A Critical Assessment of Methodologies for Estimating Urban Flood Damages-Prevented Benefits

by

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OF METHODOLOGIES FOR ESTIMATING
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CHAPTER 1

Introduction

Purpose

Of all the benefit categories in water resource economics, reduced urban flood damages are usually seen by study managers, as being among the most precise. Benefits are calculated in a straightforward manner by combining various engineering-economic relationships. Inherent in this methodology are assumptions and potential pitfalls which the analyst and reviewer should be aware of and which are often obscured by the extensive stacks of calculations generated by computers. Few of these caveats are addressed in the literature.

The purpose of this paper is to (1) provide a clear and complete discussion of methods of calculating urban flood damages-prevented benefits, and (2) critically appraise these methods with emphasis on identifying data, assumptions, and techniques which may lead to erroneous estimates of benefits. The methods discussed are those which are currently being used and refined. They represent the current state of the art. These methods were identified by an extensive literature search, the author's experience in three different Corps of Engineers Districts, and informal discussions with various economists dealing in flood control evaluations. By far, the most common method to estimate urban flood damage-reduction benefits is the frequency-damage method. Accordingly, emphasis will be on this method and its variations.

Definitions

Classifications and definitions in this paper are consistant with those published by the Water Resources Council.[1] Flood control benefits may be classified as inundation reduction benefits, intensification benefits, and location benefits. These are defined below:

- Inundation reduction benefit. If floodplain use is the same with and without the plan, the benefit is the increased net income generated by that use. If an activity is removed from the floodplain, this benefit is realized only to the extent that removal of the activity increases the net income of other activities in the economy.
- Intensification benefit. If the type of floodplain use is unchanged but the method of operation is modified because of the plan, the benefit is the increased net income generated by the floodplain activity.
- Location benefit. If an activity is added to the floodplain because of a plan, the benefit is the difference between aggregate net incomes (including economic rent) in the economically affected area with and without the plan.

The focus of this paper is on inundation reduction benefits.

This paper will restrict its discussion of benefits to reduced property damages to structures and contents. This benefit category typically comprises the largest portion of urban flood control benefits. Although other flood damages-prevented categories (e.g., increased travel cost or damages to roads) will not be specifically addressed, many of the comments may be applicable to such categories. For semantic ease urban inundation reduction benefits to structures and contents may be referred to as flood control benefits.

Theory

The theory of measuring flood damages-prevented benefits is relatively simple. Flood control is, perhaps, the classic public good. If a flood

[1]Water Resources Council, "Procedures For Evaluation of National Economic Development (NED) Benefits and Costs In Water Resources Planning (Level C); Final Rule", Federal Register, December 14, 1979.

control project (e.g., upstream reservoir, levee, or channel enlargement) is constructed there is no easy way to market the demand for flood control since non-paying individuals cannot be excluded without government intervention. With no market demand to directly measure, benefits are based on the assumption that rational individuals would be willing to pay an amount up to the expected flood damage in order to avoid the flood damage.[2] Benefits are estimated as the present value of flood damages without a project minus the present value of flood damages with a project.

Some have argued that measuring flood damages-prevented benefits as the difference between damages without a project and damages with a project may be an overestimation of benefits. It has been observed that many people are unwilling to buy flood insurance which, ignoring administrative costs and assuming actuarial rates, has a cost equal to expected annual flood damages. The argument is that if people are not willing to pay up to the expected amount of damages then benefits are overestimated.

It has been suggested that people do not buy flood insurance, even when it is subsidized, because people tend to ignore what they perceive as a remote possibility. But whatever the *ex ante* willingness to pay for flood control, once a flood has occured people do repair their homes and businesses unless, of course, the repair cost would exceed the value of a similar unflooded structure. As long as people who are financially capable of repairing and replacing flood damaged items do repair and replace those items, flood damages are an indication of willingness to pay and a valid measure of potential benefits.

[2]Given the trauma, disruption and inconvenience of having one's house flooded, it has been hypothesized that a person may be willing to pay an amount in excess of monetary damages.

Within this theoretical framework it is assumed that prices reflect social values. There has been much written on this, and it will not be repeated here. There is one area, however, in which analyses have been inconsistent and which, to the author's knowledge, has not been recognized in the literature. It has been widely acknowledged that where the construction of a project will utilize labor which otherwise would be unemployed, the cost to society for the labor is less than the market wage cost. Although this is, conceptually, a reduction in cost, it is usually counted as a benefit to simplify presentation, cost allocation, and cost sharing.

If unemployment exists in the construction trades used to build the project such that wages paid to construct the project would overestimate the social cost of labor then, to the degree that the same skills are needed to repair and reconstruct flood damaged structures and to the degree that unemployed people will find work in repairing and replacing damaged contents, the social cost of such damage would be overestimated. Therefore, for all flood control projects where benefits to unemployed labor resources are calculated, it seems likely that the social value of flood damages prevented should be reduced for whatever period the unemployment is expected to persist. Use of otherwise unemployed labor in project construction has long been accounted for in analyses. The fact that such labor may also be used to repair flood damages appears to have gone unrecognized.

If the construction trades are fully employed prior to a large flood the increase in demand for repairs may result in "overfull" employment. This issue will be addressed in Chapter 2 and Appendix B.

Overview This paper consists of 4 chapters; (1) this introduction, (2) estimates of expected damages to one structure at one point in time, (3) estimates of expected damages to many structures at one point in time, (4) estimates of expected damages over time, and (5) the conclusion.

By far, the most common method to estimate urban flood damage reduction benefits is the frequency-damage method. Accordingly, focus will be on this method and its variations.

CHAPTER 2

Expected Damage To One Structure At One Point In Time

Introduction

The frequency-damage method is the most common method used to estimate flood control benefits. The frequency-damage method involves calculation of expected damages where the damages are weighted by the probability of occurrence. Calculation of expected damages involves 4 steps: (1) estimating a stage-frequency relationship, (2) estimating a stage-depth (of flooding) relationship, (3) estimating a depth- (of flooding) damage relationship, and (4) determining and integrating the frequency-damage relationship. Typically these steps are explained in terms of a four-quadrant graphical analysis whereby the steps are related by common axes.[3] An alternative tabular presentation of steps 1-3 is shown in Table 1. Step 4, which relates damages (the last column) to frequency (the first column) to derive an expected value, is presented later. It is felt that this presentation is easier to understand and, with the proliferation of the computer, more accurately represents the way calculations are actually made today.

Stage-Frequency Relationship

Step 1, estimating the stage-frequency relationship, is the province of hydrologists and hydraulic specialists. Hydrologists estimate rainfall areal patterns, intensity, duration, and run-off for storms of selected

[3]See, for example, Guidlines for Flood Loss Prevention and Management in Developing Countries, p. 118, United Nations Department of Economic and Social Affairs, 1976.

TABLE 1

Estimating Expected Annual Damage
Steps 1-3

Step 1		Step 2			Step 3		
Year Flood	Expected Flood Frequency	Flood Stages at all River Miles	Flood Stages at River Mile of Structure (R.M. 2.5)	First Floor Elevation of Structure	Depth of Flooding	Percent Damage	Damage ($)
500	.002		510.1		7.1	50	25,000
100	.01		508.3		5.3	44	22,000
50	.02		505.8		2.8	31	15,500
25	.04		503.1	503.0	0.1	11	5,500
10	.10		502.8		-0.2	0	0
5	0.2		501.5		-1.5	0	0

frequencies. Hydraulic specialists combine this data with additional data such as river cross-sections and estimates of channel roughness to route the flood peak down the river. The result of these calculations (as far as the economist is concerned) is water surface profiles which show the water surface elevation for various frequency floods throughout the relevant river length. A hypothetical profile is shown in Figure 1.

Much has been written on the advantages and disadvantages of various techniques used to calculate these profiles and on the inherent problem of estimating the profiles based on limited data. With the heavy use of computer modeling and statistical techniques, this may be a fruitful field for formalized discussions of risk and uncertainty.[4] But detailed discussion of such factors is beyond the scope of this paper.

