Chapter 6
Uncertainty of Stage-Damage Function

6-1. Stage-Damage Function Development

a. Traditional method. A stage-damage function is a summary statement of the direct economic cost of floodwater inundation for a specified river reach. For residential structures, the function traditionally has been developed as shown in Table 6-1. Similar information on value, damage as a function of depth, and flood depth at a site is necessary to develop the stage-inundation damage functions for non-residential structures and for other property.

b. Function development accounting for uncertainty.

(1) In the procedure outlined in Table 6-1, much is uncertain. Table 6-2 identifies some of the sources of uncertainty. The remainder of this chapter presents methods for describing uncertainty of these individual components. With these descriptions, an aggregated description of uncertainty of the stage-damage function can be developed with the procedure shown in Figure 6-1. In this, probabilistic descriptions are developed to describe uncertainty or errors in estimating (a) the first-floor elevation of the structure; (b) the percent damage to a structure for a given water depth; (c) the structure value; (d) percent damage to the contents for a given water depth; and (e) the structure-to-content value ratio. Each is sampled to develop a description of the overall uncertainty or error. This uncertainty description then can be included in the sampling for expected annual damage and annual exceedance probability computations, as described in Chapter 2.

(2) This chapter addresses only description of uncertainty in inundation flood damage to residential structures.

Table 6-1
Traditional Procedure for Development of Stage-Damage Function

Step	Task
1	Identify and categorize each structure in the study area based upon its use and construction.
2	Establish the first-floor elevation of each structure using topographic maps, aerial photographs, surveys, and/or hand levels.
3	Estimate the value of each structure using real estate appraisals, recent sales prices, property tax assessments, replacement cost estimates, or surveys.
4	Estimate the value of the contents of each structure using an estimate of the ratio of contents value to structure value for each unique structure category.
5	Estimate damage to each structure due to flooding to various water depths at the structure's site using a depth-percent damage function for the structure's category along with the value from Step 3.
6	Estimate damage to the contents of each structure due to flooding to various water depths using a depth-percent damage function for contents for the structure category along with the value from Step 4.
7	Transform each structure's depth-damage function to a stage-damage function at an index location for the floodplain using computed water-surface profiles for reference floods.
8	Aggregate the estimated damages for all structures by category for common stages.

Table 6-2
Components and Sources of Uncertainty in Stage-Damage Function (USACE 1988)

Parameter/model	Source of uncertainty
Number of structures in each category	Errors in identifying structures; errors in classifying structures
First-floor elevation of structure	Survey errors; inaccuracies in topographic maps; errors in interpolation of contour lines
Depreciated replacement value of structure	Errors in real estate appraisal; errors in estimation of replacement cost estimation-effective age; errors in estimation of depreciation; errors in estimation of market value
Structure depth-damage function	Errors in post-flood damage survey; failure to account for other critical factors: flood water velocity, duration of flood; sediment load; building material; internal construction; condition; flood warning
Depreciated replacement value of contents	Errors in content-inventory survey; errors in estimates of ratio of content to structure value
Content depth-damage function	Errors in post-flood damage survey; failure to account for other critical factors: floodwater velocity, duration of flood; sediment load; content location, floodwarning

