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of Engineers**

Hydrologic Engineering Center

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# **HEC-FIA Flood Impact Analysis**

## **Technical Reference Manual**

**Version 3.0  
February 2018**

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# **HEC-FIA**

# **Flood Impact Analysis**

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## **Flood Impact Analysis Package, HEC-FIA, Technical Reference Manual**

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# Foreword

The U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center's (HEC) Flood Impact Analysis (HEC-FIA) software allows a user to evaluate the consequences of single event floods. The first version of HEC-FIA (Version 1.0) was released in 2001. Since that time, there have been several major releases of HEC-FIA, including Versions 2.0 and 2.2. Development of HEC-FIA Version 3.1 is underway.

The HEC-FIA software was developed at HEC, which is an organization within the Institute for Water Resources (CEIWR), U.S. Army Corps of Engineers (USACE). HEC-FIA is the successor to the Project Benefits Accomplishment (HEC-PBA) software. The original HEC-FIA software design team was led by Mr. Bill (James) Haines, CENAB (USACE, Baltimore District), and included Mr. Mike Burnham and Ms. Donna Lydon from HEC. Currently, Mr. William Lehman leads the HEC-FIA Version 3.1 development team. Mr. Shannon Newbold of Resource Management Associates (RMA) is the primary programmer for HEC-FIA.

Many other HEC staff members also contributed in the development of HEC-FIA. Messrs. Woodrow Fields and Jason Needham (Risk Management Center, CEIWR-RMC) contributed significantly to the direction and quality of the computational methods for evaluating life loss. Ms. Lea Adams was the Chief of the Water Resource Systems Division (CEIWR-HEC-WRS), and Mr. Christopher Dunn was Director of HEC during the development of Version 3.0 of the software.

The Technical Reference Manual was prepared for HEC by WEST Consultants, Inc. and Ms. Sara O'Connell (CEIWR-HEC-WRS) was critical in finalizing this document. Additional information can be found in the HEC-FIA Version 3.0 User's Manual. These manuals and the HEC-FIA software are available from the HEC website: ([www.hec.usace.army.mil](http://www.hec.usace.army.mil)).



# Chapter 1

## Introduction

### 1.1 Overview

The HEC-FIA Technical Reference Manual defines the methods, internal algorithms and computations of the HEC-FIA software. A strong understanding of these internal processes will increase the user's ability to identify model limitations, provide suitable inputs, communicate the importance of results, and help validate decisions that HEC-FIA supports. This manual, in conjunction with the HEC-FIA User's Manual and the HEC-FIA Applications Guide, will help users apply the full capabilities of HEC-FIA Version 3.0. The development history, purpose statement, and features of HEC-FIA are documented in the HEC-FIA Version 3.0 User's Manual.

### 1.2 Organization of Technical Reference Manual

This manual is organized based on the computational procedures of HEC-FIA; each chapter highlights a particular computational process. Information on a specific topic can be found by going directly to the related chapter. However, since all damage computations rely on how hydraulic information is interpreted at a point location in the study area, it is highly recommended that Chapter 2 be reviewed before any of the subsequent chapters.

**Chapter 2, Hydraulic Event Input Conversions:** This chapter describes how HEC-FIA takes various hydraulic inputs and converts them into summary information at point locations in the floodplain. The conversion processes for four hydraulic input options are described: 1) cross sections; 2) grids; 3) a combination of grids and cross sections; and, 4) prescribed common computation points.

**Chapter 3, Direct Damage Computations:** This chapter describes how HEC-FIA computes direct economic damage using defined depth-percent damage relationships and hydraulic inputs. The inputs, computational steps, and outputs of the direct damage computational routine are described.

**Chapter 4, Life Loss Computations:** This chapter describes how HEC-FIA calculates life loss at a structure. The life loss computations also includes a method to calculate life loss occurring during evacuation.

**Chapter 5, Indirect Loss Computations:** This chapter describes how HEC-FIA summarizes indirect impacts on a county-by-county basis, and divides the indirect impacts by the total available workforce and capital for each county to determine inputs to the Economic Consequences Assessment Model (ECAM). This chapter also describes and provides reference material for the ECAM calculations.

**Chapter 6, Agricultural Area Damage Computations:** This chapter describes how HEC-FIA computes agricultural damage by location due to a hydraulic event.

**Chapter 7, Population Distributions:** This chapter describes how HEC-FIA distributes population from a census database over an existing structure inventory. The population is distributed based on time of day, occupant age, and occupancy type.

**Chapter 8, Monte Carlo Simulation Computations:** This chapter describes how HEC-FIA uses the various inputs to evaluate the uncertainty of a result for a deterministic hydraulic event.

**Appendix A, References:** This appendix provides a list of USACE guidance, software documentation, online references, and other references.

**Appendix B, Glossary:** This appendix provides definitions in regards to terms that are used throughout this document.



# Chapter 2

## Hydraulic Event Computation

### 2.1 Overview

This chapter illustrates how HEC-FIA summarizes hydraulic inputs for computations performed at point locations (e.g., structures) in the flooded area. HEC-FIA uses geo-referenced structure databases, hydraulic inputs, and terrain data to determine the hydraulic characteristics (e.g., depth, arrival time, etc.) at each point location or structure. The following sections detail the inputs required for the computations, the computational procedures, and the outputs produced from the computations.

### 2.2 Computational Inputs

A minimum of two inputs are required to simulate a hydraulic event in HEC-FIA. These inputs are point locations and hydraulic data. Some computation methods discussed in this section require a third input, terrain data.

#### 2.2.1 Point Locations

In HEC-FIA, structure and critical infrastructure inventories are described in point shapefiles. Although other damageable elements are not stored as points, during computations the elements are converted to point locations. Hydraulic information is then evaluated at these explicitly input or internally generated point locations. This conversion and evaluation process is true for all components of every damageable element recorded in the software, including impact response curves and warning scenario nodes.

#### 2.2.2 Inundation Data

Inundation data contains information about hydraulic characteristics that drive the consequence computations of HEC-FIA. The inundation data required for HEC-FIA should be prepared by an experienced hydraulic engineer in conjunction with an economist familiar with the computational procedures in HEC-FIA. A variety of hydraulic modeling programs are suitable for this preparation, including HEC-RAS (River Analysis System; including two-dimensional output), HEC-HMS (Hydrologic Modeling System), HEC-ResSim (Reservoir System Simulation), MIKE 21 (DHI, Denmark), or FLO-2D (FLO-2D Software, Inc.), among others. Inundation data can be imported into HEC-FIA in four formats: 1) cross sections/storage areas; 2) grids; 3) a combination of grids and cross sections/storage areas; and, 4) common computation points. The characteristics of each of these data types are described in the following paragraphs.

## Cross Sections/Storage Areas

Cross section and storage area shapefiles provide HEC-FIA with georeferenced locations at which hydrographs contained in a DSS (HEC's Data Storage System) file should be applied. Time-series information is exchanged between DSS files and HEC-FIA at each of the georeferenced cross section and storage area locations. Cross section shapefiles are used to define regions for the application of interpolated hydrographs. Each region is defined by connecting the ends of adjacent cross sections with straight lines. The storage area shapefiles are used to describe the extents of the storage area within each storage area-linked hydrograph, which should be applied.

## Grids

Grids can be used to define hydraulic characteristics throughout a study area. The six hydraulic characteristics that can be represented by grids are maximum depth; maximum instantaneous depth-times-velocity; arrival time for life loss calculations; arrival time for agricultural calculations; and, flood duration for agricultural calculations. Structures will be assigned hydraulic characteristics based on the value of the grid cell for each grid in which the structure point is contained.

Hydraulic grid datasets can be imported into HEC-FIA in many gridded formats, including a tagged image file (\*.tif); ArcInfo® ASCII grid (\*.asc); ArcGrid® (\*.flt); Segmented Multi-Resolution Multi-Parameter (\*.smrmp); and, tile map service (\*.tms) format. HEC-FIA will prompt users to convert the files into the \*.tif format for more efficient operation once the file has been imported.

A *depth grid* represents the maximum depth reached in a given cell. HEC-FIA will use the depth grid to calculate damage to structures, damage to agricultural assets, and life loss consequences. Depth grids are typically generated using HEC-GeoRAS or the HEC-RAS Mapper tool if HEC-RAS is the hydraulic model used to produce the results for a study.

An *instantaneous depth-times-velocity grid* represents the maximum product of depth and velocity calculated for each time step in the hydraulic simulation. Depth-times-velocity grids can be easily generated from FLO-2D results using the FLO-2D Mapper program, or from HEC-RAS using the HEC-RAS Mapper tool.

An *arrival time grid* represents the time that floodwaters of a given depth (usually two feet for life loss and any value greater than zero feet for agricultural damage) reach each cell. When modeling the evacuation process for life loss, HEC-FIA assumes that after a given depth is reached, the individuals remaining in a structure will no longer be able to evacuate successfully, thus they will remain in the structure for the flood event. In HEC-FIA, this portion of the population is termed as "Not Mobilized". The arrival time grid for agricultural damage calculations is used to determine when the flood arrives compared to the planting and harvesting times. Arrival time grids can be developed using the post-processing tools for a number of different hydraulic modeling programs, such as FLO-2D and HEC-RAS.

*Duration grids* contain information about the duration of time that a cell is inundated greater than zero feet. Duration grids can also be developed using the post-processing tools for a number of different hydraulic modeling programs, such as FLO-2D and HEC-RAS.

## Grids and Cross Sections/Storage Areas

The grids and cross sections inundation datasets utilize a combination of the two datasets. The ability to use two datasets is particularly useful when the only grid result available is an inundation depth grid, as the cross section-linked DSS (\*.dss) data can provide the remaining necessary input information for the arrival times and durations. The ability to use two datasets can also be useful when using gridded data for depth and arrival time, which is typically more accurate, while using cross sections to warn the population based on a depth exceedance threshold drawn from the hydrograph data. Structures will be assigned hydraulic characteristics first based on any gridded data that has been imported. After all of the gridded data inputs have been assigned, the program will reference the cross section-linked DSS files to define the remaining variables for the computations.

## Common Computation Points

A common computation point (CCP) shapefile provides HEC-FIA with geo-referenced locations along a stream alignment to which hydrographs contained in a DSS file should be applied. Time-series information is exchanged between DSS files and HEC-FIA at each of the geo-referenced common computation points. Hydraulic characteristics for each section of the stream alignment are linearly interpolated based on the hydraulic characteristics of the bounding common computation points.

### 2.2.3 Terrain Model

A terrain model in HEC-FIA is defined by importing a Digital Elevation Model (DEM). The DEM represents the ground elevation for the region being studied in a gridded format, which is used to provide elevation data for the structure inventory. The terrain is only used in the HEC-FIA computations when the input hydraulics data is defined using cross sectional data with hydrographs. The HEC-FIA Version 3.0 User's Manual should be used to determine the types of terrain model files that can be imported.

## 2.3 Computational Procedures

This section details the computational procedures used by HEC-FIA to convert hydraulic data into summary information at point locations across a floodplain. The procedures used, depend upon the type(s) of inundation data input to the model. The computational procedure for each of the four types of inundation data are described in the following subsections.

### 2.3.1 Cross Sections/Storage Areas

The following procedures discuss how cross sectional inundation data is applied to point locations. The internal procedure used by HEC-FIA to calculate flood depths at point locations is

described in this section. The procedure used to compute other hydraulic characteristics is generally the same.

To facilitate a description of the general process by which cross sectional inundation data is applied to a point location, a generic hydrograph with example parameters is displayed in Figure 2.1. The lowest horizontal dashed line represents the ground surface elevation (GSE); the middle horizontal dashed line represents the elevation computed by adding the non-evacuation threshold to the GSE; and, the highest horizontal dashed line represents the maximum water surface elevation (WSE). For structures, the non-evacuation elevation is equal to the foundation height (FH). The difference between the maximum WSE line and the GSE line is the maximum inundation depth at a structure.

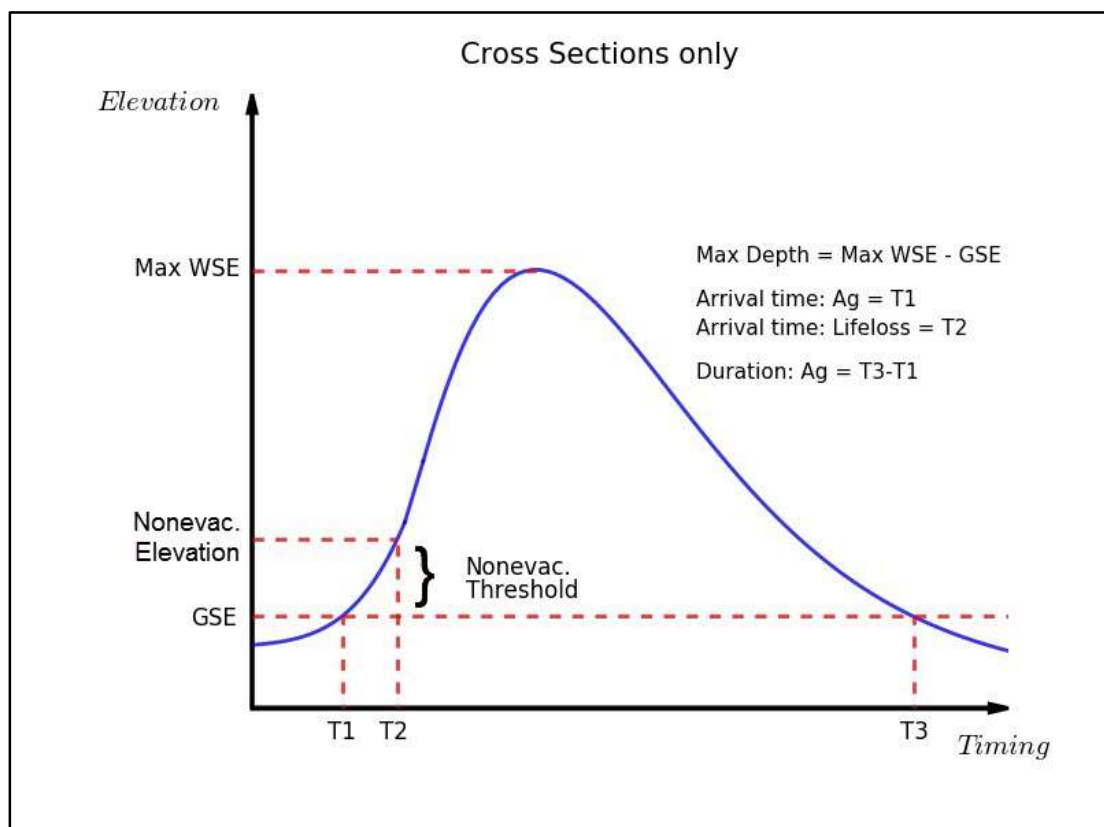


Figure 2.1 Event Computations using Cross Section Inundation Data

In Figure 2.1, the T1 vertical dashed line represents the first time at which the WSE exceeds the GSE at a structure. The T2 middle horizontal dashed line represents the time at which the WSE exceeds the non-evacuation elevation. The right-most vertical dashed line, T3, represents the final time at which the WSE exceeds the GSE. The difference between T3 and T1 represents the duration of flooding for agricultural purposes, while the difference between T3 and T2 represents the duration of flooding for ECAM calculations.

An example of how to assign cross section data to an individual structure will now be explained. Figure 2.2 displays a simple cross section layout, with the black lines representing cross sections and the yellow line representing the stream centerline. From a storage area shapefile (not required), the geographic extents for the storage area-linked hydrographs could be applied.

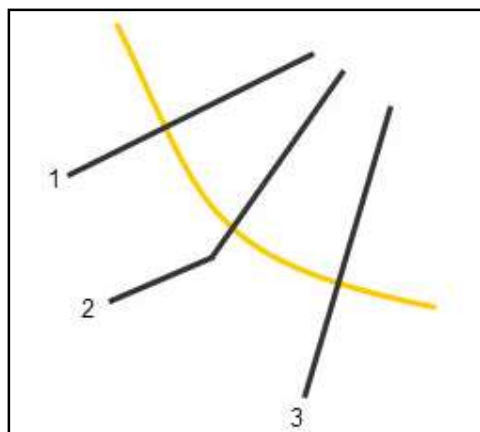


Figure 2.2 Generic Cross Section Layout

During a compute, time-series information (e.g., stage, arrival time) is read from a DSS file at each cross section and storage area. To support this compute process, HEC-FIA needs to link the geographic location, naming convention, and a DSS file path to the shapefile attributes of each cross section and storage area. For detail on the linking of DSS time-series to cross sections and storage areas, see Chapter 5.3 and Appendix G of the HEC-FIA Version 3.0 User's Manual. During the compute, HEC-FIA will sort the cross sections based on the *River Name* and *River Station* attributes to ensure that structures between two cross sections are assigned to the correct hydrograph data (Figure 2.3). When storage areas are used, similar information is required to link the storage area shapefile to the hydrographs, using the same DSS file that linked the cross sections to the storage area hydrographs.

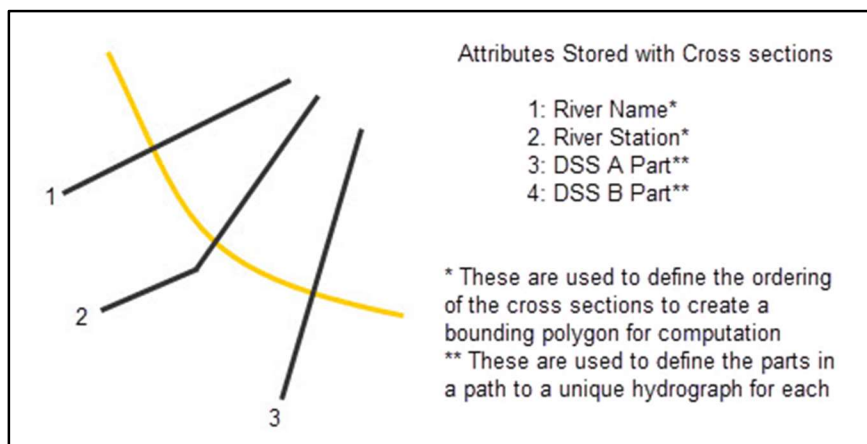


Figure 2.3 Cross Section Shapefile Attributes and DSS File Mapping

Hydraulic characteristics in the regions between cross sections are linearly interpolated based on the hydraulic characteristics of the bounding cross sections. To interpolate the results from the cross sections to a structure located between the cross sections, the cross sections are first sorted by *River Name*, then by *River Station*. The ends of each cross section are connected with a straight line to form polygons that group structures. Within the corresponding upstream and downstream cross sections, any structures that fall outside a polygon will not be considered in the HEC-FIA simulation. For example, Figure 2.4 displays two cross section bounding polygons, with the black lines representing cross sections, the yellow line representing the stream centerline, and the dotted blue lines representing the edges of the cross section polygons.

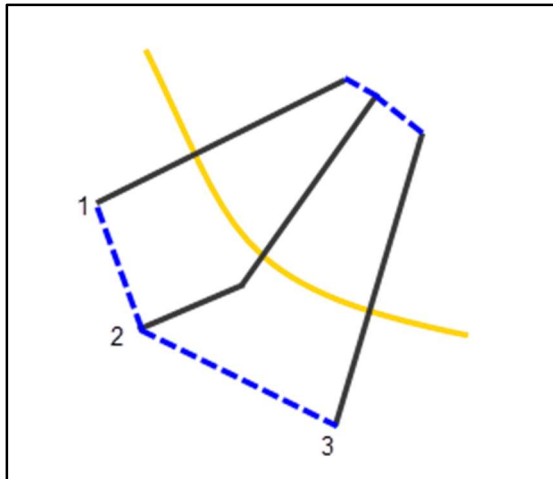


Figure 2.4 Cross Section Bounding Polygon Creation

The bounding polygon scheme can result in issues, particularly near river confluences (Figure 2.5). Polygons may not be created for some areas, resulting in missing data (red shading). In other areas, polygons may overlap (orange shading in Figure 2.5), in which case the depth will be considered for only one polygon. The modeler should check for these issues and correct as needed.

