Appendix G
PROPERTY LOSS ESTIMATION – FLOOD

This appendix describes the approaches followed for estimating property loss due to flood.

G.1 Locating the Structure within the Flood Plain

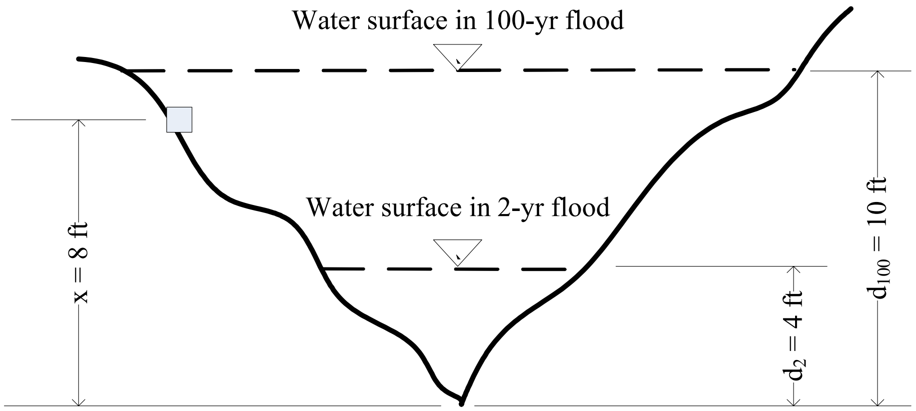

Figure G-1. Illustration of flood-loss calculation

Given: Let d_n denote the n-yr flood depth at the stream channel center. For example, d_{100} denotes the 100-year flood depth at a stream channel center, d_2 denotes the 2-year flood depth at a stream channel, etc. These flood depths are calculated using the methodology that is documented in Section G.5. For this illustration, assume that $d_{100} = 10$ ft and $d_2 = 4$ ft.

Let $\underline{d}$ denote the set of flood depths at the stream channel center, d_5, d_{10}, d_{20}, d_{50}, d_{100}, etc. (It is common notation to use an underline to indicate that a parameter is a vector, potentially containing many scalar values.)

Let x denote the height of the building site above the stream channel center, assuming that $x \geq 0$, i.e., the building is located at a higher elevation than the stream channel center. In the Figure G-1, $x = 8$ ft.

Let h_n denote the depth of flooding at the site in the n-yr flood. For example, h_{100} denotes the depth of flooding at a particular site in the 100-yr flood, h_{50} denotes the depth of flooding at the site in the 50-yr flood, etc. For any return period n,

$$h_n = \text{larger of } (h_n - x) \text{ and } 0 \qquad \text{(G-1)}$$

For example, in Figure G-1 and using the above equation, $h_{100} = 2$ ft, and $h_2 = 0$ ft. If x and $\underline{d}$ were known, it would be possible to calculate all the associated values of h.

Let & (ampersand) denote all of the information needed about a building to calculate loss, other than flood depth, such as the value of the building.

Let y_n denote the loss in the n-yr storm. For example, y_{100} denotes the loss given 100-yr flooding.

Let f denote a function that calculates loss for a known flood depth h and &. (Note: the depth-damage relationships in HAZUS are used but these functions are not detailed here.) Since h_n is a function solely of y and d_n, y_n can be expressed as:

$$y_n = f(x, d_n, \&) \tag{G-2}$$

Let y_{ann} denote the average annualized loss to the facility, considering all possible depths h_n, the resulting losses y_n and their associated return periods, n. (Typically y_{ann} is calculated by numerical integration, which is not detailed here.)

Let g denote the function used to perform the numerical integration for y_{ann}. It uses several values of n for y_n. We denote by $\underline{y}_n$ the set of values y_n, and the associated set of return periods by $\underline{n}$, and write

$$y_{ann} = g(\underline{y}_n, \underline{n}) \tag{G-3}$$

Problem statement: Assume that $\underline{d}$ can be calculated (this calculation is treated elsewhere), that "&" is known from the grant-application data, that the depth-damage relationships are known (which are taken from HAZUS), and that the numerical integration of the various values of loss and frequency can be calculated. In this case, x is not known precisely, owing to shortcomings in the grant-application data, geocoding difficulties, and the lack of a very accurate nationwide elevation model. The problem is: how can y_{ann} be calculated without a known value of x?

Solution:

Uncertain X. In this case, the elevation difference is recognized as uncertain, and is denoted using a capital letter, X. (Common mathematical notation. That is, x is a particular value, whereas X is uncertain and has a probability distribution.)

Uncertain Y_{ann}. Since X is uncertain, so is y_{ann}, in which case, the uncertain annualized loss is denoted by Y_{ann}. The goal is to obtain the expected value of Y_{ann}, which is denoted by $E[Y_{ann}]$. (That is, y_{ann} is a particular value for a known value x, Y_{ann} is uncertain and has a probability distribution, and $E[Y_{ann}]$ is a best-estimate, average value of Y_{ann}.)

