamma.

If a very long series of floods were plotted on paper corresponding to the appropriate theoretical distribution, the data would lie in a straight line, except for sample aberrations. Such linearity permits confident extrapolation to rare probabilities. The only line with predictive use on flood frequency paper is a straight line. Use of the word "line" in this discussion will exclude any curved line.

The Log Pearson Type III (LP) curve fitting technique, which has reemerged in the United States (Reich, 1977) over about the last decade, cannot be linearized (Cunnane, 1978) on one type of probability paper. It is, therefore, intractable to the advantages of judgmental visual analysis to be discussed here. Users of LP computer programs, in which data are not plotted or are incorrectly plotted by the Weibull Equation (1) on only one type of paper, should realize the pitfalls that await. Subsequent discussion is devoted to some of the anomalous results that can be produced by LP predictions.

## ILLUSTRATIONS OF MULTIPAPER GRAPHICAL ANALYSIS

Many examples will be discussed to convey the technique for graphically fitting the best flood frequency line and simultaneously selecting the most appropriate probability paper. The data used were measured with laboratory calibrated and well maintained critical depth flumes on the U.S. Department of Agriculture's Walnut Gulch Experimental Watersheds.

Walnut Gulch is an ephemeral tributary to the San Pedro River in southeastern Arizona. The 58-square mile basin is bounded on the east by the Dragoon Mountains, on the south by the Tombstone Hills, and on the north by low alluvial hills; its rolling basin and range topography are typical of the southeastern Arizona basin and range land resource area (Austin, 1965). The vegetation in the basin is predominately brush on the lower elevations with mixed grass brush on the upper portions. Most of the area is covered by the Tombstone pediment, which is a deep Quaternary and Tertiary alluvial fill of

disconnected layers of sands, gravel, and conglomerate. The soils of Walnut Gulch are, primarily, moderately to poorly developed, and thus exhibit characteristics of the parent rock of geological alluvium. Almost 80 percent of the soil surface is developed on geological alluvium derived from limestone. The other 20 percent consists of lithosols on limestone, granite rock, and granodiorite. With few exceptions in this latter group, the soils are base saturated, if not calcareous, and have sandy to gravelly sandy loam surface textures.

Runoff from the entire basin and from the main subbasins is measured with prerated supercritical depth flumes (Gwinn, 1970; Smith and Chery, 1974). Rainfall on the basin is measured with 95 well distributed recording raingages. The 14-inch annual rainfall is distributed between low intensity limited areal extent air mass thunderstorms that produce essentially all stream flow from July to October. The main physical characteristics of the basins used in this study are listed in Table 1. Locations of the watersheds and subbasins within Walnut Gulch are shown in Figure 2.

We will begin by examining data from watershed 63.010, which is 9.15 miles long, is narrow, and contains no stock ponds. In Figure 3a, peak discharges from this watershed are plotted on EV paper and have slight but systematic J-shapes. Not even the largest half of the flood series is free from this trend. It would thus be unwise to fit any straight line, and consequently any curve, to such points. When these same 11 annual maximum flood peaks are plotted on LN paper (Figure 3b), the curved upswing toward larger values, already mentioned on the EV plot, is considerably reduced. The three smallest floods plot progressively further below the line. Such small events need not be considered when estimating rare floods like  $Q_{100}$ . However, the four larger floods still show a slight upswing, rather than merely random variations, about the LN straight line. The LEV plot (Figure 3c) shows that the seven larger floods average only 33 cfs deviation from the line, which is about half that about the LN line. Moreover, the random arrangement of their deviations on LEV paper suggests this distribution has eliminated any slight curvature that had remained on the LN paper. So for this watershed, the LEV is the most appropriate paper to use for predicting  $Q_{100}$ , which is 7,100 cfs.

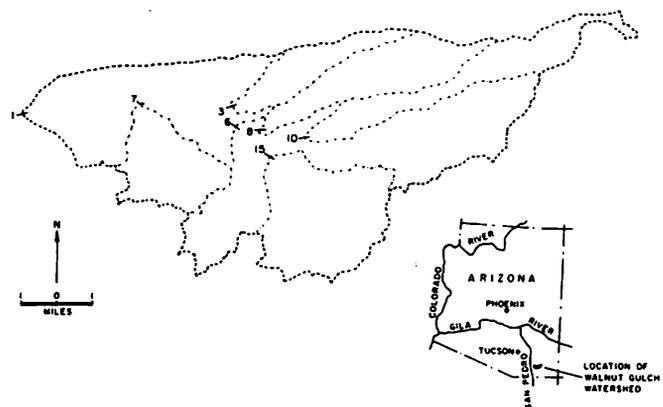


Figure 2. Location Map Showing the Watersheds Used in This Study.