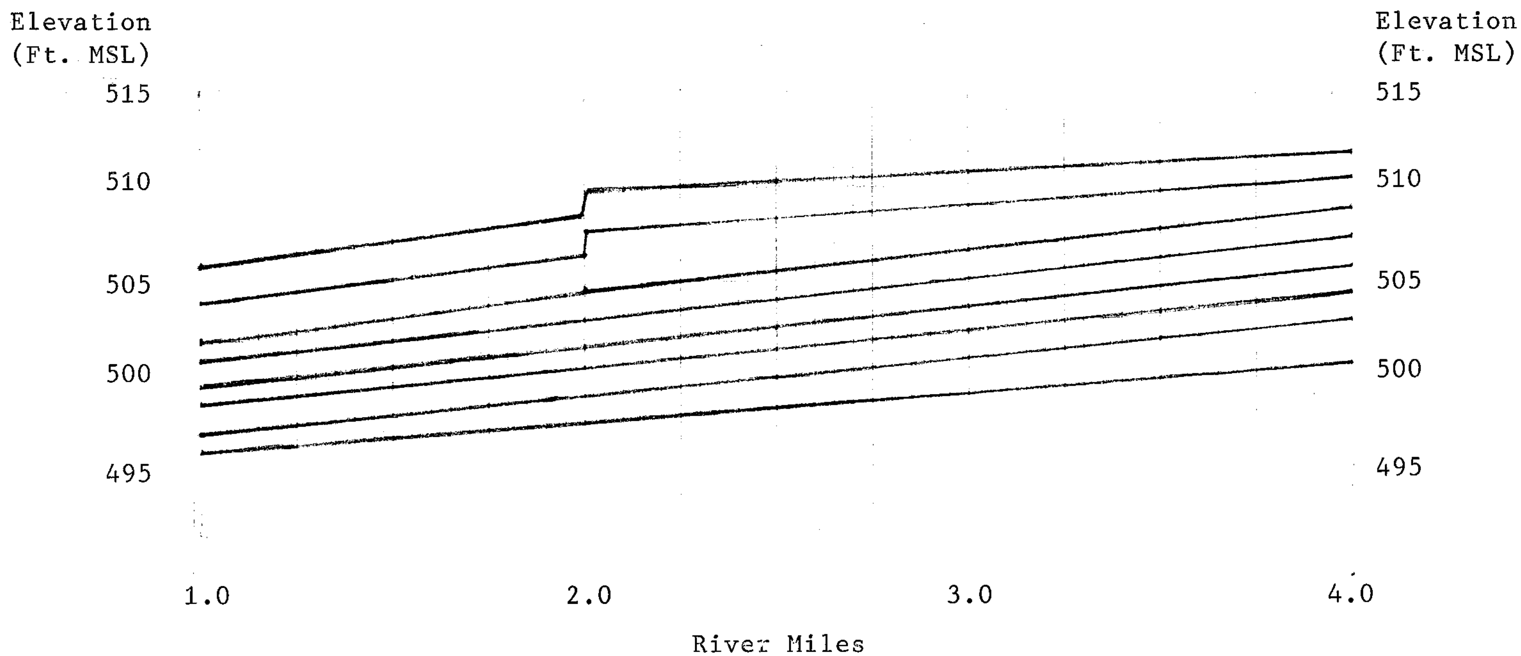
Stage-Damage Relationship

Water Depth Step 2, estimating the stage-depth relationship, consists of several parts. First, the structure must be located relative to the flood profiles (Figure 1). In the simple case of a straight river this consists of drawing a line perpendicular with the river through the structure. The river mile at which the line intersects the river is then looked up on the flood profiles to reveal the elevation of the various flood frequencies at that river mile. Assuming the structure is at river mile 2.5 (Figure 1) the elevations of various frequencies of floods are shown in column 3 of Table 1.

Next, the elevation of the structure is determined. This can be done

[4]See, for example, G.W. Kite, Frequency and Risk Analysis in Hydrology, Fort Collins, Water Resource Publications, 1977.

Figure 1 Hypothetical Flood Profiles



in several ways. The elevation can be exactly surveyed. The elevation can be estimated from available countour maps. Based on a known nearby spot elevation the structure elevation may be estimated. The process is mundane but it can be a source of significant error. For every one foot error in elevation, depth of flooding to the structure will be off by one foot. Reliance on maps with a contour interval greater than two feet can lead to errors, particulary when there is little difference in the elevations of floods of very different frequencies.

Intuitively it would seem that for a large number of structures the errors should approximate a normal distribution, would average out, and would not affect the final result. But the effect of over- and underestimates of elevation is asymmetrical and thus will not balance out. This is true because depth-damage curves tend to be non-linear, and thus within the range of damaging depths equal over- and underestimations of flooding do not result in equal over- and underestimations of damages. But even if the depth-damage curve were linear over- and underestimates of structure elevation will not offset each other because overestimates of elevation can not result in negative damages. Underestimates of elevation may substantially increase damages and are only limited by the structure value. Overestimates of elevation may not decrease damages below zero. Appendix A presents a numerical example of this.

The averaging out argument also assumes that the map contours are correct. In a flood study in Hamlin, TX the city map, with a one-foot contour interval, was shown by survey to be off by as much as two feet. Where maps with larger contour intervals are used, the chances of significant error are correspondingly greater. Inaccurate contour maps may result from human error or changed geologic conditions, such as land subsidence.

As a test case, the author estimated existing expected annual damages to 204 structures in Hamlin, TX using estimated and actual first floor elevations. Estimated first floor elevations were based on a structure-by-structure survey using the one-foot countour maps. In a later stage of the study when detailed cross-sections were being surveyed for more detailed hydraulic studies, floor elevations were obtained to the nearest 0.1 feet at a relatively small incremental cost. Flood profiles were generally close (less than 3 feet difference between the 5 year and 100 year flood through the developed area) indicating that damages should be sensitive to errors in floor elevation. Using estimated floor elevations expected annual damages were $337,000. Using surveyed floor elevation expected annual damages were $207,000. The difference of $130,000 (63 percent) is not insignificant.

Whether the economist relies on contour maps or detailed surveys, he should check with the engineers to insure data consistency. If, in an area of rapid subsidence, the engineers and economist use datum applicable at different points in time the resulting analysis will be in error.

Once the elevation of the various flood frequencies and the structure have been estimated, the depth of flooding is estimated by finding the difference between the flood elevation and the elevation of the first floor. This is shown in column 5 of Table 1.

Property Value The next step is to calculate the damage associated with the various depths of flooding. To do this one needs to know the value of the damageable property and the percent damage to the property associated with various depths of flooding.

Damageable property is usually divided into structure and contents. Both structure value and contents value should consist of replacement cost less depreciation.[5] In real estate appraisal there are three basic approaches to valuation, market sales, cost, and income. The market sales approach estimates the value of a structure based on the sales price of comparable structures with appropriate adjustments made for size, lot, location, quality, etc. The cost approach estimates the value of a structure as its replacement cost less depreciation. The income approach estimates the value of a structure as the present value of expected income from the property with an appropriate adjustment for land value. While the income method can be used to value residential properties some heroic assumptions are needed.[6]

Within the framework of the classical competitive economy (many buyers and sellers, a homogenous product, perfect knowledge, mobile resources, and no barriers to entry or exit) the three methods should yield the same result. Given measurement problems and the degree to which the perfectly competitive assumptions may not hold in a given real estate market, the cost approach appears to be the simplest, most accurate method.

Structure value may be estimated by qualified appraisers or may be

[5]As used in this discussion, depreciation is defined as a factor to account for physical deterioration and obsolescence. This is not the same as depreciation in the accounting sense. Penning-Roswell and Chatterton opt for an accounting definition of depreciation (The Benefits of Flood Alleviation, A Manual of Assessment Techniques, p. 29). They contend that the price of goods sold in the second-hand market is not a measure of the value of an item since a flood which destroys such an item constitutes a forced sale. But if the flood plain occupants know and willingly accept the flood risk the sale of such items cannot be said to be forced. In view of the imperfect knowledge associated with the true (as opposed to apparent) condition of second-hand goods, an argument might be made that due to such uncertainty such goods are discounted below their "true" value. In the absence of a resolution of this issue the value of goods in the second-hand market appears to be a reasonable approximation of their value.

[6]Maurice Unger, Elements of Real Estate Appraisal. New York: John Wiley & Sons, 1982, pp. 51-52.

estimated by less qualified personnel, usually with consultation with local appraisers and/or real estate agents. Such estimates are usually done without entering the house, although detailed estimates may be done on a sample basis. Sometimes structure values are based on appraised values available in tax records. If this is done, care must be taken to make any necessary adjustments to reflect full structure value at a given point in time.

Given the comprehensiveness, accuracy, and accessibility of publications which can be used to estimate construction cost, such as the Marshall and Swift series, estimates of replacement cost should be fairly consistent and accurate. The estimate of depreciation is less precise.

> What, in fact, occurs in these depreciation calculations is the application of a rule of thumb. In this case, the rule of thumb is derived from experience, which may vary widely among appraisers.[7]

Values of contents are usually obtained from secondary sources. Residential contents are usually expressed as a percent of the structure value. This percent may be constant or may vary with the value of the structure. The reliability of these estimates will depend on the validity of the techniques used to generate them and their applicability to the area in question. For common commercial establishments (e.g., fast food restaurants) content value estimates should be identical across regions. For more unusual establishments, especially large industries, contents should be individually estimated.

Depth-Damage Relationships

Once one knows the depth of flooding and the value of the structure,

[7]Ralph E. Thayer, "Rethinking the Cost Approach to Valuation", Appraisal Journal, Vol. LI, No. 2, September 1983, p. 281.

TABLE 2

SAMPLE DEPTH-DAMAGE RELATIONSHIPS
(One Story Residential Structures, No Basement)

	Damage as Percent of Structure Value			
Water Depth (in feet) Relative to First Floor	COE, Fort Worth District	1970 FIA	1974 FIA	TVA
-1	0	0	0	0
0	10	8	7	0
1	21	22	10	10
2	27	30	14	18
3	32	35	26	27
4	37	39	28	31
5	43	41	29	35
6	46	44	41	39
7	50	46	43	43
8	54	48	44	54
9	58	50	45	58

COE Corps of Engineers
FIA Federal Insurance Administration
TVA Tennessee Valley Association (curve is for structures with slab foundation)

one need only to apply a percent damage factor related to the depth of water. Table 2 shows some sample depth-damage relationships. Using the first relationship in the table, if a $50,000 structure is flooded two feet then damage would be $50,000 x .27 = $13,500.

The fact that the relationships are not more closely aligned should make one suspect that although depth-damage relationships may appear to be simple and believable there are factors which may complicate their estimation. A closer examination reveals that several such factors are at work.

A single depth-damage relationship ignores the effects of other flood variables on damages. In reality damages are not only a function of depth, but also of velocity, duration, water quality, and debris. At high water velocities a structure may be pushed off its foundation and completely destroyed. With long duration not only will materials coming in direct contact with flood water become waterlogged, but water will have a greater opportunity to wick its way up adjacent materials. Water quality may also importantly affect the amount of damage from a given depth of flooding. If the water is saline (as is not unusual in coastal flooding), has a high sediment content, or contains toxic chemicals, damage will tend to be greater. When velocity, duration, and water quality are considered, one can easily conceive of a wide range of possible values for a given depth.