Distribution of X. Next, it is assumed that $0 < X < d_{100}$, i.e., the building site elevation is somewhere between that of the stream channel center ($x = 0$) and the edge of the mapped 100-yr floodplain ($x = d_{100}$). Without any additional knowledge, according to information theory, the proper assumption is that X is uniformly distributed between 0 and d_{100}. That is, the difference in elevation between the building site and the stream channel center is equally likely to be 0, d_{100}, or anywhere in between. If more were known about the difference in elevation, a better assumption could be made, but without more knowledge, the best assumption for X is the uniform distribution.

Alternatives for simulating Y_{ann}. Given the values $\underline{d}$, the information &, the functions *f* and *g*, and the assumed distribution for *X*, samples of *X* can be created, y_{ann} can be calculated for each sample, and the expected value $E[Y_{ann}]$ can be calculated using the samples of y_{ann}. There are at least four reasonable methods (as described below) to select samples of *X*, illustrated in Figure G-2, which shows a cross-section (or transect) of a floodplain, gray boxes for sample sites, and the calculated flood level in the 100-yr flood.

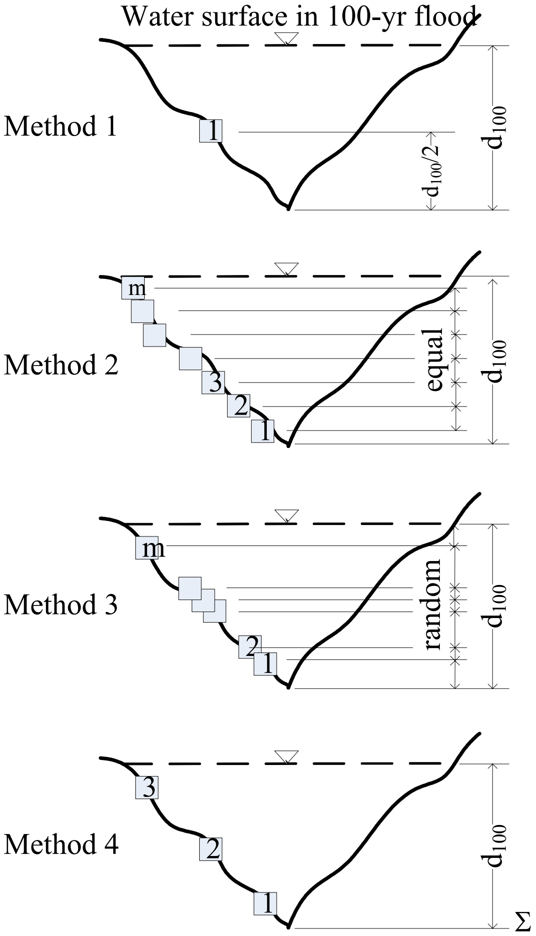

Figure G-2. Four methods of simulating X

Method 1: Select the best-estimate value of *X*, namely $x = d_{100}/2$, which yields x, $\underline{d}$, &, *f*, and *g*, and enables the calculation of y_{ann} as before. The problem is that f is a nonlinear function, in which case the estimate of y_{ann} might be significantly biased.

Method 2: Select *m* evenly spaced values of X: $x_i = i/m + d_{100}/(2m)$, where $i = 0, 1, \ldots m-1$. Calculate y_{ann} for each site *i*, and take the simple average, $E[Y_{ann}] = \Sigma_i(y_{ann,i})/m$, where $y_{ann,i}$ corresponds to sample x_i. This avoids the problem of nonlinear *f*, if enough samples are used.

Method 3: Use various Monte Carlo simulation approaches, in which *X* is simulated randomly *m* times. Calculate $E[Y_{ann}]$ as in Method 2.

Method 4: Use Hermite-Gauss quadrature, in which case a few samples of X are carefully selected and assigned weights (or probabilities) w_i, so that they match the first several moments of X (mean, variance, etc.). The losses $y_{ann,i}$ for each value of x_i, and a weighted average of the values $y_{ann,i}$ using the weights w_i are then calculated. This approach is similar to Method 2, except the values of x_i are not evenly spaced, and a weighted, rather than simple, average of the sample losses $y_{ann,i}$ is created. This approach provides a good estimate of $E[Y_{ann}]$ and is exact if f can be represented by up to a 5th-order polynomial.

Preferred Method: Hermite-Gauss quadrature for $E[Y_{ann}]$ (Method 4). Without presenting the pros and cons of each choice, we note that Method 4 is more accurate and efficient.

Following is the approach followed for estimating $E[Y_{ann}]$ using Method 4. Again, X is assumed to be uniformly distributed between 0 and d_{100}, and three Gauss points are used, which means that the uncertain X is replaced by three particular values, denoted here by x_1, x_2, and x_3, each with an associated weight (or probability), denoted by w_1, w_2, and w_3. Under these conditions,

$$\begin{aligned} x_1 &= 0.1127 * d_{100} \qquad & w_1 &= 0.2778 \\ x_2 &= 0.5000 * d_{100} \qquad & w_2 &= 0.4444 \\ x_3 &= 0.8873 * d_{100} \qquad & w_3 &= 0.2778 \end{aligned} \tag{G-4}$$

$E[Y_{ann}]$ is then computed as

$$E[Y_{ann}] = \Sigma_i(w_i * y_{ann,i}) \text{ where } i = 1, 2, 3 \tag{G-5}$$

where Σ_i denotes summation over the three values of i, and where $y_{ann,i}$ denotes the annualized loss given site i. The methodology is illustrated in Figure G-3.