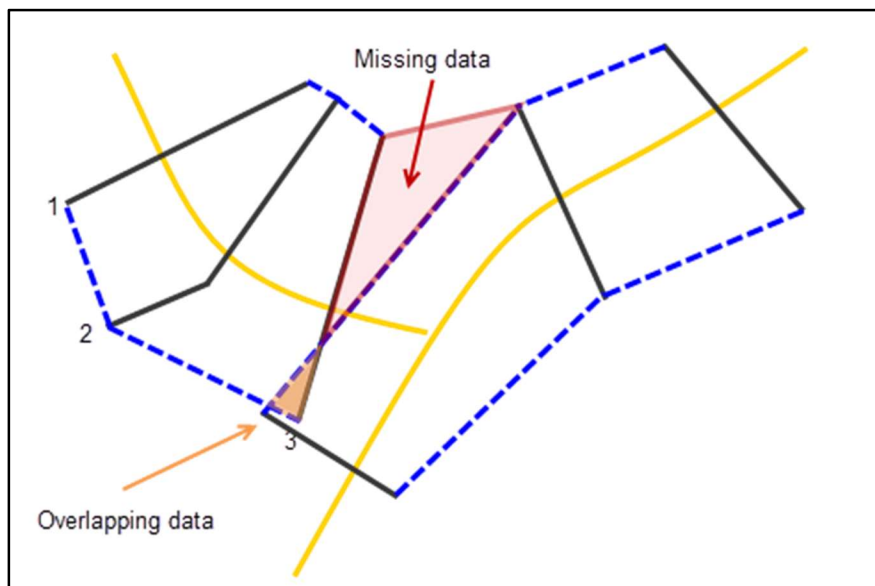


Figure 2.5 Common Bounding Polygon Creation Issues at Confluence

If a structure is within more than one bounding cross section polygon (e.g., from overlapping data), HEC-FIA defaults to using the first river in the list of alphabetically sorted rivers. The user will need to manually assign the correct river to structures within overlapping polygons in the shapefile, if data should be assigned to a river other than the one selected by default.

Polygon creation issues can also arise near sharp river bends (Figure 2.6). If a bend occurs between two cross sections and the cross sections do not extend far enough into the overbank, the bounding polygon may not cover the intended area. To remedy this situation, additional cross sections should be added to define the bounding polygon extents more appropriately.

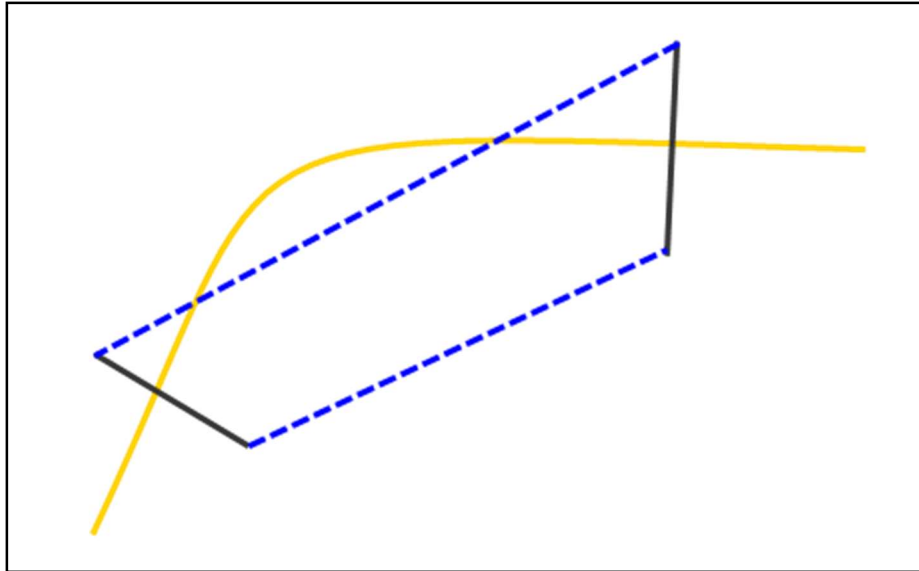


Figure 2.6 Common Bounding Polygon Creation Issues at River Bend

The distance from each structure to its bounding cross sections is calculated by HEC-FIA, using a shortest distance algorithm, which is illustrated in Figure 2.7. The distance to the upstream cross section is added to the distance to the downstream cross section ( $x1$  plus  $x2$ ), and this value is used as the interpolation distance. The hydraulic properties for the individual structure is then interpolated between the properties of the upstream and downstream cross sections.

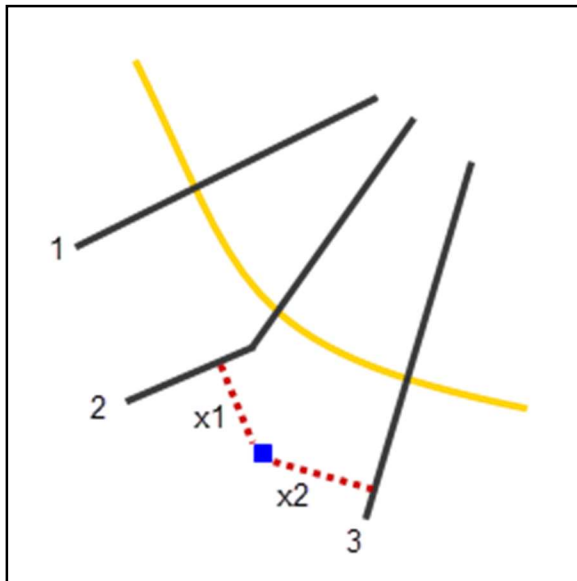


Figure 2.7 Shortest Distance Determination

As an example, assume that HEC-FIA calculates the River Station (RS) of a structure to be located at RS 1175. The structure is bounded by a cross section located at RS 1200 and a cross section located at RS 1100. The cross section at RS 1200 has a maximum WSE of ten feet, while the cross section located at RS 1100 has a maximum WSE of six feet. Therefore, a linear interpolation of the WSE to the structure located at RS 1175, means that the structure will be modeled as experiencing a maximum WSE of nine feet.

Because the depth of flooding at a structure is computed by subtracting the structure elevation from the WSE when using cross section data, it is possible for HEC-FIA to compute structures with basements as being flooded. For example, if the WSE at a structure is 100 feet and the structure elevation is 102 feet, the calculated depth at the structure is negative two feet. If this structure has a basement that extends five feet below the GSE, the basement will be modeled as being inundated by three feet of water, which would result in damage being calculated for the structure even if the first floor elevation was above the calculated WSE.

Assigning hydrographs to structures is significantly simpler when the structures are located within a storage area. The DSS hydrograph associated with the storage area is imported into HEC-FIA and assigned to each structure located within the storage area polygon.

## 2.3.2 Grids

The algorithm used to apply flood depth data to structures is described in this section. However, the algorithm is general enough to describe the process through which every type of hydraulic information is applied to structures. To describe the general approach in which the inundation data from grids is applied to structures, a generic grid schematic with structures is provided in Figure 2.8. For example, Figure 2.8 displays an inundation depth grid, with the depths of each grid cell represented by the blue numbers and two buildings represented by the red polygons. Note that building locations are reduced to points in HEC-FIA; the buildings were drawn as polygons in Figure 2.8 solely for illustrative purposes.

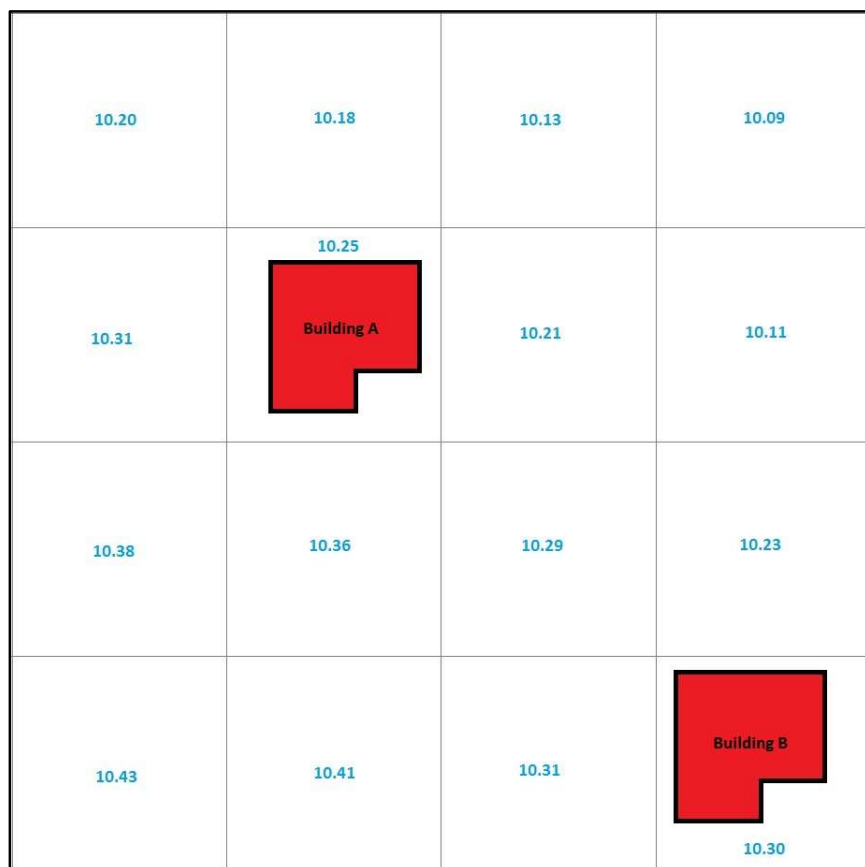


Figure 2.8 Event Computations using Grid Inundation Data



A hydraulic characteristic is assigned to buildings based on the value of the grid cell in which the point representing the building is contained. Each structure is represented as a discrete point, which is typically the centroid of a parcel shapefile; therefore, each structure exists in a single grid cell even if the parcel covers many grid cells. Interpolation of hydraulic characteristics is not necessary due to this assignment methodology. Using the example in Figure 2.8, an inundation depth of 10.25 feet would be assigned to Building A and an inundation depth of 10.30 feet would be assigned to Building B. The same procedures are followed for all of the types of gridded data that can be accessed by HEC-FIA.

Because the depth of flooding at a structure is computed in HEC-FIA for gridded data directly from the provided grid (which represents depth above the GSE), it is not possible for HEC-FIA to compute structures as only having basements inundated. When using gridded data, the basement will be either completely dry or completely wet, depending upon whether a positive depth is noted in the inundation grid cell corresponding to the building location.

The same hydraulic information is assigned to all structures within any given grid, regardless of the structure's position within that grid. Therefore, the accuracy of the assigned hydraulic data is a function of the degree to which the hydraulic data is constant across the portion of each grid containing structures.

### 2.3.3 Grids and Cross Sections/Storage Areas

The grids and cross sections/storage areas computational procedures depend upon the amount of data that is provided as a grid. Structures will be assigned hydraulic characteristics first based on the gridded data, using the computational procedures outlined in Section 2.3.2. After all gridded data inputs have been assigned, HEC-FIA will use the computational procedures outlined in Section 2.3.1 to determine the depth and arrival time for each structure, as necessary.

To describe the general approach in which the inundation data from cross sections is applied to structures, a generic hydrograph is provided. Figure 2.9 displays the generic hydrograph along with key parameters. The lowest horizontal dashed line represents the GSE, the middle horizontal dashed line represents the elevation computed by adding the non-evacuation threshold to the GSE, and the highest horizontal dashed line represents the maximum WSE. If gridded data is supplied, the value at each structure will be taken from the grid. If not, the inundation depth will be determined from the cross section data as the difference between the maximum WSE line and the GSE line.

In Figure 2.9, the left-most vertical dashed line, T1, represents the first time at which the WSE exceeds the GSE. The middle horizontal dashed line, T2, represents the time at which the WSE exceeds the non-evacuation elevation. The right-most vertical dashed line, T3, represents the final time at which the WSE exceeds the GSE. The difference between the T3 and T1 lines represents the duration of flooding for agricultural purposes, while the difference between the T3 and T2 lines represents the duration of flooding for ECAM calculations.

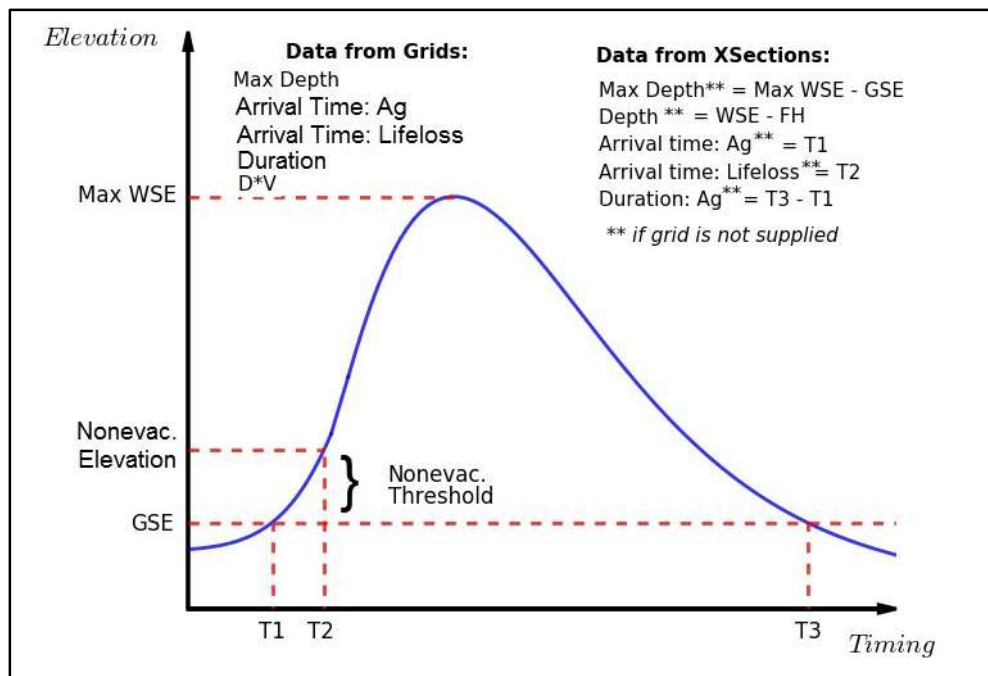


Figure 2.9 Event Computations using Grid and Cross Section Inundation Data

### 2.3.4 Common Computation Points (CCPs)

The general methodology used by HEC-FIA for applying inundation data from the common computation points to the structures is displayed in Figure 2.10. In general, inundation data for each structure is determined using common computation points in a similar manner to using cross sections.

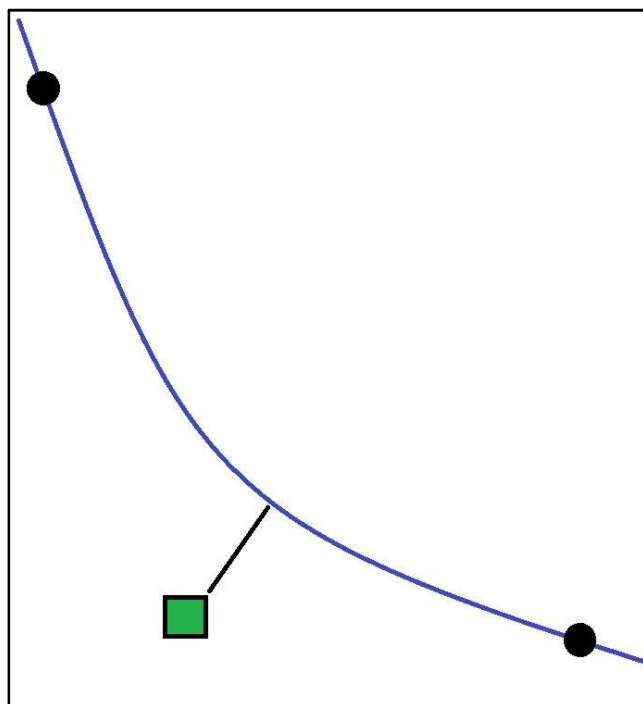


Figure 2.10 Common Computation Points Methodology Example

The first step in the process is to calculate the stationing of the common computation points (black points in Figure 2.10). Each common computation point is located directly on the stream alignment centerline (blue line in Figure 2.10), which allows for a straightforward river station calculation. Next, the stationing of each structure (green box in Figure 2.10) is determined by interpolating between the upstream and downstream common computation points. The interpolation uses the shortest distance algorithm, as described in Section 2.3.1, whereby the stationing is determined from where a straight line drawn from the structure and perpendicular to the stream alignment crosses the stream alignment (black line in Figure 2.10). Finally, using the stationing of the upstream and downstream common computation points and the stationing of each structure, the inundation data from the hydrographs linked to each common computation point can be interpolated for each structure, based on that structure's stream stationing.

A difference between the common computation point and cross section/storage area interpolation methodology is that no boundary is established for how far away from the stream the common computation point is valid. While the cross section data is limited to the extent of the cross section shapefile and the storage area data is limited to the extent of the storage area shapefile, the point nature of the common computation points does not allow a known extent to be established. While this approach eliminates the possibility of some of the potential errors discussed in the cross section methodology section (Section 2.3.1), the approach can cause unusual results.

For the example, in Figure 2.11, the structure (green box) is located on the landward side of a high ridge (represented by the red line) separating a river (blue line) from the structure. The structure would take on the stage attribute of the river, even though water cannot actually reach the structure due to the ridge being higher than the river stage. This issue is less likely to occur when using cross sections, as the cross sections and resulting bounding polygon would likely end at the high ridge. The possibility of this issue occurring when using cross sections can be limited

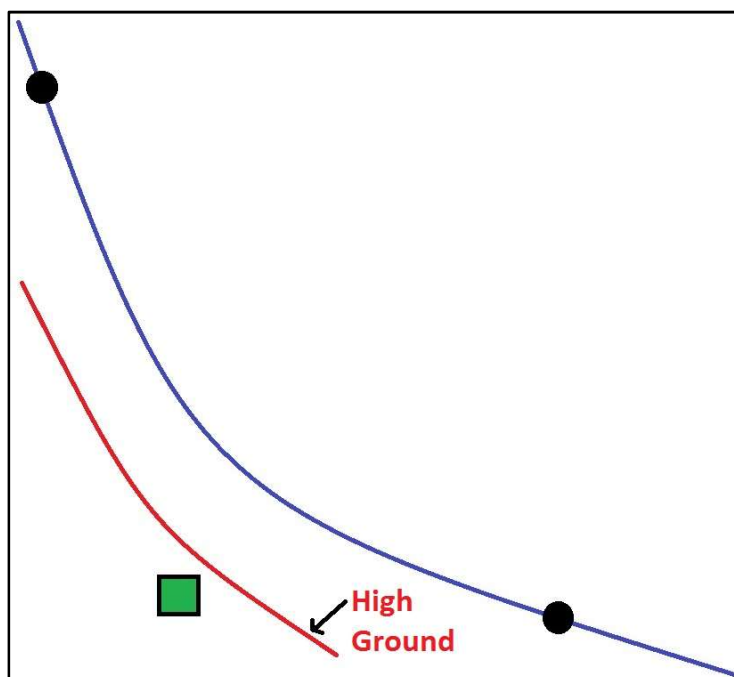


Figure 2.11 Common Computation Points Potential Error

by using an appropriate hydraulic model setup. If the high ground issue does cause problems in the HEC-FIA modeling, HEC-FIA includes a "**High Ground Tool**" for editing watersheds. This HEC-FIA tool is available in the HEC-FIA map window toolbar when the **Watershed Configuration** is displayed in an HEC-FIA map window. The **High Ground Tool** allows the user to define a polygon that is behind high ground, and provides the stationing of the overtopping location and the overtopping elevation. After the threshold is met at the overtopping station, all structures in the polygon are flooded based on each structure's depth from either the gridded or the cross section data.

Because the depth of flooding at a structure is computed by subtracting the structure elevation from the WSE when using common computation point data, it is possible for HEC-FIA to compute structures with basements as being flooded, even if the stage fails to reach the GSE at the structure. HEC-FIA will compute damage for each structure to the lowest ordinate on the depth-damage curve that is associated with the occupancy type for each structure.

## 2.4 Computational Results

Results from the hydraulic event computation procedures in HEC-FIA include depth of water above ground; depth of water above foundation at each structure; optionally, arrival time of critical depth thresholds, duration of water above critical thresholds, maximum of the product of depth and velocity; and, number of structures inundated.

# Chapter 3

## Direct Damage

### 3.1 Overview

In HEC-FIA, direct damage is described by the magnitude of damage to structures and the individual structure's contents, vehicle values, and loss of life resulting from a flood event. This chapter describes how HEC-FIA computes direct damage for structures using depth-percent damage relationships and a flood event, including the use of results from the hydraulic event computation process highlighted in Chapter 2. The following sections describe the inputs required for the direct damage computations, the computational procedures, and the results produced from the direct damage computations.

