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THE SYNTHETIC ESTIMATION OF FLOOD DAMAGES: A NEW APPROACH

By Robert W. Kates*

For thousands of years, floods were considered by men as the recurring blessing of a bountiful nature or a terrifying catastrophe that visited death and hunger on entire regions. It is the mark of our developed economy that sees the slow shift from these extremes to the measure of flood impact in more prosaic terms of monetary flood damage.

This paper will review some current methods of estimating and projecting flood damage, their limitations, and a promising new approach. The need for refined flood damage estimates arises from the desire to assess the magnitude of local and national flood losses and the requirements for evaluating flood damage reduction alternatives.

FLOOD PROBLEMS, ALTERNATIVES AND ECONOMIC ANALYSIS

The Magnitude of Flood Losses

Table 1 presents in comparable annual averages, some recent estimates of flood damages in the United States. The great range in the estimates, from a quarter of a million to a billion dollars a year, is a direct outgrowth of variation in the procedures for the collection and projection of flood damage data.

Of equal interest is the widely-held view that flood damages (measured in constant dollars) are increasing over time. This is exemplified by the Corps of Engineers' projection of their 1957 estimate of damage potential that totaled $955 million to $1,313 million (1957 dollars) in 1980.[1]

Three factors have been suggested to account for increases in annual damages: (1) improvement in damage data collection; (2) a short-run increase in flooding; (3) expanding investment in areas subject to flood.[2] After discounting the effects of data collection and an increase in flooding, the increase in annual flood damages is primarily due to the steady pressure to occupy and develop flood plain land, particularly in urban and metropolitan areas. The Corps of Engineers' projection averages a 1.4% annual increase in flood damage potential, and White has estimated the annual rate of increase at 2.7%.[2]

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(Note: Numbers refer to List of References at the end of this paper.)

The increase in damage potential should be considered in the light of our national expenditures for flood control of $5 billion with an annual increase of about $300 million. There is considerable evidence that this flood control effort, while substantially reducing existing damages, actually encourages an increase in damage potential.[2] This appears to be inherent in the nature of flood control which can only provide partial protection, there being few known works protecting against the maximum probable flood. Partial protection, while eliminating the damages from the more frequent floods, may intensify the ongoing trends of flood plain development. When the rare floods occur that are larger than the measure of protection provided for, catastrophic damages result. Furthermore, flood plain invasion has been triggered by the mere anticipation of future flood protection. Partly in response to this somewhat negative appraisal of the success of the flood control program, there has been a broadening of the range of alternatives available for flood damage reduction.

Elements in a Comprehensive Flood Damage Reduction Program

Tables 2 and 3 present the elements available to individuals and public agencies desiring to review alternatives for a comprehensive flood damage reduction program. Some are in widespread use, others are found only in selected situations, and still others are frankly speculative. Taken as a group, they do provide a variety of tools and actions, both public and private, that can reduce flood damages and in ways other than construction of flood control structures: reservoirs, levees, and channel improvements.

In the Lehigh Valley, where we are engaged in a research study, one can find examples of at least five of the six major classes of alternatives. Managers of establishments in the flood plain are bearing losses and reducing losses through emergency actions and flood-proofing structural changes. Land use in the flood plain is being changed by urban renewal and there are examples of reservoir, levee, and channel protection. However, in no case was the course of action chosen by a decision process that lends itself to comparing and choosing an optimal combination of actions from among the variety of available alternatives. In only one case, that of the flood control structures, was there available an organized choice process. that prescribed by federal flood control law.

Economic Analysis in Flood Plain Management

The organized choice process prescribed by the Flood Control Act of 1936 and modified and enlarged both by law and Corps of Engineers practice, deviates considerably from more common governmental decision-making. Congress, by directing the Corps to consider practical alternatives and prescribing the limited decisions criterion that, "the benefits to whomsoever they may occur are in excess of estimated costs," sets forth the basis for a