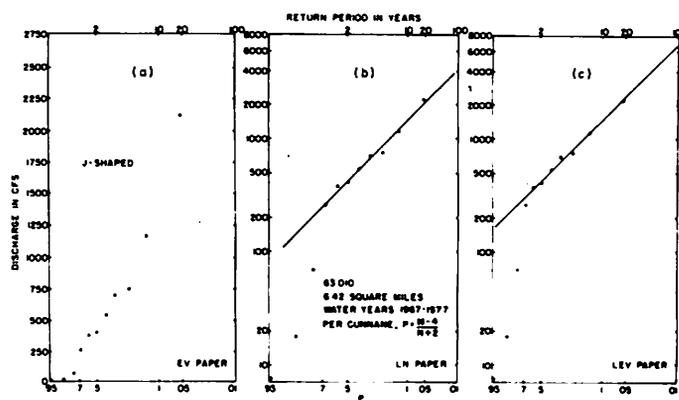


Figure 3. Elimination of J-Shape and Choice of Log Extreme Value Distribution for One Flood Series.

### GUIDE FOR PROGRESSIVELY SELECTING MORE APPROPRIATE PAPER

In an excellent book on theoretical and graphical statistics, King (1971) presented a scheme for moving from systematic

TABLE 1. Walnut Gulch Watershed Data.

Watershed Ident.	Drainage Area		Number of Stock Ponds	Area of Pond (acres)	Pond Volume Below Spillways (acre-ft.)	Watershed Shape Remarks	Length of Main Channel (mi.)	Range of Elevation (ft. mean sea level)	Figure No. Containing Flood Frequency Plots
	(sq. mi.)	(acres)							
63.001	57.70	36,900	26	3,861	153.7	Elliptical	20.3	4000-6300	8
63.003	3.47	2,220	3	963	28.4	Long	6.5	4460-4800	7
63.006	36.70	23,500	12	2,650	113.8	Elliptical	13.5	4360-6300	6
63.007	5.22	3,340	0	0	0.0	Circular	3.8	4220-4970	9
63.008	5.98	3,830	2	208	16.1	Long	8.0	4420-5040	5
63.010	6.42	4,110	2	236	16.5	Very long and narrow	11.1	4500-6200	3
63.015	9.24	5,912	4	1,599	62.7	Circular	3.2	4450-5220	10

nonlinearity on one trial plot to another probability paper, which should produce acceptable linearity. A simplification of that chart is presented in Figure 4, and its use in flood frequency analysis will be discussed. The true probability distribution of the population is unknown, as indicated by the label on the rows of papers shown in Figure 4. The type of overall curvature that resulted from plotting a series of annual maxima on several types of probability paper indicates which paper should be chosen next when trying to approach linearity. As an example of the hints provided by King's array of probability curves (Figure 4), let us examine the floods plotted in Figure 3.

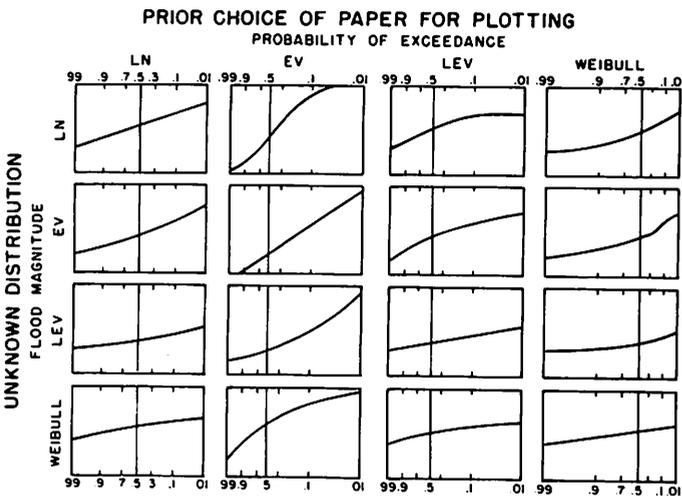


Figure 4. Comparative Probability Plots of the Four Major Probability Distributions on Different Types of Paper (from King).