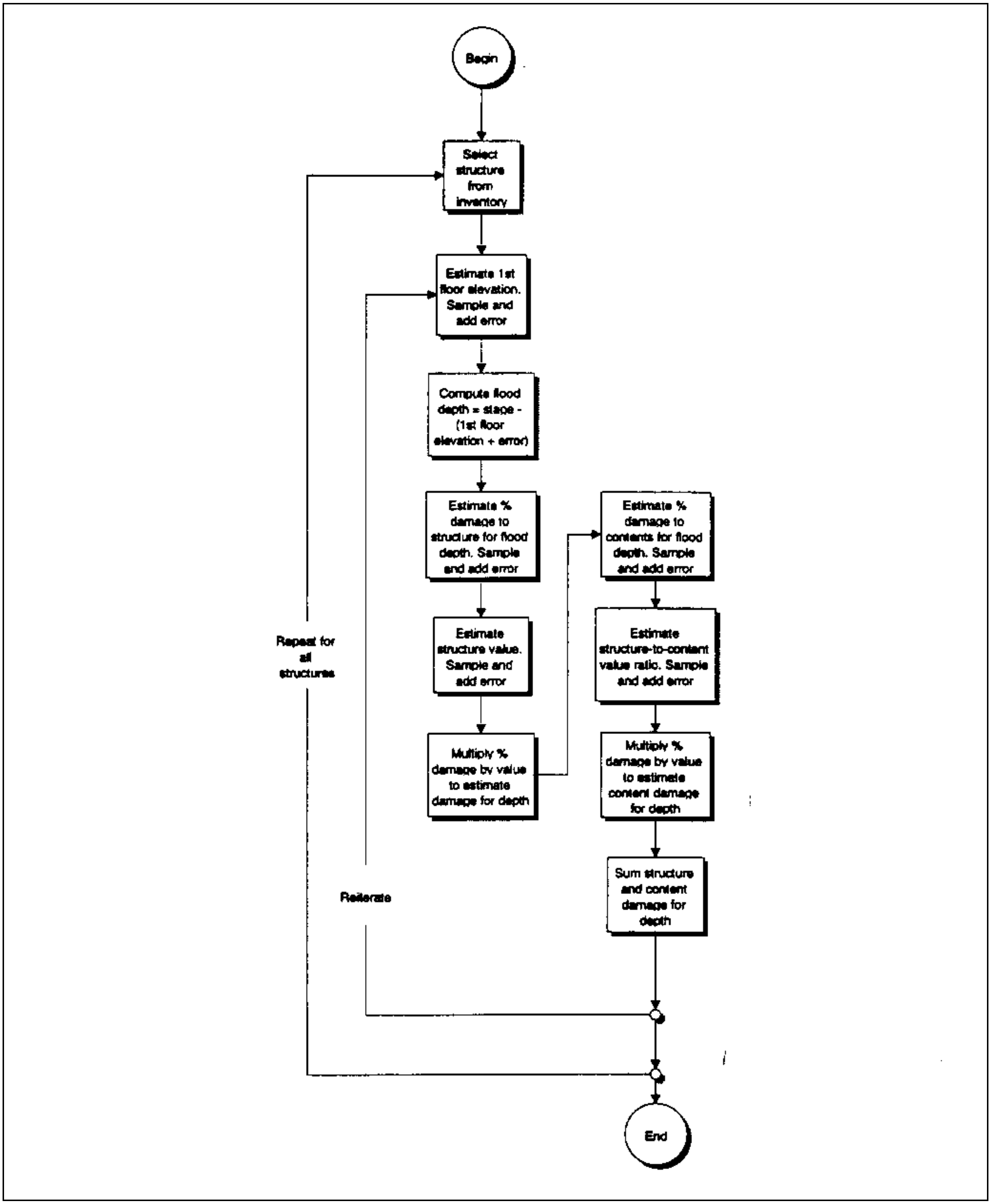

Figure 6-1. Development of stage-damage function with uncertainty description

However, the approach presented can be used to describe uncertainty of the stage-damage relationship for businesses, utilities, transportation and communication systems, and flood emergency costs.

6-2. Description of Parameter Uncertainty

a. Structure value.

(1) Structure value is a critical parameter of the stage-damage function, as it determines directly the structure damage and indirectly the content damage. Based upon the “rational planner” model and the willingness-to-pay principle, depreciated replacement value is used as the appropriate measure of this value for Corps studies. Acceptable methods for estimating depreciated replacement value are summarized in Table 6-3.

(2) To develop a description of error or uncertainty in structure value, one of the following may be used:

(a) *Professional judgment*. With this method, each structure's value is estimated by an expert in real-property valuation and is expressed as a range or as minimum and maximum values. From these, a uniform or triangular distribution can be fitted to describe the error. With a uniform distribution, all values between minimum and maximum are considered equally likely. With a triangular distribution, such as that shown in Figure 6-2, the best estimate is considered most likely. Alternatively, a normal distribution may be fitted. A common method for approximating the standard deviation in that case is to use the range of the variable. For instance, appraisers may attest that the depreciated replacement cost of a structure is between $60,000 and $70,000. Dividing this range by 4 provides an estimate of the standard deviation of $2,500. By implication, this method assumes that the error range is approximately equivalent to a 95-percent confidence interval. One caution in using this method, as with any method using "expert judgment," is that experts tend to be overly confident and provide an error range that is too narrow (Kahnemen, Slovic, and Tversky 1982).