TABLE 1

ESTIMATES OF MEAN ANNUAL FLOOD LOSSES IN THE UNITED STATES

Source of data	Estimated mean annual food losses: Period of record	Price levels used in published data	Amount in millions of dollars: Published data	Adjusted to 1962 price levels[g]
Total losses				
1. Weather Bureau - published data[a]	1924-1953	Current years	148	232
2. Weather Bureau - release of Apr. 23, 1956[a]	1944-1955	1956	300	312
3. Weather Bureau - published data[b]	1903-1955[g]	Current years	116	194
4. Corps of Engineers allowing for effect of works constructed[c]	1954	1954	419	454
5. Corps of Engineers - allowing for effect of works constructed[d]				
Upstream	1957	1957	417	426
Downstream	1957	1957	538	550
Total	1957	1957	955	976
6. Hoyt and Langbein - adjusted for cost and development[e]	1903-1927	1950-1951	174	190
	1928-1951	1950-1951	240	263
	1903-1951	1950-1951	206	225
7. Department of Agriculture [f]				
Upstream	1952	1952	545	585
Downstream	1952	1952	528	566
Total - including sediment damage	1952	1952	1,200	1,288
Potential losses without protection				
Corps of Engineers[c]	1954	1954	911	986
Corps of Engineers[d]	1957	1957	1,148	1,174

[a] U.S., Weather Bureau, "Notes on Flood Losses in the United States," [illegible] 5614, April 23, 1956.

[b] U.S., Congress, Senate Committee on Banking and Currency, "Federal Disaster Insurance," Senate Report No. 1313, 84th Cong., 2nd Sess. (1956), pp. 37, 57-61.

[c] U.S., Congress, House Committee on Public Works, Comm. Print No. 1., op. cit., p. 2.

[d] U.S., Senate, Select Committee on National Water Resources, Comm. Print No. 15, Floods and Flood Control, 86th Cong., 2nd Sess., p. 5, 27.

[e] William G. Hoyt and Walter B. Langbein, Floods (Princeton: Princeton University Press, 1955), pp. 88-90.

[f] Senate Report No. 1313, supra. pp. 69-71.

[g] Dollar values are adjusted to 1962 price levels according to the wholesale price index for all commodities. Monthly Labor Review LXXXIII, p. 481.

[h] Weather Bureau data were collected for fiscal years (July 1 through June 30) through June 30, 1924, and for calendar years thereafter.

Source: A revision of Table 2 in Changes in the Urban Occupance of Flood Plains in the U.S.

TABLE 2

ELEMENTS IN A FLOOD DAMAGE REDUCTION PROGRAM

INDIVIDUAL ACTIONS

Theoretical Choice of Actions	Possible Individual Actions
Bearing the loss	Bear an unexpected loss** Bear an expected loss* Set aside funds for future loss
Emergency flood fighting, evacuation, and re-scheduling	Maintain stand-by preparations for flood fighting* Prepare advance plans for temporary evacuation of life and property and the re-scheduling of production*
Structural change and land elevation	Use wide variety of structural adjustments presently available for old and new buildings* Land elevation above flood level for new buildings*
Changing land use	Locate structures so as to minimize damage** Change land to open use, such as: playgrounds, parking lots, etc. Abandon high hazard areas*
Controlling floods	Construct levees or walls, channel improvements, detention reservoirs* Request and promote local, state and federal flood control projects** Share in costs of local, state, and federal projects*
Flood insurance	Obtain a policy* (Available under one of the following conditions: (a) High premium (b) Pooled risk with off-flood plain structures in comprehensive policies (c) Structural adjustments reduce more frequent flood damage)

*Present application limited **Present application widespread

TABLE 3

ELEMENTS IN A FLOOD DAMAGE REDUCTION PROGRAM

PUBLIC ACTIONS

Theoretical Choice of Actions	Public Actions to Encourage, Reinforce, or Mandate Individual Actions	
	State-County-Municipal	Federal
Bearing the Loss	Provide flood hazard information* Provide relief to ease suffering and distress but in such manner as to reduce future flood damages	
Emergency flood fighting, evacuation, and re-scheduling	Provide men and materials for emergency flood-fighting**	
	Organize community warning and evacuation assistance plans*	Provide federal warning assistance and expanded radar network** Encourage local disaster plans to provide for flood-damage reduction*
Structural change and land elevation	Use building codes to make mandatory structural changes and/or land elevation Use channel encroachment laws to prevent increased damage to others as a result of land elevation (fill)*	Provide hazard information on which to design structural changes and land elevation* Require structural changes and/or land elevation in flood-prone areas as requirement for HHFA and other loan assistance
Changing land use	Mandate patterns of land use by flood plain regulations* Encourage open uses** Prohibit uses subject to high damage or loss of life** Use condemnation power and/or urban renewal to change land use	Provide hazard information for design of regulations* Require flood plain regulations as a provision for flood control, urban renewal, and similar assistance Use HHFA and other federal loan assistance powers to discourage improper flood plain use* Provide federal aid to permanently evacuate flood plain*
Controlling floods	Construct flood control projects* Request and promote state and federal flood control projects** Share in costs of federal projects*	Provide flood control in the form of levees, walls, channel improvement, land treatment, detention reservoirs**
Flood insurance	Provide standardized flood hazard information on which to base rate structure	
	State supervision of insurance companies to encourage commercial policies that promote minimization of flood damages Subsidize a state-federal insurance program	Subsidize a federal or federal-state insurance program (Administered to promote minimization of flood damages)
	*Present application limited	** Present application widespread

