Kates, R. W., 1962, Hazard and Choice Perception in Flood Plain Management, University of Chicago, Department of Geography Research, Paper No. 78.

CHAPTER IV

PROBABILITY AND HAZARD EVALUATION

In each of the towns it is possible to discern the current information on flood hazard and how it is evaluated or, in the framework of decision theory, the conditions of flood knowledge.

The flood hazard information of each manager is compounded of experience and knowledge, and such information, or the lack of it, is known to be related to some perceived probability distribution of flood hazard. This relation, however, does not appear to be a simple one. In each town the possession by individuals of what appears to be similar information does not result in either similar perceptions of hazard or of desirable behavior.

To help account for the variation in perception and behavior, it is hypothesized that individuals behave as if they possess some underlying perception of the state of nature and that this perception aids in an interpretive process through which information is transformed into a personal evaluation of flood hazard.

Concretely, this chapter will examine for the six study sites, the quantity and quality of information available in both the common and technical variants of knowledge, the perceived distributions of future flood hazard, and the implications of such information for choosing between alternative measures of flood damage reduction.

Information and Flood Hazard Evaluations in LaFollette

The elements that are subsumed under the title of information can be described in a variety of ways. This study will specify two such elements, knowledge and experience, and in such broad terms as to include all the variety of information available to respondents.

Common knowledge and experience.--A knowledge of floods in LaFollette describes that part of the spectrum of information ranging from a rudimentary awareness of flood events to a detailed knowledge of LaFollette's flood history. In acquiring such knowledge, a respondent might have been exposed to a variety of channels and messages ranging from an informative neighbor to a detailed exposition of flood problems presented to members of the Planning Commission.

Experience is that element of information that describes the presence of the manager's establishment on the flood plain during the passage of a major flood. It implies physical presence only and not that the manager's establishment was necessarily damaged or even inundated.[1]

The range of information in LaFollette.--The existence of floods as natural phenomena is widely known, with only 8 of 109 respondents not sharing in such common knowledge (see Table 7). Almost half the respondents had personally experienced the flood of May 1950, and for these at least, such experience implied knowledge, that is, no respondent who experienced a flood in LaFollette (by the presence of his establishment on the flood plain) failed to display at least a rudimentary awareness of the passage of a flood event.

The expectation of a future flood.--However widely flood hazard information is distributed in LaFollette, its possession does not imply a personal awareness of flood hazard in the sense of a danger to person or property, or even the expectancy of a flood in the future.

The simplest and most reliable estimate of hazard evaluation obtained from respondents, the expectancy of a future flood, was in reply to the following question: "Do you think that you will have, or there will be, another flood while you are (in business) (living) here?"

The answers to the question, classified as yes, no, and uncertain, are shown in Table 7. A substantial reluctance to make even a simple dichotomous estimate of flood expectation might be noted. With considerable probing, the uncertain category had been reduced to twenty-four respondents, who represent two types of uncertainty. The first type of uncertainty, verbalized as "I just don't know," reflects a genuine puzzlement as to the future. The second type of uncertainty, verbalized by "You just can't tell what's going to happen," reflects not merely puzzlement, but doubt as to the predictability of the future.

Table 7 suggests that the expectation of a flood in the future is associated with a higher order of information and, as an individual moves up a knowledge-experience scale, his likelihood

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[1] A further distinction is made between experience onsite at the present location of an establishment and experience elsewhere at locations outside the LaFollette flood plain or at locations on the flood plain not comparable to the present site, but subject to flooding.

TABLE 7

INFORMATION AND FUTURE FLOOD EXPECTANCY IN PERCENTAGE OF COMMERCIAL AND RESIDENTIAL RESPONDENTS

Information	Commercial (71 Respondents)				Residential (38 Respondents)				Total (109 Respondents)			
	% Future Flood Expectancy				% Future Flood Expectancy				% Future Flood Expectancy			
	Yes	No	Uncer-tain	Total	Yes	No	Uncer-tain	Total	Yes	No	Uncer-tain	Total
No knowledge No experience	....	5.6	1.4	7.0	....	2.6	....	2.6	....	4.5	0.9	5.4
No knowledge Experience elsewhere	....	....	....	....	....	2.6	2.6	5.2	....	0.9	0.9	1.8
Knowledge No experience	8.4	11.2	9.8	29.4	5.2	18.4	2.6	26.2	7.3	13.7	7.3	28.3
Knowledge Experience elsewhere	5.6	8.4	1.4	15.4	7.8	....	5.2	13.0	6.4	5.5	2.7	14.6
One experience Onsite	22.5	5.6	5.6	33.7	10.5	21.0	10.5	42.0	18.3	11.0	7.3	36.6
Two or more experi-ences onsite	11.2	1.4	1.4	14.0	5.2	....	5.2	10.4	9.1	0.9	2.7	12.7
Total	47.7	32.2	19.6	99.5	28.7	44.6	26.1	99.4	41.1	36.5	21.8	99.4

for an affirmative future flood expectation increases. However, such association, while statistically significant for the commercial and total group of respondents, is relatively weak when measured by a variety of appropriate correlation measures, and is apparently lacking in the residential group.[1]

The differential measure of association between information and future flood expectancy for the commercial and residential respondents can be ascribed in part to their qualitative differences in experience. Though the number of individuals in each group who recalled having suffered any damage in the 1950 flood was roughly proportional to the respective group size, the eleven individuals suffering substantial damage (in excess of $150) were all commercial respondents. Ten of these eleven had affirmative future flood expectations. Other commercial respondents, who may not have suffered monetary damage, expended considerable effort in flood fighting during the 1950 flood and this action might have added to the impact of their experience. The differences in socio-economic status between the groups that were discussed in the previous chapter would appear to little influence contrasts in future flood expectancy; the various measures of socio-economic status including age, income, and education showing no apparent association with future flood expectancy.

In considering the total response, it is clear that despite the widespread minimum level of knowledge displayed in

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[1]In this volume, a statement that an association is statistically significant implies that such association (when measured by chi-square, representing the sum of the differences between the observed distribution and one that might be expected if there was no association between the variables in question) had but one chance in twenty or less of arising purely by sampling variability or chance (.05 level of significance).

In the example being considered, a condensation of Table 8 into a 3 x 3 contingency table results in a measure of association significant at a level that allows but one chance in a hundred (.01 level of significance) that the apparent association between information and future flood expectancy for the commercial and total respondent groups arose as a result of sampling variability or chance. For the residential group the chance is in excess of one chance in twenty and not significant.

A statistical test of significance is primarily a measure of the presence or absence of a relationship. The strength of such relationships can be measured by correlation statistics based on chi-square, such as Tschuprow's T in the case of 3 x 3 tables, and ϕ for a 2 x 2 condensation of Table 7. The values of these measures range from .24 to .40, the largest value being the value of ϕ for the 2 x 2 table associating onsite flood experience and affirmative expectations. It should be noted that while these measures are analogous to more common correlation measures, taking on the values of 1.0 for a perfect relationship and 0.0 for the absence of any relationship, the interpretation of the non-extreme values leaves something to be desired.

LaFollette, almost 60 per cent of the respondents either fail to perceive a personal flood hazard or are uncertain. It would further appear that, although the propensity to perceive such hazard is heightened by flood experience and particularly either repetitive experiences or those entailing personal loss or effort on the part of the respondents, some 24 of the 54 managers experiencing a flood fail to anticipate another experience or are uncertain. A precise understanding of the way managers evaluate flood hazard requires more than the simple specification of their knowledge and experience.

It seems likely that between the common knowledge (or even experience) of a flood event and the expectation of other such events in the future a process that might be conveniently called _interpretation_ takes place. _Interpretation_ describes that process whereby information is referred to an individual's underlying perception of the state of nature, and is assimilated in a unique personal way.

While interpretation may help explain the relationship between flood information and flood hazard evaluation, it is not suggested that the writer really knows that such a process takes place, but only that the verbalizations and actions of the respondents are those that one might logically infer as being consistent with it.

The variety of interpretations that might follow from several perceptions of the state of nature and how these are related to hazard evaluation will occupy much of this chapter. However an examination of the interpretation of the respondents in LaFollette might be enhanced by the prior consideration of the perception of the state of nature held by the possessors of technical knowledge and the kinds of hazard evaluation they might make.

A Technical Perception of the State of Nature

One kind of hypothetical perception of the state of nature can be illustrated by reference to a favored model for probability illustration and experiment; the balls of varying color or size in the well-mixed urn. It is hypothesized that nature has filled the urn with a large number of balls representing future annual floods and the volume of each ball is proportional to the peak discharge of such floods.[1] The exact distribution of the

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[1]A _peak discharge_ is the largest momentary volume of water passing a point along a stream and is generally expressed as cubic feet per second, abbreviated cfs. An _annual flood_ is the largest peak discharge in a water year. A _water year_ is the twelve-month period commencing on October 1st of each calendar year.

balls is unknown, but one is conscious that a niggardly or capricious nature has filled the urn with a great many more smaller balls than larger ones.

The contents of the urn are not immutably fixed and may be changed by the actions of men, the size of the balls being altered, but the process is viewed either as uncertain or requiring great effort. In this analogy, the annual flood for any given year is found by reaching into the well-mixed urn and drawing a ball, the choice being random and independent of any other. A sequence of such draws might be conceived as a sample of the urn or the historical record of floods at a point, similar to the records presently available from some 7,000 sites in the United States.

Given this simplified perception of nature, three general problems may be distinguished that have caught the imaginations of engineers, hydrologists, meteorologists, statisticians, and mathematicians. They are:

1. Given a very large urn, and the relatively short life of man, what may be safely inferred from the small samples that represent his prior experience as to the contents of both the urn and future samples to be drawn from it?

2. Is it feasible to define the volume of the largest and smallest balls in the urn?

3. Can a basic underlying mathematical distribution that would describe the contents of the urn be hypothesized on an _a priori_ theoretical basis?

The three questions are not unrelated and for some researchers reflect only differences in emphasis. At the risk of doing considerable violence to hydrology's hard won body of knowledge, as well as to the many divergent views in the field, some answers might be suggested by a brief survey of the present state of the art.

The sampling inference problem.--The record of past occurrences of floods is the best guide to the shape of the total distribution and predicting the composition of future samples. However, extrapolation beyond the predictive power of small samples is fraught with uncertainty. A recent study by M. A. Benson provides some measure of that uncertainty. Benson found that it would take at least a 39-year record to define the magnitude of a fifty-year flood (probability of occurrence in any year .02) within ± 25 per cent accuracy, 95 per cent of the time. To increase such accuracy to within ± 10 per cent accuracy, 95 per cent of the time, would take a record of 110 years.[1]

A number of techniques have been designed to reduce the uncertainty connected with flood magnitude-frequency analysis. Many of these are found in the current practice of the U.S. Geological Survey, which includes the following:[2]

1. Extending records backwards in time by historical research.

2. Utilizing the mathematical distribution of extreme values as developed by Gumbel as a framework in which to place small samples. However, the USGS relies on its actual observations where they do not plot according to the theory of extreme values.

3. Improving the estimating power of small samples by the pooling of records in homogeneous regions.

4. Limiting extrapolations to probabilities of .02 or .01.

5. Using graphical rather than arithmetical procedures to minimize the effect of extreme events in short records.

The application of sampling-inference techniques to the LaFollette flood data.--In the brief discussion of LaFollette flooding contained in the previous chapter, it was noted that Big Creek had flooded severely twice within the memory of local residents and that there was no provision for the systematic recording of streamflow. This poses one of the more difficult examples of the sampling inference problem; the need to make inferences without an actual sample.

While LaFollette lacks a stream gage, there are some 26 gages operated on the Cumberland Plateau, an area whose edge forms LaFollette's watershed. It is from the pooled relationships of these gages that a prediction of the discharge-frequency relationship of Big Creek can be made. The rationale for doing so is the following: Over fairly extensive areas, physiographic variables and drainage area size can be related empirically to a measure of the central tendency of flood flows, the mean annual flood.[3] The mean annual flood serves as an index flood related,

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[1]M. A. Benson, "Characteristics of Frequency Curves Based on a Theoretical 1,000 Year Record," Flood-Frequency Analysis (Washington: U.S. Geological Survey Water Supply Paper 1543-A, 1960), p. 64.

[2]Dalrymple, Flood-Frequency Analysis, pp. 1-48; M. A. Benson, Evolution of Methods for Evaluating the Occurrence of Floods (Washington: U.S. Geological Survey Water Supply Paper 1580-A, 1962), pp. 16-23.

[3]The mean annual flood is the arithmetical average of annual floods or the graphic average represented by a flood with

by dimensionless ratios, to a whole series of floods of varying magnitude and frequency. The relationship of magnitude (expressed as a ratio to the mean annual flood) to frequency (expressed as a return period or recurrence interval in years) is also constant for large areas. For Tennessee, one such curvilinear relationship for all small streams in the state has been derived.

The discharge-frequency curve plotted on extreme value probability paper and labelled USGS on Figure 4 was derived in this way. From the 26 gaging stations the mean annual flood was defined as:

$$\text{Mean annual flood} = 170\ \text{Drainage Area}^{.77}$$

For LaFollette the USGS calculates its value at 1,950 cfs. The relationship of magnitude (expressed as a ratio to mean annual flood) to frequency (recurrence interval) completes the data for the plot.[1]

The plot illustrates well the USGS policy for minimizing uncertainty. The discharge-frequency curve is laid out on extreme value paper, but curvilinear and more in keeping with the data than the theory. The curve represents the pooling of homogeneous records but is projected only to fifty years, even though the discharge of the fifty-year flood so determined is actually considerably less than the two observed LaFollette floods.

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a return period of 2.33 years when plotted on extreme value probability paper, that being the return period for the mean of the distribution. The return period or recurrence interval is a measure of frequency and is the long-run average interval of time within which a flood of a given magnitude will be equalled or exceeded once. It is thus the reciprocal of the probability of equalling or exceeding such a flood in any year.

An important assumption of annual flood methods might be noted here. By definition annual floods are derived using only the largest peak in any year and infrequently omit second and third largest peaks that are actually larger than many of the annual peaks.

This objection might be overcome by the use of a partial duration series in which all floods greater than some base are listed. This method also provides problems particularly in defining the independence of consecutive flood events.

A relationship between the two methods has been shown to exist by Walter B. Langbein in "Annual Floods and the Partial-Duration Series," *Transactions of the American Geophysical Union*, XXX (1949), 879-881; where the differences in recurrence interval appears to diminish for large floods.

[2]The actual plot of frequency-discharge was received by personal communication from the Tennessee District of the U.S. Geological Survey. The methods used in its computation are fully described in Clifford T. Jenkins, *Floods in Tennessee, Magnitude and Frequency* (Nashville: State of Tennessee, Department of Highways, 1960), pp. 26-35.

