Hazus Flood Model Technical Manual

Hazus 6.1

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FEMA

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Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
AAL	Average Annualized Loss
BCAR	Benefit-Cost Analysis Re-engineering
BFE	Base Flood Elevation
CDMS	Comprehensive Data Management System
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIMA	Federal Insurance and Mitigation Administration
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
ft	Foot/feet
ft^2	Square Feet
GBS	General Building Stock
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HvyTrk	Heavy Trucks
HWM	High Water Mark
IWR	Institute for Water Resources
LtTrk	Light Trucks
NACCS	North Atlantic Coast Comprehensive Study
NBI	National Bridge Inventory
NFIP	National Flood Insurance Program
SLTT	State, Local, Tribal, and Territorial
SQL	Structured Query Language
UDF	User-Defined Facility
USACE	U.S. Army Corps of Engineers
WGS1984 UTM	World Geodetic System 1984 Universal Transverse Mercator

Section 1. Introduction to the FEMA Hazus Loss Estimation Methodology

1.1 Background

The Hazus Flood Loss Estimation Methodology provides state, local, tribal, and territorial (SLTT) officials with a decision support software for estimating potential losses from flood events. This loss estimation capability enables users to anticipate the consequences of floods and develop plans and strategies for reducing risk. The Geographic Information System (GIS)-based software can be applied to study geographic areas of varying scale with diverse population characteristics and can be implemented by users with a wide range of technical and subject matter expertise.

This Methodology has been developed, enhanced, and maintained by the Federal Emergency Management Agency (FEMA) to provide a tool for developing flood loss estimates for use in:

- Anticipating the possible nature and scope of the emergency response needed to cope with a flood-related disaster.
- Developing plans for recovery and reconstruction following a disaster.
- Mitigating the possible consequences of floods.

The use of this standardized Methodology provides nationally comparable estimates that allow the federal government to plan flood responses and guide the allocation of resources to stimulate risk mitigation efforts.

This manual documents the methods used in calculating losses. A companion document, the *Hazus Inventory Technical Manual* (FEMA, 2024), provides more detailed Methodology and data descriptions for the inventory shared by each hazard model. Together, these documents provide a comprehensive overview of this nationally applicable loss estimation Methodology.

The *Hazus Flood Model User Guidance* (FEMA, 2024) outlines the background and instructions for developing a Study Region and defining a scenario to complete a flood loss estimation analysis using Hazus. It also provides information on how to modify inventory, improve hazard data and analysis parameters for advanced applications, and guidance on calculating and interpreting loss results.

1.2 Hazus Uses and Applications

Hazus can be used by various types of users with a wide range of informational needs. A state, local, tribal, or territorial government official may be interested in the costs and benefits of specific mitigation strategies, and thus may want to know the expected losses if mitigation strategies have (or have not) been applied. Emergency response teams may use the results of a loss study in planning and performing emergency response exercises. In particular, they might be interested in the operating capacity of emergency facilities such as fire stations, emergency operations centers, and police stations. Emergency planners may want estimates of temporary shelter requirements for different flood scenario events. Federal and state government agencies may use loss analysis to obtain quick estimates of impacts in the hours immediately following a flood to best direct resources to the disaster area. Insurance companies may be interested in the estimated monetary losses so they can determine asset vulnerability.

Flood loss estimation analyses have a variety of uses for various departments, agencies, and community officials. As users become familiar with the loss estimation Methodology, they are able to determine how to use it to best suit their needs and how to appropriately interpret the study results.

The products of Hazus analyses have several pre- and post-flood applications in addition to estimating the scale and extent of damage and disruption. Examples of pre-flood applications of the outputs include:

- Development of flood hazard mitigation strategies that outline policies and programs for reducing flood losses and disruptions indicated in the initial loss estimation study. Strategies can involve elevating structures or examining areas for potential buyouts.
- Development of preparedness (contingency) planning measures that identify alternate transportation routes, planning flood preparedness, and education seminars.
- Anticipation of the nature and extent of response and recovery efforts, including the identification of short-term shelter requirements and debris management requirements.

Post-flood applications of the outputs may include:

- Projection of immediate economic impact assessments for state and federal resource allocation and support for state and/or federal disaster declarations by calculating direct economic impact on public and private resources and local governments.
- Activation of immediate emergency recovery efforts, including estimates of needs for the provision of emergency housing shelters and initiating debris clean-up efforts.
- Application of long-term reconstruction plans that include the identification of long-term reconstruction goals, implementation of appropriate wide-range economic development plans for the impacted area, allocation of permanent housing needs, and the assessment of land use planning principles and practices.

1.3 Assumed User Expertise

Users can be divided into two groups: those who perform the analysis and those who use the results from analyses. For some analyses, these two groups occasionally consist of the same people, but generally this will not be the case. However, the more interaction that occurs between these two groups, the better the analysis will be. End users of the loss estimation analysis need to be involved from the beginning to make results more usable.

Any risk modeling effort can be complex and would benefit from input from an interdisciplinary group of experts. A flood loss analysis could be performed by a representative team consisting of the following:

- Floodplain managers
- Structural engineers
- Architects
- GIS specialists
- Economists
- Social scientists
- Emergency planners
- Policy makers

The individuals needed to perform the study can provide valuable insight into the risk assessment process. In addition to subject matter expert involvement, at least one GIS specialist should participate on the team.

If an SLTT agency is performing the analysis, some of the expertise may be found in-house. Experts are generally found in several departments: building permits, public works, planning, public health, engineering, information technologies, finance, historical preservation, natural resources, and land records. Although internal expertise may be most readily available, the importance of the external participation of individuals from academic institutions, citizen organizations, and private industry cannot be underestimated.

1.4 When to Seek Help

The results of a loss estimation analysis should be interpreted with caution because baseline values have a great deal of uncertainty. Baseline inventory datasets are the datasets that are provided with Hazus. Further information on these can be found in the *Hazus Inventory Technical Manual* (FEMA, 2024). If the loss estimation team does not include individuals with expertise in the areas described above, it is advisable to retain objective reviewers with subject matter expertise to evaluate and comment on map and tabular data outputs. A floodplain manager, hydrologist, or hydraulic engineer may be needed to provide scenario data or review the software parameters.

If the user intends to modify the baseline inventory data or parameters, assistance from an individual with expertise in the subject will be required.

1.5 Technical Support

Technical Support contact information is provided in the Hazus application at **Help | Obtaining Technical Support**; technical assistance is available via the Hazus Help Desk by email at: FEMA-Hazus-Support@fema.dhs.gov (preferred) or by phone at 1-877-FEMA-MAP (1-877-336-2627). The FEMA Hazus website also provides answers to Frequently Asked Questions, and information on software updates, and training opportunities.

FEMA-provided resources also include the Hazus Virtual Training Library, a series of short videos arranged into four playlists that cover various Hazus topics, from an introduction to Hazus methodologies, to targeted tutorials on running Hazus analyses, to best practices when sharing results with decision makers. This easily accessible learning material provides quick topic-refreshers, free troubleshooting resources, and engaging guides to further Hazus exploration.

The application's **Help** menu references the help files for ArcGIS. Since Hazus was built as an extension to ArcGIS functionality, knowing how to use ArcGIS and ArcGIS Help Desk will help Hazus users.

Technical support on any of the four hazards is available at the contacts shown via **Help | Obtaining Technical Support.**

1.6 Uncertainties in Loss Estimates

Although the Hazus software offers users the opportunity to prepare comprehensive loss estimates, it should be recognized that uncertainties are inherent in any estimation methodology, even with state-of-the-art techniques. The Hazus Flood Model is only a tool for loss estimation from modeled flood events. Hazus does not compute uncertainties in the loss estimates, provide ranges for possible losses, or offer any confidence levels. The results of a flood loss study should not be looked upon as a prediction. Instead, they are only an estimate, as uncertainty inherent to the model will be influenced by quality of inventory data and the hazard parameters.

Section 2. Introduction to Flood Loss Estimation Methodology

This brief overview of the Flood Methodology is intended for state, local, tribal, and territorial officials contemplating a flood loss analysis.

The Hazus Methodologies will generate an estimate of the consequences of a scenario or probabilistic flood event to a city, county, or region. The resulting "loss estimate" will generally describe the scale and extent of damage and disruption that may result from the modeled flood event. The following information can be obtained:

- *Quantitative estimates of losses* in terms of direct costs for repair and replacement of damaged buildings and Transportation and Utility System Components, direct costs associated with loss of function (e.g., loss of business revenue, relocation costs), vehicle losses, and annualized losses for buildings.
- *Functionality losses* in terms of loss of function and restoration times for Essential Facilities, such as hospitals, and loss of function of select Utility System Components.
- *Extent of induced hazards* in terms of displaced population, population seeking short-term shelter, and quantity of debris.

To generate this information, the Methodology includes:

- Classification systems used in assembling inventory and compiling information on the General Building Stock (GBS), Essential Facilities, the Transportation and Utility Systems Components, vehicle types, and demographic and economic data.
- Standard calculations for estimating type and extent of damage and for summarizing losses.
- National and regional databases containing information for use as baseline (built-in) data useable in calculation of losses if there is an absence of user-supplied data.

These systems, methods, and data have been combined in user-friendly GIS software for this loss estimation application.

The Hazus software uses GIS technologies for performing analyses with inventory data and displaying losses and consequences on applicable tables and maps. The Methodology permits estimates to be made at several levels of complexity, based on the level of inventory data entered for the analysis (i.e., baseline data versus locally enhanced data). The more concise and complete the inventory information, the more accurate the results.

The following figure (Figure 2-1) provides a graphic representation of the modules that the Hazus Flood Model Methodology is composed of, and their interrelation in deriving estimates.

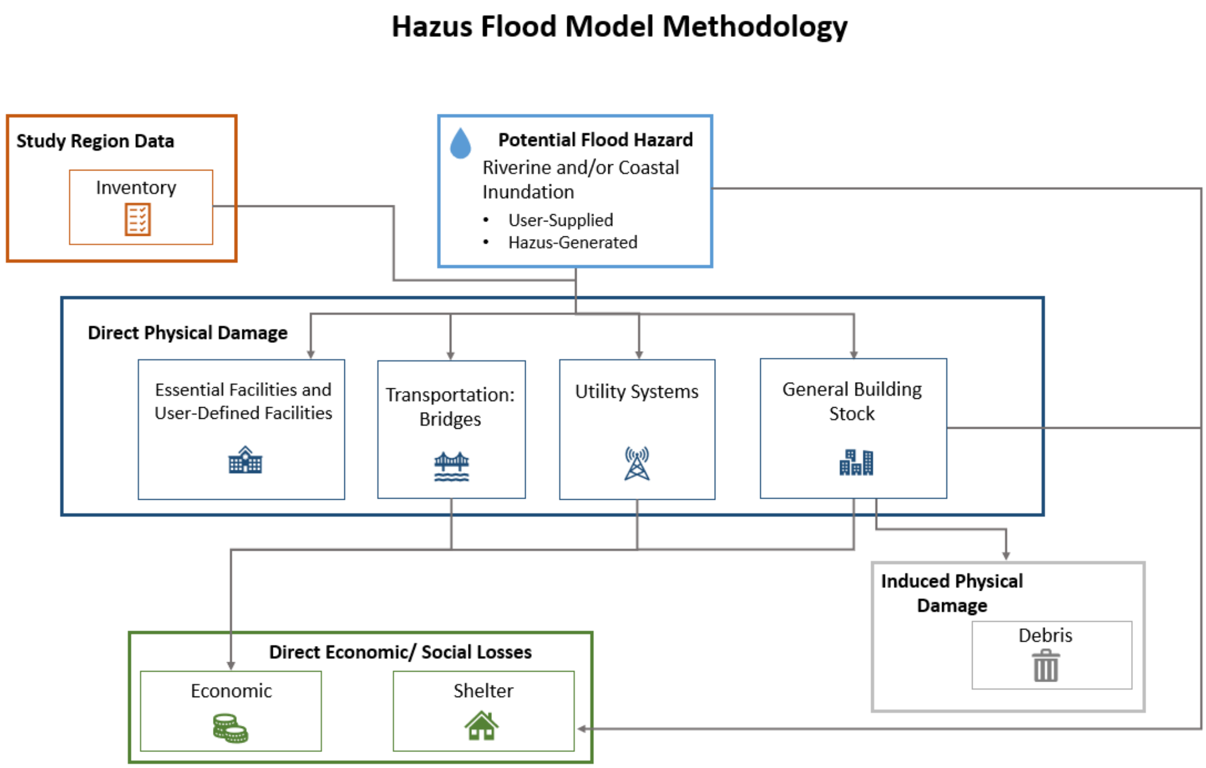

Figure 2-1. Hazus Flood Model Methodology Schematic

While Figure 2-1 shows the conceptual relationships, the steps used in the Hazus Flood Model are as follows:

- *Select the area to be studied.* The Hazus Study Region (the region of interest) is created based on watershed, National Flood Insurance Program (NFIP) Community, Census block, Census tract, county, or state/territory level aggregation of data. The area generally includes a city, county, or group of municipalities.
- *Specify the flood hazard scenario.* In developing the scenario flood, the hazard can be specified as riverine, coastal, or a combination of riverine and coastal.
- *Integrate local inventory data.* Include Essential Facilities, Transportation and Utility Systems, updates to GBS characteristics, or User-Defined Facilities.
- *Compute estimates of direct economic loss and short-term shelter needs.*
- *Estimate the amount and type of debris.*

The user plays a significant role in selecting the scope and nature of the output of a loss estimation analysis. A variety of maps can be generated for visualizing the extent of the losses. Generated reports provide numerical results that may be examined at the level of the Census block, Census tract or aggregated by county or region.

2.1 Flood Hazards Considered in Methodology

The flood-related hazards considered by the Hazus Methodology in evaluating damage and resultant losses are collectively referred to as potential flood hazards.

The primary factors considered by the Hazus Methodology in contributing to losses from flooding are:

- *Depth:* Flood depth is the difference between flood and ground surface elevations. Flood depths are used to determine losses for various flood frequencies and scenarios.

- *Type of Flooding:* Riverine and coastal flooding can have different impacts on buildings and other structures. The type of flooding can be set to riverine and/or coastal for each Study Region.

2.2 Definitions of Structures

There are differences between terminology used to designate distinctions between types or categories of structures. The term “structure” refers to all constructions, such as a building, bridge, water tank, shed, carport, or other man-made thing that is at least semi-permanent. A building is a structure with a roof and walls that is intended for use by people and/or inventory and contents, such as a house, school, office, or commercial storefront. A facility corresponds to a particular place, generally a building, with an intended purpose such as a school, hospital, electric power station, or water treatment facility. Some facilities are defined as ‘Essential Facilities’ meaning the facility is critical to maintaining services and functions vital to a community, especially during disaster events. The buildings, Essential Facilities, and Transportation and Utility Systems Components considered by the Methodology are as follows:

- GBS: The key GBS databases in Hazus include square footage by occupancy and building type, building count by occupancy and building type, building and content valuation by occupancy and building type, and general occupancy mapping. Most of the commercial, industrial, and residential buildings in a region are not considered individually when calculating losses. Buildings within each Census block are aggregated and categorized. Building information derived from Census and employment data are used to form groups of 36 specific building types and 33 occupancy classes (additional information on the Hazus baseline GBS inventory data is provided in the *Hazus Inventory Technical Manual* (FEMA, 2024). Percent damage is computed for each grouped combination of specific building type and occupancy class.

- Essential Facilities: Essential Facilities are the facilities that are vital to emergency response and recovery following a disaster. These facilities can include, but are not limited to, medical care facilities, emergency response facilities, and schools. For this class of structures, damage and loss-of-function are evaluated on a building-by-building basis. There may be significant uncertainties in each estimate.

- Transportation Systems: Transportation Systems, (including highways, railways, light rail, bus systems, ports, ferry systems, and airports) are classified into components such as bridges, stretches of roadway or track, terminals, and port warehouses. Probabilities of failure are computed for highway bridges, but other components and total system performance are not evaluated.

- Utility Systems: Utility Systems, including potable water, electric power, wastewater, communications, and liquid fuels (oil and gas), are classified into components such as facilities, control stations, and pipelines. Percent damage and losses are computed for select components of potable water, wastewater, oil, and natural gas systems. Detailed system performance is not evaluated, nor are cascading impacts from one system to another.

Specific data can be used to estimate potential damage and hazard effects using the User-Defined Facilities (UDF) module, which are addressed in the *Hazus Flood Model User Guidance* (FEMA, 2024).

2.3 Levels of Analysis

Hazus is designed to support two general types of analysis (Basic and Advanced), split into three levels of data updates (Levels 1, 2, and 3). Figure 2-2 provides a graphic representation of the various levels of analysis.

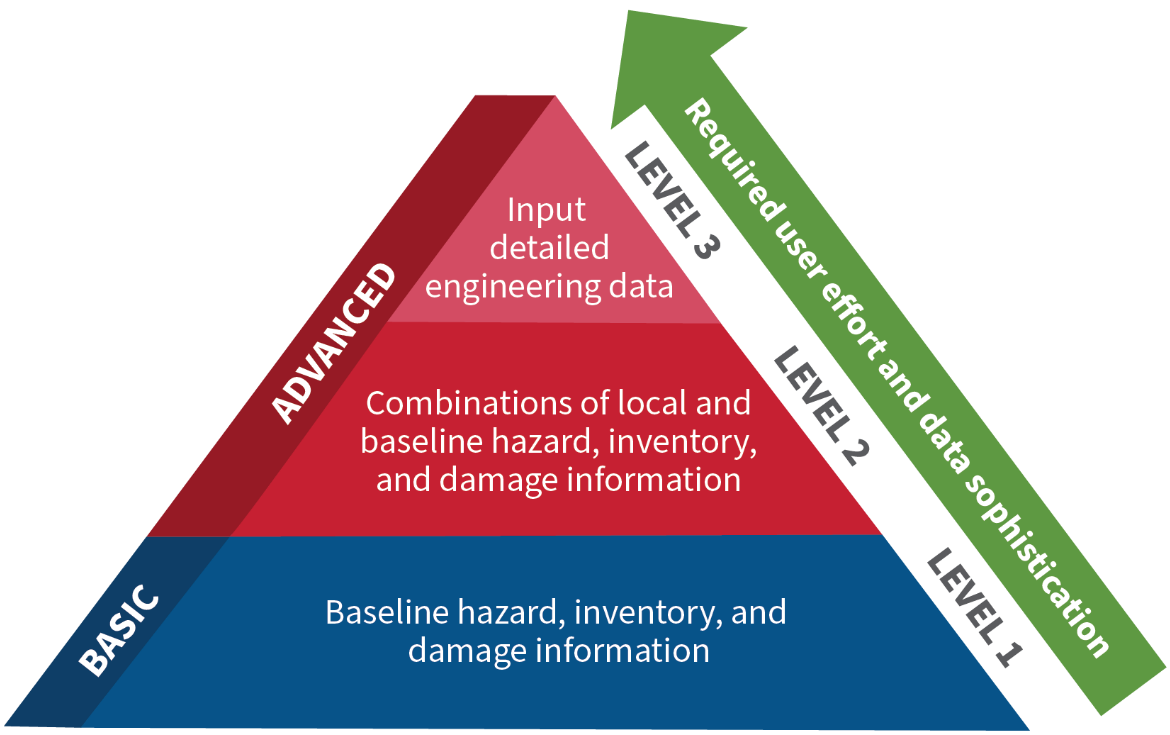

Figure 2-2. Levels of Hazus Analysis

2.3.1 Analysis Based on Baseline Information

The basic level of analysis uses only the baseline databases built into the Hazus software and Methodology on building square footage and value, population characteristics, costs of building repair, and certain basic economic data. This level of analysis is commonly referred to as a Level 1 analysis. In a basic analysis (Level 1), Hazus is used to generate the potential flood hazard. Direct economic and social losses associated with the GBS and Essential Facilities are computed. Baseline data for Transportation Systems, and Utility Systems, are included; thus, they are considered in the basic level of analysis. However, there is a significant level of uncertainty pertaining to the estimates.

Other than defining the Study Region, selecting the flood scenario and type, and making decisions concerning the extent and format of the output, an analysis based on baseline data requires minimal effort from the user. As indicated, the estimates involve large uncertainties when inventories are limited to the baseline data. This level of analysis is suitable primarily for preliminary evaluations and crude comparisons among different Study Regions with a Census block as the smallest regional unit. A basic Level 1 analysis could be used for comparisons and preliminary evaluations to assist in identifying potential mitigation actions within a community, which could be useful if evaluating funding priority for projects.

