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[illegible]-MAPPING FOR FLOOD INSURANCE

By W. B. Langbein

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RATE MAKING FOR FLOOD INSURANCE

By W. B. Langbein, Walter Basil, 1907-

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RATE MAKING FOR FLOOD INSURANCE

By W. B. Langbein 1/

Introduction

Soon after the 1951 floods on the Kansas and lower Missouri Rivers, President Truman submitted to Congress (82d Cong., 1st sess., 1951) a proposal for a national flood insurance fund. Although the proposal was not acted upon by the 82d Congree, there was considerable discussion of it in the press and in the technical literature. Among the latter were papers by Langbein (1953), Foster (1954), and by the Insurance Executive Association (1952). The paper by Langbein discussed flood insurance as a means of promoting wise use of the flood plain. Foster's paper reviewed his work for the Insurance Executive Association without, however, reaching any independent decision as to the workability of hydrologic techniques in an insurance program. The report of the Insurance Executive Association presented mainly the industries' viewpoint that flood insurance is not feasible. It is interesting to note, however, that in a recent report McGuinness (1957), of the Allstate Insurance Co., says "This position has been taken without recourse to actuarial or statistical methods which might be used to fit an insurance company's underwriting retentions to the exposures it would meet."

The major floods of August 1955 in the Northeast and those of December 1955, in California, renewed interest in flood insurance and, as a result, several bills were introduced in both Houses of Congress. These bills differed in various ways that will not be analyzed here; a draft prepared

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1/ Hydraulic Engineer, U. S. Geological Survey.

by the Bureau of the Budget had the significant distinction of providing for an experimental program. After extensive hearings, including a staff study (1955), a bill was enacted (P. L. 1016, 84th Cong., 2d sess.) to authorize a full-scale program.

The act assigned the administration of the program to the Housing and Home Finance Agency, which invited several hydrologists* to discuss the technical problems of flood insurance with personnel of that agency and with representatives of the fire insurance industry. In these discussions in the offices of that Agency before and after the enactment of the bill, it was pointed out by the author that the rate determination would be the key item in the success or failure of a flood insurance scheme. (See also statement by W. B. Langbein, Congressional Documents, Hearings on Disaster Insurance.) It was evident early in these discussions that the fire insurance companies approached the problem with the point of view that average rates would most ideally meet the insurance concept of having all those insured contribute equally, and that average rates would be most easily administered. However, the approach of the hydrologists in these discussions was that the rates should reflect the highly variable exposures to risks and that the rates should be such as to deter improvident development of the flood plain.

These two different points of view were not resolved, and as the flood insurance program is in abeyance, it appears desirable to record the techniques discussed with the officials of the Housing and Home Finance Agency.

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* Harry Adams, Nat Back, Max Kohler, L. P. Disney, Jones, Karl Jetter, W. B. Langbein. Although professionally engineers, meteorologists, oceanographers, or economists, they are designated "hydrologists."

Some Possible Methods of Assessing Premiums and Their Limitations

Two methods of rate determination that have a hydrologic base were discussed. The first, called the general method, is an example of those procedures in which an assessment is made of the risk to each individual property, to determine the proper premium rate for indemnifying the owner against damages to the limit of his policy. The second method is an example of a procedure that minimizes the need for individual assessment of risk. A brief description is given of possible combinations and variations in the procedures, including comments on their relative merits.

General Method

The general method closely parallels and indeed is but an adaptation of the procedures employed by the Corps of Engineers in determining the average annual damages in areas proposed for protection by flood-control works. The objective is to relate the magnitude and frequency of flood to damages. In brief, the essential steps are these:

a) The determination of the frequency of floods in terms of river stages. The flood record is usually expressed graphically as shown on figure 1, which shows the frequency of floods in terms of the recurrence interval--the mean return period between floods of indicated stages. It is emphasized that this is a mean period--the actual intervals between floods are quite irregular and dates of recurrence are not predictable. The weight of evidence, though not conclusive in all details, is that floods occur fortuitously or at least with sufficient degrees of randomness to warrant taking advantage of statistical theories based on that assumption. The flood-frequency curve for a gaging station is intended to represent a river reach, the basic unit for flood studies. The river reach may be defined as a stretch of river with uniform flood characteristics that may be represented by a single gage. The reach in a major river may extend between mouths of major tributaries--as long as 50 or even 100 miles. In small streams it may be quite short, perhaps as short as 1 mile.

b) The second step is the construction of the stage-damage curve. (See figure 2.) In the flood-control study, the stage-damage curve represents the whole reach of the river. For an insurance program, the stage-damage curve represents one property, or one class of properties within a reach. Figure 2 shows a type of this curve as applied to a river reach.

These two, the flood-frequency curve and the stage-damage curve, represent the basic data from which the subsequent curves are derived--namely,

c) A damage frequency-curve constructed by (1) entering the stage-frequency curve for a given stage and reading the frequency, (2) entering the stage-damage curve and reading the damages, and (3) plotting a graph of frequency versus damage. (See fig. 3.)

d) The average annual damage is computed by integrating the damage-frequency curve. The computation is carried out in the example shown below. The first two columns list damages and recurrence intervals as read from figure 3. The third column shows the average recurrence intervals for each \$100,000 damage range. The average annual damage in the final column is computed by dividing the damage range by the recurrence interval in years.