### 3.2 Computational Inputs

Three inputs are required to compute direct damage at locations throughout a study area. Two of these inputs are described in Chapter 2 - structure inventory and inundation data. The third input, depth-percent damage relationships, is described in the following sections. Depending on the type of hydraulics data, a fourth input of a terrain grid may be required (Chapter 2).

### 3.3 Depth-Percent Damage Relationships

A depth-percent damage relationship (i.e., curve) defines the percent damage caused to a structure, a structure's contents, and any vehicles stored at a structure at incremental depths. As depth increases, percent damage also increases. Depth-percent damage relationships are defined in HEC-FIA within the **Structure Occupancy Type** dialog. An example depth-percent damage relationship is shown in Table 3.1. For depths between ordinates, the percent damage is linearly interpolated.

Table 3.1 Example Depth-Percent Damage Relationship

| Depth<br>(feet) | Percent<br>Damage |
|-----------------|-------------------|
| 0.00            | 0.00              |
| 1.00            | 32.00             |
| 2.00            | 38.70             |
| 3.00            | 45.50             |
| 4.00            | 52.20             |
| 5.00            | 58.60             |
| 6.00            | 64.50             |
| 7.00            | 69.80             |
| 8.00            | 74.20             |
| 9.00            | 77.70             |

### 3.4 Computational Procedure

Direct damage to a structure and the structure's contents and vehicles, are calculated as shown in Equation 3.1:

$$D_i = d_i * v_i \quad (3.1)$$

where:

$D_i$  is the direct damage, where the subscript  $i$  is used to represent buildings, contents, or vehicles

$d_i$  is damage (in percent) as a function of depth and occupancy type

$v_i$  is the monetary value

To determine the percent direct damage to a structure and the structure's contents and vehicles, both the depth at the structure and the occupancy type of the structure need to be known. The depth is considered the maximum depth minus the FH. The occupancy type is specified as part of the structure inventory and is associated with three individual depth-percent damage relationships, one each for the building, contents, and vehicles. In addition, another option is available to define a fourth depth-percent damage curve for an additional "other" category, examples of "other" category could include any user specified relationship that relates damage to a computed depth. Therefore, the depth at the structure can be used to determine the percentage that the four components of the structure are damaged. This percent damage can then be multiplied by a structure and the structure's contents and vehicle values (specified in the structure inventory) to determine the total direct damage that occurs at and within a structure.

A schematic of the direct damage computation procedure for a structure is displayed in Figure 3.1. At a maximum depth of seven feet, the structure is 42 percent damaged, based on the depth-damage relationship. Multiplying the structure's value (\$100,000) by the damage (42 percent) results in a direct damage of \$42,000 for the structure. The direct damage to the structure's contents and vehicles will also need to be added to the structure damage of \$42,000 to determine the total damage at and within the structure.

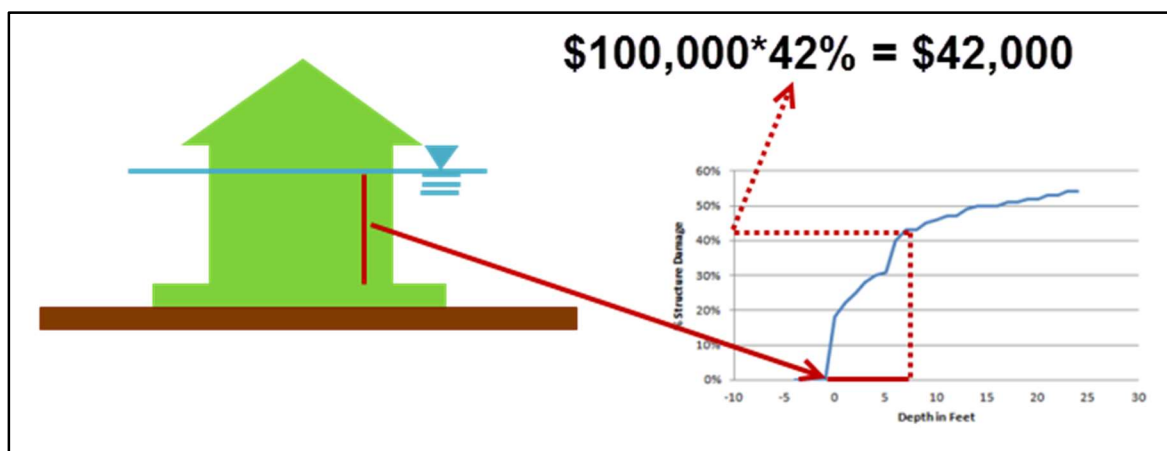


Figure 3.1 Direct Building Damage Calculation Procedure

Two additional considerations can also affect the direct damage computations. First, direct damage to vehicles may be reduced for structures if the population receives adequate warning time to vacate the structure and clear the flooded area. The value of vehicles that are available to be damaged at a structure ( $C'$ ) is calculated using Equation 3.2:

$$C' = \begin{cases} \text{if } \frac{P * \%clear/100}{k} < N & , \quad C - C * \frac{\left[ \frac{P * \%clear/100}{k} \right]}{N} \\ \text{if } \frac{P * \%clear/100}{k} \geq N & , \quad 0 \end{cases} \quad (3.2)$$

where:

$C$  is the total original vehicle value per structure

$N$  is the total number of vehicles per structure

$k$  is the carrying capacity per vehicle (in persons)

$P$  is the population per structure

$\%clear$  is the percentage of the structure population that cleared the flooded area

The cleared population is used to estimate the fraction of vehicles that left the structure. The ratio  $[P * \%clear/100]/k$  is an approximation of the number of vehicles that were needed to carry the cleared population away. The rest of the vehicles are left at the structure to incur flood damage. Multiplying the total original vehicle value ( $C$ ) by a ratio of the vehicles evacuated to the total number of vehicles ( $N$ ) gives the value of the vehicles evacuated. The difference between that value and the total original vehicle value is the value of the remaining vehicles ( $C'$ ), which is the value used in the direct vehicle damage computations. If no population evacuated from a structure, the available vehicle value ( $C'$ ) equals the total original vehicle value ( $C$ ). Conversely, if all of the vehicles were needed to evacuate the cleared population, the available vehicle value ( $C'$ ) is zero.

The second consideration that can affect the direct damage computations occurs when depth-times-velocity information is entered into HEC-FIA. Prior to any direct damage computations, HEC-FIA will check whether the depth-times-velocity threshold for total damage is exceeded. If the threshold is exceeded, the structure, contents, and vehicles will all automatically be assigned a 100 percent loss.

### 3.5 Computational Results

The primary result from the computational procedures described in this chapter is direct damage to individual structures, contents, and vehicles.





# Chapter 4

## Life Loss

### 4.1 Overview

This chapter illustrates how HEC-FIA estimates the loss of life when a flood event occurs. HEC-FIA utilizes the Simplified LIFESim methodology to calculate life loss estimates using a number of different parameters, including warning system effectiveness and mobilization curves. The Simplified LIFESim methodology incorporates a number of simplifying assumptions:

- The population is homogeneous in response to warnings.
- The evacuation route is a straight line from the structure to the nearest safe location (e.g., road networks and obstacles are not factored in to the computation).
- The population will stop evacuating once the non-evacuation depth (by default, two feet) is exceeded.
- The population knows if their safe location is or is not wet prior to evacuating their structures.

### 4.2 Computational Inputs

A number of computational inputs are required to compute life loss throughout the study area. Two of these inputs are described in Chapter 2 - structure inventory and inundation data. At a minimum, the inundation data should include depths and arrival times. Additional required inputs are Evacuation Information; Warning System Characteristics; Warning Times; and, Mobilization Relationships. Lethality Rates, which are also used in the computations, are pre-defined in HEC-FIA and cannot be modified.

#### 4.2.1 Evacuation Information

The evacuation information input is used to determine the amount of time required for an individual to evacuate a building and reach a safe zone. HEC-FIA determines the evacuation time necessary by referencing the spatial extents of the flood hazard area; computing the straight-line distance between the structure and nearest endpoint of the flood hazard area; and, applying the user defined nominal evacuation speed. HEC-FIA determines the linear distance between a defined flood-hazard area boundary and each structure (Figure 4.1). HEC-FIA calculates a total time of evacuation from each structure using a given evacuation speed. Alternatively a pre-defined evacuation time can be entered in the model for all structures, each impact area, or on an individual structure-by-individual structure basis. The evacuation information is entered into HEC-FIA in the **Alternatives Editor**.

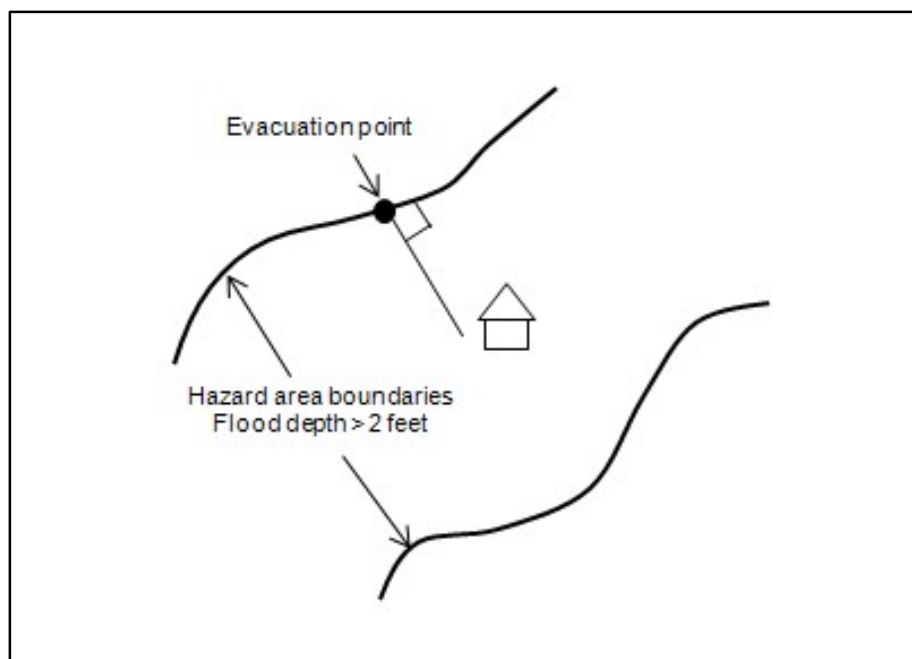


Figure 4.1 Evacuation Time Calculation Representation

## 4.2.2 Warning System Characteristics

Warning systems can be simulated in HEC-FIA to inform residents of an impending flood event in an effort to reduce or eliminate the loss of life resulting from a flood event. Six warning system setups are defined in HEC-FIA, each with a unique effectiveness over time in terms of time of day (e.g., day or night) and the activity type of the population (e.g., sleeping, working, watching TV, etc.). The six warning system types are:

- sirens
- tone-alert radios
- auto-dial telephones
- Emergency Alert System (EAS)
- a combination of EAS and tone-alert radios
- a combination of EAS, sirens, and auto-dial telephones

In addition, user-defined warning systems can be created. The warning system characteristics are defined in HEC-FIA in the **Impact Area Editor**.

The warning system curve expresses the portion of the population warned per unit of time based on warning type, time of day, and time since warning issuance. For more information on the meaning of the parameters see Rogers and Sorensen, 1991 (Appendix A). The rate of warning for a community is represented by Equation 4.1:

$$\frac{dn}{dt} = k(a_1 * a_1 f(N - n)) + (1 - k)(a_2 n(N - n)) \quad (4.1)$$

where:

- $\frac{dn}{dt}$  = the change in people warned per timestep, or the rate of warning
- $k$  = the fraction of population alerted via the broadcast process
- $(1-k)$  = the fraction of the population left to be warned
- $a_1$  = the effectiveness of the warning system at broadcasting an alert
- $a_1f$  = an adjustment factor that varies by time of day and activity
- $a_2$  = the effectiveness of the secondary alerting process
- $N$  = the maximum fraction that the system is designed to warn in the first thirty minutes after issuance
- $n$  = the fraction warned at the beginning of the current time step

### 4.2.3 Warning Times

The time at which the warning system (Section 4.2.2) is activated, must be defined in HEC-FIA. For example, in the case of a dam or levee breach, the warning system may be activated a few minutes after the breach occurs. The user must input the time of the warning relative to the simulation start time. The warning time can be specified universally for all structures or for individual warning zones. The warning times are entered into HEC-FIA in the **Warning Issuance Scenario** dialog.

### 4.2.4 Mobilization Relationships

Mobilization relationships define the percentage of the population that is mobilized after receiving a warning from the warning system. Three default mobilization relationships exist within HEC-FIA: 1) default (i.e., normal mobilization rate); 2) below average mobilization rate; or 3) above average mobilization rate. In addition, user-defined mobilization relationships can be created. Mobilization relationships are defined in HEC-FIA in the **Impact Area Editor**. An example mobilization relationship is shown in Table 4.1, with the values in the **Time** column referring to the amount of time that has passed since the warning was received. For times between ordinates, the **Percent Mobilized** is determined by linear interpolation.

Table 4.1 Example Mobilization Relationship

| Time (min) | Percent Mobilized |
|------------|-------------------|
| 0.0        | 0.0               |
| 15.0       | 50.0              |
| 60.0       | 75.0              |
| 120.0      | 85.0              |
| 240.0      | 98.0              |

### 4.2.5 Fatality Rates

Fatality rates are used in HEC-FIA to evaluate life loss for different lethality zones (e.g., safe, compromised, or chance) where the population might be caught responding to a flood event. The following, provides definitions of the three lethality zones:

- **Safe Flood Zone:** Represents conditions in which population is either dry or exposed to relatively quiescent floodwater or shallow flooding unlikely to sweep population off their feet.
- **Compromised Flood Zone:** Represents conditions in which shelters have been severely damaged by the flood, increasing the exposure of flood victims to violent floodwaters.
- **Chance Flood Zone:** Represents conditions in which population has no shelter from the flood, and have a chance of being rescued or finding floating debris while drifting.

A set of visuals describing the general methodology for determining lethality zones are provided in Figures 4.2 and 4.3. Figure 4.4 displays the **Safe**, **Compromised**, and **Chance** flood zone empirical distributions for fatality rates and Table 4.2 contains the default lethality zone thresholds for each zone by occupancy type and age group.

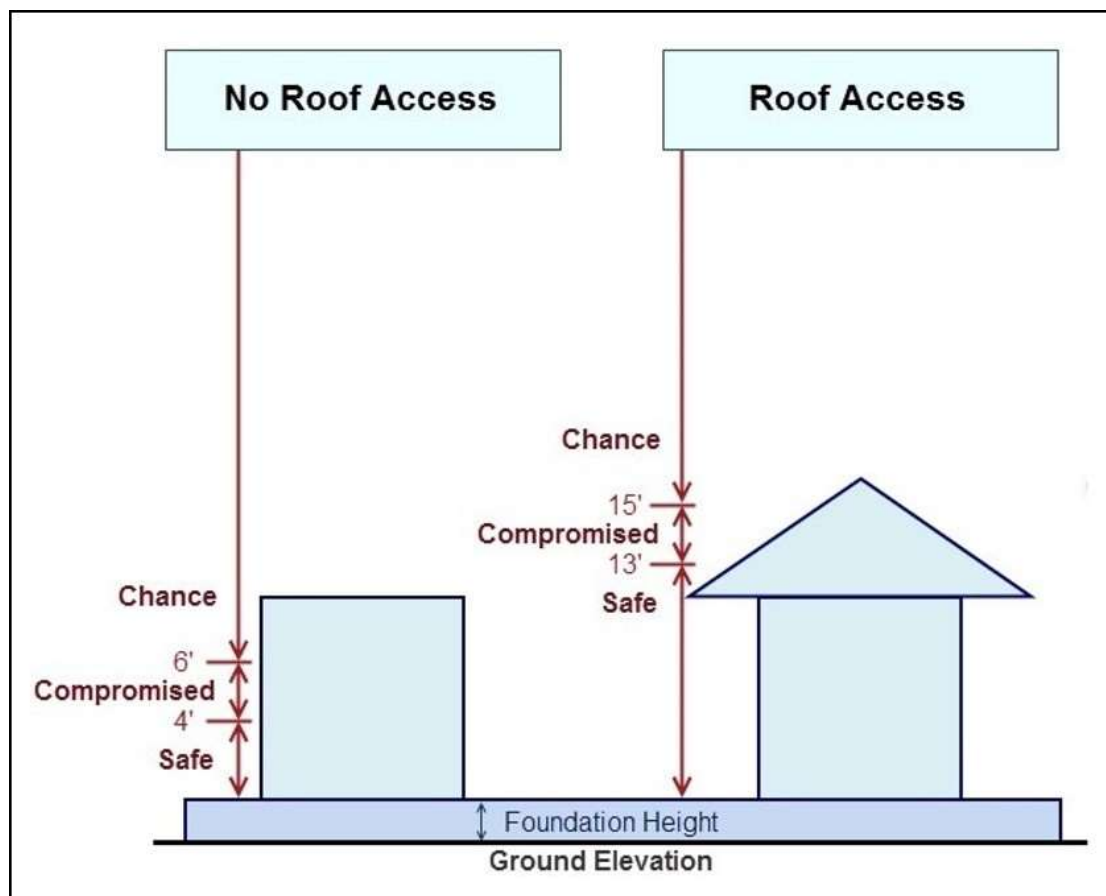


Figure 4.2 Flood Lethality Zones and Default Heights for a One-Story Structure

When the uncertainty compute option is checked, the fatality rate distributions are sampled using the bootstrapping statistical methodology (Appendix A, Section A.2). The default average fatality rates are displayed in Table 4.3; these rates are used when the uncertainty compute option is unchecked. The fatality rate distributions are not editable by the user, but the average fatality rates are editable. The user can change the average fatality rates to conduct a sensitivity analysis using deterministic simulations.

Table 4.2 Default Flood Lethality Zone Values by Occupancy Type and Age Group

| Occupancy Type | Default Flood Lethality Zone Height (feet) |             |        |         |             |        |
|----------------|--|-------------|--------|---------|-------------|--------|
|                | Under 65                                   |             |        | Over 65 |             |        |
|                | Safe                                       | Compromised | Chance | Safe    | Compromised | Chance |
| AGR1           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| COM1           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| COM10          | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| COM2           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| COM3           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| COM4           | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| COM5           | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| COM6           | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| COM7           | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| COM8           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| COM9           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| EDU1           | 2 or FH                                    | 22          | 24     | 2 or FH | 13          | 15     |
| EDU2           | 2 or FH                                    | 22          | 24     | 2 or FH | 13          | 15     |
| GOV1           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| GOV2           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND1           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND2           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND3           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND4           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND5           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| IND6           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| REL1           | 2 or FH                                    | 13          | 15     | 2 or FH | 4           | 6      |
| RES1-1SNB      | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES1-1SWB      | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES1-2SNB      | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES1-2SWB      | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES1-3SNB      | 2 or FH                                    | 13          | 15     | 2 or FH | 4           | 6      |
| RES1-3SWB      | 2 or FH                                    | 13          | 15     | 2 or FH | 4           | 6      |
| RES1-SLNB      | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES1-SLWB      | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES2           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES3AI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES3BI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES3CI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES3DI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES3EI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES3FI         | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES4           | 2 or FH                                    | 13          | 15     | 2 or FH | 13          | 15     |
| RES5           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |
| RES6           | 2 or FH                                    | 4           | 6      | 2 or FH | 4           | 6      |

Note: FH = foundation height.