TABLE 4

ECONOMIC ANALYSIS FOR ALTERNATIVE ACTIONS OF A BUSINESS ESTABLISHMENT

ALTERNATIVES

HYDROLOGIC ASSUMPTIONS	INTEREST RATE	BEARING THE ENTIRE LOSS	RESERVOIR PROTECTION		IMPROVED FLOOD WARNING		FLOOD PROOFING		FLOOD WARNING AND FLOOD PROOFING	
		RESIDUAL[a]	B/C[b]	RESIDUAL	B/C	RESIDUAL	B/C	RESIDUAL	B/C	RESIDUAL
A	2-5/8%	$41,390	1.41	$14,663	5.31	$27,667	0.69	$38,872	3.10	0
	5%	27,311	0.69	9,676	5.14	18,256	0.46	25,650	2.13	0
B	2-5/8%	19,118	0.67	3,458	4.57	8,095	0.63	16,855	1.45	0
	5%	12,615	0.44	2,282	4.43	5,342	0.41	11,122	0.99	0
C	2-5/8%	6,889	0.23	1,245	1.62	2,850	0.21	6,131	0.52	0
	5%	4,546	0.15	822	1.57	1,880	0.14	4,046	0.36	0
D	2-5/8%	5,423	0.27	0	1.84	1,400	0.22	4,615	0.42	0
	5%	3,578	0.18	0	1.78	924	0.15	3,045	0.28	0

a: Present value of 50 year stream of residual damages discounted by 2-5/8% or 5% .

b: Ratio of present value of benefits (damages averted) to present value of costs.

process of economic analysis when the federal government participates in flood plain management. If the development of more sophisticated benefit-cost analysis, linear and dynamic programming techniques, systems analysis, and the like find the present practice suboptimal and economically unsound by not maximizing welfare, we should not denigrate the historical importance of this process. If we examine other governmental activity, we find that highways are built, cities are redeveloped, farm prices juggled, all without the benefit of even this minimal economic analysis. Furthermore the very inadequacies found in present practice have spurred the rapid development of theory in water resource allocation.

In the benefit-cost analysis of flood control activity, costs are of the same straightforward variety as those of other water resource activities. Construction costs, labor costs, etc., are estimated by well-established practices. It is in the concept of benefits that flood control seems to differ from other river development purposes. Barring an active flood control market, we turn to the with-and without procedure by asking what is the value of the stocks and flows of goods and services that would appear with the project compared to that without the project. However, with flood control benefits, only a small portion of benefits are usually attributable to increases in value and this often to enhancement of land value. Instead, the greater portion of the benefit is derived from preventing an anticipated impairment of the present stocks of goods and services and a decrease in future flows of the same.

From this brief look at the magnitude of flood losses and the range of available alternatives and their evaluation, we can identify at least four areas for which flood damage estimates are required:

1. Measuring the magnitude of local or national flood problems over time;

2. Testing the economic feasibility required for congressional approval of flood control projects;

3. Providing alternative sets of benefits with which to choose combinations of flood damage reduction programs;

4. Providing benefits that might be compared with other uses of water resources and reservoir storage.

THE CONSTRUCTION OF FLOOD DAMAGE ESTIMATES

The Estimate of Damage From Historical Flood Events

For an experienced flood event there is wide agreement that tangible flood damages can be classified in at least three major categories:

(1) physical damages to property from the immediate or delayed effects of inundation, (2) costs associated with emergency flood fighting, evacuation and relief, (3) losses resulting from flood-induced interruption of economic activity.

The procedures for the collection of flood damage data for even a single flood event might vary considerably. The Weather Bureau, which maintains the only consistent time series of flood damages, relies primarily on mail questionnaires to local officials and industries. Agencies with substantial funds for flood damage data collection such as the Corps of Engineers or Tennessee Valley Authority might dispatch appraisers to the scene of a particular flood. The personnel might vary considerably in skill and experience, depending on the availability of manpower at the time. In the case of the 1955 flood in the Lehigh Valley, the work was contracted to a large consulting firm.

The field damage survey is basically a questionnaire type of survey, with managers of damaged property being interviewed as to the various types of damages experienced in accord with a pre-existing classification. The reported damages both in type and valuation are reviewed by the interviewer-appraisers for whom there are fairly clear guidelines as to admissable damage.