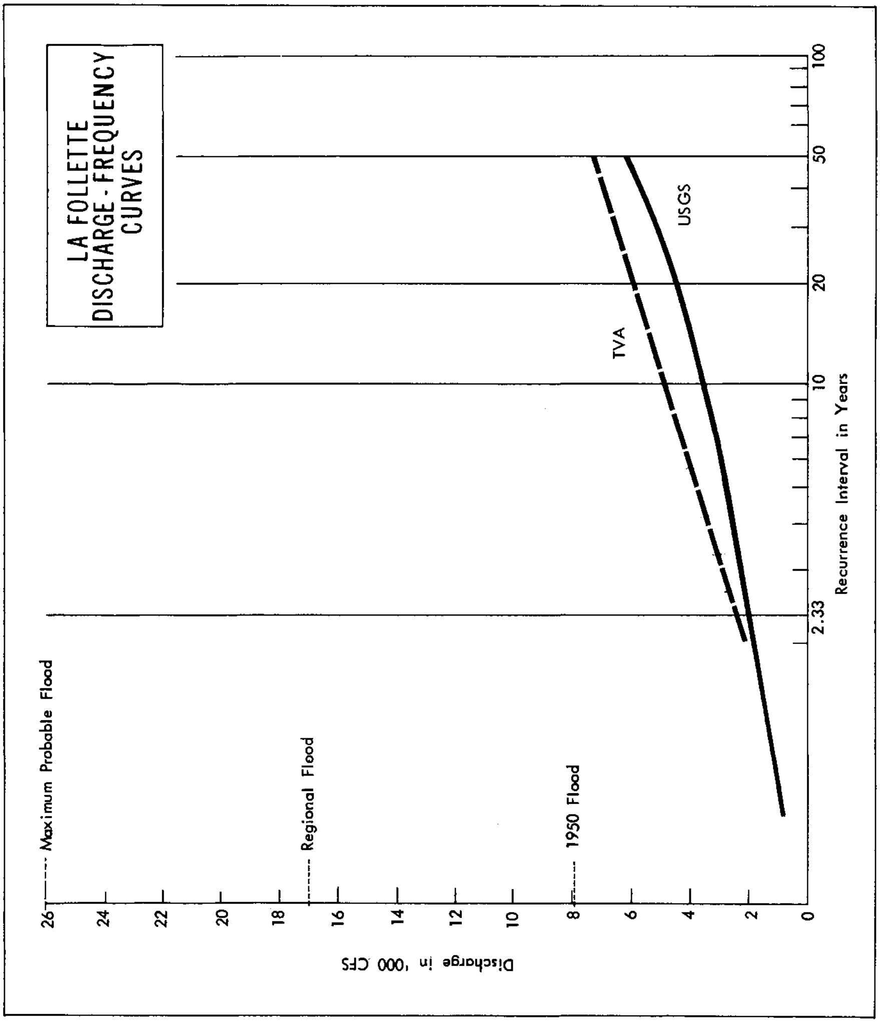
LA FOLLETTE
DISCHARGE-FREQUENCY
CURVES
Maximum Probable Flood
Regional Flood
1950 Flood
TVA
USGS
Discharge in '000 CFS
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Recurrence Interval in Years
2.33
10
20
50
100

Fig. 4

The problem of defining the extreme of extremes.--There have been three main approaches developed for the problem of defining the extreme of the extremes, or more practically defining a maximum probable or possible flood. They are:

1. Assume that the magnitude of the largest possible flood is finite and bounded by some theoretical limit of the energy exchange of earth and atmosphere over the watershed.[1]

2. Assume that the magnitude of floods is infinite, but asymptotically so, and that operationally the magnitude is limited by the shape of the asymptotic distribution.

3. Ignore the question of the finite vs. infinite assumption and try to define a maximum probable flood by the pooling of analogous records, transposition of storms, and the like.

The application of extreme of the extreme techniques to the flood data at LaFollette.--The floods that the Tennessee Valley Authority suggests might be reasonably expected at LaFollette even though they have not as yet occurred are illustrative of the third approach to defining the extreme of the extremes. The TVA identifies in its flood reports two such floods; a regional flood and a maximum probable flood.[2] The regional flood is ostensibly derived from a study of extreme floods that have occurred in a region similar to LaFollette. The floods used to estimate the regional flood for Big Creek are shown on Figure 5 by drainage area size and discharge. All are from observations within 110 miles of LaFollette and drain the Cumberland Mountains. A set of floods and storms for a larger area is considered in estimating the maximum probable flood and this includes "floods that have occurred elsewhere but could have occurred in the LaFollette area." These too are shown on Figure 5. (The discharge of the estimated regional and maximum probable flood is also shown without frequency on Fig. 4 for comparative purposes.)

Considerable engineering judgment appears to have been employed in the actual estimation of the regional and maximum probable floods. An envelope curve, called by the TVA the "regional experience line" is identified on Figure 5. The actual estimated regional flood is some 4,200 cfs. below such a line (17,000 cfs.) and the estimated maximum probable flood is some 4,200 cfs. above the line (26,000 cfs.). It might be noted also that the regional

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[1]Herbert Riehl and Horace R. Byers, "Computing a Design Flood in the Absence of Historical Records," Geofisica Pura E. Applicata, XLV (1960), 3-14.

[2]All of the following flood data are from TVA, Floods on Big Creek, pp. 24-33.

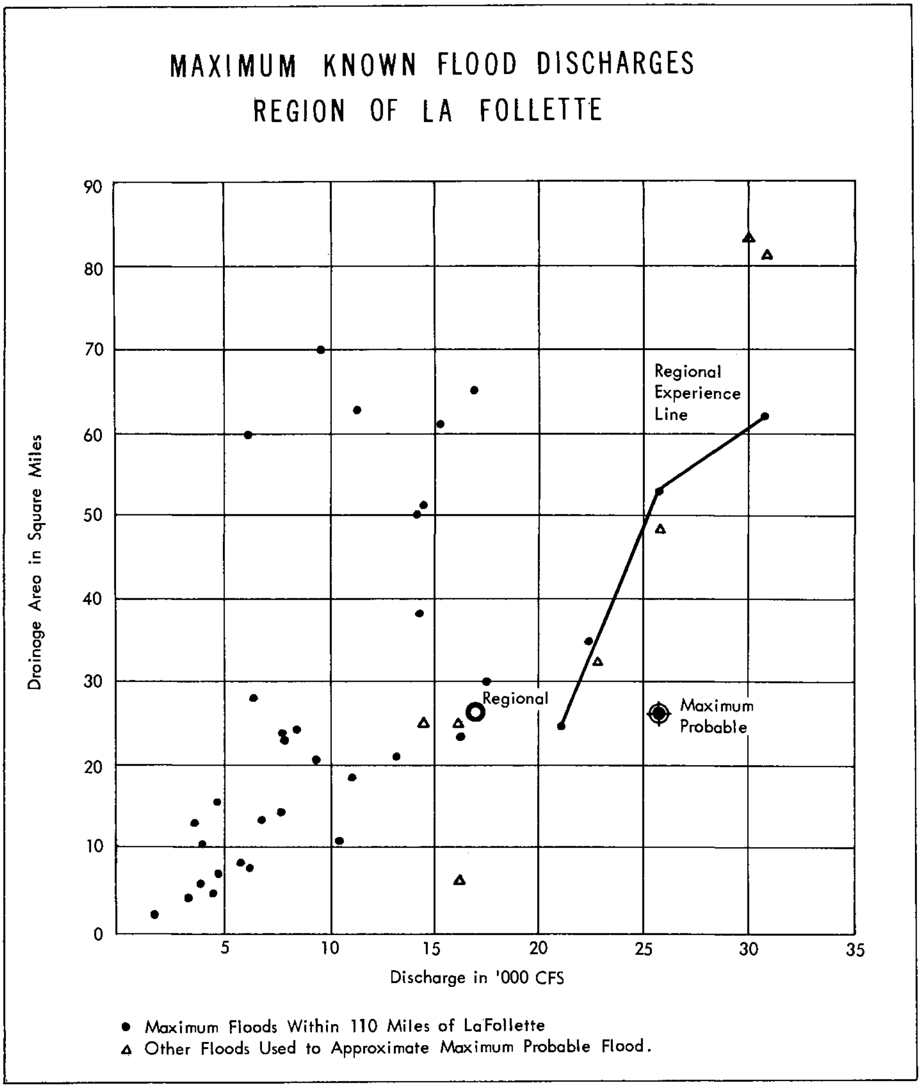
MAXIMUM KNOWN FLOOD DISCHARGES
REGION OF LA FOLLETTE
Drainage Area in Square Miles
Discharge in '000 CFS
0
10
20
30
40
50
60
70
80
90
5
10
15
20
25
30
35
Regional Experience Line
Regional
Maximum Probable
● Maximum Floods Within 110 Miles of LaFollette
▲ Other Floods Used to Approximate Maximum Probable Flood.

Fig. 5

experience line would give a good fit to all the non-regional floods ostensibly considered in defining the maximum probable flood except for the truly outstanding flood at Moorehead, Kentucky in 1939 (not shown on Fig. 5).

The problem of identifying an underlying distribution.--For many streams, an array of observed annual flood peaks closely corresponds to those predicted by the theory of extreme values.[1] When such an array is plotted on the special probability paper constructed on the basis of the theoretical distribution of extreme values, it tends to plot as a straight line relation between magnitude and frequency and the extrapolation of such a line enables one to predict the magnitude and frequency of floods greater than have been previously recorded.[2]

For many streams a straight line plot of observed floods may be at best an approximation and at worst a distortion of what is essentially a curvilinear plot. One can either ascribe such variance to the inadequacy of the theory or the violation of the independence of events assumption, error of measurement, random sampling variability, and the like.[3]

While confidence bands can be constructed around a straightline plot of magnitude and frequency, the range of magnitude for floods of rare frequency becomes so great as to render such a range worthless for predictive purposes.

The application of an extreme value distribution to the LaFollette flood data.--By personal request, and not as common practice of its flood information program, TVA prepared a discharge-frequency plot for Big Creek. The result is quite similar to the USGS plot.[4] (See Fig. 4.) The TVA mean annual flood is some 500 cfs. greater, but there is reason to think that a drainage area 2.3 square miles larger measured downstream from LaFollette was used in the TVA calculation. The major difference is

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[1]An introductory discussion of extreme value theory may be found in E. J. Gumbel, Statistical Theory of Extreme Values and Some Practical Applications (Washington: U.S. National Bureau of Standards Applied Mathematics Series No. 33, 1954).

[2]Figs. 4 and 6 are examples of extreme value probability paper with an arithmetic ordinate of discharge and an abscissa of probabilities derived from an extreme value function and expressing flood frequency either as an average recurrence interval (return period) or annual probabilities of a flood of given magnitude being equalled or exceeded.

[3]Benson, Evolution of Methods . . . , p. 9.

[4]Personal communication from the Tennessee Valley Authority, Local Flood Relations Branch, July 25, 1961.

the TVA use of a straight line plot, an assumption implying that in the limited range of frequency shown (50 years) the extreme value distribution is the best guide to the discharge-frequency relationship.

Accompanying the TVA and USGS plots come cautions that they are not to be extrapolated further. If for reasons to be discussed in the following section, one must throw caution to the wind, the minor differences observable in this range between straight and curvilinear plots take on considerable significance.

Technical Flood Hazard Evaluations

In the previous section, it was shown that technical and scientific personnel seem to share a common perception of nature, but often choose somewhat different techniques in seeking to reduce the uncertainty related to probability distributions of flood hazard.

The problems of sampling and inference, defining the extremes of the extremes, and the underlying distribution of flood events are challenging as abstract scientific questions. Solutions to these problems also bear directly on practical matters. In the work-a-day world a narrow but existent line is crossed between scientific enquiry into the nature of probability distributions of flood events and the evaluation of flood hazard with special constraints of time, money, and penalty for error. In short, hazard evaluation, while resting strongly on the shared perception of nature, and mathematical and hydrologic theory, introduces another series of factors related to the perceived hazards arising from floods and the skills and purposes of the organization or individuals evaluating such hazard.

The use of flood hazard evaluation data.--Two general types of flood hazard evaluation are commonly made:

1. Flood hazard evaluations to be used as basic data and not oriented to some specific application. Such data are most frequently supplied by the USGS and in its region, the TVA, and then reinterpreted for a variety of purposes. However, even basic data are designed with a probable set of users in mind.

2. Flood hazard evaluations designed for specific applications, including engineering works, the planning and regulation of land use, economic analysis, flood warning, architectural flood-proofing, insurance, and the like.

Flood hazard evaluations cannot be separated from their purpose. The design of a spillway for a great dam engenders a more careful hazard evaluation than that of a highway underpass.

The penalty for error is also considered greater in spillway design, but mainly in the direction of failure, and the charge of "overdesign" is common.[1]

Basic data, with great potential for abuse, are cautiously presented. Where magnitudes of floods are estimated, magnitudes that appear to be greater than the 50-100 year frequency range, seldom is the frequency associated with such magnitudes stated in print or even estimated. In general, the range of measurement error and the degree of uncertainty vary considerably with the projected application of a hazard evaluation.

A field of research, as yet little explored, involves the real and perceived costs of error in flood hazard evaluation. The application of organization theory to research into the social and organizational pressures that influence hazard evaluation might prove useful. A case study of a flood forecast might provide a start for such inquiry.

Though there may be a multitude of sins concealed beneath the pat phrase "engineering judgment," a glaring one is the obscuring of the probabilistic framework of flood hazard evaluation. Such evaluations are derived from probability distributions, but somewhere in the process of flood hazard evaluation the concept of "engineering judgment" is often substituted for estimates of sampling variability, ranges of measurement error, or even the high-median-low format that has become common in other types of projection and extrapolation in the face of uncertainty.[2]

To be sure, faced with the great uncertainties inherent in flood hazard evaluation, the statement of ranges of error or the quantification of uncertainty is a difficult task. However, the general reluctance of engineering organizations to even attempt to specify their doubt has led to scepticism on the part of water management _cognoscenti_ as to the reliability of flood hazard evaluations, a scepticism that might be reinforced by examining some of the flood hazard evaluations of Big Creek.

The evaluations of the flood hazard of Big Creek.--Evaluations of the flood hazard of Big Creek have been made over the

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[1]Luna B. Leopold and Thomas Maddock, Jr., _The Flood Control Controversy_ (New York: The Ronald Press, 1954), pp. 147-148.

[2]When compared with other fields in which such formulations are common, one is struck by the relative conservatism of the engineering fraternity. Two reasons might be offered to account for their reluctance; the first deals with the origins of much of civil engineering in a mechanical, deterministic physics of the early 19th century, and the second, by a type of professionalism that fears the misunderstanding of the client if the engineer were to voice his real doubts, a fear which might have considerable basis in fact.

years by a number of organizations for a variety of purposes. Table 8 presents a comparative summary of such evaluations, and a brief discussion of their origins might be in order.

The evaluations of the USGS and the TVA were discussed in the previous section as illustrative of varied approaches for inferring the probability distribution of flood hazard (Table 8, lines 1 through 6, 12, 13 and 19). The estimate of the Corps of Engineers for the frequency of what is described as "damaging floods" is derived from a Letter Report of 1954 (Table 8, line 7).[1] The estimate of the Schmidt Engineering Company is from the most recent of two investigations into water supply needs for LaFollette (Table 8, lines 24 and 25).[2] The estimate of the LaFollette Planning Commission used for its floodway proposal is derived from the TVA estimate of the regional flood (Table 8, line 14).[3]

The final set of estimates of frequency and magnitude, those developed by White for the companion study's comparative economic analysis of alternative measures of flood damage reduction, deserve further elaboration.

In general these estimates were derived by using the magnitudes of three levels of floods distinguished by the TVA: the experienced 1950 flood, the regional flood, and the maximum probable flood. Frequencies were then attached to each of these discharges on the basis of four different assumptions shown in Figure 6.

The "A" assumption or "common advice" is a graphic representation of the impression of flood frequency that a LaFollette citizen might glean from published sources and conversations with interested officials. As a technical estimate it probably severely overestimates the actual flood hazard. However in its estimate of the recurrence interval of the 1950 flood (20 years) and in its approximation of the frequencies which zealous officials concerned with arousing flood awareness might attach to the larger floods, it approaches the kind of flood hazard evaluation which

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[1]Letter Report on Flood Conditions on Big Creek by Col. G. M. Dorland, District Engineer of the Nashville District, Corps of Engineers, n.d.