While incorporation of these variables into the depth-damage relationship does seem theoretically possible, incorporation of the debris content does not seem realistically possible. Flood debris may result from loose items of any sort in the flood plain and may even be previously non-loose items such as poorly anchored structures or even trees. Prediction of debris content would appear to be highly speculative. To the extent that there is flood debris damages would be higher. Debris may not only cause higher damages by providing items with which flood waters may batter structures, but also by increasing the flood height as may happen if a mobile home floats away and lodges underneath a bridge.

Depth-damage relationships will also vary with warning time. This is true to a limited extent for damages to structures where sandbagging and hole-plugging may reduce damages from low-depth flooding. It is more true with respect to contents, which can be moved to higher elevations within the structure and sometimes evacuated from the structure. But a simple warning-response model hides the complex details of the real world. The model presented by Sniedovich and Davis, shown as Figure 2, reflects the full sequence of events. The degree to which depth-damage relationships will vary with warning time depends on both technological and sociological factors. Technological factors will limit the warning time, accuracy and dissemination of flood predictions. Sociological factors will determine the degree to which people respond and the efficiency of those responses. It is one thing to estimate what people can accomplish with various warning times. It is quite another to predict what people <u>will</u> do given possible disbelief in flood predictions, the probability of their being at work or otherwise not at home, a lack of knowledge of what to do, etc.

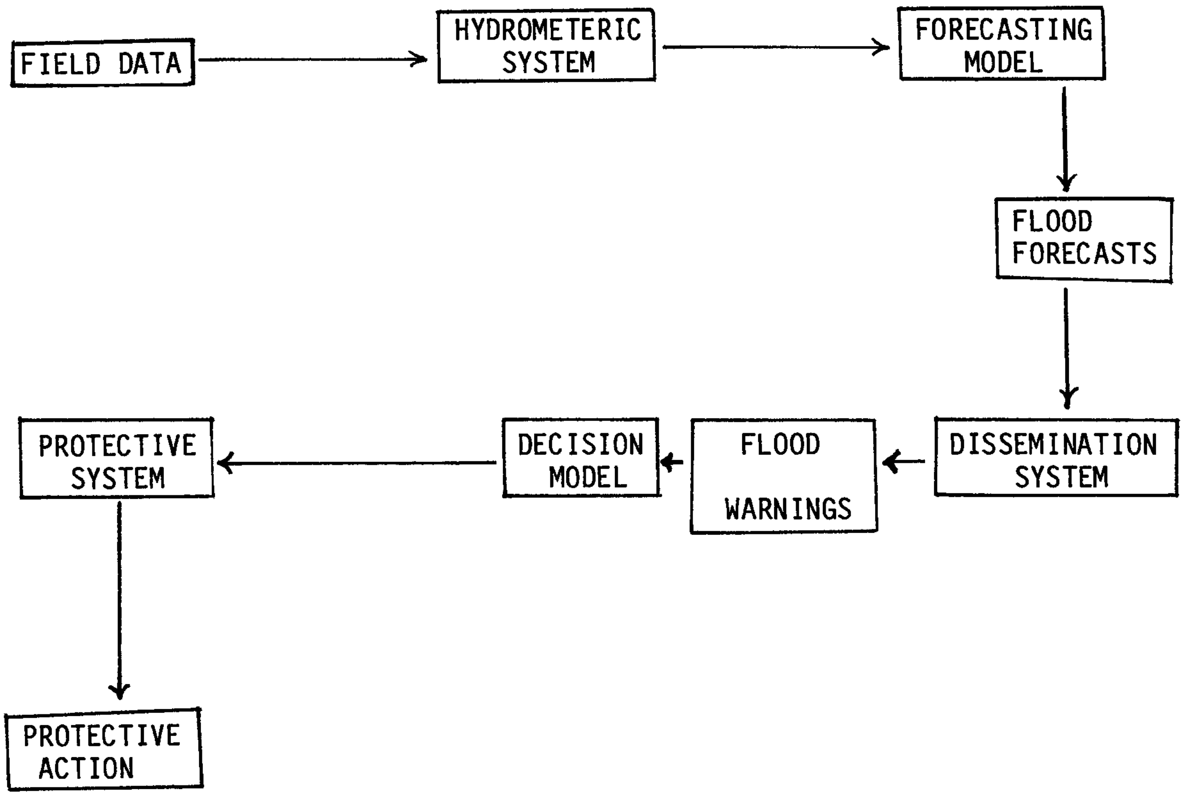
Indeed, it is possible for people to increase damages if they attempt to floodproof their house. Most structures are not designed to withstand vertical and uplift hydrostatic pressures.

> The principal reason more structures do not collapse during flooding is that water enters the structure equalizing inside and outside pressures. If the objective is to prevent water from entering a structure it is imperative that the structure be analyzed to insure that it can withstand the pressures anticipated.[8]

[8]William Johnson, Hydrologic Engineering Center, <u>Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures</u>, March 1978, p.14.

FIGURE 2

FLOOD FORECASTING-RESPONSE MODEL



Source: Sniedovich and Davis

A single depth-damage relationship also assumes that all structures in a certain class (e.g., single-story residential with no basement) incur the same percent damages with a given flood depth or, alternatively, that the depth-damages will average out. Single-story residences may be built with slab-on-grade or pier and beam foundations, with wood, brick, stone, stucco, or various combinations thereof. Construction materials and techniques also vary across time. For example, today's houses have more wall insulation than the houses of 20 years ago. Different construction techniques, materials, building codes, etc., do not necessarily mean that a single depth-damage relationship does not hold, but such variation should make one cautious.

Alternatively, one might assume that any variations within a class will average out. To the extent that the proportions of each type of single-story residence in the flood plain being studied are equal to the proportions of types in the sample on which the depth-damage relationships are based, the depth-damage relationships will be valid. Thus, a study may involve a very large number of structures and the actual depth-damage relationships still may not average out to those assumed in the study. Neighborhoods may, in some sense, be defined in terms of structures having similar characteristics. If the mix of neighborhoods in the flood plain being studied is the same as the mix of neighborhoods on which depth-damage relationships are based, then the averaging-out argument may be valid.

The above argument is equally applicable to commercial structures. Commercial structures are often aggregated on the basis of function (e.g., drugstore) for the purpose of determining depth-damage relationships. This is a desirable breakdown for content depth-damages. It is not as desirable for structure depth-damages. For structure depth-damage relationships a more desirable breakdown would be on the basis of construction material such as brick, sheet metal, etc. A given structure will incur the same damage from a given flood depth whether it is being used as a drugstore or a florist shop. A breakdown on the basis of construction material would increase accuracy (and reduce uncertainty) by increasing the sample size used for each depth-damage relationship and by avoiding the problem of reflecting the mix of construction materials on which the depth-damage relationship is based.

Another complicating factor is structure condition. Structure condition is a function of both age and the extent to which the structure has been properly maintained. Structures in poor condition may be more susceptible to flood damages than structures in good condition.

Even if, in a given flood plain, depth-damage variations among, for example, single story residences with no basement do average out to the single depth-damage relationship used, the resulting answers may still be erroneous. Depth-damage variations among single story residences with no basement must also be vertically distributed within the flood plain. For example, assume one-half of the flood plain structures are wood and one-half are brick. Assume wood structures incur more damage at each flood depth. Assume a single depth-damage relationship is derived reflecting a mix of one-half wood and one-half brick. If all brick structures in the flood plain are in the 0-50 year flood plain and all of the wood structures are in the 50-500 year flood plain, then damages for 0-50 year floods will be overestimated and damages in the 50-500 year flood plain underestimated.

The errors are not offsetting because, as is explained in more detail in the frequency-damage section of this chapter, expected damages are estimated by multiplying the damage of each frequency flood with its probability of occurrence. More frequent floods have greater effect on expected damages than less frequent floods.

Aside from the difficulties in accounting for all of a flood's physical characteristics, the amount of and response to warning time, and the plethora of structural variations, there are several problems just in measuring damages. First, damages should measure the cost to restore something (or replace it) to its pre-flood configuration, no better, no worse. This involves considerable judgement on the part of the estimator. For insurance purposes the estimator may only be interested in replacement cost, with no adjustment for the pre- and post-flood condition of a structure or item.

Secondly, all of the adverse effects of flooding may not manifest themselves for some time. Apparently unaffected appliances may develop, at some later time, mechanical and electrical problems which would not have otherwise occurred. Structural damages to foundations may not show up for years.

Thirdly, post-flood actions may be taken by flooded residents to minimize damages to structures and contents. Pamphlets describing these post-flood measures are available.[9] As is the case with flood warning, what can be done is not the same as what will be done. Even if people had perfect knowledge of what could be done they may not have time to do it all. After a flood there are myriad things to be done and only limited time.

The issue of finite time raises an important point seldom addressed in the literature. Depth-damage curves may be constructed by statistical analyses of estimates of past damages or by analyzing the probable effects of

[9]See, for example, After the Flood Handbook on Salvage and Insurance, Pennsylvania State Insurance Dept., July 25, 1977.

various flood depths on a hypothetical structure. The hypothetical structure analyses and often the estimates of damages from historical floods may be based on unit repair costs which do not consider the possible existence and effects of widespread flooding. If flooding causes significant damage relative to an area's repair capability unit repair costs may rise. Data on the effects of Hurricane Camille, which struck the Mississippi coast in 1969, and Hurricane Agnes, which struck Pennsylvania in 1972, indicates that in some areas unit repair costs were significantly, albeit only temporarily, increased above pre-disaster values.[10]

Such increased costs represent real economic losses. Where unit repair costs increase as a result of flooding, owners of scarce resources and skills are obtaining above normal profits or, to an economist, economic rents. Economic rents occur because labor and materials are not instantly mobile. These issues are discussed in more detail in Appendix B.