Imagine the 100-yr flood depth at the center of a certain basin (d_{100}) is 10 ft, as shown in Figure G-3, and that d_{20} = 3 ft and d_{50} = 6 ft. (In practice additional flood depths are used, but for illustration, consider just these three.) From Equation G-4, rounding for illustration purposes, x_1 = 1 ft, x_2 = 5 ft, and x_3 = 9 ft. Those elevations would put the building at sites 1, 2, and 3, respectively.

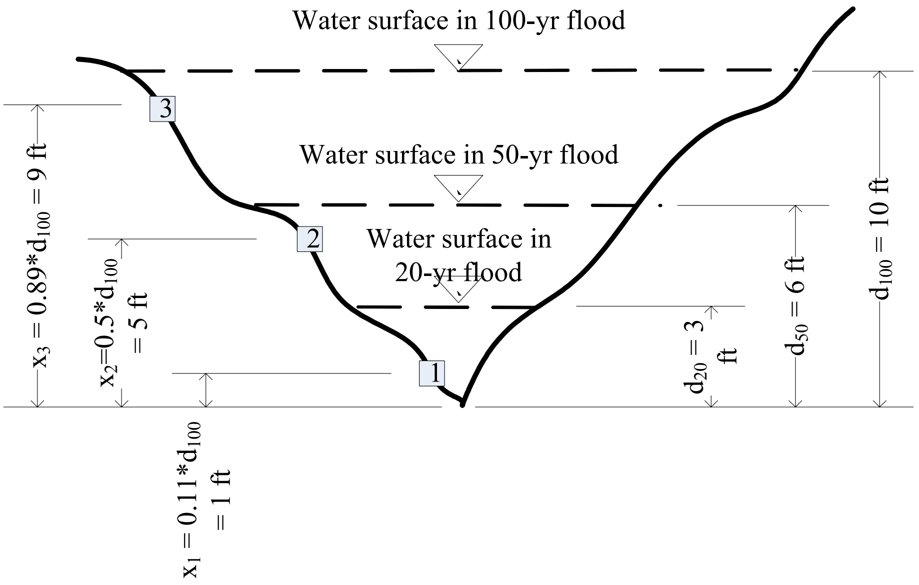

Figure G-3. Illustration of elevation differences X used in Hermite-Gauss quadrature for flood loss.

The next step is to calculate flood depths for each storm (20, 50, and 100-yr) for each sample site, using Equation G-1, as shown in Table G-1

Table G-1 Flood depth h_n given return period and site elevation

Site	20 yr	50 yr	100 yr
1	2 ft	5 ft	9 ft
2	0 ft	1 ft	5 ft
3	0 ft	0 ft	1 ft

Next, the loss for each site and each storm is calculated, using these flood depths, and integrated to get the expected annualized loss for each site, y_{ann}, using Equation G-3. Assumed losses are as shown in Table G-2.

Table G-2 Annualized losses Y_{ann} for each site elevation X

Site	y_{ann}	weight w_i
1	\$10,000/yr	0.2778
2	\$5,000/yr	0.4444
3	\$2,000/yr	0.2778

Finally, a weighted average of the loss for all three sites is created, using the weights in Equation G-4 and the weighted average in Equation G-5:

$$E[Y_{ann}] = 0.2778*10{,}000 + 0.4444*5{,}000 + 0.2778*2{,}000$$
$$= \$5{,}600/\text{yr}$$

G.2 Quality Control/Quality Assurance

The following steps were implemented to assure the reliability of the results:

1. The geographic locations of all properties were checked against the Q3 digital floodplain boundaries and stream data by plotting each site on maps and performing visual inspections. This was done for the 486 properties included in the analysis.
2. Simple models reflecting the loss calculation process were developed to ensure that the damage functions from HAZUS were being implemented correctly.
3. Independent hand calculations were performed for five (5) projects to check the accuracy of the software program developed to estimate BCA ratios. These calculations were performed by an individual who was not involved with the initial development of the methodology.
4. The results of the current analysis were compared to benefit-cost analysis ratios documented in the NEMIS database. In general, there was good agreement between these estimates.
5. Sensitivity studies were performed to quantify the variability of results to changes in key input parameters. The results did not identify any unusual trends or anomalies.

G.3 GIS Data used in Flood Hazard Analysis

USGS NED:

The National Elevation Dataset (NED) conveniently provides USGS Digital Elevation Models (DEM) in a seamless form that corrects many data artifacts such as mismatched edges, data sinks, and rippling effects. The NED has a resolution of 30 meters, and is based on a variety of data collection techniques including stereoscopic interpretation, processing of Digital Line Graph (DLG) data, and Shuttle Radar Topography Mission (SRTM).