2.3.2 Analysis with User-Supplied Inventory

Results from an analysis using only baseline inventory data can be improved greatly with at least a minimum amount of locally developed input. Improved results are highly dependent on the quality and quantity of improved inventory data. The significance of the improved results also relies on the user's analysis priorities. This level of advanced analysis is commonly referred to as a Level 2/Level 3 analysis. The following inventory improvements impact the accuracy of Level 2/Level 3 Advanced Analysis results:

- Development of user-supplied depth grids. The use of such products improves the accuracy and performance of Hazus Flood Model loss analyses and leverages the development and improvements of external flood hazard data models.
- Use of locally available data or estimates of the square footage of buildings in different occupancy classes.
- Use of local expertise to modify the mapping scheme databases that determine the percentages of specific building types associated with different occupancy classes.
- Preparation of a detailed inventory of all Essential Facilities.
- Collection of detailed inventory and cost data to improve evaluation of losses in Transportation and Utility Systems.
- Use of locally available data concerning construction costs or other economic parameters.

SQL Database tables that previously contained Census vehicle data are now left blank, as this type of data was not made available in the latest Census data updates. Users can provide their own vehicle data in the SQL tables if they wish to run this part of the analysis

Section 3. Inventory Data

The technical guidance related to inventory data associated with the Hazus Flood Methodology and software is detailed in the *Hazus Inventory Technical Manual* (FEMA, 2024). The *Hazus Inventory Technical Manual* (FEMA, 2024) describes the classification of different buildings and Transportation and Utility Systems, data and attributes required for performing damage and loss estimation, and the data supplied with the Hazus software.

Section 4. Potential Flood Hazards

Flood hazards can be defined in terms of the chance that a certain magnitude (area and depth) of flooding is exceeded in any given year (probabilistic event) or as a specific, deterministic event, such as a historic peak flow or recent event captured with high water marks. Users can develop potential flood hazards using Hazus-generated data or import user-supplied data for use in loss analysis.

4.1 Hazus-Generated Flood Hazard

The Hazus Flood Model can be used to generate a flood depth grid that identifies depths of flooding, and a flood inundation polygon for riverine flooding (probabilistic and single discharge deterministic) and coastal flooding (probabilistic).[1] The Methodology the Hazus Flood Model uses to generate flood depth grids is complex and not well documented. Users interested in reviewing existing information on how Hazus-generated depth grids are developed should refer to the *Hazus 2.1 Flood Model Technical Manual* (FEMA, 2012) or reach out to the Hazus Help Desk with specific questions. Due to known issues regarding depth grid generation within Hazus, it is highly recommended that users import user-supplied depth grids whenever possible and use Hazus-generated flood hazards, with caution, only when no other data are available.

4.2 User-Supplied Flood Hazard

Importing a user-supplied depth grid into the Hazus Flood Model allows for the use of high-resolution, authoritative depth grid products. The use of such products improves the accuracy and performance of Hazus Flood Model loss analyses and leverages the development and improvements of external flood hazard data models. This topic is discussed in detail in the *Hazus Flood User Guidance* (FEMA, 2024). User-supplied depth grids are allowed for import in Riverine, Coastal, Riverine & Coastal, and Coastal Surge Scenarios. [1]

The user-defined depth grid accuracy is dependent on the resolution of the (Digital Elevation Model) DEM or terrain data used during the processing of a depth grid. The method used for collecting information on the elevation of the flood surface may vary. Common surface information that can be used to generate a flood surface include the following:

- High Water Mark (HWM) data
- Base Flood Elevation (BFE) cross sections

[1] In addition to providing wind losses, the Hazus Hurricane Model can also be used to drive storm surge and wave models, which, in turn, can be used as inputs to the Coastal Flood Model to estimate flood losses associated with a hurricane. Details concerning combining hurricane and flood losses are addressed in the *Hazus Hurricane Model Technical Manual* (FEMA, 2024).

- Local hydrology and hydraulics models

Determining the resolution requirements for a depth grid is dependent on the type of analyses that will be conducted with the processed depth grid.

When a user-supplied depth grid is imported, Hazus will process the data before it is used. After the user selects the depth grid and enters the required parameters, Hazus will begin processing. Hazus will verify that the depth grid intersects the Study Region, rename the input depth grid to a Hazus generated name, and copy the grid to the Study Region folder. Hazus will also check the spatial reference of the grid and convert it into a projected coordinate system (WGS1984 UTM) required to perform the area weighted analyses. If the user imports a Hydrologic Engineering Center - River Analysis System (HEC-RAS) -generated file into Hazus and enters the return period, Hazus will process the file and create its processing outputs in the Study Region folder.

Section 5. General Building Stock – Direct Physical Damage

The Hazus Flood Model provides estimates of GBS building damages resulting from riverine and coastal flooding by occupancy, by building type, and by count.

The flowchart of the Methodology, including GBS building damage components, is shown in Section 2 (Figure 2-1).

5.1 Input Requirements and Output Information

Input requirements to estimate GBS building damage in the Study Region include the following:

- Building parameters related to flood damage: specific occupancy class, number of stories, and foundation type
- Depth and type of flood hazard throughout the Census block
- Damage functions appropriate for occupancy, foundation type, number of stories, and flood hazard type

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus can be used to meet the input requirements.

The output from the application of damage functions is an estimate of the damage to the GBS expressed as a percentage of the repair and replacement cost by square footage or building count, and later translated into dollars (see Section 6).

5.2 GBS Building Parameters Related to Flood Damage

Hazus baseline GBS inventory includes square footage and building count estimates for each specific occupancy class for each Census block (see the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information). To optimize processing, Hazus uses the primary flood hazard type assignments (Riverine, Coastal, and Lake) and the Flood Specific Occupancy Mapping to calculate ratios of specific occupancy classes, number of stories, and foundation types in each Census block during Study Region aggregation. These ratios are used to assign appropriate damage functions and to calculate damages as described in the remainder of this section.

5.3 Type and Depth of Flooding throughout the Census Block

The Hazus Flood Model determines the type of flooding for a given analysis based upon user inputs. If a user sets the Flood Hazard Type under the Hazard menu as riverine only, then all flooding within the Study Region is assumed to be riverine. If a user sets the Flood Hazard Type as coastal only, then all flooding within the Study Region is assumed to be coastal. If the user sets the flood hazard type as riverine and coastal then the controlling hazard is determined by the Hazus software.[2]

In the case of coastal flooding, the Hazus Flood Model further distinguishes between coastal flooding hazard types. If a user is conducting a coastal or combined riverine and coastal flood analysis and the flood hazard is generated by the Hazus Flood Model (i.e., Level 1 analysis), Hazus delineates a raster file that shows the zones for each type of coastal flooding.[3] If a user is conducting a coastal or combined riverine and coastal flood analysis using a user-supplied depth grid (i.e., Level 2 or 3 analysis), Hazus assumes that all coastal flooding is A-Zone coastal flooding.[4]

For GBS analyses, the Hazus Flood Model uses the Hazus-generated or user-supplied depth grids to calculate the percent of every Census block that is affected by flooding in 0.5-foot increments. Flood depths are area weighted across the developed (Dasymetric) areas of the Census blocks comprising the Study Region and can be viewed by the user in the flAnGBSCombineAWTemp SQL table within Hazus. For more information on the development of Dasymetric Census blocks see the *Hazus Inventory Technical Manual* (FEMA, 2024).

5.4 Direct Physical Damage to GBS Due to Flooding

This section discusses the building structure damage functions provided within Hazus for riverine, coastal A-zone, and coastal V-zone flooding as well as the outputs from the application of these damage functions to the baseline GBS.

The damage functions provided with Hazus were compiled from a variety of sources described in Section 5.4.1.1 and Section 5.4.1.2. Section 5.4.1.1.1 provides the default assignments within the Flood Model. The default damage functions for each occupancy within each flood type can also be viewed in Hazus in the Damage Functions for Buildings dialog under the Analysis menu.

5.4.1 GBS Structure Damage Functions

Within Hazus, buildings are defined to include both the structural (load-bearing) system, as well as architectural, mechanical and electrical components, and building finishes. It is unlikely that a building will suffer structural failure in a flood unless the floodwaters flow at a high velocity and the structure and the foundation become separated, or the structure is impacted by flood-borne debris. In general, it is expected that the major structural components of a building will survive a flood, but that the structural finishes and contents/inventory may be severely damaged due to inundation (see

[2] The controlling hazard for each Census block in a Study Region can be viewed in the flGBSfinal SQL table in the HazardTypeId column (1 = riverine and 2 = coastal).

[3] The coastal zone raster file (zonerp) can be viewed by the user in in the Depth folder of the Coastal folder of the Study Region in the Hazus Data folder (1=Riverine, 2=A-zone coastal, 3=Coastal A-zone, 4=V-zone).

[4] The coastal zone raster file (zonerp) produced for user-supplied coastal depth grids assigns all flood areas as “2,” A-zone coastal.

Section 6 for more information on contents/inventory losses). It is important to understand that structural failure should be distinguished from suffering substantial damage, wherein the damage exceeds 50% of the structure's total, pre-damage, repair and replacement cost.[5]

Appropriate damage functions are applied to the baseline GBS based on the type of flooding (see Section **Error! Reference source not found.** and Table 5-1) and the attributes of the GBS within a given Census block (specific occupancy class, number of stories, and the foundation type).[6]

Table 5-1. Damage Function Types Applied for Each Flood Hazard Type and Analysis Level

Flood Hazard Type[1]	Hazus Analysis Level[2]	Damage Function Type[3]
Riverine only	Level 1	Riverine
Riverine only	Level 2	Riverine
Coastal only	Level 1	Coastal A and Coastal V
Coastal only	Level 2	Coastal A
Riverine and coastal	Level 1	Riverine, Coastal A, and Coastal V
Riverine and coastal	Level 2	Riverine and Coastal A

1. *Flood hazard type as selected by the user under the Hazard menu*
2. *Please see Section 2 for discussion of analysis levels*
3. *Please see Section 5.4.1.1 for more information on default damage functions*

5.4.1.1 Default GBS Structure Damage Functions

This section provides the default GBS structure damage function assignments within Hazus and a description of the sources that developed these functions.

[5] While damage functions may be applied to a single building, as well as to all buildings of a defined type, they are more reliable as predictors of damage for larger inventories of structures. An appropriate amount of caution should be advised when using and reporting results, especially for individual structures.

[6] For more information on the distribution of specific occupancy classes, number of stories, and foundation types within the baseline General Building Stock, see the *Hazus Inventory Technical Manual* (FEMA, 2024).

5.4.1.1.1 Assignment of Default GBS Structure Damage Functions

Default functions to estimate building structure damage have been selected for each Hazus occupancy for riverine, coastal A-zone flooding, and coastal V-zone flooding. These functions are identified in Table 5-2 through Table 5-4.[7]

Table 5-2. Default Damage Functions for Estimation of Structure Damage in Riverine Flood Zones

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
RES1	1	No Basement	USACE - IWR	One story, no basement, Structure	129
RES1	1	Basement	BCAR - Jan 2011	One story, w/ basement, Structure (B14)	704
RES1	2	No Basement	FIA	Two floors, no basement, Structure, A-Zone	107
RES1	2	Basement	FIA (MOD.)	Two floors, w/ basement, Structure, A-Zone	108
RES1	3	No Basement	FIA	Three or more floors, no basement, Structure, A-Zone	109
RES1	3	Basement	FIA (MOD.)	Three or more floors, w/ basement, Structure, A-Zone	110
RES1	Split Level	No Basement	FIA	Split level, no basement, Structure, A-Zone	111
RES1	Split Level	Basement	FIA (MOD.)	Split level, w/ basement, Structure, A-Zone	112
RES2	1	No Basement or Basement	FIA	Mobile home, structure, A-Zone	189
RES3A	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3A	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205

[7] Please note that the specific occupancy IDs shown in Hazus in the General Building Stock Damage Functions window are a combination of occupancy type, number or stories, and basement status. For example, a RES1 occupancy with one-story and no basement has the occupancy ID of R11N.

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
RES3B	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3B	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205
RES3C	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3C	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205
RES3D	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3D	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205
RES3E	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3E	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205
RES3F	1 or more	No Basement	USACE - Chicago	Apartment Unit Grade, Structure	204
RES3F	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Structure	205
RES4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of Hotel & Motel, structure	209
RES5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average institutional dormitory, structure [Note that there is no specific damage function available, so was developed from the RES6 Default]	214
RES6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Nursing Home, structure	215
COM1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 47 Retail classes, structure	217

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
COM2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 22 wholesale/warehouse classes, structure	341
COM3	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 16 personal & repair service classes, structure	375
COM4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average prof/tech services, structure,	431
COM5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Bank, structure	467
COM6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Hospital, structure	474
COM7	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 4 Medical Office/clinic classes, structure	475
COM8	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 15 Entertainment/Recreation classes, structure	493
COM9	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 3 theatre classes, structure	532
COM10	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Garage, structure	543
IND1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 16 Heavy Industrial classes, structure	545
IND2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 14 Light Industrial classes, structure	559
IND3	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 10 Food/Drug/Chemical classes, structure	575

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
IND4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 4 Metals/Minerals processing classes, structure	586
IND5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average High Technology, structure [Note: No specific damage function so uses IND3 default]	591
IND6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 8 Construction classes, structure	592
AGR1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average of 3 Agriculture classes, structure	616
REL1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Church, structure	624
GOV1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average government services, structure	631
GOV2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average emergency response, structure	640
EDU1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average school, structure	643
EDU2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE - Galveston	Average college/university, structure [Note: No specific damage function so uses EDU1 default]	652

1. *See Section 5.4.1.1.2 for a description of default building structure damage function sources.*
2. *Please note that the default riverine damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA policy exclusions) to reflect total damage. The Methodology for this modification is provided in Section 5.4.1.1.2.2.*
3. *Please note that the descriptions were compiled from a variety of sources and have differing levels of detail and purposes.*

Table 5-3. Default Damage Functions for Estimation of Structure Damage in Coastal V Flood Zones

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
RES1	1	No Basement	BCAR - Jan 2011	All floors, slab - no basement, Coastal A or V Zone	658
RES1	1	Basement	FIA (MOD.)	One floor, w/ basement, Structure, V-Zone Combined curve (average of with and without obstruction)	114
RES1	2	No Basement	FIA	Two floors, no basement, Structure, V-Zone	115
RES1	2	Basement	FIA (MOD.)	Two floors, w/ basement, Structure, V-Zone; Combined curve (average of with and without obstruction)	116
RES1	3	No Basement	FIA	Three or more floors, no basement, Structure, V-Zone	117
RES1	3	Basement	FIA (MOD.)	Three or more floors, w/ basement, Structure, V-Zone	118
RES1	Split Level	No Basement	BCAR - Jan 2011	All floors, slab - no basement, Coastal A or V Zone	658
RES1	Split Level	Basement	FIA (MOD.)	Split level, w/ basement, Structure, V-Zone	120
RES2	1	No Basement	BCAR - Jan 2011	Manufactured Home (Mobile), Structure, Coastal A or V Zone	667
RES2	1	Basement	FIA	Mobile home, structure, V-Zone	190
RES3A	1 or 2	No Basement	BCAR – Jan 2011	1 to 2 stories, slab – no basement, Coastal A or V zone	659
RES3B	1 or 2	No Basement	BCAR – Jan 2011	1 to 2 stories, slab – no basement, Coastal A or V zone	660

Note: All occupancies not listed use the same default damage functions for riverine and coastal flooding. See Table 5-2. While the importance of reflecting the differences between coastal and riverine flooding damage is recognized, well-documented coastal damage functions are available only for the RES1 occupancy type (single-family homes). However, since single-family dwellings make up most of the coastal exposure in the baseline GBS, this limitation was deemed adequate.

1. *See Section 5.4.1.1.2 for a description of default building structure damage function sources.*
2. *Please note that the default coastal damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA policy exclusions) to reflect total damage. The Methodology for this modification is provided in Section 5.4.1.1.2.2.*
3. *Please note that the descriptions were compiled from a variety of sources and have differing levels of detail and purposes.*

Table 5-4. Default Damage Functions for Estimation of Structure Damage in Coastal A Flood Zones

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID[4]
RES1	2	No Basement	FIA	Two floors, no basement, Structure, A-Zone	107
RES1	2	Basement	FIA (MOD.)	Two floors, w/ basement, Structure, A-Zone; Combined curve (average of with and without obstruction)	108
RES1	3	No Basement	FIA	Three or more floors, no basement, Structure, A-Zone	109
RES1	3	Basement	FIA (MOD.)	Three or more floors, w/ basement, Structure, A-Zone	110
RES1	Split Level	Basement	FIA (MOD.)	Split level, w/ basement, Structure, A-Zone	112
RES2	1	Basement	FIA	Mobile home, structure, A-Zone	189

Note: All occupancies not listed use the same default damage functions for coastal A zone and coastal V flooding. See Table 5-3.

1. *See Section 5.4.1.1.2 for a description of default building structure damage function sources.*
2. *Please note that the default coastal damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA policy exclusions) to reflect total damage. The Methodology for this modification is provided in Section 5.4.1.1.2.2.*
3. *Please note that the descriptions were compiled from a variety of sources and have differing levels of detail and purposes.*
4. *Please note that these damage functions are not Coastal A-zone specific as they are also used as default damage functions in riverine flooding scenarios.*

5.4.1.1.2 Description of Default GBS Structure Damage Function Sources

The default damage functions provided within Hazus were compiled from the following sources: FEMA Benefit-Cost Analysis Re-engineering (BCAR) report (2011), the Federal Insurance and Mitigation Administration (FIMA) FIA credibility-weighted damages, and the U.S. Army Corps of Engineers (USACE) Chicago District, Galveston District, and Institute for Water Resources (IWR). A description of each of these damage functions is provided in the sections that follow.

5.4.1.1.2.1 FEMA Benefit-Cost Analysis Re-engineering (BCAR) Damage Functions

FEMA BCAR-based damage functions estimate the flood damages at different water depths and the annual percentage chance that an event will occur. These damage functions are used to estimate expected flood damages for various types of buildings, their contents, or their functions at different water depths. This relationship is expressed as depth versus percentage of damage to the element being considered. The depths for the damage functions integrated into the Hazus software typically range from minus 2 to 16 feet. Damages are calculated at flood depths based on the damage function associated with the building type selected. The BCAR damage functions are used as the default damage functions for some residential buildings in both riverine and coastal flood hazard zones (see Section 5.4.1.1).

The BCAR damage functions developed for Coastal A and V Zone structures were based on the following assumptions:

- Since waves of 1.5 feet or greater can destroy walls and structures, there is no need to distinguish between Coastal A and V Zone damage functions.
- Expert panel damage functions were developed based on foundation type and estimated wave heights and flood depths. In general, foundation type and structure type are interchangeable when using the expert panel damage functions.

5.4.1.1.2.2 FIMA (FIA) Residential Damage Functions

Within FEMA the FIMA, formerly known as the Federal Insurance Administration (FIA), is responsible for administering the National Flood Insurance Program (NFIP). FIA created riverine and coastal flooding damage functions that are used in the FEMA Hazus Flood Model and the FEMA Benefit Cost Analysis Toolkit. The original damage functions, developed in 1970 and 1973, are referred to as “theoretical base tables”. Some of the information used to develop the initial functions came from post-flood surveys conducted by the USACE.

FIMA (FIA) Residential Damage Functions – Riverine

With time, a wealth of damage and loss data was collected as part of the flood insurance claims process. Losses included both structure and contents losses and were determined relative to actual cash value (depreciated replacement cost). A majority of claims were for residential structures. A statistical credibility analysis was used to combine the “theoretical base tables” and the insurance claims. When a sufficient number of claims existed to provide statistical confidence, the damage relationships were based exclusively on the claims data. When claims data were insufficient, the claims data and base tables were combined using a weighting process. The result was two sets of functions: pure summaries of claims data and credibility analyses combining available claims data into weighted functions.

The “Damage” report prepared by the NFIP Actuarial Information System (1998)[8] indicated that actual claims data representing statistically significant damage relationships were available for 10 categories of structures. The damage functions are based on these claims. Each category, along with the historic number of claims for the period of 1978–1998 are given below.