Damage (dollars)	Recurrence interval (years)	Average recurrence interval (years)	Damage range (dollars)	Average annual damage (dollars)
0	4.5			
		12	100,000	8,300
100,000	20			
		35	100,000	2,900
200,000	50			
		80	100,000	1,200
300,000	110			
		145	100,000	690
400,000	180			
		Total for river reach		13,090

The procedure outlined roughly accords with current practice in flood-control surveys, where the analysis applies to communities or river-reaches as a whole. Some form of generalized treatment is needed is the technique is to be applied in an insurance program where the risks are insured singly. The major modifications are in the preparation of flood-risk maps that present the flood-frequency data in general form and in the preparation of general depth-damage curves.

Flood-risk maps.--A flood-risk map is one that shows in plan view the relative degree of flooding of lands. There are several ways in which such maps can be prepared, and perhaps the most familiar are maps showing areas flooded by some severe flood of record. Such maps prepared from field surveys of high-water marks or aerial photographs can be found in many flood reports of the Corps of Engineers or the Geological Survey. (For example, see Water-Supply Paper 1137B, pp. 125, 128, and 137; Water-Supply Paper 1320A, p. 8.) Although they afford direct and tangible evidence of the flood hazard, these maps do not provide any measure of the probability of the flood depicted, such as shown on figure 4 for Columbus, Ga. Each "contour" shows the height reached and area inundated by a flood on the Chattahoochee River of the designated return periods. The "contours" are not level lines like the usual lines of equal elevation on a map, but lines marked by the flood stages of the river. This type of map supplies direct information on areas subject to floods of different return periods but it has the disadvantage that it must be revised to accord with any change in the estimate of the flood frequency. Also, depths of flooding cannot be read from a map contoured in probabilities or return periods.

These disadvantages can be eliminated by contouring the river heights rather than the return periods. The map for Harrisburg, Pa. (fig. 5) is an example of this type of flood-risk map. The auxiliary scale shows the relations between flood heights and the return periods. If a uniform interval is selected for contouring the flood heights (5 feet in the Harrisburg example), the return periods will conform to an approximately uniform ratio (a ratio of 3 in the example). The contours of height of floods are unaffected by a change in the estimation of the flood-frequency curve, only the probability scale needs revision. Depths of flooding can be read directly from the map. A piece of property, say at the edge of the 25-foot contour (a 40-year flood) would be under 5 feet of water during the 100-year flood, 10 feet during the 300-year flood, and so on.

Depth-damage curves.--Figure 6 is a schematic presentation of a kind of graph that can be prepared from past flood experience. Curves like these are sometimes prepared by the Corps of Engineers in connection with flood-control surveys for estimates of damage by past floods. It shows for a dwelling the damage in percent of the total value in relation to the depth of flooding. It is not to be expected that such graphs would fit each property exactly, and in fact it is not possible to forecast what might happen to a particular house. Silt deposition might or might not cause extensive damage, wiring might or might not need replacement, or foundations might or might not be disturbed. However, the important need is that the curves represent classes of property in the average.

These two tools, flood-risk maps and typical depth-damage curve, enable one to compute the annual insurance premium equal to the average annual damage. The following steps are involved.

1) Locate the property on the flood-risk map.

2) Construct a table showing the frequency of flooding of different depths on the property.

3) Enter a graph showing damage in relation to depth of flooding (such as figure 6 for frame dwellings).

4) Multiply, frequency times percent damage, times total value to compute annual damage in dollars.

The table below is an example of how the flood-risk maps and the depth-damage curves are applied to the computation of the average annual damage to a dwelling in flood-zone C on the Harrisburg map.

Level	Frequency a/	Probability for range	Percent damages b/	Rate
First floor	0.025			
		0.015	25	0.0038
5-feet deep	.01			
		.0065	39	.0025
10-feet deep	.0035			
		.0035	45	.0016
Over 10-feet deep	0			
Total rate				0.0079

a/ From figure 5.
b/ From figure 6.

The general method described enables the insurer to specify the premium in terms of the value of the property to be covered and in terms of the flood hazard imposed by the location and type of structure. Its disadvantage is the amount of work involved in the preparation of the essential charts and graphs and the degree of sophistication required in its application to each property.

Specific-Gage Method

Recognizing the potential disadvantages of the general method, it would be desirable to develop a method that would minimize the need for some of these engineering tools, and yet remain technically sound. For example, information provided by the assured as to his past flood experience might be incorporated into a premium determination and might ideally avoid the need for a flood risk and depth-damage curves entirely. However, such information, though perhaps useful as a check in any scheme, would be variable in quality and would not be available from new owners or from owners of new properties.

The general method meets all technical needs. It is obvious that abbreviation of the work required would involve some compromise. This is satisfactory provided that the compromise does not impair or erode the basic principle that each premium reflect the risk and indemnity is made on proof of damage.

In the general method, indemnities, not to exceed face value of policy, are paid on proof of damage. If to this condition the requirement that river level reach a designated stage is imposed, it becomes possible to write insurance that eliminates appraisal of risk to each property. The plan works like this. A property owner buys an insurance policy that will indemnify him for damage to his property caused by any flood during which the river stage reaches or exceeds a designated height. The policy would also state a maximum amount of damage for which the owner would be indemnified. The river stage is the elevation of water at a specified gage at some point within the community where the property is located. The water height elevation at the gage would not necessarily be the same as at the insured property during the flood, but would be the same in relation to the river grade.

As an example, an owner might purchase a policy with a face value of $5,000 to indemnify him against loss caused by a flood which reaches a level on the specified gage of 20 feet or more. If the stage does not reach 20 feet during a particular flood, no indemnity is paid regardless of the amount of damage incurred. Again, if stage exceeds 20 feet but there is no damage, no indemnity is paid. The stage event establishes eligibility for indemnity; payment is conditioned on proof of damage.