USGS NHD level 1 stream data:

The National Hydrography Dataset (NHD) from the USGS contains information about surface water features such as streams. The NHD is based on USGS Digital Line Graph (DLG) hydrography data, which correlates with the USGS NED elevation data. Additionally, these data integrate with the EPA Reach File Version 3 (RF3) stream designation. These data are at a scale of 1:100,000, but may incorporate more detailed data in certain areas.

FEMA Q3 digital flood maps:

The FEMA Q3 digital flood maps are digital versions of FEMA's Flood Insurance Rate Maps (FIRM) that are intended for planning use. The Q3 digital flood maps were developed by scanning the existing FIRM paper maps which had street layers that did not always correspond with real world coordinates. The Q3 data captures only the major features of the paper maps, such as the 1% annual chance of flooding, and does not include the base flood elevation or cross section data.

G.4 Assumptions used in Modeling Flood

ASSUMPTION	JUSTIFICATION
A building included in a FEMA-funded mitigation project is located in a floodplain.	Although FEMA’s Flood Insurance Rate Maps are the basis for local regulation of flood hazard areas, it is widely acknowledged that the maps do not show all areas that actually experience flooding. The evidence is found in FEMA’s statement that nearly one-third of all flood insurance claims paid are on buildings that are not within the flood hazard areas shown on the maps. Furthermore, about 60% of the nation’s waterways have flood maps that were delineated using approximate methods that have insufficient detail to delineate all flood-prone areas. FEMA is authorized to provide grant funds for flood mitigation projects that will avoid or reduce future flood damage. Grants are provided only for projects that are in the floodplain. If a location is not in a FEMA-mapped flood hazard area then applicants must demonstrate that the area is subject to flooding.

ASSUMPTION	JUSTIFICATION
The depth of flooding at the center of the channel of the 1%-annual chance flood is at least 5 feet deep. (This depth, d_{100}, is computed using the routine described in Section G.5 of this appendix).	The height to which water will rise above the stream bottom (flood depth) is a function of many variables. When water rises out of the channel, the adjacent land begins to flood. The horizontal extent of land that is affected, and the depth of flooding above any point of ground, depends on the elevation of the ground relative to the flood depth. If the 1%-annual chance flood depth is 5 feet (measured in the channel), the depth of water in the adjacent floodplain will always be less than 5 feet. For most parts of the country, flood depths this shallow would be found only in small streams. The elevation information used to estimate the flood depth in the channel is taken from the 30-meter Digital Elevation Model (DEM). Although there is no estimate of how elevations from the DEM vary from actual elevations, some smoothing is expected. The assumption that the flood depth in the channel of the 1%-annual chance flood is at least 5 feet underestimates the actual flood depth at locations other than along small streams.
The first (finished) floor of the building is at-grade (i.e., the floor elevation is the same as the ground elevation).	Virtually all flood-prone buildings that are mitigated using FEMA funds are older buildings that were built before communities joined the NFIP or had begun regulating construction (most notably to require new buildings to have their lowest floor raised above the ground to be at or above the depth of flooding associated with the 1%-annual chance flood). Barring specific information about prevalent foundation types, the assumption is that all buildings included in mitigation projects have their first (finished) floor levels "at grade." At specific locations, this disregards the fact that the types of foundations and construction practices vary regionally (basements, crawlspaces, piers/columns, slabs-on-grade). Traditional foundation types (before floodplain regulations) are influenced by local conditions such as high groundwater, frost depth, soil types, termite activity, and simple historic practices.
For non-basement buildings, there is no damage to the building when the water surface elevation is at or below the ground floor elevation at the building site, which is also assumed to the first (finished) floor.	It is assumed that the first (finished) floor is at-grade (the floor and the ground are at the same elevation). Therefore, when the flood level does not rise to the elevation of the floor/ground, the building is not touched by floodwater. Buildings that are not touched by floodwater are not damaged.

ASSUMPTION	JUSTIFICATION
Where descriptions of building types and building/contents values and project costs are available, they are used. Otherwise, average values determined from the entire dataset (486) are used.	1. 2/3 of buildings (out of the 486) do not have basements. 1/3 have basements. 2. 88% of the buildings are 1 story, 12% are 2 story. 3. Where the values of the structure and the property are unknown, a value of $42,576 is used, which is the median of the known values. Where the value of the structure is unknown, the ratio of structure value to the sum of the value of the structure and the property (where both values are known) is used (this ratio is 75%). Where both values are unknown, 75% of $42,576 or $31,932 is used.
Benefits are calculated using a discount rate of 3% for 50 years.	This assumption is being used for all benefit-cost analysis calculations.
Contents are 50% of structure cost.	This assumption comes from HAZUS-MH.

G.5 Flood Depth-Frequency Methodology Options[72]

G.5.1 Background

In order to examine the benefits of a flood mitigation measure located at a specific site, characteristics of the flood hazard at that site are required. The standard default parameter used to characterize flood hazard is depth. Flood characteristics that may contribute significantly to damage include velocity, duration, wave impacts, debris impacts, and scour/erosion. The depth-damage functions developed by FEMA, the Corps of Engineers, and others, generally aggregate damage from all types of flooding so that the influence of each flood characteristic is not separately considered.