These general guidelines suggest the following: Physical damages are best appraised by the restoration cost-less-depreciation or comparative sales methods. Income capitalization methods are best used in the case of agricultural damages. Emergency damages are appraised by the out-of-pocket costs of emergency activities induced by the flood event. The interruption of economic activity is to be measured by the net loss of goods and services not recouped elsewhere in space and time.[3]

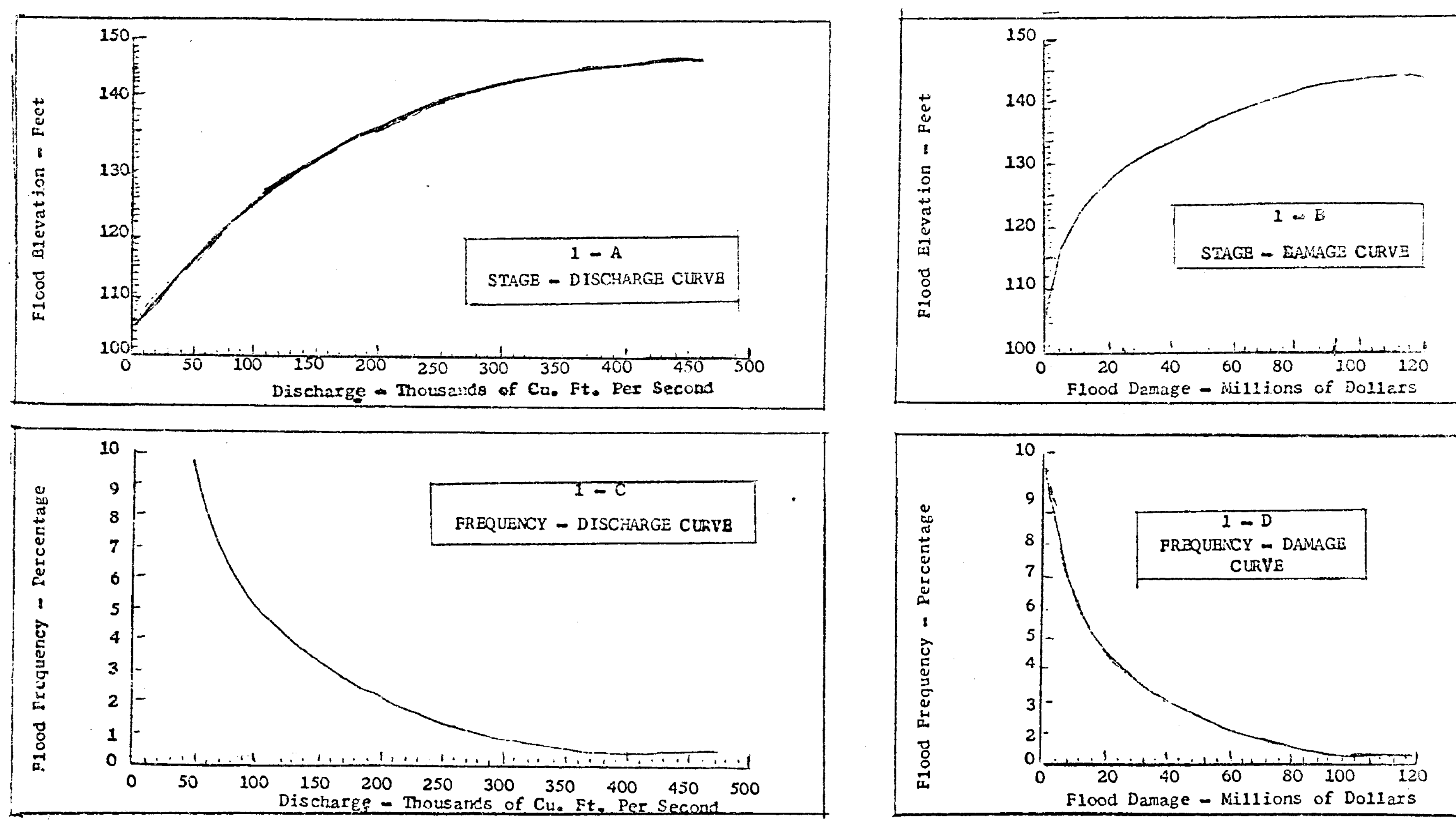
The construction of a historical flood damage series requires the aggregation of the damage surveys of many such flood events. The damage series for even a single location may be of mixed accuracy. In most cases the damages reported for early historical floods are those found in newspaper reports. For some flood occurrences, no damage data will be available. Thus it is not strange to find that some of the increase in damage previously noted is directly attributable to improvement in the coverage of data collection. Despite these shortcomings a historical damage series is on safer ground than the calculation of flood benefits, which must rely on the projection of a historical flood damage series to the future.