The owner may distribute his coverage to provide protection at more than one stage. Thus, taking the same example as above, the owner may elect to take $3,000 coverage at the 20-foot stage and $2,000 at a 25-foot stage. Thus he becomes eligible for $3,000 indemnity upon experiencing a 20-foot stage, and for $5,000 indemnity on experiencing a 25-foot stage.

Premium rates under this plan are directly equal to the probability of occurrence of a flood reaching the designated stages at the specified gage. Thus, the needs for writing insurance under this plan involve only the preparation of tables showing the relation between probabilities of various flood stages at specific gages as read from flood-frequency graphs (see figs. 1 and 5.) The method does not require preparation of flood-risk maps or diagrams of flood damage versus depth of flooding. Under this plan, the owner assumes all responsibility for estimating (1) the possible damage to his property and (2) the damage stages. A flood-risk map for the city (fig. 5) would be helpful to the owner in estimating the damage stage, but it is not essential in the method.

Owners will vary in their skill or their intent in estimating these two factors, raising questions on how these variations affect the owners or the insurance fund's interest.

If the owner selects a stage below the level of his property, he is obviously paying for coverage that is doing him no good, because payments are made only on evidence of damage. If the owner selects a stage above the level at which his property is damaged, his rate may be low but a flood may occur for which he will receive no indemnity.

If the owner selects a policy value less than the potential damage to his property, he may experience damage for which he is not indemnified. If he selects a policy value more than the potential damage, he will be paying for coverage from which he can expect no return.

If the owner selects too low a stage or excessive coverage, the insurance fund stands to make a profit. If the owner selects a high stage or deficient coverage, the insurance fund theoretically breaks even in the long run, and the owner receives back just what he paid for, although the indemnities may be insufficient to cover his actual losses.

The method adequately protects the insurance fund, but may penalize an owner if he misjudges his damage stage or the potential damage to his property. Owners of extensive property might have surveys made to assist them in making these decisions but the average homeowner would not be able to do so. In some cities the flood gage is well known, as gage readings are often in the daily newspapers. Those owners of property that has been flooded would quite likely make rather close estimates of the gage reading for which they would need coverage, and the damage experience would help in fixing the needed coverage. Others, especially new owners, would need help to make the necessary decisions. In some cases, the city engineer would be able to give the needed advice, and indeed the city engineer might find it desirable to prepare and distribute a flood-risk map to assist the community in buying insurance and in setting up zoning standards.

The advantages of the method are that premium charges reflect the risk and thus safeguard the insurance fund, yet avoid the need for extensive preparation of flood-risk maps and charts of damage versus depth of flooding. The method is therefore adapted to launching a flood-insurance program on a hydrologically sound basis without a great deal of preliminary investigation. The need for owners to decide on their damage stages, and the possible adverse returns to insurers are perhaps the most critical deficiencies of the method. A further disadvantage is that the method is limited in application to river reaches or coastal harbors that contain official river gages. However, over half of the people in the United States live in cities that contain river gaging or coastal tidal gage stations.

The idea that indemnity is conditioned on experiencing a previously selected stage may appear to be a psychological barrier. A river stage may cause damage and yet fail to reach insured stage by 0.1 foot or less. However, this is the principle that is successfully applied in rain insurance where indemnity is based on rainfall measured at the nearest U. S. Weather Bureau rain gage (N. Y. Times, Oct. 6, 1957, page 4F).

On the other hand, the rule can be modified so as to give partial indemnity in proportion to the relative premium rates. For example, if the assured were to buy coverage for a 20-foot stage and a 15-foot flood occurs that causes damage, his indemnity would be reduced in proportion to the rates for the two stages. If the rate for the 20-foot stage is only half of that for a 15-foot stage, the indemnity would be half of what would be paid if a 20-foot stage occurred. Premium rates would necessarily need to be modified if this rule were incorporated.

For the owner who selects too low a stage and thus overpays, Max Kohler* of the Weather Bureau suggests this possibility: A policy might carry two values. The lower value would be paid on occurrence of a flood that produces no damage, so that the owner may recoup excess premiums paid by selecting too low a stage. The higher value would be paid only on a showing of damage. After a flood has occurred, the owner might then wish to revise his coverage and lower his premium.

The specific-gage method and its modifications described in this paper, are only a few of the possibilities that might be devised and put to test in an experimental flood-insurance program.

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* A personal communication.

Property along small streams.--Both the general and the specific-gage methods are inapplicable to river reaches along streams not served by existing gaging stations. Nearly all streams draining more than 1,000 square miles are gaged, and a large number of smaller streams are also gaged. Nevertheless, there are a myriad of small streams that are not gaged. To insure property along these streams involves an estimate of the flood characteristics of the ungaged streams. Methods now in use for making such estimates for use in flood-control work or for the design of highway bridges are much too involved for use in a flood insurance program. Further research is needed to develop simpler methods that depend only on data available on maps or from field inspection, such as drainage area, width and depth of channel and the flood plain, that would make it possible to set down rough estimates of height of flooding for any stream in the region. To apply the results to a particular property to be insured requires further information on the height of the ground at the property above the bed or banks of the channel. This information may or may not be known to the owner or available from existing maps.