Damage functions based on summaries of claims data:

- One floor, no basement (255,717 claims)
- One floor, with basement (3,310 claims)
- Two floors, no basement (65,623 claims)
- Two floors, with basement (86,236 claims)
- Three of more floors, no basement (28,434 claims)
- Three of more floors, with basement (28,989 claims)
- Split-level, no basement (4,278 claims)
- Split-level, with basement (10,280 claims)
- Mobile home, no basement (8,182 claims)
- Mobile home, with basement (285 claims)

According to the NFIP Actuarial Information System “Credibility and Weighting” report (1998), credibility analyses and the resulting weighted functions were available for six structure categories. These categories represent aggregations of the original ten categories.

Damage functions based on credibility analysis:

- One floor, no basement
- Two or more floors, no basement

[8] While the current discussion references FIA data through 1997, the final damage functions incorporated into the Hazus Flood Model software are based on FIA data through 2001.

- Two or more floors, with basement
- Split-level, no basement
- Split-level, with basement
- Mobile home

Categories with fewer documented claims rely more heavily on the theoretical base tables. Figure 5-1 presents the six FIA credibility-weighted damage functions. Please note that several of the damage curves are not continuous. That is because claims data are often sparse therefore damage values (% damage) are not provided for all depths. Missing damage values (e.g., damage at 6.0 feet for structures with two floors, no basement) have been interpolated between known water depths to facilitate damage functionality in the Hazus Flood Model.

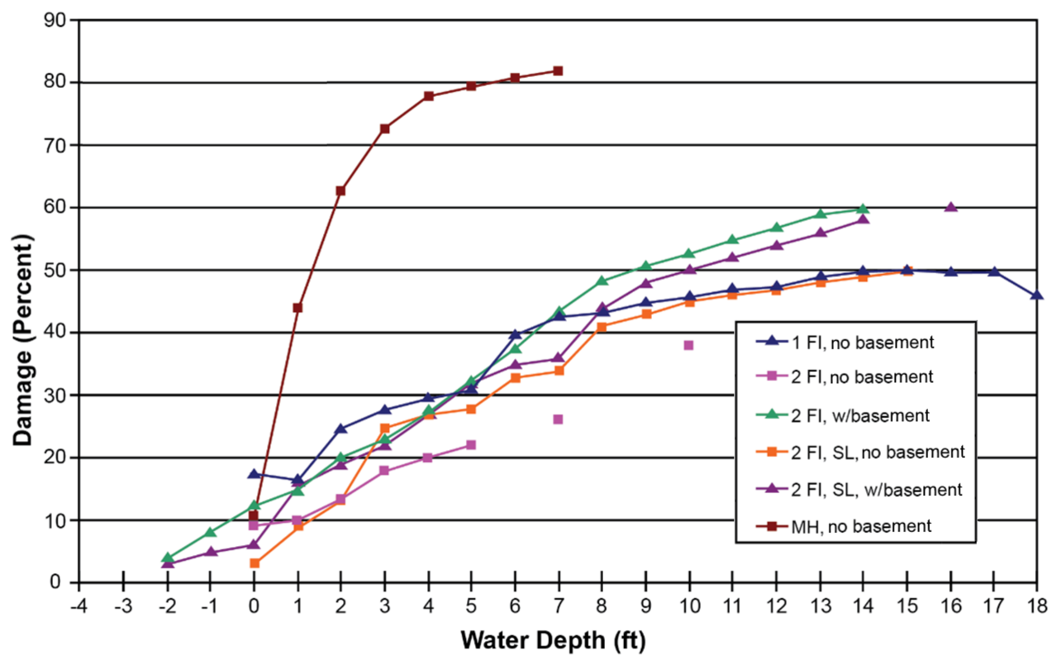

Figure 5-1. FIA Credibility-Weighted Building Damage Functions as of 12/31/1998

FIMA (FIA) Residential Damage Function – Coastal

In addition to the riverine (non-velocity zone) damage functions, FIA developed damage functions appropriate for velocity zones, designated as V-zone functions by FIA. These functions are applicable to areas subject to 3 feet wave action associated with 100-year flood events. Three functions are available for estimating structure and contents damage: “no obstruction,” “with obstruction,” and “combined”. The obstruction designation refers to the possible presence of machinery, equipment, or enclosures below the elevated floor.

Damage Functions to Reflect Basement Exclusions

As noted, the FIA claims data and credibility-weighted damage functions reflect the limitations of FIA insurance coverage. That is, damage to items not covered by FIA policies (e.g., basement flooring and other finishes) are not represented in the FIA damage functions. Because the intent of Hazus is to estimate flood damage, the damage curves for structures with basements (two-floor, with basement, and split-level with basement) were modified to estimate likely basement losses.[9]

To estimate likely basement damage, a distribution of basement component replacement cost, relative to the total structure replacement cost was required. Table 5-5 also indicates the extent of the policy exclusion as it applies to each component. As shown, two-thirds of the cost of wall finishes are covered, while one-third is excluded (typically the cost to tape and finish and paint the walls). Costs for floor finishes, finished ceilings, light fixtures, and additional heating ductwork are assumed to be excluded from coverage.

Table 5-5. Basement Component Cost Expressed as a Percent of Total Structure Replacement Cost[10]

Type	Economic	Average	Custom	Luxury	Used for Final	Excluded
Total finished basement cost/ SF of main	$14.25	$18.10	$26.10	$32.30	NA	NA
Total structure cost/ SF, including basement	$69.00	$96.88	$125.63	$152.55	NA	NA
Basement as a percentage of total	21%	19%	21%	21%	NA	NA
Unfinished basement walls	9.7%	7.0%	7.4%	7.4%	8%	none
Wall finishes	1.0%	1.3%	2.0%	2.0%	1.5%	~33%
Floor finish	3.6%	3.5%	4.2%	5.5%	4%	100%
Ceiling	2.7%	3.3%	3.4%	3.0%	3%	suspended = 100%, drywall = ~33%
Heating	0.0%	0.6%	0.6%	0.6%	0.5%	100%
Lighting	3.6%	3.0%	3.2%	2.8%	3%	100%

[9] Please note that the Hazus Flood Model produces loss estimates beginning at -4 feet for buildings with basements located in Study Region areas where flood depths are greater than 0 feet.

[10] This illustrative example assumes a two floor, 1600 sq ft single family residence with a basement using legacy Hazus data adjusted to 2018 dollars.

Type	Economic	Average	Custom	Luxury	Used for Final	Excluded
Total	21%	19%	21%	21%	20%	

Flood damage thresholds for basement components were estimated based on 2 basic conditions: 1) flood water at -4 feet (4 ft below the top of the First Floor Height Above Grade, approximately 4–5 ft of water in the basement, the lowest depth reported by FIA); and 2) flood water at -1 ft (basement assumed to be completely inundated). Damage to basement components have been estimated as follows:

- Unfinished concrete basement walls are not expected to suffer damages from flood waters of any height
- -4 ft (4 ft below the First Floor Height Above Grade, approximately 4 ft of water in the basement):
    - Floor finishes must be replaced (100% loss, 100% exclusion).
    - Due to water entry, seepage, and moisture due to standing water, wall finishes will need to be replaced (100% loss, 1/3 exclusion).
    - Due to water entry, seepage, and moisture due to standing water, ceiling tiles would need to be replaced, but the associated suspension system would be salvageable (damage = 33% of ceiling cost, 100% excluded). Drywall ceilings would require complete replacement (100% loss, 1/3 exclusion).
    - Electrical plugs, receptacles and switches would need to be replaced (33% loss, 100% exclusion).
    - Ductwork for heating would also require replacement (100% loss, 100% exclusion).
- -1 ft:
    - Ceiling suspension system requires replacement (remaining 67% of cost, 100% exclusion).
    - Light fixtures require replacement (remaining 67% of cost, 100% excluded).

To complete the damage functions modification, the excluded damage cost for each damaged component (expressed as a percent of total building replacement cost) was added to the tabulated FIA Damage functions. A total of 7% damage was added in at -4 ft, with an additional 4% added in at -1 ft, for a total of 11% added damage. This equates to the net basement value of 20% minus 8% for undamaged walls, and an additional 1% for items already covered by FIA, including one-third of the cost of wall finishes, and in some cases, part of ceiling costs. The resulting structure damage functions for “two or more floors, with basement” is given in Figure 5-2. Figure 5-3 shows the functions for “split level, with basement”.

The resulting damage functions may be compared to the limited claims data available for basement structures with water depths below 0 feet. While basement coverage was discontinued in 1983, it is assumed some of the claims data for basement buildings with damage below the first floor reflects claims made prior to the implementation of the exclusions. Review of the claims database for "two-floor with basement" structures (where 13% of the 86,236 claims were for structures with water depths less than 0 ft) indicated average damages (average damage amount divided by property value) on the order of 7–15% for water depths between -10 and -1 ft, roughly consistent with the proposed function.

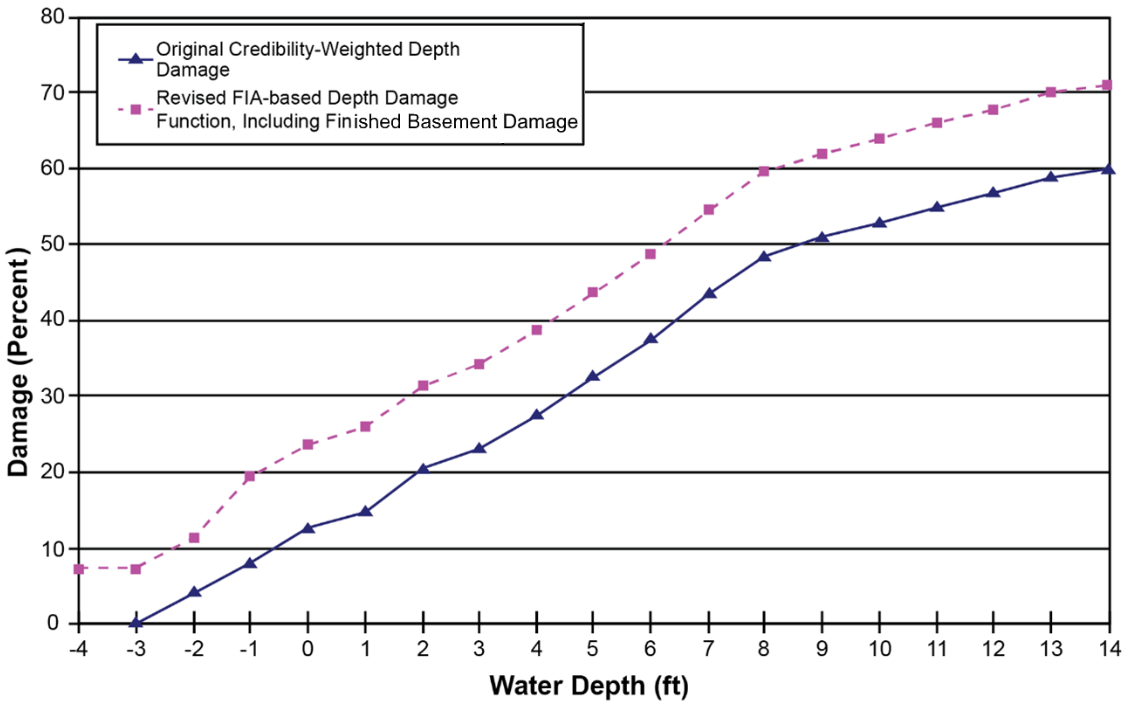

Figure 5-2. FIA-Based Structure Damage Function,
2 or More Stories, Finished Basement-Modified

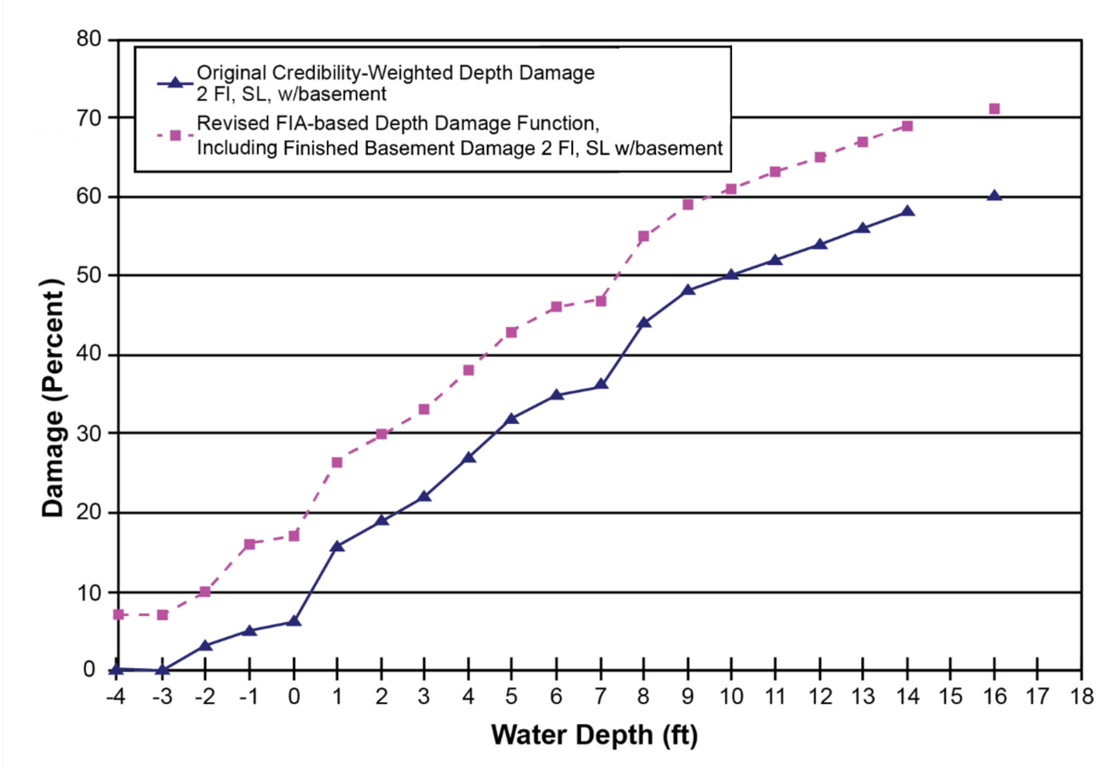

Figure 5-3. FIA-Based Structure Damage Function, Split Level, Basement-Modified

Similarly, content claims data for a variety of basement structures ranged from about 15% to 40% for water depths between -10 and -1 ft. The “contents-residential, first floor only” FIA credibility-weighted damage function reaches its maximum of about 60% damage at 10 ft of water, as does the “contents-residential, first floor and above” credibility-weighted damage function (see Section 6 for more information on contents damage functions). The difference between these 2 functions is small, and both are based on a limited number of claims; approximately 57,000 claims contribute to the credibility weighting for the first function, while only 17,400 claims are available for the second. Most claims are for depths of 5 ft and less, and full credibility (i.e., resulting function based entirely on claims history) is available only for a depth of 1 ft for the first function.

For comparison, detailed contents damage functions developed by the USACE New Orleans District (for structures with no basements) were reviewed. These expert opinion-based functions were developed on a component basis for one- and two-story structures. The resulting contents damage function for one-story residences reaches its maximum damage of about 91% damage at 5 ft of water. At 5 ft, damage to the two-story structure is 55%, and it reaches its maximum of 92.5% at 14 feet (approximately 5 feet above the finished second floor). This implies an approximate 60/40 split of contents on the first and second floor of a two-story structure.

This information was used to adjust the FIA credibility-weighted damage function for contents. Based on the limited claims data, it is assumed that approximately one-third of a building’s contents will be in the basement. For two-story structures, the 60/40 first/second-story split was used, resulting in a contents distribution of 33% in the basement, 40% on the first floor, and 27% on the second.

The adjusted contents function for “two-floor with basement” (resulting from the modification of the “first floor only” FIA function) is given in Figure 5-4. At –4 ft (the lowest point on the FIA function), it is assumed that basement contents (33% of total contents) are a total loss. The remainder of the function simply reflects the addition of the basement losses. As shown, the function reaches its maximum of about 93% at 10 ft. To adjust the multi-story function, the slope of the original function was applied, using the 33% basement damage as the y-intercept. The resulting function, also shown on Figure 5-4, reaches about 75% at 8 ft (total loss of basement and first-floor contents), and 100% at 13 ft (total loss of all contents when water is about 4 ft above the second floor).

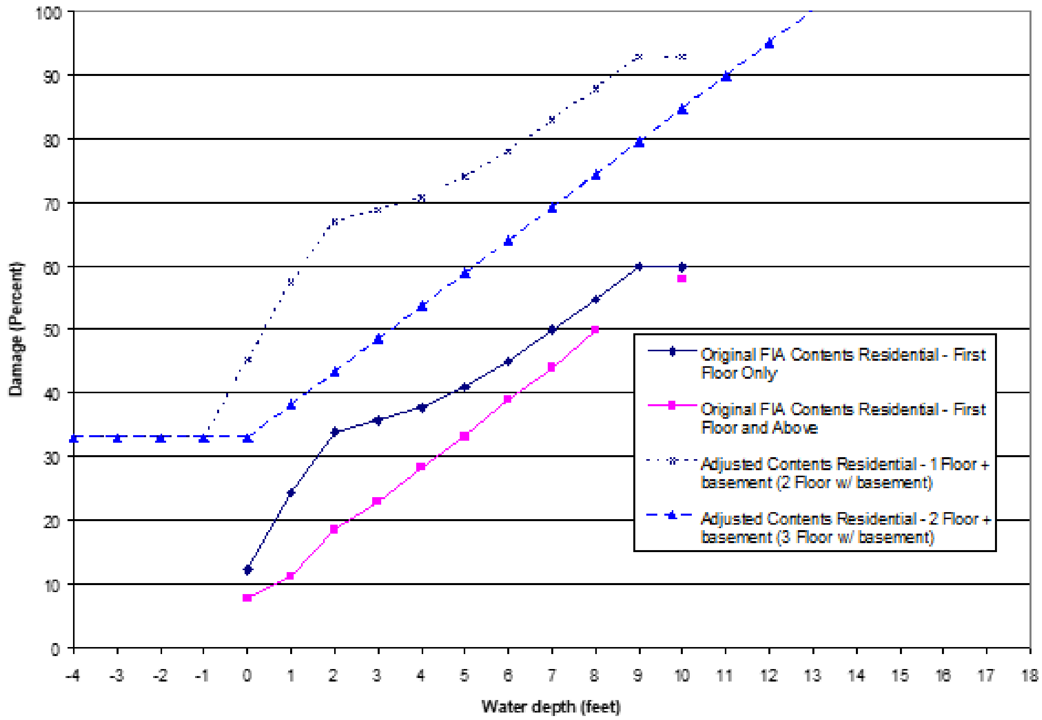

Figure 5-4. FIA-based Residential Contents Damage Function

5.4.1.1.2.3 USACE Chicago District Damage Functions

The USACE Chicago District developed seven sets of generic structure and content damage functions to represent commercial, industrial, and public occupancies in conjunction with the 1996 Feasibility Study on the Upper Des Plaines River in northeast Illinois. These damage functions, based on models developed by the Baltimore and Galveston Districts, classify structures as low, mid, and high structure vulnerability and low, mid, and high contents vulnerability. The result is seven functions representing the various ranking combinations. In addition, seven residential damage functions (one-story, two-story, split-level with and without basement, and manufactured home) were also provided.

5.4.1.1.2.4 USACE Galveston District Damage Functions

The USACE Galveston District began keeping a large file of flood damage records in 1968 under a contract with the FIA, using FIA forms. The initial survey was very comprehensive, with 10,000 properties included and a thorough room-by-room survey was made for every building. These damage functions were then updated based on flood damage records, as well as post-event surveys, including surveys following Hurricane Claudette in 1979. Most residential structures were flooded with up to three feet of water. Because of the small sample size of structures that experienced higher levels of inundation, Galveston District had to rely on additional information from the FIA to derive damage percentages above three feet. Galveston has numerous damage functions, including six residential and more than 145 non-residential flood damage functions (USACE, 1985). These non-residential damage functions include damage to the structure and to its inventory and equipment/fixtures. The damage functions are used by Galveston and other Districts, including Tulsa and Fort Worth, and are applicable to freshwater flooding, under slow-rise, slow-recession conditions, with little velocity. In addition, the functions are based on damage to structures without basements, as structures along the Texas Coastal Plain are built without basements because of the high-water table.

5.4.1.1.2.5 USACE Institute for Water Resources

The USACE IWR has the Flood Damage Data Collection Program designed to compile generic damage relationships, estimation models, and data collection tools for organizing floodplain inventory data (USACE, 2003). The only model that has been finalized is for single-family residential structures, without basements (IWR concluded that available data on basement damage are insufficient to develop statistical functions at this time).