(b) *Sampling to fit a distribution*. With this procedure, a sample of the structure values, stratified by structure category, is drawn from the real-estate

Table 6-3
Methods for Estimating Depreciated Replacement Value

Approach	Description	Comments
Replacement cost estimating using Marshall Valuation Service (both printed and computerized versions)	Develops a replacement construction cost estimate based on information on foundation, flooring, walls, roofing, heating system, plumbing, square footage, effective age, and built-in appliances. This estimate is then adjusted for depreciation.	No independent assessments of errors in resulting depreciated replacement value are available. Experienced building contractors and others may be useful in estimating error bounds.
Real estate assessment data	Involves adjusting real estate tax assessment values for deviations between assessed value and market value and subtracting land component of market value. Presumption is that remainder is depreciated replacement value of structure.	No general method for estimating error in resulting structure values. One approach is to compare results from a sample of individual structures to results using replacement cost estimating method. Random stratified sampling techniques should be used to assure that all structure categories and construction types are verified. Alternatively, verification should cover structure categories and construction types that are located in most flood-prone segment of study area. Sample size for verification should be sufficient to establish range of error, even if it is not large enough to develop empirically a frequency distribution of error in structure values. Easy, yet useful, approach to quantifying errors in structure values using real estate assessments is to query local real estate experts and appraisers.
Recent sales prices	Requires sufficient recent property sales in area for each of structure and construction types for which structure value is to be estimated. As with real estate assessment data, adjustments must be made to subtract land value to yield structure component.	Theoretically, sales prices should be a more accurate basis for estimating depreciated replacement value than real estate assessments. Obvious source of error is estimating and subtracting land portion of sales price to yield structure value estimate. Methods for estimating error when using recent sales prices to estimate structure values are same as those when using real-estate assessment data.

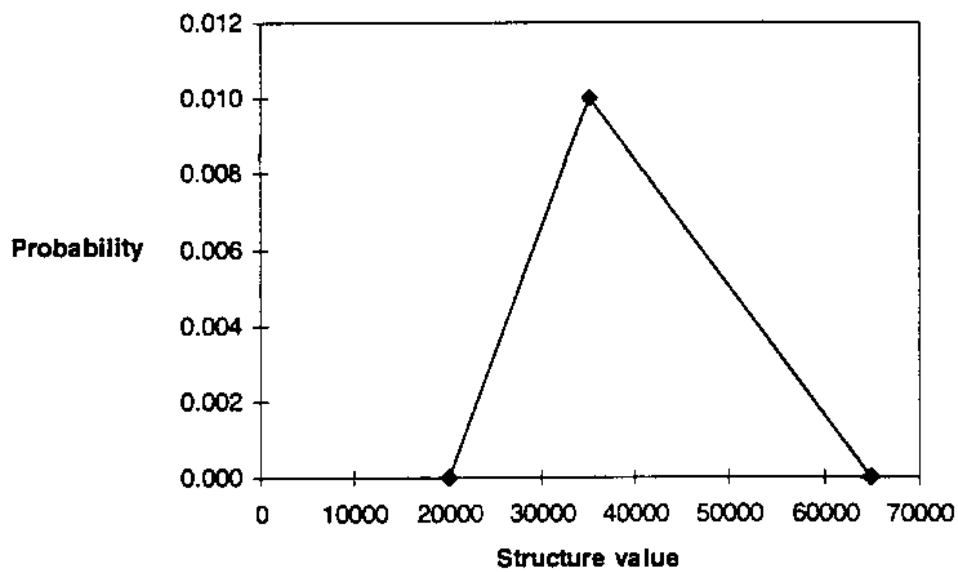

Figure 6-2. Example triangular distribution of structure value

assessments and is used to estimate statistics that describe errors in each category. From these statistics, the parameters of a probability function are estimated. For example, from the mean and standard deviation of logarithms of values in each category, parameters of a log normal distribution of values can be estimated.

b. Content-to-structure value ratio.