Deficiencies in presentation of data.--There are available over 6,500 continuous records of river stage and discharge in the United States, and these records include stations at nearly all important centers of flood damage. The flood record also includes about 1,500 flood-crest gages mainly on small streams. Simple in design, these gages are built so that a flood leaves a mark at its crest. In addition, flood marks on buildings, trees, and fences are often surveyed after important floods. The data accumulated are impressive in bulk--the major difficulty is that (1) they have not been presented in a form useful to an insurance program, and (2) there are important deficiencies and gaps.

The most desirable form to present flood data for administering an insurance program would be in the form of flood-risk maps.

Dalrymple (1957) puts the matter this way. "The agent that sells flood insurance must have more help than a table of rates based upon flood probabilities. He needs a map of the locality showing areas or zones that will be inundated by various flood stages. Such a map can be prepared by considering the slope, or profile, of the stream through the locality. Many flood profiles have been surveyed by various agencies, and are available for use in the preparation of flood zone maps. Low water slopes, the profile of bankfull stage, highwater marks of past floods, synthetically developed stage-discharge rating curves, a study of flood deposits, and other information may be used to define the boundaries of probable areas of flooding.

"One of the important needs, and one not adequately provided for, is good maps. As there is not a great difference in stage for floods of greatly different frequencies, especially for the more rare floods, the need is for maps of small contour interval. Some cities have maps showing the elevation at each curb corner, but many do not. A very few cities have prepared maps showing areas inundated by specific floods; these are excellent. Cincinnati has done an outstanding job in this respect, and also the TVA has obtained much flood data that will be very valuable.

"The problem for coastal areas is simplified, as there is no slope to the flood zone lines. A complication is the generally high ground next to the sea, with resultant flooding from inlets admitting water to the back of the area. Also, wind induced waves may cover areas with water without reflecting on the gage upon which rates are based."

There are sufficient data and techniques available at present to prepare flood maps for nearly every major damage center in the United States. Although this would be a big job, it would be justified if only by the inducement it would give to flood-plain zoning. The job would be made simpler if there were an atlas of aerial photographs of floods. The pictured flood waters would provide a direct means for extending river gage data up and downstream.

How to remedy the deficiency of flood-risk maps is a major problem facing the implementation of a flood-insurance program. Their usefulness in flood-plain zoning as well as an insurance justifies a program for the preparation of such a series of maps for major drainage centers that would merit the cooperative effort of all governmental agencies concerned with floods.

Errors and limitations of data.--The flood-frequency graph as prepared from the flood records is the key to the assessment of flood risks. It is, however, subject to error. A period of record is but one sample of the whole history of floods of a river. The flood-frequency curve is subject to a "sampling error" that is roughly proportional to the square root of the ratio of the return period to length of record. This formula expresses the intuitive thought that the error is greater for the rare floods than for the frequent floods, and is greater for short records than for long records.

When we speak of length of record we mean the longest record in the general region, because it is possible to extend a short record by correlation with the longer record. There are in the United States about 80 flood records 50 years or more in length that can be used as base records for extending short-term records. In most areas there is therefore a favorable possibility of constructing the flood experience for a 50-year period.

The problem of errors in estimation of flood-frequency is quite similar to that encountered in flood control where the flood-frequency curve is used to determine the average flood damages. The important distinction is that in flood control the subsequent accounting is indirect. However, an error in the flood-frequency curve that would cause the premium collections to fail to cover indemnities in an insurance operation would show up as red ink in the ledger.

The matter can be handled by evaluating the probability of error in the flood-frequency curve. In other words, instead of fitting a curve to the flood data, the curve should be drawn higher to give reasonable assurance that future flood experience would not exceed the estimated frequencies. If only one area were to be insured, this margin of error might be rather great. But in a national flood insurance program it is possible for error in one curve to be compensated by an opposing error in another curve. The degree of compensation depends first on independence of flood experience in the United States. We know, for example, that floods often affect broad regions, sometimes as great as 200,000 square miles. Flash floods on small streams may affect areas as little as 10 or 20 square miles. Much research is still needed to evaluate regions in which occurrence of floods is independent of floods in contiguous regions. From a general appreciation of the subject of floods, it is surmised that there are about 20 of such independent regions in the United States. If this estimate is correct, then the allowance for the sampling error can be reduced to about 22 percent ($= 1/\sqrt{20}$) of that which would be required for each area independently.

A second consideration is the unequal distribution of potential flood damage. The allowance for error for a curve used for determining the premiums for a river reach containing large insurable values must be greater than for a rather isolated location. Further research is required to establish criteria and methods for determining margins of error that will properly reflect (1) period of record, (2) independence of flooding between different flood reaches, and (3) total insurance to be written on each curve.

Average Rates

The insurance concept does not depend on evaluation of each risk exactly. And, in fact, if this could be done, there would not be any insurance. But insurance does require evaluations of those risks calculable by or sensible to an informed person, otherwise the fund would be subject to selective risks. But there is a necessary terminal point to the evaluation of risk, beyond which the risks are averaged and the departures from "average" are insured. The evaluation stops short of the physically unpredictable in the two basic items of data. In the case of the flood-frequency curve--future floods are predictable only in a statistical or "average" sense. One insures against deviations from this average. In the case of the stage-damage curves--the stage or depth of flooding is hydraulically determinable, but the actual damage to a particular piece of property is physically predictable only in an average sense based on the experience of similar buildings. Averaging is intrinsic for those events that are unpredictable.