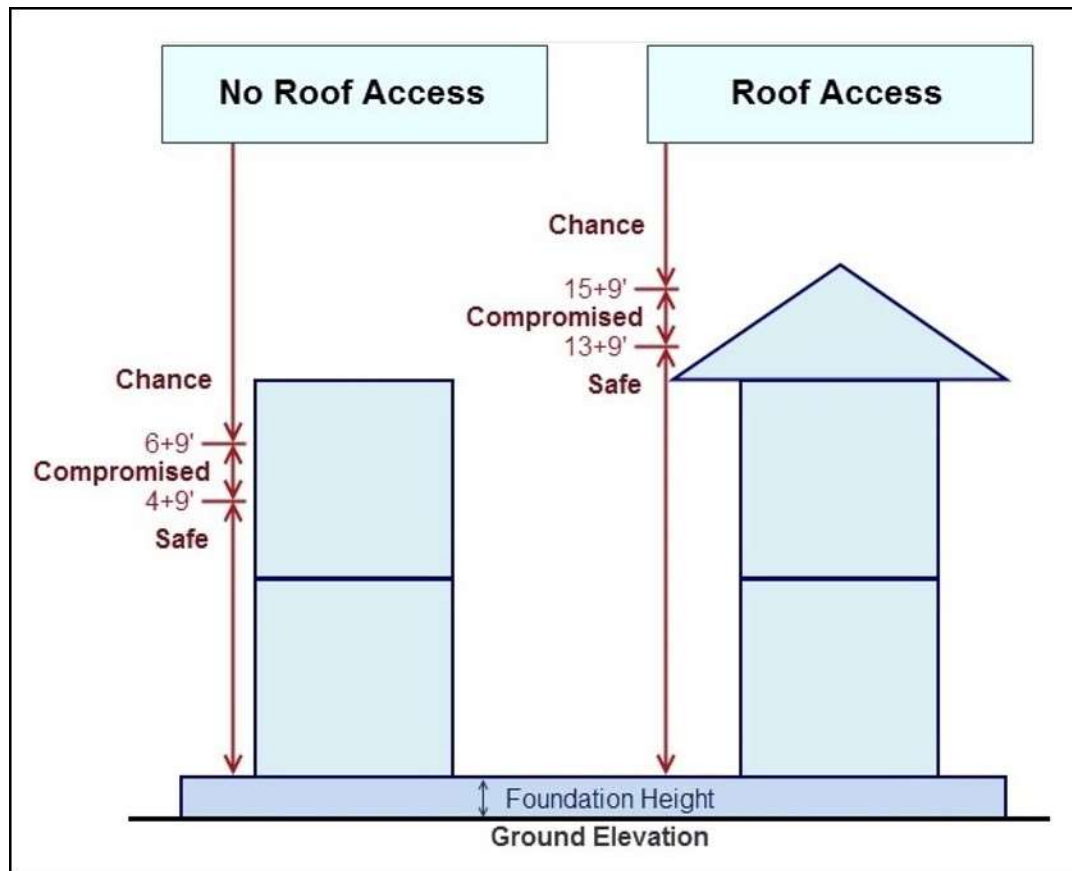


Figure 4.3 Flood Lethality Zones and Default Heights for a Two-Story Structure

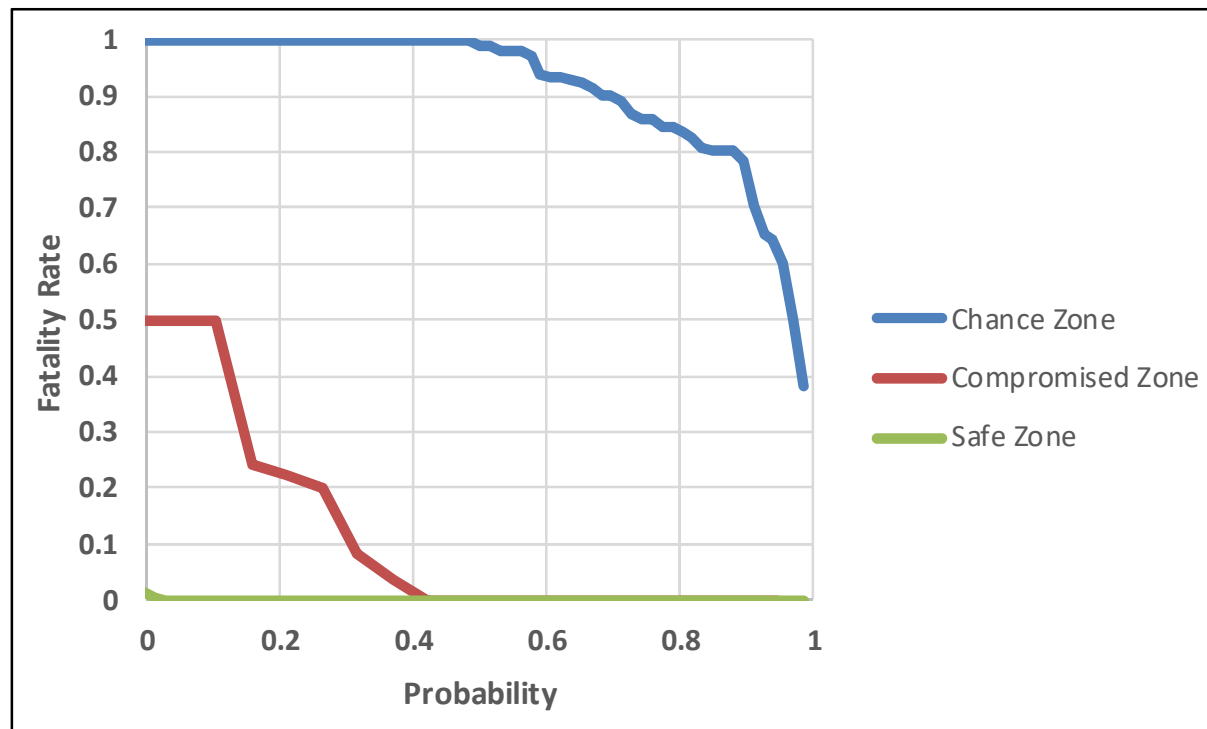


Figure 4.4 Flood Zone Empirical Distributions

Table 4.3 HEC-FIA Fatality Rates for Evacuation Outcome Categories

| Evacuation Outcome   |                  | Fatality Rate                             |
|----------------------|------------------|---|
| <b>Cleared</b>       |                  | zero percent                              |
| <b>Caught</b>        |                  | (percentage caught evacuating) x 0.9145   |
| <b>Not Mobilized</b> | Safe Zone        | (percentage stayed in structure) x 0.0002 |
|                      | Compromised Zone | (percentage stayed in structure) x 0.12   |
|                      | Chance Zone      | (percentage stayed in structure) x 0.9145 |

### 4.3 Computational Procedure

The computation of life loss resulting from a flood event assumes a structure inventory has been generated (Chapter 3); the depth and flood arrival time at each structure has been determined (Chapter 2); and that the population has been distributed (Chapter 7).

For a flood event, a warning is issued at a user-defined time,  $t_w$ . Based on hydraulic data, HEC-FIA then calculates the time when a structure becomes inundated (more than two feet), defined as  $t_a$ . The time when depth arrives at the structure's safe location, is defined as  $t_b$ . From these three times, HEC-FIA can calculate the amount of time available for evacuation, defined as  $t_e$  (Equation 4.2):

$$t_e = \begin{cases} 0, & \text{if } t_b \leq t_w \\ 0, & \text{if } t_a \leq t_w \\ t_a - t_w, & \text{if } t_a \leq t_b \\ t_b - t_w, & \text{if } t_b < t_a \end{cases} \quad (4.2)$$

For a safe evacuation, HEC-FIA either uses the evacuation time specified by the user or calculates the amount of time required for the people to evacuate to a safe location after they have mobilized, defined as  $E_t$ . HEC-FIA calculates  $E_t$  using Equation 4.3:

$$E_t = \frac{d}{s} \quad (4.3)$$

where:

- $d$  is the distance to the nearest safe location from the structure
- $s$  is the user-defined nominal evacuation velocity

HEC-FIA then calculates an additional relevant time, the amount of time available for a successful evacuation, defined as  $t_s$  in Equation 4.4:

$$t_s = t_e - E_t \quad (4.4)$$

Given the total available evacuation time and the amount of time available for a successful evacuation, HEC-FIA calculates three evacuation outcome categories using the combined

warning and mobilization curve (Equation 4.3) above, using  $t_e$  and  $t_s$  (Equations 4.5 and 4.6, respectively):

$$C(t_e) = \sum_{t=1}^{t_e} (W(t) - W(t-1)) * M(t_e - t) \quad (4.5)$$

$$C(t_s) = \sum_{t=1}^{t_s} (W(t) - W(t-1)) * M(t_s - t) \quad (4.6)$$

The percentage of population in the zone who evacuated to a safe location, *Cleared* and is defined in Equation 4.7:

$$\text{Cleared} = C(t_s) \quad (4.7)$$

The percentage of population in the zone who are caught evacuating, *Caught* and is defined in Equation 4.8:

$$\text{Caught} = C(t_e) - C(t_s) \quad (4.8)$$

The percentage of population in the zone that remained in a structure, *Not Mobilized*, and is calculated using Equation 4.9:

$$\text{Not Mobilized} = 1 - C(t_e) \quad (4.9)$$

The next step in the process is to sort the *Not Mobilized* population into vertical lethality zones by structure type. The population in structures are assigned to flood lethality zones based on maximum depth of flooding over the entire flood event and the occupancy type of the structure. For example, it is assumed that the population over the age of 65, will not be able to access the roof of a structure, and thus this population lethality zone thresholds (i.e., heights) are lower by default in HEC-FIA. Lethality zone thresholds can be modified for each occupancy type.

The modifications can be made for each zone's start threshold, for over and under the age of 65. For example, this need may occur for a senior living facility, as special accommodations for the population over the age of 65 may have been provided easy access to the roof of the structure. Illustrations of the flood lethality zones for one- and two-story structures are displayed in Figure 4.2 and Figure 4.3, respectively.

The general methodology of the lethality rate assignment for population under 65 residing in a one-story structure in the *Not Mobilized* category is described in the following steps. Using HEC-FIA default values for the lethality zone thresholds, for each additional story, nine feet is added to the depth criteria below to determine the flood lethality zone.

1. If maximum depth is less than FH plus 13 feet, then assign the population to the *Safe Flood Zone*.



2. If the maximum depth is greater than or equal to FH plus 13 feet and less than the FH plus 15 feet, then assign the population to *Compromised Flood Zone*.
3. Else event maximum depth greater than or equal to FH plus 15 feet, then assign the population to *Chance Flood Zone*.

The exception to the above criteria is that if the depth-times-velocity exceeds specified maximums, the structure is either considered to be partially or totally damaged, and the population of the structure is assigned to either the *Compromised* or *Chance* flood zones, respectively, regardless of the maximum depth of flow occurring at the structure. The depth-times-velocity criteria used in HEC-FIA for different structure types is displayed in Table 4.4.

Table 4.4 Structure Type: Depth-Times-Velocity Damage Criteria

| Structure Type                 | Partial Damage<br>(Occupants Assigned to<br>Compromised Zone)          | Total Damage<br>(Occupants Assigned to<br>Chance Zone)                 |
|--------------------------------|--|--|
| Unanchored Wood Framed         | $d*v \geq 21.5 \text{ ft}^2/\text{s}$                                  | $d*v \geq 32.3 \text{ ft}^2/\text{s}$                                  |
| Anchored Wood Framed           | $d*v \geq 32.3 \text{ ft}^2/\text{s}$                                  | $d*v \geq 75.3 \text{ ft}^2/\text{s}$                                  |
| Masonry, Concrete,<br>or Brick | $v \geq 6.6 \text{ ft/s}$ AND<br>$d*v \geq 32.3 \text{ ft}^2/\text{s}$ | $v \geq 6.6 \text{ ft/s}$ AND<br>$d*v \geq 75.3 \text{ ft}^2/\text{s}$ |

If the user is computing without uncertainty, the average fatality rates from Table 4.2 are used for each flood lethality zone. If the user is computing with uncertainty, the fatality rate distributions in Figure 4.4 are used for each flood lethality zone (McClelland and Bowels, 2002). Three uniform random numbers are drawn for each structure (one for each zone), the inverse of the empirical distribution is called, and the resulting fatality rate is utilized as displayed in Figure 4.4.

The loss of life for each structure is calculated by multiplying the remaining population in the structure by the appropriate fatality rate. The Population At Risk (PAR) value is computed by determining the number of people in structures that get wet, i.e., structures at which depths are greater than zero feet, for day and night.

## 4.4 Computational Results

Results from the life loss computational procedures are PAR and life loss.



# Chapter 5

## Indirect Loss

### 5.1 Overview

In HEC-FIA, indirect loss is defined as the reduction in the income of and the labor pool for businesses due to infrastructure damage and life loss resulting from a flood event. This chapter describes how HEC-FIA computes indirect losses on a county-by-county basis. Specifically, describing the inputs required for the computations, the computational procedures, and the outputs produced from the computations.

### 5.2 Computational Inputs

Computations of indirect losses require county-specific data in addition to an inundation dataset and a structure inventory. The inundation dataset and structure inventory are discussed in Chapter 2.

#### 5.2.1 County Boundary Shapefile

The first required input for indirect loss computations is a polygon shapefile representing each county in the study area. This shapefile must include an attribute that contains the five-digit county Federal Information Processing Standard (FIPS) code for each county in an "SSCCC" format. For the SSCCC format, SS is the two digit state code and CCC is the three digit county code. These can be obtained from the United States Census Bureau TIGER/Lines. The shapefile is used by HEC-FIA to delineate computational boundaries on a county-by-county basis and reference input data to the appropriate county via the FIPS codes.

#### 5.2.2 ECAM Data

The second necessary input to the HEC-FIA indirect loss computations is ECAM data. ECAM is a computable general equilibrium model that contains information for each county in the United States related to that county's ability to respond to external economic shocks. ECAM requires total capital (a summation of the structure and content values for all commercial, public, and industrial structure types) and total labor (a summation of the daytime population for all commercial, public, and industrial structure types) for its computations.

In general, capital losses resulting from a flood event make it more difficult (but not impossible) to produce business output. Labor losses occur when people are displaced from an impact area, preventing them from reporting to their jobs as they would under typical circumstances. Like capital losses, labor losses reduce the quantity and efficiency of production. Total capital and labor values can be either manually entered or imported from a HAZUS database.

ECAM also requires users to enter flood duration, the reconstruction period duration, and cleanup period duration. Flood duration depends on how quickly the floodwaters recede and is a single value for the entire watershed. This data can usually be obtained from a hydraulic model. Currently, the user must provide a single value for the entire flooded area, so thought and judgment must be given to the definition of the flood duration time. The reconstruction and cleanup period durations largely depend on the types of structures located in the flooded area.

## 5.3 Computational Procedure

This section details how capital and labor losses are calculated using the ECAM component within HEC-FIA. Within the calculations, direct damage and life loss, are utilized to evaluate the losses of capital and labor as a ratio of the overall available capital and labor by sector. After capital and labor losses are described, they are submitted to the ECAM module as inputs. ECAM then computes indirect losses.

### 5.3.1 Capital Losses

Capital loss results are computed through three steps: 1) calculating the total exposed value per county; 2) calculating the losses per county resulting from the event; and 3) dividing the losses per county by the total exposed value per county for all non-residential structures, which results in a capital loss ratio per county. The procedure for calculating capital loss results is described in the following steps:

1. Calculate the total capital ( $TC_c$ ) for a County ( $c$ ) by summing the structure and content values for all non-residential structures within a County ( $c$ ) using Equation 5.1:

$$TC_c = TIC_c + TCC_c + TPC_c \quad (5.1)$$

where:

$TIC_c$  is the total industrial capital for a County ( $c$ )

$TCC_c$  is the total commercial capital for a County ( $c$ )

$TPC_c$  is the total public capital for a County ( $c$ )

2. Calculate the total lost capital by summing the damage for each structure category, as computed in the direct damage computations (Chapter 3). The total lost capital ( $LC_c$ ) for a County ( $c$ ) is calculated using Equation 5.2:

$$LC_c = LIC_c + LCC_c + LPC_c \quad (5.2)$$

where:

$LIC_c$  is total lost industrial capital for a County ( $c$ )

$LCC_c$  is total lost commercial capital for a County ( $c$ )

$LPC_c$  is total lost public capital for a County ( $c$ )

- Finally, a comparison between ( $LC_c$ ) for a County ( $c$ ) and ( $TC_c$ ) for a County ( $c$ ) is expressed in terms of a capital loss ratio ( $CL_r$ ). This ratio, which cannot be greater than one nor less than zero is calculated using the following formula (Equation 5.3):

$$CL_r = \frac{LC_c}{TC_c} \quad (5.3)$$

### 5.3.2 Labor Losses

To compute labor losses within HEC-FIA, the population for all structures within the structure inventory that are impacted by an event are utilized. This means that the population in both residential and non-residential structures will be utilized to calculate labor loss based upon the population under the age of 65 at 2:00 p.m. The justification for including all residential and non-residential structures is that although the entire population is not part of the workforce, the assumption is that the distribution of laborers (those under 65) and non-laborers (those over 65) within the study area is fixed both geospatially and temporally. The procedure for calculating labor losses was derived from FEMA's formulas for estimating population damage (Table 13.2, HAZUS-MH Technical Manual). The methodology used in HEC-FIA is described in the following steps:

- Identify the number of people located in each impacted structure at 2:00 p.m.
- Calculate the impact duration ( $I_s$ ) for each structure ( $s$ ) in hours using the following formula (Equation 5.4):

$$I_s = D_s + C_s + R_s \quad (5.4)$$

where:

$D_s$  is a user provided study wide duration value of flooding at structure ( $s$ ) (hr)

$C_s$  is cleanup time at structure ( $s$ ) (hr)

$R_s$  is reconstruction time at structure ( $s$ ) (hr)

$I_s$  may not exceed 8,766 hours (equivalent to one year, or 365.25 days).  $D_s$ ,  $C_s$ , and  $R_s$  are defined by the user in the **ECAM** tab of the HEC-FIA **Edit Alternative** dialog box.

- Calculate the number of labor hours displaced ( $LHD_s$ ) for the working population at each structure ( $s$ ) using the following formula (Equation 5.5):

$$LHD_s = I_s * \left( \frac{2000}{365.25 * 24} \right) * (P_s - L_s) \quad (5.5)$$

where:

2,000 is the number of working hours per laborer per year

365.25 is the number of days per year

24 is the number of hours per day

$P_s$  is the total population under 65 in structure ( $s$ )

$L_s$  is the life loss under 65 for structure ( $s$ )

4. Calculate the total labor loss ( $LL_s$ ) at each structure ( $s$ ) in hours by adding the number of labor hours displaced ( $LHD_s$ ) for the working population to the number of labor hours lost due to life loss using the following formula (Equation 5.6):

$$LL_s = LHD_s + L_s * 2000 \quad (5.6)$$

where:

$L_s$  is life loss at structure ( $s$ )

2000 is the number of working hours per laborer per year

5. Calculate the cumulative labor loss for County ( $c$ ) using the following formula (Equation 5.7):

$$LL_c = \sum_s^n LL_s \quad (5.7)$$

where:

$LL_c$  is the labor loss for County ( $c$ ) in hours

$LL_s$  is the labor loss for structure ( $s$ )

$n$  is the number of structures within County ( $c$ )

6. Calculate total population during the day ( $Popday$ ) per county using the following formula (Equation 5.8):

$$Popday = 95\%ResidDay + 98\%WorkingCom + 80\%WorkingInd + Hotel + Visitor + 80\%SchoolEnrollmentKto12 + College + 5\%Pop \quad (5.8)$$

where:

*ResidDay* is the daytime residential population

*WorkingCom* is the number of people commuting

*WorkingInd* is the number of people employed in the industrial sector

*Hotel* is number of people staying in hotels in the census tract

*Visitor* is the number of regional residents who do not live in the study area

*School EnrollmentKto12* is the number of grade school students

*College* is the number of university students

*Pop* is the census tract population

7. Calculate the total available workforce ( $WF_c$ ) for County ( $c$ ) using the following formula (Equation 5.9):

$$WF_c = \sum_i^n Popday_i * (1 - EldersFrac_i) \quad (5.9)$$

where: *EldersFrac* is the fraction of the population over age 65

8. Finally, a comparison between the labor loss for the County ( $c$ ) ( $LL_c$ ) and the available labor for the County ( $c$ ) is expressed in terms of a labor loss ratio ( $LL_r$ ). This ratio, which cannot be greater than one nor less than zero, is calculated using the following formula (Equation 5.10):

$$LL_r = \frac{LL_c}{2000 * WF_c} \quad (5.10)$$

### 5.3.3 Indirect Economic Losses

To convert the capital loss ratio ( $CL_r$ ) and labor loss ratio ( $LL_r$ ) into a reduction in economic output, the ECAM system model requires information about the specific nature of the economy being analyzed. The ECAM system model determines whether the economy in question is capital or labor intensive, and what the rate of exchange is between labor and capital. Each County has a unique dataset that is used to define the specific economic characteristics assessed in the ECAM system model. Statistics for production, employment, income and all other economic indicators are based upon the IMPLAN (IMpact analysis for PLANing) dataset, unless otherwise indicated. Each of these datasets can distinguish up to 440 separate production activities, ten household types, and four levels of government. The dataset used for evaluating indirect economics with ECAM and HEC-FIA has been aggregated from the full 440 sectors to thirty sectors. Additional information on the IMPLAN dataset is available from IMPLAN Group, LLC. (Appendix A). Additional information on the ECAM system model can be found in Lehman, et al. (2013).