<u>The Estimates of Damage From Future Flood Events</u>

The projection of historical damage data into the future may be done

FIGURE 1

FLOOD DISCHARGE AND DAMAGE FREQUENCY CURVES



in two ways, both of which assume that future flood damage bears a direct relationship to the damage experienced in the past.

The "historical floods of record" method is used only where there has been developed a long historical series of flood damages. This historical series is then projected directly into the future with the assumption that the best estimate of the future is to assume the reoccurrence of the past.

The second method, in more common usage, uses the historical series of floods and flood damages to develop four functions. A graphic example of these functions is shown on Figure 1. Function 1-A is the relation between discharge, a volumetric-time measurement of streamflow, and flood height or stage. This is known as the stage discharge curve and is derived from the physical relations of a homogeneous reach of the river. Function 1-B is the stage-damage relation derived from the historical series, in which height of flooding is related to constant dollar estimates of recurring damage. Function 1-C is derived from a probability analysis of the historical record of flood events and attempts to fix the probability or frequency of occurrence in any year of floods of given magnitudes or greater. These graphic functions are conbin ed in function 1-D that relates frequency and damage. When weighted correctly, the area under the curve 1-D represents the average annual damages for the specific reach of the river. Similarly, the effects of structural improvements can be determined.

Both methods lend themselves to the additional refinement of assuming some growth rate of flood plain development and using this as an escalating factor to increase the projected future flood damages. It is Corps practice to consider growth rates greater than would normally occur without a flood control project as a benefit of enhancement to land and property rather than that of damages averted.

While this review of existing practice has been too brief to develop the evolution of damage estimating methodology, we should take note of the considerable effort expended by the appropriate agencies in the improvement of damage collection procedures and in methods of projecting future damages.

Difficulties in Historical Flood Damage Estimation

The methodology just described is prone to a variety of difficulties that impair the usefulness of the damage estimates.

The first group of difficulties are related to the nature of the damage survey as a sample both in time and space. A flood covers a large segment of the earth's surface when it occurs. There are a variety of emergency needs that tax the manpower of agencies, such as the Corps of Engineers or the weather bureau, which combine operating, planning and research duties.

Despite the fact that manpower is frequently limited, random sampling designs are seldom or never used. Surveys are designed for 100% coverage even at the cost of superficiality or serious problems of interpolation when they cannot be fully completed.

A damage survey takes place at a fixed point of time, while many damages result from dynamic processes set in motion by the flood. A survey taken immediately after a flood tends to underestimate long-term effects such as the warping of floors or the settling of buildings. On the other hand, they would tend to overestimate the effects of business disruption; the full potential for recouping losses not having been realized as yet. Surveys of damage are undertaken when they can be organized, in many cases on the heels of floods, in others, months, or even years, afterwards.

There are serious sampling problems of interviewer and respondent error. We have already noted the variability in appraiser personnel quality that may effect the reliability of estimates. Sources of respondent error would appear to be even higher. Floods are traumatic human experiences that often color damage reports. Widespread misunderstandings about the insurance coverage, depreciation, salvage potential, and business losses provide motivation for non-random biases in respondent replies.

Another source of difficulty arises from trying to make operational the guidelines for the admissibility of damages. To follow the guidelines stringently, a great deal of economic data is required. In practice the guidelines frequently appear to be watered down, generally in the direction of accepting inadmissible damage claims. Even with the best of intention such amorphous statements as "assume relative high levels of economic activity" are subject to wide interpretation. There are very real problems of evaluating factors for which no markets exist, for tracing transfers of flood disrupted production of goods and services through an integrated economy, of determining the permanency of the depressant effect of a flood on the land market, and the like.

A further problem arises out of an inherent quality of the damage data that sharply limits their usefulness in assessing alternatives that involve the behavior of individual flood plain users. Damage data represents residual damages, i.e., those damages that remain after the effect of damage-reducing actions. If behavior was fairly uniform, the effect of emergency flood fighting actions, flood proofing, and the rescheduling of production might be estimated. However, studies carried out in six small flood-prone communities suggest one of the characteristics of certain flood areas is tremendous variability in flood damage reducing behavior.[4] Thus it was not unusual to find, as we did in El Cerrito, California, in the space of several city blocks a heavily flood-proofed plant and brand new apartment buildings built in total ignorance of the flood hazard.