Depth-damage functions are developed for different types of buildings. They relate damage (expressed in a percent of value) to the depth of floodwater above the lowest floor. Ideally, one would know the floodwater depths for different frequency floods. The floodwater depths at a specific building are functions not only of the flood frequency, but the ground elevation and the elevation of the lowest floor (Figure G-4).

G.5.2 Problem Statement

In order to examine flood losses it is necessary to know the depth of flooding, for different frequency floods at different project locations along riverine bodies of water (rivers, streams, creeks and the like, that flow downstream under the force of gravity). This project was

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[72] Source: R. Quinn project memo.

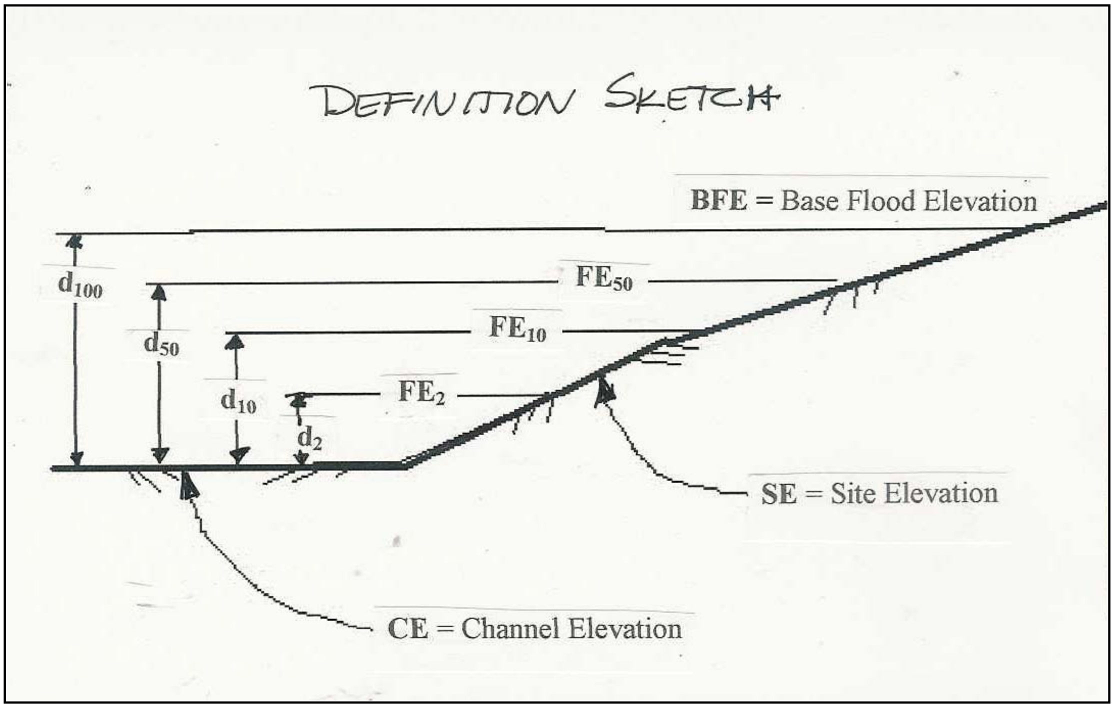

Figure G-4 Sketch showing definitions of various parameters of interest in flood studies.

constrained, however, by the need to apply a method to many different locations with a minimum level of effort.

While depth of flooding is the parameter of interest, it is useful to talk in terms of elevations in order to arrive at depths. For any given location, the flood hazard area associated with the 1%-annual chance flood is usually refered to as the Base Flood Elevation (BFE). The BFE is the height to which floodwaters of the 1%-annual chance flood will rise. Flood discharges of different frequencies produce different water surface elevations (Figure G-4). Many factors influence discharge and elevation, and those factors vary as one moves up and down a stream or river valley (see Figure G-2) and from watershed to watershed. Those factors include:

a. **Hydrology variables** influence the volume and rate of rainfall-runoff (climatic region, drainage area, basin shape, elevation, longitudinal channel slope, land use, vegetation types, soil types, drainage patters, storage (ponds), etc.).

b. **Hydraulic variables** affect the height to which water rises at a given location (valley shape, longitudinal channel slope, frictional effects, constructions such as roads and buildings, etc.)

Within any given floodplain, water depths along the cross-section that is perpendicular to the channel (Figure G-3) as a function of the ground elevation. Thus, in order to apply a depth-damage function at a specific location, it is necessary to know the depth of water above the ground for a range of flood frequencies.

Following are four possible solutions to the problem statement.

G.5.3 Alternative 1 - Solution to the Problem Statement

Alternative 1 would involve accessing flood hazard maps prepared by FEMA. FEMA has prepared Flood Insurance Rate Maps (FIRMs) to show flood hazard areas along most of the waterways in the U.S., except for those in the many rural locations. The maps show Special Flood Hazard Areas that are considered to be the area inundated by the Base Flood (1%-annual-chance flood):

a. **Approximate zones**. More than 60% of the stream miles mapped by FEMA show approximate flood zones, areas that are designated using approximate methods that do not produce BFEs.

b. **Numbered zones.** About 40% of the stream miles mapped by FEMA were done so with detailed hydrologic and hydraulic methods that produced computed water surface elevations. These maps show BFEs referenced to a datum (i.e., a BFE of 285 would mean 285 feet above mean sea level – which in turn is defined based a national datum).