## 5.4 Computational Results

Results from the indirect losses computations include the Indirect Economic Damage Report and Indirect Employment Loss Report.





# Chapter 6

## Agricultural Damage

### 6.1 Overview

When flooding occurs in agricultural areas, damage to existing crops and interruptions to the planting, growing, and harvesting of crops results in economic impacts. HEC-FIA can be used to compute the economic impacts of flooding in these types of areas. This chapter discusses the inputs required for the HEC-FIA agricultural damage computations, the computational procedures, and the outputs produced from the computations. Due to changes in the NASS (National Agricultural Statistics Service) API, and an HEC-FIA 3.0 data processing issue, HEC-FIA 3.0 is not recommended for computing agricultural damage. To ensure quality of agricultural damage computations, and to enable the download of NASS data from the NASS API within HEC-FIA, use the patch version HEC-FIA 3.0.1.

### 6.2 Computational Inputs

Computations of agricultural flood damage require a number of different inputs. Specifically, five inputs are required: 1) duration grids or DSS hydrographs (discussed in Section 2.2.2), 2) NASS data, 3) crop budgets, 4) crop values, and 5) duration-Damage relationships. The duration data required to compute agricultural flood damage was discussed previously in Chapter 2. The remaining four required inputs are described in the sections below.

#### 6.2.1 National Agricultural Statistics Service Data (NASS)

The NASS Cropland Data Layer is a product that represents the type of crop and the geographic location of crops throughout the entire United States (Appendix A). NASS provides the Cropland Data Layer in GeoTiff format, where each cell represents a crop type. HEC-FIA can import this data directly from the NASS API to streamline the collection of the type and distribution of crops in the study area. Alternatively, the user can go to the following website to download, research, and pre-process NASS Cropland Data:

[https://www.nass.usda.gov/Research\\_and\\_Science/Cropland/SARS1a.php](https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php).

HEC-FIA also allows the user to import an existing GeoTiff file with agricultural data into HEC-FIA. The distribution of each agricultural category in the study area is used in combination with the planting, harvesting, and crop loss relationships in the calculation of agricultural flood damage.

Damage to crops is dependent upon the value added by the farmer to the field at the time of flooding, and how much of that value is susceptible to flooding. The driving damage parameters are duration and the timing of the event. Similarly, to structure depth-damage relationships, it is possible for crop damage to increase with longer durations. However, since crop damage is also a function of how hardy the plant is the damage for a given duration may change with time. For

simplicity, the damage calculation is split into two pieces, the seasonally based value (Equation 6.1), and the seasonally based damage (Equation 6.3). A general expression of the damage calculation is as follows:

$$S(t, c) = (a \cdot (V(c, t) - H(c))) \cdot B(t) \quad (6.1)$$

where:

- $S$  = seasonally based value as a function of date and crop type
- $t$  = date
- $a$  = the area of the grid cell in acres
- $c$  = crop type
- $H(c)$  = harvest cost as a function of crop type
- $B$  = percentage of the total crop value that is available to be flooded due to the crop budget
- $V(c, t)$  = is the value as a function (Equation 7.2) of crop type and date as follows:

$$V(c, t) = \begin{cases} q * p, & \text{if } t > \text{firstplantdate} \\ ((q * p) * (1 - \text{lateplantloss})), & \text{if } \text{firstplantdate} < t < \text{lastplantdate} \end{cases} \quad (6.2)$$

$$D(t, d) = S(t, c) \cdot L(d, c) \quad (6.3)$$

where:

- $D$  = damage to the crop as a function of date and duration
- $d$  = duration of flooding
- $L$  = the loss for the crop as a function of duration and crop type

To illustrate how the seasonally based value changes with time (Equation 6.1), an example plot (Figure 6.1) is provided. From Figure 6.1, the seasonally based value is expressed as a ratio of seasonal value to total value.

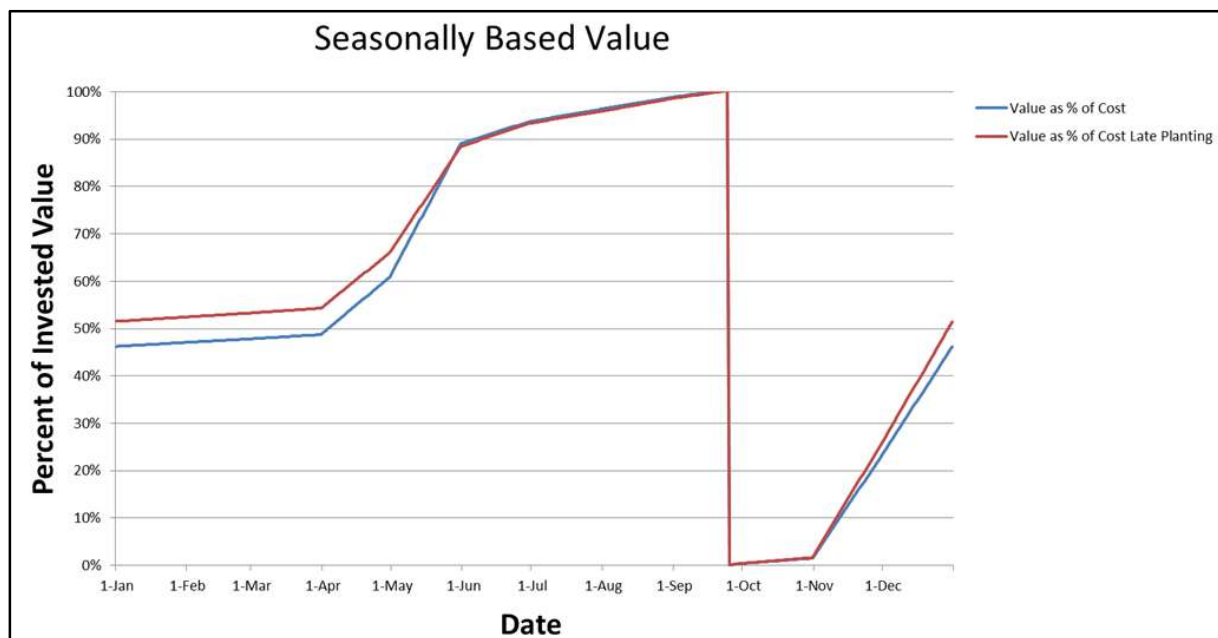


Figure 6.1 Seasonal Crop Value Example

As shown in Figure 6.1, if a crop is planted later in the season, the crop has a different value curve (e.g., red curve in Figure 6.1). For seasonally based value changes, it is assumed that if the flood does not interrupt the farmer, the crops will be planted by the first plant date. Thus, late planting will only occur if the flood start plus the duration ends before the late plant date but after the first plant date. This seasonally based value is intended to reflect that farmers may adopt different schedules for application of watering, fertilizer, and other processes in raising the crop; or, the farmer may choose to grow another crop altogether.

Damage can also fluctuate based on seasonality (Equation 6.3). Some crops can better withstand short duration floods if the crops are out of critical development stages. Figure 6.2 gives a general example of what seasonal duration damage relationships look like.

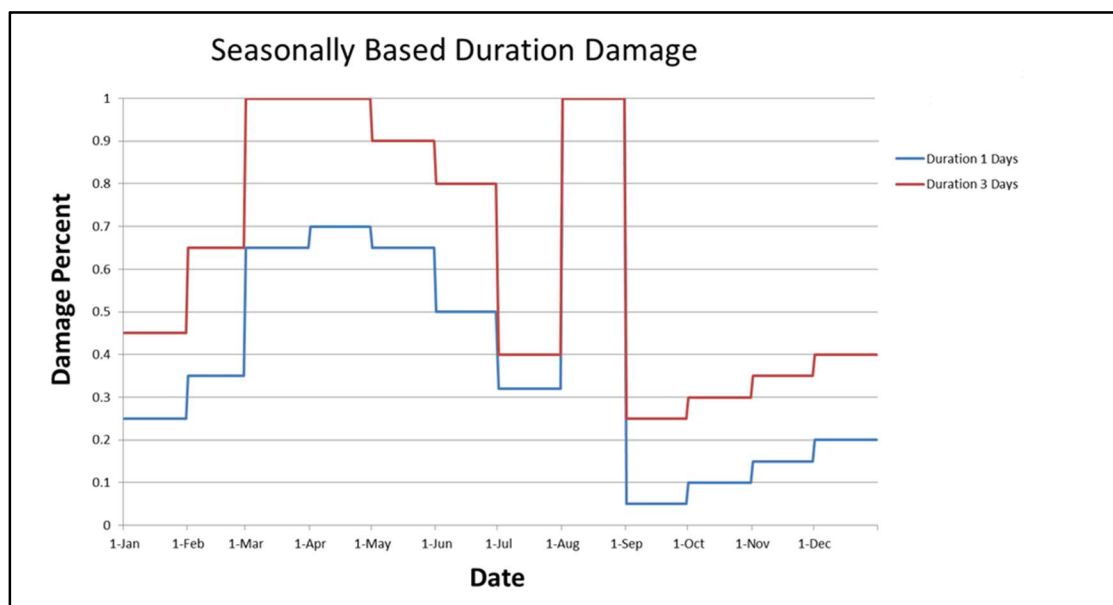


Figure 6.2 Seasonal Crop Duration Damage Example

As shown in Figure 6.2, longer duration flooding would yield larger losses, but more mature plants would be more robust to damage. This input (planting, harvesting, and crop loss relationship inputs) is provided by the user, and must reflect their expectation of how plants will react to different durations of flooding throughout the growing season.

## 6.2.2 Crop Budget Data

Costs required to produce crops are necessary for the economic loss computations for agricultural areas. In HEC-FIA (**Crop Loss Editor**), crop budget data is used to define the cost of planting each crop type. Monthly crop planting costs in HEC-FIA can be either fixed or variable. The crop planting cost input data required for the economic loss computations is available from local Cooperative Extension System Offices, which can be found on the USDA's National Institute of Food and Agriculture (NIFA)'s website (Appendix A, Section A.1). The final components of the crop planting data required are the dates of the first possible and last possible plantings. The crop planting data is used to create a curve (similar to Figure 6.1), that represents the cumulative cost of the inputs in the field at any point during the year from the first plant date.

The cumulative cost is converted to a percentage of the maximum total cost of the inputs in the field to calculate the potential losses at any point during the year. The maximum total cost input into the field is not necessarily equivalent to the total cost experienced by the farmer for the crops pulled from the field. First, the harvest cost and shipping costs need to be added to all of the inputs to get the full cost to produce the crops. HEC-FIA uses a proration of the total cost input less the harvest costs as a proxy for an exposed value.

### 6.2.3 Crop Value Data

Crop characteristics are necessary for HEC-FIA to compute the appropriate reduction in crop value due to the costs associated with harvesting. The required input characteristics are harvest date, harvest cost, yield, unit price, and percentage of total crop value lost due to late planting.

### 6.2.4 Crop Loss Relationships

Crop loss relationships are required for HEC-FIA to calculate the agricultural damage. Crop loss relationships in HEC-FIA define the percentage of crop loss based on the number of days (i.e., duration) crops are inundated each month.

## 6.3 Computational Procedure

This section details the computational procedures used by HEC-FIA to calculate agricultural damage at a single crop cell. The procedures assume inundation durations throughout the project area are known and have already been input. Additionally, the procedures assume that crops are planted at the first available date after flooding and that crops will be planted immediately before an event (meaning that weather forecasting is not taken into account). The computational procedures are:

1. Determine what type of crop the cell represents.
2. Determine the arrival date and time of flooding for the crop cell.
3. Determine the duration of flooding for the crop cell.
4. Based on the arrival time and duration, determine if planting dates are impacted or if the crop is damaged before harvest.
5. If damaged during the growing season, determine if the duration is longer than the longest duration damage curve; if so, the farmer loses all value placed in the field so far. The loss is equivalent to the marketable value minus harvest costs, prorated by total value input to the field to that point in time.
6. If flooding limited the ability to plant and the farmer was unable to plant the preferred crop, the secondary crop will be used, and the loss will be the total marketable value for the secondary crop less harvest costs, minus the total marketable value for the primary crop less harvest costs.

7. If the flooding made the farmer plant later than the first day of the season for the primary crop, but the farmer was able to plant the primary crop, the damage is based on a reduction in full yield due to late planting. This procedure is equivalent to the total marketable value less harvest cost, times one minus the percent loss due to late planting.
8. Calculate the loss for each crop cell in the inundated area using the process described above and output the crop type, location, duration, and total damage for each crop cell damaged.

## **6.4 Computational Results**

Results from the agricultural damage computations include: a point based shapefile specifying the crop type; arrival time; duration; location; and total damage for each damaged grid cell. These results can be aggregated by crop type, or by any polygon loaded as a boundary shapefile.



# Chapter 7

## Population Distribution

### 7.1 Overview

HEC-FIA distributes population data from FEMA's HAZUS database over an existing structure inventory (Appendix A, Section A.1). This data is readily available from sources like FEMA's HAZUS. HEC-FIA has an import tool that can be used to assign population characteristics directly from a HAZUS database to each structure in a structure inventory. HAZUS data is available at no cost from the FEMA website (<http://www.fema.gov/hazus>).

The distribution of population over the structure inventory is required for life loss calculations (Chapter 4). The following sections detail the inputs required for the distribution computations, the computational procedures, and the outputs produced from the computations. Alternatively, the user can manually distribute population on the structure inventories.

### 7.2 Computational Inputs

Two computational inputs are required to distribute a population throughout a study area. One of these required inputs, structure inventory, is described in Chapter 2. A critical element of the structure inventory is the occupancy type-naming scheme, which is addressed in Section 7.2.1. The additional required input is population information from the HAZUS database, which is contained in the *HzbndrygrbsB.mdb* database.

#### 7.2.1 Occupancy Type Schema

Population information is imported into HEC-FIA in the form of totals of people at the census block level, subcategorized to represent industrial, commercial, and residential groups (occupancy types). These categories need to be aggregated based on times of day, but also need to be disaggregated to represent the count in each structure. To perform the aggregation or disaggregation, the population in each structure is prorated using the average number of households by occupancy type. This proration is based on the description of the 36 standard HAZUS MH occupancy types, which is currently not editable by the user. Definitions for these occupancy types can be found in Table 3.1 of the HAZUS-MH Flood Technical Manual (Appendix A, Section A.1). Table 7.1 is provided to give the user insight to the weights applied by occupancy type.

#### 7.2.2 HAZUS Population Data

Population information is imported into HEC-FIA from the *HzDemographicsB* table in the HAZUS database.

Table 7.1 Number of Households per HAZUS MH Occupancy Type

| <b>Occupancy Type</b> | <b>Households_day</b> | <b>Households_night</b> |
|-----------------------|-----------------------|-------------------------|
| RES1-1SNB             | 1.0                   | 1.0                     |
| RES1-1SWB             | 1.0                   | 1.0                     |
| RES1-2SNB             | 1.0                   | 1.0                     |
| RES1-2SWB             | 1.0                   | 1.0                     |
| RES1-3SNB             | 1.0                   | 1.0                     |
| RES1-3SWB             | 1.0                   | 1.0                     |
| RES1-SLNB             | 1.0                   | 1.0                     |
| RES1-SLWB             | 1.0                   | 1.0                     |
| RES2                  | 1.0                   | 1.0                     |
| RES3AI                | 2.0                   | 2.0                     |
| RES3BI                | 3.5                   | 3.5                     |
| RES3CI                | 7.0                   | 7.0                     |
| RES3DI                | 14.5                  | 14.5                    |
| RES3EI                | 34.5                  | 34.5                    |
| RES3FI                | 50.0                  | 50.0                    |
| RES4                  | 50.0                  | 50.0                    |
| RES5                  | 50.0                  | 50.0                    |
| RES6                  | 50.0                  | 50.0                    |
| COM1                  | 2.0                   | 0.1                     |
| COM2                  | 2.0                   | 0.1                     |
| COM3                  | 2.0                   | 0.1                     |
| COM4                  | 2.0                   | 0.1                     |
| COM5                  | 2.0                   | 0.1                     |
| COM6                  | 2.0                   | 0.1                     |
| COM7                  | 2.0                   | 0.1                     |
| COM8                  | 2.0                   | 0.1                     |
| COM9                  | 2.0                   | 0.1                     |
| COM10                 | 2.0                   | 0.1                     |
| IND1                  | 5.0                   | 1.0                     |
| IND2                  | 5.0                   | 1.0                     |
| IND3                  | 5.0                   | 1.0                     |
| IND4                  | 5.0                   | 1.0                     |
| IND5                  | 5.0                   | 1.0                     |
| IND6                  | 5.0                   | 1.0                     |
| AGR1                  | 5.0                   | 0.1                     |
| REL1                  | 5.0                   | 0.1                     |
| GOV1                  | 5.0                   | 0.1                     |
| GOV2                  | 5.0                   | 0.1                     |
| EDU1                  | 5.0                   | 0.1                     |
| EDU2                  | 5.0                   | 0.1                     |



### 7.3 Computational Procedure

Population distribution is based on the procedures outlined in the HAZUS-MH 2.1 Earthquake Model Technical Manual, Tables 3.26 and 3.27, following the logic from Table 13.2 (Appendix A, Section A.1). The computational procedure for the population distribution is described below:

1. Generate census block population by a HAZUS damage category for night (2:00 a.m.) and day (2:00 p.m.) conditions. To do that, HEC-FIA:
  - a. Obtains census block population from the HAZUS *hzDemographicsB* table for the HAZUS demographics categories.
  - b. Computes census block population for night and day conditions by HAZUS occupancy type.
2. Compute the number of households per census block. This computation uses information from the HAZUS demographic categories, the number of structures from the structure inventory, and the following formula (Equation 7.1):

$$\text{NumberHouseholds} = (\text{households per structure}) \times (\# \text{ of structures}) \quad (7.1)$$

3. Distribute population based on time of day:
  - a. Calculate total population during the day from the *hzDemographicsB* table in the HAZUS database using the formula (Equation 7.2):

$$\begin{aligned} \text{PopulationDay} = & \text{residday} + 98\% \text{workingcom} + \text{hotel} + \\ & 80\% \text{schoolenrollmentkto12} + \text{schoolenrollmentcollege} + \\ & 80\% \text{workingind} + 80\% \text{visitor} \end{aligned} \quad (7.2)$$

- b. Calculate total population during the night using the formula (Equation 7.3):

$$\text{PopulationNight} = \text{residnight} + 2\% \text{workingcom} + 10\% \text{workingind} + \text{hotel} \quad (7.3)$$

- c. Calculate the population per household (day) using the formula (Equation 7.4):

$$\text{PopHouseholdDay} = \text{PopulationDay} / (\# \text{ of households}_{\text{day}}) \quad (7.4)$$

- d. Calculate the population per household (night) using the formula (Equation 7.5):

$$\text{PopHouseholdNight} = \text{PopulationNight} / (\# \text{ of households}_{\text{night}}) \quad (7.5)$$

- e. Distribute population to each structure based on households per occupancy type and the population per household day and night.

- f. Determine a percentage reduction to the population for both over and under the age of 65 using the following formula (Equation 7.6):

$$\% \text{ Over65} = \frac{(\text{males Over65} + \text{females Over 65})}{(\text{total population})} \quad (7.6)$$

- g. Apply the percentage reduction to the population for individuals over 65 (from Equation 7.6) and use the *PopulationDay* and *PopulationNight* calculated values per structure (from Equation 7.2 and 7.3, respectively), to determine the over 65 day and night population per structure (Equation 7.7 and 7.8, respectively):

$$\text{Over65PopDay} = (\text{PopulationDay}) \times (\% \text{Over65}) \quad (7.7)$$

$$\text{Over65PopNight} = (\text{PopulationNight}) \times (\% \text{Over65}) \quad (7.8)$$

- h. Calculate the under 65 day and night population values using the *PopulationDay* and *PopulationNight* calculated values per structure (from Equation 7.2 and 7.3, respectively), and the over 65 day and night population per structure (Equation 7.7 and 7.8, respectively), to determine the under 65 day and night population values (Equation 7.9 and 7.10 respectively), at each structure:

$$\text{Under65PopDay} = \text{PopulationDay} - (\text{Over65PopDay}) \quad (7.9)$$

$$\text{Under65PopNight} = \text{PopulationNight} - (\text{Over65PopNight}) \quad (7.10)$$

## 7.4 Computational Results

Results from the population distribution procedure include the following:

- Daytime population under the age of 65 for each structure.
- Nighttime population under the age of 65 for each structure.
- Daytime population over the age of 65 for each structure.
- Nighttime population over the age of 65 for each structure.