While the above discussion does not reveal any theoretically insurmountable barriers to more accurate depth-damage relationships, the practical barriers are appreciable. If one-story residences were divided into 5 subgroups by type of construction, condition into 2 groups, velocity into 3 groups (e.g., less than 8 feet per second, 8-15 feet per second, more than 15 feet per second), duration into 3 groups, sediment into 3 groups, and warning time into 3 groups, there would be a total of 5 x 2 x 3 x 3 x 3 x 3 = 810 possible combinations of independent variables for one depth of flooding. A large data base would be needed to calculate, with any accuracy, the percent damages resulting from the interaction of these variables.

[10]Thomas N. Yancey, Jr., et al., "Disaster-Caused Increases in Unit Repair Cost", ASCE Journal of the Water Resources Planning and Management Division, November, 1976, p. 271, 275.

Data gathered from across the nation might provide enough points for reliable estimates. But in aggregating data across regions differences in structural techniques and materials (e.g., amount of insulation) are being ignored.

Some might view this discussion as overly pessimistic. To the extent that entities develop depth-damage curves which accurately reflect flood characteristics in a region the range may not be so wide. The problem is in defining such a region and obtaining an adequate number of observations with all of the independent variables, all properly measured.

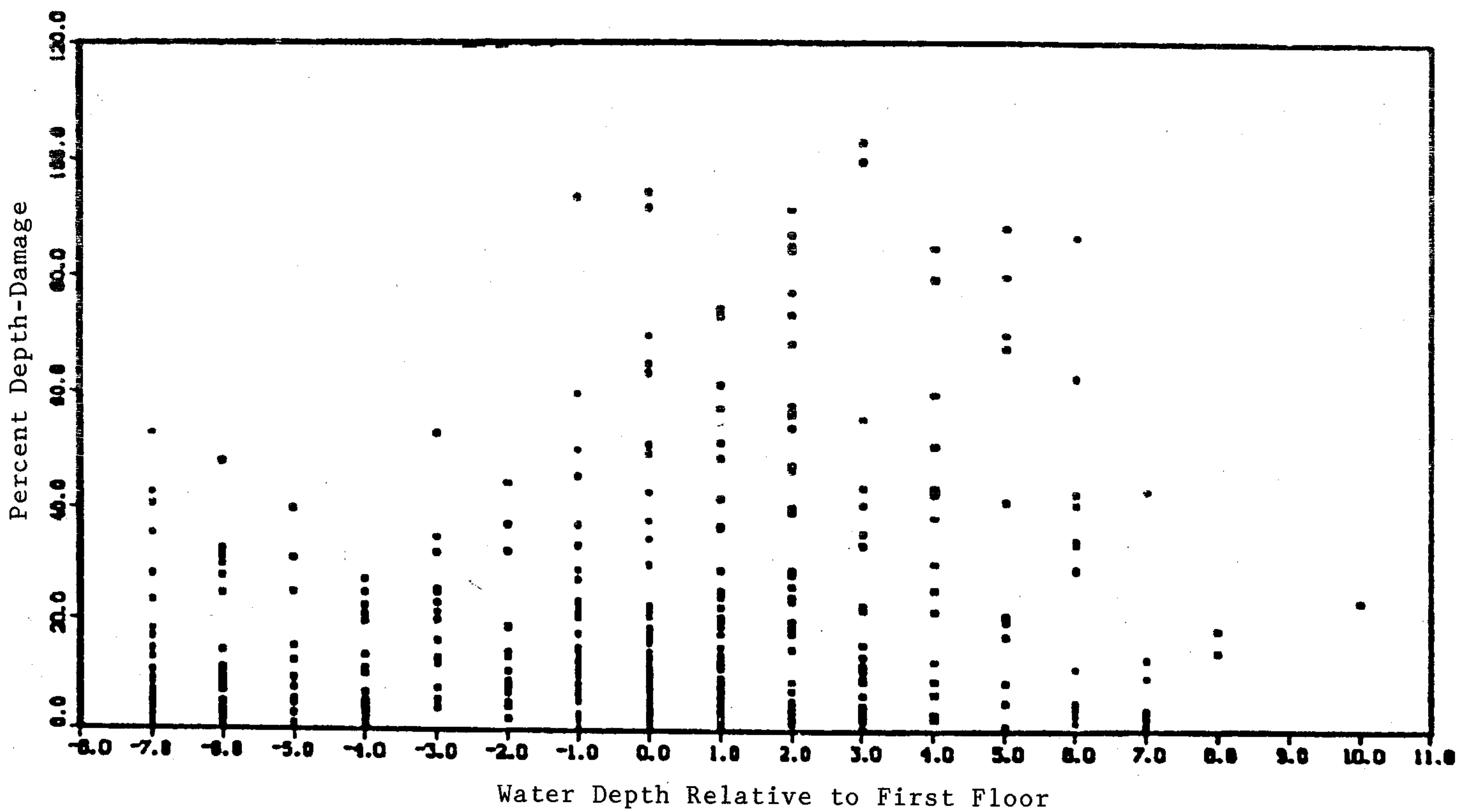
The preceeding discussion indicates that wide variations in percent damage at a given flood depth are possible. As shown in Figure 3, empirical evidence shows this possibility to be borne out in fact. Statistically speaking it should be possible to sort out the effects of the many variables and develop depth-damage curves with more narrow confidence intervals. But the combination of numberous variables, measurement problems, lack of complete data, and inconsistently coded data have made this difficult to do in practice.

Frequency-Damage

The fourth and last step in calculating expected damages consists of weighting the damages from each frequency flood (column 7 in Table 1) by its probability of occurrence (column 1 in Table 1). In practice this usually consists of multiplying the average damage in a probability interval by the probability of that interval. This is shown graphically in Figure 4 and in tabular form in Table 3.

If the stage-damage relationship is, in fact, linear between computed frequencies, then this method will yield the same result as if damages were computed for each frequency flood (1 year, 2 year, 3 year, etc.). If dama-

Figure 3 Empirical Depth-Damage Data



Source: Stuart Davis, "User's Guide to the Federal Insurance Administration's 1978-1979 Flood Claims File for Computation of Depth-Damage Relationships," IWR Research Report 81-R11, December 1981, p. 38.

ges are not linear between computed frequencies then the estimated expected damages will be in error. One way to strengthen the assumption of linearity would be to include more flood frequencies in the calculations. Alternatively, computer techniques are available to interpolate damages for intermediate frequencies.[11]

Theoretically, there exists for any area floods with return intervals of 10,000 years, 50,000 years, 100,000 years, etc. As a practical matter, analyses are usually limited to floods with a return interval of the order of 300 to 1,000 years. As shown in Figure 4 and Table 3, damages are estimated at $25,000 for a 500 year flood. To account for the probability of floods which exceed that magnitude, the probability of all floods greater than the 500 year flood is multiplied by the damage from the 500 year flood. Theoretically, damages should be estimated for all floods. Practically, such calculations are not worth doing because (1) estimation of flood heights of extremely rare events would be highly unreliable, (2) the additional cost to evaluate such events would be significant, and (3) because expected damages are the product of the probability of a flood and its damage, the extremely low probability of such events means that such events will have little effect on total expected damage. Thus, the traditional compromise in evaluation procedure has been to account for the fact that greater floods than the maximum flood studied can occur, but to assume that such floods will not cause any additional damage.

That large floods with low probabilities tend to contribute little to expected damages is an important point and worthy of further elaboration.

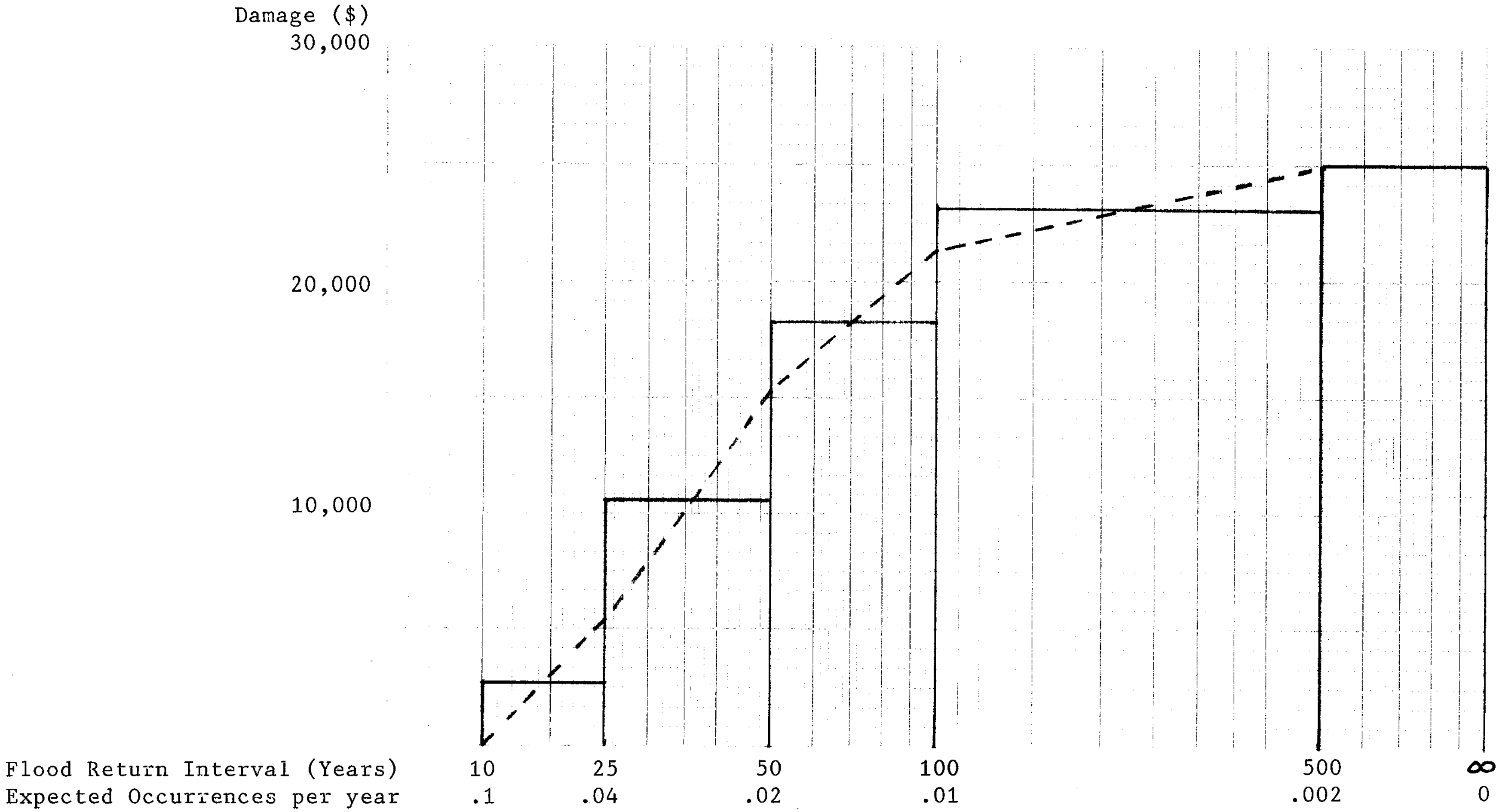
[11]Hydrologic Engineering Center, Corps of Engineers, "Expected Annual Flood Damage Computation User's Manual", June 1977, Exhibit 2.