Although FEMA has captured flood hazard areas in digital format for about 1,000 counties (called Q3), the digital files do not contain BFEs. Thus, the paper maps would have to be accessed in order to determine the BFE at specific sites (if the BFE was determined by FEMA; additional manual steps are required to estimate the BFEs for approximate zones). Obtaining the depths for other frequency events involves another manual operation using the flood profiles (only prepared for waterways studied in detail) that are contained in each community's Flood Insurance Study.

Most applications for FEMA grant funding are accompanied by flood depth/elevation data derived from the FIRMs and flood profiles to describe the flood hazard. Other site-specific data are provided, including the ground elevation and lowest floor elevation of specific buildings.

PROS	**CONS**
1. Precision of data	1. Time to obtain paper FIRMs and companion Flood Insurance Studies 2. Manual determination of BFEs and elevations of other frequency floods from paper FIRMS, (including estimating BFE for unnumbered zones) 3. Replicates the methods likely used by applicants

Analysis

Using the paper maps is not only labor intensive, but it is not an independent check because they are the source of data provided by grant applicants. The cons clearly outweigh the pros.

Recommendation for Alternative 1

Do not consider Alternative 1.

G.5.4 Alternative 2 – Solution to the Problem Statement

Alternative 2 would involve using FEMA's loss estimation methodology, Hazards US (HAZUS). FEMA developed a basic automated flood hazard analysis capability as part of HAZUS. The tool can generate discharges and depths for different frequency flood events. The tool will estimate losses "out of the box" for any return period. However, the analysis is very time consuming in terms of both set-up and analysis. The program analyzes single stream segments, rather than a large geographical area. An analysis of properties nationwide would not be reasonable. Additionally, there have been several revisions to the software platform since the release this year, addressing both analytical and software deficiencies.

PROS	**CONS**
1. FEMA and NIBS approved.	1. Software has not been pilot tested. 2. Analytical and software bugs remain. 3. Time consuming to set-up and run. 4. Interactive process not suitable for nationwide automation.

Analysis

Alternative 2, in addition to offering use of software that is not fully prepared for use, is not appropriate for automated, nationwide analysis.

Recommendation for Alternative 2

Do not consider Alternative 2.

G.5.5 Alternative 3 – Solution to the Problem Statement

In this alternative, we consider the flood depth data for different frequency flood events that is generated during in-depth analysis for specific locations in the community studies. Using just five study regions, a single "flood-depth frequency curve" could be developed as a function of the depth of the 1%-annual chance flood. This curve could be used to estimate flood depths at any location to yield depths for various return periods, provided the depth of the 1%-annual chance flood depth is known.

PROS	**CONS**
1. Utilizes data from Track B. 2. Simple to implement.	1. Still requires knowing the 1%-annual chance flood depth at specific locations (discussed in Alternative 3) 2. Flood depths at any location have multiple local variables which would not be accounted for 3. Extremely wide error distribution for flood-depth frequency curve. 4. Relies on questionable HAZUS analysis where higher return intervals often result in decreased flooding.

Analysis

The cons out-weigh the pros, in particular the unmet need to determine the depth of the 1%-annual chance flood at project locations. Even if that depth is determined as described in Alternative 4, the use of depth-frequency data from only 5 locations to develop a single relationship is unacceptable. The relationship between depth and frequency varies significantly in different parts of the country.

Recommendation for Alternative 3

Do not consider Alternative 3.

G.5.6 Alternative 4 – Solution to the Problem Statement

Using statistical parameters developed for discharge records at USGS stream gages and GIS-based methods to estimate the Base Flood Elevation and certain ground elevations in the vicinity of project sites, estimation of flood depths for different return intervals can be automated using a standard hydrologic method that applies statistical relationships at nearby gages. The matter of the starting depth, the depth of the 1%-annual chance flood, is addressed.

PROS	CONS
1. Applicable in 1000 counties, where digital flood data are available 2. Using statistical parameters developed for 'nearby' USGS gages to approximate conditions is a common practice 3. Can be automated with GIS programming 4. More likely to produce results that are applicable to each location than reliance on a national average	1. BFE and ground elevations are selected using 30-meter DEMs 2. Elevations from the DEM at a point corresponding to the location of the stream (on stream layer) is assumed to be the elevation of channel bottom 3. Without digital flood maps for several communities, it is not possible to fully test this method

Analysis

The most significant advantage of this approach is that it is based on stream gage data so that regional and hydro-geomorphic variations are captured. The drawback is in the selection of the depth of the 1%-annual chance flood at project location, a drawback that are found in Alternative 3. No methodology can be automated with current tools to account for very local variations, such as presence of a bridge.