5.4.1.2 Damage Function Library

In addition to the default damage functions described in Section 5.4.1.1.2, the Hazus Flood Model includes a library of damage functions that the user can select for application within an analysis. This section describes the sources of the damage functions that are available for selection. See the *Hazus Flood Model User Guidance* (FEMA, 2024) for additional information on selecting these functions for use in analysis.

5.4.1.2.1 Colorado State University Damage Functions

Colorado State University created a method to develop building fragility and building loss functions applied to an archetype portfolio that can be used to model buildings in a typical community. The typical single-variable flood vulnerability function, normally based on flood depth, is extended to a multi-variate flood vulnerability function, which is a function of both flood depth and flood duration, thereby creating fragility surfaces. The portfolio consists of 15 building archetypes that can serve to populate a community-level model to predict damage and resulting functionality from a scenario flood event (Water, 2020).

5.4.1.2.2 FEMA Risk MAP Damage Functions

FEMA used a team of experts to develop residential structure depth damage functions for different flood water conditions and foundation types. The curves represent freshwater inundation (riverine), saltwater inundation (no waves), moderate wave conditions (defined as 1.0 to 2.9 ft wave heights), and high waves (3.0 ft and higher waves). During the evaluation, damage to 1-story single-family houses were first assessed for freshwater flood conditions, and this curve was used as a baseline for comparison against the other coastal curves. Post-disaster building assessment knowledge was leveraged against the compared curves to aid in the selection of the appropriate curve for the flood conditions. Once the freshwater inundation curve was selected, the saltwater inundation curve was estimated based on a limited number of saltwater curves in the literature and based on the knowledge that damage to structural elements would be higher than during freshwater flooding due to potential saltwater corrosion. Next, the V Zone (high wave) condition was evaluated as the most severe type of damage that a 1-story single-family house would experience in a coastal flood event. Finally, the Coastal A Zone or A Zone with waves condition (moderate waves) was evaluated. These curves included finished and unfinished basements, deep foundations, shallow foundations, pier and crawlspace with and without openings, and slab on grade foundation types (FEMA, 2020).

Additional work was completed in 2021 to develop depth damage functions for coastal multi-family residential structures. Damage functions from an expert team included freshwater inundation curves, saltwater inundation curves, a moderate wave curve, and a high wave curve. Three building heights were modeled including: low-rise (one to three stories with at least five dwelling units), mid-rise (freestanding structure with four to seven stories containing at least five dwelling units), and high-rise (freestanding structure with eight or more stories having at least eight dwelling units) (FEMA, 2021a).

In 2021, an additional study provided single-family structure depth damage functions for inland areas subjected to high velocity flooding, moderate velocity flooding, long duration inundation flooding, and inundation flooding (FEMA, 2021b).

5.4.1.2.3 USACE New Orleans District Damage Functions

The USACE New Orleans District developed expert opinion damage functions for the flood control feasibility study in Jefferson and Orleans Parishes (GEC, 1996), and for the Lower Atchafalaya Re-evaluation (GEC, 1997). Damage functions include residential and non-residential structure and contents damage for four types of flooding:

- Hurricane flooding, long duration (1 week), saltwater
- Hurricane flooding, short duration (1 day), saltwater
- Riverine or rainfall flooding, long duration (2 or 3 days), freshwater
- Riverine or rainfall flooding, short duration (1 day or less), freshwater

Single-family residential structures are classified by number of stories (one, two, or manufactured home), and by foundation (piers or slab). Commercial structures are classified according to material and typical configuration (metal frame, masonry bearing, wood, or steel frame). In addition, non-residential contents damage functions are provided for a variety of occupancies:

- Eating/recreation – restaurants, bars, bowling alleys, theatres, etc.
- Groceries/gas stations – grocery stores, bakeries, liquor stores, gas stations, convenience stores, etc.

- Multi-family residences – garden apartments, high-rise apartments, condominiums, etc.
- Professional businesses – banks, offices, medical offices, funeral homes, etc.
- Public/semi-public – schools, government facilities, utility companies, etc.
- Repairs & home use – auto repair, watch repair, reupholstery, home repair, etc.
- Retail & personal – department stores, furniture stores, clothing stores, barbershops, laundromats, etc.
- Warehouse & contractor services – warehouses, manufacturers, etc.

Structures are assumed to be “no basement” structures, as damage functions typically begin at -1 ft of water and the reference point for water depth appears to be the top of the finished floor, based on review of detailed component loss tables.

5.4.1.2.4 USACE New York District Damage Functions

The Passaic River curves were based on over 3,500 interviews and an inventory of over 50,000 structures in the floodplain. Property owners were interviewed regarding the amount of damage expected from various flood stages. Interview data was calibrated with post-flood data from 1981 through 1985 to verify the depth-damage functions. Flooding was characterized as high velocity, short duration flash floods along streams and small rivers or low velocity, extended duration, low depth of inundation floods along larger rivers near the coast.

As part of the Passaic River Basin studies, the USACE New York District developed a variety of residential and non-residential structure and contents damage functions for buildings with and without basements. Also included in the damage functions are models for 10 utility facilities, such as electric power substations, pump houses, and water treatment plants (USACE, 1985).

Residential damage functions include bi-level, cape, colonial, manufactured home, split, two-family, and other types. Commercial structures are handled with 1 damage function, while for contents assessment the occupancies are organized into 10 different groups. For commercial facilities, both structure and contents damage functions consider the presence of a basement. In addition, there are 35 different industrial damage functions.

5.4.1.2.5 USACE North Atlantic Coast Comprehensive Study (NACCS)

The USACE NACCS developed a series of 74 residential, commercial, and mixed-use structure and content depth damage functions using a three-day workshop and a panel of nine experts. Examples of storm impacts from Hurricane Sandy were reviewed during the workshop. These curves included building prototypes with different foundation types including basement, crawl space, slab, open pile, and closed pile. Damage due to inundation, waves, and erosion were considered (USACE 2015).

5.4.1.2.6 *USACE Sacramento District Damage Functions*

The USACE Sacramento District developed 20 content damage functions for non-residential structures using a two-day expert-opinion elicitation session in Sacramento, California in March of 2007. The selected water type for evaluation was polluted freshwater, Category 3 as described by the Institute of Inspection, Cleaning and Restoration Certification Standard for Professional Water Damage Restoration. Category 3 is defined as grossly contaminated and can contain pathogenic, toxigenic, or other infectious agents. It can include sewage, silt, organic matter, pesticides, heavy metals, regulated materials, and toxic organic substances (USACE, 2007). Both short (less than a day) and long duration flooding was evaluated with water depths -1 to +15 feet. Additional curves were developed in 2009 by the Sacramento District for non-residential content damage functions. The 2007 curves were modified using FIA data to generate 38 additional damage functions (USACE, 2009).

5.4.1.2.7 *USACE St. Paul District Damage Functions*

The USACE St. Paul District estimated damage to the Grand Forks area as part of a flood control project, as documented in “General Reevaluation Report and Environmental Impact Statement” (USACE, 1998). The damage functions used in that report include residential and non-residential functions, whose source is the Vicksburg District. All non-residential uses, including commercial, professional (e.g., offices), industrial, public, semi-public (e.g., churches), recreation, and warehouses, are represented by one single damage function. Flooding was characterized by lower depths of inundation (up to 8’) of moderate duration (up to two weeks) and low velocity.

Please note that these damage functions are identified as “no basement”. For the USACE’s Grand Forks application, it appears that the USACE essentially shifted the damage function to the left for structures with basements, allowing damage to occur at lower water depths.

5.4.1.2.8 *USACE Wilmington District Damage Functions*

The USACE Wilmington District modified Galveston District curves using FIA data to develop 13 residential structure and contents damage functions, and 49 non-residential structure functions, which may be applied to contents using a contents-to-structure value ratio, as well as several damage functions reflecting erosion. The residential damage functions consider structure size (one, one and a half, and two-story, split-level, and manufactured home), and configuration (basement, no basement, high-raised, high-raised with one-half living area below). Non-residential classes include: apartments, appliances, auto dealership, auto junk yard, auto parts, bait stand, bank, barber shop, beauty shop, boat stalls, book store, bowling alley, business, church, cleaners, clinic (medical), clothing, dentist office, department store, doctor’s office, drug/super, funeral home, furniture, garage, halls, hardware, hotel, jewelry, laundry, liquor, lumber, market/super, market/drive, motel, newspaper, office building, post office, private club, restaurant, rest home, school, service station, theater, theater (drive-in), TV station, tavern, variety store, and warehouse (USACE, 1992).

5.4.2 GBS Structure Damage Estimates

The Hazus Flood Model provides GBS damage by occupancy (general and specific) and by building type for pre-Flood Insurance Rate Map (FIRM), post-FIRM, and total damaged building counts for each Census block. Damage estimates, expressed as a percentage of the repair and replacement cost, include the square feet (shown in thousands of square feet) of Census block buildings estimated to be substantially damaged, undamaged, and in each damage range (1%-10% damage, 11%-20%, etc.). The number of buildings in each Census block estimated to be substantially damaged, undamaged, and in each damage range are also provided.[11]

5.5 Guidance for Expert Users

An advanced user can:

- **Select Alternate Damage Functions**— The Hazus Flood Model provides the user with the opportunity to compare and select alternative damage functions from the extensive library of functions within the model (see Section 5.4.1.2). The user can identify and select the damage function they would prefer to use in the estimation of damage to buildings of any occupancy class. See the *Hazus Flood Model User Guidance* (FEMA, 2024) for additional information.[12]

- **Develop Custom Damage Functions**— Additional damage functions may be available from local USACE Districts or floodplain managers and may include damage relationships developed from post-flood surveys. Users can also develop custom damage functions reflecting the unique characteristics of their community within the model. See the *Hazus Flood Model User Guidance* (FEMA, 2024) for additional information.

- **Account for NFIP Community Participation Changes since 2014**— Because NFIP community participation status is based on 2014 data, default GBS parameters will not reflect any changes in community status that have occurred since 2014. Significant customization is required to update parameters to account for these changes, so it is recommended that interested users contact the Hazus Help Desk (see Section 1.5). Additionally, users should note that such customization will not result in a substantial change in losses in riverine flood zones due to a lack of substantive differences between pre- and post-FIRM mapping schemes (see the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information on mapping schemes).

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[11] Please note that building damage counts should be used with caution due to the way counts are calculated and rounded in Hazus. Significant under- or over-reporting may occur depending on the specific parameters of the flood analysis being conducted.

[12] Please note when changing default damage function assignments, some damage functions have been developed for particular foundation types. Hazus does not validate user damage function assignment with foundation type.

Section 6. General Building Stock – Direct Economic Losses

The Hazus Flood GBS Module provides estimates of GBS building repair and replacement costs and the associated loss of building contents and business inventory. Building damage can also cause additional losses by restricting the building's ability to function properly for its intended purpose. To account for this, the Hazus Flood GBS Module estimates business interruption costs (relocation costs, loss of income, wage losses, and rental income losses) and direct output losses.

These loss estimates can provide an indication of the impact of building damage on the community, the financial consequences to the community's businesses due to business interruption, the financial resources that will be needed to repair the damage, and potential housing losses.

The flowchart of the overall Methodology, including direct economic loss components, is shown in Section 2 (Figure 2-1).

6.1 Input Requirements and Output Information

Input requirements to estimate GBS direct economic loss in the Study Region include the following:

- GBS economic parameters including repair and replacement values, restoration times, rental and disruption cost estimates, income, wage, and rental income estimates, and recapture factors
- Building, contents, and inventory damage functions appropriate for specific occupancy types
- Estimated percent damages based on the depth of flooding hazard throughout the Census block

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus can be used to meet the input requirements.

The output from the application of the percent damage estimates to the GBS economic parameters is an estimate of the repair and replacement costs (full and depreciated), business interruption costs, and direct output loss in thousands of dollars.

The output from average annualized loss (AAL) estimates is an estimate of averaged economic losses for the building, contents, and inventory in thousands of dollars.

6.2 Direct Economic Losses to GBS Due to Flooding

The Hazus Flood Model provides estimates of direct economic losses to the GBS including:

- GBS repair and replacement costs

- Business interruption costs
- Direct output loss
- Average annualized loss

The Hazus Methodology by which these losses are estimated is discussed in the sections that follow.

6.2.1 GBS Repair and Replacement Costs

The Hazus Flood Model Methodology for estimating repair and replacement costs for the GBS depends upon the physical damage estimates derived from damage functions as described in Section 5. Separate damage functions are used to estimate losses for buildings, contents, and inventory as described in the sections that follow.

6.2.1.1 Building Loss: Structural and Non-Structural Repair and Replacement Costs

Within the Hazus Flood Model, buildings are defined to include both the structural (load bearing) system, as well as architectural, mechanical and electrical components, and building finishes.

The estimated percent damage for a given occupancy class, at a given flood depth, in a given Census block (see Section 5) is multiplied by the replacement value of the occupancy class to produce an estimate of the economic loss. Estimated losses are provided for both full and depreciated cost models in thousands of dollars (see the *Hazus Inventory Technical Manual* (FEMA, 2024)) for more information on how repair and replacement values were derived).

6.2.1.2 Building Contents Loss: Replacement Costs

Within the Hazus Flood Model, building contents are defined as furniture, equipment that is not integral with the structure, computers, and other supplies. Contents are excluded from structural components and do not include inventory or nonstructural components such as lighting, ceilings, mechanical and electrical equipment, and other fixtures.

Building contents losses in the Hazus Flood Model are determined by the application of damage functions in a manner consistent with building losses (see Section 6.2.1.1). Default damage functions for structure contents are shown in Table 6-1 and Table 6-2 for riverine and coastal zones, respectively.[13] Estimated losses are provided for both full and depreciated cost models (see the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information on how replacement values were derived).

[13] In addition to the default damage functions described, the Hazus Flood Model includes a library of damage functions that the user can select for application within an analysis (see Section 5.4.1.2 for more information).

Table 6-1. Default Damage Functions for Estimation of Contents Damage in Riverine Flood Zones

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
RES1	1	No Basement	USACE – IWR	one story, no basement, Contents	45
RES1	1	Basement	BCAR – Jan 2011	one story, w/ basement, Contents (B14)	535
RES1	2	No Basement	FIA	two floors, no basement, Contents, A-Zone	23
RES1	2	Basement	FIA (MOD.)	two floors, w/ basement, Contents, A-Zone	24
RES1	3	No Basement	FIA (MOD.)	three or more floors, no basement, Contents, A-Zone	25
RES1	3	Basement	FIA (MOD.)	three or more floors, w/ basement, Contents, A-Zone	26
RES1	Split Level	No Basement	FIA	split level, no basement, Contents, A-Zone	27
RES1	Split Level	Basement	FIA (MOD.)	split level, w/ basement, Contents, A-Zone	28
RES2	1	Basement or No Basement	FIA	Mobile Home, Contents, A-Zone	74
RES3	1 or more	No Basement	USACE – Chicago	Apartment Unit Grade, Contents	81
RES3	1 or more	Basement	USACE - Chicago	Apartment Unit Sub-Grade, Contents	82
RES4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of “Hotel – Equipment” and “Motel Unit – Inventory”, Contents (Equipment/Inventory)	85
RES5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average institutional dormitory, contents [Note: No RES5 curves were available –RES6 default are used]	88

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
RES6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Nursing Home, contents (Equipment)	89
COM1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 47 retail trade classes, Contents (Inventory/Equipment)	90
COM2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 22 wholesale/warehouse classes, Contents, equipment and inventory, when available	195
COM3	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average pf 16 personal/repair services, Contents (Inventory), equipment and inventory, when available	240
COM4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Prof/tech services, Contents (Equipment/Inventory), Average of “Business – inventory” and “Office, equipment”	280
COM5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Bank, Contents, Average of Bank inventory and equipment	304
COM6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Hospital, Contents, Average of Hospital inventory and equipment	309
COM7	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 4 Medical Office/Clinic, Contents (Equipment/Inventory)	312
COM8	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 13 Entertainment/Recreation, Contents (Equipment/Inventory)	322
COM9	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 3 Theater, Contents (Equipment)	352

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
COM10	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Garage, Contents (Inventory)	357
IND1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 16 Heavy Industrial, Contents (Equipment/Inventory)	358
IND2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 14 Light Industrial, Contents (Equipment/Inventory)	384
IND3	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 10 Food/Drugs/Chemicals, Contents (Equipment/Inventory)	408
IND4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 4 Metals/Minerals Processing, Contents (Equipment/Inventory)	433
IND5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average High Technology, Contents (Equipment/Inventory) [Note: No IND5 curves were available –IND3 default are used]	442
IND6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 8 Construction, contents (Equipment/Inventory)	443
AGR1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average of 3 Agriculture, Contents (Equipment/Inventory)	460
REL1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Church, contents, Average of “Church” inventory and equipment	467
GOV1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Government Services, contents (Equipment), Average of “City Hall” and “Post Office” equipment	472

Occupancy	Number of Stories	Basement	Source[1, 2]	Description[3]	Damage Function ID
GOV2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average emergency response, contents (Equipment/Inventory), Average of “Police Station” equipment and “Fire Station” inventory	477
EDU1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average School, contents (Equipment/Inventory), Average of “School,” Equipment and “Library,” Inventory	480
EDU2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average College/University, Contents (Equipment/Inventory), Average of “School,” Equipment and “Library,” Inventory	485

1. *See Section 5.4.1.2 for a description of default contents damage function sources.*
2. *Please note that the default damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA policy exclusions) to reflect total damage. The Methodology for this modification is provided in Section 5.4.1.1.2.2.*
3. *Please note that the descriptions were compiled from a variety of sources and have differing levels of detail and purposes.*

Table 6-2. Default Damage Functions for Estimation of Contents Damage in Coastal A and V Flood Zones

Occupancy	Number of Stories	Basement	Source[1,2]	Description[3]	Damage Function ID
RES1	All	No Basement	BCAR – Jan 2011	All floors, slab – no basement, Coastal A or V Zone	488
RES1	1	Basement	FIA	1 floor, w/ basement, Contents, Coastal A or V Zone, Combined curve (average of with and without obstruction)	30

Occupancy	Number of Stories	Basement	Source[1,2]	Description[3]	Damage Function ID
RES1	2	Basement	FIA (MOD.)[4]	two floors, w/ basement, Contents, V-Zone, Combined curve (average of with and without obstruction)	32
RES1	3	Basement	FIA (MOD.)[4]	three or more floors, w/ basement, Contents, V-Zone, Combined curve (average of with and without obstruction)	34
RES1	Split Level	Basement	FIA (MOD.)[4]	split level, w/ basement, Contents, V-Zone, Combined curve (average of with and without obstruction)	36
RES2	1	No Basement	BCAR – Jan 2011	Manufactured Home (Mobile), Structure, Coastal A or V Zone	497
RES2	1	Basement	FIA[4]	Mobile Home, Contents, V-Zone	75

Note: All occupancies not listed use the same default damage functions for riverine and coastal flooding. See Table 6-1.

1. *See Section 5.4.1.2 for a description of default contents damage function sources.*
2. *Please note that the default damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA policy exclusions) to reflect total damage. The Methodology for this modification is provided in Section 5.4.1.1.2.2.*
3. *Please note that the descriptions were compiled from a variety of sources and have differing levels of detail and purposes.*
4. *Damage function is applied for Coastal V zones only. Coastal A zone uses riverine damage function (see Table 6-1).*

6.2.1.3 Business Inventory Losses

Business inventory losses in the Hazus Flood Model are determined by the application of damage functions in a manner consistent with the other building losses. Only a subset of the Hazus occupancies included in the GBS baseline inventory include business inventory values (COM1, COM2, IND1 - IND6 and AGR1) and can produce business inventory loss estimates.

To estimate business inventory losses, the percent damage (determined from the damage function) is multiplied by the total business inventory value (please see the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information), as shown in Equation 6-1.[14]

Equation 6-1. Business Inventory Losses

$$\text{Inventory Losses}_i = \sum_j (\%\,\text{DAMINV}_{i,j} \times \text{FA}_{i,j} \times \text{SALES}_i \times \text{bi}_i)$$

Where:

i	Hazus specific occupancy i
$\%\text{DAMINV}_{i,j}$	percent inventory damage for occupancy i and depth j (from damage function)
$\text{FA}_{i,j}$	floor area of occupancy i and depth j (in ft^2)
SALES_i	annual gross sales or production (per square foot) for occupancy i (provided in the *Hazus Inventory Technical Manual)* (FEMA, 2024))
bi_i	business inventory (%) as a percentage of annual gross sales for occupancy i

6.2.1.3.1 Default GBS Inventory Damage Functions

Table 6-3 provides the default damage functions for business inventory losses.