TABLE 3

Frequency-Damage Integration

Year Flood	Expected Flood Frequency	Damage ($)	Average Damage ($)		Interval Frequency		Expected Annual Damage ($)
∞	0	25,000					
			25,000	x	.002	=	50
500	.002	25,000					
			23,500	x	.008	=	188
100	.01	22,000					
			18,750	x	.01	=	188
50	.02	15,500					
			10,500	x	.02	=	210
25	.04	5,500					
			2,750	x	.06	=	165
10	.1	0					
5	.2	0					
Total Expected Annual Damage							801

Figure 4 Graphical Depiction of Frequency-Damage Integration



Each study area is different but, in general, even though large floods may cause catastrophic losses, it is the smaller floods which are the source of the preponderance of expected damages. Therefore, it is important that the frequency-damage relationship be accurate for the more frequent floods, and especially so in estimating the point at which damages begin.

The expected damage calculations in Figure 4 and Table 3 assume that damage from the 10 year flood would be $0 and would increase linearly to $5,500 from the 25 year flood. If no damage occured prior to the 25 year flood, expected annual damages would be reduced by the expected annual damages for frequencies less than the 25 year flood. This amount, $165, is represented by the first rectangle in Figure 4. The difference of $165 (21 percent) is entirely attributable to the assumption of damages below the 25 year flood.

Assuming that the frequency-damage relationship is linear between adjacent frequencies (i.e., there is, on average, neither a convex nor concave tendency) the typical integration technique of assuming a linear relationship of damages between the last frequency showing zero damages and the first frequency showing damages (the first rectangle in Figure 4) will result in an upward bias in expected damages. For example, in Figure 4 one may know that zero damages occur from the 10 year flood and $5,500 of damages occur from the 25 year flood. If zero damages also occur at any frequency between the 10 and 25 year flood then expected damages will be overestimated. Again, computers can be programmed to minimize this inaccuracy by estimating the frequency of this elevation by interpolation between the elevations of estimated frequencies.

Estimating the point at which damages begin brings up a potential problem which the economist should be aware of. A river may have a top bank which is higher than the adjacent land (see Figure 5). One could assume that no damage may occur until the water surface exceeds the top

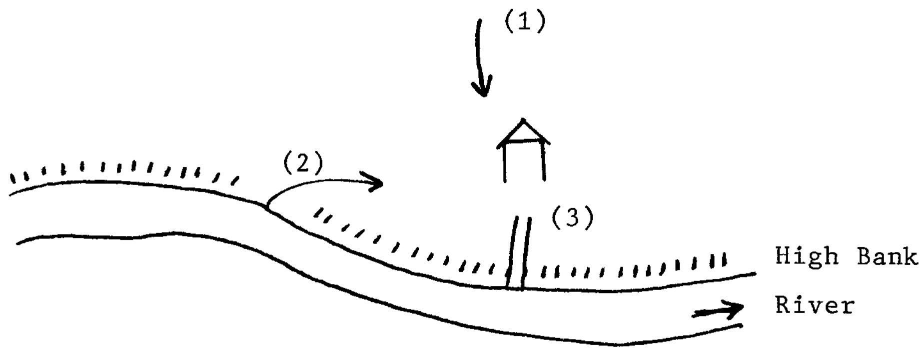
Figure 5

Hypothetical Cross Section View

bank elevation. But this may not be the case. Flooding may come from (1) internal drainage trapped behind the top bank, (2) flood waters which exceeded the bank elevation at some upstream point, and (3) flood waters which may back up storm sewer outlets or drainage ditches (see Figure 6). Close coordination is needed with the hydraulics specialist to determine when flooding begins.

Figure 6

Potential Sources of Flooding Without Top Bank Being Overtopped



CHAPTER 3

Expected Damages to Many Structures at One Point in Time

Introduction

Preceding discussion has focused primarily on calculation of expected damages to a single structure. In calculating damages to all flood plain property several methods of aggregation are used, each of which has various degrees of uncertainty associated with it. This chapter examines the two principal methods of aggregation as well as alternative approaches.

Flood Profile Method

The most accurate method is a direct extension of the method already presented. This will be called the flood profile method. Using the stage-frequency relationship at the river mile at which each structure is located, the structure value and elevation, and the depth-damage relationship, damages to each property from each frequency flood are calculated. Damages are converted to expected annual flood damages for each structure and then summed for all structures in the flood plain. The method is simple and introduces no uncertainties which have not already been addressed.

Index Point Method

The more traditional method, which is the one found in the literature, may be called the index point method. With this method the flood plain is divided into reaches based on river miles for which the flood profiles are approximately parallel. The appearance of parallelity is much affected by the horizontal and vertical scaling of the flood profiles. Thus, division into reaches is a subjective judgement on the part of the economist. Since damages are calculated by reach, further divisions may be made as needed, but the divisions based on parallelity are the minimum needed.

Next, for each reach, damages are calculated for the highest level of flooding being considered in the study (typically one which has a return interval of 300 to 1,000 years) and by one foot decrements below that until no damages occur.

The next step is selection of one point (or index location) which is representative of the relative magnitude of difference among flood profiles in the reach. If the flood profiles are perfectly parallel throughout the reach then any location will suffice. If most of the development in a reach is at one end of a reach then the index point should be at that end of the reach. Selection of the index point is a subjective judgement.

The stage-frequency relationship at the index point is combined with the stage-damage data to derive the frequency-damage relationship. The expected annual damages are calculated as described above.

The index point method assumes that each flood is the same distance below the highest flood at the index point everywhere in the reach (or at least everywhere there is damageable property). Flood profiles may not be parallel because channel constrictions such as narrow valley sections or bridges may cause water to back up, especially during large floods. In Figure 1 the flood profiles indicate a channel constriction at river mile 2.0. Flood profiles also will not be parallel under with-project conditions immediately upstream from the uppermost improvement where with-project flood profiles phase into without-project flood profiles.

When flood profiles in a reach are not parallel the resulting estimate of expected annual damage may be in error. The index point algorithm assumes that the relative stage-frequency relationship at the index point is valid throughout the reach. For example, Figure 1 represents hypothetical flood profiles. Assume river mile 3.0 is selected as the index point. The 25 year flood is 5.6 feet below the 500 year flood at the index point. If the index point algorithm calculates damages for the highest level of flooding and by decrements below that until no damages occur, damages occurring at elevations 5.6 feet below the 500 year flood (throughout the reach) will be assumed to be those of the 25 year flood. It can easily be seen that between river miles 2.0 and 3.0 the frequency attributed to 5.6 feet below the 500 year flood will be underestimated and at river miles greater than 3.0 the frequency will be overestimated. Given the relative importance of frequent floods on expected annual damages, such errors could importantly affect the results.

Alternatively, a lower frequency flood could be selected to which the other frequency floods could be related. In this example the 25 year flood could be selected as a "base" flood and all development 5.6 feet above the 25 year flood would be considered as in the 500 year flood plain. Damages to all development in the reach would be calculated relative to the 25 year flood. The frequency-damage estimation and integration would be done as described above. While this method may not correctly estimate the properties within the 500 year flood plain, estimates of expected annual damages would be more accurate since estimates of damages from high frequency floods would be more accurate.

The lack of parallel lines can be alleviated by further subdividing the reach. As more and more reaches are added the results approach those of the flood profile method. When the floodplain is divided into so many reaches that only the structures at one river mile (e.g., all structures at river mile 2.7) are in a reach, the index point method and flood profile methods are identical.

Because of the subjective judgements used in selecting reaches and the index point with the index point method, there is more room for error. A proficient analyst is aware of these limitations and will try to select reaches and the index point carefully. As a sample test, the author evaluated a proposed project using the flood profile and index point methods. The proposed project was on Chacon Creek in Laredo, Texas. The floodplain development is along 4.8 miles of the creek and contains 215 structures, almost all residences. Based on the author's experience in flood control studies (about 5 man-years) the study area was divided into 7 reaches for the index point method.[12] The results are shown in Table 4.