Early in this paper we stated the broadened range of choice available for flood damage reduction. Unfortunately the present classification of flood losses distinguishes only between the residual destructive and disruptive losses. To compare alternatives of flood damage reduction, we require a classification scheme for flood losses by their susceptibility for reduction through alternative means. We should be able to estimate what proportion of flood losses could be reduced by an organized flood warning system, by flood proofing masonry structures, by reorganizing seasonal production, by restricting land use, and the like.

Difficulties in Future Flood Damage Estimation

The projection of damage estimates into the future requires two hazardous assumptions.

The first assumes that the hydrology of the past, the magnitudes, velocities and patterns of overbank flow of the experienced floods are an adequate sample of future hydrologic time. In effect we are trying to predict the nature of an almost infinite period of climatological time with hydrologic records limited in length from 10 to 100 years. While wanting to spare this audience a detailed analysis of our statistical frailty in the face of the great uncertainty of an indeterminate nature, a warning is in order. Graphic relationships such as shown in the discharge-frequency function of Figure 1-C are at best loose approximations of the relative frequency of flood events of varying magnitudes. With the best hydrologic methodology wide differences occur. By way of illustration, one can cite the long-run average return period of the flood of record of the Lehigh River at Bethlehem, Pennsylvania, which ranges from 27 to 75 years depending on which of three highly respected methods are used in its calculation.[5]

The second assumption is the projection of past land use, with or without a growth factor, and the ensuing flood damage into the future. To most economists the hazard of this type of projection is an occupational disease and I would scarcely need to dwell on the potential for error in this process. It is worth noting, however, that even when one is armed with a deep understanding of relevant local economic factors and possesses adequate projections of economic activity and the demand for land, the market for flood plain land may vary considerably from overall economic trends.

The assumption that the past pattern of flood damages would be repeated by floods of a similar magnitude in the future is further modified by the Corps provision for eliminating non-recurring damages. Thus a bridge washed out and replaced by a more flood-resistant structure is not to be projected into the future as damage potential. However, the actual operation of this provision leaves much to be desired. Most flood resistant replacements of damageable property take place long after a flood survey. Recent research indicates that many minor flood damage reduction actions take place incidental to normal replacement, expansion, remodeling, and the like.[4] Further, the occurence of frequent flooding seems to generate a process of adaptation, akin to learning by trial and error, that tends to reduce or stabilize damage potential in some areas. This second assumption, with the exceptions noted, assumes a static human behavior and this is never a confortable assumption in a dynamic world.

Finally, the discounting of flood benefits to present value must always result in under-/or over-statement of the present value of damages. This arises out of the probabilistic nature of the damage estimates. Since our discharge-frequency curves only tell us of long-run average occurrences, we assume a steady stream of damages and the resulting benefits over time. But floods never come in average annual installments and the probability of an even distribution through time is minute. Therefore the average annual damage method, when summed as a stream of benefits discounted to the present, will overestimate the actual flood benefit when the major floods occur late in the planning period and understate the benefit if the floods come early in the planning period.

THE CHALLENGE POSED BY SYSTEMS ANALYSIS FOR IMPROVED FLOOD DAMAGE ESTIMATES

We have seen a rapid expansion in the recognition of valued outputs of water resources. While supply facilities have been strained, the quantity and variety of demand for water-oriented goods have rapidly increased. Faced with a multiplicity of ends and large combinations of means, it was only a matter of time for river planning to turn to the tools of the high speed computer and the methods of systems analysis for assistance. In this respect, the work of the Harvard Water Resources Program has been outstanding.[6]

The computer also lends itself to simulating stochastic processes; the ability to generate realistic simulations of river flows including floods is a most promising development. Using these methods, one can run hydrologic traces over thousands of years and explore the variations in flow through time for their effect on benefits and costs as well as operating procedures of flood control structures.[6 7]

Still a third development is the potential for detailed modeling of regional economies and simulating them through time. I see on the program that a pioneer model of this type will be discussed tomorrow.

This computer capability poses a technological incentive for improvement of flood damage estimates. If we can optimize alternative water resource use, why not flood-damage reduction alternatives as well? If we can synthesize hydrology, then why not synthesize flood-damage estimates? If we can simulate a regional economy, then why not simulate flood plain growth or decay?

THE SYNTHETIC ESTIMATION OF FLOOD DAMAGES

The title of this talk is somewhat misleading. Like all new approaches, synthesizing flood damages has early and distinguished forebears.