Table 6-3. Default Damage Functions for Estimation of Inventory Damage for All Flood Zone Types

Occupancy	Number of Stories	Basement	Source[1]	Description	Damage Function ID
COM1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Retail Trade, Inventory	1
COM2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Wholesale Trade, Inventory	46
IND1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Heavy Industrial, Inventory	70

[14] Please note that due to rounding of values before summation, inconsistencies may occur when analyses are conducted at small scales. These inconsistencies are mitigated over large Study Regions.

Occupancy	Number of Stories	Basement	Source[1]	Description	Damage Function ID
IND2	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Light Industrial, Inventory	81
IND3	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Food/Drugs/Chemicals, Inventory	93
IND4	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Metals/Minerals Processing, Inventory	106
IND5	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average High Technology, Inventory [Note: IND3 default]	111
IND6	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Average Construction, Inventory	112
AGR1	Low-, Mid-, or High-Rise	Basement or No Basement	USACE – Galveston	Agriculture/Dairy Processing, Inventory	116

Note: Only occupancies with inventory damage functions are listed.

1. *Please see Section 5.4.1.1 for a description of default inventory damage function sources.*

6.2.1.3.2 Business Inventory Damage Function Library

In addition to the default damage functions provided in Section 6.2.1.3.1, the Hazus Flood Model includes a library of damage functions that the user can select for application within an analysis. The business inventory damage function library assembled includes 116 business inventory damage functions (including default functions) provided by the USACE Galveston District. These functions include:

- Forty-five damage functions for facilities classified according to their SIC code and description as COM1 Retail Trade (e.g., grocery store, furniture store)
- Twenty-four functions for COM2 Wholesale Trade (e.g., food warehouse, paper products warehouse)
- Eleven functions for IND1 Heavy Industrial (e.g., fabrication shop, machine shop-heavy)
- Twelve functions for IND2 Light Industrial (e.g., furniture manufacturing, commercial printing)
- Thirteen functions for IND3 Foods/Drugs/Chemicals (e.g., chemical plant, feed mill)

- Five functions for IND4 Metals/Mineral Processing (e.g., foundry)
- One function for IND5 High Technology[15]
- Four functions for IND6 Construction (e.g., roofing contractor, plumbing company)
- One function for AGR1 Agriculture

6.2.2 GBS Business Interruption Costs

The Hazus Flood Model estimates business interruption costs including relocation expenses, income loss, wage loss, and rental income loss.[16] Business interruption loss estimates are provided in thousands of dollars by Census block and by general occupancy, specific occupancy, and by general building type and are viewable by the user via the GBS economic loss by full replacement value dialog under the Results menu.

6.2.2.1 Restoration Time

Business interruption losses are time-dependent, meaning the losses will depend on the amount of time required to restore business operations. Restoration times generally include time for physical restoration of the damage to the building, clean-up time, time required for inspections, permits and the approval process, and delays due to contractor availability. Table 6-4 through Table 6-15 provide the default estimated maximum restoration times used in the Hazus Flood Model. These times were developed using limited expert opinion and are generally provided in 4-foot flood depth increments to coincide with likely physical repair strategies. For example, once inundation has exceeded the finished floor and damaged the lower portion of the wall, a sheet of 4-foot by 8-foot dry wall will be laid horizontally to replace the damaged wallboard.

Table 6-4. Maximum Restoration Time for RES1, RES3A, RES3B and COM3 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	180
0	4	360
4	8	450
8	24	720

[15] Please note that no IND5 specific damage function was available. The default damage function for IND5 is identical to the default damage functions for IND3.

[16] Please note that the Employment Loss module in the Hazus Flood Model is not functional, so the Employment Loss column in the Direct Economic Loss results dialog window will always display zero days of employment loss.

Table 6-5. Maximum Restoration Time for RES2 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	0
0	1	360
1	24	720

Table 6-6. Maximum Restoration Time for RES3C, RES3D, RES3E, RES3F, and RES4 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	270
0	4	450
4	8	540
8	12	630
12	24	720

Table 6-7. Maximum Restoration Time for RES5, RES6, COM4, COM5, COM7, GOV1, GOV2, EDU1, and EDU2 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	360
0	4	480
4	8	630
8	12	720
12	24	900

Table 6-8. Maximum Restoration Time for COM1, COM2, COM8, COM9, and REL1 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	180
0	4	540
4	8	630
8	12	720
12	24	900

Table 6-9. Maximum Restoration Time for COM6 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	360
0	4	540
4	8	720
8	24	900

Table 6-10. Maximum Restoration Time for COM10 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	0
0	24	30

Table 6-11. Maximum Restoration Time for IND1 and AGR1 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	0
0	24	210

Table 6-12. Maximum Restoration Time for IND2 and IND6 Occupancies

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	0
0	24	150

Table 6-13. Maximum Restoration Time for IND3 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	390
0	4	510
4	8	660
8	12	750
12	24	900

Table 6-14. Maximum Restoration Time for IND4 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	420
0	4	540
4	8	690
8	12	780
12	24	900

Table 6-15. Maximum Restoration Time for IND5 Occupancy

Minimum Depth (ft)	Maximum Depth (ft)	Maximum Days for Restoration
-4	0	240
0	4	600
4	8	690
8	12	780
12	24	900

6.2.2.2 Relocation Expenses: Rental and Disruption Costs

Relocation expenses in the Hazus Flood Model represent disruption costs, the cost of shifting and transferring activities, and the rental of temporary space to building owners for all specific occupancies except for COM10 (parking facilities). Relocation expenses are estimated in Hazus using Equation 6-2.[17] See the *Hazus Inventory Technical Manual* (FEMA, 2024) for default rental and disruption cost parameters for each specific occupancy.

Equation 6-2. Relocation Expenses by Occupancy

$$\text{Relocation Expenses}_i = \sum_j \text{Fa}_{i,j} \times \left[(1 - \%\text{OO}_i)(\text{DC}_i) + \%\text{OO}_i\,(\text{DC}_i + (\text{RENT}_i \times \text{RT}_{i,j}))\right]$$

Where:

i Hazus specific occupancy i

[17] Please note that relocation expense estimates are available in thousands of dollars in the Relocation Cost column in the General Building Stock Economic Loss results.

$Fa_{i,j}$	floor area of occupancy i and depth j (in ft²)
$\%OO_i$	percent owner occupied for occupancy i
DC_i	disruption costs for occupancy i ($/ft²)
$RENT_i$	rental cost ($/ft²/day) for occupancy i
$RT_{i,j}$	restoration time (in days) for occupancy i and water depth j (see Table 6-4 through Table 6-15)

6.2.2.3 Income Loss

Income loss is estimated in the Hazus Flood Model using Equation 6-3.[18] See the *Hazus Inventory Technical Manual* (FEMA, 2024) for default income loss and recapture parameters for each specific occupancy.

Equation 6-3. Income Loss by Occupancy

$$\text{Income Loss}_i = \sum_j (1 - \text{IRF}_I) \times \text{FA}_{i,j} \times \text{INC}_i \times \text{RT}_{i,j}$$

Where:

i	Hazus specific occupancy i
IRF_i	income recapture factor (%) for occupancy i
$FA_{i,j}$	floor area of occupancy i (in ft²) at depth j
INC_i	income per day (per ft²) for occupancy i
$RT_{i,j}$	restoration time (in days) for occupancy i and water depth j (see Table 6-4 through Table 6-15)

6.2.2.4 Wage Loss

Wage loss is estimated in the Hazus Flood Model by using Equation 6-4. See the *Hazus Inventory Technical Manual* (FEMA, 2024) for default wage loss and recapture parameters for each specific occupancy.

Equation 6-4. Wage Loss by Occupancy

[18] Please note that Income Loss is sometimes referred to as capital related losses within the Hazus Flood Model.

$$\text{Wage Loss}_i = \sum_j (1 - \text{WRF}_i) \times \text{FA}_{i,j} \times \text{WA}_i \times \text{RT}_{i,j}$$

Where:

i	Hazus specific occupancy i
WRF_i	wage recapture factor for occupancy i
$\text{FA}_{i,j}$	floor area of occupancy i (in ft^2) at depth j
WA_i	wages per day (per ft^2) for occupancy i
$\text{RT}_{i,j}$	restoration time (in days) for occupancy i and water depth j (see Table 6-4 through Table 6-15)

6.2.2.5 Rental Income Losses

Rental income loss is the income in dollars that a property owner would receive if the unit was fully occupied but is unable to receive due to the building being damaged. Rental income loss is estimated in the Hazus Flood Model using Equation 6-5. See the *Hazus Inventory Technical Manual* (FEMA, 2024) for default rental income loss parameters for each specific occupancy.

Equation 6-5. Rental Income Losses by Occupancy

$$\text{Rental Income Losses}_i = \sum_j (1 - \%\text{OO}_i) \times \text{FA}_{i,j} \times \text{RENT}_i \times \text{RT}_{i,j}$$

Where:

i	Hazus specific occupancy i
$\%\text{OO}_i$	percent owner occupied for occupancy i
$\text{FA}_{i,j}$	floor area of occupancy i (in ft^2) at depth j
RENT_i	rental cost ($/ ft^2/day) for occupancy i
$\text{RT}_{i,j}$	restoration time (in days) for occupancy i and water depth j (see Table 6-4 through Table 6-15)

6.2.3 GBS Total Loss

The Total Loss results shown in the Direct Economic Loss dialog window and summary report are a combination of several of the other loss estimates produced by the Hazus Flood Model as shown in Equation 6-6.

Equation 6-6. GBS Total Loss Estimates

$$\begin{aligned}\text{Total Loss} = & \text{ Building Loss} + \text{Contents Loss} + \text{Inventory Loss} + \text{Relocation Cost} + \text{Income Loss} \\ & + \text{Rental Income Loss} + \text{Wage Loss}\end{aligned}$$

6.2.4 GBS Direct Output Loss

Direct Output Loss, the loss of productivity not captured in inventory or business interruption losses, is estimated in the Hazus Flood Model by using Equation 6-7. See the *Hazus Inventory Technical Manual* (FEMA, 2024) for default output loss and recapture parameters for each specific occupancy.

Equation 6-7. Direct Output Loss by Occupancy

$$\text{Direct Output Loss}_i = \sum_j (1 - \text{WRF}_i) \times \text{FA}_{i,j} \times \text{DO}_j \times \text{RT}_{i,j}$$

Where:

i	Hazus specific occupancy i
WRF_i	wage recapture factor for occupancy i
$\text{FA}_{i,j}$	floor area of occupancy i (in ft^2) at depth j
DO_i	direct output (\$/ft^2/day) for occupancy i
$\text{RT}_{i,j}$	restoration time (in days) for occupancy i and water depth j (see Table 6-4 through Table 6-15)

6.2.5 GBS Average Annualized Loss

The Hazus Flood Model requires flood losses from 10-year, 25-year, 50-year, 100-year, and 500-year recurrence intervals to complete AAL calculations. Depth grids for these recurrence intervals can be generated via Hazus using the Full Suite of Recurrence intervals analysis in the Hazard menu (Level 1 analysis) or can be provided by the user (Level 2 analysis).[19]

GBS losses (building loss, contents loss, and inventory loss) are calculated by Census block (and by occupancy and building type) for the suite of recurrence intervals and losses are in thousands of

[19] Please note that users conducting a Level 2 average annualized loss analysis must ensure that all depth grids are loaded into Hazus via User Data at the same time and that the parameters are set to the correct recurrence interval for each grid.

dollars. For more information on the AAL functionality see the *Hazus Flood Model User Guidance* (FEMA, 2024).

AAL estimates are produced by the Hazus Flood Model using Equation 6-8.

Equation 6-8. Simplified Average Annualized Loss Equation used in Hazus

$$\mathrm{AAL} = 0.030\mathrm{L}_{10} + 0.040\mathrm{L}_{25} + 0.015\mathrm{L}_{50} + 0.009\mathrm{L}_{100} + 0.006\mathrm{L}_{500}$$

Where:

L_{10}	10-year recurrence interval
L_{25}	25-year recurrence interval
L_{50}	50-year recurrence interval
L_{100}	100-year recurrence interval
L_{500}	500-year recurrence interval

Table 6-16 shows an example of how average annualized loss is calculated based upon Equation 6-8.[20]

Table 6-16. Example Average Annualized Loss Estimate

Recurrence Interval (RI)	Sample Economic Loss		Frequency Constant (C) by RI[1]		AAL contribution by RI
10	L_{10}	1	C_{10}	0.030	0.030
25	L_{25}	3	C_{25}	0.040	0.120
50	L_{50}	9	C_{50}	0.015	0.135
100	L_{100}	14	C_{100}	0.009	0.126
500	L_{500}	85	C_{500}	0.006	0.510
				AAL Total	0.921

1. *Derived from detailed average annualized loss equations. (See the Hazus 2.1 Flood Technical Manual (FEMA, 2012) for more information on the detailed equation.)*

[20] Please note that due to rounding of calculations within the Hazus Flood Model, hand calculations of average annualized loss may not match Hazus outputs precisely.

6.3 Guidance for Expert Users

The baseline data provided with the Hazus Flood Model are sufficient for a Level 1 analysis. However, depending on the type of analysis required, much more detailed economic cost information can be obtained from various public data sources or from private consultants. For example, more accurate rental costs may be obtained from local realtors or from the local chamber of commerce. For replacement costs, professional building cost estimators maintain detailed records of costs and trends and have knowledge of local building practices that might affect a loss estimate.

Certain kinds of estimates, for example one focused on the implications of hospital or specific industry losses, would require individual building cost estimates, together with similar individual building damage estimates. These estimates might result in costs considerably different than the typical aggregated costs provided as part of the baseline database.

Section 7. User-Defined Facilities – Direct Physical Damage and Direct Economic Loss

The Hazus Flood User-Defined Facilities Module provides site-specific estimates of direct physical damage and direct economic loss to user-defined facilities due to flooding. If input requirements are met, the Hazus Flood Model can also provide AAL estimates for user-defined facilities.

The flowchart of the Methodology, including user-defined components, is shown Section 2 (Figure 2-1).

7.1 Input Requirements and Output Information

Input required to estimate user-defined facility damage and direct economic loss in the Study Region include the following:

- User-Defined Facility database populated with attributes related to flood damage
- Depth and type of flood hazard at the site-specific building locations
- Damage functions appropriate for occupancy, number of stories, foundation type, and flood hazard type

User-Defined Facility analysis cannot be completed with only the baseline inventory included with Hazus, as no user-defined facilities are included in the baseline data. If a user imports user-defined facility data (see Section 7.2), Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus (see Section 7.4) can be used to meet the remaining input requirements for direct physical damage and direct economic loss. Average annualized loss estimates require additional flood hazard inputs to calculate losses (see Section 7.6).

The output from the application of the damage functions is an estimate of the damage to the building at a given depth, expressed as a percentage of the replacement cost of the building, and an estimate of the direct economic losses for the building, contents, and inventory (if appropriate) in dollars. The output from average annualized loss estimates is an estimate of averaged economic losses for the building, contents, and inventory in dollars.

7.2 User-Defined Facility Database

The baseline inventory included with Hazus does not include user-defined facilities. User-Defined Facilities can be imported into the Model using the Comprehensive Data Management System (CDMS). The *Hazus Comprehensive Data Management System User Guidance* (FEMA, 2024) provides instructions for import. The *Hazus Flood Model User Guidance* (FEMA, 2024) provides information on attributes that are required and how to format them to meet Hazus import requirements.

7.3 Depth and Type of Flooding at Site-Specific Locations

The depth of flooding at each user-defined facility is determined by an extract value to point geoprocessing tool that uses the flood depth grid for the Study Region scenario and the latitude and longitude of each user-defined facility.

The type of flooding is determined using the same Methodology as for the GBS (see Section **Error! Reference source not found.**).

7.4 Direct Physical Damage to User-Defined Facilities Due to Flooding

The Hazus Flood User-Defined Facilities Module uses the default damage functions for the specific occupancy, number of stories, foundation, and flood hazard type of each user-defined facility (see Section 5.4.1).[21,22] If no occupancy is entered for a user-defined facility, the Hazus Flood Model assumes that the specific occupancy is RES1.

For combined riverine and coastal Study Regions, the Controlling Hazard field in the User-Defined Facilities Damage Loss dialog shows whether coastal or riverine (C or R) damage functions are being used for each user-defined facility. This determines the depth that is used when depth grids overlap.

The percent damage estimate for each structure is interpolated by Hazus from the 1-foot depth increments shown in the Damage Function Library based on the flood depths at the user-defined facility location minus the first-floor height above grade included in the inventory for that user-defined facility (see Section 7.2). First floor height above grade is rounded to the nearest whole number with 0.5 feet and below rounding down and 0.51 feet and above rounding up.

7.5 Direct Economic Losses to User-Defined Facilities Due to Flooding

The methods for estimating direct economic losses to user-defined facilities are very similar to those presented for determining direct economic losses to the GBS (see Section 6.2.1), except losses are expressed in dollars on a facility-specific basis and depreciated economic losses are not provided.

7.6 Average Annualized Loss Estimates for User-Defined Facilities

The methods for estimating AAL for user-defined facilities are identical to those presented for determining AAL to the GBS, except results are presented in dollars on a facility-specific basis (see Section 6.2.5).

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[21] Please note that there is a known defect where default damage function assignments cannot be changed by the user by entering a damage ID into the inventory for building, content, or inventory damages.

[22] Please note that if the user-defined facility is assigned a Flood Protection level in the inventory greater than or equal to the scenario return period, then no damages will be reported for that facility.

Section 8. Essential Facilities – Direct Physical Damage and Direct Economic Loss

The Hazus Flood Essential Facility Module provides site-specific estimates of direct physical damage and direct economic losses to Essential Facilities due to flooding.

The flowchart of the overall Methodology, including essential facility components, is shown in Section 2 (Figure 2-1).

8.1 Input Requirements and Output Information

Input requirements to estimate essential facility damage and direct economic loss in the Study Region include the following:

- Essential Facility parameters including location, occupancy class (or classification), building type, foundation type, first floor height above grade, number of stories, functional depth, flood protection, and building replacement cost[23]
- Depth and type of flood hazard at the site-specific building locations
- Damage functions appropriate for facility classification and flood hazard type

For users conducting a Level 1 analysis, the essential facility baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus (see Section 5.4) can be used to meet the input requirements.

The output from the application of the damage functions is an estimate of the expected percent damage to a building and its contents, a determination on if the facility will be functional, an estimated restoration time (provided as the estimated days to 100% functionality), and an estimate of direct economic losses for the building and contents of the essential facility (in thousands of dollars).

8.2 Essential Facility Parameters Related to Flood Damage

Facilities that provide services to the community and those that should be functional following a flood are Essential Facilities. Facilities designated in the Hazus Flood Model as essential include medical care facilities, police stations, fire stations, emergency centers, and schools. The *Hazus Inventory Technical Manual* (FEMA, 2024) provides more information about essential facility location, classification, flood protection and information on essential facility inventory default

[23] Please note that building age is not a required parameter within the Hazus Flood Model for estimating direct physical damage and direct economic losses to Essential Facilities.

parameters including building type, foundation type, first floor height above grade, number of stories, and functional depth.

8.3 Depth and Type of Flood Hazard at Site-Specific Locations

The depth of flooding at each essential facility is determined by an extract value to point geoprocessing tool that uses the flooding depth grid being utilized for the Study Region scenario, and the latitude and longitude of each facility. For combined riverine and coastal Study Regions where depth grids overlap, the flood hazard type (riverine or coastal) can be determined by the Controlling Hazard field in the Essential Facilities Damage and Economic Loss dialog.

Type of flooding is determined in the same way as for the GBS (see Section 5.4); however, the default damage functions for Essential Facilities are the same regardless of flood type (see Section 5.4).

8.4 Direct Physical Damage to Essential Facilities Due to Flooding

The following sections discuss the Methodology by which the Hazus Flood Essential Facility Module estimates the percent damage to essential facility buildings and contents, provides a determination on essential facility functionality following a flood event, and estimates restoration time (provided as the estimated days to 100% functionality).

8.4.1 Essential Facility Damage Estimates

The methods for estimating direct physical damage to Essential Facilities are very similar to those presented for determining direct physical damage to the GBS (see Section 5) except that hazard exposure is determined on a site-specific basis (see Section 8.3) and percent damage for each essential facility is interpolated from the one-foot depths shown in the damage function library based on flood depth at the facility location minus the first flood height above grade for that facility.