# Chapter 8

## Monte Carlo Application

### 8.1 Overview

HEC-FIA uses the Monte Carlo algorithm to incorporate uncertainty in HEC-FIA calculations. Incorporating parameters that consider uncertainty allows for the evaluation of consequences, yielding results that span the range of possible outcomes for a modeled event. Furthermore, policy requires all calculations that contribute to a benefit-to-cost ratio for USACE projects, be evaluated with a risk-based analysis (ER-1105-2-101, 2017).

Therefore, to evaluate risk and uncertainty, HEC-FIA uses a mathematical model to describe the relationship between the range of all input parameters (e.g., depth-damage relationship, time-percent mobilization relationship, etc.) and the output parameters (e.g., flood damage, life loss, etc.) that HEC-FIA produces. Using this approach, each input parameter can be expressed as a continuous distribution and input parameter values for each Monte Carlo simulation are selected using randomly drawn numbers. The mathematical model then selects samples from that randomly described set of input parameters. This process is repeated to provide a set of deterministic results, with each result in that set arising from the randomly sampled input parameters.

The set of deterministic results from the Monte Carlo simulation can then be analyzed as an empirical distribution of possible outcomes. Summary statistics that describe the range of possibilities, such as the central tendency (i.e., probability-weighted average of all possible outcomes) can be computed using the outputs of the Monte Carlo analysis. This mathematical modeling process is generally referred to as a Monte Carlo application (simulation). This chapter discusses the inputs required for an HEC-FIA Monte Carlo simulation, the computational procedures, and the outputs produced from the computations.

### 8.2 Computational Inputs

Two computational inputs are required for HEC-FIA to conduct a Monte Carlo simulation: 1) continuous distributions, and 2) Monte Carlo application controls. Relevant information about each input data type is contained in this section.

#### 8.2.1 Continuous Distributions

All distributions used in HEC-FIA are continuous distributions. The continuous distributions are used to convert a randomly drawn number into a value that is transformed through the distribution, which is the basis of the HEC-FIA Monte Carlo algorithm. In the Monte Carlo algorithm, the inverse of the cumulative distribution function is utilized to find a randomly distributed value that can be used as an input to the deterministic mathematical function

describing the desired relationship. Four different forms of continuous distributions can be selected in HEC-FIA: 1) uniform; 2) triangular; 3) normal; and, 4) log normal.

Any of the four continuous distributions can be defined for a number of parameters and inputs to HEC-FIA. A list of the parameters and inputs for which a continuous distribution can be specified in HEC-FIA is shown listed:

- Structure, Content, Other, and Vehicle Depth-Damage Functions
- Foundation Height
- Structure Value as percent of Mean
- Content to Structure Value Ratio (percent)
- Other to Structure Value Ratio (percent)
- Vehicle to Structure Value Ratio (percent)
- Warning Issuance Delay time
- Time-Percent Mobilization Functions

The four different forms of continuous distributions are described in the following sections.

## Uniform Distribution

The uniform distribution is the most basic of the four distributions. The two required input parameters for the uniform distribution are the maximum and minimum possible values for the parameter of interest. The maximum and minimum values may be any real number. The Probability Density Function (PDF) of a uniform distribution is shown in Figure 8.1. The PDF is described mathematically in Equation 8.1, where  $a$  is the minimum and  $b$  is the maximum value of  $x$ .

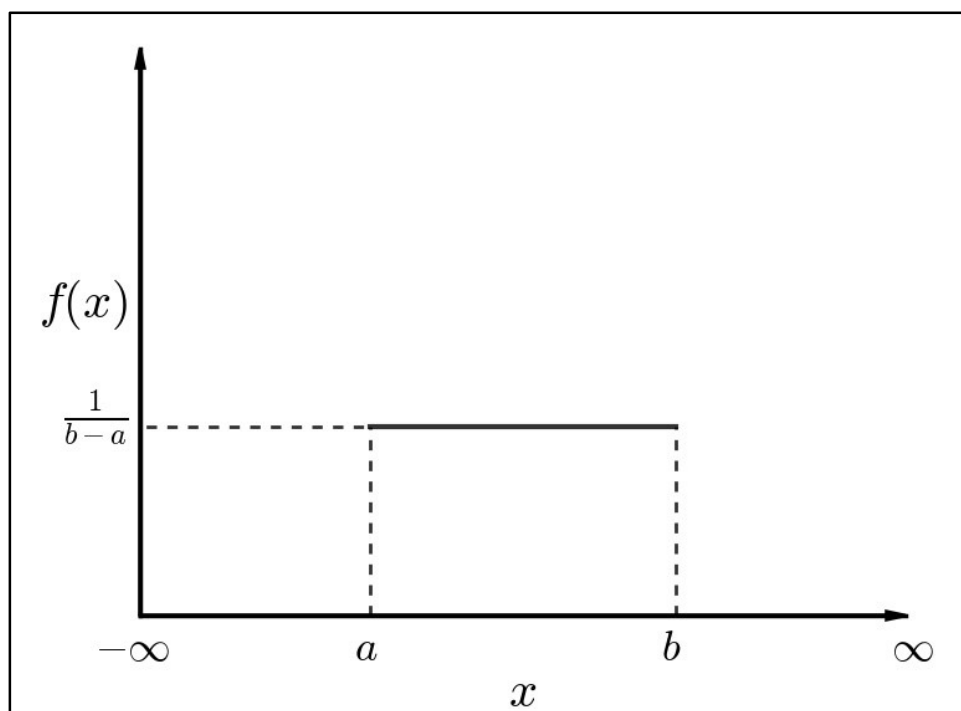


Figure 8.1 PDF of a Uniform Distribution

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{for } a \leq x \leq b \\ 0 & \text{for } x < a \text{ or } x > b \end{cases} \quad (8.1)$$

The Cumulative Distribution Function (CDF) of a uniform distribution is shown in Figure 8.2. The CDF is described mathematically in Equation 8.2:

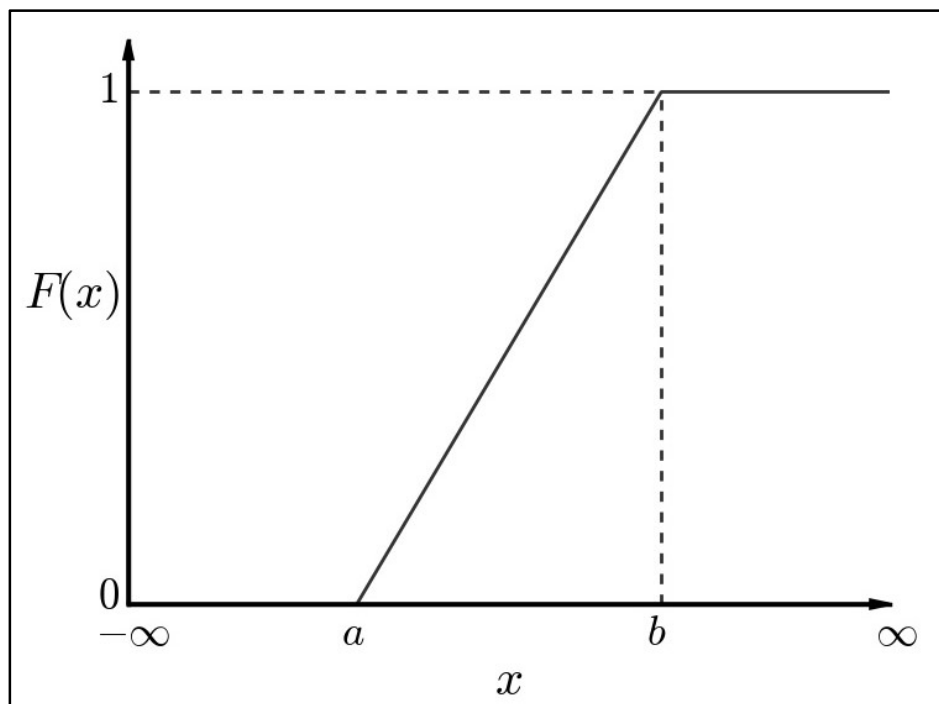


Figure 8.2 CDF of a Uniform Distribution

$$F(x) = \int_{-\infty}^{\infty} f(x) dx = \begin{cases} 0 & \text{for } x < a \\ \frac{x-a}{b-a} & \text{for } a \leq x < b \\ 1 & \text{for } x \geq b \end{cases} \quad (8.2)$$

Solving for  $x$  in the solution space of  $(0,1]$ , the inverse CDF for the continuous uniform distribution is shown in Equation 8.3:

$$F^{-1}(p) = a + ((b-a) * p) \mid 0 \leq p < 1 \quad (8.3)$$

## Triangular Distribution

A triangular distribution requires that the minimum, maximum and mode values of the parameter of interest be entered into HEC-FIA. Note that the mode value may or may not be the mean of the distribution, and must fall between the minimum and maximum values. The PDF of a triangular distribution is shown in Figure 8.3. The PDF is described mathematically in Equation 8.4, with the assumption that  $a \leq c \leq b$ .

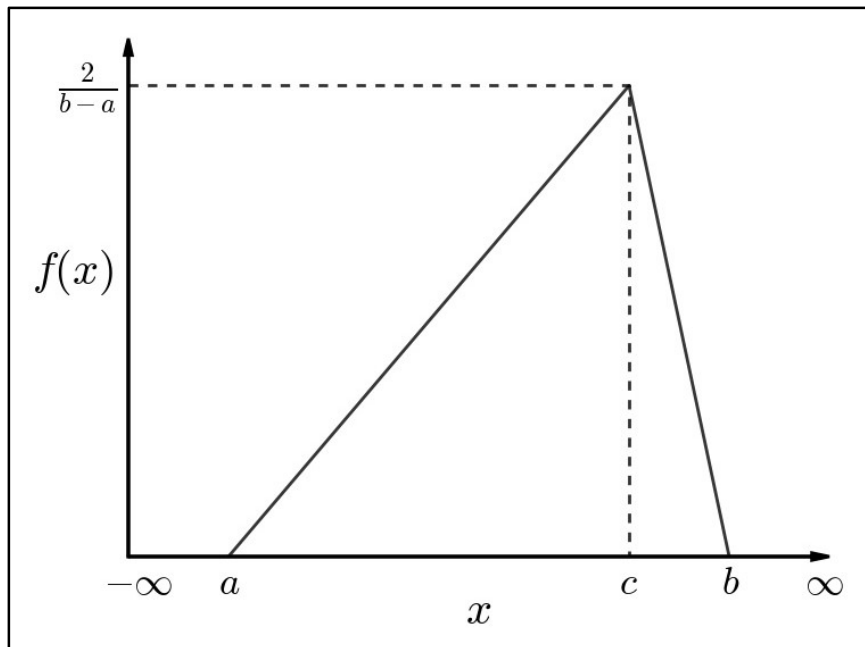


Figure 8.3 PDF of a Triangular Distribution

$$f(x) = \begin{cases} 0 & \text{for } x < a \\ \frac{2(x-a)}{(c-a)(b-a)} & \text{for } a \leq x \leq c \\ 1 - \frac{2(c-x)}{(c-a)(c-b)} & \text{for } c < x \leq b \\ 0 & \text{for } b < x \end{cases} \quad (8.4)$$

The CDF of a triangular distribution is shown in Figure 8.4 (assuming that  $a \leq c \leq b$ ), and is described mathematically in Equation 8.5.

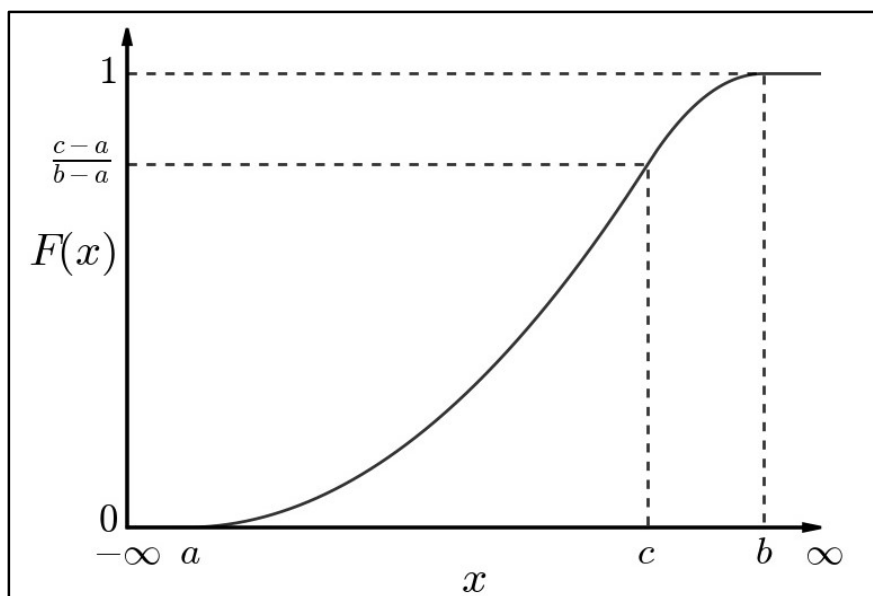


Figure 8.4 CDF of a Triangular Distribution

$$f(x) = \begin{cases} 0 & \text{for } x < a \\ \frac{(x-a)^2}{(c-a)(b-a)} & \text{for } a \leq x \leq c \\ 1 - \frac{(c-x)^2}{(c-a)(c-b)} & \text{for } c < x \leq b \\ 1 & \text{for } b < x \end{cases} \quad (8.5)$$

The inverse cumulative distribution for a triangular distribution, given  $a \leq c \leq b$ , is as follows (Equation 8.6).

$$F^{-1}(p) = \begin{cases} a + \sqrt{p(c-a)(b-a)} & \text{for } 0 \leq p \leq \frac{b-a}{c-a} \\ c - \sqrt{(1-p)(c-a)(c-b)} & \text{for } \frac{b-a}{c-a} < p < 1 \end{cases} \quad (8.6)$$

## Normal Distribution

The normal distribution is one of the most commonly used distributions in evaluating uncertainty. HEC-FIA requires that the mean ( $\mu$ ) and the standard deviation ( $\sigma$ ) of the distribution be specified. In a normal distribution, the value range is always negative infinity to positive infinity, so it is important to consider the repercussions of choosing this distribution.

The PDF of a normal distribution is displayed in Figure 8.5, and is described mathematically in terms of  $\mu$  and  $\sigma$  in Equation 8.7.

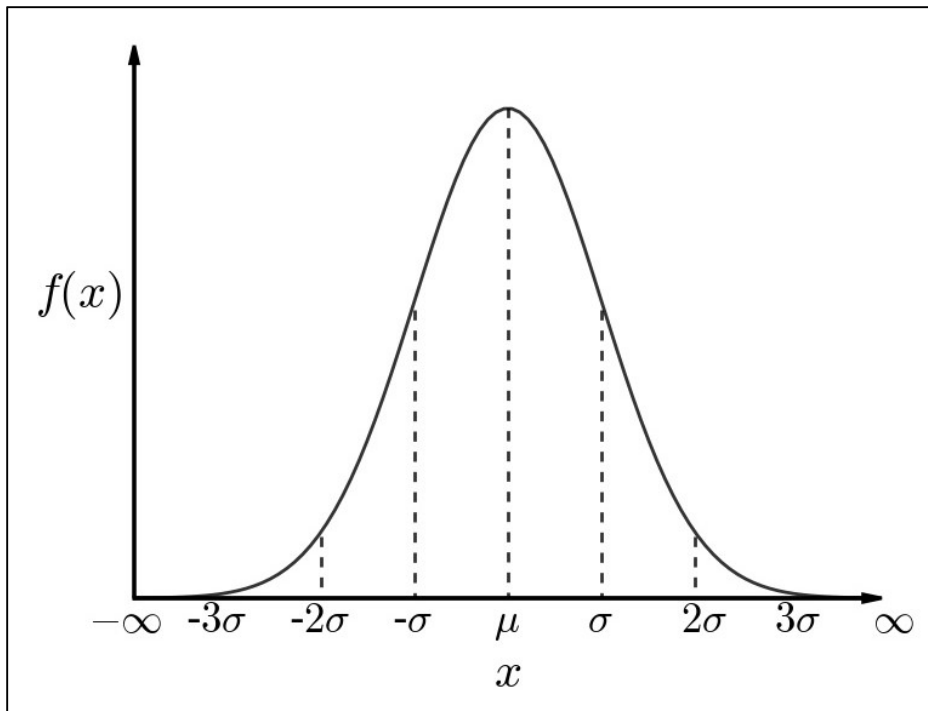


Figure 8.5 PDF of a Normal Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (8.7)$$

The CDF of a normal distribution is displayed in Figure 8.6 and described mathematically in Equation 8.8.

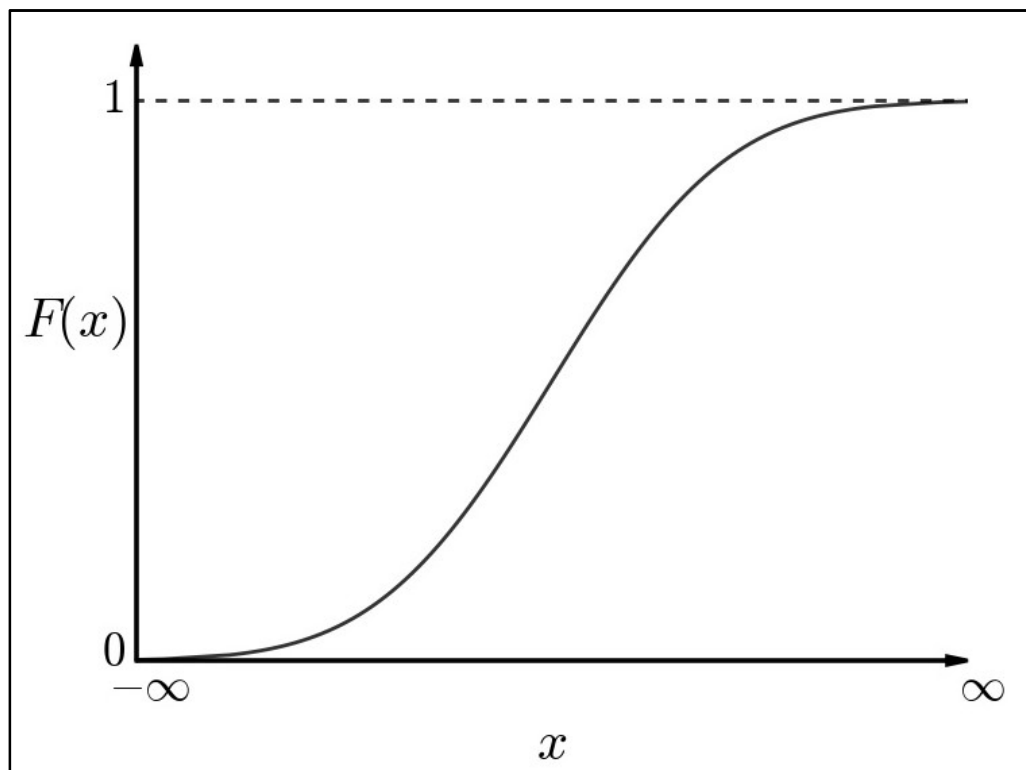


Figure 8.6 CDF of a Normal Distribution

$$F(x) = \frac{1}{2} \left[ 1 + \operatorname{erf} \left( \frac{x - \mu}{\sigma\sqrt{2}} \right) \right] \quad (8.8)$$

The error function, denoted as  $\operatorname{erf}(x)$  in Equation 8.8, is an integral that cannot be expressed in elementary functions and can only be approximated. To determine the inverse of this function requires an approximation as well. To evaluate the inverse CDF, a Taylor series polynomial is used to approximate the normal distribution.