To interpret the J-shape obtained from an original choice of EV paper for examining floods in Figure 3, we should look for its shape in the second (extreme value) column of Figure 4. The J rising steeply to the right of the third line of Figure 4 indicates an LEV may be the unknown true distribution of the floods. The slight upswing of floods with  $P_e < 0.6$  on LN paper in Figure 3 also matches the shape in the third line and first column of Figure 4, thus confirming that the unknown distribution of this flood population is LEV.

Physical processes operating in the genesis of desert floods require that our attention is directed to the larger half of the flood series. These physical processes are discussed subsequently, and are responsible for the departure of the smaller floods from the theoretical straight line for probabilities exceeding 0.5 on the LN and LEV plots. We feel these departures should not be considered when seeking to match one of the distributions of Figure 4. When the observed flood sequence does give a straight line on a probability paper for the large floods, then we can assume we have selected the appropriate probability distribution and can be confident of the extrapolation towards larger floods. The Weibull distribution included in Figure 4 is not commonly used in flood frequency

analysis, but we feel it could be valuable in analyzing some hydrologic phenomena.

### OTHER EXAMPLES IN CHOOSING LINES AND PAPERS

The practitioner should be aware that all decisions are not as simple as the one in Figure 3. This is best illustrated by discussing the reasoning for our paper selections for plotting data from other Walnut Gulch stations. Additional information is available on the intensity and position of particular storms on these experimental watersheds. Such input, not usually available to one analyzing simply runoff maxima, can aid in decisions concerning the largest flood. For example, the 4,000 cfs discharge plotted about 1,200 cfs above the line on LN paper in Figure 5b. The precipitation associated with this storm was not extraordinary. With the LEV paper,  $P_e = 0.04$  is spaced further to the right and the point plotted nearer to the line.

The largest and second largest floods in this series deviate +400 and -300 cfs from the LEV line, versus +1200 and -200 cfs from the LN line. This consideration, plus recognition of improved linearity for all floods of  $P_e < 0.7$ , led us to accept LEV as providing the best distribution investigated for this watershed in Figure 5. Thus,  $Q_{100}$  is acceptably estimated as 7,800 cfs on LEV paper as compared with the unacceptable estimate on LN paper of  $Q_{100} = 4,250$  cfs. The far less acceptable slightly J-shaped plot on EV paper would incorrectly give  $Q_{100} = 3,400$  cfs, only 85 percent of an event that occurred in 15 years.

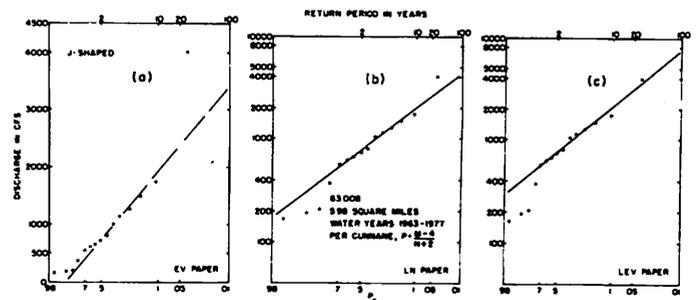


Figure 5. Best Distribution of Large Floods (LEV) Gives  $Q_{100}$  Almost Double That From Second Best (LN) Paper.

Another characteristic often noticed with desert flood series shows in all three plots in Figure 5. The three smallest annual maxima seem to be separated from the trend of larger floods by a drastic drop in discharge. The analyst should also notice that relative opening up of flood scales on LN and LEV paper accentuates the apparent separation of these very small floods. A possible explanation of this departure may be that the small diameter intense storms often only produce runoff from the upper portions of this eight-mile long, narrow watershed. Transmission losses reduce the runoff peak discharge as the

flow traverses the dry alluvial bed. Other storms cover more of the watershed or follow prewetting of the sand channel, and they result in larger peak discharges for similar size precipitation events. Whether stock watering ponds were empty or full before the rain storm may influence floods observed downstream. Table 1 shows that pond storage is significant on some of these watersheds. These factors and their significance to flood frequency will be investigated by the authors in the future.