TABLE 4

Expected Annual Damages With Flood Profile and Index Point Methods

	Flood Profile Method ($)	Index Point Method ($)	Percent Error
Without Project	80,500	90,100	+12
With Project	4,300	3,000	-30
Benefits	76,200	87,100	+14

It would be a mistake to conclude from this one test case that the index point method is biased one way or another. It does show that an

[12]With the flood profile method, it is not necessary to divide the floodplain into reaches to calculate expected annual damages. This would be done, of course, for discernible channel portions to assure that each logically separable section of channel is incrementally justified.

experienced analyst, being careful, may be in error by 14 percent assuming all other data (hydraulics, structure elevations, depth-damage curves, etc.) are exactly correct. Given the increased computer capacity and decreased computer costs available today there seems to be no reason to inject additional uncertainty into the analysis by use of the index point method.

With either the index point or flood profile method, structures may be aggregated to reduce study cost. For example, in a homogeneous, flat neighborhood all structures on a block may be assigned the same structure value and elevation. In large urban flood control studies there appears to be a greater tendency to aggregate structures, perhaps on the belief that errors will average out. The reductions in study cost from such aggregations must be balanced against the additional uncertainty and study resources.

Other Methods

Grid Cell Method Methods have been developed to estimate flood damages using a grid cell approach.[13] Such an approach integrates well with other spatial analysis planning tools, especially land use. The grid cell approach divides the flood plain into grids, each bounded area being a cell. In terms of flood damage calculations, each cell is assigned an average elevation and a depth-damage function based on the type and value of development in that cell. Average flood depths per cell are estimated for floods of various frequencies and expected annual flood damages are estimated.

[13]See, for example, Hydrologic Engineering Center, Corps of Engineers, "DAMCAL (Damage Reach Stage-Damage Calculation) User's Manual", February 1979.

The preceding discussion would indicate that a great deal of uncertainty should be associated with this method. Conversations with economists who have used the method in test cases in the Fort Worth and Memphis Districts of the Corps of Engineers have verified that significant uncertainty exists. Digitizing costs are high and the only way to properly calibrate the model is with the flood profile method. When cells are aggregated into classes such as high density residential and medium density industrial, the variance in depth-damages may be so wide as to make the classifications useless.

Land Value Method Another way to estimate flood damages is by using data on land values.

> The net income that can be ascribed to land is the residual remaining after deducting from the gross income all the production costs, including labor, materials, capital and management at their market values...flood damage directly reduces the net residual income, and in the long run, is reflected in the market price of land.[14]

The reduction in flood damages between without- and with-project conditions would be capitalized into the value of flood plain land. *Ceteris paribus*, annual flood damages should be the amortized difference between flood plain and flood-free land.[15] Although this technique is more often used for evaluating agricultural flood damage reduction, theoretically it could be used to measure urban flood damage reduction. In practice this is difficult. To accurately estimate flood damage reduction on the basis of land values the following conditions, as a minimum, must hold.

[14]Corps of Engineers, "Relation of Flood Damages and Flood Control Benefits to Market Value of Land", EM 1120-2-111, June 1957, p. 11.

[15]This assumes perfect knowledge and risk neutral behavior. Given the trauma, disruption, and inconvenience of having one's house flooded one may be willing to pay an amount in excess of expected monetary damages.

1) There must be perfect knowledge of the expected flood damages. This knowledge must be constant over time, that is, it exists independent of the time since the last flood.

2) The implicit interest rate and time horizon used to capitalize flood damages must be known.

3) There must be an adequate sample of flood plain lands to reflect not only the flood hazard but the variation in flood hazard within the floodplain.

4) There must be an adequate sample of flood-free lands with similar characteristics to those of the flood plain lands (except for flooding). If the flood-free lands are not similar then all relevant differences (location, aesthetics, etc.) must be somehow accounted for.

5) Land values must include no externalities.

6) Land values must not reflect the expectation that a project will be built.

Given the above assumptions, one can see that this method is difficult to apply in urban situations. In addition to the dubious applicability of the above assumptions, there are theoretical problems in applying regression analyses to estimate flood damages based on changes in land value.[16]

Historical Damage Method. One last method to estimate flood damages should be mentioned, the historical damage method. This method typically consists of obtaining estimates of a frequency-damage relationship which may then be integrated to derive expected annual damages.

Unfortunately, there are few cases in which this method will yield accurate results. Among the problematic assumptions are (1) an adequate sample of data is available, (2) estimates of damages are accurate and do not include regional transfers of economic activity, (3) hydrology and hyrdaulics were constant over the period of record (no change in run-off or

[16]Reuben Weisz, John C. Day, "A Methodology for Planning Land Use and Engineering Alternatives for Floodplain Management", IWR Paper 74-75, October 1974, pp. 141-155.

cross-sections), and (4) the amount, value, location, and damageability of property were constant over the period of record. Because of these problems this method is seldom used.

CHAPTER 4

Estimates of Expected Damages Over Time

Introduction

Preceding chapters dealt with estimating expected flood damages at a given point in time. Expected flood damages must be estimated over the period of analysis. This chapter discusses the various factors which affect projected damages (and benefits) over time and notes more potential problems of which the analyst should be aware.

Hydrology and Hydraulics

Future hydrologic and hydraulic conditions may differ significantly from present conditions. Future weather patterns may change. Increased urbanization in the basin may increase run-off. Prediction of changes in the magnitude and direction of weather patterns seems highly speculative with our present knowledge. To the extent that land-use changes and their hydraulic effects are accurately predicted, the hydraulic model can be adjusted to reflect future hydraulic model can be adjusted to reflect future changes. Usually hydrologic and hydraulic models are run for current conditions and, if appreciably different, for the year in which ultimate development occurs (or the last year of the period of analysis, whichever is earlier). Increases in flood stages (and thus expected damages) between these two points in time are usually assumed to be linear. If the land-use changes causing the hydraulic changes are expected to be non-linear, hydraulic conditions and damages can be calculated for intermediate years.

OBERS In its early years the Water Resources Council funded a project to establish a consistent set of projections from which to evaluate water resource projects. The project was originally carried out by the Office of Business Economics (OBE), now the Bureau of Economic Analysis, of the Department of Commerce, and the Economic Research Service (ERS) of the Department of Agriculture with assistance from the Forest Service. Hence, the name OBERS. Although the most recent set of projections, printed in July 1981, were done entirely by the Bureau of Economic Analysis the name OBERS has been retained. The projections are for a wide range of variables (population, employment, personal income, earnings by industry, etc.), for a long time (to year 2030), and for a variety of geo-political areas (water resources regions, standard metropolitan statistical areas, etc.).

These projections serve as the basis for local projections, thus insuring some degree of consistency and reasonableness. The analyst must insure that proper techniques are used to "step down" these projections to the project level. Federal water resource studies may, with proper documentation, use non-OBERS projections. Projections are significant to the extent that future benefits are expected to change based on the projections The assumptions and techniques used to project are contained in the OBERS publication and no attempt will be made to either summarize or criticize them here.

Depth-Damage Structures being built today are different than houses built 20 years ago. Materials, amenities, configuration, and construction techniques change. Structures built in the future will probably be different than ones built today. As structures change the depth-damage relationship of new structures may also change. Currently it is possible to incorporate construction techniques and materials into new structures which will reduce flood damages.[17] Many of these methods involve little or no additional cost.

Depth-damage relationships to existing structures would be affected by adoption of floodproofing measures in existing structures. Depth-damage to contents would be affected by locating contents at higher elevations (e.g., putting industrial motors on platforms, locating appliances on upper floors). To the extent that such measures are instituted damages for a given flood depth to a given structure will be reduced over time.

Value of Damageable Property Value of damageable property may also change over time. As real incomes in a given area increase over time it seems reasonable that the value of houses will also increase. In testing the validity of this hypothesis it is important that any increase in housing cost be net of the value of land. It is also important that any increase in values be in real terms, that is, adjusted for inflation.[18]

Empirical data indicate that as households become more wealthy, contents, as a percent of structure value, may increase over time. The reduced damages to future increases in contents is often called affluence benefits. The Water Resources Council has stated that increased content values for residences should be based on expected increases in per capita income and that, except where special studies indicate otherwise, content values may not be projected to increase beyond project year 50, nor beyond 75 percent of structure value. Similar increases for commercial and industrial establishments are prohibited by the Water Resource Council

[17]See, for example, D. Earl Jones, Jr., "Floodproofing Limitations and Flood Loss Mitigation" and "The Economics of Water-Resistant Construction" in Proceedings of Joint ASCE-Engineering Foundation Conference on Flood Proofing and Flood Plain Management, 1977.

[18]Typical practice is to perform a benefit-cost analysis in real terms using a real discount rate. If the discount rate used is in nominal terms (includes a factor for expected future inflation) then the values to be discounted should also be in nominal terms. This is discussed further in the discount rate section below.

since empirical studies have not established that such a relationship exists among structures, contents, and per capita income for commercial or industrial establishments.[19]

Land Use Projection of future land use with and without a project is necessary for both existing and future conditions. A detailed discussion of projection techniques is beyond the scope of this paper. Suffice it to say that the certainty associated with such projections should be judged on a case-by-case basis.

Projection of future land use affects expected flood damages not only by changing the hydraulic conditions, but also by changing the amount of development in the flood plain itself. Where additional development in the flood plain is expected, the analyst must estimate the amount, value, elevation, and timing of such development.

It is imperative to note that the engineering and economics are interdependent. The engineer and economist must closely coordinate to assure that their analyses are based on consistent assumptions on the location, type, and amount of development for without project conditions and with the various plans of improvement.