Vulnerability to flood damage is less dependent on building type and more related to the depth of flooding; therefore, damage functions developed for the GBS can be reasonably applied to other structures. For each class of essential facility, a default damage function for a selected occupancy class has been identified (see the *Hazus Inventory Technical Manual* (FEMA, 2024)).[24] For example, the default damage function for small, medium, and large hospitals (EFHS, EFHM, and EFHL), as shown in the Essential Facilities Damage Function dialog, are the same as the hospital occupancy class in the GBS (COM6).

[24] Please note that if the essential facility is assigned a Flood Protection level in the inventory greater than or equal to the scenario return period, then no damages will be reported for that component. All Essential Facilities have flood protection fields that can be modified in the inventory.

8.4.2 Essential Facility Functionality

The Hazus Flood Essential Facility Module estimates the number of facilities in each facility class that will be non-functional after a flood event. A determination is made based on the functional depth indicated for each facility classification in the Restoration Functions for Essential Facilities dialog. If the depth of flooding at the facility location exceeds the functional depth threshold by 0.1 feet or more, the facility will be considered non-functional. The default functional depths for each facility classification are provided in Table 7-4 in the *Hazus Inventory Technical Manual* (FEMA, 2024). Default parameters are editable in the Restoration Functions for Essential Facilities dialog.

8.4.3 Essential Facility Restoration Time

The Hazus Flood Essential Facility Module estimates the maximum restoration time for each essential facility impacted by flooding. The default restoration functions for each essential facility class are shown in Table 8-1 through Table 8-5 and are editable in Hazus via the Restoration Functions for Essential Facilities dialog.[25]

Table 8-1. Medical Care Facility Maximum Restoration Times

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFHL	Large Hospital (greater than 150 beds)	-4	0	360
EFHL	Large Hospital (greater than 150 beds)	0	4	540
EFHL	Large Hospital (greater than 150 beds)	4	8	720
EFHL	Large Hospital (greater than 150 beds)	8	25	900
EFHM	Medium Hospital (50 to 150 Beds)	-4	0	360
EFHM	Medium Hospital (50 to 150 Beds)	0	4	540
EFHM	Medium Hospital (50 to 150 Beds)	4	8	720
EFHM	Medium Hospital (50 to 150 Beds)	8	25	900
EFHS	Small Hospital (less than 50 Beds)	-4	0	360
EFHS	Small Hospital (less than 50 Beds)	0	4	540
EFHS	Small Hospital (less than 50 Beds)	4	8	720
EFHS	Small Hospital (less than 50 Beds)	8	25	900

[25] Please note that the Hazus Flood Model presents users with the Days to 100 Functionality regardless of if the facility is determined to be functional or nonfunctional based on the threshold depth. This error is reflected in the Essential Facilities Damage and Economic Loss dialog and in the summary report average.

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFMC	Medical Clinics and Labs	-4	0	360
EFMC	Medical Clinics and Labs	0	4	480
EFMC	Medical Clinics and Labs	4	8	630
EFMC	Medical Clinics and Labs	8	12	720
EFMC	Medical Clinics and Labs	12	25	900
MDFLT	Default for Medical	-4	0	360
MDFLT	Default for Medical	0	4	540
MDFLT	Default for Medical	4	8	720
MDFLT	Default for Medical	8	25	900

Table 8-2. Emergency Centers Maximum Restoration Times

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EDFLT	Default for Emergency Response Facility	-4	0	360
EDFLT	Default for Emergency Response Facility	0	4	480
EDFLT	Default for Emergency Response Facility	4	8	630
EDFLT	Default for Emergency Response Facility	8	12	720
EDFLT	Default for Emergency Response Facility	12	25	900
EFEO	Emergency Operation Centers	-4	0	360
EFEO	Emergency Operation Centers	0	4	480
EFEO	Emergency Operation Centers	4	8	630
EFEO	Emergency Operation Centers	8	12	720
EFEO	Emergency Operation Centers	12	25	900

Table 8-3. Fire Station Maximum Restoration Times

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFFS	Fire Station	-4	0	360
EFFS	Fire Station	0	4	480
EFFS	Fire Station	4	8	630
EFFS	Fire Station	8	12	720
EFFS	Fire Station	12	25	900
FDFLT	Default for Fire Station	-4	0	360
FDFLT	Default for Fire Station	0	4	480
FDFLT	Default for Fire Station	4	8	630
FDFLT	Default for Fire Station	8	12	720
FDFLT	Default for Fire Station	12	25	900

Table 8-4. Police Station Maximum Restoration Times

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFPS	Police Station	-4	0	360
EFPS	Police Station	0	4	480
EFPS	Police Station	4	8	630
EFPS	Police Station	8	12	720
EFPS	Police Station	12	25	900
PDFLT	Default for Police	-4	0	360
PDFLT	Default for Police	0	4	480
PDFLT	Default for Police	4	8	630
PDFLT	Default for Police	8	12	720
PDFLT	Default for Police	12	25	900

Table 8-5. School Maximum Restoration Times

Hazus Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFS1	Grade Schools (Primary and High Schools)	-4	0	360
EFS1	Grade Schools (Primary and High Schools)	0	4	480
EFS1	Grade Schools (Primary and High Schools)	4	8	630
EFS1	Grade Schools (Primary and High Schools)	8	12	720
EFS1	Grade Schools (Primary and High Schools)	12	25	900
EFS2	Colleges/Universities	-4	0	360
EFS2	Colleges/Universities	0	4	480
EFS2	Colleges/Universities	4	8	630
EFS2	Colleges/Universities	8	12	720
EFS2	Colleges/Universities	12	25	900
SDFLT	Default for School	-4	0	360
SDFLT	Default for School	0	4	480
SDFLT	Default for School	4	8	630
SDFLT	Default for School	8	12	720
SDFLT	Default for School	12	25	900

8.5 Direct Economic Losses to Essential Facilities Due to Flooding

The methods for estimating direct economic losses to Essential Facilities are identical to those presented for determining direct economic losses to the User-Defined Facilities (see Section 7.5). Losses are expressed in thousands of dollars.

8.6 Guidance for Expert Users

The following sections provide guidance for expert users who wish to make changes to the default parameters used in estimating direct physical damage and direct economic losses to Essential Facilities.

8.6.1 Selection of Alternate Damage Functions

The Hazus Flood Model provides the opportunity to compare and select alternative damage functions from the extensive library of damage functions within the model. The user can identify and select the preferred damage function to use in the estimation of damage to Essential Facilities by adjusting the BldgDamageFnID in the Essential Facilities Inventory dialog. Within any scenario that impacts that facility, the selected damage function is utilized by the Hazus Flood Model.

The damage function library includes fire and police station specific damage functions; however, these damage functions were not selected to be used as the default functions for these facility types. Users may select these functions for use in their Study Region if desired.

8.6.2 Floodproofing of Essential Facilities

Floodproofing of Essential Facilities can be accounted for by modifying existing damage functions to reflect the level of expected protection from the floodproofing measures or by creating a custom damage function for specific floodproofed facilities. See the *Hazus Flood Model User Guidance* (FEMA, 2024) for more information.

Section 9. Transportation Systems – Direct Physical Damage and Direct Economic Loss

The Hazus Flood Transportation Systems Module provides site-specific estimates of direct physical damage and direct economic losses for select Transportation System Components due to flooding. Highway bridges are the only Transportation System Components analyzed by the software for the flood hazard. Damage functions are included within the Hazus Flood Model for railway and light rail bridges; however, due to an existing defect, no analyses are performed. The remaining system components (buses, ports, ferries, and airports) can be viewed and mapped within the Hazus Flood Model but are not analyzed, and damage or loss estimates are not produced.

The flowchart of the overall Methodology, including Transportation System Components, is shown in Section 2 (Figure 2-1).

9.1 Input Requirements and Output Information

Input requirements to estimate bridge damage and direct economic loss in the Study Region include the following:

- Bridge parameters including location, bridge class, scour index rating, and bridge valuation
- Presence of flood hazard at the site-specific bridge locations
- Probabilities of failure for bridge classes at various flood intervals

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default failure probabilities provided with Hazus can be used to meet the input requirements.

The output from the analysis is an estimate of the expected damage (expressed as a probability of failure), an estimate of the probability that the bridge will be functional, and an estimate of repair and replacement costs (in thousands of dollars).

9.2 Bridge Parameters Related to Flood Damage

Hazus includes the National Bridge Inventory (NBI) database as part of the baseline inventory. For more information on the location, classification, and value of bridges, see the *Hazus Inventory Technical Manual* (FEMA, 2024).

The scour potential index (Scour Index) describes the susceptibility of erosion surrounding bridge foundations. The Hazus Flood Transportation Systems Module only analyzes a subset of bridges with scour index categories more prone to failure (1-3 and U). The scour index categories are derived from the NBI data and are described in Table 9-1.

Table 9-1. Scour Potential Index Descriptions and Hazus Analysis Status

Scour Index Category	Description	Hazus Analysis Status
0	Bridge identified as structurally deficient. Bridge is closed to traffic.	Not Analyzed
1	Bridge is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.	Analyzed
2	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations.	Analyzed
3	Bridge is scour critical; bridge foundations determined to be unstable for assessed or calculated scour conditions.	Analyzed
4	Bridge foundation is determined to be stable for assessed or calculated scour conditions; field review indicates action is required to protect exposed foundations.	Not Analyzed
5	Bridge foundation is determined to be stable for assessed or calculated scour condition.	Not Analyzed
6	Scour calculation/evaluation has not been made.	Not Analyzed
7	Countermeasures have been installed to mitigate an existing problem with scour and to reduce the risk of bridge failure during a flood event.	Not Analyzed
8	Bridge foundations determined to be stable for the assessed or calculated scour condition.	Not Analyzed
9	Bridge foundations (including piles) on dry land well above flood water elevations.	Not Analyzed
T	Bridge over "tidal" waters that has not been evaluated for scour but considered low risk.	Not Analyzed
U	Bridge with "unknown" foundation that has not been evaluated for scour.	Analyzed (Treated as category 1)
N	Bridge not over waterway.	Not Analyzed

9.3 Presence of Flooding at Bridge Location

The Hazus Flood Model identifies bridges within a Study Region that are exposed to flooding by using an extract value to point geoprocessing tool that uses bridge latitude and longitude to identify those bridges where flood depths are greater than 0 feet. If the bridge is inundated (exposed to flood depths greater than 0 feet), then Hazus checks the bridge’s scour index rating in the highway bridge inventory. An analysis is performed on only those bridges with scour index categories of 1-3 and U as shown in Table 9-1. The depth and type of flooding do not impact results.

9.4 Direct Physical Damage to Bridges Due to Flooding

Typically, flooding causes damage to Transportation System Components through either inundation, scour/erosion, or debris impact/hydraulic loading. Inundation causes water to submerge the component (partially or completely), causing damage through water exposure. Scour/erosion can occur when floodwaters flow with higher velocity, undermining supports or foundations by eroding the soil beneath. Debris impact/hydraulic loading can occur when high-velocity floodwaters flow above flood stage and carry debris such as limbs, trees, rocks, or other items that can impact components or become lodged in areas causing additional pressure on system components.

9.4.1 Probability of Bridge Failure

Due to a lack of a comprehensive nationwide database of bridge damage, the damage relationships for bridges included in the Hazus Flood Model are estimates based on the best available information and expert opinion. The damage relationships presented have not been calibrated and use probability of failure as a proxy for damage. “Failure,” in this instance, is loss of function due to scour damage.

Most bridge failures are single spans. Scour of bridge piers on continuous spans does not usually result in collapse. Similarly, bridges with multiple piers provide redundancy that reduces their vulnerability. Though the span type is included in the NBI database, the number of piers is not included. Overall, the Hazus Flood Model damage functions for continuous span bridges assume damages to be reduced to 25% of that expected for single span bridges.

Table 9-2 shows a sample of the default probability of bridge failure assumptions for single-span and continuous-span bridges.[26] Probability of failure functions are provided in the Damage Functions for Transportation Systems dialog under the Analysis menu from 0 to 1,000-year recurrence intervals for every 25 years. The recurrence interval selected when delineating the floodplain drives the recurrence interval selection for each bridge being analyzed. Results are interpolated between recurrence intervals as needed (e.g., if the recurrence interval is set to 10, the results will be between the probability for failure shown for 0 and 25).

[26] Please note that the Damage Functions for Transportation System dialog under the Analysis menu displays Probability of Bridge Failure as decimals while the Transportation System Damage and Economic Loss dialog under the Results menu provides results as percentages. The probability of failure functions must be multiplied by 100 in order to match results.

Table 9-2. Probability of Bridge Failure Relative to Scour Damage and Span Type

Flood Return Period	Probability of Bridge Failure[1]		
	1	2	3
Single-Span Bridges			
100-year	5%	2%	1%
500-year (2 x 100-year probability)	10%	4%	2%
1,000-year (1.5 x 500-year probability)	15%	6%	3%
Continuous-Span Bridges			
100-year	1.25%	0.5%	0.25%
500-year (2 x 100-year probability)	2.5%	1%	0.5%
1,000-year (1.5 x 500-year probability)	3.75%	1.5%	0.75%

Note: See the Damage Functions for Transportation System dialog under the Analysis menu for the full array of probabilities of bridge failure relative to scour damage and span type.

1. *The Scour Potential is a field in the Hazus Bridge database and is from the Federal Highway Administration National Bridge Inventory*

9.4.2 Probability of Bridge Functionality

The Hazus Flood Model provides an estimate of the probability a bridge will be functional for bridges that have been identified as inundated and have a scour index category of 1-3 or U (see Table 9-1). The probability of a bridge being functional is estimated by determining the probability that a bridge will not fail (Equation 9-1).

Equation 9-1. Probability of Bridge Functionality

$$\text{Probability of Being Functional (PctFunctional)} = 1 - \text{Probability of Failure}$$

See Table 9-2 for Probability of Failure information.

9.5 Direct Economic Loss to Bridges Due to Flooding

The Hazus Flood Model estimates the direct economic losses to bridges due to flooding using the probability of failure as a proxy for percent damage to calculate repair and replacement costs (Equation 9-2). Losses are expressed in thousands of dollars.

Equation 9-2. Bridge Repair and Replacement Costs

$$\text{Repair and Replacement Cost (LossUSD)} = \text{Probability of Failure} \times \text{Inventory \$ Value (Costs)}$$

See Table 9-2 for Probability of Failure information.

9.6 Guidance for Expert Users

Baseline values for bridges are provided as a guide. It is recommended that the user input more accurate replacement values based on knowledge of bridge values in the region when possible. See the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information on how baseline values were derived.

Section 10. Utility Systems - Direct Physical Damage and Direct Economic Loss

The Hazus Flood Utility Systems Module provides site-specific estimates of direct physical damage and direct economic losses for select utility system components due to flooding. Table 10-1 provides the Utility System Components included in the baseline inventory in Hazus, and the Hazus analysis capability for each facility type.

The flowchart of the overall Methodology, including utility system components, is shown in Section 2 (Figure 2-1).

Table 10-1. Utility System Components and Hazus Analysis Capabilities

Facility Type[1]	Hazus Analysis Capabilities
Potable Water System Facilities	Direct Physical Damage & Direct Economic Loss
Potable Water Network System Pumps	Direct Physical Damage & Direct Economic Loss
Potable Water Control Vaults & Control Stations	Direct Physical Damage & Direct Economic Loss
Potable Water Network System Tanks	Direct Physical Damage & Direct Economic Loss
Potable Water Network System Wells	Direct Physical Damage & Direct Economic Loss
Potable Water Pipelines Segments	Mapping Only Capabilities
Wastewater Treatment Plants	Direct Physical Damage & Direct Economic Loss
Wastewater Lift Stations	Direct Physical Damage & Direct Economic Loss
Wastewater Control Vaults & Control Stations	Direct Physical Damage & Direct Economic Loss
Wastewater Water Pipelines	Mapping Only Capabilities
Oil Refineries	Direct Physical Damage & Direct Economic Loss
Oil Pumping Plants	Direct Physical Damage & Direct Economic Loss
Oil Tank Farm	Direct Physical Damage & Direct Economic Loss
Oil Control Vaults & Control Stations	Direct Physical Damage & Direct Economic Loss
Oil Pipelines	Mapping Only Capabilities
Natural Gas Compressor Plants	Direct Physical Damage & Direct Economic Loss
Natural Gas Control Vaults and Control Stations	Direct Physical Damage & Direct Economic Loss
Natural Gas Natural Gas Pipelines	Mapping Only Capabilities

Facility Type[1]	Hazus Analysis Capabilities
Electric Power Plants	Mapping Only Capabilities
Electric Power Substations	Mapping Only Capabilities
Communications Central Offices and Switching Stations	Mapping Only Capabilities
Communications Control Vaults and Control Stations	Mapping Only Capabilities
Communications Broadcast Facility	Mapping Only Capabilities

1. *For Hazus Labels for each facility type, see the Hazus Inventory Technical Manual (FEMA, 2024) or the Utility Systems Classification dialog under the Inventory menu.*

10.1 Input Requirements and Output Information

Input requirements to estimate utility system damage and losses in the Study Region include the following:

- Utility System Component parameters including location, utility classification, equipment height, functional depth, flood protection, and building replacement cost
- Depth of flood hazard at the site-specific component locations
- Damage functions appropriate for Utility System Component

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus can be used to meet the input requirements.

The output from the application of the damage functions is an estimate of percent damage of the system component, a determination of the system component functionality following a flood event, and direct economic losses for the system component (in thousands of dollars).

10.2 Utility System Component Parameters Related to Flood Damage

See the *Hazus Inventory Technical Manual* (FEMA, 2024) for information about Utility System Component location, classification, equipment height, functional depth, and flood protection.

10.3 Depth and Type of Flooding at Site-Specific Locations

The depth of flooding at each Utility System Component is determined by an extract value to point geoprocessing tool that uses the flood depth grid for the Study Region scenario and the latitude and longitude of each Utility System Component. The type of flooding does not impact results.

10.4 Direct Physical Damage to Utility System Components Due to Flooding

The following sections discuss the Methodology by which the Hazus Flood Utility Systems Module estimates the percent damage to Utility System Components and provides a determination on the Utility System Component functionality following a flood event.

10.4.1 Utility System Component Damage Estimates

The Hazus Flood Model provides damage estimates for select potable water, wastewater, oil, and natural gas facilities (see Table 10-1). The damage functions for these Utility System Components are similar to the damage functions used in the GBS (see Section 5.4.1). The depth of flooding at the Utility System Component location is compared to the height of critical equipment components, as indicated in the inventory, and the amount of damage is estimated.[27] In the Hazus Flood Model, Utility System Components reach maximum damage at 10 feet of flooding.

The default damage functions for each Utility System Component can be viewed in Hazus in the Damage Functions for Utility System dialog.[28,29] For all Utility System Components, changing the damage function ID in the Utility Systems Inventory dialog (editing the DamageFunction field) does not change the damage function used to analyze the facility. Selecting a different damage function from the Damage Functions for Utility Systems dialog correctly changes the damage function of the selected Utility System Component type.

Equation 10-1 shows how Hazus calculates the percent damage estimate for each Utility System Component using the Utility System Component damage functions.[30]

Equation 10-1. Utility System Component Percent Damage Estimate

$$\%\ \text{Damage} = \text{Damage function damage at (depth of water at facility location} - \text{equipment height)}$$

[27] Please note that there is a known issue within the Hazus Flood Utility Systems Module where default utility equipment heights, as indicated in the *Hazus Inventory Technical Manual* (FEMA, 2024) and viewable in the Damage Functions for Utility Systems dialog under the Analysis menu, are not used consistently across the baseline state inventories. Most default values in the baseline utility system inventory are 0.

[28] The Hazus Flood Model contains default damage functions for electric power facilities viewable in the Damage Functions for Utility Systems dialog; however, these damage functions are not enabled, and no results will be produced for electric power facilities included in the inventory.

[29] Please note that there is a known defect where the Facility Class for Potable Water Facilities is not able to be changed and saved within the Hazus Utility Systems Inventory dialog.

[30] Please note that if the Utility System Component is assigned a Flood Protection level in the inventory greater than or equal to the scenario return period, then no damages will be reported for that component. All Utility System Components aside from pipelines (potable water, wastewater, oil, and natural gas) and communication facilities have flood protection fields that can be modified in the inventory.

Where: Equipment heights is rounded to the nearest whole number with 0.5 feet and below rounding down and 0.51 and above rounding up

The Hazus Flood Model extrapolates the percent damage between the 1-foot increments listed in the Damage Functions for Utility Systems dialog. Figure 10-1 provides a graphical example of the default damage function for a default wastewater facility (WDFLT).