Observed floods in Figure 6 are clearly not EV distributed. A line has been drawn on this paper simply to facilitate detection of the slight but consistent J-shape. Neither the LN nor LEV paper present a clear choice for the best distribution. The LEV paper may have a slight advantage, because floods with a  $P_e < 0.4$  scatter around the line somewhat less, and in a more alternating fashion. From the LEV graph,  $Q_{100}$  is 13,700 cfs rather than  $Q_{100} = 9,700$  cfs that would have resulted from following exactly the three largest observations on LN paper.

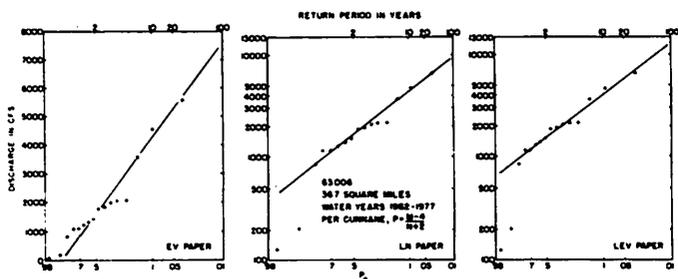


Figure 6. Unclear Choice of LEV Paper Over LN Paper.

Figure 7 is best interpreted by consulting Figure 4. The S-shape plot on EV paper suggests (the first row of column two) that the population could be LN. This explanation is also substantiated because the LEV paper plot drops off steeply from its plateau as  $P_e$  exceeds about 0.15 as it does in row 1, column 3 of Figure 4.

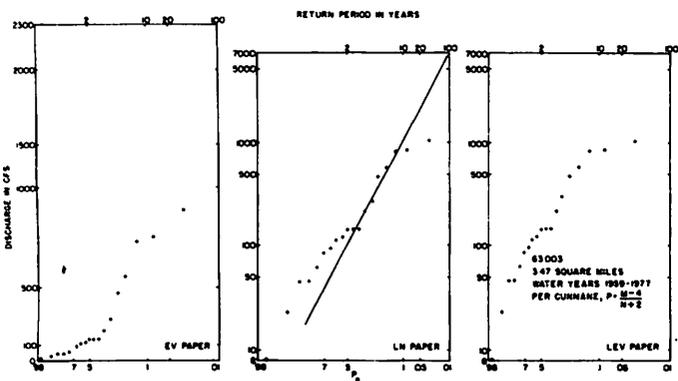


Figure 7. Instance Where Figure 3 Assists With Unclear Choice.

The same flattening of the three plots in Figure 7 can be found on the bottom row of Figure 4, which suggests the unknown distribution was Weibull. No such paper has been prepared by PCFCD, so this means that achieving absolute linearity could not be tested. We must be satisfied that, for floods with  $P_e < 0.5$ , all but the largest two events form a reasonable line on LN paper. The dearth of large storms in the desert could well result in one small watershed's 19-year record being deficient in a large flood, whose return period was about 40 years. By chance, the second smallest event from this time series of annual peak discharges could also have a return period of almost 13 years. This rationalization, however, does not answer the constant curvature implied by the seven larger floods on this watershed. In fact, this example provides an incentive to prepare compatible Weibull paper to use when suggested by Figure 4. However, we must make a tradeoff to hold down the number of different plots prepared with each data set.

SOME SAMPLING PROBLEMS WILL ARISE

Instances may be encountered when the flood series data exhibit linearity on more than one probability paper. This may further complicate the choice of the most suitable probability distribution, as in Figure 8. On the LEV paper,  $Q_{100}$  is 8,400 cfs. The distribution on LN paper appears slightly more linear, and  $Q_{100}$  is 7,600 cfs. Most interesting is the fact that EV also provides a satisfactory line, especially when the absolute deviation (in cfs) of points from the straight line is considered. The EV distribution indicates  $Q_{100}$  is 7,400 cfs. The three values are probably well within the confidence limits for the estimates. The closeness of these three estimates illustrates that if good visual fits to the larger one-third of the data are obtained on any type paper, then paper choice does not drastically influence graphical determination of  $Q_{100}$ . In contrast, least squares fitting of the same mathematical distributions to all the data give  $Q_{100}$ 's of 61,460, 20,403, and 7,821 cfs, respectively, for the LEV, LN, and EV models. Theoretical Log Pearson III calculation gives  $Q_{100} = 5,508$  using sample skew, and  $Q_{100} = 17,322$  cfs with a regional skew of  $-0.2$ . The largest observation in 20 years was 6,060 cfs, although bridge damage records for a railroad bridge upstream from the station indicated three large floods occurred between 1900 and 1960.