In the last 10 years the character of flood plain development has been altered by the national flood insurance program. Of about 20,000 communities identified as having a flood problem, about 19,000 participate in this program.[20] For a community to participate in the program it must

[19]Water Resources Council, "Procedures for Evaluation of National Economic Development (NED) Benefits and Costs in Water Resources Planning (Level C); Final Rule, Federal Register, December 14, 1979, p. 72934.

[20]Jeffery S. Bragg, Federal Insurance Administration, address to Natural Hazards Research and Applications Workshop, Boulder, Colorado, July 16, 1984.

agree to the following conditions.

- All new development in the floodway (that portion of the flood plain where flood waters are deepest and most swift) must be limited to uses which are consistent with the flood hazard (e.g., agricultural or recreational use).[21] (see Figure 7)

- New residential structures must be built such that the first floor elevation is above the level of the 100-year flood (that flood which has a 1 in 100 chance of occurring in a given year).

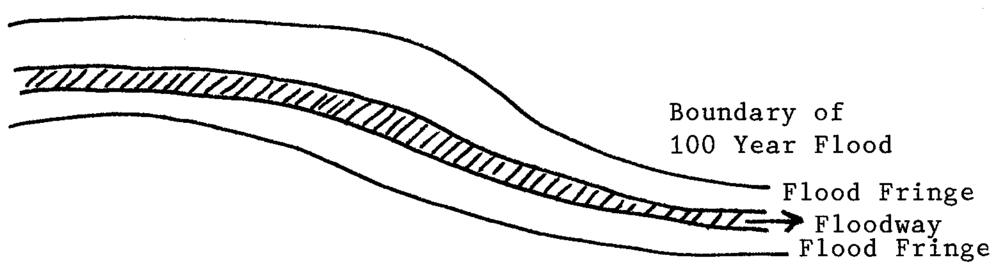
- New non-residential structures must be built so as to incur no damages from the 100-year flood (flood proofing is permissible).

- If any structure in the flood plain is to be substantially improved (any repairs or addition which involves a cost which equals or exceeds 50 percent of the market value of the structure either before or after being damaged) it must meet the same elevation or floodproofing criteria as new development.

- New development in the flood plain must be properly anchored and constructed so as to take into consideration the flood hazard.

Figure 7

Depiction of Floodway



Since all new construction in participating communities must be constructed so as to incur no damages from the 100-year flood, the level of expected damages is not as sensitive to projected new development in the flood plain. Even if the community is not participating in the flood insurance program, federal agencies evaluating flood control proposals are

[21]All structures are classified as new or existing. New structures consist of those begun after December 31, 1974, or the effective date of the detailed flood hazard map, whichever is later.

directed to assume that the community will join the program under without-project conditions and will join the program under with-project conditions if a residual hazard remains.[22]

Prior to the national flood insurance program, if a floodplain were fully developed, and if there were no change in hydraulic conditions, the expected annual flood damages could be expected to be constant over the period of analysis. That is, the type, value, configuration, and elevation of floodplain development under current conditions could be expected to be representative of the period of analysis since worn-out or damaged structures could be replaced in-kind and in-place. With the flood insurance program this is no longer true. Structures wear out from improper maintenance, become technologically obsolete, and are destroyed by hazards (flood, fire, earthquake, etc.). As this occurs to flood plain structures they may no longer be replaced in-kind and in-place. Some structures may last more than 200 years, but the average stucture life, especially of small commerical structures, is certainly much less than this.

As an indication of the importance of the in-kind, in-place replacement assumption, calculations were made of the effect of different structure lives and the interest rate on average annual equivalent damages.[23] Estimates were made of average annual equivalent damages for a 50 year period of analysis at 5, 8, and 10 percent for structures with a 50 year, 100 year, and infinite lives. Calculations for 50 (and 100) year structure lives assume that each year 1/50 (and 1/100) of the structures in the flood plain as of some designated point in time are replaced such that they will

[22]Water Resources Council, p. 72931.

[23]Average annual equivalent damages are the total present value of damages amortized over the period of analysis.

incur no further damage.[24] An infinite structure life is equivalent to assuming that all development will be replaced in-kind and in-place.

The results of the calculations, shown in Table 5, indicate that replacement in-kind and in-place may be an important assumption. At 8 percent and a 50 year life, damages (and thus, benefits) are 25 percent lower ($75) than they would be with an infinite structure life ($100). As expected, the higher the interest rate the less the effect of fewer damageable structures in future years, and the less important the assumption.

The numbers in Table 5 can not be used to adjust estimated benefits for specific projects. For actual calculations the value, age, location, and residual damages of flood plain structures must be accounted for and may result in different percents from those shown in Table 5.

The probability of a structure being damaged 50 percent or more introduces further risk into the estimate of expected annual damages. Under the regulations of the national flood insurance program, a structure which receives damages of 50 percent or more of its value may not be replaced at that location. Since traditional flood damage calculations assume no such damage limitation they have a degree of upward bias. It appears that the best way to eliminate this bias would be to estimate flood damages with a series of Monte Carlo simulations of the period of analysis. With a large number of structures and a 50 or 100 year period of analysis this could quickly become expensive. Research is needed to determine the significance of this bias.

[24]The assumption that replaced structures will incur zero residual damage may be a reasonable approximation of reality since if a replaced structure will receive no damage from the 100 year flood the expected annual damages to that structure will probably be small.

TABLE 5

AVERAGE ANNUAL EQUIVALENT DAMAGES
FOR SELECTED STRUCTURE LIVES

Interest Rate	Structure Life (in years) 50	100	Infinite*
5	$68	$84	$100
8	$75	$88	$100
10	$79	$89	$100

*equivalent to assuming structures will be replaced in-kind, in-place.

Assumptions

- constant value per structure
- age of structures equally distributed over the average structure life
- each structure will have a life equal to the average life
- replaced structures will have no residual damages

Discount Rate The importance of future projections on the present value of expected flood damages depends on the discount rate. To the extent that the discount rate is high, the present value of expected flood damages will be less sensitive to risk and uncertainties associated with projections.

The arguments for various discount rates will not be recounted here. Often, interest rates are institutionally dictated. It is worthwhile to emphasize that if the discount rate is in real terms, the values to be discounted should be in real terms. If the discount rate is in nominal terms the values should be in nominal terms. Either procedure will yield the same answer. But real and nominal values should not be mixed.

Calculation of Benefits

Where land use is the same under without- and with-project conditions, benefits are estimated as the difference between flood damages without a project and flood damages with a project. If the with-project condition is a measure such as channelization or a reservoir which will affect the flood profiles, then the with-project damages are calculated in the same manner as the without-project conditions. If the with-project condition involves floodproofing or a flood warning system, then appropriate adjustments should be made in depth-damage relationships. If the with-project condition involves a levee then the without-project frequency damage relationship should be truncated at the appropriate level.

If a project induces additional development in the flood plain then flood damage will be incurred by that additional development due to the residual flood hazard. However, such damages are an adjustment to the increased net income of the new development (usually called location benefits) and should not affect benefits in the flood damages prevented category.

If a project involves a change in land use via permanent flood plain evacuation, flood damages prevented are not a valid measure of project benefits.[25] This is because flood damages prevented do not reflect the foregone utility in that use. Analogously if a farmer stops growing crops in a flood plain, society is not better off by the amount of flood damages prevented because society is also foregoing the crop production. If the evacuated activity (the farmer) were relocated to non-flood plain land that had no alternative use and identical productivity, flood damages prevented would be a valid measure of benefits. This is an unlikely upper limit to benefits because land has some positive value and the productivity of the alternative land is likely to be less (or else the activity would have located there in the first place). If the evacuated activity were relocated to non-flood plain land such that it displaced an activity of equal value, the benefits to society would be zero. This is an unlikely lower limit to benefits because usually, at the margin, some lesser value land use will exist. The estimated level of benefits for permanent evacuation plans will usually be between these two limits.

[25]One may find in the literature cases where flood damages prevented are asserted to be the benefits for an evacuation plan. See, for example, Kwang K. Lee et al., "Progress in Simulation of Integrated Flood Plain Analysis and Management", Proceedings from Second World Congress, International Water Resources Association, New Delhi, India, December 1975, vol. IV, pp. 265-275.

CHAPTER 5

Conclusion

Results

This paper has examined, in detail, the frequency-damage method of estimating urban flood damage prevented benefits. The examination revealed a large number of sources of potential uncertainty and bias. Few of these potential problems have been addressed in detail in the literature. Some of the problems, such as use of the index point method, will probably wither as use of more powerful computers and software becomes more widespread. Several issues were identified which, to the author's knowledge, have not been previously addressed, (1) bias resulting from inaccurate estimates of structure elevations, (2) failure to consider that unemployed labor may be used to repair flood damages, (3) failure to consider replacement of existing structures, and (4) underestimation of willingness to pay for repairs. These issues indicate areas in which analyses may need to be more careful and, in the latter two cases, in which additional research may yield important results.

Table 6 summarizes the potential sources of uncertainty and bias. Table 6 does not indicate, *a priori*, that an overall upward bias exists. The degree of uncertainty and bias must be determined on a case-by-case basis.

Significance

This detailed critical appraisal has identified weaknesses in assumptions and techniques used to estimate benefits from preventing urban flood damages. Given the chain of calculations necessary to estimate these bene-

TABLE 6

Potential Sources of Uncertainty, Upward Bias, and Downward Bias in Estimating Urban Flood Damages Prevented Benefits

Uncertainty

- hydrology and hydraulics
- use of index point method
- estimate of property value (existing and future)
- depth-damage relationships (existing and future)
- frequency-damage integration procedure
- projected increase in structures

Upward Bias

- inaccurate estimates of structure elevations
- lack of estimation of exact point at which damages begin
- failure to consider that unemployed labor may be used to repair flood damages
- failure to consider replacement of existing structures

Downward Bias

- underestimation of willingness to pay for repairs
- overestimation of salvage value after large floods

fits and the uncertainty associated with each calculation, the resultant degree of error may be much wider than is commonly believed.[25] Within the constraints of limited resources the range of error may be the best that can be done. Depending on the purpose and results of the analysis, the additional cost of additional accuracy may not be warranted.