Recommendation for Alternative 4

Use Alternative 4

G.5.7 Overall Recommendation

Based on the analysis above, Alternative 4 was recommended and used for this project.

G.6 Approximating Flood Depths for Different Frequency Floods

Following is an approach to approximate depths for different frequency flood events if the depth of the 1%-annual chance flood – as measured in the channel – is known.[73] The key formula is :

$$\log d_T = \log d_{100} - 0.6\ [(K_{100} - K_T)\ S_{logQ}\ ]. \qquad \text{(G-6)}$$

where:

d_T is the depth for a flood with recurrence interval T; specifically, d_{100} is the depth of the 1%-annual chance flood (estimated as the BFE minus the estimated elevation of the bottom of the channel, see following notes).

K_T is a Pearson Type III frequency factor that is a function of recurrence interval T; K_T values can be obtained from Appendix 3 in Bulletin 17B for various values of skewness G.

$S_{\mathrm{log}Q}$ is the standard deviation of logarithms of discharges for each USGS gage (available in HAZUS)

G is skewness computed for each USGS gage (available in HAZUS)

Therefore, if d_{100} is known, as well as the other variables, then depths for other frequencies can be estimated which, in turn, allows estimation of depths d_T at a site.

Before outlining the specific steps necessary, the following notes provided additional explanation, background, justification, and assumptions.

A. Notes on d_{100}

This depth, used in the depth-frequency relationship (above), is the depth of the 1%-annual chance flood as measured in the channel.

The following ways to estimate d_{100} do not meet the need for ease of use and nationwide applicability for this project:

a. For waterways studied with detailed methods, d_{100} and/or the elevation of the channel bed, referenced to a datum, can be obtained manually by accessing the water surface profiles found in the Flood Insurance Study.

b. Thomas' paper (see footnote 7 above) for FEMA's Unnumbered "A Zone" workgroup has a table that lists 20 states (or parts of states) for which USGS has some depth-area relationships that yield d_{100}. Those states are AL, AR, CO, GA, IL, KA, LA, MD, MA, MO, NJ, NY, NC, OK, OR, PA, TN, UT, VA, WY.

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[73] Wilbert Thomas, "*An Approximate Method for Estimating Flood Depths for Various Recurrence Intervals*" prepared for Christopher P. Jones, December 2003.

c. For each USGS gage, there is a “gage height”. This is an arbitrary datum, selected so that stage (height of water above the datum) is always a positive number. Thomas’ paper indicated that the gage height is not the channel bottom, but probably “close” in most cases. In order to relate the gage height to the point of zero flow (bottom of the channel), one would need to reference the gage’s rating curve (stage-discharge curve).

Therefore, it is necessary to explore more traditional approaches that rely on standard analyses of long records of discharges at USGS stream gages. Flood discharge is a function of many variables, including volume and rate of rainfall-runoff (climatic region, drainage area, basin shape, elevation, longitudinal channel slope, land use, vegetation types, soil types, drainage patters, storage (ponds), etc.).

B. Notes on G (skew)

A value of *G* is provided for every USGS gage and is contained in HAZUS. G is shown with three decimal places. The lookup table in Appendix 3 of 17B (used to extract values of K_T) is set up for values of *G* in decimal increments from +1 to -1. Given the grossness of other assumptions, Thomas’ paper (see footnote 7 above) indicates that it would be acceptable to round *G*. Or, if the Appendix 3 lookup table is automated, interpolation could be done. However, it is notable that the values of K_T do not vary much between whole decimal values of *G*.

C. Notes on $S_{\log Q}$ (Standard Deviation)

A value of $S_{\log Q}$ is provided for every USGS gage and is contained in HAZUS.

D. Notes on Watersheds with USGS Gages

For locations in the same watershed as a USGS gage, the values of $S_{\log Q}$ and *G* for the gage can be applied if the location is “near.” That is, the values at the gage are “usually applicable if the drainage area [at the location of interest] is within 50 to 200 percent” of the area at the gage (per the FEMA standards & guidelines). This approach is better than using the gross regional values (see paper by Wilbert Thomas for Chris Jones).

E. Notes on Watersheds without USGS Gages (or where drainage area is more than 200% of the gage in the same watershed)

In geomorphologically similar areas, the factors of $S_{\log Q}$ and *G* do not vary strongly with drainage area. Therefore, it is acceptable to apply values determined for one site to others, within reason. The methodologies for doing so in a very detailed manner are outlined in USGS publications, and generally involve looking for gaged watersheds that are similar in several characteristics.

There are two approaches, with different degrees of reasonableness, for approximating values of $S_{\log Q}$ and *G*:

1. Use the gross regional values (see paper by Wilbert Thomas for Chris Jones), which advises that using nearby gages is always preferable provided they are in watersheds that are not too dissimilar.
2. Use the average values for the closest gage or gages (ideally selecting gages where the drainage area and other characteristics are similar). Using the average values for the closest gage or gages involves developing a routine to determine the closest gages to each project site. The latitude and longitude of each gage are in HAZUS.