Some averaging may be desirable to save costs of administration, as for example in defining flood zones, in which each property is deemed to have the same probability of flooding. But the averaging principle cannot safely extend to fixing rates that disregard elemental considerations of the location of property in relation to a river. Averaging rates by cities, counties, or river basins may recognize the regional differences in flood hazard, but where each individual decides whether to buy or not to buy, such average rates cannot avoid selective risks. The incentive to buy would be with those river-ward of the theoretical limit of the average rate. For example, if the average rate is one percent, the insurance would be attractive only to those flooded more often than once in a hundred years. The relative frequency of flooding is known to enough people living in potential flood areas, that this knowledge could dangerously bias the insurance coverage.

Conclusion

Problems in rate making include the collection of premiums sufficient to cover indemnities, and the assessment of premiums in proportion to the respective risks. Perhaps the important problem concerns the Federal flood abatement programs because any plan that provides insurance on property at rates less than the actual risks would tend to favor use and development of such properties with consequent increase in flood damages. Such development would impose additional demands on Federal resources for flood protection. It would also add to the difficulty of State and local governments to zone these lands.

To undertake a flood insurance program raises many questions to which answers can only be speculative. There are many deficiencies in presentation of flood data. Despite the work done, new techniques need to be developed. Despite the many conferences that have been held, policies and objectives need to be defined. It is not known what premiums are marketable and what, if any, subsidy would be advisable. These deficiencies can only be repaired through experience. Moreover, it is believed that to begin with a full-scale program is not advisable. A small-scale experimental program though national in scope is not in coverage, on the model of the experimental county plan of crop insurance, would give time to develop the needed data. It would also provide the experience required to test techniques and to define the objectives without either endangering the insurance fund, or adding to the present difficulties of trying to reduce flood perils.

It is believed that tools and techniques are yet insufficiently developed to put any plan of insurance into general operation.

The present inactive status of the federal flood insurance program offers an opportunity to prepare the necessary data and to carry out the essential studies. These data and studies would provide a sound base for rate making, should the program be reactivated, possibly as a consequence of the next major flood.

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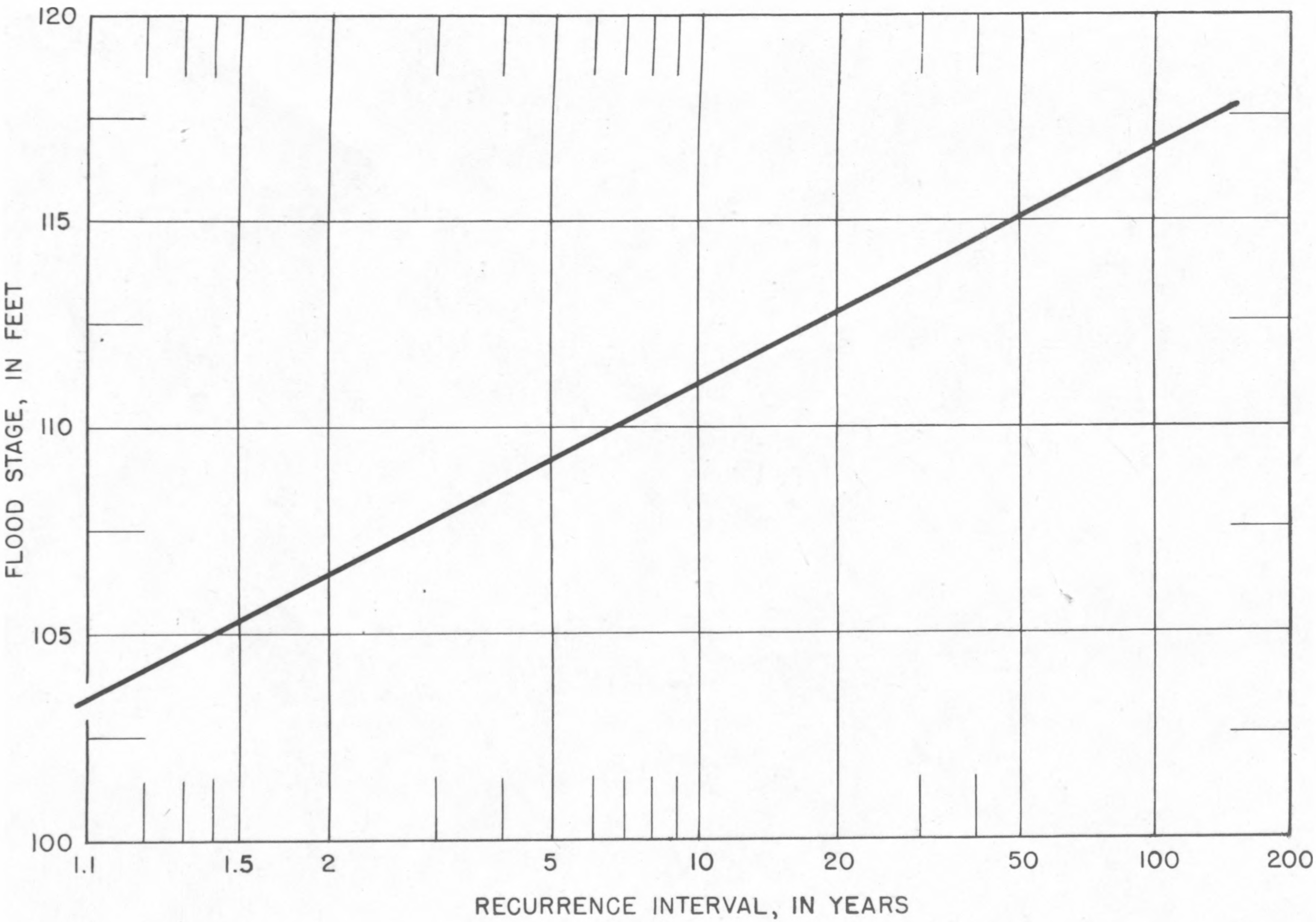


Figure 1.--Schematic representation of frequency of annual floods at river gage.