The  $t$  value is only evaluated from zero to 0.5, so if  $p$  is greater than 0.5, the value  $1-p$  is evaluated in  $t$ . This assumption is appropriate given that the normal distribution is symmetrical. The inverse CDF for a normal distribution is shown in Equation 8.9.

$$F^{-1}(p) = \begin{cases} (a * \sigma) + \text{Mean} & \text{for } p < 0.5 \\ \text{Mean} & \text{for } p = 0.5 \\ (-a * \sigma) + \text{Mean} & \text{for } p > 0.5 \end{cases} \quad (8.9)$$



Where  $a$  is defined in Equation 8.10 as:

$$a = t + \frac{(c0 + c1 * t + c2 * t^2)}{(1 + d1 * t + d2 * t^2 + d3 * t^3)} \quad (8.10)$$

where:

$$\begin{aligned} c0 &= 2.515517 \\ c1 &= 0.802853 \\ c2 &= 0.010328 \\ d1 &= 1.432788 \\ d2 &= 0.189269 \\ d3 &= 0.001308 \\ t &= \sqrt{\ln(1/p^2)} \end{aligned}$$

The standard normal distribution, where mean ( $\mu$ ) = 0 and standard deviation ( $\sigma$ ) = 1, is generally expressed as  $Z$  as shown in Equation 8.11.

$$Z = \sqrt{n} \left( \frac{1}{n} \sum_{i=1}^n X_i \right) = \sqrt{n}E(X) = \sqrt{n}\bar{X} = \sqrt{n} \frac{\bar{X} - \mu}{\sigma} = \frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \quad (8.11)$$

## Log Normal Distribution

A variable  $x$  is log-normally distributed if  $\ln(x)$  is normally distributed. Log normal distribution is often used to assist in parameterizing random variables that are always greater than zero. HEC-FIA requires that the mean ( $\mu$ ) and the  $\log_{10}$  of the standard deviation ( $\sigma$ ) be specified for this distribution. The PDF of the log normal distribution is described mathematically in terms of  $\mu$  and  $\sigma$  as follows in Equation 8.12:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu)^2}{2\sigma^2}} \quad (8.12)$$

The CDF of the log normal distribution is described mathematically in Equation 8.13:

$$F(x) = \frac{1}{2} \left[ 1 + \operatorname{erf} \left( \frac{\ln(x) - \mu}{\sigma\sqrt{2}} \right) \right] \quad (8.13)$$

The inverse CDF is a simple transformation of the normal distribution CDF and is shown in Equation 8.14:

$$F^{-1}(p) = e^{\mu + \sigma * Z(p)} \quad (8.14)$$

## 8.2.2 Monte Carlo Controls

Three input variables are required for the Monte Carlo simulation in HEC-FIA. The first input variable, *Initial Seed*, is used in the random number generator to create a uniformly distributed pseudo random number sequence. The pseudo random number sequence will be duplicated if the same *Initial Seed* value is used, which ensures that results in HEC-FIA are repeatable. The default *Initial Seed* value is 0.

The second input variable, *Convergence Tolerance*, is used to specify when the Monte Carlo has reached the established criteria for convergence. A smaller *Convergence Tolerance* will yield more iterations and potentially provide a more reliable output distribution. The default *Convergence Tolerance* value is 0.05.

The third and final input variable required by HEC-FIA is the *Convergence Confidence Interval*. This variable is used in conjunction with the *Convergence Confidence Tolerance* to define the alpha ( $\alpha$ ) value in the tail of the output distribution for which to track convergence.

### Evaluating Convergence

It is important for the HEC-FIA user to evaluate the number of runs needed to get a reasonable representation of the result space. Convergence testing is used to determine when sufficient runs have been computed. The approach used is to evaluate the change in the mean value of the sample space from one run to the next.

A simple way to test for convergence is to compare the mean from the previous sample set to the new sample mean with the addition of each additional simulated result. The test would evaluate when the change in value is less than some critical threshold (Equation 8.15).

$$\left| \frac{\bar{x}_n - \bar{x}_{n-1}}{\bar{x}_{n-1}} \right| \leq \varepsilon \quad (8.15)$$

Equation 8.15 is a test that simply evaluates the slope of the running average and compares the slope to some arbitrarily small positive quantity,  $\varepsilon$ . The theory is that if the slope of the running average is approaching zero, the average is not changing any longer, and the sample size is large enough that the additional sample is no longer capable of influencing the mean.

While this test describes convergence testing at its simplest, convergence is not a very good test since it is possible for the next sampled value to be close enough to the mean that its value is not enough to change the running average, thus exiting the Monte Carlo early. To overcome this possibility, tests that are more stringent are used in HEC-FIA.

### Sample Size Selection

Sample size for each parameter is selected based on an evaluation of how far a value can be from the mean to be within a specified tolerance level, with a specified amount of confidence. A confidence interval can be expressed with Equation 8.16 and is graphically described in Figure 8.7.

$$P[-z_{\alpha/2} \leq Z \leq z_{\alpha/2}] = 1 - \alpha \quad (8.16)$$

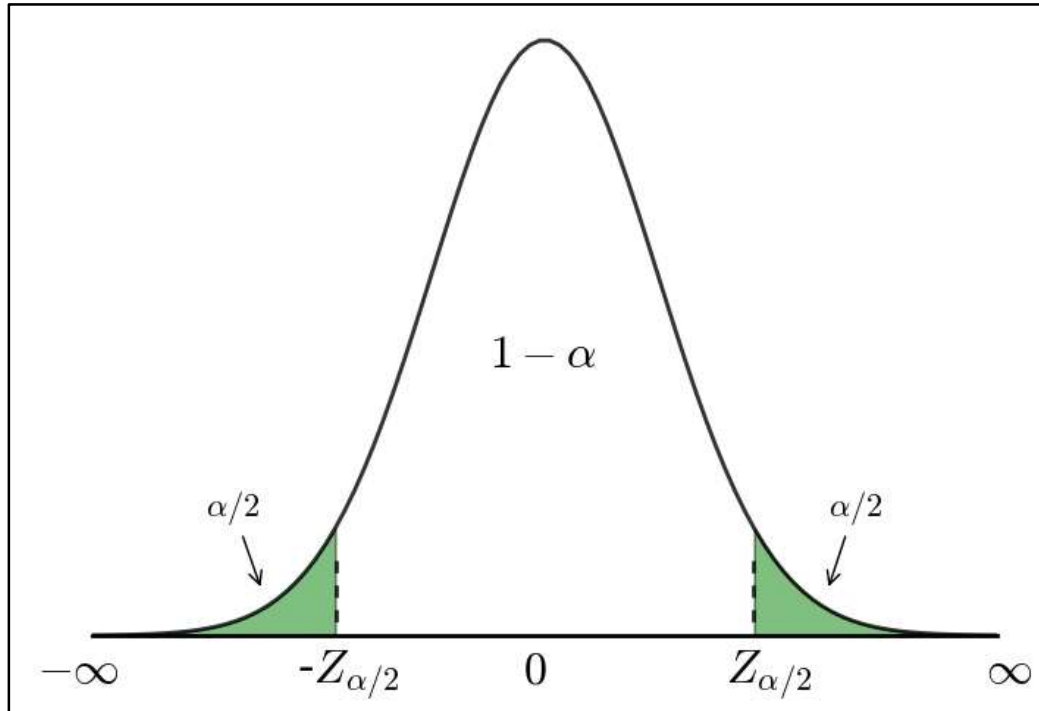


Figure 8.7 Confidence Intervals for a Standard Normal Distribution

The inequality (Equation 8.16) is then simplified by replacing  $Z$  using the Central Limit theorem (Equation 8.17).

$$Z = \frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \quad (8.17)$$

Which yields the following (Equation 8.18):

$$P\left[-z_{1-\alpha/2} \leq \frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \leq z_{1-\alpha/2}\right] = 1 - \alpha \quad (8.18)$$

Equation 8.19 is then produced after rearranging within the inequality (Equation 8.18) by multiplying all terms by  $\sigma/\sqrt{N}$ :

$$P\left[-z_{1-\alpha/2} \frac{\sigma}{\sqrt{N}} \leq \bar{X} - \mu \leq z_{1-\alpha/2} \frac{\sigma}{\sqrt{N}}\right] = 1 - \alpha \quad (8.19)$$

The population standard deviation in Equation 8.19,  $\sigma$ , is substituted with  $S$ , which is the estimate of the standard deviation from the sample of size  $N$ , to produce Equation 8.20.

$$P \left[ -z_{1-\alpha/2} \frac{S}{\sqrt{N}} \leq \bar{X} - \mu \leq z_{1-\alpha/2} \frac{S}{\sqrt{N}} \right] = 1 - \alpha \quad (8.20)$$

Thus, the resulting expression (Equation 8.20) yields a  $1-\alpha$  probability that the sample mean is less than the distance of the estimate is from the true mean (Equation 8.21).

$$\left| \frac{z_{\alpha/2} S}{\sqrt{n}} \right| \leq \bar{X} - \mu \quad (8.21)$$

The minimum distance threshold from the true mean can be specified by setting an acceptable value for the error. For this example, the error is  $\bar{X} - \mu$  (Equation 8.21). However, the error could alternatively be represented as a percentage of the mean estimate, which would be as follows in Equation 8.22:

$$\left| \frac{z_{\alpha/2} S}{\bar{X} \sqrt{n}} \right| \leq \varepsilon = \frac{\bar{X} - \mu}{\bar{X}} \quad (8.22)$$

Expressing the error as a percentage, allows the calculation to be evaluated regardless of the magnitude of the random variable (Equation 8.23).

$$\left| \frac{z_{\alpha/2} S}{\bar{X} \sqrt{n}} \right| \leq \varepsilon \quad (8.23)$$

Since neither the sample mean,  $\bar{X}$ , nor the sample standard deviation,  $S$ , known *a priori*, this equation must be evaluated at the completion of every iteration. Once the equation becomes true, sufficient samples have been made to conclude that the sample mean is within  $\varepsilon$  distance from the true mean with  $1-\alpha$  confidence.

## Random Numbers and Seeds

To evaluate any of the inverse CDF functions described above in a Monte Carlo simulation, it is imperative that the input probabilities for each of the sampled random variables be random and uniformly distributed. The assumption that the probability of any given random variable is equal to  $1/n$  (where  $n$  is the number of random variates drawn) is predicated on the fact that any probability of any of the random variates occurring is equally likely to occur. Any resulting parameter is distributed as described by the functional relationship and the distributions of any input parameters.

To accomplish this goal, a random number generator is utilized. Pseudo random numbers are created in many ways. The approach implemented by the Java platform and utilized by most HEC software is described here. This random number generator creates a uniformly distributed pseudo random number sequence that can be duplicated if the same seed is used.

The method deployed by Java is a linearly congruential method, as described by D. H. Lehmer and described by Donald E. Knuth in *The Art of Computer Programming*, Volume 3: *Seminumerical Algorithms*, Section 3.2.1 (Appendix A). The random number generator is described by the following relation in Equation 8.24:

$$X_{n+1} \equiv (aX_n + b) \pmod{m} \quad (8.24)$$

where  $X_n$  is the sequence of pseudo random variables,  $a$  and  $b$  are the multiplier and increment, and  $m$  is the modulus, which is the value describing the divisor in modular arithmetic. In the Java library the values of  $a$ ,  $b$  and  $m$  are fixed (as defined below); however, the value  $X_0$  can be set by the user and is generally referred to as the "seed".

$$a = 25214903917$$

$$b = 11$$

$$m = 2^{48}$$

In the random number generator relation described in Equation 8.24 the general meaning of congruent modular numbers is that the values on each side of the " $\equiv$ " have the same remainder when divided by the modulus ( $m$ ). In computer calculations, the method to determine the remainder is more difficult than the division to do a byte shift on a binary representation of a number; therefore, the modulus ( $m$ ) is chosen to be an exponent of two so that the remainder can be calculated by removing the exponent number of bytes from the right of the array. The results of this byte shift method is equivalent to dividing by the modulus value. However, Equation 8.24 will always equate to an integer value. To convert the integer value to a number between (0,1), two numbers are drawn and then a modulus of  $2^{27}$  is drawn; the numbers are then combined as one number (concatenation of the bytes for lack of a better description) and divided by  $2^{53}$ . Therefore, the value of  $X_{n+1}$  is entirely predicated on  $X_0$  (or "seed") and the current value of  $n$ .

The actual process that the number generator uses to create the next integer relies on the truncation of bits from the right (in Java's case the last 48 bits in the sequence) which is equivalent to modular division.

### 8.3 Computational Procedure

The Monte Carlo simulation procedures are described in the steps below.

1. Create a uniformly distributed pseudo random number sequence based on the initial seed value entered by the user as a Monte Carlo control.
2. Calculate economic damage and life loss results for each random number in the sequence, based on the continuous distribution type selected and the related input parameters for that distribution.
3. Test for convergence within the user-specified confidence interval.

4. If convergence has not occurred within the user-specified confidence interval, repeat Steps 1 through 3 until convergence is obtained.

In the above procedures, Step 2 requires sampling of the continuous distribution and in HEC-FIA, there are four sampling techniques available. The four sampling techniques are: single parameter, two parameter, tabular relationship, and standard deviation as a percentage of the mean. Moreover, the sampling technique utilized by HEC-FIA depends on the input parameter and how that parameter relates to the Monte Carlo computational procedure overall. For instance, depth damage relationships are sampled using tabular relationship sampling while foundation heights are sampled using single parameter sampling. Furthermore, each technique samples a value from the CDF by utilizing the random numbers provided in Step 1, and then selects a value based on the provided random number. The following sections discuss the procedures for the four possible sampling techniques used by HEC-FIA in Step 2.

### 8.3.1 Single Parameter Sampling Technique

If one input variable is described by a continuous distribution, the CDF samples that single parameter using the single parameter sampling technique. As an example, if parameter  $x$  is triangularly distributed with a minimum value of  $0.0$ , a mode value of  $0.5$ , and a maximum value of  $1.0$ , the following inverse CDF will be produced as shown in Equation 8.25:

$$F^{-1}(p_x) = \begin{cases} \sqrt{(p_x) * (0.5)} & \text{for } 0 \leq p_x \leq 0.5 \\ 1 - \sqrt{(1 - p_x) * (0.5)} & \text{for } 0.5 < p_x < 1 \end{cases} \quad (8.25)$$

Assuming an input set of  $p_x$  values of  $\{0.1, 0.4, 0.7, 0.8\}$ , the CDF sampling would result in a solution set of  $\{0.223607, 0.447214, 0.612702, 0.683772\}$ , respectively.

The solution set is evaluated for a constant value with respect to the parameter  $d$  (Equation 8.26):

$$g(d, F^{-1}(p)) = d - F^{-1}(p_x) \quad (8.26)$$

For example, assuming  $d = 5$  and using Equation 8.26, the following values would be obtained:

$$g(p_d, F^{-1}(p_x)) = \{4.776393, 4.552786, 4.387298, 4.316228\}$$

### 8.3.2 Two Parameter Sampling Technique

If two input variables are described by a continuous distribution, the two parameter sampling technique is used. As an example, if parameter  $d$  (Section 8.3.1) is assumed to be triangularly distributed, rather than a constant value, and has a minimum value of  $4.0$ , a mode value of  $5.0$ , and a maximum value of  $7.0$ , the following inverse CDF will be produced for parameter  $d$  as shown in Equation 8.27.

$$F_d^{-1}(p_d) = \begin{cases} 3 + \sqrt{(p_d) * (3)} & \text{for } 0 \leq p_d \leq \frac{1}{3} \\ 1 - \sqrt{(1 - p_d) * (3)(2)} & \text{for } \frac{1}{3} < p_d < 1 \end{cases} \quad (8.27)$$

Next, the solution set obtained is evaluated for parameters  $d$  and  $x$  using Equation 8.28:

$$g(F_d^{-1}(p_d), F_x^{-1}(p_x)) = F_d^{-1}(p_d) - F_x^{-1}(p_x) \quad (8.28)$$

If  $p_d = \{0.45, 0.24, 0.31, 0.85\}$  and  $p_x = \{0.1, 0.4, 0.7, 0.8\}$ , the result would be the following solution sets:

$$\begin{aligned} F_x^{-1}(p_x) &= \{0.223607, 0.447214, 0.612702, 0.683772\} \\ F_d^{-1}(p_d) &= \{5.1834097875, 4.8485281374, 4.964365076, 6.0513167019\}. \end{aligned}$$

Using the preceding solution sets and equations, the following values would be obtained:

$$g(F_d^{-1}(p_d), F_x^{-1}(p_x)) = \{4.959802, 4.4013145, 4.35166341, 5.36754446\}.$$

As more parameters are defined with uncertainty, the computational complexity of these functions becomes exceedingly more difficult.

### 8.3.3 Tabular Relationship Sampling Technique

To compute uncertainty associated with a tabular relationship, HEC-FIA employs sampling techniques to obtain tabular relationships that maintain a certain required criteria. An example of a required criteria is that the tabular relationship is monotonically increasing, or that the maximum value cannot be greater than 100.

Therefore, to compute uncertainty, the curve characterizing the tabular relationship is represented as a collection of distributions, with one distribution for each ordinate. A single probability is sampled for all of the distributions and a curve is created for each ordinate. For example, a minimum, maximum, and most likely ( $Y$ ) value are used to describe the triangular distribution for each  $X$  ordinate. The example ( $Y$ ) values and  $X$  ordinates are listed in

Table 8.1, while Figure 8.8 plots the curves for each of these example values.

For this type of tabular relationship sampling, the probability value is provided one time per Monte Carlo iteration, yielding an entirely new curve. Within each Monte Carlo iteration, the probability value is held constant. As a result, all  $X$  ordinates used within the iteration are drawn from the same probability for each distribution within the tabular function; an example result is shown as a purple line in Figure 8.9.

In addition to the resulting curve (Figure 8.9), Figure 8.10 also provides an example result (also drawn as the purple line). For these two examples, Figure 8.9 displays the curves for the probability value 0.25, while Figure 8.10 shows the curves for the probability value 0.05.