Generalized Stage Damage Relationships

The various agencies concerned with flood damage estimation have displayed over the years interest in deriving more general relationships of damage, land use, and type of structure. This effort has primarily centered on residential housing which, by its relative simplicity and repetitive nature, would provide a good point of departure. Thus one finds in materials used by the Corps, as early as 1947, stage damage curves reflecting average generalized experience of the effect of floods on specific classes of residential housing. In Figure 2, curves A, B and C represent functions of this type. Curve D is taken from a more ambitious study of the Stanford Research Institute undertaken at the behest of the Soil Conservation Service and is derived from the study of 355 flood damaged properties in 1958.[8] It is my understanding that all the curves are derived from interviewer-appraiser type of data.

These generalized relationships, when conservatively constructed and applied to land use distribution in various flood zones, go far in meeting some of the difficulties previously posed. They provide the consistency of estimates often lacking from present data and are less dependent on respondent observation and estimates. Their application requires less experienced help, employs common definitions of damage admissibility and provides a better basis for allowing for future growth or decline in the flood plain than across-the-board factors. However, they have been developed only for residences and display considerable variation in their estimates for floods of the same height. But most important, they are still estimates of residual damage data and do not provide the basis for evaluating alternative flood damage reducing actions.

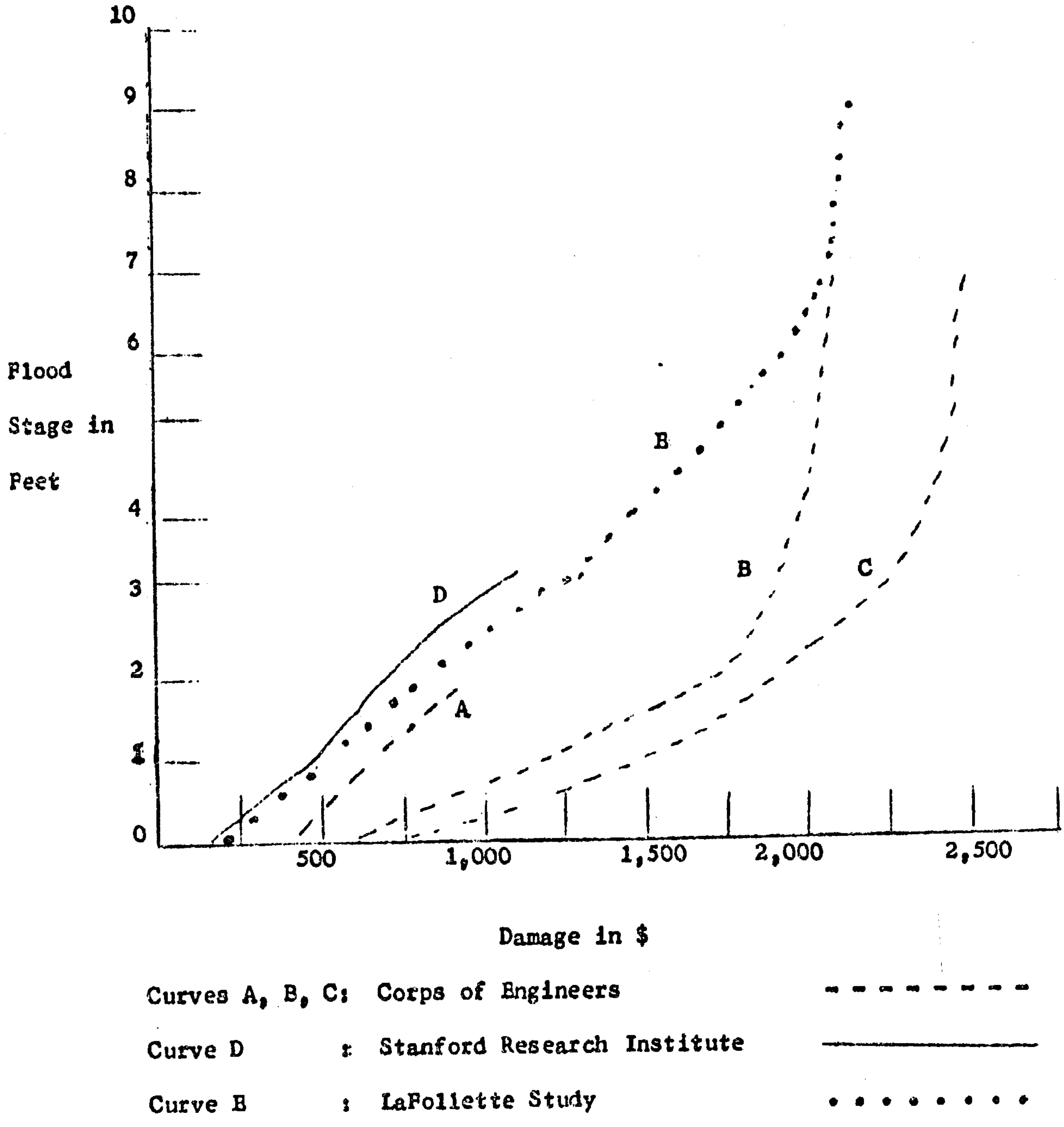
The LaFollette Study

A related but somewhat different approach is exemplified by Curve E in Figure 2. This stage damage relation is derived from a forthcoming study of 250 commercial and residential establishments in the flood plain of Big Creek, LaFollette, Tennessee, (pop. 7,000).[9] In the summer of 1960,

Figure 2

COMPARISON OF STAGE DAMAGE ESTIMATES FOR

$4,000 RESIDENCE



field work was undertaken by Professor Gilbert White and a group from the University of Chicago. The study resulted in the estimation of stage-damage curves for residences of different types and values and for a variety of commercial enterprises as well.

The stage-damage curves possess two unique features. First they were simulated independent of the flood experience or opinion of the manager of each establishment. They provide a set of consistent estimates of flood damage made under conservative economic assumptions by a small close-knit team of geographers. In general they are based on restoration-less-depreciation using local costs obtained as part of the field work.

The second unique feature was the division of the damage data by potential alternative flood reducing actions. For each of five different alternative actions, a separate stage-damage curve was derived. The stage damage function shown in Figure 2 is "pure", i.e., it is based on the assumption that a flood strikes with little or no warning during the night and that emergency actions other than the evacuation of persons is impossible. Other stage-damage curves embody the assumption of an upstream flood control reservoir, a modern flood warning system and planned evacuation of property, structural changes by flood proofing and land elevation where technically feasible, and the shift in land use by municipal zoning control. Based on these curves and data on the costs of these alternatives as well, benefit-cost ratios were calculated using four different assumptions of hydrology and two discount rates. These data are being readied for publication but Table 4 gives a sample of the output.