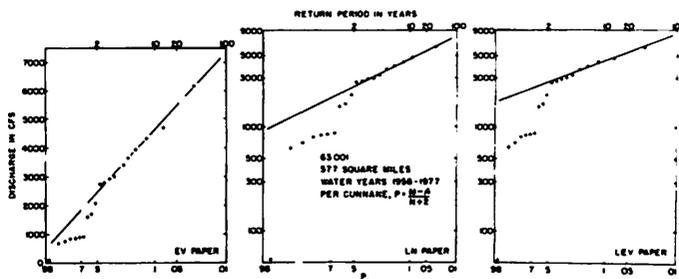


Figure 8. Good Eye Fits of Largest Floods Can Give Similar  $Q_{100}$ 's on All Probability Papers.

Lest we create the impression that plotting a flood series is always a panacea, Figure 9 will show otherwise. These 12 annual flood peaks were measured on another Walnut Gulch watershed with the same accuracy as the other series we have discussed. Trouble arises because the record period is undoubtedly too short to establish a trend that may be extrapolated for accurate prediction of  $Q_{100}$ . The six smaller floods observed on this watershed were an order of magnitude below the two major events measured. It is unsound to use such small events to predict large floods which result from different hydrologic and hydraulic mechanisms. These small discharges in the toe of the J-shaped EV paper plot should be disregarded. The six largest floods scatter unsatisfactorily about the line on EV paper, which intersects the 100-year scale at 4,800 cfs.

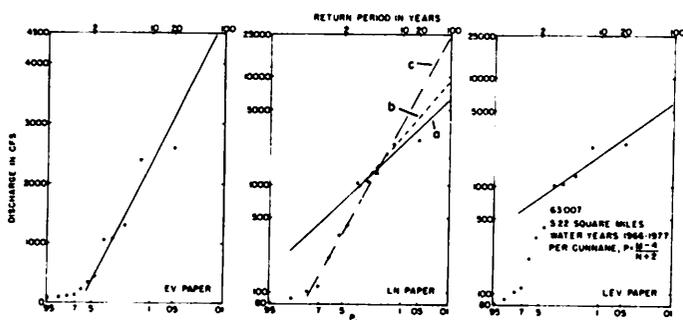


Figure 9. Some Short Records Make Flood Frequency Estimates Impossible.

The logarithmic transformations in Figure 9 do not produce perfect linearity of the five largest floods on either LN or LEV papers. Nevertheless, they do produce a flattening of the large floods and a separation from the smaller events, in a similar fashion to Figures 8, 6, 5, and even 3. Adding such prior regional knowledge to Figure 9 may lead the analyst to the eye fit on LEV paper, which results in selecting  $Q_{100} = 6,600$  cfs. The choice of LEV paper is also suggested because it proved best for the other four Walnut Gulch watersheds. The very short series plotted in Figure 9 gave such a poor fit with LEV paper that line "a" on LN paper may give a very similar  $Q_{100}$  of 6,100 cfs. Of course, a more conservative estimate is line "b" on LN paper which gives  $Q_{100} = 8,500$  cfs. Without excusing such bias, the estimate lies within confidence bands (Reich, 1976) that would encompass a mathematically fitted line.

Another LN paper line, "c," has been added to Figure 9 for the sake of discussion. It is a fair fit to eight floods comprised of some large floods and all but the smallest of the smaller floods. Its estimate of  $Q_{100} = 22,000$  cfs is entirely disregarded because line "c" attempts to fit almost all floods, and disregards the fact that floods with  $P_e < 0.4$  have a different trend than those with  $P_e > 0.4$ . This mechanical process of average fitting to all data, rather than understanding where

bimodal distributions may be suggested by frequency plots and substantiated by hydrologic process, is inexcusable when one is applying judgment and understanding of physical systems rather than computer calisthenics.