[2]Report on the Water Supply of the City of LaFollette, Tennessee to the LaFollette Board of Public Utilities prepared by the Schmidt Engineering Company, Inc. of Chattanooga, Tennessee, February, 1960, p. 13.

[3]LaFollette Planning Commission, "Proposals for Adjusting to Flood Conditions at LaFollette, Tennessee," October, 1959, p. 5 (processed).

TABLE 8

ESTIMATES OF MAGNITUDE AND FREQUENCY OF FLOODS USED IN EVALUATIONS OF THE FLOOD HAZARD OF BIG CREEK

No.	Magnitude			Frequency	Flood Description	Source	Purpose of Evaluation
	Discharge (Cfs.)	Drainage Area Miles^2	Discharge (Cfs./Mile^2)	Recurrence Interval (Yrs.)			
1	1,950	23.9	81.6	2.33	Mean annual flood	USGS	Basic data
2	2,500	26.2	95.4	2.33	.....	TVA	By request
3	4,780	23.9	200.0	25.	.....	USGS	Basic data
4	6,000	23.9	251.0	50.	.....	USGS	Basic data
5	6,500	26.2	248.0	25.	.....	TVA	By request
6	7,550	26.2	288.2	50.	.....	TVA	By request
7	.....	23.9	.....	20.	"Damaging flood"	Corps of Engineers	Preliminary benefit-cost analysis
8	7,900	23.9	330.5	20.	1950 A	G. F. White	Comparative economic analysis
9	7,900	23.9	330.5	30.	1950 B	G. F. White	Comparative economic analysis
10	7,900	23.9	330.5	80.	1950 C	G. F. White	Comparative economic analysis
11	7,900	23.9	330.5	80.	1950 D	G. F. White	Comparative economic analysis
12	8,000	23.9	334.7	.....	Maximum known flood	TVA	Planning & flood damage reduction

TABLE 8--Continued

13	17,000	26.2	648.8	.....	Regional flood	TVA	Planning & flood damage reduction
14	17,000	26.2	648.8	.....	Regional flood	LaFollette Planning Commission	Floodway design
15	17,000	26.2	648.8	50.	Regional A	G. F. White	Comparative economic analysis
16	17,000	26.2	648.8	200.	Regional B	G. F. White	Comparative economic analysis
17	17,000	26.2	648.8	500.	Regional C	G. F. White	Comparative economic analysis
18	17,000	26.2	648.8	30,000.	Regional D	G. F. White	Comparative economic analysis
19	26,200	26.2	1,000.0	.....	Maximum probable flood	TVA	Planning & flood damage reduction
20	26,200	26.2	1,000.0	80.	Maximum A	G. F. White	Comparative economic analysis
21	26,200	26.2	1,000.0	2,000.	Maximum B	G. F. White	Comparative economic analysis
22	26,200	26.2	1,000.0	20,000.	Maximum C	G. F. White	Comparative economic analysis
23	26,200	26.2	1,000.0	10,000,000.	Maximum D	G. F. White	Comparative economic analysis
24	14,000	13.1	1,068.7	100.	"100 year flood"	Schmidt Engineering	Spillway design
25	22,000	13.1	1,679.4	1,000.	"1,000 year flood"	Schmidt Engineering	Spillway design

Sources: Various; see text.

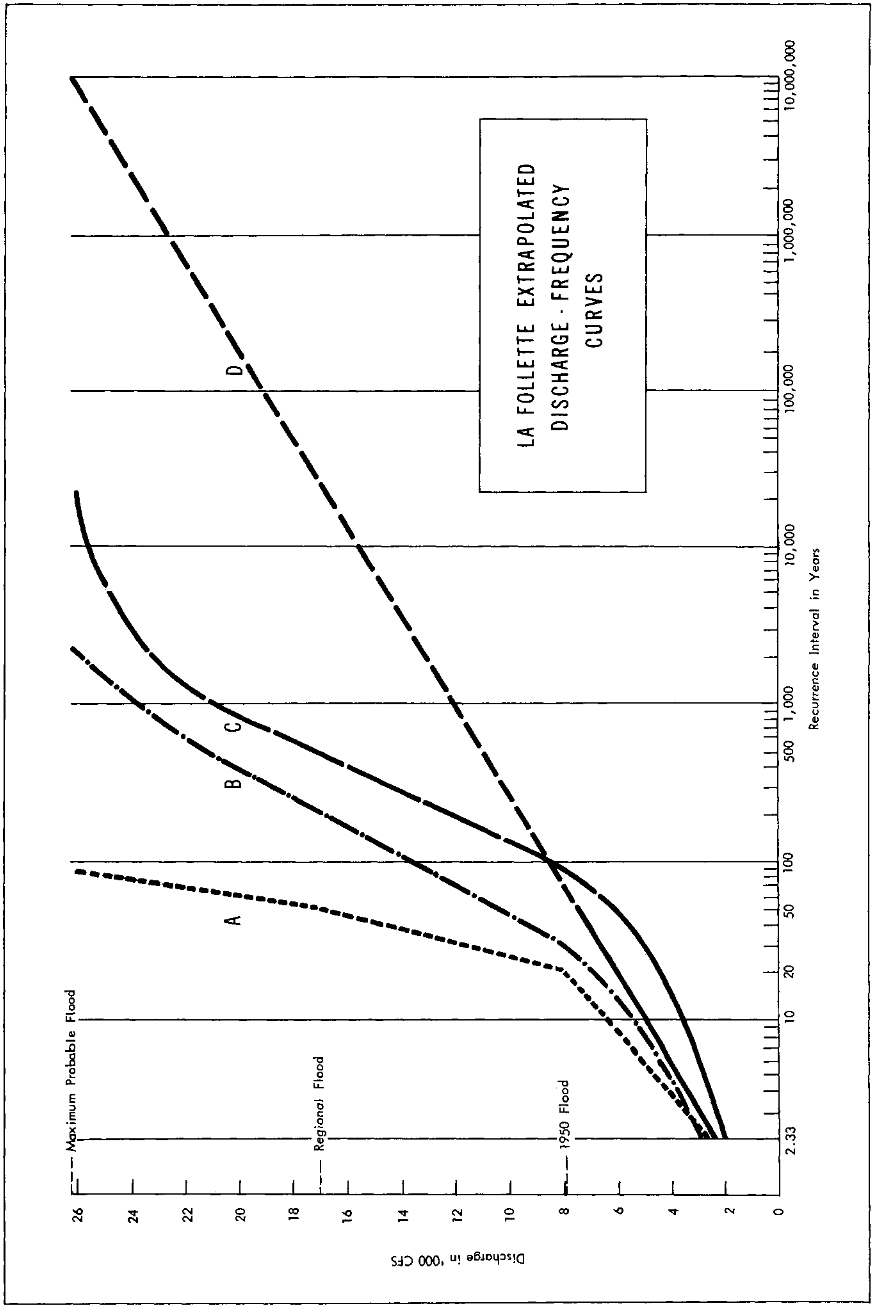
LA FOLLETTE EXTRAPOLATED
DISCHARGE - FREQUENCY
CURVES
A
B
C
D
Maximum Probable Flood
Regional Flood
1950 Flood
Discharge in '000 CFS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Recurrence Interval in Years
2.33
10
20
50
100
500
1,000
10,000
100,000
1,000,000
10,000,000

Fig. 6

might actually be used for decision-making, despite its obvious technical error (Table 8, lines 8, 15, and 20).

The "B" and "C" assumptions are derived by extrapolating curvilinear plots.

The "B" is an extrapolation of a curve constructed in a manner similar to that of the USGS in Figure 4. However it uses a larger valued constant in equation 1, which in the engineering judgment of TVA personnel, appears more suitable for Big Creek hydrology (Table 8, lines 9, 16, and 21).

The "C" is an extrapolation of the USGS curve shown in Figure 4 as an ogive or "s" shaped curve (Table 8, lines 10, 17, and 22).

The "D" assumption based on extreme value theory is to extend the TVA plot in Figure 4 as a straight line on extreme value probability paper (Table 8, lines 11, 18, and 23).

It might be recalled in connection with the last three assumptions that both the TVA and USGS warn against extrapolating their curves in such a manner. A realistic economic analysis, that would take into consideration all floods weighted by their probabilities of occurrence, requires frequencies to be attached to large floods despite the hazards of such a procedure. Though the agencies rightly caution against extrapolation, they would probably do the same or some variant thereof if called upon to make a similar economic analysis.

A comparison of flood hazard evaluations of Big Creek.--The series of flood hazard evaluations presented in Table 8 might be best compared as points in Figure 7.

Agencies and individuals using defensible logical methods arrive at estimates of greatly varying frequency for the same magnitude flood. When one considers the great uncertainty involved, such results are understandable. Generally such uncertainty is understated and what is in effect a "guesstimate" or in terms of probability theory a "degree of belief" is often stated as a fact.[1] An extreme example is the following quotation from the report of the Schmidt Engineering Company:

> Ollis Creek runs in rugged terrain with reasonably fast runoff and approximately 50 inches of rain per year. A record month of 14.51 inches of rain occurred at the LaFollette gaging station in May 1950. Because the valley channel is narrow, one of the physical problems to overcome in constructing a dam is to provide adequate spillway capacity. For a

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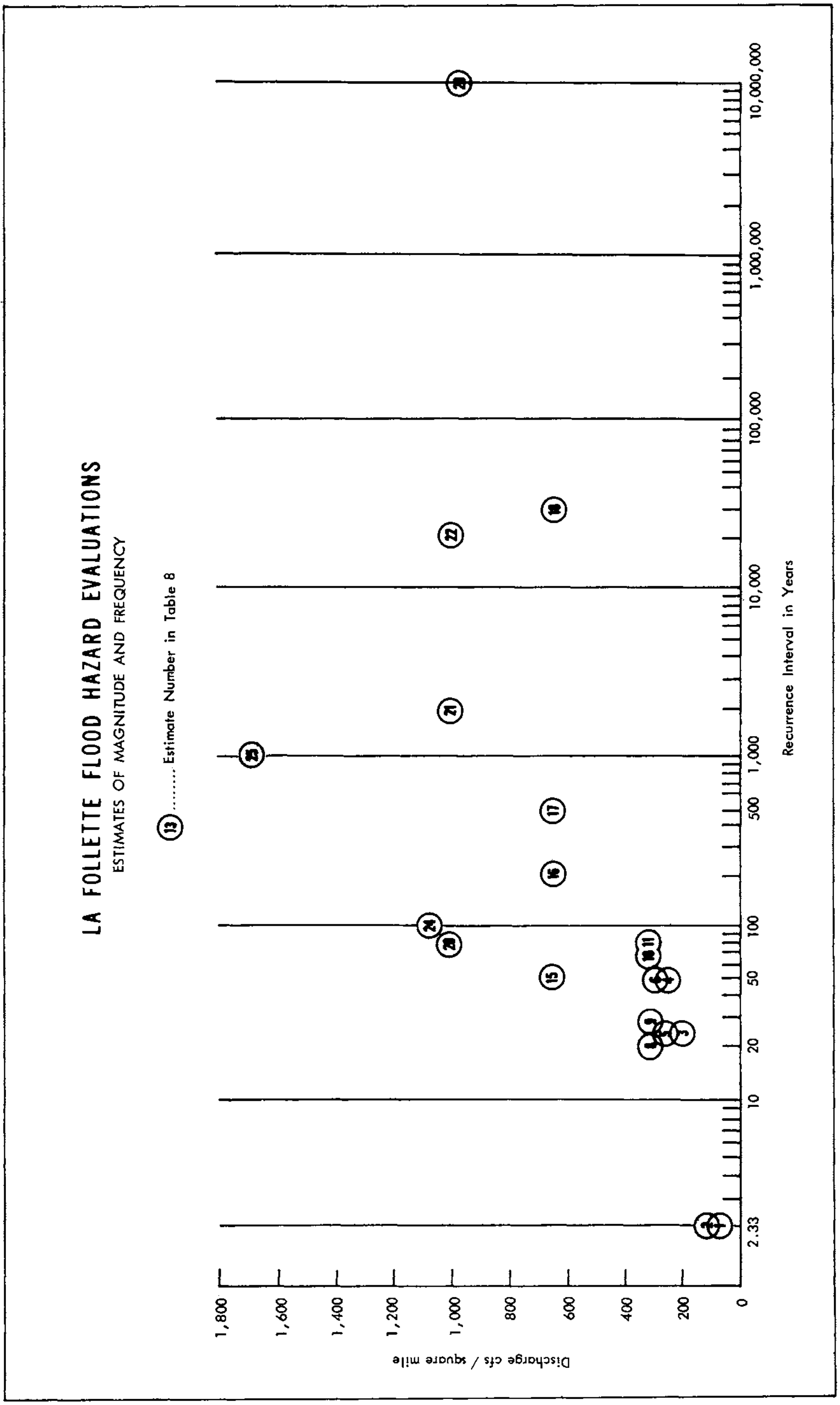
[1]For a discussion of the kinds of probability, see I. J. Good, "Kinds of Probability," Science, CXXIX (February, 1959), 443-447.



LA FOLLETTE FLOOD HAZARD EVALUATIONS
ESTIMATES OF MAGNITUDE AND FREQUENCY
13 ....Estimate Number in Table 8
Discharge cfs / square mile
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Recurrence Interval in Years
2.33
10
20
50
100
500
1,000
10,000
100,000
1,000,000
10,000,000

Fig. 7

concrete dam it is possible to construct the spillway to accommodate a 100 year flood. This would be 14,000 cfs. at Site A. For earth fill or Nantahala rock fill dams it would be necessary to design the spillway for a 1,000 year flood because this type of structure must not be overtopped under any circumstances. Therefore, the spillway for earth fill, conventional or Nantahala type rock fill dams would have to be designed to pass a flood of 22,000 cfs.

By comparison with the other estimates, the unqualified estimate of the 1,000-year flood is one and one-half times as large as the maximum probable flood in cfs./sq. mile of drainage area. While it is human to play it safe and overbuild, a more precise statement of such humanity might be desired.

How good are the estimates of flood hazard made by possessors of technical knowledge?--A judgment as to the value of the varying estimates of flood hazard might be formed on the basis of the following considerations:

1. Big Creek places a special burden on any analytic hydrology. It is a small drainage area, and much less is generally known about flood characteristics of small drainage areas; it has no gaging station, and only a short and spotty history of flood occurrence.

2. Relatively small amounts of time, money, and effort have been expended in deriving estimates of flood hazard for LaFollette. Conceivably a greater investment, including stream gaging might have improved such estimates, but with limited success.

3. For floods within the range of the fifty-year flood, the estimates correspond fairly well, while beyond such a range they diverge greatly. An attempt to estimate magnitude only, without frequency, while reflecting the genuine uncertainty of the analyst, might generate considerable ambiguity for a potential user of such estimates.

4. The method of stating magnitude in terms of discharge (volume flow) rather than stage (depth of water) exaggerated the practical aspects of the divergence of estimates of rare flood events. In many valleys, sizable increases in discharge yield only slight increases in stage particularly for the magnitudes of rare events. Thus while estimates might diverge greatly, practically such differences might result in only a slight fluctuation in stage for a given establishment on the flood plain.