Table 8.1 Example Values Used to Describe Triangular Distribution

| X  | Y <sub>min</sub> | Y <sub>mostlikely</sub> | Y <sub>max</sub> |
|----|------------------|-------------------------|------------------|
| 0  | 0.00             | 0.00                    | 0.00             |
| 1  | 0.16             | 0.22                    | 0.28             |
| 2  | 0.22             | 0.31                    | 0.40             |
| 3  | 0.27             | 0.38                    | 0.49             |
| 4  | 0.32             | 0.44                    | 0.57             |
| 5  | 0.35             | 0.49                    | 0.64             |
| 6  | 0.39             | 0.54                    | 0.70             |
| 7  | 0.42             | 0.59                    | 0.75             |
| 8  | 0.45             | 0.63                    | 0.80             |
| 9  | 0.47             | 0.66                    | 0.85             |
| 10 | 0.50             | 0.70                    | 0.90             |

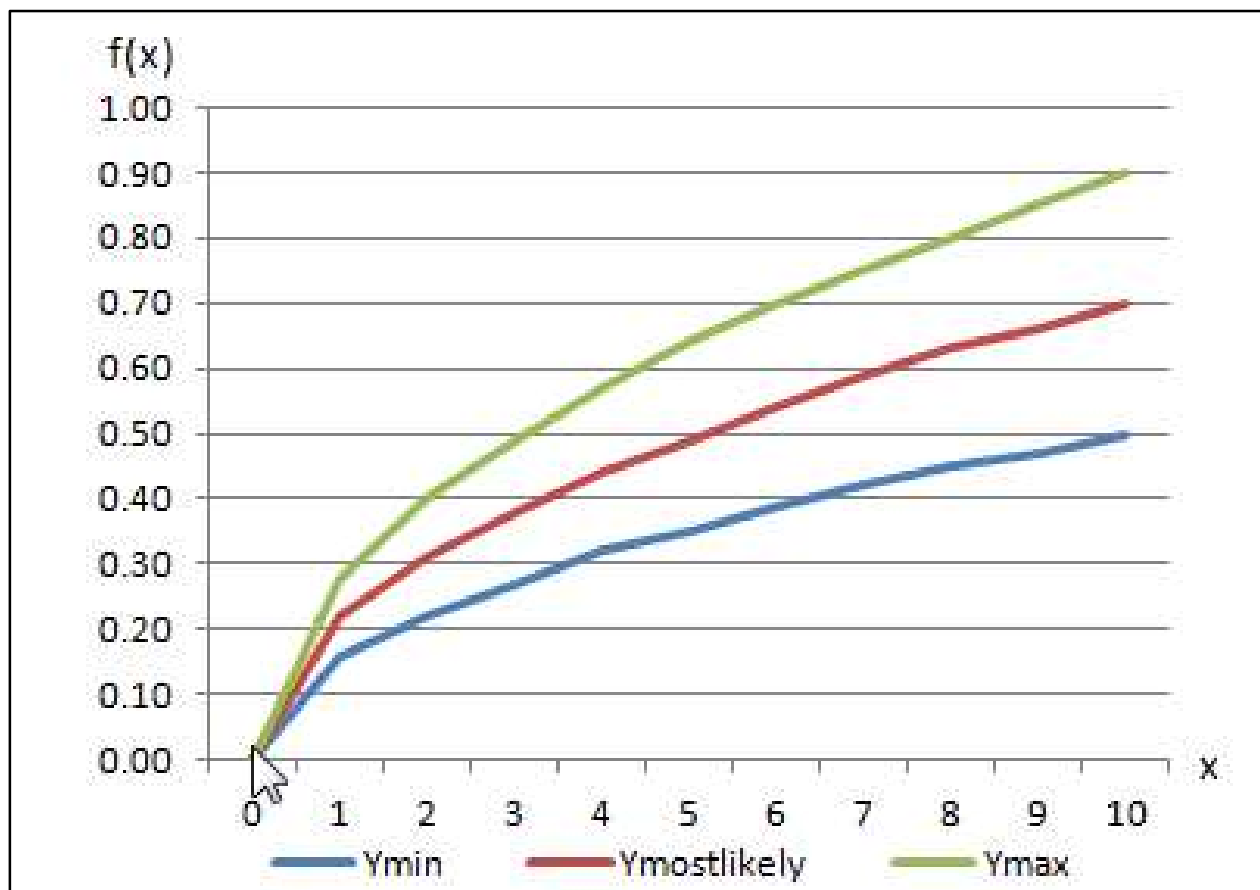


Figure 8.8 Curves Used to Describe Triangular Distribution Example



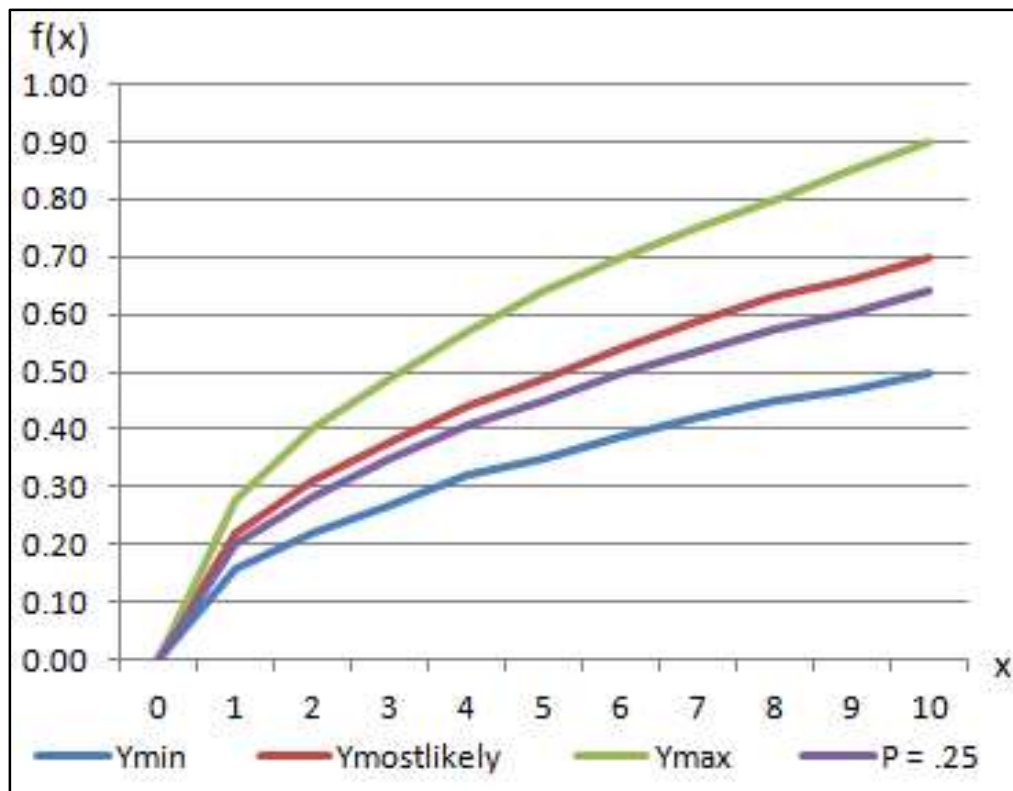


Figure 8.9 Curves Used to Describe Triangular Distribution Example for a Probability Value of 0.25

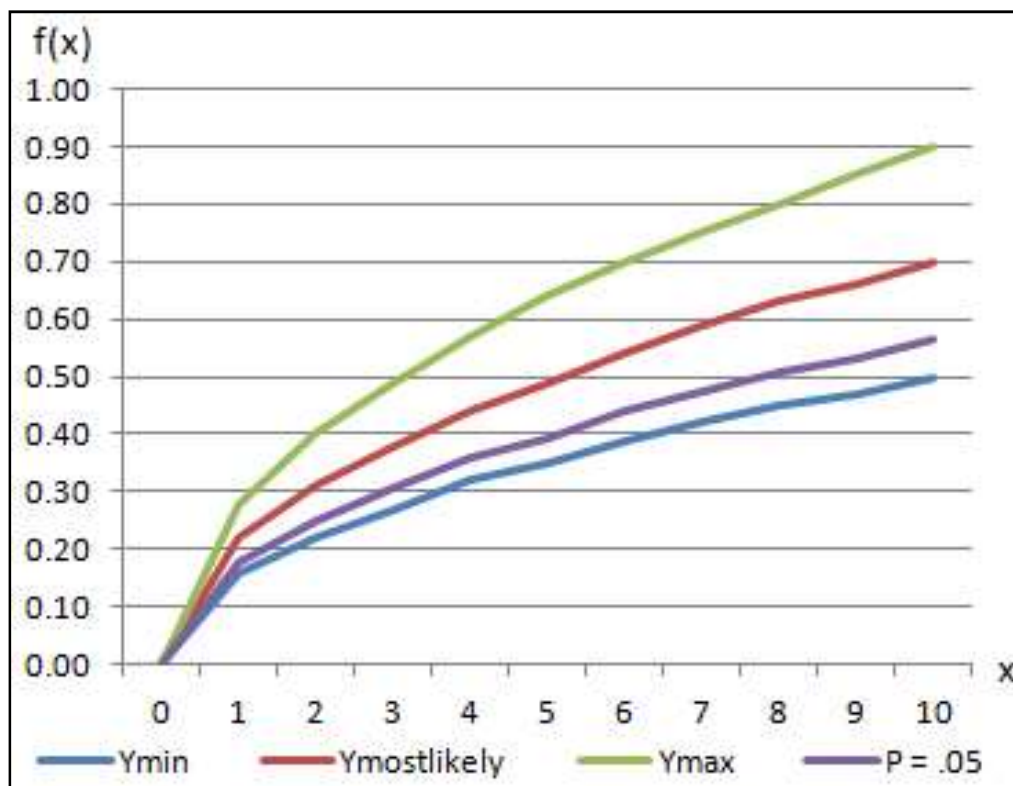


Figure 8.10 Curves Used to Describe Triangular Distribution Example for a Probability Value of 0.05

### 8.3.4 Standard Deviation as a Percentage of the Mean Sampling Technique

The final typical sampling technique employed in a Monte Carlo simulation is to evaluate a group of values' relative deviations from their respective means. This evaluation is beneficial when a consistent measure of error in the parameter exists. Examples may be structure values, rock sizes, foundation heights, and flow values measured by the same flow gage, among others. This type of sampling allows a consistent percentage error to be applied across all items of the same type.

The evaluation is similar to a standard single parameter sample; however, the magnitude of the mean is inserted into the equation and instead of a typical standard deviation, the standard deviation is expressed as a percentage of the mean. For example, if assuming a normal distribution, the mean value is described for each random variable, and the standard deviation (*stdev*) in Equation 8.9 is expressed as a percentage (*%stdev*) of the mean. Therefore,  $stdev = \%stdev * Mean$  and Equation 8.9 is transformed (Equation 8.29):

$$F^{-1}(p) = \begin{cases} (a * \%stdev * Mean) + Mean & \text{for } p < 0.5 \\ Mean & \text{for } p = 0.5 \\ (-a * \%stdev * Mean) + Mean & \text{for } p > 0.5 \end{cases} \quad (8.29)$$

## 8.4 Computational Results

Results from the computational procedures described in this chapter are the following:

- Uncertainty analysis by iteration for monetary damages and life loss
- Life loss by warning issuance
- Users can elect to save most random numbers and sampled values

# Appendix A

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# Appendix B

## Glossary

**Agricultural Flood Damage** – The agricultural economic loss resulting from a flood event, including the investment cost to bring a crop to market and net revenue (income minus harvest costs).

**Arrival Time Grid** – A grid that specifies when water reaches a predefined threshold at each cell. For a typical loss of life assessment, default arrival time threshold is two feet. For an agricultural damage assessment, the arrival time threshold will typically be when the cell gets wet, which would be described as an arrival of anything greater than zero feet of water.

**Capital** – This generally refers to the produced durable goods that can be used in the production of goods and services. In HEC-FIA, the value of structures and the value of their contents are used as a proxy for the capital in an area.

**Capital Loss** – The reduction in available capital of a region from some sort of shock to the economy of a region.

**Chance Zone** – Flood lethality zone with conditions in which people have no shelter from the flood, and have a chance of being rescued or finding floating debris while drifting (refer to the references in Section A.3).

**Cleanup Period Duration** – The amount of time necessary to clean the damages caused by a flood.

**Common Computation Point** – A location along a stream alignment where time-series information is exchanged between models. In HEC-FIA, common computation points (CCPs) are the locations of the hydrographs, stage-damage (or discharge) relationships, flood or drought impacts, and emergency response information that was developed for an impact area.

**Compromised Zone** – Flood lethality zone with conditions in which shelters have been severely damaged by the flood, increasing the exposure of flood victims to violent floodwaters (refer to the references in Section A.3).

**Continuous Distribution** – For any given probability between zero and one, a continuous distribution is a function that produces a result that is continuous and is a real number.

**Convergence Confidence Interval** – As sample size increases, the value of the running mean of the results of the Monte Carlo sample should approach the expected value. The user-specified confidence interval gives the user indirect control of how many iterations to run,

based on how likely it is that the result and the full distribution of the sample is within the user's specified level of confidence.

**Convergence Tolerance** – Used to specify when the rate of change in the computed confidence interval has reached the specified level of stability to satisfy the convergence criteria for the simulation. When the tolerance is met on the confidence interval, the simulation stops iterating.

**Crop Loss Relationship** – Defines the percentage of crop loss based on the number of hours (i.e., duration) crops are inundated each month.

**Cross Section** – A one-dimensional line defined perpendicular to the streamflow defining the X-Y coordinate points along that line.

**Depth** – For HEC-FIA flood damage analyses, depth is the difference between the water surface elevation at a damageable asset and a critical elevation (some threshold or the ground).

**Depth-Percent Damage Relationship** – Defines the percent damage caused to a structure, a structure's contents, and any vehicles stored at a structure at incremental depths.

**Digital Elevation Model (DEM)** – A representation of continuous elevation values over a topographic surface by a regular array of z-values (elevations), referenced to a common datum (refer to the references in Section A.3).

**Duration** – The length of time an area is inundated. In HEC-FIA, duration is defined as the total amount of time between the first time the floodwater depth exceeds the threshold depth (zero feet for agricultural damage calculations and two feet for ECAM calculations) and the last time the floodwater depth exceeds the threshold depth.

**Duration Grid** – A grid that specifies the duration of inundation for each cell.

**Economic Consequences Assessment Model (ECAM)** – A computable general equilibrium model with separate datasets for each county in the United States used to compute indirect economic impacts.

**Elevation** – A vertical distance compared to a selected vertical datum. In this document, the terms "stage" and "elevation" are used interchangeably. Stage and elevation should not be confused with depth, which is the stage/elevation less a local datum such as the ground surface elevation or a structure's first floor elevation.

**Evacuation** – The movement of people from a hazardous area to a safe location.

**Evacuation Outcome Category** – One of three categories to which people are assigned by HEC-FIA depending upon where they are when the flood wave arrives. These categories include *cleared* (people who evacuate safely), *caught* (people who are caught evacuating), or *not mobilized* (people who remain in structures).



**Evacuation Point** – The point on the hazard boundary that is determined by drawing a straight line from a structure perpendicular to the hazard boundary.

**First Planting Date** – The first date that a crop can be planted to reach a full yield.

**Fixed Crop Planting Cost** – The unchanging monetary cost of planting an agricultural crop. Usually, this would represent rent or land payments.

**FLO-2D** – A model used to route floods in two dimensions through the simulation of channel flow, unconfined overland flow, and street flow over complex topography.

**Flood Duration** – The length of time from the beginning to the end of a flood event.

**Flood Lethality Zone** – See Lethality Zone.

**Georeferenced** – A feature that is spatially referenced to a particular location with a known geographic coordinate system.

**Harvest Cost** – The monetary cost of conducting gathering, picking, and hauling operations to get a crop to market.

**Harvest Date** – The date on which the harvest of a crop occurs.

**Hazard Area Boundary** – The border for the area where flood depths are equal to or greater than the user-defined depth of flow resulting in dangerous conditions.

**HAZUS Database** – A national geodatabase containing consistent data (for example, demographics, structural inventories, essential facilities, and public utilities) for every state, county, census tract, and census block. HEC-FIA can import portions of this database for rapid assessments or reconnaissance level studies.

**HEC** –HEC (Hydrologic Engineering Center) is an organization within the Institute for Water Resources (IWR), which is the designated Center of Expertise for USACE in the technical areas of surface and groundwater hydrology, river hydraulics and sediment transport, hydrologic statistics and risk analysis, reservoir system analysis, planning analysis, real-time water control management, and a number of other closely associated technical subjects.

**HEC-DSS** – HEC Data Storage System, a database system that stores time-series and paired data for inventory, retrieval, and archiving for water resource applications.

**HEC-FIA** – HEC Flood Impact Analysis, a USACE software application, is a tool for quantifying the consequences of flood events that provides the capability of estimating the impacts, damage, loss of life associated with flood events, and the benefits attributed to flood risk management projects.

**HEC-GeoRAS** – An ArcGIS® extension specifically designed to process geospatial data for use with HEC-RAS, HEC's River Analysis System. HEC-GeoRAS provides a set of procedures, tools, and utilities for processing geospatial data in ArcGIS®, including visualizing inundation depths and boundaries.

**HEC-HMS** – HEC's Hydrologic Modeling System, a USACE software application that is designed to simulate the complete hydrologic processes of dendritic watershed systems.

**HEC-LifeSim** – HEC-LifeSim, a USACE agent-based software application that estimates life loss with the fundamental intent to simulate population redistribution during an evacuation. This application requires detailed consideration of these factors: the flood event, the number of people exposed to the flood event, and the loss of life among the threatened population.

**HEC-RAS** – HEC's River Analysis System, a USACE software application that conducts one-dimensional hydraulic calculations for a full network of natural and constructed channels.

**HEC-RAS Mapper** – HEC's River Analysis System interface included in HEC-RAS beginning with Version 4.1, which allows for the use and visualization of floodplain geospatial data, along with HEC-RAS simulation results, within a single modeling environment.

**HEC-ResSim** – HEC's Reservoir System Simulation, a USACE software application used to model reservoir operations.

**Hydraulic Characteristic** – A trait that is used to describe one attribute of a flood event, such as depth, arrival time, or flood duration.

**Indirect Loss** – Losses resulting from reductions of capital and labor for a region. Indirect losses are characterized as the change in production of the economy due to a change in the market equilibrium.

**Initial Seed** – A value entered into the random number generator to create a uniformly distributed pseudorandom number sequence as part of a Monte Carlo simulation.

**Inundation Data** – Information that is used to describe a flood event based on input from grids, cross sections, storage areas, and common computation points.

**Labor** – The portion of the population involved in providing goods and services to the economy.

**Labor Loss** – A reduction in available labor due to some shock to the economy. This could be due to inability to report to work, or due to evacuations from the floodplain for safety.

**Last Planting Date** – The latest date that a crop can be planted, but with a reduction in yield.

**Lethality Rate** – A relationship between number of deaths and water depth used in HEC-FIA to define potential loss of life for the lethality zones.

**Lethality Zone** – Categorization of physical flood environments based on the available shelter and local flood depths and velocities. HEC-FIA assigns people to one of three zones (safe, compromised, or chance), depending upon their evacuation outcome categories.

**Log Normal Distribution** – A distribution used to parameterize random variables that are always greater than zero.

**MIKE 21** – A two-dimensional hydraulic modeling software program developed and maintained by DHI.

**Mobilization Relationship** – Describes how quickly the population mobilizes given they have received and understood a warning.

**Model** – A mathematical representation of a system that relates something unknown (the output) to something known (the input). For HEC-FIA, the inputs include hydrologic/hydraulic data, watershed data, economics data, and various global data; outputs include various estimated flood impacts and loss of life and project benefits.

**Monte Carlo Simulation** – A mathematical model used to describe the relationship of the input variables to the output variable of interest. Each input parameter is expressed as a continuous distribution and a randomly drawn number can be obtained for each parameter. The mathematical model then calculates a sample from the randomly described set of input variables. This process is repeated to provide a set of deterministic results each from a different set of input parameters. The result is then a distribution of possible outcomes based on the model, from which the central tendency can be evaluated.

**Non-evacuation Depth** – Depth at which it becomes unsafe to evacuate. The default non-evacuation depth in HEC-FIA is two feet, based on the assumption that most vehicles float will float at a depth of two feet.

**Normal Distribution** – Data is described by this distribution using a mean and standard deviation, with the mean serving as the maximum result that can be achieved in the result space. The value range is always negative infinity to positive infinity.

**Population At Risk (PAR)** – The number and location of people within the potentially inundated area during day and night conditions exposed to the flood hazard. PAR includes people permanently residing in the inundated area (and accounting for commute patterns), as well as temporary residents.

**Population Impacted** – The number of people within structures that get wet from a flood event.

**Probability Density Function** – Represents the instantaneous relative change of the cumulative distribution, which is beneficial in displaying the relative likelihood of a parameter to take on a particular value within a range.

**Reconstruction Period Duration** – The amount of time necessary to repair structures and/or construct replacement structures after a flood event.

**Safe Zone** – Flood lethality zone with conditions in which people are either dry or exposed to relatively quiescent floodwater or shallow flooding unlikely to sweep people of their feet (refer to the references in Section A.3).

**Shapefile** – A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class (refer to the references in Section A.3).

**Simplified LIFESim** – A simulation method that estimates the loss of life resulting from a dam failure based upon HEC-LifeSim concepts and methods, but with reduced data requirements. Simplified LIFESim is used within HEC-FIA.

**Stream Alignment** – A geographic representation of a stream system in a watershed. The alignment indicates where junctions occur and provides a sense of distance and scale. In HEC-FIA, stream alignments are composed of stream elements.

**Stream Station** – A station along a stream normally denoted as miles above the mouth of a stream.

**Structure** – A building or infrastructure facility that may be analyzed during flood events.

**Structure Inventory** – A geospatial record of the attributes of unique structures relevant to flood impact analysis. Structure inventory data is used to compute an estimate of consequences at the individual structure, occupancy type, damage category, and impact area.

**Terrain Model** – A terrain model is a Digital Elevation Model that represents the ground elevation for the region being studied in a grid cell by grid cell format.

**Triangular Distribution** – Data is described by this distribution using a minimum, maximum, and mode value, with the mode serving as the maximum result that can be achieved in the result space.

**Uniform Distribution** – Data described by this distribution are uniformly spread between the minimum and maximum values that can be achieved in the result space. Every value outside of the minimum and maximum values results in a zero.

**Unit Price** – The monetary cost of each unit of an agricultural crop.

**Variable Crop Planting Cost** – The monetary cost of planting an agricultural crop based on the timing of when the planting occurs.

**Water Surface Elevation** – Stage referenced to a particular elevation datum.

**Yield** – The amount of crop produced per unit area.