NONONO

The consequences of playing blind man's bluff with computerized curve fitting to floods has been discussed elsewhere (Reich, 1973, 1976, 1977, 1978). An example illustrates how computers generated "Numerical Output Neither Omnipotent Nor Optimum," whence the acronym titling this section. Data from a 24-year record for a 9.24 square mile watershed are plotted on both LN and LEV papers in Figure 10. The EV plot is not shown because it exhibited a clear J-shape. Linearity was best with LEV paper, which indicated  $Q_{100} = 11,000$  cfs. The Log Pearson Type III (LP) curve, using the skewness from the station data, is steep for low discharges, and tends to flatten towards the right. This occurred because the fitting with the method of moments was strongly influenced by the four smallest observations. The result is a  $Q_{100} =$  about 3,000 cfs. This is smaller than two floods that actually occurred within 24 years of record. Suggestions (WRC, 1977) to overcome problems have included the substitution of a mapped regional skewness value. The result of such a computation is shown dashed on the LN paper. This blind mathematical fitting with the LP, even using the regional skew, overpredicts  $Q_{100}$  by a factor of two as compared to the good eye fit on the LEV paper.

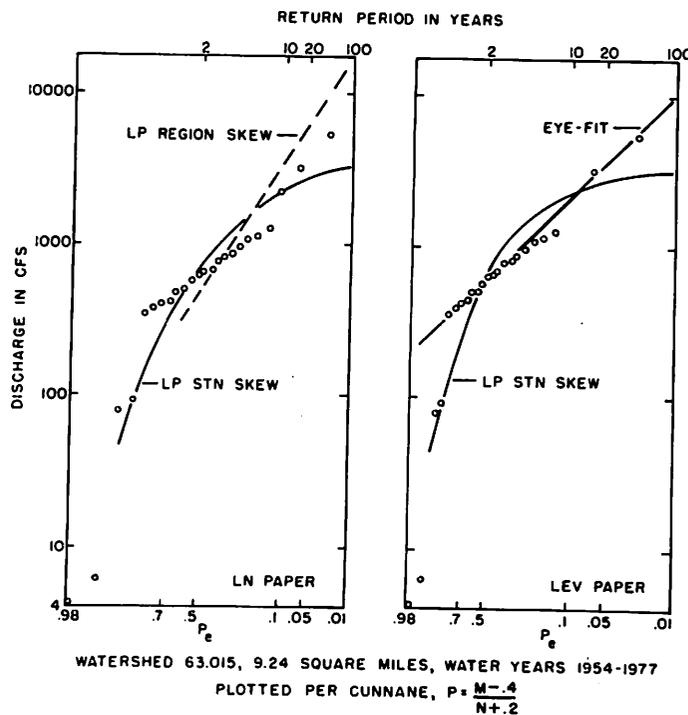


Figure 10. Illustration of Mathematical Curve Fitting That Conflicts With Common Sense (NONONO).

## CONCLUSIONS

Flood frequency analyses can be completed using computer programs which are widely available. Serious errors can be produced by blindly accepting such results. Our analysis suggests:

(1) Use of the frequency paper developed by the Pima County Flood Control District with compatible scales facilitates the visual interpretation of observed flood series.

(2) The Cunnane plotting position is superior to the more widely used Weibull equation, having a mathematically sound basis for locating observed floods on an assumed probability.

(3) Graphical display of observed flood series assists in the selection of a probability distribution which allows extending relatively short flood series with a straight line. The assumption of an incorrect distribution and extrapolation with mathematical modeling can lead to serious errors in selection of a flood design value, such as the 100-year flood.

(4) The more infrequent floods may constitute a separate set from the more frequent floods. In ephemeral streams, this is due to the combined effects of (a) runoff producing storms covering only a portion of the contributing area; (b) of transmission losses in the normally dry streambed, which may reduce the flood peak; and (c) of some runoff being stored in stock water ponds which, therefore, leads to partial area runoff. Thus, graphical interpretation can be used to assist with such an evaluation.

(5) The use of comparative probability plots on different types of probability paper, such as that developed by King, can assist hydrologists in choosing a probability distribution that will allow extrapolation of the flood series to select a reasonable design storm.

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