5. Though the estimates of rare flood events diverge considerably, for many purposes greater accuracy might be unnecessary. If present value discounting is being used in economic analysis, the value of flood benefits from rare events quickly

approaches zero. At the other extreme, highways and sewer structures are often designed for frequencies with high probability and more certain magnitudes.

6. Nevertheless, the large divergence of the frequencies of floods of great magnitude engenders considerable confusion. From a theoretical point of view, such confusion arises from what is in effect a shift from one kind of probability formulation to another, a shift from "relative frequency" probability to "degrees of belief" probability. Floods of frequent occurrence can have their probability of occurrence approximated by their relative frequency or counting the number of floods of a given magnitude or greater that occur in n years. Beyond this range of frequent and actual occurrence, estimates as to probability are actually "degrees of belief" held by the estimator as to what the objective probability in the long run might actually be and are consequently subject to wide variation.

7. On balance, the estimates of more frequent events might prove quite useful. Even these, however, should be viewed in terms of a range and recalling Benson's data should not be expected to have much greater accuracy than ± 25 per cent. Beyond the range of the 50- or 100-year recurrence interval lies a realm of great uncertainty and the value of any estimate may be questioned.

The Interpretation of Flood Hazard Information at LaFollette

In the previous section, a single perception of nature described as a classic urn was sufficient to account for the several ways that possessors of technical knowledge interpret flood information and make hazard evaluations. This section returns to the problem of the interpretation of the common knowledge and experience, to attempt to make more precise the link between flood information and hazard evaluation.

Here, the actions and verbal assertions of the LaFollette respondents suggest that information is interpreted with reference to both a deterministic and indeterministic perception of the state of nature.

The perception of a deterministic nature.--In this generalization a less capricious and more deterministic nature has provided a track, rather than an urn, from the end of which is derived an annual flood. The mix of balls on the track is somewhat repetitious, albeit imperfectly so. The magnitude of the largest ball is not much beyond the community's shared experience. Although tending to supply floods in cycles, the track is particularly sensitive to the action of men, and in contrast to the previous state of nature alterations in the mix are obtained with relative ease.[1]

For those who act as if they perceive nature in this manner, the perception has no intrinsic value as an intellectual exercise and they do not share in the scientist's preoccupation with probing the nature of the distribution. For these, the majority of respondents in LaFollette, this perception, compounded out of folklore, experience and intuition, made reasonable by a strong motivation to simplify the uncertainty surrounding human existence, serves as a personal framework with which to interpret new incoming items of experience and knowledge.

Beyond the apparent need to assess the impact of man's tinkering with nature, the concern of the LaFollette respondent, of such concern is at all indicated, is to assess his personal time path relative to the next cycle of events.

The perception of an indeterministic nature.--For these managers, a distinct but relative minority, nature is indeterministic, and they perceive neither urn nor track.

For some, either by ignorance or the denial of the common shared experience, floods do not exist at all. For others, floods do not occur as repetitive events but as true acts of God and are not subject to the ken of man. If an urn does exist, it would be beyond their power to understand or control it. If they have pondered their future personal relationship to a potential hazard, it is only then to shrug it off. They have but pondered one more of life's many imponderables.

Interpretation and the determinate perception of the state of nature.--A determinate perception of nature which implies a track with cyclical or patterned flood events insures that for these respondents the 1950 flood is interpreted within a framework of repetitive events. The fact that the 1950 flood was practically the same size as the 1929 flood tends to reinforce such notions (see Class I-A, Table 9.)

Within the group of respondents who seem to interpret the 1950 flood as a repetitive event, two other assessments add variety to such interpretations. The first is an assessment of a

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[1] It is not entirely clear why a deterministic perception should allow for such considerable influence on the part of man. A likely explanation might lie in the fact that the largest ball conceived of is quite small compared to the magnitude of some of the balls in the urn of the more probabilistic perception. Therefore since timing is approximately known and magnitudes are small, it is well within the powers of men in this case to do something about it.

TABLE 9

INTERPRETATION OF THE FLOOD OF MAY, 1950 BY COMMERCIAL AND RESIDENTIAL RESPONDENTS

Interpretation Class	Commercial		Residential		Total	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
I. Respondent shares in common knowledge of 1950 flood:						
A. Tends to think of flood as one of a series of repetitive events:						
1. Decreasing in time	9	12.7	9	23.7	18	16.5
2. Constant in time	21	29.6	9	23.7	30	27.5
3. Increasing in time	7	9.8	....	....	7	6.4
4. Expectation of trend in time, not ascertained	11	15.5	3	7.9	14	12.8
5. Personally excluded by virtue of present or future location and/or time horizon	8	11.3	2	5.3	10	9.2
B. Tends to think of flood as unique	6	8.4	3	7.9	9	8.2
C. Denies to 1950 flood image of "real flood"	1	1.4	8	21.0	9	8.2
II. Respondent does not share in common knowledge of 1950 flood .	4	5.6	3	7.9	7	6.4
III. Not ascertained	4	5.6	1	2.6	5	4.6
Total	71	99.9	38	100.0	109	99.8

secular trend for repetitive events, closely linked to an appraisal of the effect of human action on the pattern of floods. The second is an assessment of personal time path relative to the perceived pattern of repetitive events.

Repetitive events constant in time.--A majority of respondents interpreting the 1950 flood as one of a series of repetitive events foresee no secular change in time. Phrases used to verbalize such interpretations included: "It seems to be a pattern" and "Floods come in cycles" (see Class I-A-2, Table 9).

Repetitive events decreasing in time.--Eighteen respondents while acknowledging the repetitive nature of flood events appeared much impressed with the efficacy of a small creek dredging effort undertaken by the city of LaFollette in 1956. They believed that the effort to dredge the creek had resulted in either the complete (or partial) elimination of future floods. Residential respondents appeared more prone to this line of reasoning[1] (see Class I-A-1, Table 9).

Repetitive events increasing in time.--Seven respondents, including some of the best-informed perceived floods as repetitive with an increasing secular trend due to human intervention in the form of strip mining, timber cutting, and channel encroachment (see Class I-A-3, Table 9).

Repetitive events with little indication as to expectancy in time.--Fourteen respondents whose interviews suggested that they interpreted the 1950 flood in a framework of repetitive events gave little indication of an assessment of secular trend (see Class I-A-4, Table 9).

Personal exclusion.--The interview attempted to focus the respondent on his personal relationship to flood hazard and omit the broader social role as a member of the community. With leading members of the community, who possessed well-defined social roles, this was difficult; with others it was successful to an unforeseen degree.

Such respondents, while indicating a general notion of floods as repetitive events, appear completely dominated by the idea that they are personally excluded and cannot make other assessments. The basis for believing that while the community is subject to flood hazard, one is personally excluded, varied. For some it was their short-time horizon, because of plans to move or

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[1] Of the 49 commercial respondents and 13 residential respondents familiar with the creek dredging, 18 per cent of the commercial as opposed to 69 per cent of the residential respondents appeared to conclude that such dredging had a substantial effect on future floods.

retire from the management of an establishment. Others felt that their particular location on the flood plain obviated any need to think of floods (see Class I-A-5, Table 9).

An outstanding example of such thinking was the management of the local shirt factory, the major employer in town, and subject to the highest potential damage. (The shirt factory, with its absentee corporate ownership and its completely different scale of operation, has been omitted from the respondent data as it is part of a separate population of managers.)

The shirt factory is in the midst of plans and negotiations with its present landlord, the City of LaFollette, to move to a new location, which among other things would not be subject to flood. Between the press of day-to-day production and the anticipated move, the local management, while generally quite well-informed, was unable to focus on some of the estimates and information requested of them relative to flood hazard. With the anticipated move, such hazard had apparently ceased to exist.

Interpretation and the indeterminate perception of nature.--The occurrence of the 1950 flood is consistent with a determinate perception of nature. For those who act as if they possessed an indeterminate perception considerable stress is generated.[1] To return to the analogy, if no urn or track exists, a flood must either not be acknowledged or so acknowledged as to deny either its replication or the predictability of its replication. The LaFollette respondents do both; some by viewing the 1950 flood as a unique case and others by denying it the image and quality of being a "real flood" (see Classes I-B and I-C, Table 9).

The unique characteristic of a flood.--A persistent theme in many interviews attributes the 1950 flood to some freak occurrence that turns a heavy rain or "normal high water" into a flood.

A variety of causes are cited by such respondents as freak occurrences. The most common one is to attribute the flood to a surge of water caused by the rupturing of a slate dam upstream, the slate having been dumped into the river as a by-product of strip-mining operations. The second most popular explanation is to ascribe the flood to the damming of the Central Avenue Viaduct by debris, whose precise nature varies from respondent to respondent but includes bus bodies, beer cases, lumber and the like. Other suggestions were the clogging of sewers along Central Avenue and the rupture of a water supply dam (see Class I-B, Table 9).

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[1]Such stress is akin to what Festinger calls dissonance. See Leon Festinger, "The Motivating Effect of Cognitive Dissonance," Assessment of Human Motives, pp. 65-86.

Was the 1950 flood a product of some freak occurrence and in some sense unique?

It might be first noted that every flood is unique, that is, a given pattern of damage and overland flow, product of many random factors, is not duplicated even by floods of equal magnitude.

If the exact pattern of a flood in time and space is not predictable, the character of the flood and its damage is not particularly baffling. The effects of such constrictions as the Central Avenue Viaduct and their potential for temporary damming are well recognized in hydrologic literature.

To account for the observed flooding upstream of the viaduct, one does not have to hypothesize debris damming; the constricted channel alone accounts for the five feet of heading on the upstream side.

As for a surge, there was no suggestion from observed reports that one took place, and certainly the one permanent upstream dam did not rupture. The final "cause," clogged sewers, are effects, not causes of riverine floods.

<u>The denial of flood characteristics.</u>--An alternative of ascribing the 1950 flood to some freak occurrence was to exclude it and others in the region from some common image of floods. These "real floods" are modeled on the characteristics of the Mississippi and its main tributaries. Their characteristics include rising waters presaging the arrival of floods that commit great damage and do not run off quickly.

Respondents who desired to exclude the May 1950 flood from such an image would either minimize it by calling it a "flash flood" or a "cloudburst," or completely explain it away by saying: "The creek gets up once in a while" or "It was just water coming up." By calling the 1950 flood a flash flood, respondents imply that flash floods as opposed to "real floods" come quickly, are indeterminate, and run off quickly, doing little damage. The second type of phrase denies to the 1950 flood any quality of flood and implies that the water was just a little higher than usual (see Class I-C, Table 9).

What merit lies behind this denial of flood characteristics? In a technical sense, floods on Big Creek have different characteristics than those of the large streams. They are flashy; that is, they have a short flood-to-peak interval, they are less predictable (but this is rapidly being improved upon by new techniques), and their quick rate of runoff lessens the type of damage ascribed to prolonged inundation.[1] It is not the characterization of such floods as flashy that is inaccurate, but the implication in the words of one respondent that "towns can live with flash floods." To the contrary, there have been increasing signs that damage has been increasing faster along the tributary streams than along the main stems.[2] As for the complete denial of any characteristics of flood, such action can be best explained in terms of "wishing it away," but with one qualification: respondents dwelling on the edge of the flood plain might well consider a flood as "just water coming up" even though some of their less fortunate neighbors had a foot of water on their floors.

The two tendencies: to see the 1950 flood as unique or to deny it the characteristics of a real flood, were found in varying degrees among one-third of the respondents. However, only 18 of them were considered to have their interpretative process dominated by such tendencies. The distribution is not even, with residential respondents more inclined to an indeterminate perception of nature.

This would appear to be consistent with the variation in attitude towards fate and planning noted between respondent groups; 50 per cent of the residential group displaying a skepticism towards planning and a strong belief in fatalism as measured by a fatalism test (Appendix, Questions 34, 36, and 38) in contrast with 4.3 per cent of the commercial respondents displaying similar tendencies.

Interpretation and future flood expectation.--Given the widespread common knowledge having been interpreted in a variety of ways, how do such interpretations relate to the simple hazard evaluation measured by future flood expectancy? Table 10 presents a cross-classification of interpretations by future flood expectation, indicating an extremely high consistency between the two characteristics.

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[1]The flood-to-peak interval is that time interval between the rise of a stream to the elevation at which damage ensues and its peak crest.

The predictability of streams is more a function of their observation than of their characteristics. Improved use of radar holds out the prospect of providing warning systems for the small tributaries comparable to those of large streams in accuracy but not in time period between warning and flood.

[2]The shift in damage potential from the main stem of the tributary valleys has not been studied comprehensively. It would appear to come about through the increased levels of protection along the main stems of the larger rivers and the growing attractiveness of tributary valleys as residential sites in rapidly expanding urban areas.

TABLE 10

INTERPRETATION OF THE FLOOD OF MAY, 1950 BY EXPECTATION OF FUTURE FLOODS

Interpretation Class	Expectation of Future Floods					
	Yes		No		Uncertain	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Interpretations related to affirmative expectations:						
I. A. Respondent shares in common knowledge, tends to think of floods as repetitive:						
2. Constant in time	28	93.3	1	3.3	1	3.3
3. Increasing in time	7	100.0	....	....	....	....
Interpretations related to negative expectations:						
I. A. Respondent shares in common knowledge, tends to think of floods as repetitive:						
1. Decreasing in time	2	11.1	16	88.9	....	....
5. Personally excluded	....	....	10	100.0	....	....
II. Does not share in common knowledge	....	....	6	85.7	1	14.3
Interpretations related to uncertain expectations:						
I. A. Respondent shares in common knowledge, tends to think of floods as repetitive:						
4. Expectation of trend in time, not ascertained	5	35.7	1	7.1	8	57.1
B. Tends to think of flood as unique	2	22.2	2	22.2	5	55.6
C. Denies to 1950 flood image of "real flood"	1	11.1	4	44.4	4	44.4
Total	45	43.3	40	38.5	19	18.3

With but two exceptions, those respondents who interpret past knowledge and experience in such manner as to imply a pattern of constant or increasing repetitive events also indicate a personal expectation of a future flood. Conversely, with three exceptions, those respondents who interpret floods as decreasing in time, exclude themselves, or are unaware of the common knowledge, do not expect a flood in the future.

The tendencies to see floods as unique events leads to uncertainty, and the denial of the characteristics of a real flood leads either to a negative future expectation or uncertainty. The large number of uncertain expectations associated with respondents whose interviews lack a secular trend suggests that such failure may reflect the respondents own uncertainty rather than an omission in the interview procedure.

Besides indicating the strong association between interpretation and the expectation of a future flood, Table 10 also probes the diversity of understanding that is concealed by even the simplest of hazard evaluations.

In terms of their studies, Roder and Burton would probably have classified a negative reply to the question: "Do you think your house will be flooded in the future?" as unduly optimistic.[1] In LaFollette there might be four types of replies, none of which could be described as optimistic:

1. No, they have cleaned the creek out.
2. No, I won't live here next year.
3. No, we don't have floods here.
4. No, we only have cloudbursts here.

The association of interpretation and future flood expectancy expressed as a condensation of Table 10 into a 3 x 3 contingency table is quite high, with a correlation measure of Tschuprow's T of .72 in contrast with the association of knowledge and experience in a similar 3 x 3 table that yielded a T value of .24.

It should be emphasized, though, that interpretation has not been presented for predictive purposes. The allocation of respondents to various classes of interpretation is based on an analysis of their entire questionnaire, interviewer's notes, careful study of their verbal assertions, and the specific answers to nine questions. (The future flood expectation of an individual respondent was not considered in allocating individuals to interpretative classes and to the extent possible in an admittedly

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[1]Roder, p. 68.