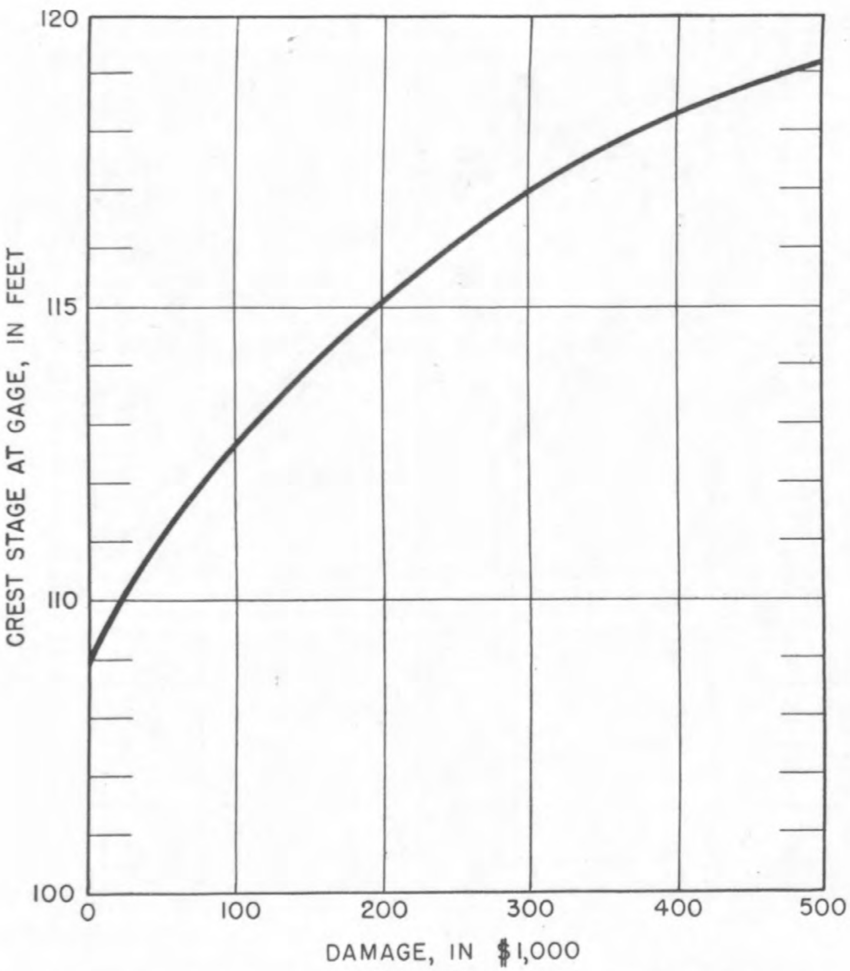


Figure 2.--Schematic stage-damage curve for a river reach.

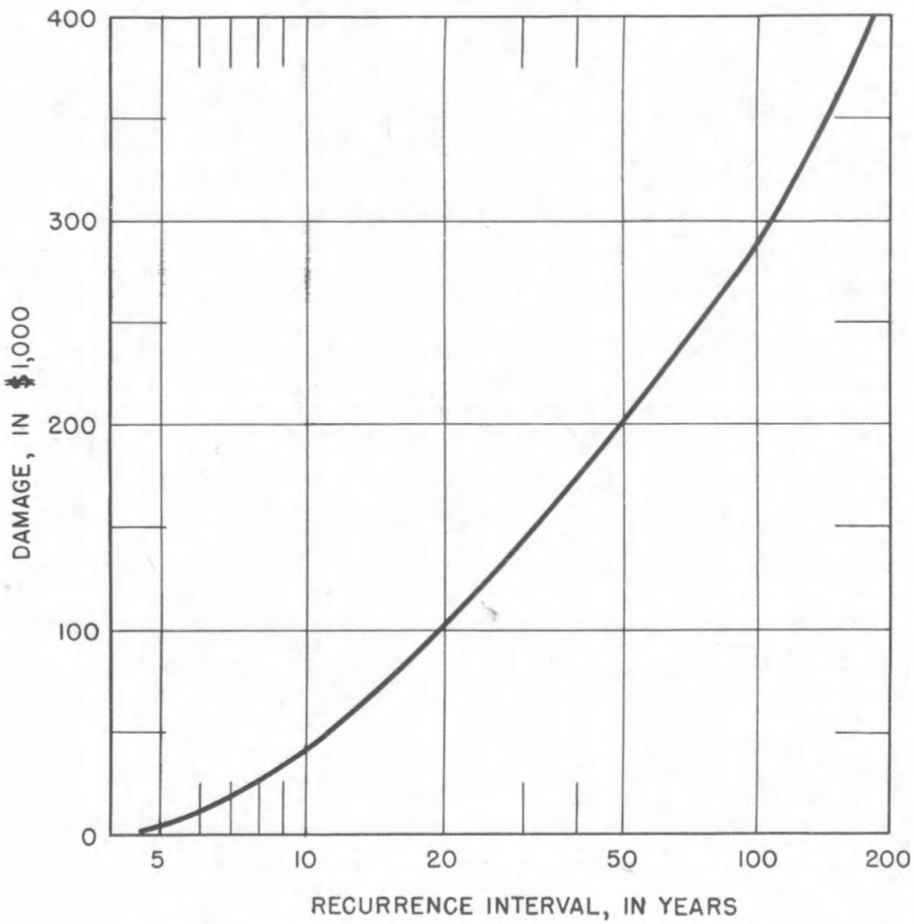
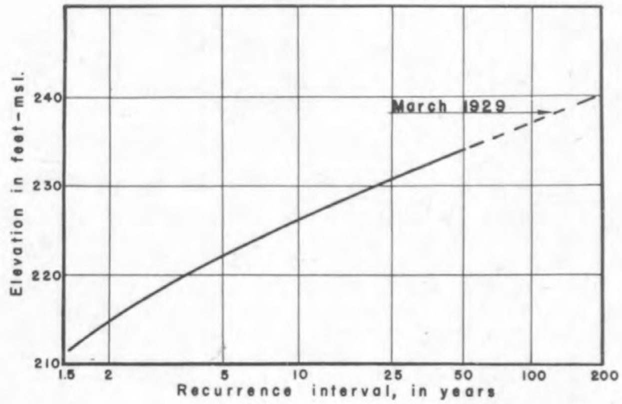
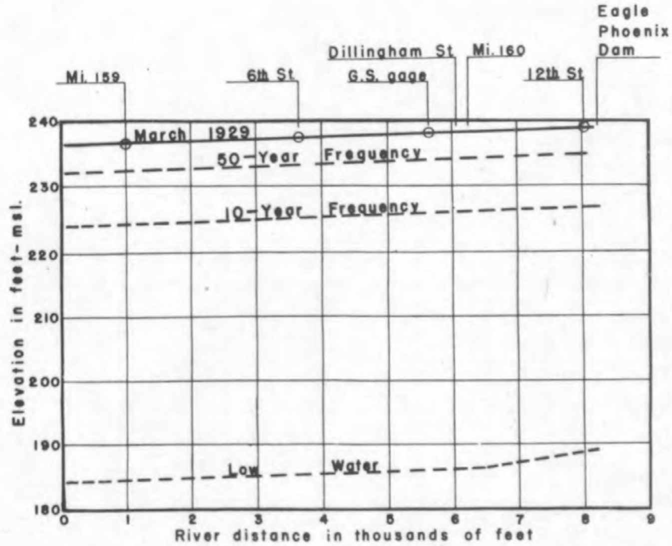