Equation 10-2 provides an example of how Equation 10-1 is applied using the default damage functions and equipment height at 8.5 feet of water depth at the component location.

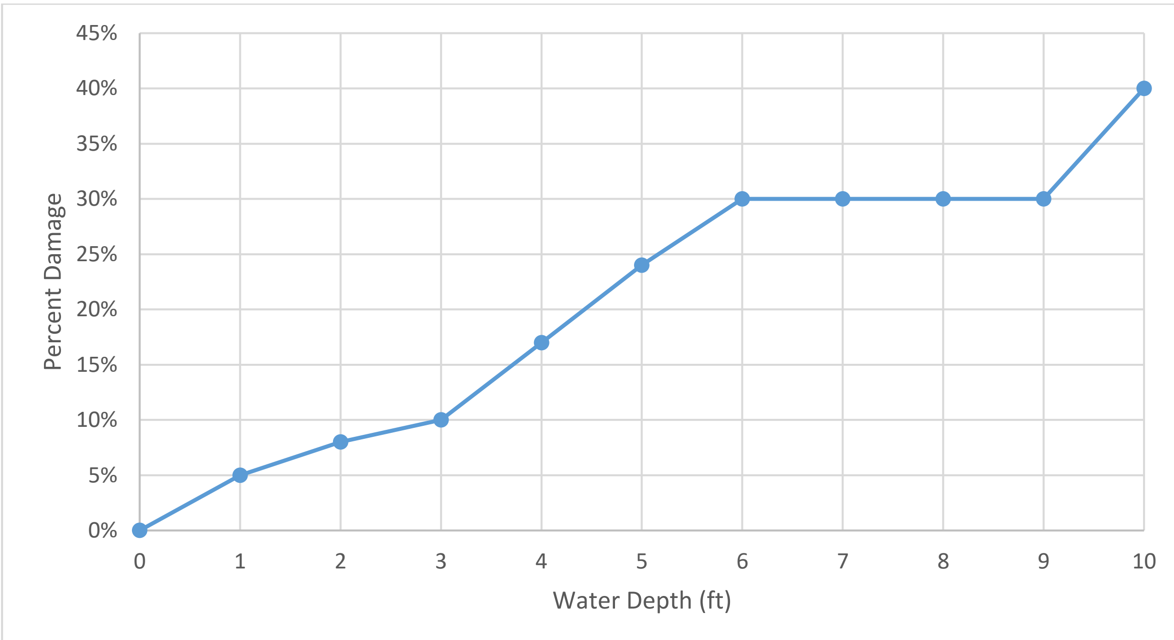

Figure 10-1. Default Damage Function for Default Wastewater Facility (WDFLT)

Equation 10-2. Wastewater Facility (WDFLT) Percent Damage Estimate Example

$$27\% \text{ Damage} = \text{WDFLT damage function damage at } 5.5 \text{ ft } (8.5 \text{ ft depth} - 3 \text{ ft equipment height})$$

10.4.2 Utility System Component Functionality

The Hazus Flood Utility Systems Module estimates the number of each Utility System Component that will be non-functional after a flood event. In the Hazus Flood Model, Utility System Component functionality is based primarily on an estimation of damage to critical equipment rather than building damage.[31] A determination is made based on the functional depth indicated for each facility type in

[31] Please note that the functional depth for Utility Systems Components is not editable by the user and is not directly linked to the equipment height specified for each component in the inventory. As a result, if changes are made to the default

the Damage Functions for Utility Systems dialog. If the depth of flooding at the component location exceeds the functional depth threshold by 0.1 feet or more, the component will be considered non-functional. For additional information on assumptions regarding equipment height and functionality, see the *Hazus Inventory Technical Manual (FEMA, 2024).*

10.5 Direct Economic Loss to Utility System Components Due to Flooding

The Hazus Flood Model estimates the direct economic losses to Utility System Components by multiplying the percent damage estimated via the application of damage functions (see Equation 10-1) by the valuation of the component as provided in the Utility System Component inventory (Equation 10-3). Losses are expressed in thousands of dollars.

Equation 10-3. Utility System Repair and Replacement Costs

$$\text{Repair and Replacement Cost (LossUSD)} = \text{\% Damage (DamagePct)} \times \text{Inventory \$ value (Costs)}$$

10.6 Guidance for Expert Users

The following sections provide guidance for expert users who wish to make changes to the default parameters used in estimating direct physical damage and direct economic losses to Utility System Components.

10.6.1 Baseline Values for Utility System Components

Baseline values for Utility System Components are provided as a guide. It is recommended that the user input more accurate repair and replacement values based on knowledge of facility values in the region when possible. See the *Hazus Inventory Technical Manual* (FEMA, 2024) for more information on how baseline values were derived.

10.6.2 Utility System Components with Varied Equipment Height Elevations

For some facilities, such as treatment plants, there may be multiple structures with different equipment height elevations. For these facilities, the default elevation height parameter can be modified to select the elevation that best represents the vulnerability of the overall facility. One approach might be to select the equipment height elevation of the facility with key process electrical equipment. Another approach would be to enhance the baseline inventory with additional inventory items for each component structure.

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equipment height assumptions in the inventory, functionality determinations will not reflect those changes. Similarly, the functional depth for Utility Systems and level of flood protection indicated in the inventory are also not linked in Hazus. If a system component is assigned a level of flood protection greater than or equal to the scenario return period, the component may be shown as non-functional regardless of its protection from the flood event.

Section 11. Vehicles - Direct Physical Damage & Direct Economic Loss

Motor vehicles of all types can be damaged during flood events. These damages can be significant, particularly for events with limited warning. The Hazus Flood Model estimates the dollar value of flood related damages to vehicles and the number of vehicles damaged due to flooding, for vehicle data provided by the user. By default, the vehicle inventory in Hazus is blank.

The flowchart of the Methodology, including vehicle components, is shown in Section 2 (Figure 2-1).

11.1 Input Requirements and Output Information

Input requirements to estimate vehicle damage and direct economic loss in the Study Region include the following:

- Vehicle parameters including location, vehicle classification, vehicle counts, and the value of vehicle inventory (provided by user)
- Depth of flooding hazard throughout the Census block
- Damage functions appropriate for each vehicle type

For users conducting a Hazus Level 1 analysis, there is no baseline or default vehicle data provided in Hazus. If the user provides their own vehicle data, the Hazus-generated flood hazard information (see Section 4.1), and default damage functions provided with Hazus (see Section 11.4.1) can be used to meet the input requirements.

The output from the application of the damage functions is an estimate of the number of vehicles in each damage state (intervals of 10% damage), the total number of damaged vehicles, the total number of undamaged vehicles, and an estimate of the direct economic loss by Census block, vehicle type, and by day or by night (in dollars).

11.2 Vehicle Parameters Related to Flood Damage

Vehicle parameters related to flood damage include the location, classification, counts, and value of the vehicle inventory within a Study Region. The *Hazus Inventory Technical Manual* (FEMA, 2024) provides information on how to develop a baseline inventory of vehicles in Hazus, including how the number, location (day and night), distribution of classifications, and values can be derived. Please note that the inventory is split between used vehicles and new vehicles for valuation purposes; however, the results do not make this distinction and are a summation over the two classes.

11.2.1 Vehicle Classification

Hazus classifies vehicles into three types: cars, light trucks (LtTrk), or heavy trucks (HvyTrk). The classification of the vehicle determines the vehicle profile, which is used to determine the direct damage to the vehicle from inundation at various flood depths as various components of the vehicle are exposed to flood waters. Table 11-1 shows the generalized profiles for each vehicle type from which the vehicle depth damage functions were derived.

Table 11-1. General Profile for Each Vehicle Type

Vehicle Classification	Vehicle Height (ft)[1]	Below Carpet (ft)	Between Carpet & Dashboard (ft)	Above Dashboard (ft)
Car	1.5	<1.5	1.5-2.4	>2.4
Light Truck	2.7	<2.7	2.7-3.7	>3.7
Heavy Truck	5	<5	5-7.5	>7.5

1. *Vehicle height indicates the height above ground.*

11.2.2 Vehicle Location

Vehicle locations are determined by the GBS as shown in the Vehicles Table within the Inventory Menu (see the Hazus Flood User Guidance (FEMA, 2024) and Section 11 of the *Hazus Inventory Technical Manual* (FEMA, 2024)). Vehicle inventory provided by the user is assumed to be distributed evenly over each dasymetric Census block. There are no parameters for the elevation of the vehicle as this is implicit in the damage functions.

11.3 Depth and Type of Flooding throughout the Census Block

Depth of flooding throughout the Census block is determined in 0.5-foot increments in the same fashion as for the GBS analysis (please see Section **Error! Reference source not found.**). The type of flooding does not impact results in the Hazus Flood Vehicle Module.

11.4 Direct Physical Damage to Vehicles Due to Flooding

The following sections discuss the Methodology by which the Hazus Flood Vehicle Module estimates the number of vehicles in each damage state (intervals of 10% damage), the total number of damaged vehicles, and the total number of undamaged vehicles.

11.4.1 Vehicle Damage Functions

For each vehicle type, the percentage of damage for the flood depth is estimated depending, roughly, on whether the flood is below the carpet, between the carpet and the dashboard, or above dashboard (see Section 11.2.1). Flood damages are estimated for each vehicle type in 0.5-foot increments from 0 to 13.5 feet. The damage functions can be seen in Figure 11-1 below and are visible to the user in foot increments via the Analysis menu in Hazus.[32, 33]

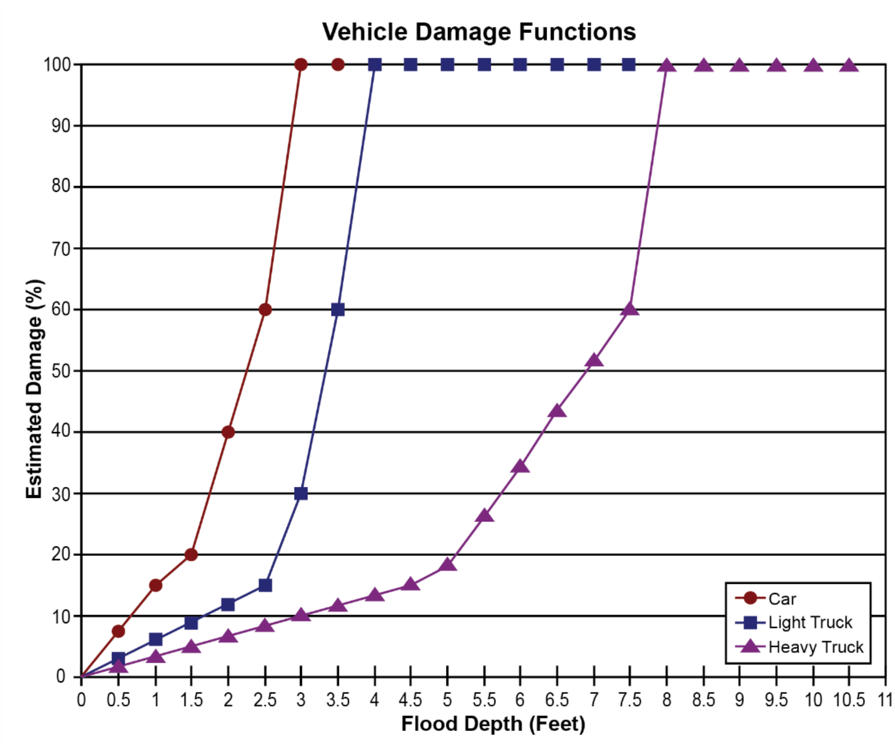

Figure 11-1. Vehicle Damage Functions

11.4.2 Vehicles Damaged Due to Flooding

The number of damaged vehicles in each damage state (intervals of 10% damage) is estimated by multiplying the damage percent at the given flood depth for the given vehicle type (see Figure 11-1), by the percentage of the Census block at the given flood depth (in half foot increments), by the day and night vehicle counts (see Equation 11-1).

The total damaged vehicles per Census block is the sum of these damage counts for each vehicle type and flood depth present in the Census block. These counts are established by rounding partial vehicle counts: a vehicle count for a given type at a given flood depth of less than .5 will round to 0 vehicles damaged, while a vehicle count of .5 or greater will round to 1 vehicle damaged. The total undamaged vehicles per Census block is calculated using vehicle counts in only those Census blocks where damaged vehicles equal 0.

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[32] Please note that the damage function library uses the terminology “occupancy” to describe vehicle type and “stories” to describe vehicle height.

[33] Please note that default damage functions cannot be edited by the user directly within Hazus.

Please note that vehicle damage counts by type should be used with caution due to the way counts are calculated and rounded in Hazus. Significant under- or over-reporting may occur depending on the specific parameters of the flood hazard being analyzed. Direct economic loss results (see Section 11.5) are more accurate estimates of vehicle losses.[34]

Equation 11-1. Damaged Vehicle Counts by Percent Damage and by Type

$$\text{Count Damaged by Type} = \text{A} \times \text{DP} \times \text{TypeCount}$$

Where:

A	the percent of the Census block area at the given flood depth
DP	the damage percent at the given flood depth for the given vehicle type
TypeCount	the total count of Cars, LtTrk, or HvyTrk for the given Census block

11.5 Direct Economic Losses to Vehicles Due to Flooding

The Hazus Flood Model estimates direct economic losses to vehicles due to flooding by multiplying the total dollar exposure in each Census block for each vehicle type, by the percentage of the Census block at the given flood depth, by the damage percent for that flood depth (see Equation 11-2). The total dollar loss per Census block is the sum of the estimated losses for each vehicle type at each flood depth present in the Census block.

Equation 11-2. Vehicle Repair and Replacement Costs by Type

$$\text{Loss by Type(\$)} = \text{A} \times \text{DP} \times \text{TypeExp}$$

Where:

A	the percent of the Census block area at the given flood depth
DP	the damage percent at the given flood depth for the given vehicle type (derived from the damage functions, see Section 11.4.1)
TypeExp	the total dollar exposure of Cars, LtTrk, or HvyTrk for the given Census block

[34] Please note that there is a known defect impacting mapping of vehicle damage results. When results are mapped, only information for cars is displayed and no information is mapped for light or heavy trucks.

Section 12. Induced Damage Module – Debris

Debris disposal can be a significant issue following floods. Flood debris can include flood-damaged building finishes (e.g., carpeting, drywall) and contents (e.g., furniture, appliances), and, in extreme cases, materials from buildings requiring major structural repair or demolition. Flood-fighting efforts and the floodwaters themselves add additional debris, such as sandbags, mud, and sediment. The Hazus Flood Debris Module provides estimates for building-related debris (finishes, structure, and foundation) and does not address building contents or additional debris loads, such as vegetation and sediment.

The flowchart of the overall Methodology, including debris components, is shown in Section 2 (Figure 2-1).

12.1 Input Requirements and Output Information

Input requirements to estimate the expected amounts of debris generated within each Census block in the Study Region include the following:

- Building inventory parameters including square footage by occupancy class and foundation distributions for each Census block
- Depth of flooding throughout the Census block
- Analysis parameters related to debris generation including estimated debris weights by debris type and depth of flooding

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default analysis parameters provided with Hazus can be used to meet the input requirements.

Output from the Hazus Flood Debris Module is an estimate of the debris weight (in tons) by Census block for each type of debris, which are building finishes, structural components, and foundation materials. The Hazus Flood Model does not estimate debris loads associated with building contents, vegetation, sediment, and other natural debris carried by floodwaters.[35]

12.2 Building Inventory Parameters Related to Debris Estimation

The Hazus Flood Model uses the building square footage by occupancy class and foundation types to estimate the tons of debris that will be generated after a flood. Study Region specific information can be viewed via the GBS Square Footage and Flood Specific Occupancy Mapping dialogs under the

[35] For additional information on debris management, the reader is referred to material published by the Environmental Protection Agency (US EPA, 2019) and FEMA (FEMA, 2007).

Inventory menu.[36] Debris estimates are not produced for non-GBS inventory, such as Essential Facilities or User-Defined Facilities.

To implement the Hazus Flood Debris Module, the flood foundation types for pre- and post- FIRM buildings in each Census block, shown in the Flood Specific Occupancy Mapping dialog, are reclassified by Hazus into general foundation types used for debris estimation: slab and footing. Table 12-1 provides the association of the detailed foundation types into the more general foundation types. For additional information on the detailed foundation types, see Section 5.6.1 of the *Hazus Inventory Technical Manual* (FEMA, 2024).

Table 12-1. Foundation Types for Debris Estimation

Foundation Types Considered Slab	Foundation Types Considered Footing
Fill	Basement or Garden-Level Basement
Slab-on-Grade	Crawlspace
	Pier
	Pile
	Solid wall

12.3 Depth and Type of Flooding throughout the Census Block

Depth of flooding throughout the Census block is determined in the same fashion as for the GBS analysis (see Section **Error! Reference source not found.**). Type of flooding does not impact debris results.

12.4 Analysis Parameters Related to Debris Generation

The Hazus Flood Model debris estimation Methodology was developed using a simplified engineering-based factor analysis to identify building components requiring replacement (e.g., wood sub-floor, carpet, wall finishes) at various depths of water and to estimate their weight.

12.4.1 Debris Weights by Occupancy Class and Flood Depth

For each occupancy class, debris type weights have been estimated as an average of typical model building types associated with that occupancy class. These default parameters can be viewed and modified in the Debris Parameters dialog under the Analysis menu. Table 12-2 provides the debris

[36] Please note that the baseline inventory includes a “basement” field that is not being used in debris calculations. The Hazus Flood Debris Module utilizes foundation mapping schemes as shown in the Flood Specific Occupancy Mapping dialog.

weights by occupancy class and flood depth for footing foundations, and Table 12-3 provides the debris weights by occupancy class and flood depth for slab foundations (see Section 12.2).

In most, but not all, cases, the greatest flood depths and the corresponding debris weights for each occupancy class in Table 12-2 and Table 12-3 assume that the entire building will be demolished with no salvage. This means that the weights for finishes, structure, and foundation debris sum to the entire estimated weight of the building. There is a known limitation with this Methodology in that buildings with basements (classified as footing) often include concrete slabs; however, their weight is not being included in the foundation debris weight in Hazus calculations. For the purposes of estimating debris, the Hazus Flood Model assumes that a basement does not have a slab foundation. This limitation only applies to basements that have slab foundations.