TABLE 11

INTERPRETATION OF FLOOD OF MAY, 1950 BY FREQUENCY ESTIMATES OF COMMERCIAL AND RESIDENTIAL RESPONDENTS

Interpretation Class	Commercial			Residential		
	Number in Class	Number Making Estimate	Mean Estimate Floods Per 100 Years	Number in Class	Number Making Estimate	Mean Estimate Floods Per 100 Years
I. Respondent shares in common knowledge of 1950 flood:						
A. Tends to think of flood as one of a series of repetitive events:						
1. Decreasing in time	9	6	2.9	9	6	1.9
2. Constant in time	21	18	7.9	9	5	55.1
3. Increasing in time	7	6	7.3	...	...	...
4. Expectation of trend in time, not ascertained	11	3	4.6	3	1	1.5
5. Personally excluded by virtue of present or future location and/or time horizon	8	5	3.4	2	2	15.0
B. Tends to think of flood as unique	6	1	2.0	3	1	12.0
C. Denies to 1950 flood image of "real flood"	1	1	4.0	8	3	50.0
II. Respondent does not share in common knowledge of 1950 flood	4	3	0.0	3	1	1.5
Total	67	43	5.63	37	19	25.38

subjective process, a respondent's interpretation class <u>assignment</u> is independent of his future flood expectancy.) The classification of respondents by interpretative class, depending as it does on intensive interviewing and analysis, is not replicated with sufficient ease to be useful as a predictor of an individual's future flood expectancy in other studies. It would be far simpler to inquire of managers directly regarding their expectations.

The high association of interpretation class and future flood expectation is most useful for its instruction as to the variety of ways information is assimilated and for the range of reasons that underlie even the simplest of hazard evaluations.

<u>A more refined hazard evaluation, estimates of frequency.</u>--The study posed an additional question dealing with hazard evaluation to respondents.

> If you were to live one hundred years, how many floods would you expect to have here?

Respondents resisted making such an estimate, a finding interesting in itself considering the ease with which some decision-making analysts assume the ability or willingness of individuals to make complex probability computations. Some respondents termed the question "silly" and only with considerable encouragement from the interviewers were 57 per cent of the respondents induced to make a "guesstimate."

These frequency estimates have been grouped by interpretation class in Table 11 and future flood expectancy in Table 12, and for each group the mean estimate has been computed. The usefulness of the data is limited because of the respondents' reluctance to make the estimates, the varied interpretations given "floods" in response to the question, and the fact that some respondents seemed to discount perceived temporal trends and others ignored them. This was especially true for the residential group, over half of which made extreme estimates (either 0 or $\geq$ 100 floods per 100 years) leading to erratic mean estimates.

Despite these limitations the frequency estimates provide several insights. The mean estimates shown in the tables do not appear to be generally inconsistent with interpretation and future flood expectancy. The overall mean estimate for the commercial respondents of 5.6 floods per 100 years closely approximates the actual experienced flood frequency in LaFollette, that is, a return period of twenty years. Finally the estimates indicate that for those willing to make them, floods of the order of the 1950 flood are considered to recur more frequently than possessors of technical knowledge would estimate.

TABLE 12

EXPECTATION OF A FUTURE FLOOD BY FREQUENCY ESTIMATES OF COMMERCIAL AND RESIDENTIAL RESPONDENTS

Future Flood Expectation	Commercial			Residential		
	Number	Number Giving Estimate	Mean Estimate Floods Per 100 Years	Number	Number Giving Estimate	Mean Estimate Floods Per 100 Years
Yes	34	27	7.2	11	6	47.9
No	23	13	3.1	17	10	4.2
Uncertain ..	12	3	2.7	10	3	51.0
Total ..	69	43	5.6	38	19	25.4

Factors affecting flood hazard evaluation.--A variety of variables thought to bear on flood hazard evaluation were tested for association with future flood expectancy. The results for sixteen of the variables are shown in Table 13.

An interesting finding is the lack of association between the expectation of a flood in the future and such diverse variables as: (1) a high score on a test of abstract flood knowledge, (2) education, (3) the length of time that a manager has been on-site, (4) a knowledge of floods at the time of the original decision to locate on the flood plain.

As to the demonstrable associations, a number of these have already been mentioned. These include: (1) the association between the yes-no-uncertain hazard estimates and the frequency estimates; (2) the association between awareness of the creek dredging effort and a negative flood expectancy for the residential respondents; (3) the association of experience and relative location on the flood plain, to an affirmative flood expectancy for commercial respondents.

Associated with an affirmative flood expectancy and not previously cited are: (1) the nine commercial respondents who recalled having seen the TVA Flood Report, (2) the thirty-five commercial respondents who recalled having discussed floods in the past two years, (3) the seventeen commercial and residential respondents who evidenced a heightened concern for floods in a flood concern test.

Even where significant relationships are found, the strength of the relationship is low, yielding values of less than .40 for the correlation measure ϕ of 2 x 2 contingency tables.

Interpretation and Hazard Evaluation at the Reconnaissance Sites

The details of interpretation and hazard evaluation that form the substance of this chapter have, in the main, provided a portrait of complexity and diversity in a single flood plain situation. The variation has been within-group variance, of interpretation and hazard evaluation for a single group of flood plain managers. The reconnaissance studies were designed to provide measures of between group variance, comparing the set of flood plain managers in LaFollette to managers in other situations.

TABLE 13

ASSOCIATION OF SELECTED VARIABLES WITH EXPECTATION OF A FUTURE FLOOD

Variables	Commercial Interview Question Number[a]	Expectation of a Future Flood	
		Residential	Commercial
Flood knowledge and experience			
Abstract flood knowledge	33, 35, 37, 39	-	-
Knowledge of floods	13	-	-
Floods experienced elsewhere..	18	-	-
Floods experienced on site ...	14	-	+
Discussion of floods in past 2 years	24	-	+
Flood knowledge at time of original decision to locate.	27	0	-
Flood concern	4 - 14	+	+
Awareness of channel dredging.	20	+	-
Knowledge of TVA flood report.	23	0	+
Flood frequency estimate	26	+	+
Estimated height of serious flood	50	-	-
Respondent			
Education	85	-	-
Personal time horizon	93 - 94	-	-
Time in residence, business on site	1	-	-
Structure			
Flood plain location	-	-	+
Value of house and furnishings	...	-	0

[a]See Appendix for commercial questionnaire.

+ Association significant at .05 level.
- Association not significant at .05 level.
0 Not tested.

The classifications of experience, knowledge, interpretation and future flood expectancy have been fitted to the more limited data of the reconnaissance sites and are summarized in Tables 14, 15, and 16.[1]

The six sites, essentially chosen to provide diversity, appear to group themselves into three distinct pairs of towns, with the members of each pair presenting contrasts of physical setting and social milieu, but strong similarities of flooding and human response.

Darlington, Wisconsin and Aurora, Indiana, flood sites of high certainty.--In both Darlington and Aurora, with their long history of flooding, managers are presented with a flood hazard of high certainty. Most managers have had two or more flood experiences, and have evolved elaborate and widespread adjustments to flood hazard.

In such a setting, most respondents expect a future flood. This expectation is not diminished by the widespread knowledge of imagined, installed, or expected protective works, as in Darlington. In fact, both communities exhibit a strange, somewhat defensive antagonism to protective works.[2] The most striking feature of all is the similarity of experience and outlook on the part of managers, with little important variation.

LaFollette, Tennessee and El Cerrito-Richmond, California, flood sites of intermediate certainty.--In LaFollette and El Cerrito-Richmond, flood plain managers are presented with a flood hazard of intermediate certainty. LaFollette has had two major floods in 94 years and minor ones at an average interval of about 5 years; El Cerrito-Richmond has had one major flood in at least 25 years, and minor floods somewhat more frequently than LaFollette. Cleaning and dredging of the creek bed has been carried out at both sites, but the efficacy from a technical point of view is negligible and as perceived by managers, varied and speculative.

In this type of setting, human response becomes more variable. El Cerrito-Richmond is the site of the Jacuzzi Pump Plant, the most flood-proofed establishment found in the entire study.

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[1]The reader is cautioned against making absolute comparisons between sites as the specification of characteristics such as knowledge, experience, protective works, and the like varies considerably from place to place.

[2]The attitude towards protective works is better considered in the setting of the following chapter which will also include detailed discussion of adjustments to flood hazard developed in each community.

TABLE 14

SELECTED CHARACTERISTICS OF INTERVIEWED MANAGERS, LAFOLLETTE AND RECONNAISSANCE SITES

Characteristics	Desert Hot Springs, California	Watkins Glen, New York	LaFollette, Tennessee	El Cerrito-Richmond, California	Aurora, Indiana	Darlington, Wisconsin
Respondent characteristics:						
Number interviewed: Commercial	6	3	71	.....	7	13
Residential	10	7	38	11	8	.....
Median age class, in years	45-64	45-64	45-64	25-44	45-64	25-44
Median education class, by grade	11-12	9-10	11-12	11-12	11-12	11-12
Median income class	$6-10,000	$4- 6,000	$4- 6,000	$4- 6,000	$4- 6,000	$6-10,000
Mean number of years on site	5.1	21.9	13.0	10.2	11.6	13.1
Establishment characteristics:						
Mean structure size: Commercial	1,620	1,050	4,330	.....	3,660	4,330
(In square feet) Residential	1,290	880	918	1,020	1,120	.....
Mean value of residence and furnishings.	$22,050	$ 9,400	$ 7,410	$35,590[a]	$ 8,590	.....
Respondents flood knowledge and experience:						
No knowledge of floods	11	.....	8	1	.....	.....
Knowledge, no experience	3	6	47	2	1	1
One on-site experience	1	2	40	2	5	2
Two or more on-site experiences	1	2	14	6	9	10

[a]These are multi-family dwellings in contrast to other residences that are primarily single-family units.

TABLE 15

INTERPRETATION OF FLOOD EVENTS BY THE EXPECTATION OF A FUTURE FLOOD AND KNOWLEDGE OF PROTECTIVE WORKS, LAFOLLETTE AND RECONNAISSANCE SITES

Interpretation of Flood Event	Desert Hot Springs, California				Watkins Glen, New York				LaFollette, Tennessee				El Cerrito-Richmond, California				Aurora, Indiana				Darlington, Wisconsin			
	Expect Future Flood			Knowledge of Prot. Works	Expect Future Flood			Knowledge of Prot. Works	Expect Future Flood			Knowledge of Prot. Works	Expect Future Flood			Knowledge of Prot. Works	Expect Future Flood			Knowledge of Prot. Works	Expect Future Flood			Knowledge of Prot. Works
	Yes	No	Uncertain		Yes	No	Uncertain		Yes	No	Uncertain		No	Yes	Uncertain		Yes	No	Uncertain		Yes	No	Uncertain	
Respondent shares in common knowledge, and:																								
Floods are repetitive events:																								
Decreasing in time	2	2	.	4	.	3	.	3	2	16	.	17	.	3	1	4	.	1	1	2	2	.	.	2
Constant in time	1	.	.	1	1	.	.	1	28	1	1	16	2	.	.	2	13	.	.	.	9	.	.	9
Increasing in time	.	.	.	.	.	.	.	.	7	.	.	4	1	.	.	1	.	.	.	.	2	.	.	1
Insufficient data to detect time trend expectation	.	.	.	.	.	.	.	.	5	1	8	10	2	.	.	2	.	.	.	.	.	.	.	.
Personal exclusion	1	3	.	3	.	2	.	1	.	10	.	4	.	.	.	.	.	.	.	.	.	.	.	.
Floods are unique events .	.	.	.	.	.	1	.	.	2	2	5	6	.	.	.	.	.	.	.	.	.	.	.	.
Denies common image of "real" flood	.	.	.	.	.	.	.	.	1	4	4	3	.	.	.	.	.	.	.	.	.	.	.	.
Respondent does not share in common knowledge	.	3	4	1	.	.	.	.	.	6	1	2	.	1	.	.	.	.	.	.	.	.	.	.
Not ascertained	.	.	.	.	.	2	1	3	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Total	4	8	4	9	1	8	1	8	45	40	19	62	5	5	1	9	13	1	1	2	13	.	.	12

At the same time, it has been the site of newly constructed unprotected multi-apartment buildings.

TABLE 16

RANK ORDER OF STUDY SITES BY PERCENTAGE OF RESPONDENTS DISPLAYING FLOOD KNOWLEDGE, EXPERIENCE, KNOWLEDGE OF PROTECTIVE WORKS, AND EXPECTATION OF A FUTURE FLOOD

Study Site	Expectation of Future Flood		Flood Knowledge		Flood Experience		Knowledge of Protective Works	
	Per Cent	Rank	Per Cent	Rank	Per Cent	Rank	Per Cent	Rank
Darlington .	100.0	1	100.0	1	92.3	2	92.3	1
Aurora	86.7	2	100.0	1	93.3	1	13.3	6
El Cerrito-Richmond .	45.4	3	90.9	4	72.7	3	81.8	2
LaFollette .	43.3	4	92.7	5	49.5	5	59.6	4
Desert Hot Springs ..	25.0	5	31.2	6	12.5	6	56.2	5
Watkins Glen	10.0	6	100.0	1	40.0	4	80.0	3

Future flood expectancy divides almost evenly between affirmative and negative expectation with a substantial minority uncertain. The lessened certainty also seems to encourage sentiments that would credit protective works with substantial reduction of future flooding. An outstanding feature of such sites is the relative diversity of interpretation and evaluation engendered.

Desert Hot Springs, California and Watkins Glen, New York, flood sites of uncertainty.--Desert Hot Springs and Watkins Glen pose to their flood plain managers situations of great uncertainty. In the former, such uncertainty is generated by the climate (4 in. annual average rainfall), the physiography (alluvial fans at the base of dry washes), and the relatively short experience of its flood plain managers (average time on site, 5.1 years). The latter generates uncertainty by the paradox of almost universal knowledge of a flood whose replication seems beyond the pale of probability, and almost total ignorance of the ambiguous but realistic threat of the failure of works that appear to protect against floods of lesser magnitude.

In such a setting, negative future flood expectations are common. Adjustments are seldom found, either because of ignorance of hazard or its perceived catastrophic nature, in the face of which most adjustments would seem valueless.

In both communities, there is fairly widespread knowledge of protective works, and these seem to reinforce the negative flood expectations. However, so strong are the negative estimates of hazard, that they appear to be independent of a perceived efficacy of protective works. In Desert Hot Springs, such negative expectations are displayed by both respondents partially protected by a flood channel and those outside the flood channel.

As in the situation of great certainty, one is struck by the reduced variance of interpretation and evaluation, and the high predictability of respondents' attitudes.

A Certainty-Uncertainty Scale

The six study sites, although too few in number to adequately test a hypothesis, do suggest the following idea:

The certainty-uncertainty scale hypothesis.--The most significant differentiating characteristic of urban flood plain sites is their location on a scale that might be labeled as the certainty-uncertainty continuum. Such a continuum is related to the frequency of flood events, but only partly so. It is in a sense the perceived frequency of flood events.[1] Such perceptions might vary considerably from the best technical estimates, being influenced by experience, catastrophic events, the perceived effectiveness of flood control works, and the like. Along such a continuum, urban places or portions thereof might be located as illustrated by Desert Hot Springs, LaFollette and Darlington in Figure 8. (The actual location and spacing of sites along such a continuum is of course unknown.)

As one shifts along such a continuum a series of observable changes takes place in certain characteristics studied in this volume. Some of these are shown in Figure 8.