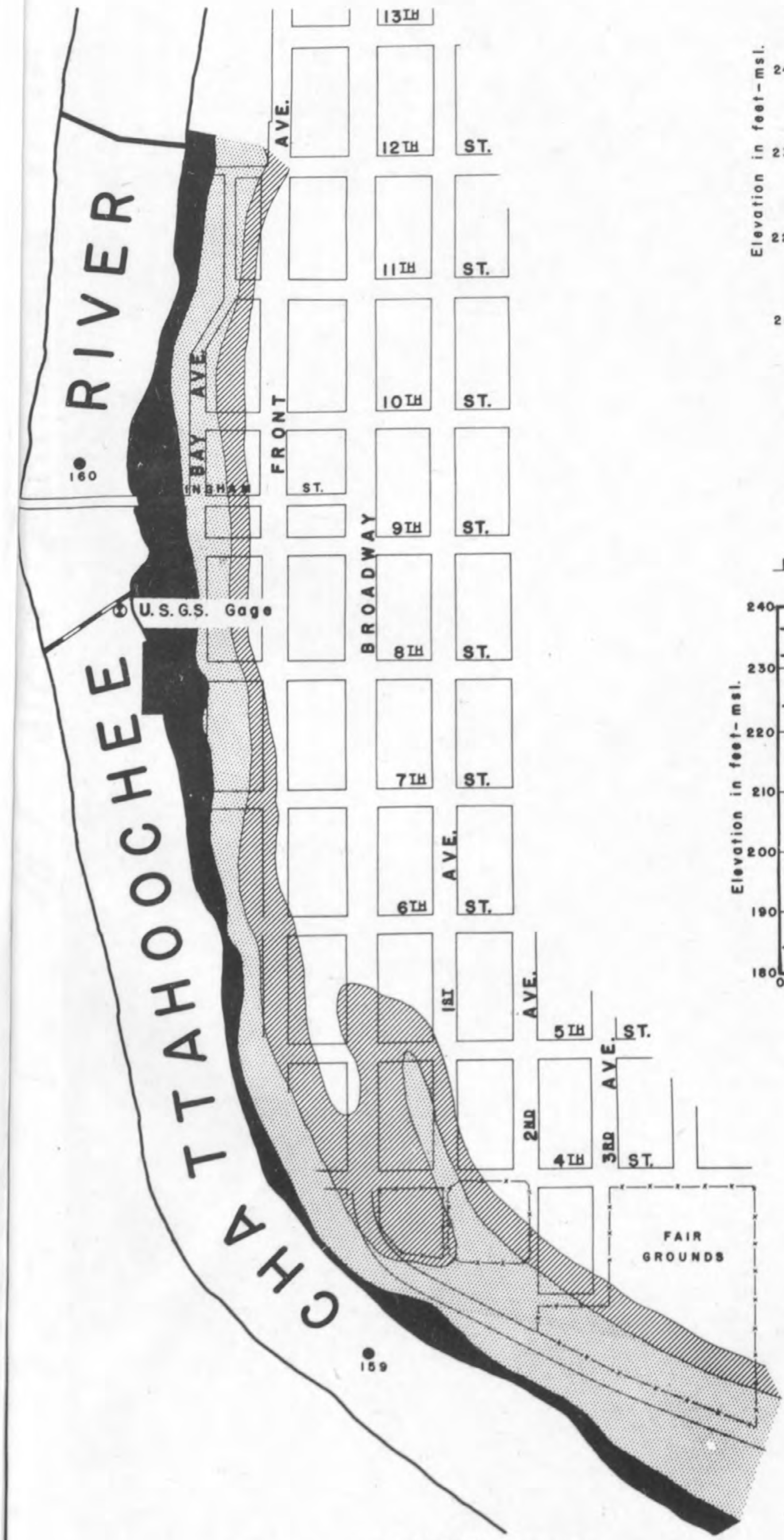
Figure 3.--Schematic damage-frequency curve for a river reach.