(1) A common approach to estimating residential content value is to estimate that value as a fraction of the structure value. This approach mimics that typically employed by residential casualty insurers in setting rates and content coverage for homeowners insurance. The value of contents found in any structure is highly variable, however. It may reflect the wealth and income of the occupants, their personal tastes and lifestyles, and a variety of other factors.

(2) Table 6-4 shows computed means and standard deviations of content-to-structure value ratios based on large samples of Flood Insurance Administration (FIA) claims records. These nationwide averages are not appropriate for all cases, but in lieu of better site-specific information, the values in this table can yield estimates of parameters of a probability distribution of errors.

(3) In some instances, content values may have been developed by using survey or inventory methods. It must be recognized that where content values are directly measured there will still be uncertainty in the actual content value due to errors in inventories, pricing, and age. It is difficult to judge the overall effect of these potential sources of uncertainty on content values. One easily implemented method is to request that the individual completing the survey or the inventory provide an estimate of the accuracy of the provided information.

c. First-floor elevation. Estimation of flood damage using depth-percent damage relationships requires specification of the first floor elevation of the structure. This elevation may be established via field or aerial surveys or by reference to topographic maps. Table 6-5 describes the elevation errors for each of these methods. This description of errors can be used to estimate parameters of a probability distribution of errors. If a Gaussian normal distribution is assumed to model the errors, the indicated standard deviation can be used, with mean error assumed equal to zero. Alternatively, professional judgment can be used to determine the most-likely, minimum, and maximum values, and a triangular distribution can be fitted.

6-3. Description of Uncertainty in Form of Depth-Damage Functions

a. The final elements required to develop the stage-damage function are the structure and content

Table 6-4
Content-to-Structure Value Ratios[1,2] (from FIA Claims Data)

Structure Category	Number of Cases	Mean	Standard Deviation	Minimum	Maximum
One story - no basement	71,629	0.434	0.250	0.100	2.497
One story - basement	8,094	0.435	0.217	0.100	2.457
Two story - no basement	16,056	0.402	0.259	0.100	2.492
Two story - basement	21,753	0.441	0.248	0.100	2.500
Split level - no basement	1,005	0.421	0.286	0.105	2.493
Split level - basement	1,807	0.435	0.230	0.102	2.463
Mobile home	2,283	0.636	0.378	0.102	2.474
All categories	122,597	0.435	0.253	0.100	2.500

[1] Note that these are less than ratios commonly used by casualty insurance companies, but those reflect replacement costs rather than depreciated replacement costs.
[2] Research by the Institute for Water Resources (IWR) suggests that errors may be described best with an asymmetrical distribution, such as a log-normal distribution. In that case, the parameters of the error distribution cannot be estimated simply from the values shown in this table.

Table 6-5
First-Floor Elevation Error and Standard Deviation Calculated from Results in *Accuracy of Computed Water Surface Profiles* (USACE 1986)

Method of Elevation Estimation	Error,[1] in ft	Standard Deviation,[2] in ft
Field survey, hand level	± 0.2 @ 50’	0.10
Field survey, stadia	± 0.4 @ 500’	0.20
Field survey, conventional level	± 0.05 @ 800’	0.03
Field survey, automatic level	± 0.03 @ 800’	0.02
Aerial survey, 2-ft contour interval	± 0.59	0.30
Aerial survey, 5-ft contour interval	± 1.18	0.60
Aerial survey, 10-ft contour interval	± 2.94	1.50
Topographic map, 2-ft contour interval	± 1.18	0.60
Topographic map, 5-ft contour interval	± 2.94	1.50
Topographic map, 10-ft contour interval	± 5.88	3.00

[1] Errors for aerial survey and topographic maps are calculated at the 99-percent confidence level, assuming the deviations from the true elevation are normally distributed with zero mean and indicated standard deviations.
[2] Standard deviation for field survey assumes that error represents a 99-percent confidence interval and assuming normal distribution.

depth-damage functions. These are models of the relationship of depth of flooding at a structure to the damage incurred. As with other models used in plan evaluation, these models are not known with certainty. For example, Table 6-6 shows factors that arguably should be included in, but that are commonly omitted from, a damage prediction model.

b. The impact of including or excluding these factors may be explored through sensitivity analysis, with the factors shown in Table 6-6 incorporated to develop a more complex relationship. For example, if duration is incorporated, a depth-duration-damage function might be developed. This function can be used in the expected annual damage and annual exceedance probability computations. In display of plan performance, the computed expected annual damage and annual exceedance probability values will then be identified as those computed with the alternative models.

c. An alternative approach suggested by the Institute for Water Resources is to treat model uncertainty directly as parameter uncertainty. In that case, the error in percent damage for each depth is described with a Gaussian normal probability distribution.