Table 12-2. Debris Weights by Occupancy Class and Flood Depth for Footing Foundations

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
AGR1	0	25	0	0	0
COM1	-4	0	2.5	0	0
COM1	0	4	4.3	0	0
COM1	4	8	5	0	0
COM1	8	12	6.8	0	0
COM1	12	25	7.5	47.1	2.1
COM2	-4	0	2.5	0	0
COM2	0	4	3	0	0
COM2	4	8	3.5	0	0
COM2	8	12	4	0	0
COM2	12	25	4.5	50.4	5.2
COM3	-4	0	2.5	0	0
COM3	0	4	3	0	0
COM3	4	8	3.5	0	0
COM3	8	12	4	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft²)	Structure Debris Weight (tons/1,000 ft²)	Foundation Debris Weight (tons/1,000 ft²)
COM3	12	25	4.5	43.7	8.7
COM4	-4	0	2.5	0	0
COM4	0	4	4.3	0	0
COM4	4	8	5	0	0
COM4	8	12	6.8	0	0
COM4	12	25	7.5	30.3	7.5
COM5	-4	0	2.5	0	0
COM5	0	4	4.3	0	0
COM5	4	8	5	0	0
COM5	8	12	6.8	0	0
COM5	12	25	7.5	23.5	8.7
COM6	-4	0	2.5	0	0
COM6	0	4	5.9	0	0
COM6	4	8	8.3	0	0
COM6	8	12	11.7	0	0
COM6	12	25	14.4	0	0
COM7	-4	0	2.5	0	0
COM7	0	4	4.3	0	0
COM7	4	8	5	0	0
COM7	8	12	6.8	0	0
COM7	12	25	7.5	31.3	8.7
COM8	-4	0	2.5	0	0
COM8	0	4	3.5	0	0
COM8	4	8	3.8	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
COM8	8	12	5.3	0	0
COM8	12	25	5.8	26.9	8.7
COM9	-4	0	2.5	0	0
COM9	0	4	3.5	0	0
COM9	4	8	3.8	0	0
COM9	8	12	5.3	0	0
COM9	12	25	5.8	44.9	8.7
COM10	0	25	0	0	0
EDU1	-4	0	2	0	0
EDU1	0	4	3.3	0	0
EDU1	4	8	4	0	0
EDU1	8	12	5.3	0	0
EDU1	12	25	7.3	30.4	21.3
EDU2	-4	0	2	0	0
EDU2	0	4	3.3	0	0
EDU2	4	8	4	0	0
EDU2	8	12	5.3	0	0
EDU2	12	25	7.3	30.4	21.3
GOV1	-4	0	2.5	0	0
GOV1	0	4	4.3	0	0
GOV1	4	8	5	0	0
GOV1	8	12	6.8	0	0
GOV1	12	25	7.5	31.3	8.7
GOV2	-4	0	1	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft²)	Structure Debris Weight (tons/1,000 ft²)	Foundation Debris Weight (tons/1,000 ft²)
GOV2	0	4	1.5	0	0
GOV2	4	8	1.7	0	0
GOV2	8	12	2.5	0	0
GOV2	12	25	2.7	50.4	5.2
IND1	-4	0	0	0	0
IND1	0	4	0.5	0	0
IND1	4	8	0.7	0	0
IND1	8	12	1.5	0	0
IND1	12	25	1.7	50.4	5.2
IND2	-4	0	0	0	0
IND2	0	4	0.5	0	0
IND2	4	8	0.7	0	0
IND2	8	12	1.5	0	0
IND2	12	25	1.7	40.2	5.2
IND3	-4	0	0	0	0
IND3	0	4	0.5	0	0
IND3	4	8	0.7	0	0
IND3	8	12	1.5	0	0
IND3	12	25	1.7	49.8	5.2
IND4	-4	0	0	0	0
IND4	0	4	0.5	0	0
IND4	4	8	0.7	0	0
IND4	8	12	1.5	0	0
IND4	12	25	1.7	34.8	5.2

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
IND5	-4	0	0	0	0
IND5	0	4	0.5	0	0
IND5	4	8	0.7	0	0
IND5	8	12	1.5	0	0
IND5	12	25	1.7	58.3	5.2
IND6	-4	0	0	0	0
IND6	0	4	1.8	0	0
IND6	4	8	2.5	0	0
IND6	8	12	4.3	0	0
IND6	12	25	5	34	5.2
REL1	-4	0	0	0	0
REL1	0	4	1	0	0
REL1	4	8	1.3	0	0
REL1	8	12	2.8	0	0
REL1	12	25	3.1	32.5	8.7
RES1	-4	0	4.7	0	0
RES1	0	6	6.5	0	0
RES1	6	25	8.5	19.3	12
RES2	0	1	4.1	0	0
RES2	1	25	6.5	10	12
RES3A	-4	0	4.7	0	0
RES3A	0	4	5.9	0	0
RES3A	4	8	8.6	0	0
RES3A	8	25	12.7	6.5	12

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
RES3B	-4	0	4.7	0	0
RES3B	0	4	5.9	0	0
RES3B	4	8	8.6	0	0
RES3B	8	25	12.7	6.5	13.8
RES3C	-4	0	4.7	0	0
RES3C	0	4	5.9	0	0
RES3C	4	8	8.6	0	0
RES3C	8	12	12.7	0	0
RES3C	12	25	15.4	6.5	13.8
RES3D	-4	0	4.7	0	0
RES3D	0	4	5.9	0	0
RES3D	4	8	8.6	0	0
RES3D	8	12	12.7	0	0
RES3D	12	25	15.4	6.5	13.8
RES3E	-4	0	4.7	0	0
RES3E	0	4	5.9	0	0
RES3E	4	8	8.6	0	0
RES3E	8	12	12.7	0	0
RES3E	12	25	15.4	47.8	19
RES3F	-4	0	4.7	0	0
RES3F	0	4	5.9	0	0
RES3F	4	8	8.6	0	0
RES3F	8	12	12.7	0	0
RES3F	12	25	15.4	47.8	19

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
RES4	-4	0	4.7	0	0
RES4	0	4	5.9	0	0
RES4	4	8	8.6	0	0
RES4	8	12	12.7	0	0
RES4	12	25	15.4	58.6	9.9
RES5	-4	0	4.7	0	0
RES5	0	4	5.9	0	0
RES5	4	8	8.6	0	0
RES5	8	12	12.7	0	0
RES5	12	25	15.4	68.7	18.3
RES6	-4	0	4.7	0	0
RES6	0	4	5.9	0	0
RES6	4	8	8.6	0	0
RES6	8	12	12.7	0	0
RES6	12	25	15.4	6.5	12

Table 12-3. Debris Weights by Occupancy Class and Flood Depth for Slab Foundations

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
AGR1	0	25	0	0	0
COM1	0	4	1.8	0	0
COM1	4	8	2.5	0	0
COM1	8	12	4.3	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
COM1	12	25	5	47.1	25
COM2	0	4	0.5	0	0
COM2	4	8	1	0	0
COM2	8	12	1.5	0	0
COM2	12	25	2	50.4	37.5
COM3	0	4	0.5	0	0
COM3	4	8	1	0	0
COM3	8	12	1.5	0	0
COM3	12	25	2	43.7	25
COM4	0	4	1.8	0	0
COM4	4	8	2.5	0	0
COM4	8	12	4.3	0	0
COM4	12	25	5	30.3	25
COM5	0	4	1.8	0	0
COM5	4	8	2.5	0	0
COM5	8	12	4.3	0	0
COM5	12	25	5	23.5	25
COM6	0	4	0	0	0
COM6	4	8	0	0	0
COM6	8	12	0	0	0
COM6	12	25	0	0	0
COM7	0	4	1.8	0	0
COM7	4	8	2.5	0	0
COM7	8	12	4.3	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
COM7	12	25	5	31.3	25
COM8	0	4	1	0	0
COM8	4	8	1.3	0	0
COM8	8	12	2.8	0	0
COM8	12	25	3.1	26.9	25
COM9	0	4	1	0	0
COM9	4	8	1.3	0	0
COM9	8	12	2.8	0	0
COM9	12	25	3.1	44.9	25
COM10	0	25	0	0	0
EDU1	0	4	1.3	0	0
EDU1	4	8	2	0	0
EDU1	8	12	3.3	0	0
EDU1	12	25	5.3	30.4	25
EDU2	0	4	1.3	0	0
EDU2	4	8	2	0	0
EDU2	8	12	3.3	0	0
EDU2	12	25	5.3	30.4	25
GOV1	0	4	1.8	0	0
GOV1	4	8	2.5	0	0
GOV1	8	12	4.3	0	0
GOV1	12	25	5	31.3	25
GOV2	0	4	0.5	0	0
GOV2	4	8	0.7	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
GOV2	8	12	1.5	0	0
GOV2	12	25	1.7	50.4	37.5
IND1	0	4	0.5	0	0
IND1	4	8	0.7	0	0
IND1	8	12	1.5	0	0
IND1	12	25	1.7	50.4	37.5
IND2	0	4	0.5	0	0
IND2	4	8	0.7	0	0
IND2	8	12	1.5	0	0
IND2	12	25	1.7	40.2	37.5
IND3	0	4	0.5	0	0
IND3	4	8	0.7	0	0
IND3	8	12	1.5	0	0
IND3	12	25	1.7	49.8	37.5
IND4	0	4	0.5	0	0
IND4	4	8	0.7	0	0
IND4	8	12	1.5	0	0
IND4	12	25	1.7	34.8	25
IND5	0	4	0.5	0	0
IND5	4	8	0.7	0	0
IND5	8	12	1.5	0	0
IND5	12	25	1.7	58.3	25
IND6	0	4	1.8	0	0
IND6	4	8	2.5	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
IND6	8	12	4.3	0	0
IND6	12	25	5	34	37.5
REL1	0	4	1	0	0
REL1	4	8	1.3	0	0
REL1	8	12	2.8	0	0
REL1	12	25	3.1	32.5	25
RES1	0	4	4.1	0	0
RES1	4	8	6.8	0	0
RES1	8	25	6.8	6.5	25
RES2	0	1	4.1	0	0
RES2	1	25	6.5	10	25
RES3A	0	4	4.1	0	0
RES3A	4	8	6.8	0	0
RES3A	8	25	10.9	6.5	25
RES3B	0	4	4.1	0	0
RES3B	4	8	6.8	0	0
RES3B	8	25	10.9	6.5	25
RES3C	0	4	4.1	0	0
RES3C	4	8	6.8	0	0
RES3C	8	12	10.9	0	0
RES3C	12	25	13.6	6.5	25
RES3D	0	4	4.1	0	0
RES3D	4	8	6.8	0	0
RES3D	8	12	10.9	0	0

Hazus Occupancy Class	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Finishes Debris Weight (tons/1,000 ft^2)	Structure Debris Weight (tons/1,000 ft^2)	Foundation Debris Weight (tons/1,000 ft^2)
RES3D	12	25	13.6	6.5	25
RES3E	0	4	4.1	0	0
RES3E	4	8	6.8	0	0
RES3E	8	12	10.9	0	0
RES3E	12	25	13.6	47.8	25
RES3F	0	4	4.1	0	0
RES3F	4	8	6.8	0	0
RES3F	8	12	10.9	0	0
RES3F	12	25	13.6	47.8	25
RES4	0	4	4.1	0	0
RES4	4	8	6.8	0	0
RES4	8	12	10.9	0	0
RES4	12	25	13.6	58.6	25
RES5	0	4	4.1	0	0
RES5	4	8	6.8	0	0
RES5	8	12	10.9	0	0
RES5	12	25	13.6	68.7	25
RES6	0	4	4.1	0	0
RES6	4	8	6.8	0	0
RES6	8	12	10.9	0	0
RES6	12	25	13.6	6.5	25

12.4.2 Estimated Debris Weight by Census Block

The Hazus Flood Model estimates the flood depth distribution throughout each Census block and applies it to the square footage exposure for each occupancy type to determine square footage exposure by depth. The square footage exposure by depth is used to calculate the estimated debris weight for each occupancy class in each Census block (see Equation 12-1).[37] The debris weight calculated for each occupancy class at each flood depth is summed to provide a total debris estimate for each Census block.

Equation 12-1. Estimated Debris Weight in Tons by Occupancy at a Given Flood Depth

$$\begin{aligned}\mathrm{EDW(i,j)} = \mathrm{Depth\%_j} \times \mathrm{Fa_i} \\ \times \left(\left(\mathrm{FoSt\%_i} \times \left(\mathrm{DWF_{i,j}} + \mathrm{DWS_{i,j}} + \mathrm{DWFo_{i,j}}\right)\right)\right. \\ \left. + \left(\mathrm{FoFT\%_i} \times \left(\mathrm{DWF_{i,j}} + \mathrm{DWS_{i,j}} + \mathrm{DWFo_{i,j}}\right)\right)\right)\end{aligned}$$

The estimated debris amount (in tons) for occupancy ‘type i' in a given Census block at a given flood depth where:

$\mathrm{EDW(i,j)}$	expected debris weight of occupancy i, for depth j
$\mathrm{Depth\%_j}$	the percent of the Census block subjected to the given depth, j
$\mathrm{Fa_i}$	floor area of occupancy i (in 1,000 square foot)
$\mathrm{FoSt\%_i}$	the percent of occupancy i with slab foundation type
$\mathrm{FoFt\%_i}$	the percent of occupancy i with footing foundation type
$\mathrm{DWF_{i,j}}$	debris weight (in tons per 1,000 square foot) of building finishes for occupancy i, and depth j, taken from Table 12-2 or Table 12-3
$\mathrm{DWS_{i,j}}$	debris weight (in tons per 1,000 square foot) of building structural components for occupancy i, and depth j, taken from Table 12-2 or Table 12-3
$\mathrm{DWFo_{i,j}}$	debris weight (in tons per 1,000 square foot) of foundation materials for buildings with footing foundations for occupancy i, and depth j, taken from Table 12-2 or Table 12-3

12.5 Guidance for Expert Users

If available, users can update the baseline GBS inventory with locally available information and can edit the default parameters for weight by debris type. Additionally, users may update the flood

[37] Please note that the Hazus Flood Debris Module in Hazus 5.1 is producing erroneous results in that hand calculated values using Equation 12-1 do not correspond with results being produced by Hazus. Hazus-produced results consistently underestimate expected debris values. Users should refer to the release notes for future Hazus versions to ascertain when this defect has been corrected.

specific occupancy mapping, which controls the foundation types used for debris estimations. Any updates made by the user will be reflected in outputs of the Hazus Flood Debris Module.

Please note that adjusting pre- and post-FIRM distributions in the default mapping scheme should result in changes to modeled results for coastal flood hazards but will not change results for riverine flood hazards due to a design decision to optimize foundation type ratios for every mapping scheme type for each state.

Section 13. Direct Social Losses – Displaced Population & People Seeking Short-term Shelter

The Hazus Flood Model provides estimates of the population that will be displaced due to flooding as well as an estimate of people who will seek publicly provided short-term shelter.

The flowchart of the overall Methodology, including shelter components, is shown in Section 2 (Figure 2-1).

13.1 Input Requirements and Output Information

Input requirements to estimate the displaced population and people seeking short-term shelter in the Study Region include the following:

- Population location and demographics including number of households, number of individuals, distribution of households by income, and distribution of individuals by age
- Depth of flooding hazard throughout the Census block
- Analysis parameters related to displacement and short-term shelter needs

For users conducting a Level 1 analysis, the baseline inventory included with Hazus (see the *Hazus Inventory Technical Manual* (FEMA, 2024)), Hazus-generated flood hazard information (see Section 4.1), and default analysis parameters provided with Hazus can be used to meet the input requirements.

Output from the Hazus Flood Shelter Module includes an estimate of the displaced population and an estimate of people who will seek publicly provided short-term shelter by Census block.

13.2 Population Location and Demographic Information

The baseline inventory included with Hazus contains the following information needed for estimation of the displaced population and people seeking publicly provided short-term shelter:

- Total number of households per Census block
- Total number of individuals per Census block
- Distribution of households by income per Census block
- Distribution of individuals by age per Census block

Users may use the baseline information or any local database that contains the same information. Should local information be used, the income data and age data need to be formatted into the categories shown in Table 13-2.

13.3 Depth and Type of Flooding throughout the Census Block

Depth of flooding throughout the Census block is determined in the same fashion as for the GBS analysis (see Section **Error! Reference source not found.**); however, relative depths and type of flooding do not impact social loss results.

13.4 Analysis Parameters Related to Displacement and Short-Term Shelter Needs

The Hazus Flood Shelter Module estimates displaced population and people seeking publicly provided short-term shelter based on the presence of flooding and characteristics of the population in inundated areas. Estimates of the displaced population and people seeking publicly provided short-term shelter are not based on the modeled damage state of structures. Population is assumed to be displaced in all areas where the depth of flooding is greater than zero.

13.4.1 Displaced Population

Hazus estimates the displaced population by estimating the number of people residing in areas where flood depths are greater than zero. If an entire Census block is flooded, the entire population residing in that Census block is assumed to be displaced. In a Census block where only a portion of the Census block is flooded, Hazus calculates the percentage of the dasymetric Census block that is flooded and multiplies that by the total population in the Census block to estimate the displaced population (see Equation 13-1).

Equation 13-1. Displaced Population due to Flooding

$$\text{Displaced Population} = \sum_{j=1}^{n} \text{In\%} \times \text{Pop}$$

Where:

In%	the percentage of the Census block where the depth of flooding is greater than 0
Pop	the population of the Census block
J	the number of Census blocks within the flooded area

13.4.2 People Seeking Publicly Provided Short-Term Shelter

The Hazus Flood Model estimates the number of people who will seek publicly provided short-term shelter by estimating the number of displaced persons with certain demographic characteristics that may increase the likelihood that they will use publicly provided shelters. In the Hazus Flood Model, the key factors in this determination are income and age.

13.4.2.1 Short-Term Shelter Weighting Factors

During flood events most displaced individuals obtain their own sheltering in hotels or with friends and family. The ability to find shelter on one's own is primarily a function of income. Age is also a factor in that young families and older families (65 years or older) will tend to use public shelters. In many respects, this is also a function of income since many young families tend to fall in the lower income brackets and many older families (65 years or older) are living on fixed incomes. The short-term shelter weighting factors, in Table 13-1, represent the importance of the characteristic in the determination of how many people will seek publicly provided shelters.

Recognizing the importance of income in individual sheltering decisions, the default weighting factor for income is set at 0.80. This automatically establishes age weighting factor as 0.20 as the sum of these factors must total 1.

Table 13-1. Short-Term Shelter Weighting Factors

Class	Description	Default
IW	Income Weighting Factor	0.80
AW	Age Weighting Factor	0.20

13.4.2.2 Short-Term Shelter Modification Factors

Short-term shelter modification factors are used to estimate the percentage of each income and age class that will seek publicly provided shelter (see Table 13-2).[38] The factors for income and age are the estimated percentage of that class that will seek public shelter. For example, the Hazus Flood Shelter Module estimates that 40% of households with incomes less than $10,000 will seek publicly provided shelter, while only 5% of households with incomes greater than $40,000 will seek publicly provided shelter. As the household annual income increases, the likelihood of the household using public shelter decreases.

[38] The short-term shelter modification factors were modified from Methodology developed for the Hazus Earthquake Model. See the *Hazus Earthquake Model Technical Manual* (FEMA, 2024) for additional information on the development of these factors.

Table 13-2. Short-Term Shelter Modification Factors

Class	Description	Default (%)
Income		
IM_1	Household Income < $10,000	0.40
IM_2	$10,000 < = Household Income < $20,000	0.30
IM_3	$20,000 < = Household Income < $30,000	0.15
IM_4	$30,000 < = Household Income < $40,000	0.10
IM_5	$40,000 < = Household Income	0.05
Age		
AM_1	Population under 16 Years Old	0.05
AM_2	Population Between 16 and 65 Years Old	0.20
AM_3	Population Over 65 Years Old	0.50

13.4.2.3 People Seeking Publicly Provided Short-Term Shelter

A shelter factor is determined for each combination of the population analysis parameters using the weighting and modification factors (Equation 13-2). Because there are 3 weighting factors and 5 modification factors, 15 individual shelter factors are calculated for use in estimating the number of people seeking short-term shelter (Equation 13-3).

Equation 13-2. Shelter Factor Based on Population Analysis Parameters

$$\alpha_{km} = (\mathrm{IW} \times \mathrm{IM_k}) + (\mathrm{AW} \times \mathrm{AM_m})$$

Where:

α_{km}	shelter factor based on population parameters
IW	shelter category weight for income
AW	shelter category weight for age
IM_k	relative modification factor for income
AM_m	relative modification factor for age

The number of people seeking short-term shelter is then determined by multiplying the shelter factor by the estimated displaced population and the percentage of the population in the respective age and income class for each Census block. The number of people seeking short-term shelter for each Census block is summed to provide an estimate of the number of people seeking publicly provided short-term shelter for the Study Region (Equation 13-3).

Equation 13-3. Number of People Seeking Publicly Provided Short-Term Shelter

$$\#STP = \sum_{k=1}^{5} \sum_{m=1}^{3} \{\alpha_{km} \times DP \times HI_k \times HA_m\}$$

Where:

$\#STP$	number of people seeking short-term public shelter
α_{km}	shelter factor based on population parameters (Equation 13-2)
DP	displaced population due to flooding (Equation 9-1)
HI_k	percentage of households in the k^{th} income class (five total classes, see Table 13-2) for each Census block[39]
HA_m	percentage of population in m^{th} age class (three total classes, see Table 13-2) for each Census block

13.5 Guidance for Expert Users

The following sections provide guidance for expert users who wish to make changes to the default parameters used in estimating displaced population and people seeking publicly provided short-term shelter.[40]

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[39] Income data is reported by the Census at the household level. Individuals not considered by the Census to be residing in households (i.e., those living in Group Quarters) will therefore not be included in income-based Hazus estimates for people seeking publicly provided short-term shelter.

[40] Please note that due to issues with outdated code, the shelter parameters dialog is not enabled in the Hazus Flood Model in Hazus 6.0. Users that would like to view or edit the FFE or shelter parameter tables are encouraged to contact FEMA-Hazus-Support@fema.dhs.gov for guidance on viewing or editing the tables using SQL Server Management Studio, or upgrade to Hazus 6.1.

13.5.1 Modification of Shelter Weighting Factors

Shelter statistics from previous flood disasters have not historically included information on household income and age. If a user has such statistics for a given Study Region, the default shelter category weights can be modified.

13.5.2 Modification of Shelter Income Modification Factors

Users can make modifications to the default income modification factors (see Table 13-2) to reflect circumstances more accurately in their own communities.

Section 14. References

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