An important concept is applicable here, the equimarginal principle. This principle, which is usually discussed in terms determining optimal size of a project, states that the marginal benefits should equal the marginal costs not only for the overall project, but for each component. This is also an important principle in allocating study funds. Not only should the overall marginal benefits of increased accuracy equal the marginal cost of increased accuracy, but the marginal benefits of each component must equal its costs if resources are efficiently allocated. The argument has been made by some study managers that since hydrologic and hydraulic data may be accurate to (for example) ± 20 percent, the other calculations need be no more accurate than this. The equimarginal principle shows that equating the degree of certainty of each step is irrelevant since the degree of certainty says nothing of the costs of the information.

Federal water resources planning often involves a multi-stage process whereby a preliminary, reconnaissance study is done before the detailed study. Such a preliminary study offers a good data base with which to assess the sensitivity of the results to the accuracy of the data and

[25]One planner felt 95 percent confident that the flood damage-prevented benefits for one study were + 15 percent of the estimated value. See Ambrose Goicoechea et al., "An Approach to Risk and Uncertainty in Benefit-Cost Analysis of Water Resources Projects", Water Resources Research, Vol. 18, No. 4, August 1982, p. 795.

assumptions. It is important to remember that analyses are seldom done for their own sake. They are usually done to provide information with which to help make a decision. If more accuracy is desired, study funds should be allocated so that the increase in overall accuracy will be the greatest. It is hoped that this paper has helped to identify areas where this can be done.

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APPENDIX A

Do Over- and Underestimation in Structure Elevation Offset Each Other?

Using the example in this paper, damages were recalculated assuming the first floor was estimated to be one foot less and one foot more than the actual elevation. This is shown in Table A-1. These damages were then converted to expected annual values on Table A-2. Since the average of the two values $846.50, does not equal the expected annual damage with the correct elevation, $801, even offsetting numbers and magnitudes of error will not exactly offset each other. As the structure elevations become more imprecise with the use of larger contour interval maps, the range of error and the resulting bias become more important.

TABLE A-1

Frequency-Damage Calculation

Year Flood	Expected Flood Frequency	Flood Elevation	If Structure Elevation is Underestimated One Foot: Depth of Flooding	Percent Damage	Damage ($)	If Structure Elevation is Overestimated One Foot: Depth of Flooding	Percent Damage	Damage ($)
500	.002	510.1	8.1	54	27,000	6.1	46	23,000
100	.01	508.3	6.3	47	23,500	4.3	39	19,500
50	.02	505.8	3.8	36	18,000	1.8	26	13,000
25	.04	503.1	1.1	11	5,500	-0.9	0	0
10	0.1	502.8	0.8	8	4,000	-1.2	0	0
5	0.2	501.5	-0.5	0	0	-2.5	0	0

TABLE A-2

Expected Annual Damage Calculation

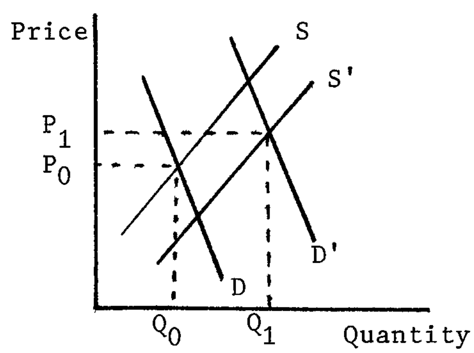
		Damage If Elevation Is Underestimated				Damage if Elevation is Overestimated			
Year Flood	Expected Flood Frequency	Damage ($)	Average Damage ($)	Interval Frequency	Expected Damage ($)	Damage ($)	Average Damage ($)	Interval Frequency	Expected Damage ($)
500	0	27,000				23,000			
			27,000	.002	54		23,000	.002	46
500	.002	27,000				23,000			
			25,250	.008	202		21,250	.008	170
100	.01	23,500				19,500			
			20,750	.01	208		16,250	.01	163
50	.02	18,000				13,000			
			11,750	.02	235		6,500	.02	130
25	.04	5,500				0			
			4,750	.06	285				
10	.1	4,000				0			
			2,000	.1	200				
5	.2	0				0			
Total Expected Annual Damage					1,184				509

APPENDIX B

Observations on the Economics of Flood-Induced
Increases in Repair Costs

As noted in Chapter 2, when floods cause damage which is significant relative to an area's repair capability, unit costs may rise. In Figure B-1 this is equivalent to an increase in demand for repairs (D to D') not being offset by an increase in supply (S to S'). Factors affecting the demand and supply of repair work are listed in Table B-1. The factors are

Figure B-1



self-explanatory and will not be individually discussed. Depending on the importance of the various factors unit repair costs may or may not increase in individual cases. This suggests that a threshold exists beyond which unit repair costs increase (see Figure B-2).

Figure B-2

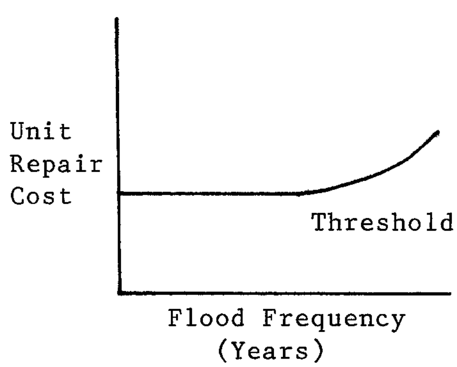


TABLE B-1

Factors Affecting Demand and Supply of Marketed Post-Flood Repair Work

Demand

- Amount of damage
- Ability and willingness to pay for repair
- Ability and willingness to do own repairs
- Abandonment of property
- Delay of repairs
- Donated labor and materials

Supply

- Capacity of local construction industry
- Willingness to temporarily redirect ongoing construction
- Unemployed local construction labor
- Ability and willingness to convert from other occupations
- Repair resources hurt by disaster
- Construction industry attracted from other areas by profit

Source: Adapted from Thomas N. Yancey, Jr., et al, "Disaster-Caused Increases in Unit Repair Cost", ASCE Journal of the Water Resources Planning and Management Division, November 1976, p. 267.

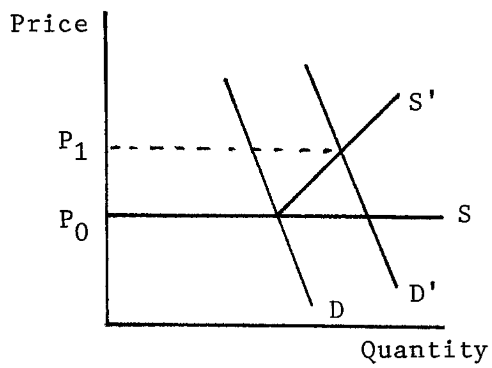
The idea that large floods shift basic demand and supply relationships for repair work such that unit repair costs substantially rise has a corollary relating to salvage value. Flood damages are equal to an items' value before the flood (replacement cost minus depreciation) minus its value after the flood. The estimated salvage value of structures and, more importantly, contents, may be based on pre-flood demand and supply relationships. If a large flood has shifted these relationships the salvage value may be lower than estimated and may even be negative if one must pay to have an item hauled away.

Another source of cost increase may be from repairs which are not properly made and must be done again. This may occur due to repair contractors being in too much of a hurry, using inexperienced labor, or being unscrupulous. Certainly these factors are always present, but after a large flood the probability of encountering them would seem to be higher.

Where the magnitude of a flood is such that unit repair cost increases, salvage values are lowered, or a large percent of repairs need to be repeated, the traditional damage-frequency relationship should be adjusted upward. The effect of such an adjustment on expected annual damages depends not only on the magnitude of the adjustment but on the threshold at which such adjustments are applicable.

This raises an important point worthy of further inquiry. One could argue that society's disutility from having 1,000 structures flooded at one time should be the same as the disutility from 100 similar structures flooded in a similar fashion on 10 different occassions. If the physical effects are the same it would seem that the economic losses should be the same. The key to this question is estimating willingness to pay. As discussed in Chapter 1 the increase in utility (benefits) attributable to a project is measured by the willingness to pay for a project. Since demand for flood control cannot be measured directly (it is not a marketed good) it is assumed that people would be willing to pay at least up to the amount of damages to avoid damages. Within a framework of demand and supply for structure repairs, presumably the demand for repairs will be limited by the price of alternative undamaged housing outside the flood plain. Under traditional assumptions the price of repairs is independent of the quantity of repairs (see Figure B-3). After a flood the demand for repairs shifts out-

Figure B-3



ward to D'. If prices rise to P_1 after a large flood the supply curve must intersect D' at P', as does, for example, S'. Since people have, generally, rebuilt after a flood, willingness to pay may be underestimated in the traditional framework.

It is not easy, though, to measure willingness to pay. After a severely damaging flood an area may be declared a disaster area, thus making property owners eligible for a variety of subsidized assitance, such as low interest loans. The existence of such subsidies must be accounted for lest willingness to pay be overestimated.

The subject of disaster-caused increases in unit repair costs appears to be a potentially important area for empirical research. Presumably, if an owner is willing to pay twice the pre-flood unit repair cost to repair property after a large flood, he would be willing to pay twice the unit repair rate following a small flood. If so, benefits should be based on a frequency-damage relationship in which damages are increased not only for larger frequency floods, but for all floods. Raising the damage estimates for frequent floods may importantly increase expected damages. Thus, the traditional assumptions in estimating benefits may be conservative.