STAGE-FREQUENCY CURVE
CHATTAHOOCHEE RIVER AT COLUMBUS, GA.



HIGH WATER PROFILE
CHATTAHOOCHEE RIVER AT COLUMBUS, GA.



FLOODED AREAS
CHATTAHOOCHEE RIVER AT COLUMBUS, GA.

Scale
0 500 1000
Feet

Figure 4.

TABLE of FEES

	Stage (Ft)	Annual Probability of Flooding	Annual Fee per $100 of Insurance
E	35	.0035	.35
D	30	.01	1.00
C	25	.025	2.50
B	20	.10	10.00
A			

1. APPROACH PREDICATED ON FLOOD FREQUENCY
2. REQUIRES DETERMINATION OF LOCATION OF INDIVIDUAL RISK IN RELATION TO RIVER GAUGE READINGS
3. DEVELOPS INDIVIDUAL FEE FOR INDIVIDUAL RISK

Figure 5.

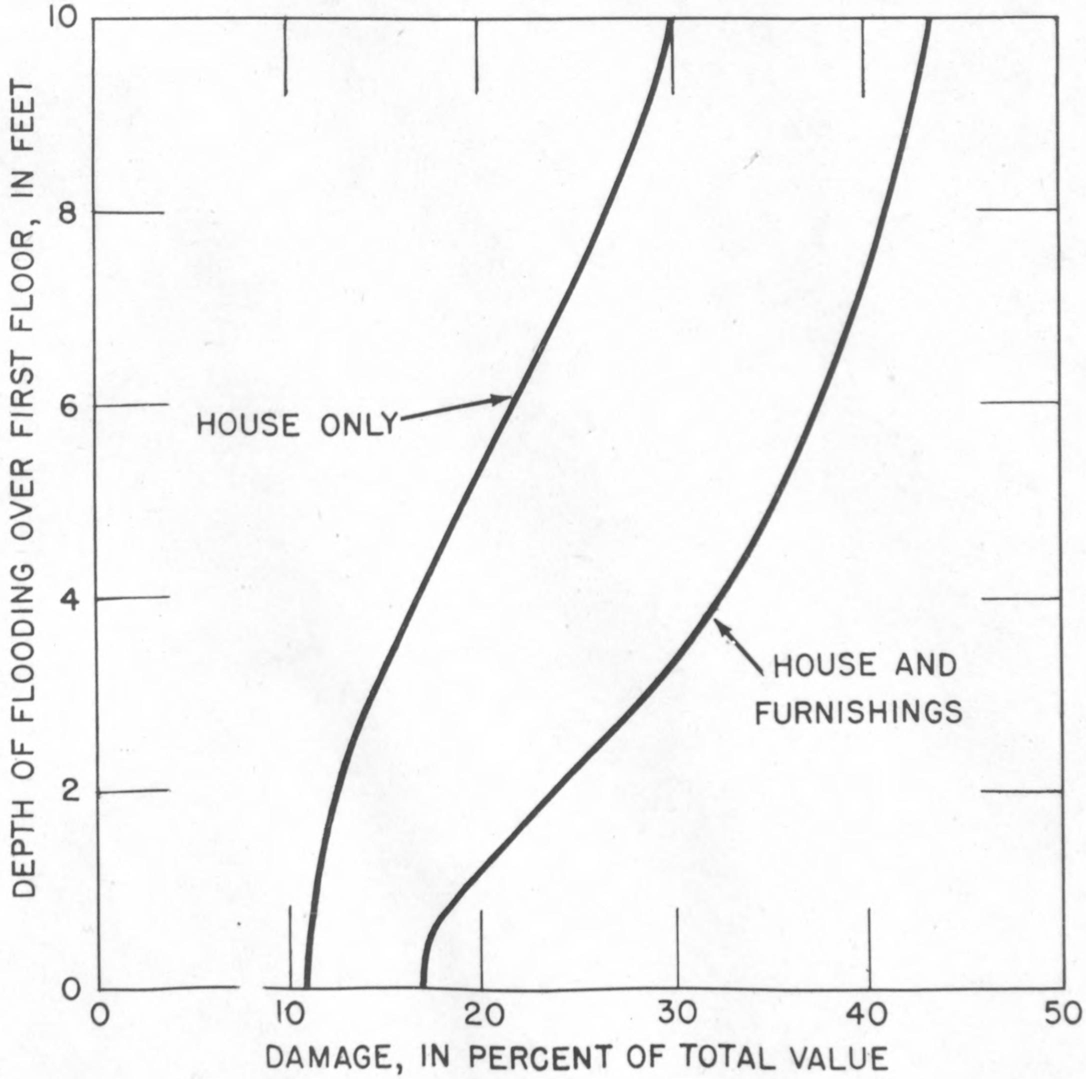


Figure 6.--Schematic residence flood-damage curve.