G.6.1 Estimating Depths for Different Frequency Floods

To estimate depth of flooding for different frequency floods (d_T in the channel), for each project site or cluster of building locations, the following steps are required:

1. Determine the *BFE* using Q3;
2. Determine d_{100} (determine the elevation from the DEM that corresponds to the location of the stream from the stream centerline layer and subtract this elevation from the *BFE*);
3. Find the one or two closest gages[74];
4. In HAZUS, extract the values of $S_{\log Q}$ and G for the one or two closest gages (and compute the average values if using two gages);
5. Using the computed G, round to hundredths and look up values of K_T (interpolate) for the frequencies of interest; and
6. Use the formula to compute d_T using K_T and $S_{\log Q}$.

G.6.2 Determining the Depth of Flooding for Different Frequency Floods at a Site

For each site (represented by the 30-meter DEM), the Site Elevation, the Base Flood Elevation, estimated depth of the 1%-annual chance flood (d_{100}) and estimated depths for other frequency floods (d_T) are known. The next step, then, is to determine the depths of those frequency floods at the site – these are the depth values used in the Depth/Damage function.
Figure G-4 is a definition sketch. If:

SE = Site Elevation (known from DEM)
CE = Channel Elevation (determine the elevation from the DEM that corresponds to the location of the stream from the stream centerline layer);
BFE = Base Flood Elevation (known from Q3)
FE_T = Elevation of Flood of frequency T
d_{ST} = Depth at Site for Flood of frequency T

then:

$$FE_T = CE + d_T \tag{G-7}$$

and

$$d_{ST} = FE_T - SE \quad \text{and} \quad d_{100} = BFE - SE \tag{G-8}$$

Note: When d_{ST} is a negative number it means the ground at the site is dry (higher than the water for that frequency event).

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[74] Need to intervene if one or both of the gages are "far away" or is on a watershed that is dramatically different than the site, i.e., the site is a "small" watershed and the gage is on a large river.

G.6.3 Cautions:

1. The differences between water surface elevations for different frequency flood events often are not large (see Figure G-5 for a sample profile from a Flood Insurance Study).
2. The differences between water surface elevations for different frequency flood events varies with several other site-specific factors, such as valley shape and presence of constrictions such as bridges (see Figure G-5).
3. Every step is an approximation.

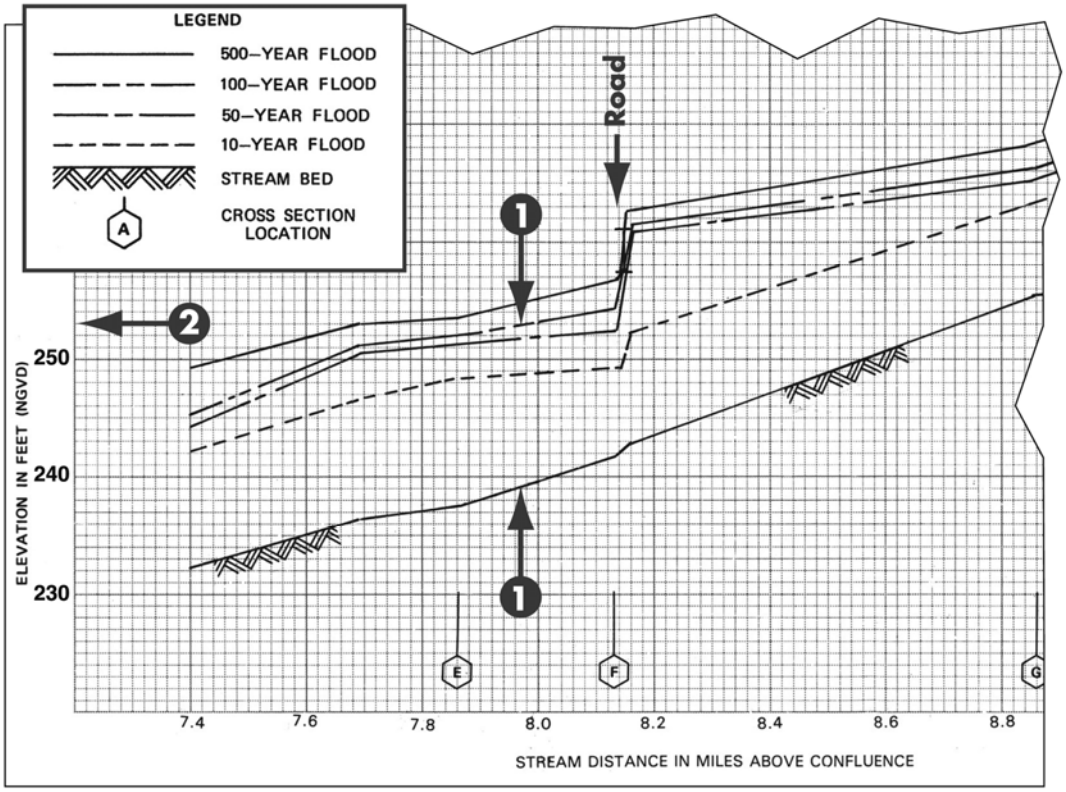

Figure G-5 Plot showing various flood levels for a sample profile from a flood insurance study