With high certainty, as at Darlington, there is wide knowledge of floods reinforced with many experiences. Most managers expect a future flood and have developed elaborate adjustments to meet this threat. Because of the greater certainty, differences of personality and personal interpretation exert little influence and the awareness of installed or prospective

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[1]Although somewhat akin to subjective probability, the implied contrast, that is, if there is a subjective probability there is some real, knowable objective probability, does not fit flood frequency data too well. Given the short span of man, climatic change and the like, all flood frequencies are subjective probabilities beyond the range of the more frequent flows.

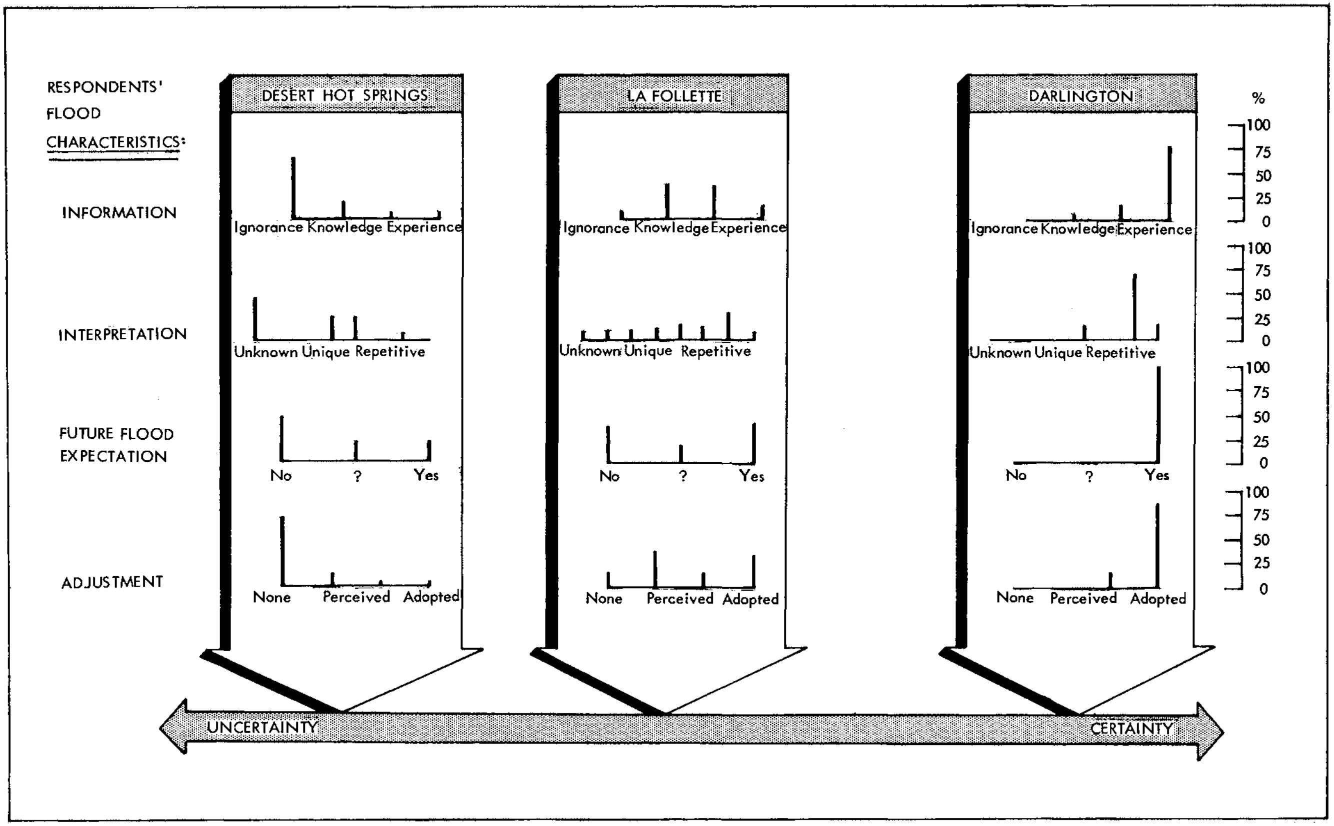

Fig. 8.--Variation in Respondents' Flood Characteristics in Towns Located on a Certainty-Uncertainty Scale.

protective works does not distort hazard evaluations. Finally, the dispersion of all characteristics is quite small.

Moving along such a scale towards uncertainty, as at LaFollette, the dispersion increases rapidly. Managers divide more evenly as to their future flood expectancy and a larger number are uncertain. Extremes of concern and ignorance are observed and establishments can exist side by side, some with elaborate adjustments and others with none at all.

In this area of intermediate certainty, the influences of personality or the perceived effectiveness of protective works increases. While individuals themselves may be quite firm as to their response to flood hazard, the community itself presents a portrait of ambivalence.

In the region of great uncertainty, as at Desert Hot Springs, the dispersion of characteristics again shrinks, but is oriented about negative or uncertain future flood expectations. Adjustment to hazard is non-existent and concern, if it exists at all, is directed towards the catastrophic event.

If this hypothesis is valid, then it suggests that the inconclusiveness of previous studies in assessing the impact of personal interpretation, personality, and awareness of protective works arises in part from a need to observe these characteristics in some framework of a certainty-uncertainty scale. It implies that, depending on the location of a site on such a scale, the observable impact of these factors would vary considerably.

It also offers an explanation for the high variation in LaFollette. While some of the variation is a function of sample size, the hypothesis suggests that it is also a function of lesser certainty. In a town at either end of the scale, such variability would diminish.

Finally, the hypothesis suggests the independence of flood response from socio-economic factors. Each pair of sites provides a wide contrast of socio-economic factors, while sharing a common dispersion of flood characteristics. Darlington is a prosperous regional farming center and Aurora is a fading river town; El Cerrito-Richmond are industrial-residential suburbs of a cosmopolitan city, LaFollette the commercial center of a depressed area; Watkins Glen is also a poor, population-losing community and Desert Hot Springs a burgeoning senior citizen retirement site.

Support for the hypothesis from an analysis of flood frequency at urban places.--Support for the certainty-uncertainty scale hypothesis and promise for its conversion into an interval scale is furnished by an analysis of unpublished frequency data obtained in an earlier study.[1]

In this earlier study of 1,020 urban places with flood problems, frequency data, expressed as the number of recorded floods per ten years, were obtained for 496 urban places with populations exceeding 1,000 persons in 1950.

TABLE 17

NUMBER OF FLOODS RECORDED PER TEN YEARS FOR 496 URBAN PLACES

Number of Floods Per Ten Years	Number of Urban Places
<.9	48
0.9-1.9	95
2.0-2.9	105
3.0-3.9	57
4.0-4.9	29
5.0-5.9	33
6.0-6.9	20
7.0-7.9	20
8.0-8.9	24
>9.0	65
Total	496

A plot on log-normal probability paper reveals that the frequency distribution of the 496 urban places is approximately normal with respect to the log of recorded floods per ten years. The distribution approximates the curve shown in Figure 9. In itself, this is a finding highly suggestive for future research. While lacking any theoretical explanation for the log-normal distribution of cities on a physical variate, flood frequency, the empirical implications are important. The well-known characteristics of the normal distribution may now be related to a population of urban places with flood problems whose actual size is unknown.

More relevant to the present discussion is the use of the log of flood frequency as an approximation of the certainty-uncertainty scale. It can only serve as an approximation for two important reasons. As noted previously, the certainty-uncertainty

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[1]The unpublished data are in the files of the Department of Geography at the University of Chicago. A description of the method of obtaining the information concerning the 1,020 places may be found in White et al., pp. 33-35.

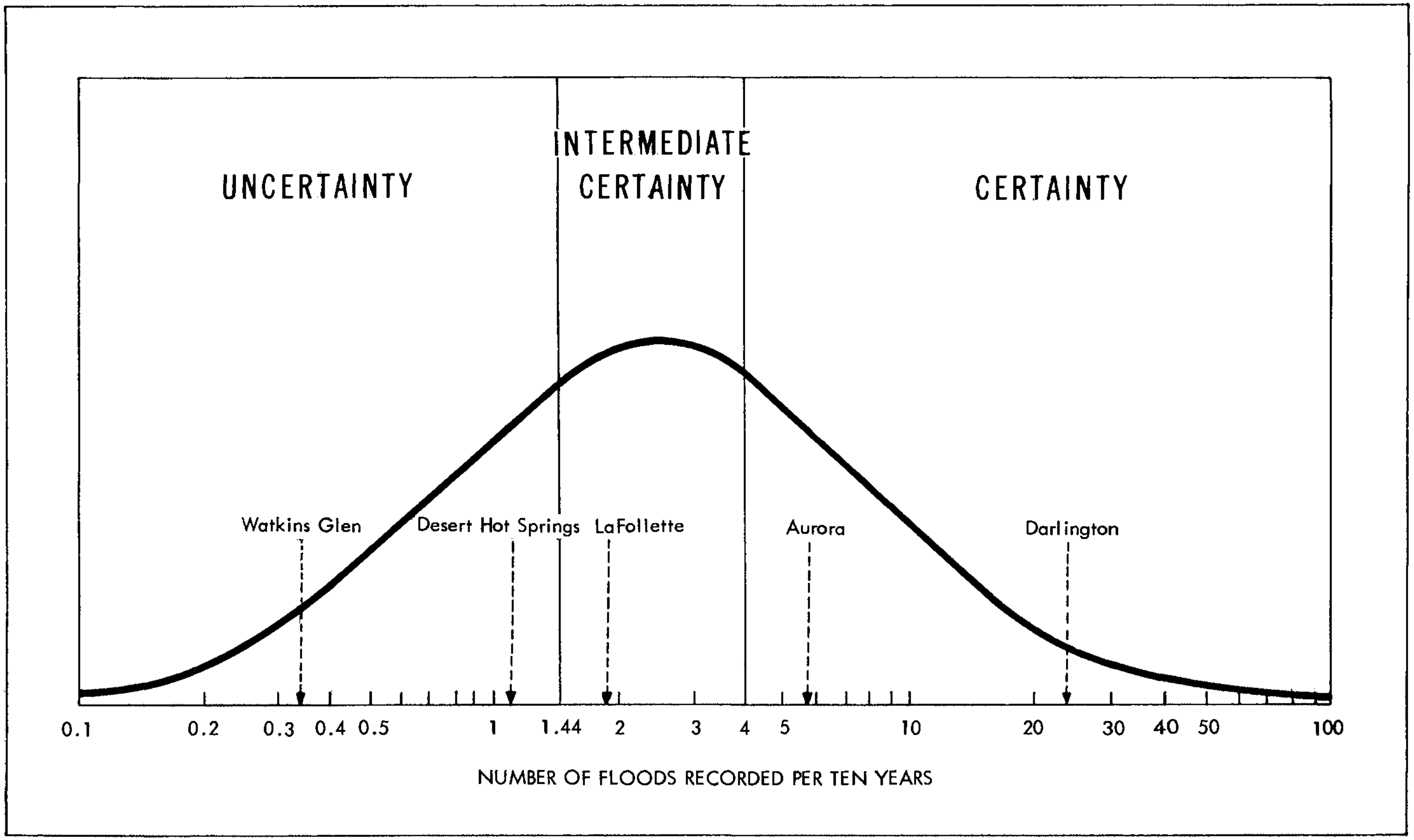

Fig. 9.--Log-Normal Distribution of 496 Urban Places by Flood Frequency

scale is hypothesized as measuring the perceived flood frequency which should vary at times considerably with the recorded number of floods per ten years. Moreover, the findings of the study indicate the importance of major floods as opposed to minor or just over-bankfull floods. The data for the 496 places records all floods and does not distinguish between major and minor floods.

Despite these drawbacks the use of the normal curve drawn in Figure 9 gives striking support to the hypothesis. The area under the curve has been arbitrarily divided into three equal parts and labeled according to the distinctions in the hypothesis; certainty, intermediate certainty, and uncertainty. The available flood frequency data for LaFollette and the reconnaissance sites were transformed into an equivalent expression with the urban place data and located on the scale.[1] In all cases the five sites fall into place within the areas for which they have been previously classified.

Perception, Hazard Evaluation, and Choice: A Commentary on Flood Hazard Information

In exploring the nature of probability distributions held by possessors of technical and common knowledge, it has been suggested that the shape of such distributions arise from underlying perceptions of the state of nature, which might be thought of as determinate, probabilistic, and indeterminate, with the parameters of such distributions dependent on the observation of the past and its extrapolation into the future.

In the case of LaFollette, the evidence of past floods is meagre and even technical extrapolations into the future show wide divergence. The possessors of the common knowledge are strongly conditioned by their immediate past and limit their extrapolation to simplified constructs, seeing the future as a mirror of that past, subject to the discounting of the perceived effect of man's work. By contrast with technical estimates, the hazard perceived in LaFollette is generally of greater frequency but of lesser magnitude.

Figure 10 attempts to present these ideas graphically, with each perception shown on an abscissa of past and future time, and an ordinate of magnitude. The probabilities of floods occurring in the past for all three perceptions are either 1.0 or 0.0, derived from the observation that floods either occur or do not occur. For the future of the indeterminate perception there is

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[1]The data for El Cerrito-Richmond were incomplete and could not be transformed.

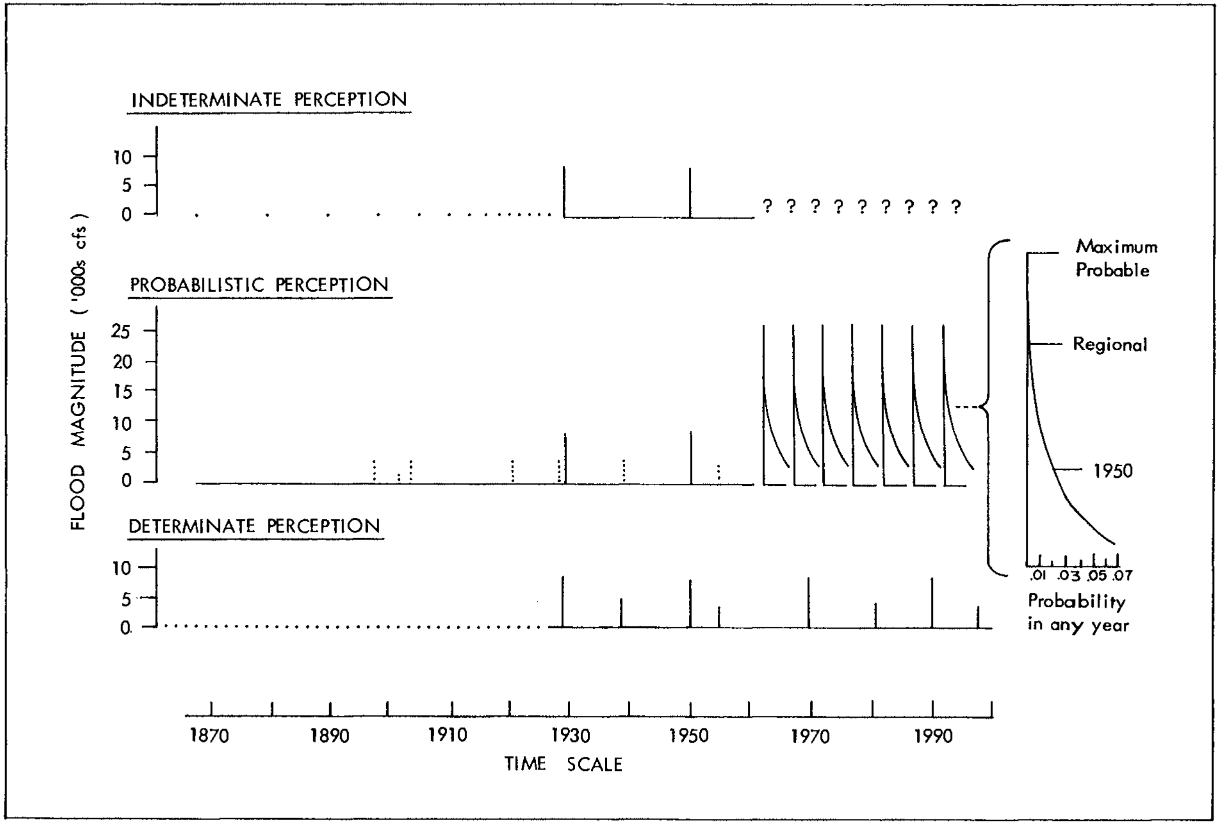

Fig. 10.--A Graphic Hypothesis of Probability Distributions and Perceptions of the State of Nature

only the unknown; and for the determinate position, a mirror of the past, with some flexibility as to year of occurrence. The future of the probabilistic perception is an infinite series of annual probability distributions of magnitude.