These data are also being analyzed for even broader relationships. Are there consistent relations for various structures or economic activities between flood damages and floor space or the values of inventory and furnishings? For many commercial activities there are well-known operating ratios and such things as floor space to inventory relations. If these can be related to flood damages, the relation of damage to economic activity will be much better understood and the simulation of future economic activity can be directly converted into refined damage estimates.

The LaFollette data covered only commercial and residential establishments. Under the aegis of the Harvard Water Resources Program and the financial support of the Corps of Engineers, we are undertaking a small pilot study in the application of these methods to reaches of the Lehigh River, particularly those heavily industrialized.

Conclusions

This approach to damage estimation is in its infancy. It is research of the risk variety and although showing great promise may also bog down by the sheer weight of both the uniqueness and variety of economic enterprise. But even our preliminary appraisal of this method suggests the following conclusions:

1. There would appear to be no operational or analytical obstacles to the simulation of both synthetic hydrology and flood damage estimates under the present state of the arts.

2. Given some well established basic relations, current inventories of flood damage potential could be maintained by efficient sampling designs of detailed land uses only.

3. Stage-damage curves derived for a variety of land using activities can help provide guide lines for the rational local control of flood plains by identifying the specific relative susceptibility of various activities to flood damages.

4. Data of this type coupled with synthetic hydrology enable computer exploration of optimal flood damage reduction programs, combining flood control structures with non-structural alternatives and exploring the response surface.

There are two major limitations of the synthetic damage approach. The first may prove to be its limited application. While we must await the results of the Lehigh study it would appear that even with most sanguine of possible results, many commercial and industrial damage estimates will be unique for some time to come. However, when coupled with a field inspection, individual stage-damage curves could be constructed for different assumptions of flood-reducing behavior.

The second major limitation is the apparent lack of realism of this process. Estimates of damages that have occurred can be readily assimilated by Congress and the general public. The synthetic damage data is fiction, albeit science fiction of a high order. In fact it may be of higher order, i.e., more scientific and less fictional than the "real" damage data themselves. As we have pointed out, all damage estimates of future floods are fictional. Neither history nor hydrology repeats itself exactly, if at all. Thus projections of carefully controlled assumptions as to what would happen may be a better index to the future than a mixed bag of assessments of what did happen.

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