Table 6-6
Factors, Other than Depth, That Influence Damage (USACE 1988)

Factor	Effect
Velocity	Major factor aggravating structure and content damage. Limits time for emergency floodproofing and evacuation. Additional force creates greater danger of foundation collapse and forceful destruction of contents.
Duration	May be the most significant factor in the destruction of building fabric. Continued saturation will cause wood to warp and rot, tile to buckle, and metal objects and mechanical equipment to rust.
Sediment	Can be particularly damaging to the workings of mechanical equipment and can create cleanup problems.
Frequency	Repeated saturation can have a cumulative effect on the deterioration of building fabric and the working of mechanical equipment.
Building material	Steel frame and brick buildings tend to be more durable in withstanding inundation and less susceptible to collapse than other material.
Inside construction	Styrofoam and similar types of insulation are less susceptible to damage than fiberglass and wool fiber insulation. Most drywall and any plaster will crumble under prolonged inundation. Waterproof drywall will hold up for long periods of inundation. Paneling may be salvageable when other wall coverings are not.
Condition	Even the best building materials can collapse under stress if the construction is poor or is in deteriorated condition.
Age	May serve as an indicator of condition and building material.
Content location	Important factor, as small variations in interior location of contents can result in wide variation in damage.
Flood warning	Major reduction in both content and structural loss can be made through flood fighting and evacuation activities when there is adequate warning.

6-4. Stage-Damage Function Using the Opinions of Experts

a. The approach illustrated in Figure 6-1 does not reflect the methodology typically employed to estimate damages for non-residential property. For these unique properties, the stage-damage function may be developed as a consequence of post-flood surveys or through personal interviews with plant managers, plant engineers, or other experts. Then, instead of employing dimensionless depth-percent damage functions, damages incurred at various water-surface elevations are approximated directly.

b. To describe uncertainty in these cases, the experts should be asked to estimate the most-likely damage for a range of depths, to provide a range of damages for each depth, and their confidence that the range contains the actual damage value that would occur. These opinions on the range and confidence can be used to estimate the parameters of a probability distribution that describes error for each depth. If the respondent cannot or will not provide information other than an estimated range, the analyst can use the mid-point of the range as the mean and one-fourth of the range as the standard deviation; this assumes a normal distribution of errors and inclusion of 95 percent of all damages in the stated range.

6-5. Approach with Limited Data

In some flood damage-reduction planning studies, data in the detail or format for proper analysis of uncertainty is not available, and the cost to enhance existing data to conduct an uncertainty analysis is not justified. In those cases, the planning team must take care to acknowledge likely sources of uncertainty and their impact.

a. The mean stage-damage function is likely most sensitive to error in the first-floor elevation, other things being equal.

b. The error in damage at any stage is not symmetrically distributed around the mean damage. This is particularly true at the lower stages, because damage cannot be negative. Thus the probability of overestimating damage is greater.

c. Although the dispersion of damages about the mean, as measured by the standard deviation, increases with increasing stage, the coefficient of variation (standard deviation divided by mean) decreases with increases in stage. Thus, the error in damage, expressed as a fraction of the mean damage decreases as the stage (and hence, mean damage) increases. This is due, in part, to the truncation of damage at zero. It is also a consequence of lessening sensitivity of error to error in first-floor elevation as stage increases.

6-6. Intensification and Location Benefits

This chapter has not addressed estimation of intensification and location benefits or description of uncertainty in those estimates, even though these benefits may be significant. Their evaluation requires speculation on the response of floodplain occupants to a flood-damage reduction plan. In that case, sensitivity analysis or development and analysis of alternative future scenarios may provide a measure of the impact of the uncertainty.