If this presentation is a fair exposition of the probability distributions believed in by the possessors of the common and technical knowledge in LaFollette, how well might they serve the needs of decision-making relative to flood damage reduction?

Three criteria can be suggested for guides to such judgments: (1) scientific accuracy, (2) comprehensibility for managers, (3) utility for choice.

Scientific accuracy.--The indeterminate perception would deny to man the opportunity to fathom the natural phenomena of floods and the deterministic perception would obscure the uncertainty such a process involves. Despite its general probabilistic orientation, the technician's perception also wears a determinate face concealed beneath engineering judgment, and an indeterminate face represented by the cautious scientist's retreat from the frequency calculation of extremely rare events.

The hydrologic literature is replete with new methods being developed to extract from the available data the last full measure of information. Nevertheless, no amount of improved statistical technique can fully overcome the limitations that small sample sizes of annual flood observations impose. They cannot substitute for a well-designed program of observation and the continued passage of time.

Equally disturbing is the suggestion that even an extended record has limited utility considering the artificial changes that are occurring in the regimen of many streams.[1] These changes introduce considerable bias into stream-flow records and impair their interpretation although with lessened effect on the analysis of extreme events.

The comprehensibility for managers of technical flood hazard evaluations.--It appears that not only are there severe bounds to the ability of managers to comprehend technical hazard evaluations but that there are limitations on their motivations to do so as well.

The experience in LaFollette with the TVA report entitled Floods on Big Creek suggests these limits of motivation. The report, typical of the genre of such reports, represents the best and

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[1]Walter B. Langbein and G. N. Alexander, "How to Figure Odds on a River Project," Engineering News Record, August 28, 1958, p. 36.

most comprehensive effort to date to combine scientific accuracy, attractive format, and non-technical presentation.

While precise records were not kept, the TVA estimates that 28 reports were distributed in LaFollette.[1] Based on the interviews in which respondents were confronted with a copy of the report, and considering the sample's bias towards including prospective report recipients, the penetration was slight and the recall even less (see Table 18).

TABLE 18

RESPONDENTS' KNOWLEDGE OF THE TVA REPORT

Never saw report		95
Evidenced no interest in report	35	
Evidenced some interest in report	52	
Interest not ascertained	8	
Claimed knowledge of report		11
Could not remember contents	1	
Evidenced vague knowledge of contents	3	
Evidenced fair knowledge of contents	3	
Knowledge of contents not ascertained	3	
Not ascertained		3
Total		109

One-third of the respondents showed no interest in the report, a finding in keeping with the lack of interest in the flood hazard map of Topeka.[2] Thus any evaluation of flood hazard information must grapple with evidence from two locales suggesting that there is a sizable portion of managers who lack sufficient motivation to even expose themselves to the informational materials presently available.

For the flood plain manager who is willing to at least expose himself to such information, there is a further set of obstacles. Limitations of vocabulary and inability to read graphs are blocks to comprehension. The reluctance to make computations of frequency may also apply towards trying to understand the computations of others.

Two other substantial blocks might be suggested. The first is the inability of individuals to conceptualize floods

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[1]Personal interview with John W. Weathers, Local Flood Relations Branch, TVA, July 16, 1961.

[2]Roder, p. 80.

that have never occurred.[1]

The second major block is the difficulty individuals have in grasping the independence assumption of random events. As an indicator of belief or disbelief in the independence of flood events, the following statement was read without comment to respondents who were polled as to their agreement with it:

> If you have a flood this year, chances are that you would not have another for some time.

Only 14 of the 109 respondents disagreed with it. To disagree would fly in the face of both intuitive and experiential perception. LaFollette, when it did have a flood, did not have another for some time. Yet agreement with the statement denies the independence of flood events for that assumption asserts the absence of relation between a flood this year and any other occurrence. The difficulty of intuitively accepting the independence of flood events is widespread, for example, the following quotations from a public administration-sociological study:

"Floods occur in cycles," the author asserts. But immediately following, a perfectly clear but obviously misunderstood statement: "As Hoyt and Langbein explained, 'We speak of a ten-year flood or a hundred-year flood, measuring in each case a flood of such magnitude that it occurs once in ten years or a hundred years on the average.'"[2]

While the evidence suggests that such notions as to interest, ability to conceptualize floods that have never occurred, and the acceptance of the independence of events should be reconsidered, little is known about the effectiveness of different presentations. In LaFollette, the penetration of the flood report was limited, and in Topeka, no one recalled seeing the flood hazard map prior to the time Roder interviewed them.[3] A fresh opportunity for practically testing the impact of flood hazard information is the program of flood hazard mapping in the Northeastern Illinois Metropolitan Area. The mapping program is being accompanied by an aggressive program of introduction to the public and an impact

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[1]The TVA, having long recognized this difficulty, goes to considerable length to try to bring home the graphic reality of potential floods. It draws analogs from regional experience, plots potential floods on easily read maps, and shows flood heights on photographs of familiar buildings. A well-designed study might usefully test the effectiveness of such measures.

[2]S. Weisman, <u>Case Study of Flood Stricken City</u> (New York: by author, 1958), p. 3.

[3]Roder, p. 80.

study of such hazard information is being planned.[1]

Despite the effectiveness of presentation designed to circumvent limitations of managers to comprehend hazard evaluations, it appears that a genuine conflict exists between scientific accuracy and comprehensibility of evaluations. There is a great gulf between the language of science and lay language. The scientist learns to live with uncertainty, the layman appears to have need to eliminate or ignore it.

Because this gulf is real, and technicians sense it, there is generated a powerful pressure to simplify statements, eliminate probabilistic constructs, and in general provide a more limited range of choice for managers to choose from.

The utility of hazard evaluations for choice.--Given the comprehensibility of a flood hazard evaluation, can it readily be used as a basis for choice in flood damage reduction?

For this discussion it would be best to consider but one common form of hazard evaluation, the magnitude-frequency plot. Immediately three problems present themselves, whose inadequate solution severely restricts the utility of such plots as a basis for choice.

The choice posed by a continuous function.--The first such problem is that of the continuous function that such plots present. For many resource management students it has been an article of faith that broadening the range of choice is desirable.[2] However, a range of choice broadened to a continuous function faces one with the paradox of the infinite range of choice potentially reducing one to impotency. In the face of a continuous function of alternatives, decision-makers, be they possessors of technical or common knowledge, shrink from the task and reduce such functions to a few discrete choices.

Acceptability of risk.--Related to the problem of continuous functions, but applicable to discrete situations, is the problem of deciding upon an acceptable risk level. Given some manageable range of choice, what kind of an acceptable level of risk should an individual decision-maker tolerate? Three approaches to the problem may be examined in search of guides.

Acceptability of risk, rules of thumb.--For some readers a discussion of risk levels immediately conjures up images of the

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[1]Personal conversation with John R. Sheaffer, Northeastern Illinois Metropolitan Area Planning Commission, July 18, 1962.

[2]G. White, "Broader Bases for Choice: The Next Key Move," Perspectives on Conservation (Baltimore: Johns Hopkins University Press, 1958), pp. 205-226.

statisticians' conventions of significance levels of .05, .01 and .001, and their wide adoption in science. For much of the world of science, risk is not a continuous function, but depending on the perceived seriousness of rejecting a null hypothesis when it is actually true, seems to move in discrete jumps from 1 in 20 to 1 in 100 and in rare cases 1 in 1,000, when one wants to be "really sure." If flood plain managers might be induced, as their more technical brethren do, to accept such conventions it would simplify the risk problem considerably.[1]

Acceptability of risk, minimum costs and maximum benefits.--A more sophisticated economist's and statistician's approach would seek to identify some point along a continuous risk function which maximizes, in some fashion, the benefits from a reduction of a given risk level of hazard.[2] Such processes while providing useful information for managers of establishments with long planning horizons or at an aggregate level in benefit-cost analysis, still depend on long-run averages to maximize such benefits. The variability of technical estimates of magnitude and frequency, the uncertainty of damage data particularly on an individual basis, and the potentially prohibitive cost of securing adequate information, further limits such an approach as an operational solution for the small individual decision-maker.

Acceptability of risk, behavioral analogs.--The first two approaches are essentially normative, suggestions of rules for selection of acceptable risk levels. Are there behavioral guides to acceptable risk levels, that is, regularities of acceptable risk for floods or other hazards that can be detected in the behavior of individuals?

Previous flood studies fail to provide clear guides. In both urban and rural situations, given some perceived reason for locating on a flood plain, the tolerance for risk levels varies considerably above some threshold. In Burton's agricultural flood plain studies, fields were found to be planted regularly subject to flood hazard with recurrence intervals ranging from 3-6 years

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[1]It is curious that the writer who chose a .05 level of significance for this volume would balk at adopting a standard for a floodway that had one chance in twenty of proving inadequate.

[2]Essentially this is a more sophisticated version of benefit-cost analysis where the risk level that maximizes the net benefits discounted to the present might prove acceptable or that risk level that provided the highest return per unit of capital invested to obtain such hazard reduction.

The companion study will attempt to identify frequency points at which net benefits discounted to present value are maximized for a variety of alternative flood damage reduction measures.

to extremely rare and such frequencies are best understood when considered in a matrix of other factors.[1]

In seeking elsewhere for analogs that would suggest behavioral guides for risk levels, fire or accident hazards might be considered. However the statistics for the occurrence of such events are not easily interpreted as frequencies of hazard partly because of the exposure frequency problem. For example, from statistics of fire in residential buildings by class of city, one might estimate that the relative frequency of fires in towns of LaFollette's class are of the order of 1 in 100.[2] However, this is not the probability of a fire in any year in a house in LaFollette, for surely few would argue that the probability is the same in a home with good safety habits as opposed to one without such preventive measures. The problem of determining the frequency of exposure has led a leading hazard investigator to declare:

> How does one measure exposure? That is, how does one define the conditions that characterize a class of risk situations? How does one measure the frequency of occurrence of risk situations? . . . Failure to recognize and deal with this problem has resulted in an unfortunate research situation. Analytical results which possess no more than speculative value are being constantly generated. Despite the seeming simplicity of these research problems, we still do not know whether men are safer drivers than women, whether it is more dangerous to cross the street with the light or against it, whether girls are stronger swimmers than boys, or whether aspirin is a more deadly accident hazard than lye. We do not know whether excessive speed is a factor common to turnpike accidents or common to turnpike driving. Despite the fact that turnpikes tend to have fewer fatalities per vehicle mile than ordinary roads, we really do not know whether turnpikes contribute fatalities or prevent them. In short, there is a major problem in separating those circumstances that are associated with the occurrence of an accident in a given risk situation from those that are associated with the occurrence of risk situations.[3]

Hazard research is also plagued by the differential perception of culturally allowable risk, succinctly described as follows:

> A report of a few cases of polio will empty the beaches, but reports of many more deaths by automobile accidents on the roads to the beaches will have little effect. The mother

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[1]Burton, Types of Agricultural Occupance . . . , pp. 42-138.

[2]Insurance Information Institute, 1960 Property Insurance Fact Book (New York: by author, 1960), p. 6.

[3]Herbert Jacobs, "Conceptual and Methodological Problems in Accident Research," Behavioral Approaches to Accident Research (New York: Association for the Aid of Crippled Children, 1961), p. 9.

who would not think of exposing her family to the risk of a polio "accident" does not apply the same logic to the risk of automobile accidents.[1]

The idea that there are culturally allowable levels of risk would further limit analog-seeking that might describe generalized risk tolerances, for even should such be found, there would always be a serious question as to their cultural comparability with flood hazard.

Long-run averages.--All expressions of frequency are subject to the law of large numbers, implying long-run averages, and one can note with I. J. Good, quoting J. M. Keynes' grim reminder, that "in the long run we shall all be dead."[2] What can long-run averages mean to a manager of a flood plain establishment?

A manager knows that people experience floods or they don't. He has never seen an average annual flood, received average annual benefits, or suffered average annual damage. Floods arrive in discrete packages, levy immediate discrete damages; and benefits in the conventional terms of damages averted, appear somewhat ludicrous. To the individual such a definition of damage provides the shallow consolation that some ill happening expected over a period of years did not happen to him this year.

From the broad view of nation or community the long-run average frequency has definite meaning. For an individual it may only serve as a source of bewilderment. Thus while the concept of the "100 year flood" represents a marked advance compared to such phrases as "Who knows?" or "Floods come in cycles," ways still need to be sought to make flood hazard evaluation suitable for individual choice. One such approach that might be explored follows.

A Probability Construct for the Individual Decision-Maker

What would be an effective method of presenting flood hazard information to the individual private decision-maker with a limited time horizon? It should be designed to make maximum use of technical hazard evaluations. It should seek to overcome the difficulty individual decision-makers have in using long-run statistics and to satisfy the need for simplifying continuous choice functions into discrete choices.

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[1]Edward A. Suchman, "A Conceptual Analysis of the Accident Phenomenon," Behavioral Approaches . . . , p. 40.

[2]Good, p. 445.

A simplified probabilistic perception of the state of nature.--A return to the analogy of the perceptions of nature will best illustrate such a method. In this perception, there is still an urn, but a friendlier nature, aware of human computational bounds, has thoughtfully colored the balls with three colors, green, yellow and red. Each flood plain manager has a personal urn in which the mix varies slightly from manager to manager. The green balls are those floods whose volume is smaller than that required to just inundate the manager's establishment, given his location on the flood plain. The yellow balls represent floods that would inundate his establishment but not cause, by some defined standard, a serious flood. The red balls, quite few in number, represent flood flows that would cause a serious flood or greater, possibly a catastrophe.

All managers are human beings with limited life spans and are spatially quite mobile. They often change location, and each such change provides a new urn, which seldom contains a large number of red balls. Thus for each manager, for any location, the number of draws of red balls and possibly yellow balls as well, is not only finite but small in number. Each manager has only passing interest in the shape or parameters of the distribution. His interest, if it exists at all, is directed to the number of red and yellow balls that might be expected in his relatively short sequence of draws. He has observed that many managers on many flood plains never experience a serious flood in their short fluctuating periods onsite.

Information required to make hazard evaluations based on a simplified probabilistic perception of nature.--To move from the perception to hazard evaluation, four items of information are needed:

1. A stage-damage relationship for the establishment, that would provide dollar estimates of damage for each increment of higher water.

2. The identification of two elevations: that marking an establishment's flood (just being inundated--yellow balls) and that defining the elevation of at least a serious flood (red balls). In this study, the beginning of flooding has been defined as the first floor elevation of each structure. Defining serious flooding is far more complex and, since damage is measured in dollars, related to the difficulty of comparing the utility of money from one person to the next.

Two separate approaches were developed for this problem and both will be used in the illustrating case.

In the interview, managers were asked to identify in feet and inches, the height that water would have to reach in their establishments to cause a serious flood. The first approach takes the manager's own estimate of a serious flood and converts it into stage.[1]

For the second approach, a serious flood is defined as some dollar equivalent of rent for the establishment and this is converted into stage using the damage-stage relationship. The rationale for such a process rests on theoretical assumptions that a flood is a natural rent or surcharge extracted by nature for flood plain location and that if the disutility of a serious flood is to be compared, it might be compared by some multiple of the actual or estimated rent of an establishment. The differences of such rents would reflect the value of the land and structure to the manager and thus provide some measure of surcharge to be tolerated by each establishment before it becomes "serious."

In the illustration that follows, a serious flood is defined as that flood that could cause damage equivalent to a year's rent. For actual decision-making, a small range of such rents might be provided.

3. A frequency or probability of occurrence in any year for the two stages previously identified, that where flooding begins, and that where serious flooding begins. Note that an entire discharge frequency curve need not be developed, and in general the two points might lie in the area where technical estimates prove most accurate ($\geq .01$ probability).

4. A time horizon expressed in years or the number of draws. Such horizons might be the manager's planning horizon, an average length in residence or business, mortgage loan periods for commercial or residential structures, and the like. In the example that follows, 25 years is used, a substantial planning period for any commercial venture.

Given the above items of information, it is a relatively simple task to compute the cumulative probabilities of drawing various numbers of yellow and red balls during the manager's time horizon by referring to the cumulative binomial probability distribution.[2] Such calculation might best be illustrated by using

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[1]It might also be noted that some managers argue that "any flood is a serious flood," however, even managers who state this argument do not appear to behave as if they believe it.

[2]Presenting flood probabilities in terms of the cumulative chances of receiving various numbers of discrete events is not common practice in flood frequency analysis. Walter Langbein has suggested a number of papers that have used such presentations for

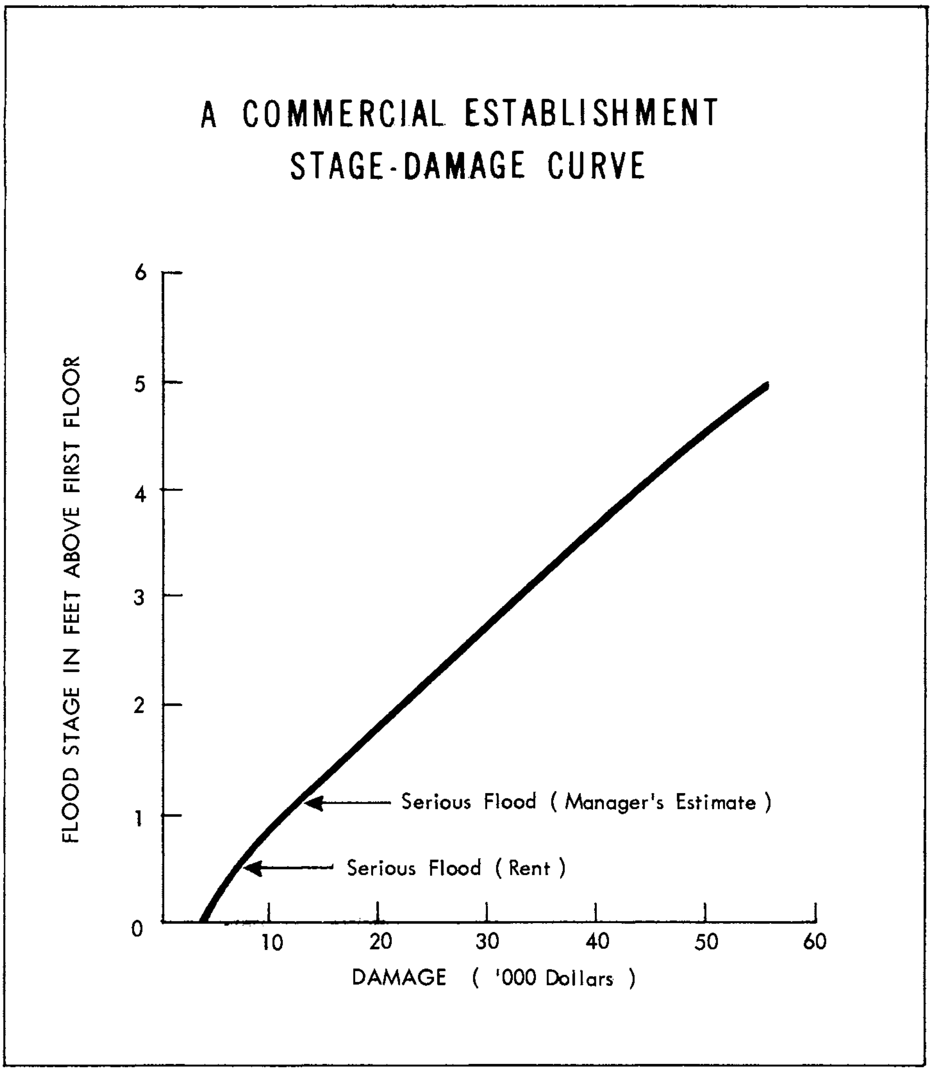
A COMMERCIAL ESTABLISHMENT
STAGE-DAMAGE CURVE
FLOOD STAGE IN FEET ABOVE FIRST FLOOR
6
5
4
3
2
1
0
10
20
30
40
50
60
DAMAGE ('000 Dollars)
Serious Flood (Manager's Estimate)
Serious Flood (Rent)

Fig. 11

an actual store in LaFollette in which the dollar expressions have been altered to preserve the confidential aspects of the data.

A flood hazard evaluation for a store in LaFollette.--The specifications of the needed information are as follows:

1. The stage-damage relationship based on a survey of the establishment is shown in Figure 11.

2. The two elevations, actually three, and their corresponding dollar damages are the following: Using increments of a tenth of an inch, flooding would begin at .10 foot above the first floor elevation. Such a flood would be equivalent to the 1950 flood and, at present, without any damage reduction measures, would cause an estimated $4,000 in damages, primarily to the basement and its contents. From a low of $4,000, damage might rise as high as $55,000 from the maximum probable flood. The damage required to equal one year's rent would be $7,200 or equivalent to that caused by .5 foot of stage. The damage equivalent of the manager's estimate in stage of a serious flood, 1.1 feet, would be $13,000. Both the rent and manager's estimates are used for defining a "serious flood."

3. The probabilities of .1, .5, and 1.1 feet of stage occurring in any year, or on any draw from the urn, are derived from the stage frequency plot of Figure 12, which presents the stage frequency relationship for the store in question based on the four assumptions used by White in the companion study. In the illustration, only the median assumption, the "C" curve is used and for the three stages give frequencies of .0125, .01 and .006 respectively of occurring in any year.

4. As stated previously the time horizon in this illustration is fixed at twenty-five years.

Given the above data and using the Poisson approximation of the cumulative binomial expression of the probability of having 0, 1, 2, and 3 or more floods of a given magnitude or greater during twenty-five years, Table 19 has been computed.

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discussion of various problems. See: American Society of Civil Engineers, Sub-Committee of the Joint Divisional Committee on Floods, "Review of Flood Frequency Methods," Transactions of the ASCE, CXVIII (1953), 1221; R. W. Davenport, "Discussion on Statistical Analysis by L. R. Beard," Transactions of the ASCE, CVIII (1943), 1139; W. Potter, Peak Rates of Runoff from Small Watersheds (Washington: Government Printing Office, 1961), p. 17; H. A. Riggs, "Frequency of Natural Events," Journal of the Hydraulics Division, ASCE, LXXXVII (January, 1961), 15-27; Harold Thomas, Jr., "Frequency of Minor Floods," Journal of the Boston Society of Civil Engineers, XXXV (October, 1948), 425-442.

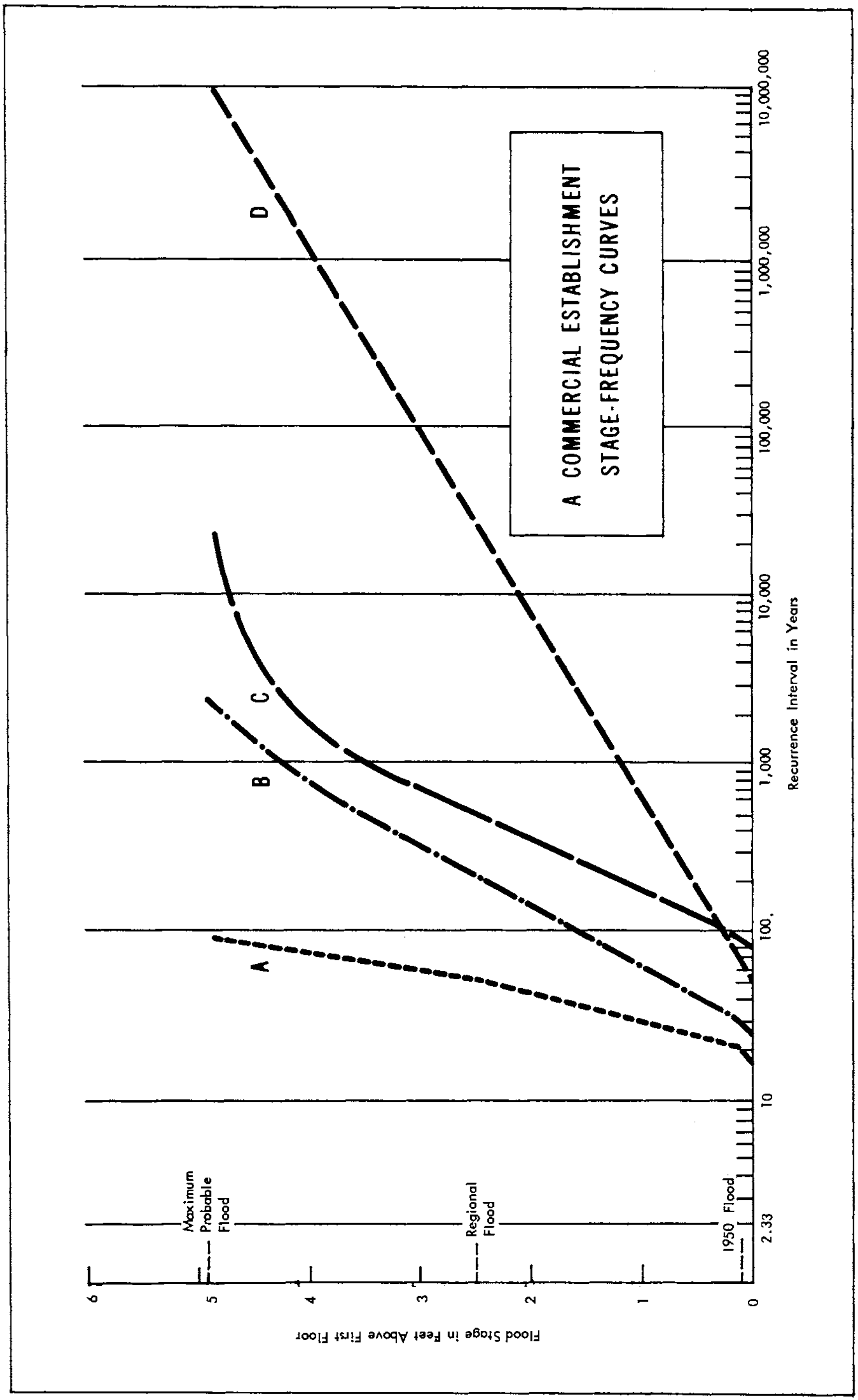
A COMMERCIAL ESTABLISHMENT
STAGE-FREQUENCY CURVES
A
B
C
D
Flood Stage in Feet Above First Floor
0
1
2
3
4
5
6
Maximum Probable Flood
Regional Flood
1950 Flood
Recurrence Interval in Years
2.33
10
100
1,000
10,000
100,000
1,000,000
10,000,000

Fig. 12

TABLE 19

EVALUATION OF FLOOD HAZARD AND SERIOUS FLOOD HAZARD FOR LAFOLLETTE COMMERCIAL ESTABLISHMENT DURING A TWENTY-FIVE YEAR PERIOD

Stage-damage data:

	Stage (Above 1st Floor)	Estimated Damage
Flood	0.1 feet	$ 4,000
Serious flood (1 yr. rent)	0.5 feet	7,200
Serious flood (manager's estimate)	1.1 feet	13,000

Frequency data: (Based on "C" curve)

Probability of a flood in any year	.0125
Probability of a serious flood (rent) in any year	.0100
Probability of a serious flood (manager) in any year .	.0060

Frequency-damage data:

Estimated average annual damage .... $ 196

Time period:

25 years

Flood hazard evaluation:

The probability of a manager having in the next 25 years:[a]

	Floods	Serious Floods (Rent)	Serious Floods (Man. Est.)
None	.7408	.7788	.8607
Exactly 1	.2222	.1947	.1291
Exactly 2	.0333	.0243	.0096
3 or more	.0035	.0021	.0005

[a]Computed by use of Poisson approximation of cumulative and individual binomial probability from E. Molina, Poisson's Exponential Binomial Limit (New York: Van Nostrand Co., Inc., 1942).

Included in Table 19 is the estimate of average annual damages of $196.00 derived by conventional benefit-cost analysis techniques. In a sense, this figure is the commonly used alternative presentation of flood hazard evaluations in economic terms.[1] It tells the manager, that if his present mode of business is projected infinitely into the future, the expected damages expressed as an annual figure would average $196.00.

In the writer's view, this type of presentation is ill-suited to individual decision-making. It implies a relatively

[1]This by no means exhausts alternative economic flood hazard evaluations. One such alternative, discounting a stream of average annual damages to its present value is used in the companion study.

small annual charge extracted by nature for the flood plain location of this establishment. In doing so, it disguises the fact that this charge results from the averaging of chances of about 3 out of 4 or not having any floods at all, and much smaller chances of having 1 or even several large floods.

The presentation of cumulative probabilities for several discrete levels comes closer to conforming to managers' intuition and experience and the bounds to their rationality that are posed by continuous functions, the absence of guides to acceptable risk levels, and long-term averages. The actual form of presentation would have to be substantially different than the technical format in Table 19 and is one for experimentation and research, there being little known about the best means of presenting probabilities to the general public. The meaningfulness of cumulative probabilities for individual decision-making as opposed to average annual damages and the presentation of flood magnitudes without frequency is also a matter that might await a future test specifically designed for that purpose.

However, regardless of its normative value for choice, the calculation of the cumulative probabilities displayed in Table 19 may be important in pointing out the high probability of never being flooded during limited time periods. This would imply that underlying the widely observed penchant for doing nothing about floods, which is often attributed to ignorance, foolhardiness, or other irrationality, lies a rational probability distribution of limited risk. It is a matter of speculation as to whether managers somehow intuitively recognize the large short-run probabilities that they may never be flooded, and the even larger ones that they may never had a serious flood. In any event, alongside other explanations for the widely observed failure of managers to react strongly to flood hazard, must be placed an explanation that is fully in accord with a theory of bounded rationality.